Studies in Applied Philosophy,
Epistemology and Rational Ethics

SAPERE

Antonio Carlos Zambroni de Souza
Maarten J. Verkerk
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Interdisciplinary and Social Nature of Engineering Practices

Philosophy, Examples and Approaches

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Foreword—A Message of Hope

For many centuries, the role of engineers was undisputed. It was believed that they contributed to the welfare of society. The idea that technology could destroy our planet was impossible. Everyone believed that society was moving toward a welfare state. Engineers were the engine that drove this progress, and economists were the fuel that kept this engine running. The results were impressive. We have broken free from the whims of nature, have an abundance of food, are fully equipped, and are dying of old age.

This picture has changed considerably in the last decades. Technology turned out not only to be the engine of progress, but also the driving force of the destruction of nature, the warming up of the planet, the increase in social inequalities, the rise of populism, and the denial of the climate crisis. Engineers cannot longer withdraw to their laboratories, cannot longer hide in their ivory towers, and cannot longer avoid the major social and political issues of our time. In fact, they are forced to face all the damage they have done to nature, the planet, and society. They are held accountable for their responsibility.

It is unfair to blame engineers for all the problems of our time. It is completely unjustified to place all responsibility on their shoulders. It is not only about engineers, but also about economists and politicians. It is also about citizens. They all believed in progress. They all acted as if progress had no price. But these considerations do not alter the fact that engineers have a social responsibility. In the design of new technology, they must contribute to the flourishing of society. That means future designs must help restore biodiversity, limit global warming, reduce social inequalities, combat populism, and fight climate crisis denial.

This book aims to contribute to the conversation and practice of the social responsibility of engineers. On the one hand, that responsibility is immense: The future of our planet and human existence are at stake. On the other hand, that responsibility is limited: An individual engineer can ‘only’ contribute by doing his or her own job well. For every engineer, he or she is ‘only’ one cog in the whole of society.

There is also a message of hope in this understanding. It shows that every individual engineer can contribute to the flourishing of society. On top of that, it shows the strength of the community of engineers. The flourishing of society requires inclusive design processes; processes in which justice is done to the fragility of our planet and the dignity of every human being.

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Preface

This book is about engineering, technology, and society. It is our conviction that the relation among these aspects cannot be treated separately and theoretically, but in an integrated and holistic way. This approach is becoming more and more crucial for the sustainability of society and development of culture.

The book covers practical and philosophical aspects of engineering, paying special attention to the social impacts of traditional and emerging technologies. The editors understand that combining the technical background with a holistic view of Engineering is not a common practice in the classical curriculum. The focus of the book is not to criticize the past approaches but rather encourage the engineering community to reflect on these issues regarding the interdisciplinary nature and social implications of engineering practices.

The engineers of the future will need a wider background of knowledge to deal with climatic challenges, social inequalities, and political pressures to develop the technical aspects of their tasks in an integrated and holistic way. In this sense, some fundamentals of philosophy of technology are introduced followed by social, economic, and environmental discussion and implications in different disciplines.

Each chapter is meant to provide insights regarding the responsibilities involved in the design of engineering projects. The examples presented combine concepts about the impacts of engineering in society while incorporates new technological models, yielding an innovative approach about the topics. Therefore, engineers and engineering students are the expected primary readers of this book. However, those not directly involved in engineering may also benefit from it, since a broad view on social responsibilities is presented and discussed. Thus, people in general who want to understand how engineering may help shaping not only a more comfortable world, but also a fair and equitable society, may also enjoy the material here presented. Engineers and scholars from Canada, Portugal, Chile, USA, The Netherlands, and Brazil were involved in this project. The work presented is expected to attract people from both the academic and industrial areas, since the authors work on different areas of knowledge and are deeply concerned with the current dramatic changes in the environment and society.

In a sense, this book is somehow autobiographical as it reflects the work of the editors at several universities where they are teaching or have taught different courses related to the issues of philosophy and development of technology.

Finally, the editors and authors of this book do not claim originality of the work presented, but rather consider a humble effort to further encourage reflection on a topic already recognized as important to the sustainability of society in association with the impact of engineering and technology, in light of the words of Prof. Lewis regarding the preparation of books in the Middle Ages:

> I doubt if they would have understood our demand for originality or valued those works in their own age which were original any the more on that account. If you had asked Chaucer ‘Why do you not make up a brand-new story of your own?’ I think he might have replied (in effect) ‘Surely we are not yet reduced to that?’ Spin something out of one’s own head when the world teems with so many noble deeds, wholesome examples, pitiful tragedies. Why make things for oneself when there are riches all about you to be had for the taking? And the paradox is that it is just this abdication of originality which brings out the originality they really possess. [*]
>
> [*]—C.S. Lewis, The Discarded Image, 1964.

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Theoretical Considerations

Introduction

Paulo Fernando Ribeiro and Rafael S. Salles

1 Introduction

What do engineering, philosophy, and sociology have in common or have to do with each other? The objective of this chapter is to highlight these concepts and interrelations in order to set up the stage for the following chapters which will cover in detail and further explanations, applications, and implications of engineering and social practices.

In Fig. 1, one can see a list of topics which is intended to show an increasing level of complexity and relationships starting with Engineering and Technology, then moving into Philosophy of Engineering and Technology. Next, the Non-Neutrality and Moral Status are emphasized. The Economic and Political Aspects are then brought together with the Dangers of Social Control. Finally, the view of Holistic Normative Engineering and its Social Implications are mentioned.

Regarding the philosophical vision proposed to integrate a holistic approach to design, some books and works bring an essential view of the topic. They are highlighted in the Annex of this chapter. Next, this section will highlight the contributions of crucial works to this base.

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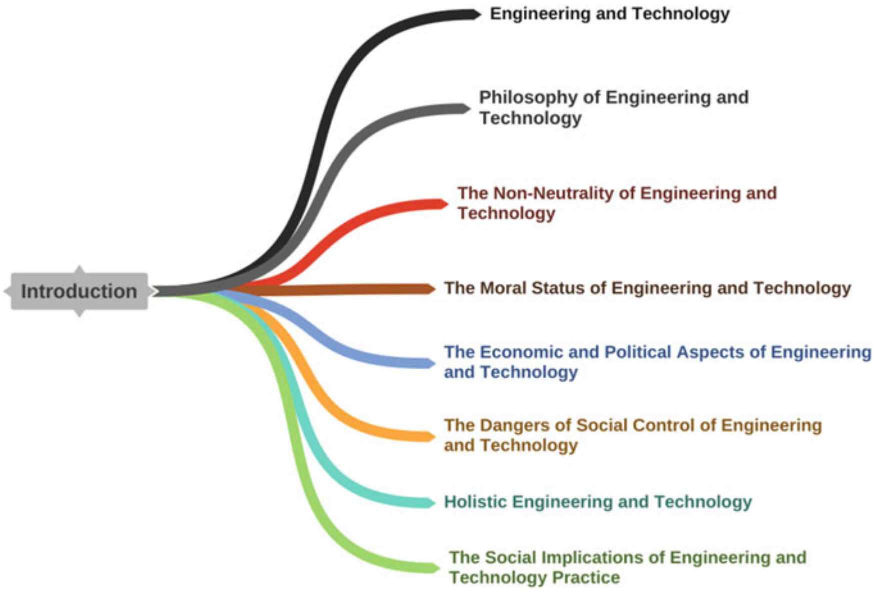


Fig. 1 Holistic normative engineering

2 Engineering and Technology

Engineering and technology in this chapter and book may be used interchangeably or sometimes as two different entities. "*Engineering is defined as a systematic and iterative approach to designing objects, processes, and systems to meet human needs and wants. Technology is defined as any modification of the natural or designed world developed to fulfill human needs or desires*" (Quellmalz, 2014).

As previously mentioned in the literature, technology can be defined in different ways. As an object, it is a tool that provides uses in human beings' applications, which would be a simplistic view of the concept. On a more complex picture of the subject, technology is how humans interfere with nature, society, and engineering systems. Technological advancement is inherent in the interaction of systems and the need for modification by thinking minds. This broad view of technical systems allows for a complete, non-limiting understanding of whether, for example, technology is a set of rules, tools, or a physical component. Thus, we can address the concept to scientific practice as a whole where ideas, solutions, and innovations, contemplating the definitions' physical and abstract view. In (Dusek, 2006), the explanations put (Gendron, 1977) and (Pacey, 1983) are combined to bring an exciting meaning, in line with what is being raised here: "*Technology is the application of scientific or other knowledge to practical tasks by ordered systems that involve people and organizations, productive skills, living things, and machines.*"

Engineering is the field of knowledge dedicated to designing and applying technologies in different areas and subjects. Due to the nature of the needs, the professional engineer tends to be reductionist, linked to the demand and operational form of the proposed projects. However, from the end of the last century, particular concerns started to be raised by philosophers and engineer thinkers who offer to break the barrier that solutions are inherent and exclusive on the technical side. It means that the engineering process can now be linked to social, humanistic and philosophical issues. It is a broad view that encompasses all those impacted by technologies because, through them, the engineering modifies the inserted environment. This look is a start to understand how holistic and philosophical concepts can culminate in more complete, robust, and intelligent solutions.

Thus, morality and ethics premises become of great importance to discuss the technological design and engineering role. Over time, the technologies' side has been approaching normative reflection, not limited to fields of information ethics and biomedical, also started to reflect on the very design of technologies (Kroes et al., 2008). This trend makes it possible for them to evaluate the use and development of these technologies not merely in the functional or tool aspect but also the moral decisions and the well-being of those impacted. If this type of concern does not exist, the project intent will fail even though its functioning is technically adequate, within a holistic view. Technologies always help transform the context in which they fulfill their function, helping to construct human comprehension or creating new practices and ways of living (Kroes et al., 2008). Technology plays a crucial role in understanding reality, given that this process takes place through how people live as a meaningful coherence (Verkerk et al., 2016). Technology is also about the good life, so technology is related to the idea of meaning.

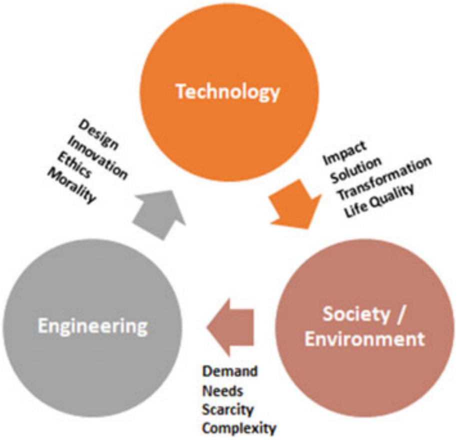
Given this scope, we can observe a recursive interaction between engineering, technology and society. As the demands and needs of society and the environment arise, the human being, through engineering and innovation, develops solutions and designs normative technologies to impact the development of systems. Thus, for this cycle to be sustainable, the demands, deliveries, and purposes must be aligned in a perspective that values broad issues, which consider aspects of reflection and thinking for different knowledge areas. Figure 2 illustrates this interaction.

3 Philosophy and Philosophy of Technology

Why is philosophy important for engineering practice? Wilfred Sellers said: "The aim of philosophy, abstractly formulated, is to understand how things in the broadest possible sense of the term hang together in the broadest possible sense of the term" (Sellars, 1962). And that is one for the reasons the authors and editors of their book are convinced that philosophy is of paramount importance for the understanding and development of human activity, of which technology is a prevailing one in society.

In this section, we define Philosophy of Technology as a subfield of philosophy that studies the nature of technology and its social implications and effects. The functions

Fig. 2 Interaction between technology, engineering, and society



of the Philosophy of Technology are analytical, critical, and direction. Figure 3 illustrates the relationship between Philosophy and Engineering Technology. In philosophy, we ask basic questions related to ontology, epistemology, methodology, etc., while in engineering/technology, designers concentrate on the methodology aspects (concept, specification, quantitative, practical implementation and operation). Nevertheless, the Philosophy of Technology needs to ask all the philosophical questions also.

The Philosophy of Technology is a young subject that brings the main tools of philosophical questioning such as epistemology, logic, metaphysics, logic, ethics, and political questions to a technology perspective at the heart of the definition.

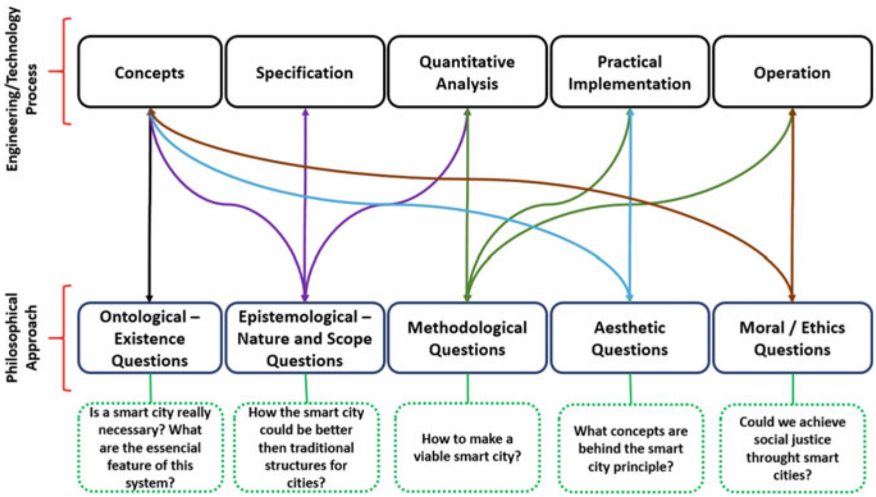


Fig. 3 Relationship between philosophy and engineering technology

Thus, we seek to answer and understand questions involving the way society as a whole relates to technology and technological systems. In "Thinking Through Technology" (Mitcham, 1994), Carl Mitcham, one of the precursors of the Philosophy of Technology, separates this field of knowledge into two strands: the engineering Philosophy of Technology and the humanities Philosophy of Technology. At this point, he intends to separate two ways of thinking about technology. The first establishes that technology is the core of human development, where the engineering method is the solution applicable to all aspects of life. On the other hand, the second does not minimize the dangers in focus on technological expansion, putting humanistic issues ahead while giving due importance to the legitimate role of technology. It has to do with the group of professionals who approach each aspect. Humanistic or technical qualifications will predominate over the development of critical analysis concerning technology. However, although Mitcham brings several interesting approaches and divisions to his work, it is more like a mosaic of ideas and suggestions, without "schools" in the Philosophy of Technology with a well-established tradition (Vries, 2005).

The Philosophy of Technology taken as a whole is a comprehension of the technological effects of the environment, society, and human existence (Olsen et al., 2012). In the subject, philosophy has an analytical function. Philosophy helps with the development of conceptual frames, and this function brings to its core the questioning that seeks an adequate representation of reality. The second role of philosophy is to look critically at reality, and this function emerges in the critical analysis of the role that technology has played, still plays, and will have to play in culture and society (Verkerk et al., 2016). The third function is directing, seeking questions found in the ethics of technology. These questions are inherent in the critical analysis and seek to address technology's influence, choice of technology, effects on the environment, and solutions to society's problems (Verkerk et al., 2016).

One must face the impact of technology on society concerning the different fields to explore a complete design. The Philosophy of Technology is an essential tool that allows access to these various issues associated with technology's role. Applying this concept will enable a broad view that considers all the benefits, adversities, and complexity associated with technology development in complex systems. Social and environmental aspects start to take a leading role in the concern for projects for the future, for example. The engineer has to bring these reflections into his design process.

4 The Moral Status and the Non-neutrality of Engineering and Technology

Technology is not neutral. Technology is value-laden as it penetrates all technological and social activities. It involves multifaceted decisions (from design to utilization), and technological objects are intertwined with their environment.

A position asserts that technology is neutral and thereby value-free: a tool that can be used for good or evil. Therefore when engineering projects and technologies cause great devastations, one is not to blame engineers and technologies, but corporations and politicians. But engineering technology is not neutral as they combine resources, materials, etc., and all involved decisions that carry the human values injected by their designers. As stated earlier, according to Verkerk et al. (2016), technology always expresses a certain view on "the good life." So, it is not neutral. Technological objects are intertwined with their environments. These interactions are very complex and not determined by the technological object itself (Monsma et al., 1986).

In the technological structure, ethical issues related to technology are taking more importance and criticality over time, and the normative reflection has sought closer contact with technologies themselves (Verbeek, 2008). Fields of knowledge such as ethical engineering and design ethics address concepts and theories that support a basis of responsibility in the process of technological development.

Understanding technology as free of philosophical bias has negative and dangerous consequences (Zhao et al., 2004). Technologies are inherently biased because they are built to accomplish certain very specific goals, good for some tasks and bad for others (Bromley, 1998). Ignoring the inherent characteristics and assumptions of a certain technology can result in incompatibility and inappropriate use of it. The design process must consider all integrations and stakeholders involved in all stages of the project. In this way, the correct employment and due responsibility for impacts and other aspects resulting from technological development are guaranteed.

How to assess the moral status of engineering technology and its impact on society is a complex problem. Recently, several proposals have been brought to the discussion table on the need to assign a moral value to engineering technology systems and products. This seems very reasonable considering the concept of non-neutrality of technology. If technology is value-laden by humans developing and applying technology its moral status seems a natural consequence.

In the book "Philosophy of Technology: From Technical Artifacts to Sociotechnical Systems" (Vermaas et al., 2011), the authors make a very reflexive counterargument regarding the neutrality thesis. The points addressed go against the view that technological artifacts are neutral and that the individual directs use, which uses the classic paradigm of war artifacts and nuclear bombs ("*guns don't kill people, people kill people*"). The arguments are highlighted and discussed below to elucidate the debate by highlighting the moral status of technological artifacts.

- In their design and layout process, engineering professionals can anticipate the possibilities of using the artifact even without being able to determine it. This factor must be considered in the design process, as technology can always be used in an activity that was not initially intended or even its incorrect use.
- The functioning of a given technology also depends on the system's social functioning inserted, not only the proper operation on the technical side, as for the sociotechnical system. In this type of system, these notions are often compromised a complicated way. There are several factors and many times divisions of

responsibilities in the design stage for different entities. Often, the morality of these aspects is raised during the use of the final products.

- The authors' third point is that new technologies can lead to new options of action that did not even exist previously, and that can be problematic from an ethical point of view. New opportunities for activities that are opened up by technology can be very controversial, and we must often oppose this use by moral considerations.
- Technical artifacts not only fulfill their designations but also bring effects and risks to their varied applications. These side effects suggest that the conception of technology alone is not just about its efficiency. Its impacts must be taken into account when they are used in society and the environment. Issues such as safety, health, sustainability, privacy, among others, must be considered in the design stage to comprise all possible effects.

The fact that technical artifacts may be used for morally good or evil purposes does not make them ethically neutral objects (Kroes & Verbeek, 2014). Thus, this debate is fundamental from the perspective of social aspects that the practice of engineering must consider.

5 The Economic and Political Aspects of Engineering and Technology

Engineering economics is a field that addresses the economic aspects and principles through the prism of engineering. It has the objective of assisting decisions and is related to the economic feasibility of the projects. Applying economics concepts in engineering practices is also to design viable and economical products and services for the consumer and manage the available resources. This topic discusses the time value of money and interest relationships that are used to define certain project criteria that engineers and project managers use to select the best economic choice among several alternatives (Whitman & Terry, 2012). Economic aspects deal with the justification and selection of projects and initiatives. Some principles are applied to this perspective: Money has an associated time value, a decision should be based on comparisons between different alternatives considered, each alternative decision must be based on its own economic merits, and an expected additional return must accompany additional risks.

Alternatively, the social and political side of engineering affects virtually every aspect of our society. But what is the nature of that activity? What is the role of engineering in responding to society's needs as well as in shaping them? How well does engineering carry out that role? These are fundamental questions that we hope this book will attempt to respond.

Economic and political factors can be impulsors or inhibitors of good engineering practice. The economic aspects are associated with scarcity management and the economic scenario where the project or technology is being inserted. It all varies with the characteristics of the systems. On the other hand, the political aspects signal an incentive or prohibition through public policies, regulation, standardization, and society management. Political aspects will determine the extent of technological development for a given economic condition. These all impact the selection of equipment, maintenance, adaptation of new products, optimization of costs, and improvement in quality.

6 The Dangers of Socially Controlled Engineering and Technology

What is technology progress? How it related to social common good and freedom? These are questions which have been asked for quite sometime. In a text written in 1933, the author (Lewis, 1933) expresses already the concerns with technological developments and make us reflect on what has happened in the last one hundred years:

> "The Guide laughed:
>
> You are falling into their own error," he said, "the change is not radical, nor will it be permanent. That idea depends on a curious disease which they have all caught--an inability to disbelieve advertisements. To be sure, if the machines did what they promised, the change would be very deep indeed. Their next war, for example, would change the state of their country from disease to death. They are afraid of this themselves--though most of them are old enough to know by experience that a gun is no more likely than a toothpaste or a cosmetic to do the things its makers say it will do. It is the same with all their machines. Their labor-saving devices multiply drudgery; their aphrodisiacs make them impotent: their amusements bore them: their rapid production of food leaves half of them starving, and their devices for saving time have banished leisure from their country. There will be no radical change. And as for permanence--consider how quickly all machines are broken and obliterated. The black solitudes will someday be green again, and of all cities that I have seen these iron cities will break most suddenly.
>
> And the Guide sang":
>
> Iron will eat the world's old beauty up.
>
> Girder and grid and gantry will arise,
>
> Iron forest of engines will arise,
>
> Criss-cross of iron crotchet. For your eyes
>
> No green or growth. Over all, the skies
>
> Scribbled from end to end with boasts and lies.

The dangers of unreflected political and social control of engineering and technology are obvious and have been explored by the powers at be for a long time. Many technologies developed for the military since ancient times to things such as the Internet have been used in other areas. In an engineered society, rationalization is seen in the application of means to ends.

The contemporary social control can be seen to reflect the set of fundamental customs and habits of the regulated prison in which conformity is sought by designing ever more features of the environment, rather than relying on trusting the individual or facing the uncertainty of human freedom of choice. Views that are more traditional treat technology in a meaningless way or as a consequence of the social environment in which it is inserted. Although it can be orchestrated and applied in the social context, which makes decisions about how engineers design these artifacts or socially oriented usage based in commercial, military directions, political, ideological, among others. Technological development can offer a series of new possibilities and be used to build thoughts and decisions, with social control being a relevant contribution of the technology impact on society. With the speed and variability of technological sophistication, there is an increase in engineering role to social control (Marx, 1995).

That is why the social side of engineering practices must consider the dangers of social control so that technology's impact is analyzed throughout its lifetime and usefulness. In the book "Hideous Strength" (Lewis, 1996), the National Institute of Coordinated Experiments (N.I.C.E.) tries to publish their ideas in newspapers across Britain to sway public opinion. N.I.C.E. relies on technology to manipulate the public. In the book, we learn that Mark Studdock is a young academic that becomes a Senior Fellow in sociology at Bracton College in the University of Edgestow. The fellows of Bracton are debating the sale of a portion of Bracton land to N.I.C.E., whose staff already includes some college faculty. The sale is controversial since the land in question (Bragdon Wood) is ancient woodland. After the deal is complete, Lord Feverstone proposes a possible post for Mark at the Institute. Mark is finally given work to write pseudonymous newspaper articles supporting the N.I.C.E.

The book author attempts to demonstrate that the rapid advancement in science and technology has the potential to control society and produce great distraction to humanity. The dangerous cycle is completed with governments enter into agreements with academic institutions, in the name of science, to formalize social control.

7 Holistic Engineering and Technology

Holistic Engineering and Technology can be defined as the activity that considers all stakeholders' interests and not only the clients of engineering and technologies projects and products. Holistic Engineering implies harmony of all aspects—technical, human, and environmental. One of the references of related works cited in the introduction, "Philosophy of Technology" (Verkerk et al., 2016), brings an excellent view that covers holistic thinking in an accessible way for engineers.

How to cope with the complexity of engineering and technology systems and products? It is impossible to take into account the full complexity of these systems! One needs to focus on: a few aspects, components or systems, the perspective of a few parties involved. Therefore, the study and design are performed on reduced realities resulting in: missing relevant dimensions, overlooking meaningful interactions between technical systems, neglecting interests of certain parties, loss of information. Consequently, reduced realities have to be integrated—for better or worse—into a single unity. It is a challenge for the designer. We need intuition, creativity and technical skills. That is the challenge for developing Holistic Engineering Technology.

Since each of these primary activities involves complex relationships of all physical reality, the Model Aspects developed by Dutch Philosopher Herman Dooyeweerd (Reference to Chap. "Key Concepts for Frameworks: Values, Aspects, Normativity and Enkaptic Structures") is an additional tool to help unfold the activities more integrated way. Therefore, it is necessary to concentrate on some fundamental components as described below by the following aspects, for example, for electrical energy systems:

1. Physical aspects
   a. Energy generation, transportation, and management.
   b. Physical laws, system performance.
   c. Instabilities compromise performance/security.
2. Bio/Life Sustaining aspects
   a. Environmental dimensions and impact.
3. Control aspects
   a. Power over individual components/whole system.
   b. Distributed/delegated to intelligent systems.
4. Social and economic aspects
   a. System and generated electricity have economic value.
   b. The breakdown can cause enormous financial losses.
5. Juridical and political aspects
   a. Generation and trading are covered by juridical contracts.
6. Moral aspects
   a. We cannot live without electrical energy.
   b. The moral obligation of energy suppliers to supply energy continuously.

Concerning the stakeholders (government, local authorities, energy suppliers, energy transporters, customers (industrial, commercial, residential), action groups, etc.), their interests need to be considered and focus on specific areas.

- Government and local authorities;
  – Focus on the juridical aspect of electricity systems.
- Customers;
  – Focus on the economic, security, and environmental aspects of energy.
- Action groups;
  – Focus on the environmental dimension of energy production and transportation.

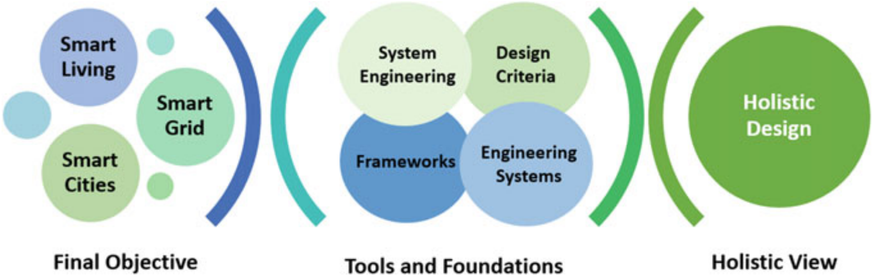


Fig. 4 Example of a holistic view of an engineering project

The different parties play a fundamental role and have their specific interests and responsibilities. Figure 4 illustrates an example of a holistic view of an engineering project, going from the engineering system to the smart city and smart living, which should be the final objective of all engineering and technology projects.

Thus, it can be inferred that electric energy systems function in several different aspects or dimensions. These aspects or dimensions have each a specific nature that is not present in the others. The particular nature of these aspects or dimensions must be investigated and integrated into the overall design and operation. For those concepts, an innovative kind of engineer is necessary, one who can think broadly across disciplines and consider the human dimensions at the heart of every design challenge (Grasso & Martinelli, 2010).

8 The Social Implications of Engineering and Technology Practice

Engineering practices have always been linked to the main activities of the society. Following the reasoning set up until now, the engineering professional with the most traditional thinking is reluctant to attach social aspects to design. They often prioritize the technical performance and economic issues, which are also very important but need to be integrated into other aspects. When creating and developing a product, one must understand the motivation, technical parameters, and social issues, or both short and long terms.

Dividing technologies and practices with good or bad social implications is possible. For example, one needs to consider the scarcity of basic materials when developing new technologies. The massive use of a particular technology can generate an absence of materials for the future, which will affect society as a whole. Engineers must also consider social contexts, communities, and a culture where it will be implanted. In this way, the engineer can use and create technological artifacts to promote quality of life, sustainability, smart development, and other benefits for a sustainable society.

Several areas can have specific benefits in today's society through a social view. New technologies have been causing disruptions concerning energy generation, services, ways of relating, and education. For example, cutting-edge technology has been used to promote accessibility, which is fantastic from a smart living perspective. As mentioned above, many other technologies are transforming the world in the places and contexts inserted.

The Institute of Electrical and Electronics Engineers (IEEE) Society on Social Implications of Technology (SSIT) is an example of an organization that seeks to address the theme of engineering fields, research, and application. SSIT is a technical society in IEEE was founded in 1982, after a decade as the Committee on Social Responsibility in Engineering (CSRE) (Stephan et al., 2012). The SSIT is a professional society of the IEEE. The society's field of interest is, according to its constitution: provide a forum for discussion of the deeper questions about the history, connections, and future trends of engineering, technology, and society.

9 Book Organization

The book is organized into four parts, starting with theoretical considerations, then applications, the third part deals with technologies and society, and ends with case studies. Table 1 describes this organization and the chapter titles.

10 Conclusions

The objective of this chapter was to define terms and describe a basic framework to set up the stage for the several chapters which will cover in a comprehensive way the topics related to the Social Aspects of Engineering and Technology Practices. The authors hope that this chapter may facilitate the reading of the next chapters. Also, a series of works are pointed out, which deal with subjects discussed in this book. These serve as the basis for the continuous work for a search for a more humane engineering practice, which seeks to abolish all the multidisciplinarity of systems, including social issues. Concepts about engineering and technologies' fundamentals are important for understanding the book, just as these elements relate to society and the environment.

Meanwhile, let the engineers continue to unfold the physical reality of engineering and create more detailed models for integrated studies and the social implications, for not forget that "nature gives most of her evidence in answers to questions we ask her." Here, as in the courts, the evidence's character depends on the examination's shape, and a good cross-examiner (or engineering researcher) can do wonders. The professional will not indeed elicit falsehoods from an honest witness. But, concerning the total truth in the witness's m'nd, the examination structure is like a stencil. It determines how much of the total truth will appear and what pattern it will suggest.

Table 1 Book organization and chapter titles

Book part	Chapter title
Part I: Theoretical Considerations	Preface
	Chapter 1: Introduction
	Chapter "Engineering Practices: Complexity—Diversity—Coherence—Meaningfulness"
	Chapter "Key Concepts for Frameworks: Values, Aspects, Normativity and Enkaptic Structures"
	Chapter "Toward a Holistic Normative Design"
	Chapter "The Engineer in the Face of Social Changes: The Cases of Health and Sustainability at Work"
Part II: Applications	Chapter "Industrial Innovation Practices Breakthrough by Process Intensification"
	Chapter "Sustainability and the Responsibility of Engineers"
	Chapter "Economics, Regulatory Aspects and Public Policies"
	Chapter "Statistics and Engineering"
Part III: Technologies and Society	Chapter "Smart Telecommunications: The Catalyst of a Social Revolution"
	Chapter "Analytical Optimization Applied to Social Aspects and Public Policies"
	Chapter "The Socio-economic Implications of the Coronavirus Pandemic: A Brazilian Electric Sector Analysis"
	Chapter "The Need of Normative Technologies for Smart Living Cities"
Part IV: Case Studies	Chapter "Social and Economic Implications of Electricity Generation Sources"
	Chapter "Amazon Region Power Plants and Social Impacts"
	Chapter "Scalability and Normativity—System Requirement Definition Based on Social and Philosophical Consideration"
	Chapter "The Interdisciplinary Nature of Engineering Education and Practice"
	Chapter "A Multi-aspect Dynamic System Model to Assess Poverty Traps"
	Chapter "Microgrid Operation and the Social Impact of Its Deployment"
Part V: Epilogue	Epilogue

11 Annex

The philosophical approach presented in this chapter is based on the philosophy of the Dutch philosopher Herman Dooyeweerd. The most accessible introduction to this philosophy with respect to technology is given by *Philosophy of Technology: An introduction for technology and business students* (Verkerk et al., 2016). This book is designed for those with no philosophical background in mind, it is excellent for technology and engineering students to think critically about how their work influences society. The text presents a critical analysis of the subject, including development, manufacturing, sales and marketing, technological products and services, and how philosophy can and should influence technology in practice.

Regarding the philosophical vision proposed to integrate a holistic approach to design, some other books and works bring an essential view about the topic. The book *Philosophy and Design: From Engineering to Architecture* (Kroes et al., 2008) provides an integrated overview of state-of-the-art research in philosophy and ethics of design in engineering. It contains several essays focusing on engineering designing in its traditional sense, designing in novel engineering domains, and architectural and environmental designing. This book enables the reader to overcome the conventional separation between engineering designing and architectural designing.

In *Philosophy of Complex Systems* (Hooker et al., 2011), one finds a great resource to understand the main issues of complex systems and in particular frameworks and architectures of complex systems.

Engineering Design: A Systematic Approach (Pahl et al., 2007) explains engineering design methods as a condition of successful product development. It divides down the design process into phases and steps, each with its working methods. It also emphasizes the scientific bases of its design ideas covering new solution fields. The economics of design and development are covered, and electronic design process technology is integrated into its practices. The work proposes the understanding of engineering design and helps the designer naturally consider a more holistic approach which is the intent of this chapter and the entire book.

The Moral Status of Technical Artefacts (Kroes & Verbeek, 2014) considers the question: To what extent does it make sense to qualify technical artifacts and technologies as moral entities? The authors' contributions trace recent proposals and topics, including instrumental and non-instrumental values of artifacts, agency and artifactual agency, values in and around technologies, and technology's moral significance. Contributions explore the contested discourse on agency in humans and artifacts, that defend the Value Neutrality Thesis. The book also investigates technological fields subject to negative moral valuations due to some of their products' harmful effects.

The Future of Engineering (Fritzsche & Oks, 2018) deals with philosophical foundations, ethical problems, and cases with applications. The book advances the idea of engineering that brings to the debate different perspectives from different stakeholders involved in the design and application of technologies, various from a traditional static view. The contributions are presented to draw a comprehensive picture of several professionals' efforts for a holistic view of society's development, covering topics of value-sensitive design, experimentation, education, interdisciplinary collaboration, sustainability, risks, and privacy.

On the other hand, *Engineering Education for Social Justice* (Lucena, 2013) brings several perspectives and approaches to highlight key concepts that help in understanding engineering education and social justice. By serving as a guiding framework for making social justice a prominent topic in engineering education, this work also brings essential points in understanding and the need for a social and reflective approach to technology design.

In the work *Philosophy and Engineering: Reflections on Practice, Principles and Process* (Michelfelder et al., 2013), conceptual developments in engineering philosophy are raised, in addition to reflections on engineering practices. Contribution as a reflective engineering approach helps to understand identity and explores how integration between engineering and philosophy can provide innovation in development. Ontological and epistemological dimensions are explored to escape the reductionist vision of the traditional solution.

Following, the book *Engineering Ethics for a Globalized World* (Murphy et al., 2015) addresses and explores a range of ethical issues in engineering in the context of economic globalization. The work's contributions lead to a deepening of a greater understanding of how globalization impacts the formulation and justification of ethical standards in engineering and how these issues are reflected in the educational engineering curriculum.

Finally, the work *Doing Good with Technologies: Taking Responsibility for the Social Role of Emerging Technologies* (Waelbers, 2011) explores how engineering practices can seek the responsibility of optimizing the social functions of technologies. Thus, the book presents an understanding of the social function of technologies, explores ways to access responsibility for this social function, and investigates some tools that help visualize the influence of technology on human behavior.

Many of the related books are present in Springer's "Philosophy of Engineering and Technology" series. In addition to those referenced here contains several publications that help bring a philosophical reflection to the debate on technology and engineering practices. These aspects covered in this book are essential for constructing a Holistic Engineering design proposed in this chapter, which also reflects in the direction of the book as a whole.

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Engineering Practices: Complexity—Diversity—Coherence—Meaningfulness

Andrew Basden

1 Introduction

During the writing of this chapter, a landmark was passed. For the first time, the total mass of humanly created structures and products exceeded the total biomass on earth (Elhacham et al., 2020). Most of those structures and products are the result of engineering. This chapter looks at the meaningfulness and complexity of engineering practices as a whole and reaches into the complexity that is the actual engineering practice.

Engineering practices are complex, whether they are engineering design, application of engineering and its delivery, or research in the engineering laboratory. This is because engineering involves many aspects simultaneously. As a result, many engineering errors occur because crucial aspects are overlooked or even culpably ignored. This has sometimes been especially true of ethics and responsibility in engineering. This complexity is not a fault or a problem but is inherent in the wonderful reality with which we have to engage and which challenges us to innovation with responsibility—which is at the very core of engineering.

My background lies first in electronics, then for many years in software engineering, leading to knowledge engineering in artificial intelligence. The latter has been in fields related to chemical and civil engineering. This places some limitations on the salience of my reflections in this chapter to other kinds of engineering, and readers should use their imagination to see how these reflections might be helpful in their fields. I cautiously hope they might be useful because I abstract away from my engineering fields to something more general, trying to reflect on the meaningfulness and complexity of engineering as a whole and in most of its kinds.

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2 The Complexity of Engineering Practices in Their Real-World Context

If engineering design starts with requirements, we find these more complex than at first appears. The idea of the design, its purpose, needs to be worked out, often as an iterative rather than logical process. The information must be gathered from clients about what is required, but frequently this is not clear and the good engineer helps them think this out. Requirements are seldom fixed, and negotiation and compromise are often required. A prototype is given to the clients—at which point they change their minds. Then there is a host of other stakeholders to consider, from those who will implement the design, to those affected by it—which moves the engineer into health and safety issues. Even more critical are indirect, long-term impacts of the implemented design on society and the wider world, including biodiversity and climate.

Then a specification must be written, usually to a tight deadline, so much is omitted or so poorly worded as to be misunderstood later. A contract is often needed, which involves lawyers.

The design activity itself has many technical intricacies, which arise only when faced with the actual reality of the medium being designed, whether physical materials, chemicals, ground conditions, electronic components, concepts, information, social relationships or even societal expectations. Each offers their unexpected twists—which sometimes requires investigation or even research. This is complicated by design errors, inconsistencies. Technical information must be obtained and its veracity checked. The thinking processes of the designer can be immensely complex, especially when faced with seemingly intractable problems, so imagination and innovation are needed. Sometimes ideas must be bounced off others or brain-stormed in a group.

Social relationships are essential: working well with colleagues, both in our team and with those elsewhere, with management, with clients, with regulators and many more. Publicity needs to be managed. Sometimes religious faith becomes a consideration. The engineer faces multiple responsibilities—not only to the client (which is often not as straightforward as we might think) but to society and the world, to colleagues, to the engineer's firm or other organizations, to do justice to the design itself, to the engineering profession, and the wider world.

All such complexities are to be taken seriously. And, when what is engineered is a whole system, such as smart grids discussed in Chap. "Towards a Holistic Normative Design", complexity increases even more. So how can we do so?

3 Gaining a Handle on Complexity

What is complexity? Manson (2001) suggests that complexity theory has recognized three main types of complexity, each with its own approach. *Algorithmic complexity* arises because of the difficulty in describing the characteristics of a system (c.f.

an engineering specification). By and large, complexity theory tries to quantify complexity as a single measure. *Deterministic complexity* arises because systems governed by deterministic rules can still be unpredictable because of sudden discontinuities (such as the well-known butterfly effect). He illustrates this by an equation for population growth, ($X_2 = A \times X_1\ (1-X_1)$), where X_1 and X_2 are populations at times 1 and 2 (measured between 0 and 1), and A is the multiplying factor. When A is between 1 and 3, the population reaches a stable amount, but when it is 3.8, population growth is completely random. What he calls *aggregate complexity* arises from the relationships and interaction between system components, learning and the emergence of "higher-level" behaviours.

All three types challenge engineering practices, as does a fourth type that Manson omits: *meeting diverse functional requirements* (El-Haik & Yang, 1999). Functional requirements can be of a wide range of types, such as resistance of electrical contacts, combinations on locks, manufacturing production schedules, space exploration (Suh, 2005).

These are very different spheres of reality, each governed by very different kinds of laws. Yet complexity theory overlooks these differences because it presupposes that "All are built on the same few rules" and so it "can explain any kind of complex system—multinational corporations, or mass extinctions, or ecosystems such as rainforests, or human consciousness" (Lewin, 1992 cited by Manson). As Manson (p. 402) remarks, there had been little progress towards that optimistic outcome; while "exciting academic cross-fertilization" might have occurred, Lewin's over-simplification is "at the expense of potentially false leads."

What is missing from most discussions within complexity theory, but underlies them, is meaningfulness and its diverse kinds. This is most obvious in the wide range of kinds of functional requirements mentioned by Suh, which are meaningful in different ways, for example, economically, technically or morally, but it challenges the other three types of complexity too. Manson mentions "topics ranging from cultural transmission and economic growth to the braiding of rivers" (p. 405). Algorithmic complexity's concern with description is challenged by the question, "Which parameters is it meaningful to include in the description, and which should we ignore?" The same question challenges deterministic complexity, and Manson implicitly recognizes that meaningful variables can be overlooked: "In the population growth example, for instance, where are the variables for culture, the state, or migration?" adding, "characterizing a human system through a few simple variables or deterministic equations is often just too, in a word, simplistic". Aggregate complexity is challenged likewise by which relationships and interactions are meaningful and which are not ("defining the boundaries" [Manson, 411]). On what grounds may emergent properties be identified except by already knowing that certain patterns are meaningful?

So, here, we focus on meaningfulness, both that of engineering practices *in the wider world* and that of what goes on *within* engineering practices.

3.1 *The Meaningful Reality of Engineering Practices*

First, what is meaningful about engineering practices *in the wider world*? What are its contributions to, and impact on, human life, to "the economy", to medicine, to education, to society's perception of itself, to reality, to God, to our perception of what it means to be human, to the natural world, to history, to our aspirations and so on? What, indeed, is engineering practice as such? And in what ways are the various branches of engineering meaningful: mechanical, electrical, civil and so on? What about social and bioengineering? This first (composite) question is the kind that might not concern those struggling with specific and immediate engineering problems and in the process of learning and gaining experience. Yet this question, of the meaningfulness of engineering practices as such, never leaves us, visiting us when sleepless at night and also returning to haunt those with a lifetime of engineering behind them. It is important at the level of strategy in business, politics and education. Suppose we lack a sound foundation on which to stand while these questions are considered and debated. In that case, we will sink into subjectivism and mere power-oriented corruption, in which engineering practices will become rudderless. Only by the meaningfulness of engineering can we begin to discuss whether it is to be applauded or regretted that engineered product exceeds biomass.

The second question is more immediate: what is meaningful *within* engineering practices? We consider all three practices—design, research, and application in the real world. (The research "lab" could be the domain of application in the world from which generic things are learned.) We may differentiate them most fundamentally, not according to their processes or personnel, but according to the kind of meaningfulness that is central in each. The practice of engineering design involves formative human power at its core. The practice of engineering research in the lab, while it involves formative power, has a human theoretical curiosity about engineering techniques, tools and technologies at its core, the same kind of curiosity found in the sciences. The practice of engineering use (or application) considers other aspects of human life, such as social, economic, artistic, legal, ethical and even sometimes religious, and aspects of physical-biotic reality, such as ground conditions encountered in building.

Each has a meaningful core rather than a boundary because there is overlap between all three. In some labs, design challenges are addressed, and in the wider world of use, design and even curiosity continue. Those engaged in design have their eye on eventual use.

Moreover, around the core of each, all the other aspects of reality are meaningful. For example, is not engineering design usually more successful when one communicates with colleagues and is generous towards them? In the everyday experience of an engineering lab, design and use, we encounter legal obligations, resource constraints, health issues, fun and excitement, courage (or cowardice) and many more, all of which can undermine or support our engineering practices. These all impose functional requirements, some explicitly stated, others implicit and some of them are the issues that unexpectedly determine outcomes.

As explained above, here we do not resort to conventional complexity theories, but to issues of meaningfulness, which underlie them. Both kinds of questions (What is meaningful *within* engineering practices and *in the wider world*) can be addressed with the same approach to meaningfulness and diversity. Thereby they may be linked together if necessary.

Let us clarify what we mean by "meaning" and "meaningfulness". To some, "meaning" is the signification we give to words, phrases and sentences. To some, "meaning" is what we attribute subjectively to things, such as my father's special chair. To some, "meaning" is what we find in the world around us by interpreting, for example, the patch of scattered feathers means a bird has been killed and might mean poaching. Yet others are concerned with the meaning of life or of one's career. The latter verges on what we mean by "meaning" here but does not quite arrive because it is usually centred on the human individual. All four treat meaning as a property. What we mean by "meaning" here is more fundamental, as follows.

All things are treated as meaningful in some way or other, whether or not there is a life or career, a patch of feathers, a chair or words, and whether or not there are humans to think about it. For example, even the smallest atom in the least significant planet of the furthest galaxy, which humans will never visit, is physically meaningful. Meaningfulness is always there, it is like an ocean in which we swim. Metaphorically, all temporal reality exists and occurs by that ocean of meaningfulness, just as it is the ocean that enables fish to swim and even to exist as fish. This includes all engineering practice.

A fuller discussion of these five types of meaning may be found in Basden (2019) and in Chapter 4 of Basden (2020), where they are called signification-meaning, attribution-meaning, interpretation-meaning, life-meaning and "oceanic" meaningfulness, and the philosophical basis is laid out, which argues that the first four arise out of, and depend on, "oceanic" meaningfulness.

By reference to this kind of "oceanic" meaningfulness, we discuss both engineering practices as such and what goes on within them, in that we treat both as occurring within that same "ocean". We aim to do this in a way that does justice to their complexity.

3.2 Diversity: Fifteen Spheres of Meaningfulness

Just as the real ocean is diverse in what it enables in fish—feeding, respiration, sensing, movement, etc.—so the ocean of meaningfulness is diverse. As engineers, we experience primarily our power to form and engineer things. We also experience distinctions among things that we encounter in engineering practice. We experience sensory feeling, sound or sight as we engage with our materials, some of which are physical, some dynamic, some spatial or conceptual, and usually a sense of quantity in most of them. As engineers, communication and relating to others is important, as are matters of economy. We experience a certain delight and beauty, a sense of doing right rather than wrong, and responsibility. We share the sense of having done a good job, especially when we not only fulfil our brief but give something more. We experience a sense of purpose, commitment and loyalty. All these things go into what makes good engineering practice—and readers will bring many more to mind.

Many aspects cut across all we do in good engineering practice, whether in the research lab, in design or in use. In fact, we find they are more-or-less the same aspects we experience in everyday life. We need a way to understand this diversity of aspects and how they relate to each other.

To understand each aspect regardless of others is the role of science (physics, sociology, psychology, design science, etc. each study their aspect and build up theoretical knowledge about it). To understand the aspects together and how they relate to each other is the role of philosophy, which Strauss (2009) calls "The Discipline of Disciplines". So, in this chapter, we employ philosophy. We do not delve into philosophy as such, but merely apply a philosophy that has an interest in this diversity at its core.

The philosophy we apply and employ is that of the twenty-century Dutch thinker, Herman Dooyeweerd. Sadly, for most of its 2500-year history, philosophy has seldom explored the nature of meaningfulness, let alone its diversity (Basden, 2019), and many philosophers have tried to reduce diversity to one aspect (e.g. materialist or social constructionist approaches), especially since many presupposed theoretical thinking as the only route to true knowledge. By contrast, Dooyeweerd began with everyday life, recognized the importance of pre-theoretical (tacit, everyday) thinking alongside theoretical and refused the seductions of reductionism. Basden (2020) argues that Dooyeweerd is the best philosopher of everyday experience to emerge so far.

By years of painstaking study, both intuitive and philosophical, and set out in Dooyeweerd (1955, II, 1–426), Dooyeweerd delineated fifteen irreducibly distinct, fundamental kinds of meaningfulness, ways in which our experience and indeed the whole of temporal reality can be meaningful. He called them "aspects", "modalities of meaning" and "law-spheres". They are given in Table 1, and can be traced in the list of what we experience, above.

Other sets of aspects have been offered, for instance in Maslow's (1943) "hierarchy" of needs and especially by systems thinkers like Wilenius, but they are largely subsets of Dooyeweerd's aspects and, in the main, lack the sound philosophical grounding worked out by Dooyeweerd (see Chapter 9 of Basden, 2020). Though Dooyeweerd's suite of aspects is probably the best available, Dooyeweerd was still adamant that it is only a best guess, because:

> "In fact the system of the law-spheres designed by us can never lay claim to material completion. A more penetrating examination may at any time bring new modal aspects of reality to the light not yet perceived before. And the discovery of new law-spheres will always require a revision and further development of our modal analyses. Theoretical thought has never finished its task. Any one who thinks he has devised a philosophical system that can be adopted unchanged by all later generations shows his absolute lack of insight into the dependence of all theoretical thought on historical development." (Dooyeweerd, 1955, II, 556)

Table 1 Dooyeweerd's aspects

Aspect	Kernel Meaning	Good
Quantitative	Amount: more and less	Reliable quantity and sequence
Spatial	Continuous extension, space	Simultaneity, continuity
Kinematic	Movement: "flowing and going"	Dynamics
Physical	Forces, energy, matter	Irreversible persistence and causality
Biotic	Life	Flourishing; organisms sustained in environment; reproduction according to kind
Sensitive	Feeling, response, emotion	Interactive engagement with world
Analytical	Conceptualising, clarifying, categorising and cogitating	Independence from the world; theoretical thinking
Formative	Formative power (deliberate shaping)	Achievement, innovation; technique, history, culture, technology
Lingual	Symbolic signification	Articulation of intended meaning
Social	Social interaction	Togetherness, institutions
Economic	Frugal management of limited resources	Sustainable prosperity
Aesthetic	Harmony, surprise, fun	Delight that seems non-necessary
Juridical	Due; appropriateness; rights, responsibilities	Justice for all
Ethical	Self-giving love	Extra goodness, beyond the imperative of due
Pistic	Vision, aspiration, commitment, creed, religion	Courage, loyalty, perseverance, hope; openness to the divine; change in direction of society

For full treatment, see "http://dooy.info/aspects.html" or "http://dooy.info/aspects.smy.html"

Dooyeweerd's aspects have proven to be an excellent conceptual tool to aid analysis, especially (a) where it is necessary to understand clearly what things mean and (b) to ensure that things often overlooked are given due regard. Many examples of this may be found in Chapter 11 of Basden (2020).

The mutual irreducibility among aspects is that the meaning of each cannot be reduced to that of others, even in combination. None can be explained in terms of others and, when we try to do so, we find our explanations thin and unsatisfying. Theories based on reductions ultimately get undermined and rules based on reductions tend to mislead.

One common reduction is to mathematics. Chapters "Economics, Regulatory Aspects and Public Policies", "Statistics and Engineering", "Analytical Optimization Applied to Social Aspects and Public Policies", and "A Multi-aspect Dynamic System Model to Assess Poverty Traps" in this book introduce algebra, statistics, calculus and simultaneous equations as tools for evaluation and decision-making in various fields. Dooyeweerd maintains, however, that functioning in each aspect works according to different laws, which cannot be reduced to each other. Expressing each meaningful issue as a quantity presupposes quantitative laws govern it. Though this is attractive because the laws of the quantitative aspect are easy to reason about, it can lead to distortion and, often, misleading results. So engineers in each field, qualified by a different aspect, must always be critically aware of how they use mathematics and be careful about treating its calculations as truths. There is always something in the laws of other aspects that cannot be fully expressed numerically. Chapter "Statistics and Engineering" recognizes this explicitly when it says, "each problem … must be treated differently from the others. … it is extremely important to understand deeply what is the problem being solved", and among experienced engineers this recognition is implicit and tacit and pervades their practice. Chapter "A Multi-aspect Dynamic System Model to Assess Poverty Traps" tries to bring multi-aspectuality into a complex mathematical model of poverty by defining many variables, but even it ignores things like ethical self-giving, pistic inspiration and aesthetic purchase of, or refusal to purchase, issues non-necessities, which the Covid-19 pandemic has brought to our attention.

3.3 Possibilities of Good

Each aspect is a sphere of meaningfulness and a sphere of law (in fact, meaningfulness implies goodness and law). Each aspect makes possible a different kind of good, ranging through things like strength of materials, health, clarity, working together, frugality, justice and courage. These and the others are shown in column 3 of Table 1.

Many of the kinds of good early in the table above we take for granted—for example, that the quantity 5 will always be more than 4—but a little imagination shows that reality would not work well if such laws were transgressed. That they are reliable makes mathematics the excellent tool it is for helping engineers think and evaluate.

Dooyeweerd's view is that all temporal reality strives towards the good in each aspect; for example, plants want to flourish. From the biotic aspect onwards, the laws can be transgressed, allowing dysfunction, for example disease rather than health, and we see that as something to be avoided, because it harms and disrupts overall flourishing. So are things like deceit, enmity and injustice, and indeed the negatives in all aspects.

All temporal activity is a functioning in all aspects simultaneously, for good or ill, and engineering practice is no exception. From Dooyeweerd, therefore, we may form the hypothesis that engineering practice works best when all those involved function well in all aspects. This has been called the Shalom Hypothesis or Principle (Basden, 2018, 83), from the Hebrew word *shalom* and the Arabic word *salaam*, denoting a broad kind of peace, prosperity, well-being, etc. In each aspect, good functioning leads to good, dysfunction leads to harm or evil. So, for example, any engineering project can be harmed by (respectively from biotic to pistic aspects) pandemic, sensory deprivation, confusion, laziness or lack of innovation, miscommunication, enmity, waste, fragmentation, injustice, self-centred attitudes and disloyalty.

Some of the good or evil are direct, perpetrated by one individual on others. However, much good and evil is indirect, especially in the social and post-social aspects, because entities respond and the response spreads. For example, when there is miscommunication, information does not flow and, as we see below, this can lead to engineering disaster. In the ethical aspect, a self-centred, cynical attitude spreads throughout a group or society, eventually pervading it. Conversely, a self-giving attitude of willingness to sacrifice ("go the extra mile") also spreads. The benefit of that often does not return to its perpetrator except very indirectly, but rather helps to set the tone of the group and society so that things in general work better.

It is the ability to differentiate the distinct meaningfulness and laws of each aspect that gives us a handle on the complexity we encounter in temporal reality—and especially that of engineering design, research and application. The laws and norms of aspects offer a conceptual tool with which to explore and understand complex normativity. They can guide engineering practice and can also be used to predict engineering outcomes. The laws of the quantitative to physical aspects are largely deterministic (except at the quantum scale), but the laws of the biotic to pistic aspects are increasingly non-deterministic. Despite non-determinism, Dooyeweerd believed we cannot escape the "retribution" that each aspect affords for good or ill.

In such ways, Dooyeweerd enables us to go beyond a mere numerical balancing of good and bad, to understanding its various kinds and the relationships among them. These relationships are discussed in the next section.

3.4 Coherence: Inter-aspect Relationships

In engineering practice, reductionism is harmful in that it tries to deny rather than face real complexity. In reductionism, we overlook or even ignore aspects that prove essential to good engineering. When we ignore an aspect we often go against its laws, so our practice becomes dysfunctional according to that aspect and jeopardizes the success of the whole, especially in the longer term. So, in both engineering and science and everyday life, it is advisable to take all the aspects together, even though we might give one more attention than others. This is because the aspects exhibit an inherent coherence.

Together the aspects form what we have called the "ocean of meaningfulness," which Dooyeweerd called "coherence of meaning" (Dooyeweerd, 1955, I, 4). Just as the ocean lends a coherence to the various functions that fish perform and their entire experience as fish, the "ocean" of meaningfulness lends coherence to all temporal reality, human and non-human, to engineering, to science and to everyday life. This does not arise from human thinking but from the very structure of meaningfulness itself. All aspects relate inherently to other aspects, and do so in several ways that are important in engineering practice.

Multi-aspectual simultaneity. All things, activities and situations exhibit all aspects simultaneously. The idea of multi-aspectual functioning will be important throughout this chapter.

No conflict. Dooyeweerd held (1955, II, 3) that there is no conflict among aspects, all contributing to the full actualization of others. This is the basis of the *Shalom* hypothesis/principle. Apparent conflicts (such as "Being virtuous jeopardizes economic success!", as expressed in Mandeville's *Fable of the Bees*, suggesting a conflict between the ethical and economic aspects) arise from aspectual dysfunction, from misunderstanding the kernel meaningfulness of an aspect (e.g. that of the economic aspect as profit-maximization rather than frugality) or from reducing one aspect to another, and all three problems can be avoided.

Inter-aspect analogy. Each aspect contains analogical echoes of all the others. For example, causality is physical but logical implication and historical bringing-about resemble this; see Dooyeweerd's own account of many analogies (1955, II, 118ff). (Inter-aspect analogy is not to be confused with the concrete analogies that we make between things, such as "She is a peach"; rather it is what enables metaphors to "work".) Inter-aspect analogy can be useful in engineering practice to stimulate fresh ideas, though too much reliance on analogy can mislead because the laws of one aspect cannot be reduced to those of another. Example: The organic metaphors of growth, health and survival have been unquestioningly applied to businesses and nations, and some argue that this has led economics astray (Pilling, 2018).

Inter-aspect dependency. Each aspect depends on other aspects (Dooyeweerd, 1955, III, 91) for the fulfilment of its meaningfulness, but differently in the two directions. *Foundational dependency* (or *retrocipatory dependency*) means that functioning in an aspect depends on good functioning in an earlier aspect. The earlier aspects provide a substratum or foundation, for example most social activity depends on good lingual functioning, and much engineering practice depends on physical functioning. *Transcendental dependency* (or *anticipatory dependency*) works in the opposite direction. An aspect's full meaningfulness cannot be opened up without anticipating later ones; for example, our lingual functioning would be limited to making notes for ourselves if not involving the social. Anticipating the social aspect introduces new issues into linguistics (and into engineering specifications!) such as agreement over word meanings. For example, in engineering practice, much civil engineering, governed primarily by spatial, physical and formative laws, anticipates the functioning of the economy.

Order of aspects. Inter-aspect dependency gives the aspects an order, not lower to higher, but earlier to later, which is shown in Table 1.

Targeting. Our actual functioning in any aspect often targets another. Examples: When we count pebbles or pronouns, we function in the quantitative aspect, targeting physical and lingual, respectively. When I utter "This rose is red" I am functioning in the lingual aspect, targeting the biotic (plant) and psychical (colour). Aspectual targeting helps define different kinds of engineering; see Table 2.

[These inter-aspect relationships are not so clearly distinguished in Dooyeweerd's own writings as is needed here for clear understanding below, but follow Basden (2020, 52–55)].

Table 2 Kinds of engineering and their target aspects

Engineering discipline	Target aspects
Mechanical engineering	Physical, spatial
Chemical engineering	Physical, kinematic (e.g. fluid and heat flows)
Aeronautical engineering	Physical, kinematic (air flow)
Civil engineering	Spatial, physical, some social
Bio-engineering	Biotic, physical
Electrical engineering	Psychical, organic[a], physical, analytical
Acoustical engineering	Physical, kinematic, spatial, aesthetic
Software engineering	Analytical (variables and instructions)
Social engineering	Social, lingual
Telecommunications engineering	See below

[a] The organic aspect (another name for biotic) is understood by some as organs and components maintaining their functioning, the psychical as analog signals, and the analytical as digital signals. Not all agree

In the multi-aspectual functioning that is engineering practice, most of these inter-aspect relationships are experienced, but especially those of simultaneity, targeting and dependency (in both directions), as will be seen below. In interdisciplinary practice especially they are important, and understanding of how each aspect relates to others can make this more fruitful. Chapter "The Interdisciplinary Nature of Engineering Education and Practice" discusses the interdisciplinary nature of engineering practice and education, and the above might help us understand the complexities therein. Basden (2021) discusses how aspects can help us understand and integrate a wide range of disciplines or fields of research.

What inspired Dooyeweerd towards his taking diversity and coherence seriously (and not seeing them as mutually exclusive) was his Christian faith. Just as it was his Christian faith that opened Faraday's mind to the possibility of magnetism being a force that acts at a distance (Russell, 2000), so it is Dooyeweerd's idea that temporal reality is Created, rather than just happening to be, and thus is meaningful, which opened his mind to the possibility that meaningfulness can be taken seriously and explored philosophically (Chapter 5 of Basden, 2020). However, just as it is not necessary to be a Christian believer to use or study magnetism, so nor is it, in order to benefit from Dooyeweerd's ideas and especially from using his aspects. This is why they are recommended here.

3.5 Things; Types of Engineering

Though all things function in all aspects, we notice that in some things one aspect is more important than others in defining its meaningfulness, and how it relates to other things. For plants, the biotic aspect is most important, for animals, the psychical, for words, the lingual, for institutions, the social, and for faiths, the pistic. Dooyeweerd called this the qualifying aspect. Qualifying aspects define main types of things.

This includes types of activity. The scientific enterprise is qualified by the analytical aspect, in its guise as theoretical thought. The mandate of science is to separate the laws that govern our functioning in each aspect so that humanity's bodies of knowledge may be clear. This generates theories—though it requires lingual functioning to express and communicate them.

Engineering practice is qualified by the formative aspect, since it wishes to form things and enable humans to achieve more.

This idea of qualifying aspect can prevent dominance by an inappropriate aspect—as found also in Chap. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures". For example, whereas engineering can help a firm make money (economic aspect), if its practice is dominated and constrained by money-making, it becomes corrupted and impoverished as engineering. Ironically, the firm can then gradually become less profitable, as we see in one of the cases of engineering failure discussed later. Understanding which aspects are most important and being aware of all aspects can help guide engineering practice.

While engineering is qualified by the formative aspect, different kinds of engineering are defined by a secondary aspect, which the formative aspect targets, as shown in Table 2.

Taking into account the target aspects of the formative functioning that is engineering helps to clarify which kinds of issues, concepts and theories are likely to be useful in that kind of engineering, and hence which disciplines the engineering activity should involve in its interdisciplinary working.

I have included social engineering above, even though many would see "engineering" as only metaphorical there, to indicate why the metaphor is appropriate, namely the formative power over social relationships and institutions. This, perhaps, also clarifies why social engineering may be an inappropriate occupation if we believe the social aspect should not be formed in such ways.

In Chap. "Smart Telecommunications: The Catalyst of a Social Revolution", on telecommunications engineering, many aspects may be detected: the spatial (distance and area), the physical in transmission medium, the biotic in organs like eyes, ears, the psychical in channels and analog signals, the analytical in digital signals, the linguistic in the meaning of signals, the social in agreed protocols and the difference between formal, informal and unofficial "channels".

Everything involves a coherence of all the aspects. Together they define or determine what the thing is, what it can become, what it should (and should not) be in the real world of actuality rather than merely the rarified world of theory or philosophy. The very meaningfulness of a thing is its coherence of meaning. So, in the next section, we seek to understand the overall meaningfulness and mandate of engineering in terms of its qualifying aspects.

4 Engineering in an Ocean of Meaningfulness

What is the meaning of engineering practice: Why bother with engineering research, design and use? Is it to be applauded or regretted that engineered product exceeds biomass? And what is meaningful within engineering practice, as we undertake it? Those questions, introduced at the start, are questions about meaningfulness. They will now be examined by reference to Dooyeweerd's aspects, as ways in which things can be meaningful.

4.1 What is Meaningful About *Engineering as Such?*

"While I'm worth
my room on this earth ..."
The Proclaimers, *Sunshine on Leith*

In Britain, especially England, there has long been a problem, that scientists and artists look down on engineers. Why? And what can be done to overcome that disdain? One reason is that scientists and artists tend to take an aristocratic view, in which they are superior to, separated from, everyday life, whereas engineers are necessarily engaged with reality.

Recognizing the meaningfulness of each function in terms of aspects can help us understand and perhaps overcome the disdain. Disdain is a dysfunction in the social and/or pistic aspects, and many artists and scientists do not succumb to it. Where they occur, different kinds of disdain have a different root, in what Dooyeweerd called the qualifying aspect of their role. This is the aspect that most makes an activity meaningful and worthwhile, and it defines their responsibility within Creation as a whole. For art, this is the aesthetic aspect, of which snobbery is a common dysfunction. For science, the qualifying aspect is the analytical, of distinction-making. Dooyeweerd argued that distinction-making is the necessary core of theoretical, abstractive thinking found in science, and is of two kinds (Geerstema, 2021, 116–7): separation of an aspect from the others as a focus of study, and separation of the thinker from the world being studied. This can become disdain—though it need not do so.

Both art and science—and all other kinds of human activity, including engineering—are given a valid role and responsibility by their qualifying aspects: to make reality more beautiful and to understand it theoretically. The formative aspect gives the role and responsibility of engineering: to innovate, to form, to achieve. These activities necessarily require engagement with the world, with the realities of the materials being formed. Though these are of different kinds, as indicated in Table 2 above, the formative aspect is common to all. It is the formative aspect that makes engineering practice worthwhile globally and is the qualifying aspect of engineering. It is engineering practice that creates tools and technologies that enable people to achieve more within the world they engage in. This is why, in engineering courses, a considerable amount of attention is given to developing good formative functioning in students, especially in the form of skills learned by practice—whatever the target aspect of the kind of engineering. All these things—skills, tools, techniques, technologies and planning, executing, constructing and achieving, and "work" discussed in Chap. "The Engineer in the Face of Social Changes: The Cases of Health and Sustainability at Work"—are qualified by the formative aspect. The formative aspect gives engineering as such its mandate and importance.

Heidegger is famous for emphasizing immersion in the world, and Dooyeweerd works this out more fundamentally. He argued that, scientific theorization, rather than giving true knowledge of reality, leads to narrow, partial and distorted knowledge. So, because of its wider engagement with the world, might it be that engineering understands reality better than either science or art?

It is usually expected that the norm that primarily guides something is that of its qualifying aspect. However, Schuurman (1980), exploring this in some depth, including philosophically, concluded that technology should not be guided only by the norm of its qualifying formative aspect but by the norms of all other aspects. The formative functioning of engineering should serve other aspects, to enable their functioning to be more effective. Readers might have noticed that the definition of engineering and technology offered in Chap. "Introduction", of meeting needs and wants and fulfilling needs and desires, does not specify whether those wants or desires are just or unjust; that is because justice is of the juridical, not formative, aspect. Both aspects must be considered together when considering the whole of reality. So, for example, electrical engineering serves the juridical aspect of just distribution via electrical grids (including local grids and renewable energy) (Verkerk et al., 2018). Chapter "The Engineer in the Face of Social Changes: The Cases of Health and Sustainability at Work" likewise may be understood as discussing the importance of the social aspect alongside the formative. But when engineering is guided only by the formative norm (e.g. "technology for technology's sake"), we find the engineers' equivalent of the disdain of artists and scientists—a dysfunction particular to the formative aspect.

The word "guided" is important. Our formative functioning in engineering should serve the norms of other aspects, but never be dominated by them. When an engineering project is dominated by other norms, such as the pistic-juridical norms of politics, the lingual-pistic demands of the marketing department or the economic-pistic demands of management, it often fails. Notice the prevalence of the pistic aspect there, the aspect of belief and ultimate meaningfulness. In its right role, it enhances engineering practice with motivation, commitment and courage, but when others function pistically to impose their own hidden agendas on engineers, the result is often failure and harm, especially in the longer term. This aspectual approach enables us to distance ourselves from the view that sees engineering as only and merely in the service of business; such a view would replace the formative aspect of engineering with the economic, and an impoverished version thereof, at that.

The aspectual approach also throws light on the difference between engineering research, design and application in aspectual terms. If engineering research aims to discover ways to achieve things, then alongside its primary formative aspect is the analytical aspect that also governs scientific research. Engineering design and application might be seen as more purely formative in its meaningfulness, but with different manifestations of the formative aspect. The meaningfulness of engineering design is to form products or systems. The meaningfulness of engineering application is to help humanity achieve more good through using those products or systems, which is meaningful in the ethical aspect.

To understand the meaningfulness of engineering practices fully, however, calls us to understand also that of the activities and issues that occur *within* them.

4.2 *What are the Meaningful Activities and Issues* Within *Engineering Practice?*

Now we look at the activities within engineering practice from an aspectual point of view, remembering that the overall mandate of all engineering practice is meaningful primarily by reference to the formative aspect, but which serves and opens up the norms of other aspects. For the practice of each of engineering research, design and application, we consider our functioning in each aspect, as individuals, as teams, companies, etc. Space prevents full discussion, so we focus on just a few aspects in order to demonstrate how such understanding may be fostered. Reference to several engineering failures will provide illustration.

4.2.1 The Multi-aspectual Functioning of Engineering Research

The functioning during engineering research in the laboratory is similar to that which occurs in the sciences, which is discussed aspect by aspect in Chapter 10 of Basden (2020), to which readers are referred. The following is a summary tailored to engineering research.

The qualifying aspect of the sciences is the analytical, the overall aim being to crisply identify pieces of (theoretical) understanding about the laws of the core aspect of that science. In engineering research, this is accompanied by the formative aspect in that the research is intended to crisply identify good ways of engineering. (Though philosophers might discuss whether analytical or formative leads, here we take both together as leading.)

In software engineering, for instance, this would include new algorithms, data structures and software engineering techniques. These take into account the laws and meaningfulness of target aspect(s): spatial for geographic information system algorithms, quantitative for those that discover prime numbers, economic and juridical for block-chains and so on.

With the formative and analytical, all the other aspects constitute, together and simultaneously, the multi-aspectual functioning that is engineering research. The engineers' psychical functioning is the feelings they have and their mental activity.

Their lingual functioning is in communicating and recording, for example in documentation, in communications with colleagues, with clients, with the public, etc. Publicity is a lingual functioning.

Of the post-social aspects, most are similar to that of the scientist. For instance, the economic is to do with management of resources guided by the norm of frugality—not only money (budgets), but time, patience, components, materials, information storage or anything that is limited.

Two aspects are particularly worth our attention in engineering. The research engineer's pistic functioning is, as with the scientist's, exhibited in their motivating ideological or religious basic beliefs and commitments as the answer to "Why do I/we research?", whether such beliefs are declared openly or are hidden (including hidden agendas). Commitments are to their research topic, to quality engineering research, which makes them persevere when faced with difficulties, to colleagues, institutions and the research project (many projects have failed when key people left), and may be seen in the personal courage of individual engineers in the face of disinterest or opposition, and also, negatively, in idolatry (elevation of something to absolute status to which other things are sacrificed), in stubbornness, in disloyalty and so on (Basden, 2020, 222–3).

The research engineer's aesthetic functioning is exhibited in their harmonizing of all aspects of their research rather than ignoring any or artificially setting one against another, and in harmonizing their research with the outside world, whether the academic world of other theories, or the world of application and practice—this leads into their ethical functioning of putting the needs of others before their own—and then also in the excitement and satisfaction encountered during research, and so on (Basden, 2020, 227–8).

These two aspects must suffice to show how each aspect manifests itself in multiple ways in the activity of engineering research, all of which constitute the real, lived experience of the research engineer. Yet other ways will be found by the engineer who reflects on what they are doing. Sadly, too little is written on such "down-to-earth" issues (Ahmad & Basden, 2013).

In learning engineering research, it is the formative and analytical aspects that form the core, especially in techniques of both research and engineering (of the relevant type). Good engineering research learning, however, will cover all the other aspects, often inculcating them by the culture that permeates the research group. This, perhaps, is what distinguishes a good from an ordinary research group.

4.2.2 The Multi-aspectual Functioning of Engineering Design

Likewise, engineering design is a richly multi-aspectual human functioning, though perhaps led more purely by the formative aspect. Designers might not need to learn so much about research, for example, but a good design school is still distinguished from ordinary ones by the way it teaches and especially inculcates all the other aspects of engineering design.

The techniques of the formative aspect of engineering design will be given priority, with practice and development of skills rather than just learning of theory. Readers will well know what these engineering activities and skills are—planning, analysis prior to design, design itself, construction (programming in software engineering), testing, etc.—because they are given explicit and detailed attention, so here I will turn to some other aspects, especially some of what Chap. "Industrial Innovation Practices Breakthrough By Process Intensification" calls the "soft" issues of design, which are crucial for success but too often sidelined. The discussion of each aspect in Chapter 10 of Basden (2020) is still relevant, though perhaps needing some imaginative reinterpretation.

The pistic aspect of engineering design is exhibited in ways similar to those of engineering research (commitment, etc.), and so is the aesthetic aspect, except that what is harmonized, enjoyed, etc. is design rather than research. How will the designed product harmonize with the context in which it will be applied? The answer is not necessarily to fit snugly therein, but to act as stimulant (compare to instruments in a symphony). The aesthetic aspect is also manifested in the beauty of the finished product; I particularly appreciate, for example, the beauty of well-engineered steel, especially on steam locomotives. Even computer programs produced by software engineering can exhibit aesthetics, as Knuth (2001, 130) remarks,

> I got hold of a program from IBM called SOAP, written by Stan Poley. That program was absolutely beautiful. Reading it was just like hearing a symphony, because every instruction was sort of doing two things and everything came together gracefully. I also read the code of a compiler that was written by …: that code was plodding and excruciating to read, because it just didn't possess any wit whatsoever. It got the job done, but its use of the computer was very disappointing. So I was encouraged to rewrite that program in a way that would approach the style of Stan Poley. In fact, that's how I got into software.

Thinking about the juridical aspect of engineering design brings to mind doing justice to the design specification, to clients, to colleagues, to management, to the profession, to society and the world—justice includes speaking truth to power. It is also especially manifested in doing justice to the design and the eventual product; corner-cutting is a juridical dysfunction and, as such, can lead to problems that emerge only in the longer term. The ethical aspect of engineering design is the attitude of the engineer, their team, their company and their profession. Many in the UK construction industry, for example, maintained an attitude of self-protection (ethical dysfunction) that led, via other functionings to the Grenfell Tower disaster. As I write, the Grenfell Tower Inquiry is ongoing, and the company that supplied combustible insulation rigged their testing (just within the law!) to show that their products were no more dangerous than non-combustible products. That testing itself is, of course, part of the main formative functioning of engineering design of a product, but the way it is carried out is influenced by the engineer's functioning in later aspects like the ethical.

Chapters "Social and Economic Implications of Electricity Generation Sources" and "Amazon Region Power Plants and Social Impacts" contain detailed discussion of hydroelectric engineering responsibilities towards many aspects, including the biotic ("environmental"), lingual (ensuring views are heard), social, economic, juridical and pistic (cultural beliefs) aspects. Chapter "Scalability and Normativity—System Requirement Definition based on Social and Philosophical Consideration" contains a more general discussion of the need for engineering design and application to consider all aspects, and which expands on what is discussed here.

Engineering design often takes place during use, especially in civil engineering, when the two must be considered together.

4.2.3 The Multi-aspectual Functioning of Engineering in Use

If the primary mandate of engineering applied in the real world is to enable human beings to achieve more than we could before, which is meaningful in the formative aspect as discussed earlier, then the second most important aspect may be the juridical, the aspect of responsibility. This because the "more than we could before" is something new, and which might impact its wider stakeholders (the world, people, especially those who have no control of the engineering) in ways unexpected and unforeseen, whether for good or ill.

Looking into the juridical aspect of engineering application more closely reveals a multitude of responsibilities—to clients, to society, to the world, and, internally, to colleagues, to the project, and the engineering institutions. However, from a Dooyeweerdian understanding of juridicality, responsibility extends further than we might expect. Responsibility to clients, for example, extends beyond "What does the client want?" to what is justice for the client, so it is the engineer's responsibility, and part of their remit, to help the client understand what is needed rather than what is wanted, and also help the client to recognize their own wider responsibilities in the world.

True juridical functioning means listening to those who have no voices as well as those who do. It means listening, for example, to the requirements of the poor and the requirements of the non-human world, especially in relation to biodiversity and climate, doing justice to animals and habitats, and of course, these closely intertwine with the requirements of future generations. These are what would be called "stakeholders" in Chap. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures", where a fuller discussion may be found for engineering of energy systems. Chapter "Amazon Region Power Plants and Social Impacts" contains a useful discussion of them in relation to hydroelectric systems.

The legal frameworks within which engineers operate—globally, nationally and locally—may be understood, not as the total of responsibility in themselves, but as lingual expressions of some portions of the whole responsibility. This is why merely keeping within the law is not enough—as has become clear during the Grenfell Tower Inquiry.

Responsibility should be tempered by attitude: the ethical aspect of engineering in the world. Good engineers see themselves as serving the world rather than expecting the world to serve the engineer—even in employing the engineer since employment for its own sake has little meaning. When the engineer's employment is in the service of something else, it becomes much more satisfying and meaningful.

Wider justice and responsibility is to think in terms of every aspect of the functioning of the engineered product or system in its situation. A good engineer will consider all these things. To discuss this, we will examine several failures as examples. Many engineering failures can be seen as arising from transgressing the laws of various aspects. CWRU (2020) briefly lists *5 Disastrous Engineering Failures Due to Ethics*, which it is instructive to analyse by aspect.

The failure of the Ford Pinto car arose from dysfunction in the ethical aspect, namely selfishness and self-protection. Late into its development (during the 1970s) engineers discovered that the fuel tank could easily be punctured, leading to fire risk, and suggested a solution that would add $11 to the cost of the vehicle. The Ford management, however, decided to continue with the design as it was, to maintain their competitive position and not delay the launch. As a result, people died when the car caught fire. The company resisted efforts to change the design until bad publicity forced them to do so. Ironically, trying to save $11 per car cost them many millions of dollars.

The Love Canal is listed as the USA's first environmental disaster. Constructed before 1900 but never completed, it was sold to a chemical company in 1947, who lined it with clay to be a dump for waste and chemicals. In 1953, filled and covered with soil, it was sold again and houses and an elementary school were built on it. In the construction of these, the clay seal was broken, so chemicals leached into the surrounding ground, causing many health problems. In choosing the site, the Board of Education had ignored strict guidelines, a juridical dysfunction.

Juridical dysfunction of failing to follow guidelines was one reason why the New Orleans Levees failed during Hurricane Katrina. The engineers who did so also relied on false information about heights and ignored information about ground sinking (pistic dysfunction). The authorities failed to fund and maintain the system (economic dysfunction). A total of 1800 people died, and the disaster cost $100 billion. This combination of aspectual dysfunction means that "No one single decision led to the disaster, but rather systemic failures were the cause."

Dysfunction in the lingual aspect, "lack of proper communication," caused the Hyatt Regency Hotel Walkway disaster in 1981, when suspended walkways collapsed, killing and injuring many. A design change, which resulted in suspension rods supporting twice the load they should have done, was not communicated to be properly analysed.

Many dysfunctions led to the Titanic disaster, including use of low-quality iron in the rivets so the ship broke up too easily, and not properly sealing the supposedly watertight cabins (physical, formative aspects). However, one above all was disastrous: insufficient lifeboats being available to serve all 2200 passengers (economic-juridical dysfunction). This occurred partly because the owners had asked for the number to be reduced because it made the ship look unsafe and too crowded—a pistic dysfunction in giving more importance to aesthetics than to safety.

CWRU emphasizes the importance of "leadership". Two aspects are most important in leadership, the final two aspects, ethical and pistic, because our functioning in them deeply influences our functioning in all earlier aspects. Ethical dysfunction is clear in the attitude of the Ford company refusing to sanction the necessary design change and the owners of the Titanic putting the marketing of their ship above the interests of passengers and crew. Pistic dysfunction is often found in what owners or project leaders most deeply believe, commit to and treat as of ultimate importance, and especially in project choices, as seen in the Titanic, and in deciding that guidelines do not matter in the cases of the Love Canal and the New Orleans Levees. Lower-level pistic dysfunction occurs among mid-range engineers, for example when relying on false information.

In most cases of failure, closer examination reveals further aspectual dysfunction, often rooted ultimately in ethical and pistic dysfunction. For example, the lingual dysfunction of lack of proper communication is actually more complex, as the source document (ASCE, 2007) makes clear, being multi-aspectual functioning by several people, with aspects inserted that make each failure meaningful:

> The engineer of record further contended that it was common practice {soc-pis} in the industry for the structural engineer to leave the design {fmv} of steel-to-steel connections to the fabricator {soc}. The original design provided in the structural drawings was intended only {pis} to be conceptual {anl}. When the fabricators found that design to be impracticable {fmv}, they requested approval {lng} of the double-rod system by telephone. The structural engineer verbally approved the change {lng}, with the understanding {pis} that a written request for the change would be submitted {lng} for formal approval {jur{. This follow-up request was never honored {pis}. In fact, the fabricators had just begun work on the shop drawings when a sudden increase in workload {eco} required them to subcontract {soc} the work to an outside detailer. That detailer, in turn, mistakenly believed {pis} that the double-rod connection on the shop drawings had already been designed and therefore {anl} performed no calculations on the connection himself.

In such ways, we see the ability of aspectual analysis to help us tease out the complexity of engineering in the real world, and the pervasiveness of the pistic aspect even at the level of the engineers, in assumptions made, which affected all other functioning.

Yet it can take us even further when we ask about the inter-aspect relationships, especially dependencies in both directions. Dooyeweerd denied there was any causality between aspects, in that our functioning in one aspect never absolutely requires, and certainly can never justify, our functioning in another, but instead Dooyeweerd points to inter-aspect dependency. So, "a sudden increase in workload {eco} required them to subcontract {soc} the work to an outside detailer" does not imply deterministic causality but rather just one manifestation of the way the economic aspect depends on the social. This can be fulfilled in several ways, so there were other options. It is management pistic functioning that is choosing between them.

Chapter "The Need of Normative Technologies for Smart Living Cities" discusses sectors of society and which technologies might make them "smart". The sectors mentioned happen to be qualified by different aspects: communications (lingual), energy (physical), food (biotic), healthcare (biotic, psychical), safety (juridical), transportation (kinematic, economic), waste management (economic, analytic), water (physical, biotic). Different technologies support good functioning in each aspect. However, Dooyeweerd's aspects might prompt us to ask whether other sectors should be considered for the missing aspects, such as ethical and aesthetic.

Thus far we have discussed aspects of how engineers impact the world. In reverse, the world impacts engineering and technologies in each aspect. Chapter "The Socio-economic Implications of the Coronavirus Pandemic: A Brazilian Electric Sector Analysis", for example, discusses in some depth how the biotic aspect (a pandemic) affected electricity systems. Similar discussions are called for about the impact of all other aspects, from physical (e.g. earthquakes) to pistic/faith aspect (e.g. both morale and religious commitment can either restrict or stimulate innovation).

An understanding of inter-aspect dependency can help engineers work out more precisely what is needed and perhaps justify it—and more fully, so nothing needs to be overlooked. Anticipatory dependency along with inter-aspect analogy can broaden and stimulate the engineers' imagination and foster innovation. Foundational dependency is about how this might be realized in practice.

5 Conclusion

This chapter has introduced a way of understanding the complex meaningfulness of engineering practices, in design, research in the lab and in the application. It has reflected on the meaningfulness of these three engineering practices in the wider world: what is their role, mandate? This was followed by a discussion of the complex nature of the activities of engineering practice. To do this, we employed the ideas of Dooyeweerd, who is arguably the best philosopher of meaningfulness and everyday experience yet to emerge. Dooyeweerd studied meaningfulness as such, not just meanings in signification, attribution, interpretation or even the meaning of life, but meaningfulness in its full diversity and coherence. His suite of 15 aspects offers us a conceptual tool with which to get a handle on both the meaningfulness of engineering as such and also the complexity that is engineering practice. We have looked at how each aspect may be relevant in this and briefly looked at inter-aspect relationships.

With this, we can understand the complexity that is engineering practice, and perhaps to offer direction for guiding it, at each of the strategic, tactical and operational levels. And it gives us norms by which we can evaluate it in a complex yet structured way, taking into account all the norms of all the aspects.

This chapter can perhaps serve the other chapters of this book in two ways. Its way of applying Dooyeweerd's ideas to engineering design, research and application, across many kinds of engineering, can act as a philosophical underpinning. Then, with this, the proposals made by other chapters might be affirmed, critiqued and perhaps enriched. Many chapters (especially "The Engineer in the Face of Social Changes: The Cases of Health and Sustainability at Work", "Sustainability and the Responsibility of Engineers", "The Socio-economic Implications of the Coronavirus Pandemic: A Brazilian Electric Sector Analysis", "Social and Economic Implications of Electricity Generation Sources", "Amazon Region Power Plants and Social Impacts", "Scalability and Normativity—System Requirement Definition Based on Social and Philosophical Consideration", "Microgrid Operation and the Social Impact of Its Deployment") emphasize the importance of "social" aspects in addition to technical ones, so Dooyeweerd's distinguishing of social to pistic aspects can bring clarity and fresh insights.

For example, Chap. "Sustainability and the Responsibility of Engineers" provides an excellent discussion of the social aspects of sustainable energy, taking into account many of the later aspects, especially the formative, social, economic, juridical and faith aspects, and does so in insightful ways. Recognizing this, however, reveals an aspect that is given less attention, the ethical aspect of self-giving attitude. In its suggestion of a co-construction stage, for example, the chapter emphasizes the need for social agreement about visions (faith aspect), but how may this be achieved except by when an attitude pervades society of willingness to give up one's vision in favour of others? Adding this to the discussion of co-construction would enrich and strengthen it.

In such ways, Dooyeweerd's suite of aspects can offer useful critique of what is proposed in most chapters, accompanied by suggestions for how their proposals may be enriched.

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Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures

Maarten J. Verkerk, Paulo Fernando Ribeiro, and Rafael S. Salles

1 Introduction

In the foregoing chapter, Andrew Basden has offered a framework to understand the complexity of real life. He argues that real life is complex at a very fundamental level: reality unfolds itself in many different aspects and dimensions, for example, physical, formative, social, economic, juridical and moral. He shows that engineers have to understand this complexity in order to design meaningful solutions.

In this chapter, we continue the journey of Basden. Especially, we will focus on networks or infrastructures that exhibit new levels of interaction and complexity, e.g. the electrical energy infrastructure of the future and the idea of smart cities. We will show that this type of networks or infrastructures bring out the need of a full understanding of their complexity and a detailed insight into their various normativities. Additionally, this type of networks or infrastructures require a multidisciplinary approach in design.

This chapter has the following set-up. Section 2 takes its starting point in the world of the engineer. This section recognises that engineers are driven by values, interact with stakeholders and are influenced by developments in society. Section 3 introduces some key distinctions to understand networks or infrastructures that exhibit new levels of interaction and complexity. Three types of complexity are identified: (a) aspect or dimensional complexity, (b) thing or whole complexity and (c) network or infrastructure complexity. Sections 4, 5 and 6 explore each of these complexities. It

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is shown that each type of complexity has its own normative structure. Further, it is argued that doing justice to these normative structures is a challenge for engineers in designing networks and infrastructures. Section 7 concludes with some conclusions.

We would like to remark that the Chaps. “Key Concepts for Frameworks: Values, Aspects, Normativity and Enkaptic Structures” and “Toward a Holistic Normative Design” form a diptych. Chap. “Key Concepts for Frameworks: Values, Aspects, Normativity and Enkaptic Structures” outlines the key concepts, values and normativity for designing networks or infrastructures that exhibit new levels of interaction and complexity. Chap. “Toward a Holistic Normative Design” focusses on the design of one of this type of networks or infrastructures: the electrical energy infrastructure of the future or the development of smart grids. It illustrates the importance of distinguishing different types of complexity and their specific normativities. To facilitate the understanding of this line of thinking, the examples presented in Chap. “Key Concepts for Frameworks: Values, Aspects, Normativity and Enkaptic Structures” are taken from Chap. “Toward a Holistic Normative Design”.

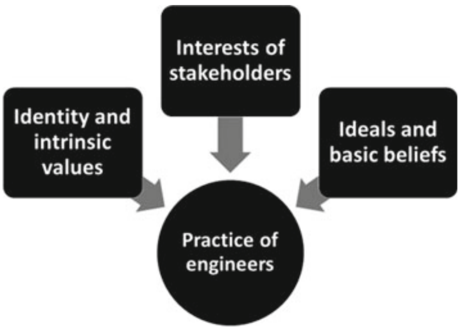
2 The World of the Engineer

I would like to start with the world of the engineer. Engineers are working in different settings, for example, in Research and Development (R&D), Manufacturing (MFG) or Operations (OPS) and Marketing and Sales (M&S). In addition, engineers are found in quality departments, maintenance departments, and management functions. In this chapter, we focus on engineers working in R&D department.

In this section, we use the expressing ‘practice of engineers’. The reason is that we would like to take our starting point in the everyday activities of engineers. It is about what they do, what they say and who they meet. The Triple I model offers three perspectives to understand the practice of engineers, see Fig. 1.

The first perspective represents the world of the engineer. The identity of the R&D department is innovation. Engineers are challenged by technology. They want

Fig. 1 Triple I model



to improve existing processes, develop new processes, improve the quality of products or develop new products. Generally, engineers in R&D departments share values: being innovative, efficiency, sustainability, safety, health and so on. The second perspective refers to the world of the stakeholders. Engineers interact with a lot of different parties, for example, customers, researchers in universities, contractors and so on. All these stakeholders have their own interests and pursue certain values. Engineers must take this into account. The third perspective is about the influence of society. Engineers are also a citizen. They do all types of activities in society. They read papers and watch television. They are influenced by the spirit of the times. For example, nowadays the ideas of renewable energy sources and sustainability are very important. Engineers also have to take the ideals and basic beliefs of society into account.

We would like to emphasise the word 'perspective'. The Triple I model does not identify different 'parts' of practice but proposes different points of view to understand the complexity of the practice of engineers. In other words, it offers different pairs of glasses 'to read' and 'to understand' a practice. The Triple I model has been developed in close cooperation with scientists and engineers (Verkerk, 2014). In Chap. "Industrial Innovation Practices Breakthrough by Process Intensification", we will discuss this model in more detail.

The key question of this chapter is: How to translate the values of engineers, the interests of stakeholders and the beliefs in society into a holistic design?

3 Key Distinctions: Aspects, Wholes and Enkaptic Structures Infrastructure

Engineers have the natural tendency to translate complex problems into simple and well-arranged models. However understandable this natural tendency is, there is a danger that important features of the complexity will be lost. As a result, the proposed solutions are not satisfactory, and a lot of time and money is invested for nothing. In popular terms: too simple models lead to too simple designs, and too simple designs will lead to large disasters.

How to prevent too simple models? The discipline that deals with such questions is the philosophy of technology. In this section, we borrow three key distinctions from this discipline to analyse and to understand the complexity of holistic designs: the distinction between aspects, wholes and enkaptic structures. These key concepts are mainly based on the ideas of the Dutch philosopher Herman Dooyeweerd (1894–1977) who has developed a couple of philosophical theories to understand the complexity of reality. Verkerk et al. (2016) have written an accessible introduction to these theories for engineers and business people. Recently, Verkerk et al., (2018) have done an explorative philosophical study of envisaging the electrical energy infrastructure of the future. In this chapter, we make extensive use of the results of that study.

Philosophical theories are not easy to digest. Even when they are written in an accessible way. The reason is that complex problems often require a new vocabulary to understand its intricacies. Additionally, it is an illusion to believe that complex problems can be solved by simple models. In other words, we have to accept that it takes time and energy to understand and to apply the key concepts proposed in this section.

Dooyeweerd (1969) has put a lot of effort into understanding the complexity of reality. One of his fundamental insights is to make a distinction between ‘aspects’ or ‘dimensions’, ‘wholes’ or ‘entities’ and ‘enkaptic structures’ or ‘networks’. In our view, this distinction is really key to understand the idea of a holistic design.

3.1 Aspects or Dimensions

The first concept is the idea of aspects or dimensions. Dooyeweerd argues that every ‘whole’ in this reality functions in different aspects. For example, my pair of glasses consists out of different materials (physical aspect), it has a specific shape or form (spatial aspect), it strengthens my eyesight (biological aspect and sensory aspect), it represents an economic value (economic aspect), and it is beautiful or ugly (aesthetic aspect). Also, a human being functions in different aspects. For example, it needs food (biological aspect), thinks rationally (logical aspect), interacts with other people (social aspect), buys and sells products (economic aspect), loves art (aesthetic aspect), cares for others (moral aspect) and believes in God (or not) (faith aspect). Also, the electrical energy infrastructure of the future functions in different aspects. The most striking are the physical aspect (materials), the formative aspect (control and design), the social aspect (influence on people’s behaviour), the economic aspect (costs) and the moral aspect (sustainability and safety). The great discovery of Dooyeweerd was that every whole functions in different aspect. In total, he distinguishes fifteen different aspects.

3.2 Wholes or Entities

The second concept is the idea of wholes or entities. Dooyeweerd argues that there are different kinds of wholes. For example, there are ‘living wholes’: human beings, animals, plants, bacteria and so on. There are also ‘technological wholes’: cars, houses, windmills, solar panels and so on. And there are also ‘societal wholes’: states, households, hospitals, shops, factories, companies, churches and museums. Dooyeweerd argues that all these wholes have an own nature or identity. For example, a windmill is characterised by the formative technological aspect: it is designed to produce electricity in a controlled manner. A hospital, that uses electricity, is characterised by the moral aspect: it is about care for sick people. And a church, that also uses electricity, is characterised by the faith aspect: believers come together to honour God.

3.3 Enkaptic Structures or Networks

The third concept is the idea of enkaptic structures or networks. In enkaptic structures, wholes are connected to each other without losing their own nature. An example of an enkaptic structure is the electrical energy infrastructure of the future. In this infrastructure, quite different wholes are connected to each other: windmills, solar panels, transmission networks, distribution networks, electricity companies, households, hospitals, churches, factories and so. All these wholes have different functions and interact with each other. All these wholes retain their own nature or identity. They have one thing in common: electricity. Another example of an enkaptic structure is the mobility infrastructure. Also, in this infrastructure, quite different 'living wholes', 'technological wholes' and 'societal wholes' are connected to each other without losing their own identity.

3.4 Different Normativities

The distinction between 'aspects', 'wholes' and 'enkaptic structures' is not only important to understand the complexity of our reality and with that the complexity of our technological designs. But it is also important because there are different normativities. Engineers have to take into account all these different normativities when designing products, systems and networks. In other words, a holistic design has to take into account normativities with respect to aspects, normativities with respect to wholes and normativities with respect to networks,

3.5 Systems Engineering and Engineering Systems

In designing complex systems or infrastructures, the concepts 'systems engineering' and 'engineering systems' are often used. The distinctions presented above help us to understand and to highlight the differences between these concepts.

Systems engineering can be described as a holistic, integrative discipline, wherein the contributions of structural engineers, electrical engineers, power engineers, human factors engineers and many more disciplines are evaluated and balanced, one against another, to produce a coherent whole that is not dominated by the perspective of a single discipline. In other words, systems engineering is about the design of complex wholes or entities.

Engineering systems, on the other hand, addresses the design and development of complex, large-scale and sociotechnical systems. In these complex systems, complex technological systems and complex social, economic, juridical and political structures are integrated. In other words, engineering systems is about enkaptic structures or networks.

In Chap. "Toward a Holistic Normative Design", the different perspectives of systems engineering and engineering systems are elaborated in view of the electrical energy infrastructure of the future.

3.6 Complexity in Normativity

Maybe some engineers will breathe a sigh now. Do we really have to take into account so many laws and norms? Can't we do it with a simple list of standards that we can tick off? The answer is 'no'. The reason is that reality is so complex. With the result that models about normativity are also complex. It is true that complexity of normativity can be seen as an inescapable fate for engineers. In our view, it can better be interpreted as a challenge: engineers particularly like complexity.

4 Aspects or Dimensions

The first key concept is that of aspects or dimensions. In Chap. "Engineering Practices: Complexity—Diversity—Coherence—Meaningfulness", Andrew Basden offered a detailed account about the idea of aspects or dimensions. He argues that every aspect has its own lawfulness or normativity. He shows that there are no just any aspects or dimensions, but that there is doing justice to laws and normativities in order to arrive at meaningful designs. In other words, holistic design means doing justice to the different aspects or dimensions. We would like to summarise some properties of these aspects or dimensions as follows:

(1) Every aspect has an own nature or modus. Therefore, also the term 'modal aspect' is used. For example, the nature of the physical aspect differs from the biological aspect, the nature of the biological aspect differs from the moral aspect, and the nature of the moral aspect in turn differs from the faith aspect.
(2) Due to the fact that each modal aspect has an own nature or modus, it cannot be reduced to other modal aspects. For example, the biological aspect cannot be reduced to the physical aspect, the economic aspect not to the social aspect and the faith aspect not to the moral aspect.
(3) Every living whole, technological whole or societal whole functions in all fifteen aspects.
(4) Each aspect has its own normativity.

Table 1 Overview of aspects and their cores

Aspect	Nature or modus	Normativity
Arithmetic	Number and quantity	Arithmetic laws
Spatial	Extent	Spatial laws
Kinematic	Movement	Speed laws
Physical	Energy and interaction	Physical–chemical laws
Biotic	Life, organic and vital	Biological laws
Psychic	Sensitive, sensorial and primary psychic reactions	Psychic laws
Analytical	Logic, rational and analytical distinction	Logical norms
Formative	Shaping, power and domination	Formative or technological norms
Lingual	Meaning and symbolic meaning	Symbolic norms
Social	Intercourse, communion and interconnectedness	Social norms
Economic	Control of rare goods, stewardship and productivity	Economic norms
Aesthetic	Harmony and beauty	Aesthetic norms
Juridical	Justice and law	Juridical norms
Moral	Love, care and willingness to serve	Moral norms
Faith	Certainty, reliability and faith	Faith norms

Table 1 gives an overview of all different aspects, their nature or modus and their normativities (lawfulness, norms).

Table 1 shows that there are two types of normativity: laws and norms. The first six aspects are modal laws, that is, laws that are specific to a particular aspect. The following nine aspects involve modal normativity, that is, norms that are specific to a particular aspect. There is a big difference between laws and norms. For example, physical laws, like the laws of gravity, hold for all matter in our world. We cannot disable those laws. Engineers must take them into account in all their designs. But this is different with norms. People can adhere to certain standards, but they can also violate them. This also applies to engineers. Designs should meet safety standards. But that does not always turn out to be the case.

This table also illustrates the difference between, for example, human beings and technological artefacts. Human beings function in all these aspects as 'subject'. That means, they function 'actively' in every aspect. For example, they are subjected to physical laws (physical aspect), they reason in a rational way (analytical aspect), they buy or sell products (economic aspect), they enjoy art (aesthetical aspect), and they believe in God or not (faith aspect). Technological artefacts function also as a 'subject' in the first four aspects: they are subjected to all laws that hold for these aspects. However, in the later eleven aspects they function as an 'object', they function 'passively' in these aspects.

For example, let us compare the way a windmill and a human being function in the physical, economic and the aesthetic aspect. Both a windmill and a human being are subjected to physical laws, e.g. laws with respect to gravity and movement. However, windmills and human beings differ strongly with respect to the economic and aesthetic aspect. Human beings function actively in these aspects: they buy or sell goods, and they like or dislike the design of a technological artefact. Windmills function passively in these aspects: they are sold and bought, and their design is liked or disliked. These examples clearly show that windmills function in the later eleven aspects only in relation to humans, and in relation to humans, they function passively in all these aspects in a normative way. It is the challenge of engineers to design windmills that comply with economic and aesthetic norms.

Finally, we would like to make a remark. Dooyeweerd distinguished fifteen different aspects. Some philosophers in this tradition propose that certain aspects have to be taken together (e.g. the biological and psychic aspect) and others suggest that specific aspects have to be added (e.g. the political aspect).

5 Wholes or Entities

The second key concept is the idea of wholes or entities. The idea of wholes or entities is strongly intertwined with the idea of modal aspects or dimensions. Firstly, because all wholes or entities function in fifteen aspects (Sect. 4). Secondly, because all these wholes have an own nature or identity.

In Sect. 3, we have argued that there are different types of wholes, e.g. living wholes, technological wholes and societal wholes. Let us start with societal wholes. Examples of societal wholes are states, households, hospitals, shops, factories, companies, churches, sports associations, political parties, museums and so on. All these societal wholes interact with each other without losing their own identity. For example, the state enacts sustainability laws that the industry must comply with and the industry in turn tries to influence the state to facilitate the development of and juridical framework for sustainable products. In all these interactions, the state has to maintain its own identity, and the same holds for the industry. The state is the only societal structure that has the authority to enact and enforce laws: so its 'qualifying' aspect (or function) is the juridical aspect. The industry is a societal structure that develops, produces and trades goods: so its qualifying aspect is the economic aspect. Another example of interaction between societal wholes is that of political parties and churches. Regularly, they have dialogues about the freedom of religion, the ideal of social justice and the idea of a sustainable future. In all these interactions, political parties have to stick to their own identity: to realise their political ideas by means of just laws (juridical aspect). Churches, on the other hand, have to stick to their own mission: to preach the gospel of Jesus Christ and to take care of fellow humans and nature.

Technological artefacts also have an own identity. A house is qualified by the social aspect: it enables a family to live together. Manufacturing equipment is qualified by the formative aspect: it is about the control of the production of goods. A church building is qualified by the faith aspect: it is designed for the gatherings of the community to celebrate God. Windmills and solar panels are also characterised by the formative aspect: it is about the production of electricity. The idea of the own identity or qualifying function is very important for engineers. In philosophical terms: the qualifying function has to guide engineers in designing artefacts. For example, the faith aspect has to be leading in designing a church, the juridical aspect in designing a court, the formative aspect in designing a production hall and the economic function in designing a shop.

And last but not least some remarks about living wholes. Dooyeweerd argues that humans are not characterised by only one aspect. They are not only rational but also religious beings, not only social but also economic beings and not only linguistic but also moral beings. For plants and trees, it is quite plausible that they are characterised by the biotic aspect. For the animals, especially the higher developed ones, there is discussion in which aspects they function as a subject.

We would like to emphasise that every whole has its own normative structure. First and for all, engineers have to respect the own normative structure of the artefact that they design and have to do justice to the qualifying function as a guide. Additionally, they have to do justice to the own normative structure of living wholes and societal wholes that are influenced in one or another way by the technological design. For example, transmission and distribution networks are wholes with an own normative structure that influence nature, human beings and society. In developing transmission and distribution networks, engineers have to do justice to a) the own normative structure of these wholes, including the guidance of the qualifying aspect and b) the own normative structure of nature, human beings and societal structures that are influenced by these wholes.

6 Enkaptic Structures or Networks

The third and last key concept is the idea of enkaptic structures or networks. This key concept is of utmost importance to understand complex structures of networks like the electric energy infrastructure, the gas and oil infrastructure, the mobility infrastructure, the infrastructure of smart cities, military infrastructures and so on.

An enkaptic structure like the electric energy infrastructure is not a 'whole'. On the contrary, it brings together a lot of different wholes in one infrastructure. For example, wind plants, solar plants, transmission networks, distribution networks, electricity companies, households, hospitals, churches, factories and so. All these wholes interact with each other in the electrical energy infrastructure, and interaction implies a mutual influence. Despite all these interactions, every whole retains its own qualification or identity. In philosophical terminology: the wholes enter into an enkaptic relationship with each other. All these wholes literally connected to each other by electricity and data.

We would like to note that the idea of ‘enkaptic relationship’ is also a normative idea. The interaction between wholes is subjected to standards and norms. The normative idea is that the infrastructure supports the functioning of every whole. No whole is allowed to dominate others. For example, it would be unacceptable if companies that generate electrical energy would force hospitals to operate patients only at the night in order to optimise their business process.

We conclude that an energy infrastructure consists of a heterogeneous assortment of differently qualified societal actors. These actors are ‘tied together’ by the phenomenon of energy and data. This conclusion is of utmost importance of engineers: in the development of products, services and systems they have to do justice to this heterogeneity.

7 Summary and Conclusions

The objective of this paper is to present some key concepts to facilitate a holistic design. We started this paper with an exploration of the practice of engineers. We used the Triple I model to investigate the complexity of this practice and to identify the most important factors that determine its functioning. The Triple I model reveals that a practice of engineers is not only determined by technological know-how, technological skills and technological facilities, but also by the (shared) values of engineers, the interests of stakeholders and the ideals and basic beliefs in society. In other words, the practice of engineers is not only about ‘hard’ factors but also about ‘soft’ factors. The Triple I model highlights values, interests, ideals and basic beliefs, but does not teach how engineers have to translate these factors in holistic designs.

The philosophy of Dooyeweerd is used to facilitate this translation. First of all, we made a distinction between aspects or dimensions, wholes or entities and enkaptic structures or networks. These distinctions are key to understand the complexity of technological designs and to identify its normative moments.

The theory of modal aspects highlights that technological designs function in fifteen different aspects or dimensions. Each of these modal aspects has an own normative structure that comes to the fore in laws or norms. A holistic design complies with all these laws and norms.

The theory about wholes reveals that every entity has an own normative structure. A holistic design complies with this normative structure. Additionally, a holistic design is guided by the so-called qualifying function that is characteristic for the present whole or entity.

The theory about enkaptic structures or networks clearly shows that infrastructures like the electrical energy infrastructure are not a whole of entity that is characterised by a specific qualifying function. On the contrary, such an infrastructure consists out of a medley of wholes that interact with each other. The whole infrastructure is ‘tied together’ by electricity and data.

We conclude that the philosophy of Dooyeweerd offers different perspectives to investigate the complexity and normativity of technological designs. Every perspective offers specific knowledge that contributes to a holistic design. It goes without saying that it is a great challenge for engineers to explore all these normativities and to design systems and enkaptic structures that comply with these normativities.

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Toward a Holistic Normative Design

Paulo Fernando Ribeiro, Maarten J. Verkerk, and Rafael S. Salles

1 Introduction

In the foregoing chapter, some key concepts were developed to understand the complexity and normativity of technological designs. The first key concept has to do with modal aspects: the specific normativity of every aspect. The second concept has to do with the identity of wholes: the specific normativity of every whole as expressed by its qualifying function. The third concept is about infrastructures: the normativity of every infrastructure as a medley of different structures.

The Chaps "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures" and "Towards a Holistic Normative Design" form a diptych. That means, the different perspectives on normativity as presented in Chap. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures" will be elaborated and refined in this chapter in view of engineering infrastructures like the electrical energy infrastructure, the gas and oil infrastructure, the mobility infrastructure, the smart city infrastructure, the World Wide Web, military infrastructures, and so on. In this chapter, the electrical energy infrastructure will be discussed as an example of an engineering infrastructure of the future.

The energy infrastructure plays a crucial role in the development of the world. It is a life-sustaining infrastructure that supports all main activities in society: mobility, living, eating, working, leisure, and so on. Our way of life leads to irreversible changes on earth, threatening the existence of humans, animals, and plants. Global warming

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poses the greatest threat from the use of fossil fuels. This leads to major changes in the climate, reduced food production, political tensions, refugees, etc. One of the main challenges of the present time is to transform the present energy infrastructure into a sustainable one.

One of the most important renewable energy sources is electricity made by wind and solar plants. For that reason, it is expected that the electrical energy infrastructure will be one of the most important engineering infrastructures in the future. The electrical energy infrastructure is overly complex. It consists out of complex electrical systems to generate electricity, to transport electricity, and to distribute electricity. In this infrastructure, many different actors are active. The energy infrastructure is not a 'stand-alone' infrastructure, but it interacts with other infrastructures in the energy sector, e.g., the oil infrastructure, the gas infrastructure, the coal infrastructure, the upcoming hydrogen network, and so on. Additionally, it interacts with other engineering infrastructures in the field of mobility, living, food, finance, industry, and cyber. Each of these infrastructures has its own characteristics and dynamics.

Presently, engineering infrastructures are overly complex. In designing new infrastructures or in renewing present infrastructures, engineers must cope with this complexity. In addition, they must cope with the complexity of normativity. The objective of this chapter is (1) to acknowledge that engineering infrastructure is extraordinarily complex, (2) to show that this complexity can be understood by analyzing modal aspects, by interpreting the nature of wholes, and by highlighting the character of infrastructures, (3) to make plausible that holistic normative design requires three perspectives on normativity: modal aspects, wholes, and infrastructures.

This chapter has the following setup. In Sect. 2, the different views on infrastructures are discussed. In Sect. 3, the difference between 'engineering systems' and 'systems engineering' is addressed. Section 4 focusses on the first perspective on normativity: modal aspects. Section 5 highlights the second perspective on normativity: wholes. In this section, the nature of societal actors is analyzed, and its importance for the normative design of systems and infrastructures underlined. Section 6 is about the third perspective: the inherent normativity of infrastructures. Section 7 presents some thoughts about guiding a normative development of infrastructures. In Sect. 8, a summary of holistic normative engineering of infrastructures is presented. We close this section with some ideas about the soft connection between technology and poetry and some conclusions.

2 Architectures of Reference

An integrated view of smart grids assumes that the concept itself is integrated by other systems, in addition to being a system of systems. Thus, the approaching model for investigating these grids must consider the different types of associated architecture and the new structures that comprise it. Reference architectures allow an integrated view of the functions and interoperability of complex systems. There are several models for example for smart grids which attempt to integrate markets, operations, service providers, transmission, distribution, customers, bulk generation, and distributed energy resources (Greer et al., 2014). NIST and SGAM show two examples of smart grid models that approach the complexity and adequacy between different subsystems and aspects (Bruinenberg et al., 2012).

The systems of the future present references and features of a smarter approach when compared to the classical point of view. Therefore, one must ask if we are not missing to consider something in the design process, it is necessary to carry out an analysis of the changing paradigms, including the holistic view. Table 1 shows the typical characterizations and differences between the classical and integrated characterization of smart grids.

The objective of this chapter is to call attention to normative design frameworks and architectures of references which attempt to cover the complexity of smart city/electric grids in a way that takes into account the most important components and relationships in an integrated holistic way.

First, it is necessary to understand what normativity is.

> 'The concept that there is right and not so right or even wrong, functional and dysfunctional, etc… in frameworks. This is because normativity is something we cannot escape from. The purpose of norms is to bring systems and life in its fullness by pointing to paths which safely lead us there. Norms allow for harmonious developments' (Dooyeweerd n.d.).

Table 1 Classical versus integrated—smart grids paradigms

Classic architecture paradigm	Smarter grid architecture paradigm	Comments
Focus on components	Focus on structure	In a block diagram, the boxes are the components, and the lines are the structure
Structure is received or improvised	Structure is formalized	Structure should have harsh mathematical basis
The grid can be described as a big circuit	Electricity markets and grid controls are related	Crentralized markets are closely related to grid controls
Stem of systems	Network of structures	The grid comprises multiple complex structures that are interconnected in complex ways
Large cluster of data	Ultra-large-scale complexity	Ultra-large-scale complexity is a consequence of the network of structures
System Integration	Convergence and platforms	The platform is a very general architectural concept that applies broadly to system structure
Architectural elegance	Architectural quantification	The elegancy is not the goal, alignment with objectives is
Holistic normative engineering design architecture/framework	**Broad and integrating all engineering and societal aspects**	**Smart living should be a consequence**

The Triple I model as proposed in Chap. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures" offers three perspectives to understand practices: identity and intrinsic values, interests of stakeholders, and ideals and basic beliefs. Each perspective highlights some characteristics (Verkerk et al., 2016). These approaches are explained below (Verkerk et al., 2018):

- The first I focusses on the identity of the practice and its intrinsic values. It stimulates our awareness that engineering practices have a different identity and different intrinsic values that for example social practices in society.
- The second I emphasizes that stakeholders have a (strong) influence on engineering practices. That influence can be positive and negative.
- The third I recognizes that ideals and basic beliefs always play a role.

Smart grids/cities can be seen as a set of social practices. It implies that these complex systems are constructed in constant development that includes technological systems and human practices. For this reason, the tools explored in this chapter seek to access the complexities of the systems regarding social and technical aspects. Another critical point is the direction towards a more humane engineering practice for future electrical networks and urban development. Other aspects need to be considered:

1. The increasing complexity of smarter cities/grids.
2. Physical operational structure: integration of renewables, communication infrastructure, protection and automation schemes, etc.
3. Regulatory aspects and dynamic market/electric system interaction.
4. Societal issues from environmental concerns to social justice, i.e., universal accessibility of electricity to all.

3 Engineering Systems and System Engineering

The view of engineering systems is essential to play this context in the design process. Engineering systems blend engineering with perspectives from management, economics, and social science to address the design and development of complex, large-scale, sociotechnical systems. Figure 1 shows the engineering systems aspects. This approach is interested in the following characteristics:

- Technologically enabled
- Large scale (a large number of interconnections and components)
- Complex
- Dynamic, involving multiple time scales and uncertainty
- Social and natural interactions with technology
- Likely to have emergent properties.

The four underlying subfields for engineering systems are as follows:

1. **Systems Engineering (including systems architecting and product development)**;

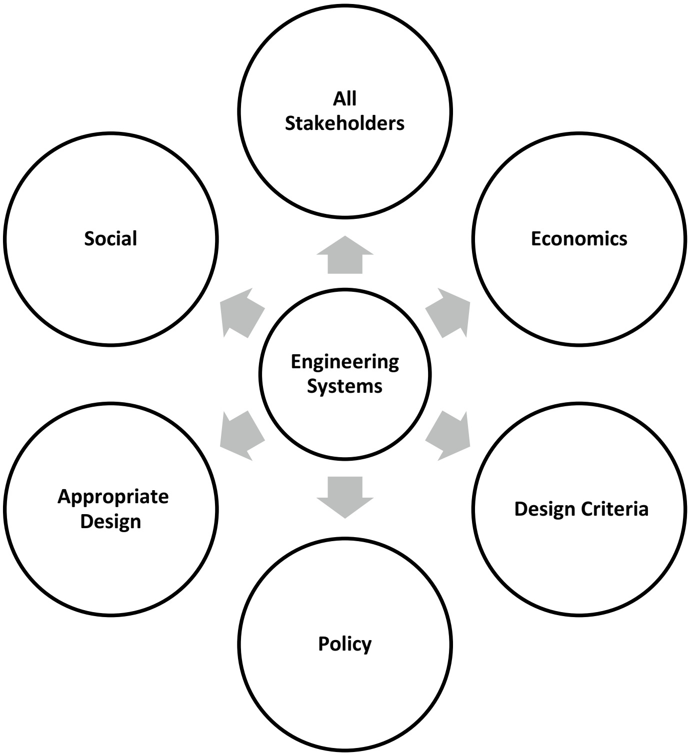

Fig. 1 Engineering systems field

2. Operations Research and Systems Analysis (including system dynamics);
3. Engineering Management; and
4. Technology & Policy.

System engineering is a holistic, integrative discipline, wherein the contributions of structural engineers, electrical engineers, power engineers, human factors engineers, and many more disciplines are evaluated and balanced, one against another, to produce a coherent whole that is not dominated by the perspective of a single discipline (Hirshorn et al. 2017). Figure 2 shows the system engineering main aspects. Take a look at other perspectives:

1. Ramo—'Systems Engineering is a branch of engineering that concentrates on the design and application of the whole as distinct from the parts…looking at the problem in its entirety, taking into account all the facets and variables and relating the social to the technical aspects' (Booton & Ramo, 1984).
2. INCOSE—Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems (Jones & Ryan, 2011).

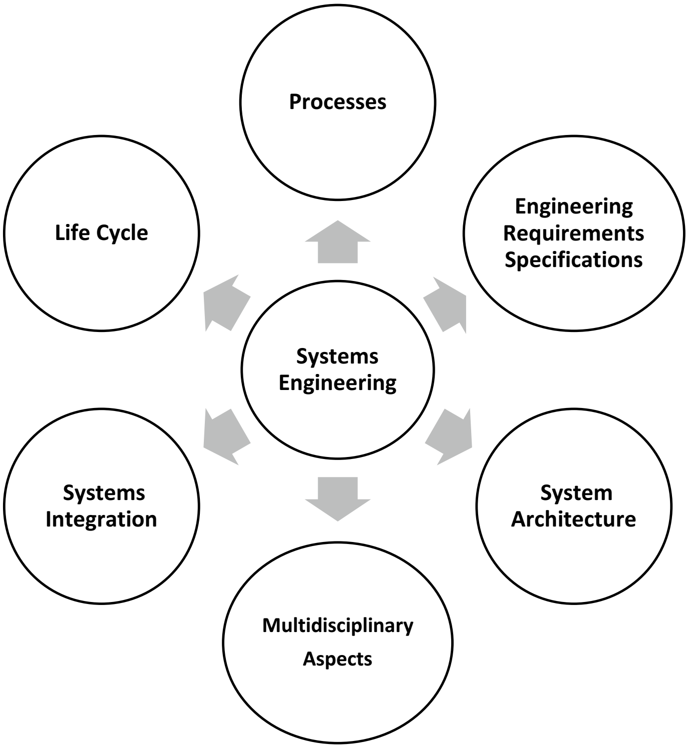

Fig. 2 Systems engineering fields

3. Kossiakoff & Sweet—The function of systems engineering is to guide the engineering of complex systems. Systems engineering is focused on the system as the whole—it emphasizes total operation. It looks at systems from the outside, that is, at its interactions with other systems and its environment, as well as from the inside (Kossiakoff et al., 2011).

Table 2 makes a comparison between engineering systems and system engineering concepts considering different aspects, and Table 3 shows an exemplification of the same comparison for smart grids. This kind of table helps to explain the relationships and how this concept could help to access these sytems in the design process.

4 Holistic Normative Engineering—Modal Aspects

The philosophy of technology is like a mosaic of ideas and suggestions, but this should not minimize its relevance to engineering and technological developments (Vries, 2005). The ongoing transformations of the network of the future, which are becoming increasingly intelligent, raise a number of technical, social, and economic

Table 2 Engineering systems versus system engineering—concepts

Aspect	Engineering systems	System engineering
Scope	**Very large-scale systems**, complex open systems	**Small to large-scale systems**, subsystems, and system of systems
Focus	**Broad, overall view to the** technology/product system and project design	**Primary focused on technology/product system**
Policy	Optimized and adaptable system solution	Steady system solution
Socio-technical	Essential for systems solutions	Substantial in engineering
Stakeholders	Focus on all stakeholders impacted by the system	Priority focus on those directly impacted by the system
Roles	System architecture, business management, project design, social science, policy, economics, and others	System architecture, performing of systems, and engineering process

Table 3 Engineering systems versus system engineering—smart grids

Aspect	Engineering systems	System engineering
Scope	**Eletric Power systems**, smart energy system	**PV generation system, isolated** microgrid system, and substation
Focus	**Philosophy of technology**, design criteria, and impact on human life	**Focus on technology, equipment, controllers**, and applications
Policy	Use of solutions to adapt the advances of electric power systems in society	Use of standards, methodology, and requirements
Socio-technical	Crucial for smart grid projects to present a holistic and empowering vision for society as a whole	Important for smart grids to work properly, matching quality and reliability
Stakeholders	Focus on environment, underprivileged by modern technologies, researchers	Focus on consumers, 'prosumers', energy agencies, and professionals
Roles	Grids architecture, energy markets, projects design, social aspects from smart grids, politics, biology, and others	Construction of new environments, smart grid performance, eletrical engineering, and information and communication

issues that cannot be addressed separately. Technological project developments must be aligned with all the faces and impacts that the final deployment is influencing. The changing scenario has promoted the development of new concepts in which smart grids have become the new design approach for the development of the future electric networks, allowing integrated and enhanced performance and diagnosis (Souza et al., 2019).

In Chap. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures", the relevance of the theory of modal aspects as developed by the

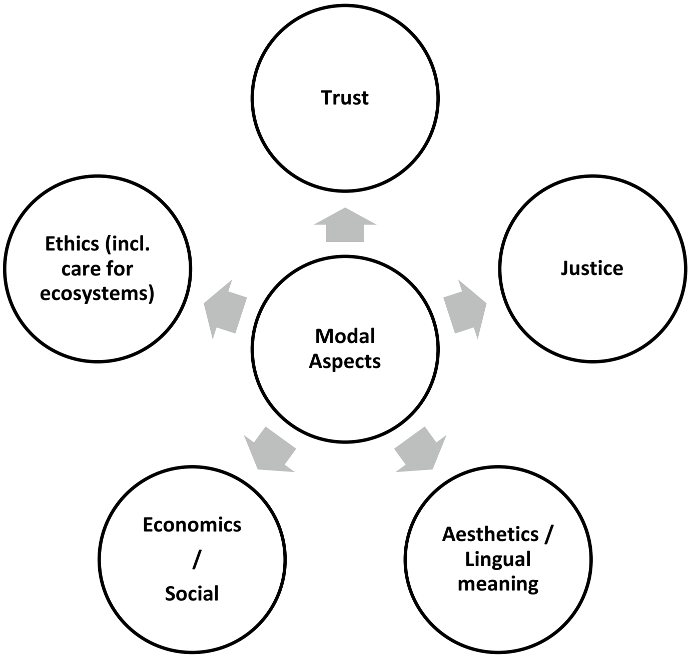

Fig. 3 Most important modal aspects with a normative character

Dutch Philosopher Herman Dooyweerd (Dooyeweerd, 1969, 2016) is emphasized to highlight normativity. Figure 3 shows the most important aspect that plays a role in designing infrastructures, and Table 4 shows each aspect's view from a perspective of smart grids compared to the traditional electrical system. Some properties are raised in works that explore this tool (Ribeiro et al., 2012):

1. Every modal aspect or dimension has its own nature that cannot be reduced to another one.
2. Every technological system functions in all fifteen dimensions.
3. The different modal aspects influence each other, and they are inextricably linked.
4. A distinction can be made between natural and human aspects. The first being those related to the natural sciences whose normativity is expressed in laws, the second with human behavior and inherent normative part of those systems.

The electrical networks of the future, which belong to a concept of intelligent cities too, will form quite complex systems. In this way, traditional design approaches cannot access all dimensions understood in this system. The design process must consider all relations between the technological, social, economic, and political nature together with the systems' natural aspects. This tool, together with others discussed in this chapter, allows an escape from the engineer's reductionist vision.

Table 4 Modal aspects within smart grid context

Aspects	Electric grids	Smart grid	Type of Normativity
Arithmetic	Numbers	Measureable quantities: voltage, current and power	Arithmetic laws
Spatial	Use of space	Transmission and distribution network	Spatial laws
Kinematic	Moving components	Rotating generators, energy flow	Speed laws
Physical	Materials and properties	More efficient and intelligent cables, transformers, generators, etc	Physical–chemical laws
Biotic	Influence on animals, human bodies, and environment	Influence electromagnetic fields and waves on life	Biological laws
Psychic	Feelings of safety	Intermittent renewable sources lead to feelings of uncertainty	Psychic laws
Analytical	Distinction between different types of grids	"Clear identification of problems" for electric and 'Clarity of energy policies and objectives' for smart?	Logical norms
Formative	Control	Control of power generation, distribution and consumption, and smart meters	Formative or technological norms
Lingual	Meaning of terminology	Term 'smart' chosen to promote technology? Should it be smarter?	Symbolic norms
Social	Influence on human behavior	Leads to more sustainable human behavior?	Social norms
Economic	Cope with the scarcity of energy and higher demands	Price differentiation depending on momentary supply and demand	Economic norms
Esthetic	Esthetics of buildings and systems	SGs are even better because they are trying more assiduously to (a) harmonize variable sources, demand, breakdowns, etc. (b) there is a design challenge, to achieve such harmonization	Aesthetic norms
Juridical	Liability, ownership of networks	Who is liable for a failing smart grid? When are smart grids appropriateness and when not?	Juridical norms
Moral	Care for the environment, humans, and animals	How do smart grids help in intentional caring for humans and the environment?	Moral norms

(continued)

Table 4 (continued)

Aspects	Electric grids	Smart grid	Type of Normativity
Pistic	Trust the grid	Vision/commitment/belief on a smarter grid	Faith norms

Subsolutions lead to significant design flaws, and this tool considers different aspects to have a great picture of the context and effects of the technology/system.

Given the systems' complexity and the proposed tool vision, there are challenges when working with all these aspects. Analyzing the properties and how they are related is essential for holistic design. However, there are considerations to be made. In private correspondence, Professor Andrew Basden concisely clarified something that fits well with what is necessary to consider all these different aspects.

> 'We need to adopt an attitude of wisdom and responsibility rather than logical definition or legalism in all those things. Especially when we consider (non-) essentiality in respect of every aspect, we may still act in defining, by drawing boundaries, but that is one functioning among many and should not dominate our wisdom but serve it. Interestingly, one of Dooyeweerd's fundamental presuppositions is that there is no over-arching rationality by which we can bring all the aspects together - for example, by which might we 'balance' supposedly competing claims of them. Instead, we are called to wisdom and responsibility' (Basden, 2021).

We would like to give an illustration of the line of thought in view of a company that generates renewable energy by developing and exploring windmill parks (onshore). A windmill park is a whole. This whole functions in fifteen differently qualified aspects. The first six aspects are governed by laws: These laws determine the design space of the engineers. The later nine aspects are governed by norms: These norms reflect the interaction of the windmill park with nature and human beings. Consequently, the ethical responsibility of the company that develops and explores windmill parks is multi-aspectual of multi-dimensional: analytical norms, formative norms, lingual norms, social norms, and so on. How to cope with multi-aspectual ethical norms? In our view, at least two different steps are required. The first step is to think over the normative content of each of the ten steps. As much as possible scientific evidence must be gathered about the interaction of the windmill parks with nature and human beings. Step by step the norms related to the logical aspect up to the religious aspect must be elaborated. Also, other windmill parks must be studied in depth in order to explore all these interactions and their normative nature. The second step is to design the park in such a way that all multi-aspectual norms are met. This last requirement is a tough one. It is a challenge for an engineer to design the windmill park in such a way that all ethical norms are met. Regularly, all kinds of dilemmas pop up. For example, dilemmas between the economic performance and the care for nature and local residents. The easiest way to cope with this type of dilemma is to make a compromise. In our view, however, a more elegant solution is to reconsider the design and use all creativity to comply both with economic norms and moral norms. Table 5 gives some examples of norms.

Table 5 Overview of normative aspects

Aspect	Examples of norms
Analytical	Logical setup of the design, logical setup of the software that controls the windmills
Formative, power	Influence of residents on the allocation and management of the windmill park
Lingual	Name of the windmill park, symbolic meaning that local daily papers give to the windmill park, framing in communication
Social	The influence of the windmill park on the social life of residents and tourists
Economic	Investments, costs per kWh, efficiency, influence of windmill park on the value of the houses in the direct neighborhood of the windmill park
Aesthetic	Visual appearance of the windmills, harmonious integration of the windmill park, and the natural environment
Juridical	Responsibility for design and exploration, liability in case of incidents, and complaint procedures
Moral	Care for passing birds, influence of the shadow of wicks on animals and humans, and safety of the windmills
Faith	Expression of faith in sustainable energy

In the context of smart grids and smart cities, each aspect treated serves to advance these systems in the future to be supported by philosophical and social considerations and high technical performance. For example, the role of renewable sources of energy distributed in electricity networks is clear, but some aspects must be investigated in this process. Holistic design can help in a planning stage of an energy distributor and determine technical criteria for the insertion of these sources in an urban network feeder. It is also possible to consider social issues, access to technology, tariff changes, political incentives, regulations, stakeholders, etc. These aspects in decision-making can guarantee that the positive effects are extremely explored and the mitigation of adverse effects, even those that are not explicit to the activity's nature.

5 Holistic Normative Engineering of Infrastructures—The Analysis of Wholes: Societal Actors, Technological Systems, and Normativity

In this section, we discuss the second perspective on normativity: the normativity that is inherent to wholes like societal actors and technological systems. We would like to recall that in infrastructures like smart cities, the World Wide Web, the energy infrastructure of the future and so on many different societal actors play a role. In this section, we will zoom in on these different actors.

Let us take for example the energy infrastructure of the future. This infrastructure consists of a plurality of actors:

(1) Professional actors that generate, transport, and control energy: oil companies, gas companies, classical plants that generate electricity based on coal, oil or gas, windmill parks, solar panel plants, companies that transport and control energy, and so on.
(2) Professional actors that use electrical energy: industry, global enterprises, small- and medium-sized businesses, transport, public organizations like government, courthouses, universities, hospitals, and so on.
(3) Non-professional actors that use electrical energy: households, social clubs, sport clubs, churches, and so on.
(4) Professional and non-professional actors that are not active in the energy business but still produce energy: department stores with solar panels, hospitals with geothermal energy, farmers with a small windmill, households with solar panels, and so on.

All these actors are qualitatively different: They have a different nature, and each of them has its own normativity. Each specific nature and normativity is expressed in the concept of 'qualification' or 'qualifying concept'. Professional actors that generate, transport, or control energy are mostly commercial organizations that are qualified by the economic aspect. Professional actors that use energy are differently qualified: Industry and business are economically qualified, hospitals and long-term care organizations are morally qualified, welfare and social work organizations are socially qualified, governments and courthouses are juridical qualified, museums and art houses are aesthetic qualified, and so on. Non-professional actors that use energy vary also in qualification: Households, social clubs, and sports clubs are socially qualified, choirs and brass bands are aesthetic qualified, churches and mosques are religious qualified, and so on.

We conclude that the energy infrastructure consists of a heterogeneous assortment of differently qualified societal actors. These actors are 'tied together' by the phenomenon of energy. This conclusion is of utmost importance of engineers: In the development of products, services, and systems, they must do justice to this heterogeneity.

In Sect. 2 of this chapter, we introduced the Triple I model to understand engineering practices. The second I was about the interests of stakeholders. The considerations presented above support us to understand the concept of stakeholders. Basically, it refers to all societal actors that are related to or effected by technological systems. On the one hand, it is about the unicity of every societal actor and on the other hand about the diversity of societal actors. In other words, in designing systems, engineers have to cope with a 'heterogeneous assortment of differently qualified societal actors'. In other words, the justified interests of stakeholders form a rich source of normativity for designing technological systems; see Fig. 6. Table 6 presents an overview of the qualification of the interests of the most import stakeholders.

Design criteria are the explicit goals that a project must achieve to be successful (Perelman & Barrett, 1997). The design criteria are intrinsically linked to the other

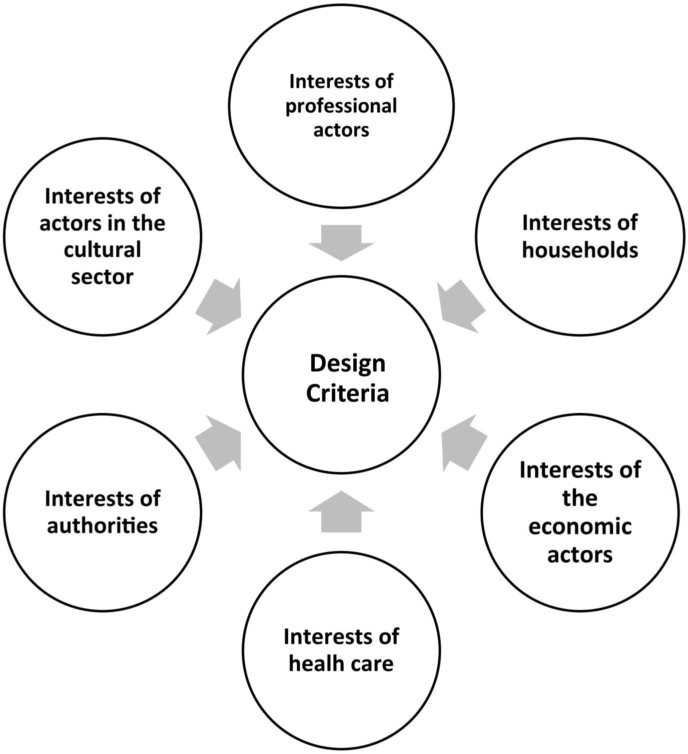

Fig. 6 Infrastructures, stakeholders, and design criteria aspects

Table 6 Design criteria aspects stakeholders

Stakeholder	Main interests
Authorities (national, local)	Juridical, moral, and economic
Professional actors	Depends on the nature of the infrastructure Often technological (formative) and economic
Industrial actors	Technological (formative) and economic
Healthcare actors	Moral
Actors in cultural sector	Aesthetic, faith (meaning of life)
Households	Social, economic
Action groups	Moral (environmental, safety)
And so on …	

tools covered in this chapter. This, technically speaking, will direct the performance parameters of the system. However, in a holistic design perspective, performance is not only directed at the technical aspects of engineering, and it is also necessary to establish a design criterion that breaks with the reductionist solution and incorporates the other social, philosophical issues, etc. Complex systems must meet more flexible requirements that increase the quality of life in search of smart living in intelligent systems.

6 Holistic Normative Engineering of Smart Grids: Enkaptic Structures

Engineers often think in terms of systems and subsystems. In this line of thinking, infrastructures are a system, and all the different societal actors that constitute this infrastructure are seen as subsystems. Thinking in terms of systems and subsystems is often fruitful. However, there are also serious dangers. The first one is that all subsystems are generalized. The specific identity of the different societal actors disappears behind the word ‘subsystems’. We discussed this danger in the foregoing section. The second one is that thinking in systems and subsystems suggests that the system is first and that the subsystems must serve the system. Especially, this last idea is very dangerous. Normatively formulated: The energy infrastructure must serve the societal actors and not the other way around. The idea of infrastructures as *enkaptic structures* (see Chap. 3) prevents us to fall into this trap. The idea of enkaptic relationships does justice to the idea that (1) the energy infrastructure consists out of differently qualified societal actors (prevention of the first danger) and (2) the function of the energy infrastructure is to serve the unique quality of every societal actor (prevention of the second danger).

The idea of enkaptic structures recognizes that in infrastructures differently qualified societal actors are connected without losing their own identity or without being absorbed by the infrastructure. The interaction between the different societal actors has become quite complex. For example, in the electrical energy infrastructure, the processes ‘energy generation’, ‘energy transport’, ‘energy control’, and ‘energy use’ are not anymore ordered in a ‘hierarchical way’. All these processes—or better: All societal actors that execute these processes—are strongly dependent on each other. ‘One-way’ interactions are replaced by ‘two-way’ interactions. To highlight the idea of ‘two-way’ interactions, we would like to introduce the concept ‘cooperability’. This concept highlights that all societal actors in the energy infrastructure must cooperate so that every actor can excel in its own function. This conclusion can be generalized. The concept of ‘cooperability’ underlines that in every infrastructure societal actors must cooperate in such a way that every actor is supported to flower.

Infrastructures are seldom ‘stand-alone’ networks. They are strongly interlaced with each other. For example, infrastructures like energy, mobility, cyber, food, finance, industry, and so on are strongly interlaced. How to understand this interlacement? We must realize that each of these infrastructures is very complex. They consist out of a ‘heterogeneous assortment of differently qualified societal actors. All these societal actors in every infrastructure relate to each other around one specific function (energy for the energy infrastructure, transport for the mobility infrastructure, information for the cyberinfrastructure, food for the food infrastructure, and so on). Interlacements of infrastructure lead to more complexity and more dynamics. The interlacement of infrastructures is not a neutral given but is also subject to normativity. Every interlaced infrastructure has its own nature, and the interlacement has to serve this nature. Negatively formulated: It is not allowed that one infrastructure dominates another one. From the perspective of the societal actors, we would like to remark that the interlacement must serve the unique quality of every societal actor. Negatively formulated: It is not allowed that interlaced infrastructures hinder the functioning of societal actors.

7 How to Guide the Development of Infrastructures

Infrastructures have an extreme complexity and an extreme size. For example, infrastructures like energy, food, cyber, transport, and so on connect regions, countries, and continents in one global system. By that, it also connects different cultures, economic systems, and political structures. In the worst-case scenario, every country will have its policy and legislation with respect to this infrastructure. These observations raise the question: How to guide the development of complex and large infrastructures? Negatively formulated: How to prevent that the energy infrastructure of the future becomes patchwork that in the end does not meet any of its requirements?

In our view, the Triple I model (Chap. 3) offers three coherent strategies. In this section, we will focus on infrastructures in the field of sustainability and renewables. The first strategy is related to the first I: the values of engineers that develop infrastructures. Engineers—all over the world—have a personal and professional responsibility to develop infrastructures that meet relevant values and norms with respect to sustainability. Generally, this role has been taken up by professional engineering associations. However, it is far from sufficient when these values and norms are formally accorded in documents. They must be in the minds and the hearts of the engineers. Additionally, engineers must share their experiences on how to map values and norms and how ‘to translate’ them into concrete designs. The path of value-conscious engineers is not always strewn with roses. Not every company and not every boss who profess the importance of sustainability and renewables has the capabilities and/or the motivation to guide the normative development of infrastructures.

The second strategy is related to the second I: the interests of stakeholders. Every institution and every company that operates in the field of infrastructures has stakeholders. Stakeholders can have dialogues with these institutions and companies to support the normative development of infrastructures. Especially, the role of shareholders, banks, and customers needs to be emphasized. For example, more and more, customers place increasingly higher demands on their suppliers about sustainability. Also, shareholders and banks growingly want to invest in sustainable companies, both from a moral and economic point of view. There are stakeholders in all shapes and sizes. Most of them are members of professional associations to serve their interests. Every stakeholder and every professional association is a cog in the machine to realize the energy transition.

The last strategy is related to the third I: the ideals and beliefs in society. In the global society, there are many organizations on a global level that address the importance of sustainable development of the energy infrastructure. The importance of the Sustainable Development Goals (2015) that have been adopted by all Member States of the United Nations needs to be highlighted. The importance of this document cannot be underestimated. It presents a shared vision: Such a shared vision is a condition sine qua non to develop an energy infrastructure that is sustainable and inclusive, now and into the future.

8 Serviceable Insight

Serviceable insight is the kind of insight that includes both theoretical and practical knowledge. That is, serviceable insight counts as components of both the one-step removed reflection and an understanding of how to work out these reflections in non-theoretic experience. Moreover, both the reflective and the practical understandings included in serviceable insight focus on norms. Serviceable insight involves knowing what, a knowing how, and a knowing why (Dyk, 1977). Figure 7 shows a diagram of the theory and practice.

This concept is an important tool that can be adapted to a holistic design vision because it deals with technology's purpose from theoretical and practical perspectives. Technology must serve a service purpose. Just as the engineer designed it, it must meet norms, standards and reach all stakeholders for the common good. Smart cities/grids deal with these paradigms that can be contemplated by serviceable insight.

9 Holistic Design

In summary, complex systems and infrastructures require a broad view in the design stage, which lead to the following practices: reflections on the purpose and nature of the system (philosophy of technology); dimensions tangible to the core problem (modal aspects); systems view in the technological or specific atmosphere (system engineering, wholes); systems view looking the big picture (engineering systems, infrastructures, and enkaptic structures); complete criteria for service to projects (design criteria); and the relationship between practice and theory for the experiment

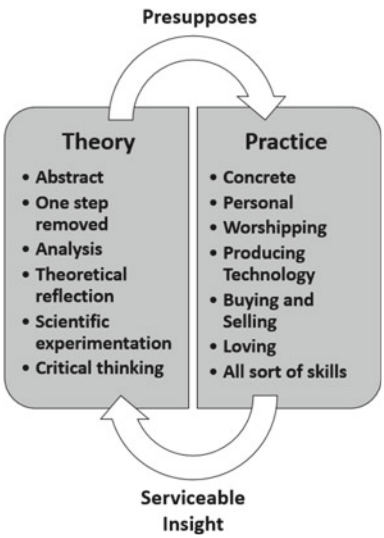

Fig. 7 Serviceable insight connection between theory and practice

the purpose of systems (serviceable insight). Figure 8 illustrates this set for holistic normative engineering.

As this design proposal is open to be completed, and the authors cannot complete it yet, since the search for a complete and holistic design must remain under development. The authors prefer to close this chapter by showing essential aspects of technological systems and art/poetry similarity. Such reflections collaborate with a better understanding of technical systems, culminating in a more humane and complete design. See it in the next section.

10 The Soft Connection Between Technology and Poetry

Designing and operating engineering and technology systems can be sometimes compared to an art rather than a science. The following observations are adapted from the works of two Oxford Professors, E. M. W. Tillyard and C.S. Lewis (Tillyard and Lewis, 1939). The words poetry, poems, etc., are replaced by engineering/technology and design, and the word language is replaced by physics.

1. Engineering/Technology (Eng/Tech) can be considered as an art or skill. Its instruments usually define a skill. Also, assume that the instrument of Eng/Tech is physics. However, since physics is used for other purposes, it needs to be distinguished from the engineering use of physics.
2. Eng/Tech is the skill of a trained habit of using all the extra-logical elements of physics/physical reality—to convey the concrete reality of experiences.
3. Eng/Tech design, it is assumed to be a composition, which communicates more of the concrete and qualitative than our usual designs do. An engineer is

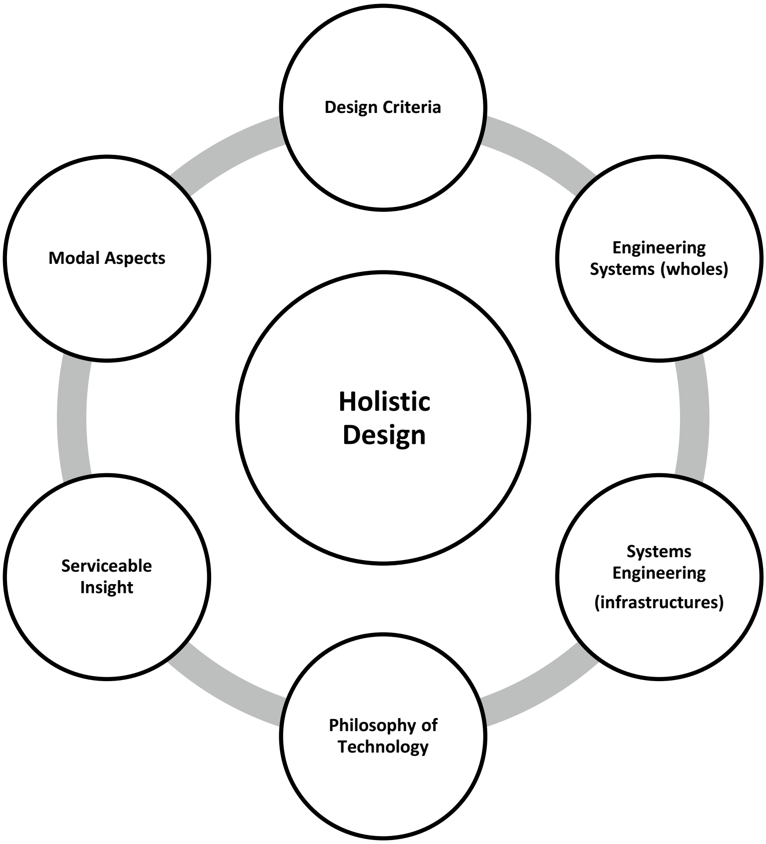

Fig. 8 Holistic normative engineering proposal

a person who produces such compositions more often and more successfully than the rest of us.

4. Eng/Tech both 'means' and 'is'. It is both Logos (something said) and Poiema (something made). As Logos, it tells a story of its development, expresses all the encountered complexities, and proposes new directions. As Poiema, by its splendors and beauties, harmony, contrasts, and integration of the multiplicity of many parts and subsystems of a design, it is an object of art.
5. Technology as a poem has two parents—its mother being the mass of engineering/technology experience, thought and like, inside of the poet-engineer´s mind, and its father the pre-existing normative forms which he recognizes in the physical reality.
6. A great engineer makes us feel about the age he lived in because he/she impresses us as a distinguished person; we trust his distinction partly because she is so sensitive to what goes on around her. The ever-varying interplay of the personal and the communal is one of the first attractions of engineering.

7. It would be a great error to suppose that this fertilization of the poet-engineer's mind by the pre-existing (normative) Forms impairs his originality…. The matter inside the poet-engineer wants the Form: in submitting to the Form (normativity) it becomes original, really the origin of great work. The attempt to be oneself often brings out only the more conscious superficial part's of one's mind. Working to produce a given kind of engineering/technology that will present a given theme as justly, delightfully, and lucidly as possible, she is more likely to bring out all that was really in her, and much of which she had no suspicion.
8. An engineer is a person with a taste for physical reality, a person more than ordinarily sensible to the associations of subsystems. We should only have to add to it the caution that these bents or talents, even if they be as natural in the first instance as the hand of the future surgeon or the ear of the future piano-tuner, can reach engineering only by training, industry, and the method of trial and error.
9. It follows that there is an ambiguity in the expression 'a great engineer'. The skill of concrete design, as we have seen, can be used for almost any purpose. Fools use it for bad design, wise persons to produce a good design. It can be used (like the telephone) by great and little ones—by anyone who can acquire the skill. This skill is, of course, a very difficult one, but it can be acquired …
10. The reverence for 'great engineers' is natural in periods when the art of engineering attracts great persons. Every art, however, has its ups and downs. The schoolmaster was a slave in Rome and a potentate in Victorian England; the prostitute, an abject in the eighteenth century, was sometimes honored in ancient Greece; the actor's profession in the last years of Paganism reached depths from which it took centuries to recover. Similarly, there are periods when engineering falls into inferior hands. Its practitioners, using their skill for trivial, perverse, or merely imbecile purposes, may nevertheless possess that skill in a high degree. There is then a danger that they will claim and enjoy that reverence and authority which are due only to great engineers.

Thus, as engineering poets let us continue to do our work of art of engineering for the common good, conscious of the difficulties, temptations, and dangers. Figure 9 shows the relationship between the concepts.

11 Conclusion

There is a need to realize that engineering designs exist in different ways and therefore can be studied from different perspectives or aspects. They have a physical aspect, but also an economical side, a social side, an aesthetical side, etc. Therefore, we can study a system from the perspective of physics and see which laws (electric circuits, elect romagnetic, electromechanical conversion, etc.) it obeys, but also from an economical perspective and see which market and economic laws it works under.

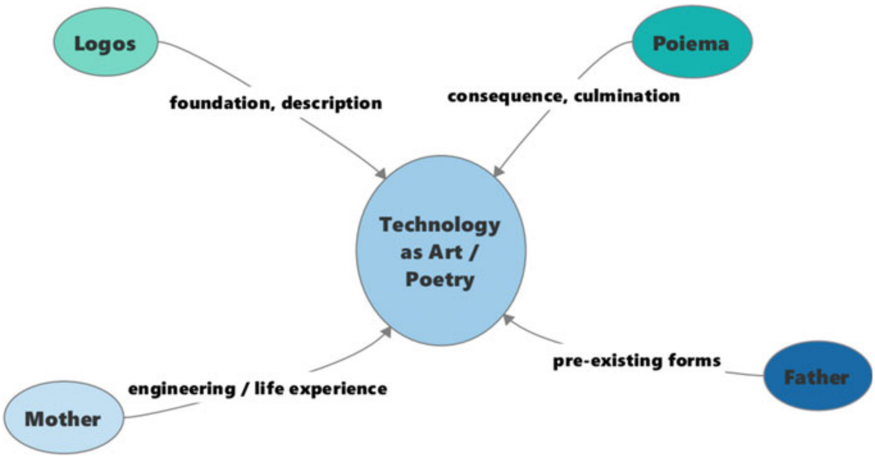

Fig. 9 Technology as art/poetry

There is a need to distinguish the different functions of an engineering system in all aspects. One important function is the qualifying function that indicates what is the main purpose of the physical aspect. Similarly, its qualifying function in the social aspect, economical, or in the legal aspects which are subjected to the proper operation of the physical aspect need to be identified.

There is also a need to understand the irreducibility and yet interconnectedness of all aspects of the system existence and relations, develop models which avoid all forms of reductionism, distortions, and disfunctionalities which arise from them, and have a constructive basis for interdisciplinary studies.

Finally, it is of paramount importance to remember that the objective of a holistic normative design in engineering and technology is to achieving smart living where, for example, all is normatively and harmoniously connected, from smarter grids to smart cities. In this process, philosophy of technology becomes a necessity rather than an academic exercise, and architectures of reference and frameworks for engineering systems and systems engineering must be continually developed.

Then, one will recognize that engineering and technology are also an art and not just science, like a poem it requires imaginative designs which take into account all aspects. In this process, modal aspects can enhance the understanding and proper development of all stages from conception to design, development, production, distribution, operation, environmental impact, maintenance, retirement, phase out, and disposal.

This integrated vision makes more natural connections with the social implications of engineering practices and will help engineers feel more like agents of social transformations than technocrats.

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Applications

The Engineer in the Face of Social Changes: The Cases of Health and Sustainability at Work

Paulo César Zamboni-de-Souza, Ivan Bolis, and Sandro de Gasparo

1 Introduction

This chapter assumes that work is central to the human species, both phylogenetically (Leroi-Ghouran, 1991) and ontogenetically (Dejours, 2016), and that changes in society necessarily involve changes in the ways of working. The reader may see that is a natural consequence of the approaches adopted in Chaps "Engineering Practices: Complexity—Diversity—Coherence—Meaningfulness", "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures" and "Toward a Holistic Normative Design". From Chap. "Engineering Practices: Complexity—Diversity—Coherence—Meaningfulness", we learned that understanding the complexity of reality is crucial for engineering practices. Chap. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures" addressed how engineers may ethically work on the transition to a sustainable infrastructure. This concept was then extended in Chap. "Toward a Holistic Normative Design", where a philosophical discussion on the nature of technology was carried out. Thus, this chapter places the problem of how the health conditions may affect the work of this complex professional, who must understand his/her ethical role in an environment that needs innovation and personal management of other workers.

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From a phylogenetic point of view, the invention of tools would have appeared and developed in conjunction with the release of hands and what this made possible in terms of intervention in their environment, forcing the improvement of the central nervous system (Leroi-Ghouran, 2014).

From the perspective of ontogenesis, each child develops physically and psychologically playing with others (Vygotski, 1997), often simulating theaters in which they play roles, telling each other that they are princesses, heroes, television characters, etc. In adulthood, you can no longer play theater as in the first years of life, so each one will play social roles, including those played at work. As with theatricalization at an early age, the roles assumed in working life play a central role in the formation and maintenance of identity (Dejours, 2016). The set of these elements in all stages of life since childhood must maintain some relation with the worker's history in the work exercise to maintain mental health, a phenomenon called symbolic resonance (Dejours, 2016). This allows each one, working alongside others, to find harmony between what they are, with their history (Lévi-Strauss, 1949), and what the activity requires in the exercise of their utilitarian function.

When working, the subject faces the real difficulties that the world poses. But it is not just about coping with a nature to be modified by human intervention, but also about doing something in a social environment. Thus, each person is confronted with their task, but there are always other subjects in the work situation since the work is something done taking into account other people, even if they are not present at a specific moment the activity, such as coworkers, potential customers, suppliers, bosses and subordinates. To continue the theater metaphor, even the monologue supposes the presence of an eventual audience, illuminators, ticket holders, etc. Thus, working is putting skills to the test, taking into account the uses that will be made by others (Schwartz, 1992). It is a relationship with reality that is necessarily social, subject to personal limits and social relationships, in which rules of power are present, including professional spaces, in such a way that "working is not, at any time, just to produce: it is also and always to live together" (Dejours, 2009).

Contemporary forms of management tend to destroy the ties of cooperation between workers, destroying collectives and leaving each one alone and weakened in the face of work organization (Dejours, 2015), favoring the appearance of diseases.

As a derivation of these statements, the central question of this text is presented: how can engineering contribute to working in ways that are more favorable to the lives of humans?

It is not intended here to try to date the beginning of the work, if it would have occurred 2.5 million years ago with the manufacture of tools by *homo habilis*, if in the Neolithic with the social organization of work around agriculture and livestock, if in the emergence of wages with the industrial revolution (Schwartz, 2000). It is not the focus, either, to debate in this chapter what the birth of engineering would have been based on its historical evidence, such as the pyramids in Egypt and different places in the world, the Roman aqueducts, the Viking boats and the use of electricity. It can be said that in all of these moments, since prehistory, that technique played a crucial role on the way humanity live (Bardin, 2015; Simondon, 1958). There is also certainty in affirming that the referred technique played a central role in the emergence and development of engineering, which, in turn, is indispensable for technical development.

However, there is no doubt that engineering played a central role in the industrial revolution in the eighteenth and nineteenth centuries when carrying out projects, construction and maintenance of large machines. The changes that occurred at that time led to an established separation between the social spaces of life and work, leaving the place of production of goods and services removed from domestic life. This phenomenon resulted, on one hand, in a great increase in the human capacity to dominate, even partially, nature and develop science and technology. On the other hand, it generated migration to the cities and overexploitation of the labor force, with illness and early deaths (Castel, 1995), in addition to the destruction of nature that led to the disappearance of several species (Leigh et al., 2019). During the twentieth century, engineering also played a central role in the search for safety at work, as employers understood the need to improve their working conditions to avoid losses (Robbins, 2002).

More recently, it is known that the 1970s were a time of great global economic crises that had neoliberalism as one of its main proposed solutions (Harvey, 2007). This led to forms of management that started to privilege the so-called quality management, together with the individual performance evaluation (Dejours, 2015), which does not evaluate the work, but only its measurable part, disregarding the efforts of people to accomplish the task. This way of working encourages everyone to always try to produce more at any cost, incites competition and discourages cooperation, tending to destroy collectives. This leaves each one to their own, weakened, a situation that affects the dynamics of family and social relationships, in addition to their health. This way of managing seeks to place itself as if it were the only possible way, as an imposition before which "one cannot but resign" (Dejours, 2015). Thus, the notion that each company or person must take care of themselves, without the support of others or the state, is increasingly taken as natural—and not as socially produced.

This management logic produced a planet on which, even before the COVID-19 pandemic, there is, on one hand, immense wealth and technological development, but on the other, 690.000.000 people are starving in different parts of the world (Food & Agriculture Organization of the United Nations, 2020), a situation that may worsen with climate change. Even among those who have jobs that supposedly could free them from hunger, many end up dying from illnesses generated at work or accidents, in a total of 2.3 million people per year (International Labor Organization, 2020). Humanity has made enormous technological progress, but social inequality, with its most cruel face—disease, hunger, and death—is part of the life scenario of the population.

2 What Can the Engineer Do in the Face of This Situation?

At first, it is worth recognizing that engineering is multiple, with several specialties, such as civil, electrical, mechanical, metallurgical, chemical, geology and mines, agronomist, of production, among others. Thus, it is a question of reflecting on the role of the engineer in a broad way, not limited to a certain field.

The code of ethics of the engineer in Brazil in its Chap. "Toward a Holistic Normative Design", article 8, determines that the profession has "as main objectives the preservation and harmonic development of the human being, his environment and his values" (Conselho Federal de Engenharia, Arquitetura e Agricultura, 2002). This statement is consistent with what is preached in the world, as can be seen, for example, in the code of ethics for electrical engineers determined by The Institute the Electrical and Electronics Electronics Engineers (The Institute of Electrical and Electronics Engineers, 2020), which determines that the engineer must "hold paramount the safety, health and welfare of the public, to strive to comply with ethical design and sustainable development practices, to protect the privacy of others and to disclose promptly factors that might endanger the public or the environment".

All work takes place in three decision poles: the state, the companies and the activity (Schwartz, 2000).

- There is the State administration, in general, exercised by the executive, legislative and judicial powers in democratic and legal societies. It makes a difference in the life of societies if the places of these powers are occupied by people who defend ideas for or against certain central issues such as labor relations, security, etc.;
- As for the management of companies, there are different managers and directors. Each of them defends different ideas regarding innovation and rising risks and results orientation. They seek to influence organizational culture, trying to establish a certain relationship with the supplier market, customers, employees, etc. For example, when customers, whether individuals or companies, often face a problem in a business relationship, they request the presence of the manager to resolve that situation;
- There is also the activity decision pole, which is often overlooked. It refers to the fact that each person makes choices when it comes to doing what needs to be done in their daily work, making use of the techniques they master to dedicate a certain amount of energy to perform the task. Hence, knowing how to do something is not enough to do well, since it requires a personal mobilization, in such a way that the individual, although always inserted in a collective, must strive for the work to be done. Each worker, even at the lowest level of the organizational hierarchy, manages his work, making a series of choices all the time. Team sports have many examples of this, in the countless cases in which teams are formed with very skilled players, but who cannot (perhaps not even want) to be champions together.

The engineer has always been one who intermediates scientific–technical knowledge with practical knowledge, the *modus operandi* of a factory floor. His profession fits exactly in this amalgamation: The State assigns him the central function in the production of goods and services (Zarifian, 2000). However, since the rise of neoliberalism, it has been gradually removed from the management of companies, replaced by managers who are often unaware of the activity. This tends to devalue the importance of the human being at work since the increasingly high production goals are imposed without taking into account the difficulties to achieve them. This tends to make people sick and increases the risk of accidents at work.

3 How Did We Get to This Point?

Modern administration has its beginnings with the works of three engineers: Taylor, Ford and Fayol (Robbins, 2002). In all of them, there was a need to improve productivity. Even though this has created health problems for workers, with an increase in the division between those who think and those who perform work, there was a concern with the analysis of work, of knowing what they need, in practice, to obtain the results. There was, therefore, respect for ways of achieving results.

The so-called management shift (Dejours, 2015), which occurred in the last decades of the twentieth century, gradually removed engineers from the top positions of large companies. Such positions started to be occupied by management specialists, namely professionals who started to designate themselves, managers, because they knew business tools, but who almost always do not know the peculiarities of a specific company/work organization. From the last decades of the twentieth century, neoliberalism came to be seen as the only possible way to manage production and life, proclaiming that "There Is No Alternative", according to the words of Herbert Spencer (Spencer, 1851), taken up by Margaret Thatcher, who became known by the acronym TINA. Such a model encourages competition between people and undermines cooperation, generates anxiety and leads to illness, through individual performance and quantitative assessments, stimulating competition among workers, who become lonely and frightened. Without being able to count on coworkers, each one finds himself alone to carry out his tasks and maintain his health. The daily work becomes the struggle of each one against everyone.

With the rise of such a model, the engineer was removed from the top of the management hierarchy and was delegated to functions restricted to the factory floor, failing to participate in the strategic decisions of the companies. On the other hand, the highest positions in companies were occupied by specialists in budget and finance, with adverse effects for people and often also for the organization. Such people often use titles like MBAs to secure places that would require knowledge of an activity that they effectively ignore (Mintzberg, 2005).

In contrast to such a way of managing, Dejours (2015) argues that the management of companies should be based on five records: quality of service, respect, and attention to what will be able to positively modify their activity conditions; productivity, in such a way that the resources are used to generate high-level results for the company; external impacts, whether on social relations or the environment; the reflexive effects of production on immaterial resources, such as the culture of the place where the company operates; profitability, that is, the positive balance sheet. It is evident that in this model, which opposes TINA, the search for profitability is maintained, but it starts to be considered alongside the other dimensions. Therefore, it is necessary to investigate and recognize the importance of work on two levels: individual, due to the ingenuity that each person can use and develop in daily life; the collective, namely the capacity to generate cooperation between the actors of the productive processes.

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b) productivity, in such a way that the resources are used to generate high-level results for the company;
c) external impacts, whether on social relations or the environment;
d) the reflexive effects of production on immaterial resources, such as the culture of the place where the company operates;
e) profitability, that is, the positive balance sheet.

For such a process to occur, the engineer must have a central role. He is the one who guarantees technical knowledge because he is the one who knows them and can dialogue with the workers. In the management of a company, therefore, the engineer must be able to know certain technical tools without which the company cannot produce quality and productivity. Such knowledge must be able to assure a position in the company's decisions, as occurred at the birth of modern management (Robbins, 2002).

4 The Specificities of the Work of the Engineer

The engineer is a professional with great technical knowledge. His work is analyzed based on his skills to deal with specific problems in his area of specialization. Although there is a technical specialization learned with a greater emphasis on their training and the direction of their action, the current work of the engineer includes other aspects, which are not only technical. The world of work is constantly evolving. In the past, the engineer could work on specific and relatively isolated tasks. However, nowadays this professional has a work approach not limited to his specific skills but also includes knowledge and social abilities. The engineer works, in most cases, in organizational (or social) environments and solves problems that can be of high technical complexity, but whose ultimate objective is to solve essentially social needs. It is still very limited, but an increasing number of undergraduate engineering courses are incorporating some more humanistic disciplines (Edneral & Safieva, 2018). This is especially true for courses in industrial engineering, manufacturing engineering and management engineering, which have a strong organizational emphasis. However, there are engineering courses, such as systems engineering, which include interdisciplinarity as an important basis for training engineers, including technical and human-centered disciplines in the curriculum (Wognum et al., 2019). This trend reflects what students will face when they leave university and start working as engineers in work systems with an increasing degree of complexity and interconnection.

When focusing on the social aspects and trying to make it understandable, three main aspects, described next, are increasingly becoming part of an engineer's job.

4.1 The Engineer's Ability to Relate to Other People

When the engineer develops his specific work activities, he works in a social context. He never works completely alone. He can also work a lot of time alone, but at some point, he needs to bond with another professional. This is the case of the simplest relationship, when, for example, an engineer works autonomously, but at some point needs to contact his customers. The current trend is that the number of relationships that the engineer must create to develop effective and efficient work is increasing. Today it is common for the engineer to co-create solutions together, and sometimes simultaneously, with other professionals in other areas. This is a consequence of the increasing degree of complexity of the products and services offered. In addition to the need to manage the growing interconnection with other professionals, the engineer is often called upon to occupy managerial positions, having to direct the activities of a group of workers. This growing needs to bond with other professionals means that the engineer must acquire interpersonal knowledge and skills. These skills are known in business contexts as "soft skills". Complementary to "hard skills", "soft skills" are behavioral or interpersonal skills that cannot be evaluated qualitatively (Srivastava & Kuri, 2021). Some examples are creativity, leadership, adaptability, empathy, etc.

4.2 Social Aspects Considered as Part of Decision Criteria

Engineers traditionally used to work receiving some technical specifications as a subsidy to develop their work. Currently, an engineer often needs to seek more information, including some of a social nature. Especially in jobs where the engineer is close to the final recipients of a product or service, he must acquire as much information as possible about the needs of these end customers. As one knows, the same solution can create different values for different types of customers. Considering the social and psychological aspects allows him to better understand how to create more value for that specific customer or for that specific segment of customers. These aspects can, therefore, be considered one of the important criteria for making decisions about the production of the work of the engineer (Kroes & Verbeek, 2014).

4.3 Position of the Engineer Regarding Work and Society

The engineer is not just a worker who follows certain procedures, certain orders or, more generally, certain tasks. He is also a worker challenged to put himself in a certain position about his activities. There are ethical postures that cause certain social impacts for some social actors, which can be positive or negative. Also, the engineer can be found in specific contexts, such as sustainability, in which his worldview is fundamental to the final result of his work. The engineer can also take different positions on certain issues, such as health. When he chooses one position over another, he causes very different results in his work.

Two loci will be presented below, in which the position of the engineer is central to conducting production in a way that respects people and the environment: the search for health at work; sustainability in companies.

5 Work, Health and Illness

5.1 Work and Subjectivity

Work is central to subjectivity and health. Although it is a notion of many definitions, it is defined here as "coordinated activity of men and women to face what, in production, cannot be obtained by the strict execution of the prescribed organization of work" (Dejours, 2016, p. 209). This meaning points to the coordination elements involved, as well as the sexual division of labor, in addition to marking its utilitarian character, i.e., of being indispensable to produce goods or services. Also, it draws attention to the fact that the production of results is linked to a careful performance of work. Thus, workers need to engage for production to be successful (Sznelwar et al., 2011). Hence, workers drive themselves to the limits of their competence, testing themselves and their abilities in such a way that eventually they are transformed into something else, positively or negatively.

Several elements present in the work confirm its eminently human character, different from that carried out by other animals:

- *Suffering* (Dejours & Gernet, 2012): "a specific experience resulting from the dynamic confrontation of the subjects with the organization of work";
- *Pleasure*, which "can meet work when suffering can be transformed into a job demand by the Ego and become a structuring experience for identity";
- *Normality*, the result of "a compromise between suffering and the defenses designed to support this suffering";
- *Individual and collective defense strategies*, which are "a whole series of psychic processes that will contribute to fighting the threat of decompensation";
- *Intelligence at work*, which "can be called 'ingenuity', in order to highlight its inventive and practical character based on work experience";

- *Coordination*, which "designates the prescription given by the organization of the relationship work between individuals";
- *Cooperation*, which "designates the bonds between the subjects in the process of voluntarily carrying out a common work";
- *Sexual division of labor*, organized by the "principle of separation (between men's work and women's work) and the hierarchy principle: a man's work has more 'value' than a woman's work".

5.1.1 Health and Suffering

Fulfilling the tasks to execute a job requires a mobilization to perform it, often generating irritation, tiredness and anguish as forms of suffering. This is not necessarily a pathogen, point to the worker the challenge to transmute suffering into pleasure. Such transmutation drives the workers to reappropriate the demands placed by the organization when they are not passive before it, avourg their identity and, thus, their health, which occurs thanks to the sublimation process. In chemistry, it is the transition from a solid to a gaseous state without going through the liquid. In Psychoanalysis, sublimation is the change of a drive from sexual energy to other purposes, as found in works of artists (Freud, 1905). Sublimation has its origin in the life story of each one through the "'symbolic resonance' between the avour of the current work situation and the internal avour inherited from the past" (Dejours, 2016). Although it has a source in everyone's life, in work activity it can only appear intersubjectively, made possible by the workgroup, which offers recognition for the beautiful work done by each one.

This teamwork builds defensive strategies to avour each worker in the constant struggle for health and, thus, not succumb to the disease. The teamwork generates, maintains and develops such strategies, which in turn create and strengthen the teamwork. Thus, to each one live in a work environment without becoming ill, teamwork plays a fundamental role, generating strategies that allow each one to work and seek their health. As contemporary management strategies encourage individualism and a lack of cooperation through the aforementioned individual assessment of performance and quality management with increasingly higher parameters, each worker remains alone in face of the demands that the work organization places. The famous phrase attributed to a Roman Caesar *divide et impera* (divide to rule) has produced profitability for companies, but it has been extremely harmful to workers, with illness and death.

5.1.2 Work and Mental Health

As previously stated, suffering is not necessarily pathogenic, but it must be overcome and transformed into pleasure in recognition of its realization, so "it brings an extra gain, in terms of benefit to the identity. Also, it increases the worker's resistance to the risk of psychic and somatic destabilization. The work then works as a mediator for health" (Dejours, 2016).

In some situations, however, suffering takes on certain forms in which workers are unable to face their work without becoming ill, especially in situations of boredom or monotony (repetitive work becomes anti-sublimation), fear, confrontation with injustice and ethical suffering (Dejours & Gernet, 2012). Suffering becomes pathogenic "when there is nothing but fixed, rigid, unavoidable pressures, generating repetition and frustration, boredom, fear, or the feeling of helplessness" (Dejours & Gernet, 2012). This maintains a direct relationship with the forms of management of organizations since the disease arises when "the social relationships of the management's choices engage suffering in the sense of being pathogenic, situations in which work functions as a mediator of destabilization and fragility health" (Dejours, 2016). The disease, then, is a construction determined by the relationship with work and its conditions of exercise (Saint-Arnaud et al., 2004). Thus, both repetitive works, in which each worker has to adapt himself to a strenuous work rhythm, as well as the intensification of work caused by individualized performance evaluations and increasingly demanding quality programs, are sources of illness. These topics exhaust the worker's energies, to the point of developing depressive and anxious disorders, often associated with Burnout.

Burnout emerged as an object of investigation from the work of the American psychoanalyst Herbert Freudenberger and developed by the psychologist Christina Maslach (Maslach & Jackson, 1981). Its name comes from the fact that the worker maintains a relatively healthy appearance for a while, but he would be in a situation as if burning from the inside out, in such a way that he ends up reaching a level of exhaustion. The subject presents emotional exhaustion, depersonalization, and lack of personal accomplishment. Also, bullying at work often becomes a form of management for companies that operate through the threat and humiliation of their employees, which leads to illness. Bullying was first described as work related by Leymann (1996a) in his work in Sweden in the 1980s, from his research in the 1970s (Leymann & Gustavsson, 1984). The author acknowledges that Brodsky had previously spoken of sexual harassment and that the phenomenon of harassment in schools had already been described in the United States. He argues that in organizational environments, bullying is based on psychological violence, while the American school phenomenon employs mostly physical violence. For this reason, Leymann prefers to use the word mobbing, importing it from the ethology that had described situations in which a group of animals, that would form the equivalent of a mob, come together to attack one of its members. Leymann (1996b) suggests "keeping the word bullying for activities among children and teenagers at school". In different countries, bullying at work currently receives different nomenclatures, but, as a rule, referring to the same phenomenon.

In addition to overload pathologies, usually associated with Burnout and harassment, the struggle to remain in the workforce, even in adverse conditions, favors the increase in occupational accidents, bringing deaths and amputations. There is also post-traumatic stress disorder, which arises in response to a stressful event or situation of an exceptionally threatening or catastrophic nature (World Health Organization, 1992).

Even suicides in the workplace or related to it have become commonplace in several countries (Dejours & Bègue, 2009). The World Health Organization defines this problem as a result of a complex interaction between individual vulnerabilities (such as mental health problems), stressful working conditions and living conditions (including social and environmental stressors) (World Health Organization, 2006).

In 2018, in Brazil, 952,127 workers were officially removed from work due to illness or occupational accidents (Ministério da Previdência Social, 2019). It can be considered, however, that the number of sick workers is bigger since due to the ideology of shame (Dejours, 2015), many endure the symptoms to the limit and only recognize themselves as sick when they can no longer go to work. Also, with the fear of losing their jobs, there is a great underreporting of illnesses and accidents, a situation that is aggravated by the fact that several of them do not know their legal rights.

Such a situation of illness inevitably brings losses for workers, for organizations and the State. Workers are affected by losses of various kinds (mental, physical, financial, in family and social relationships); organizations cannot fully count on these employees, many of them with essential skills. Worsening the situation, the State needs to defray the expenses, which are insufficient, on the other hand, for the basic needs of these workers.

Many workers experience a paradoxical situation: They face hostile means of work, organization and/or work conditions that favor suffering and illness, often leading to temporary leaves. However, quitting that oppressing job is hardly considered as an option, since the social security assistance may not be enough for the basic needs of a family.

5.2 The Role of the Engineer

The confrontation that occurs at work requires self-regulation/adjustments in face of the prescribed/real discrepancy (namely between what each worker is asked to do and what he does) that take place on two levels: individual, with ingenuity; collective, with cooperation. The task always presents limits because it is faced with real, living situations, in which the limits of human knowledge, of technique, with contradictions, as well as the variability of the environment and of the people who work impose difficulties when carrying out any task (Dejours, 2010). To account for these limits and variability, workers mobilize subjectively and together.

Science, including engineering, finds limits that require each worker to solve the problems that are posed daily. It is important to say that this does not mean to deny the importance of technical and scientific knowledge. On the contrary, it is necessary to use and value them, as well as to put them into a debate with the knowledge of the practice, through the astuteness developed by the engineer in his daily life, or his practical intelligence. In the practice of any professional, whether he

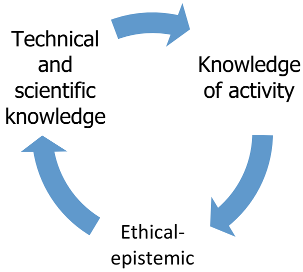

Fig. 1 Three poles of knowledge at work

is an engineer, machine worker, doctor, salesman, psychologist, janitor, etc., some situations are not provided by any protocol, since the work environment always presents a variability (Guérin et al., 2007) front, necessary to invent a solution. In this way, anyone who works has useful knowledge, either to production or to maintain the person who performs it in health. Improving quality and productivity combined with health means, therefore, putting such knowledge into dialogue. But for the dialogue to be fruitful, it is necessary to respect the knowledge of all participants.

It is, therefore, the development of a dynamic device in three poles (Schwartz, 2000), in which that knowledge maintains a fruitful relationship, intermediated by a third pole, the epistemic ethical, represented in the following figure (Fig. 1).

Among the members of each pole, there must be a constant and respectful dialogue, so that they are not closed in on themselves. We seek to build effectively dynamic devices. As an engineer occupies a higher position in the organizational hierarchy, he has a primary role in the knowledge of dialogue. If mediated by ethics, the workers' prudential knowledge can gain visibility to improve productivity, facilitating health at work. Without the engineer stimulating this dialogue, it will remain, at best, only among workers, in the dark.

The engineer can encourage formal and informal discussion spaces. In the first, meetings are scheduled to follow a specific topic like quality, productivity and health. Trust is central for a fruitful discussion in this case. Discussions about work have been present since the 1920s in the USA, with the Human Relations School (Robbins, 2002), or in Japan with the Toyota Production System (Watanabe, 1991) in the last decades of the twentieth century. The following difficulty arises many times, such exchanges of information served for their harmful use, whether using the knowledge of workers against themselves or appropriating ideas without giving credit to their author, betraying workers (Borzeix & Linhart, 1988). The engineer has, in this dynamic, the central role of also putting his knowledge about the situation under debate and, above all, guaranteeing ethics in the production and use of knowledge.

6 The Engineer in the Context of Sustainable Development and Corporate Interests

The theme of sustainable development is relatively new. It originated in the 1970s of the last century when the first major international discussions about global environmental problems began. The discussion of sustainable development is essentially a discussion created from thinking about what type of development should meet current needs, without, however, compromising the capacity of future generations (United Nations, 1972). Although an international discussion has been going on for some decades, it has not yet been possible to define in a formal language what should be done (World Comission on Environment & Development, 1987). Most authors recognize the structural need for changes in the current economic system (Faber et al., 2005), but how to do so is still unclear. The explanation for this can be found in the presence of social aspects that are not manageable. The sustainability challenge is to create solutions that can coexist with needs, behaviors, values, etc., sometimes divergent from different specific human groups. Considering that people's actions are not necessarily rational (Cruz et al., 2006), one can understand the great challenge of sustainability for humanity as a whole.

In this context, two main paradigms can be observed in promoting more sustainable development. The first fits into the current economic system. The economy would continue its natural course, but additionally, it would include sustainability issues within current principles and rules. This is mainly what is being done within organizations through sustainability policies. The second paradigm is one that promotes a change in the current economic system. In this, it does not mean just including more variables linked to greater attention to environmental, social or economic aspects. Promoting sustainability means examining the problem through a more complex view (Elkington, 1997). The engineer, during the development of his work, must, therefore, not only focus on his specific work but co-create solutions with other professionals through a reflective and transformative approach that considers social aspects in a non-Cartesian way. These two paradigms will be explained in detail below, related to the work of the engineer.

6.1 The Work of the Engineer in the Current Economic Paradigm

In the current economic context, sustainability is promoted mainly in the general context of the market and applied in organizational environments through corporate sustainability. This concern is relatively recent. Only since the 1990s has this theme evolved and been included in corporate strategic policies. It is currently very difficult to find a medium or large organization that does not declare its commitment to sustainability. Through corporate sustainability policies or corporate social responsibility, organizations are committed to the development of more sustainable business models. Some concepts widely used in companies are Triple Bottom Line (Elkington, 1997), Sweet Spot (Savitz & Weber, 2007) or Stakeholder Theory (Freeman, 2004). Another relatively common concept in organizations is that of trying to base decisions on meeting the United Nations' Sustainable Development Goals (United Nations, 2020). The application of these concepts mainly follows instrumental rationality, oriented toward alignment with the economic and financial interests of these organizations (Bolis et al., 2017).

The first phase of this movement in companies is to include some specific aspects of sustainability in their organizations. At the beginning of this movement, much emphasis was placed on the environmental aspect. One of the most explored aspects was the introduction of improvements in eco-efficiency, reducing the use of natural resources, and increasing the organization's mainly economic–financial efficiency (Cruickshank & Fenner, 2007). Another common practice is also the implementation of actions that can improve some social aspects (education, work, sanitation, etc.) of the community close to the organizations. This first phase assumes that the engineers' work considers more variables (those of sustainability) than those that they had to consider previously. The engineer working in these organizations may therefore need to add more aspects to be considered in his work (e.g., some variables that increase ecological efficiency, some variables that adapt his solutions to the most vulnerable segments of the population, etc.). This expansion of the variables to be considered, according to the Triple Bottom Line concept, obliges the engineer to consider social variables in his work, as well as economic and environmental ones. The concept of Stakeholkder's Theory, on the other hand, also forces him to expand his vision to the social aspects, thinking of the value created for all the social actors involved in his work.

When considering a greater number of variables at work, the possible consequence is the need to be involved in multidisciplinary projects developed with other professionals. For example, to achieve climate adaptation in urban environments, engineers would need to work together with planners, designers, economists, policymakers, managers, lawyers and communities (Elkington, 1994). Even in organizations, the engineer continues to work in his specialty, but he must consider and continue to align the information received from other professionals in other areas. This makes necessary to create continuous contacts and build relationships with other professionals. Also, it may be necessary to improve relations with the working group, requiring the engineer to acquire a range of additional skills beyond those traditionally connected to engineering (Du Tertre, 2013). In this context, some social aspects can also become criteria for decision-making for the engineer.

In this first phase of corporate sustainability, the engineer is encouraged to seek win–win solutions, that is, solutions that allow generating joint gains in the economic–financial and socio-environmental aspects (Cunningham & Kelly, 2017). However, only a few of the solutions can easily create win–win benefits. The challenge for engineers is to transform lose–win solutions into win–win solutions. This task is not easy and requires the engineer to learn more about sustainability and create creative and proactive solutions. He can no longer be in a passive posture only receiving the sustainability guidelines, but must inevitably understand what the sustainability challenge is, just like its ethical, social and anthropological consequences (Coeckelbergh, 2013). For this reason, its epistemological position must already be modified based on its formation (Tejedor et al., 2018), which can be transdisciplinary (Du Tertre, 2007). This positioning in the literature is already close to what is proposed by the new economic paradigms induced by the problem of sustainability.

6.2 The Work of the Engineer Facing a New Economic Paradigm Induced by the Issue of Sustainability

It is not intended to describe here all the new economic paradigms induced by the problem of sustainability. We will only analyze an approach in the context of sustainability and that allows one to examine the epistemological change of engineering from that proposed by the economy of functionality and cooperation (Du Tertre, 2013; Gallino, 2005). Historically, since the Industrial Revolution, society has greatly increased its well-being thanks to a dynamic of economic growth based on the development of the industry. Social progress was possible mainly with the increase in the production of material goods and the parallel construction of a market logic that could increase access to the consumption of these goods for growing segments of the population. In other words, the progress model was based on the production and consumption of material goods. The engineer has assumed a decisive role in this conception of production, as one of the main figures who can optimize the production processes and improve the material heritage based on his technical skills. In a sense, the engineer assumed a social role during the historical sequence in which the industry participated in a form of social progress. The dynamics of industrial development dominated for many decades, at least until the 1960s and 1970s in Organization for Economic Co-operation and Development (OECD) countries, until it became a reference model. From that period on, the goods production capacity became much higher than what the market could consume (Pessis et al., 2013). This has caused several consequences, with profound changes in companies, in the production system, and society in general. Some social consequences were the reduction in the cost of labor, the increase in the price of goods and services faster than wages, the attack on unions, the relocation of companies and the flexibility of the labor market (Gadrey, 2005). The consequences also concern the increase in environmental impact, linked in particular to the more frequent renovation of goods on the market, through various forms of obsolescence, and the relative increase in the consumption of raw materials and the production of waste of all kinds. The so-called managerial shift emerged in this context, to preserve the dominant positions of the industrial era (corporate income) and to delay the decline of a historical cycle born with the Industrial Revolution.

Today, and as of the mid-1970s, social progress no longer corresponds to industrial progress, and this is for three reasons: the first linked to the economic dynamics of production, the second to the environmental crisis and the third to the social issue of work (Agence de la Transition Ecologique, 2019). This rupture between social progress and industrial logic is visible in the fact that GDP, as a measure of the countries' development, increasingly loses its relevance, and discussions are growing about which other alternatives, not only based on econometrics, can measure development. Amid several movements that promote sustainable development, such as the search for alternative development models, the Economy of Functionality and Cooperation (EFC) arises from the desire to overcome the industrial economic model, affirming the centrality of work, both in terms of economic cohesion and social (De Gasparo, 2018).

EFC proposes to make the economic dynamics of production using less raw material. This appears to be the only tool to significantly reduce the impact of human activity on the environment. Decreasing the use of material means reducing its extraction from nature, but also eliminating or reducing production phases that can have a high environmental impact, by encouraging its reuse. Decreasing the use of material means reducing its extraction from nature, but also eliminating or decreasing production phases that can have a high environmental impact, and encouraging its reuse. This different type of growth, unrelated to production based on the flow of matter, must therefore be replaced by another type of production, which is the production of services. In this new perspective, economic value is no longer trapped in a physical asset such as a car, a smartphone or a package of frozen fish. Economic value must be thought of as fulfilling the great functions of social life, free to place itself again at the service of social progress, through new responses that guarantee, for example, the necessary mobility for people, the ability to communicate and the possibility of healthy eating. The idea of service dynamics is to create value not in the form of a material good, but through effective and relevant solutions about the needs of people and society (Laurent, 2018).

Today, the problems are visible mainly in large urban agglomerations: The car generates major traffic problems that reduce the fluidity of travel; the smartphone can create addictions and delays in children's cognitive development, which do not help to improve communication; processed foods are the source of serious public health problems. EFC is inspired by the dynamics of services to imagine "integrated solutions" that subordinate the use of material goods, objects and tools to the value of the service they provide. Economic development is no longer linked to the number of goods produced, but to the real value of these solutions. Tangible assets no longer have value in themselves but are supported by an intangible value generated thanks to work activity. By giving content to the concept of sustainable development, developing a service-based production allows opening a new approach to production, different from that characterized by the optimization and rationalization typical of the industrial model (Du Tertre et al., 2019).

In this context, production reappropriates a social function, and the question of work becomes central. In this new economic perspective, the focus is no longer on product standardization. Production depends on the relevance of service to certain social needs. The value of production arises from the evolution of a market where solitary, isolated individuals find material goods, standardized, to a dynamic of evaluation, judgment and social deliberation on the effective utilization of the proposed solutions, taking into account economic and environmental criteria.

This change in the economic nature of production implies a profound transformation in the conception of work (De Gasparo, 2018), which comes from the Taylor's scheme of scientific organization of work, which loses relevance and strength. In fact, in a situation where the value is linked to a standardized asset, the production management function, traditionally assigned to the engineer, consists of designing and ensuring the conformity of the production process with a pre-established plan. In this case, any form of a discrepancy between the prescribed work (standard process) and the actual work (human activity) is considered a problem, a dysfunction to be corrected, often using managerial discipline techniques. But when the value depends on the effective capacity to respond to a need, which sometimes the same consumer ignores, taking into account the socially defined norms (ethics, respect for the environment, etc.), then in this case the production consists of creating a quality relationship, where trust, respect and mutual recognition make it possible to better outline the specific need, the possible responses and the conditions for their realization. It is here that the gap between what was initially expected and real activity is the very source of value creation. The change in an economic perspective, induced by the need for sustainable development, reverses the relationship with the work of the product management function and, therefore, of the engineer. Human activity is no longer a productive factor to be controlled, to be subjected to an implacable and alienating mechanical logic, to be disciplined because it is always driven by an autonomous will. On the contrary, it becomes the central component of value creation, to be supported, recognized and professionalized. Cooperation, which is the ability to cooperate, each taking into account the real work of others, in a reciprocal way thanks to the working relationships that give space to the subjectivity of each one, becomes a new matrix of social organization (Laurent, 2018).

In this sense, the work of the engineer changes. In the industrial system, its function was to control the production system with norms and standards, producing products that allow the highest performance and standardization. In the production system with service, the fact of producing something immaterial allows restoring a central role to the work, creating organizational systems. For the engineer, therefore, the content of the job design activity changes. The work can no longer be prescribed entirely, but the engineer must increasingly consider the people's real work. The engineer can, therefore, put himself at the service to improve and qualify the work. Through the recognition of work, it is possible to create a more supportive and collaborative society. There is, therefore, a need to re-interrogate the design process of production systems through three possible developments:

- Transition from production centered on the means of production (machines) to one focused on intangible resources (activities);
- The production analyzed as an enabling environment (environmental enabling) and not as a process where it is the object of design and prescription;

– Change in the relationship between the (formal) organization and management: no longer management in the service of the formal organization, but the organization in the service of management.

It can thus be said that, faced with the challenge of sustainability, the engineering profession is evolving and that the content of his work is increasing. Two orientations are possible to question the relationship of the engineer with the socioeconomic and environmental context and, therefore, to interpret the meaning of this extension. The first, within the industrial paradigm, the engineer is led to consider a greater number of aspects in his work, which are not limited only to technical criteria but include more and more social and environmental aspects, which impel him to interact socially with a growing number of interlocutors and social categories with diverse interests. This evolution creates more complexity, sometimes difficulties, to the point of reaching contradictions due to the economic dynamics of an industrial type that tend to resolve situations to the detriment of social and environmental aspects. This is due to the dependence that links economic value to the flow of matter and standardized production. The second, on the other hand, when sustainability is understood more radically and rigorously, that is, when the need arises to emancipate the economic dynamics from the value of its dependence on the matter, the engineer is faced with a more substantial change. The renewal of the reference economic paradigm for thinking about the conditions of production of goods and services creates an epistemological change and a new social positioning for the engineer.

Therefore, within the company, the engineer must not only learn to design the production system and work organization within this new paradigm but also become a facilitator of this change and this new work model, especially in the direction of the company's management. The engineer, aware of the profound transformations induced by sustainability, must bring to organizations a different approach on the economy, on the social role of the company, on production and work. The engineer aware of the situation cannot limit himself to introducing social aspects in the technical design process but is invited to assume a social role about the political dimension of the projects, in the sense of collective choices within a society confronted with the problem environmental.

The conscious engineer can take the opportunity to continue to serve a particular vision of social progress, innovation, economic and cultural growth, putting the purely technological aspects with which the modern era has associated him and embracing the new challenges of contemporary society, linked to nutrition, health, social cohesion, education, emancipation, in an even more difficult context due to the recent health crisis. The conscious engineer can contribute to the social debate and, thanks to his positioning, make public policies evolve, especially on a territorial scale (Du Tertre et al., 2019).

In this sense, the initial training of new generations is important, which should prepare future professionals to reflect through a new interpretation of the social and economic situation. Equally important is continuous training, at a time when professional practices evolve rapidly, as we have seen, in which these changes require a discussion about the direction and directions to be followed, having as reference the profession's code of ethics and ethical values. The ability of the profession to organize an internal debate about the evolution of the work of the engineer, articulating the moral commitment of each one, professional ethics and contemporary environmental and social challenges seems to be a decisive factor in recomposing the central role of the engineer in development company's economic performance.

7 Conclusion

Work occupies a central place for each individual, for societies and at the same time for the origin of the human species. However, to be considered a positive value, it is necessary to go a long way. In Latin languages, a word that goes back to *tripaluim*, an instrument of torture made of three sticks, used to make people suffer. Indeed, work brings itself as a damned inheritance, evidenced in the Republic of Plato (Plato, 2007), in which handicrafts are occupied at the lowest level of the social scale, in which slaves were not even considered members of society. Also, in the Middle Ages, work was considered a curse, following the condemnation, in Genesis, of God to Adam, who, for being disobedient, had to work: *In the sweat of your face you will eat bread.* If before The Fall of Man, work was given as a privilege that granted dominion over nature, after his fall, work was established as a punishment, and it is with this sense that he reached medieval times.

Even at modern times, work, while valued as a source of wealth, was also the reason for the death of many workers, including children (Castel, 1995). During the last century, rights were acquired, and people could gradually meet their financial needs earned from their labor force in better working conditions. In the last decades, however, dangerous and destructive working conditions emerged. Even among those who are not on the margins of society, i.e. , they are not on the brink of misery, many people work an increasing number of hours a day, even on dates when they should be off, even if they do not receive orders expressed to do so or who feel sick. In this way, they succumb to the addition to work, generated by the fear that each one has to be excluded from the market and no longer being able to find another labor position.

If there are professionals that may play a central role in the process of restoring this environment, so that work may become once again productive and pleasant to people, companies, society and nature, these are the engineers.

This chapter sought to show that the engineer must have a central role in the positive transformation of societies through the ways of organizing work. From the scenarios of health, safety and sustainability at work, we showed some ways in which such a transformation can occur. On a planet where humans were able to produce great deeds, there is still hunger, illness and inequality. But from what humanity has been and is capable of doing, forms of relationship can be built in which human life becomes more respectable for life itself, through the valorization of work and people at work. After all, as José de Alencar, a nineteenth-century Brazilian writer, said, "everything passes over the Earth" (Alencar, 2015).

Any positive transformation in society depends on changes in production means. Adam Smith (2007) was right by stating, at the end of the century XVIII, that work is the source of the nation's wealth. Contemporary authors used in this chapter show that work is also a source of health (or illness), sustainability (or destruction of nature). Working is transforming raw material, but also transforming people, individually and collectively. Management became dominant in the last decades, focusing on targets, many times unreachable when profitability is the only purpose. This brought two important aspects:

- Lack of knowledge about the nature of the work realized by workers and the deterioration in the quality of life and health of workers.
- Removal of engineers from taking decision positions, contradicting the Modern Administration, born thanks to engineers (especially Fayol, Taylor and Ford).

Transforming the work, therefore, implies a constant dialogue among the agents of knowledge involved. The points addressed here are strongly linked to other parts of this book. In this sense, philosophy of emerging systems, introduced in Chap. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures", depends on the workers supposed to implement them, and the access to electricity may change the physical and mental health of people, enabling workers to have a better life, as pointed out in Chap. "Microgrid Operation and the Social Impact of Its Deployment". Even life in pandemic times discussed in Chap. "The Socio-Economic Implications of the Coronavirus Pandemic: A Brazilian Electric Sector Analysis" has an influence on the mental health of workers, since people tend to hide their problems in order to survive, aggravating their conflicts and generating a negative cycle. Obviously that societal modeling discussed in Chap. "A Multi-Aspect Dynamic System Model to Assess Poverty Traps" can bring consequences to workers, affecting (positively or negatively) their general health conditions.

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Industrial Innovation Practices Breakthrough by Process Intensification

Maarten J. Verkerk

1 Introduction

In September 2015, the United Nations General Assembly agreed on an action plan for a sustainable future under the title *Transforming our World: the 2030 Agenda for Sustainable Development* (United Nations, 2015). The objective of the 2030 Agenda is to make our world more human, sustainable, prosperous, and peaceful. The 2030 Agenda is very ambitious. Its main objectives are to free the human race from the tyranny of poverty and to heal our planet. It is stated that bold and transformative steps are urgently needed to shift the world on to a sustainable and resilient path. The member states of the United Nations promised that this ambitious plan of action is a collective journey and that no members will be left behind. The 2030 Agenda specifies 17 Sustainable Development Goals (SDGs); each goal is specified in sub-goals. The topics vary from poverty, hunger, and food to sustainable economic growth and sustainable production.

The 2030 Agenda challenges the process industry, both in terms of social and economic objectives and in technological goals. In this chapter, we will focus on the technological goals that involve the transition from an industry based on fossil energy to an industry based on renewables. The end goal is the development of climate-neutral plants.

The challenges for the process industry are enormous (Verkerk & Visscher, 2019). We would like to give one example. The estimated energy need of the overall chemical industry in the Netherlands sums up to 360 petajoules per year. This is about 10% of the total Dutch energy consumption. One of the largest chemical industrial sites in Europe is Chemelot, located in Geleen, in the South of the Netherlands. This site

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requires about 70 petajoules of energy per year. The objective of Chemelot is to be climate neutral in 2050: 'Chemelot has a clear vision to operate climate neutral in 2050, causing all products, that Chemelot makes, are also available in the future, but then sustainable. For this, Chemelot focuses on enhancing sustainable raw materials and energy. So, it is not only an energy transition but also an industry transition. Five program lines will help to enhance sustainability:

(1) Electrification based on green energy
(2) Bio raw materials
(3) Circularity
(4) Process improvement and optimalization
(5) Carbon capture and storage and carbon capture and Usage' (Chemelot, 2018).

The example of Chemelot clearly shows that different approaches are needed to realize a sustainable process industry. One of these approaches is process improvement and optimization. In this chapter, we will focus on *one* specific method to improve and to optimize processes: process intensification. We will argue that breakthroughs by process intensification only will be realized by the development of industrial innovation practices that address technological, economic, social, and moral aspects of innovation.

We would like to emphasize that the lessons learned in this chapter can be generalized. In summary: Breakthroughs in the process industry require innovation in industrial innovation. More specifically, it requires the development of industrial innovation practices and an integrative approach to the technological, economic, social, and moral aspects of innovation.

In this chapter, the Triple I model presented in Chap. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures" will be elaborated in more detail. Additionally, it will be applied on innovation practices in the process industry. The specific knowledge about innovation in the process industry is taken from the book *Process Intensification. Breakthroughs in design, industrial innovation practices, and education* by Harmsen and Verkerk (2020).

This chapter has the following setup. Section 2 reviews the field of process intensification. Section 3 presents a famous case study in process intensification. Section 4 explores the concept of industrial innovation practices. Section 5 presents the Triple I model that focuses on intrinsic values, interests of stakeholders, and ideals and basic beliefs. Section 6 delves into the importance of SDG's for the process industry. In Sect. 7, the different lines of thought will be integrated. We will argue that a climate-neutral process industry requires a change in innovation paradigms.

2 Building Blocks and Function Design

To understand the essence of process intensification, we first have to go back in history (Harmsen & Verkerk, 2020, 2021). In 1916, Arthur D. Little proposed a new method to design processes. The idea was to split up the whole process in so-called unit operations. A unit operation is a basic step in a process defined by physical, chemical, or biochemical changes, e.g., heating of feedstock, a chemical reaction, or a separation. Each unit operation then takes place in a separate unit or building block. In this way, process designs can be made quickly and reliably. This approach was seen as the beginning of process engineering as a specific discipline.

There are two different approaches in process intensification. The first approach focuses on the development of new unit operations. The first step is—as proposed by Arthur D. Little—to split up the whole process in unit operations. The second step is to redevelop one or more unit operations to realize a breakthrough in process performance, energy use, and emission of greenhouse gases. The third step is to design equipment for the new unit operations, i.e., new building blocks. An advantage of this approach is that newly developed building blocks also can be applied in other process designs. The main disadvantage is that it does not provide a systematic plant-wide approach that results in radically new designs.

The second approach leaves thinking in terms of unit operations and building blocks. It takes its starting point in the design of functions. Each function states a simple transformation such as a chemical reaction or a separation. The first step is to identify all functions that transform input streams of feedstock to output streams of the product. We would like to note that in this step the whole process is taken into account. The second step is to integrate the different functions as much as possible. The third step is to simulate the technical feasibility of the integrated design by means of modeling. Finally, equipment is designed to fulfill the integrated functions. The advantage of this approach is that it facilitates the development of totally new designs. An example of a radical new design is the Eastman case that will be discussed in the next section.

We would like to note that both the building block approach as well as the function design approach focus on the 'hard' aspects of technology, like design, modeling, validation, and so on.

3 The Eastman Case

The Eastman case is a famous example of process intensification (Harmsen & Verkerk, 2020). This case is about the production of methyl acetate. Jeff Siirola, one of the leading engineers, told us the story 'behind' the Eastman case. Originally, the process was designed according to the Arthur D. Little method: The whole process was split up into ten unit operations: two reactors and eight distillation columns. Figure 1 gives a schematical overview.

However, just before the detailed engineering of the reactors and columns, the engineers decided to go back to the drawing table. In their view, this process with ten unit operations was too complex. In the meantime, a couple of engineers were sent to the university to be trained in process design based on functions. When they came back, they immediately started to work on the methyl acetate process design using the method to analyze and integrate functions. They managed to get

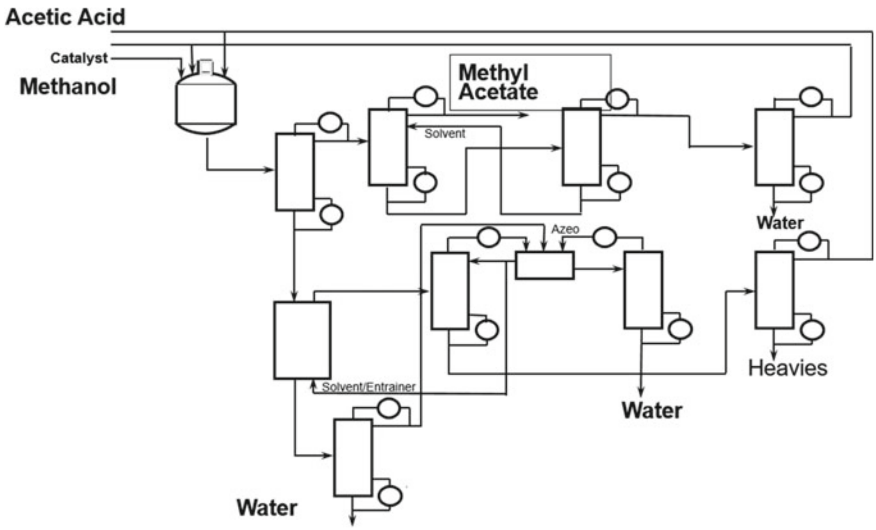


Fig. 1 Design of the methyl acetate process based on the conventional method. This figure is taken from Harmsen and Verkerk (2020) and used with permission by De Gruyter

a process combining all functions in a single column. That concept was tested and further developed. Figure 2 gives an overview of all functions. It has to be noted that the developers did not speak about 'functions' but about 'tasks'. Figure 3 gives an overview of the integration of all functions (tasks) in one column.

In a relatively short time, the whole process from the start of function design up to the start of the start-up of the normal production was performed. The results were phenomenal. At first, the investment costs were 80% less when compared to

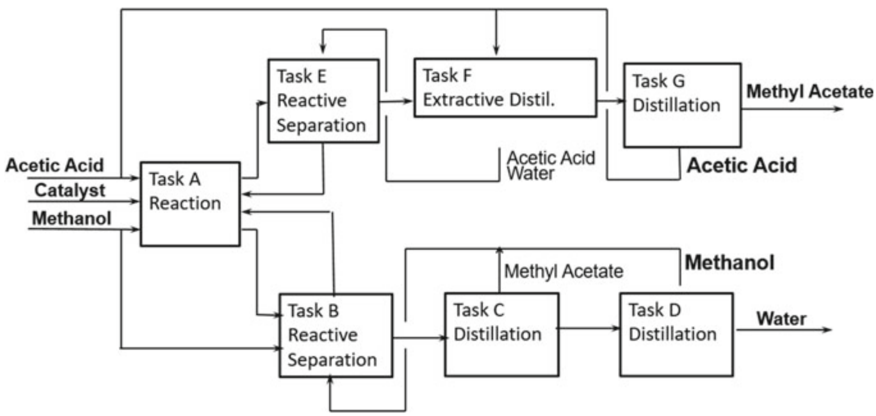
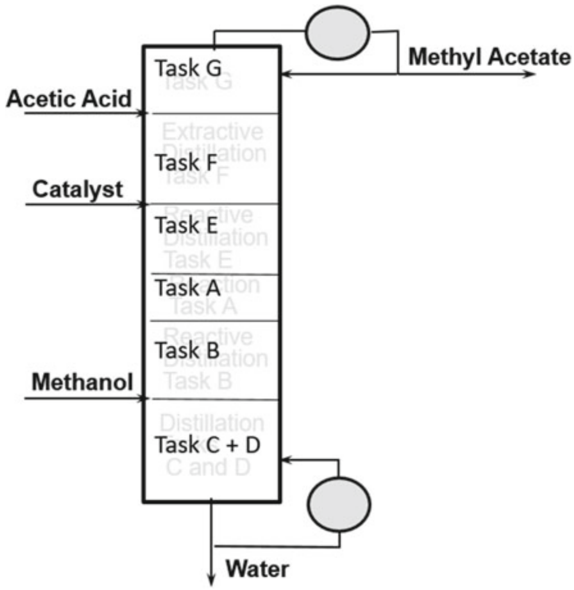


Fig. 2 Analysis of the methyl acetate process based on functions (tasks) and streams. This figure is taken from Harmsen and Verkerk (2020) and used with permission by De Gruyter

Fig. 3 Design of the methyl acetate process based on the integration of functions (tasks). This figure is taken from Harmsen and Verkerk (2020) and used with permission by De Gruyter



the conventional design. Also, the energy required to run this process was 80% less when compared with the conventional design. Further, the running costs in terms of manpower of the new design were much lower than that of the conventional design. A few years later a second column was installed to increase the production capacity.

This case is a beautiful example of a revolutionary design. The conventional method of designing would lead to an installation with two reactors and eight distillation columns. The new method of function design resulted in an installation of only one large column. This case also shows the nature of innovation: Traditional approaches are discussed critically to realize breakthroughs in design.

One would expect that the approach of Eastman would have been imitated by many other companies. However, that was not the case. The number of success stories in the field of process intensification is still limited. In our view, there are two reasons for that. Firstly, the function design approach was not comprehensively systemized into a design method that can be taught at universities and can be applied in industry. Only recently this was done by Harmsen and Verkerk (2020). Secondly, the engineers of Eastman published a couple of articles about this innovation. In these articles, they focussed on the 'hard' elements of innovation: design, modeling, validation, and so on. However, on interviewing Siirola, we found out that 'soft' elements like cooperation, intrinsic values, interests, and beliefs also played a key role. The 'how' and 'what' these soft elements will be discussed in the next sections.

4 Industrial Innovation Practices

The Eastman case raises many questions. One of these questions is: How is it possible that all decision processes went so quickly? Another one is: Why did nobody in the management laid crosswise when it was decided that the building block approach was left behind and the engineers moved on to the function design approach? We would like to note that these questions are not answered in the different articles that were written about this innovation. But they were revealed by Jeff Siirola when we interviewed him about the Eastman case. To understand what happened, we will introduce the idea of industrial innovation practices.

4.1 What is a Practice?

In this chapter, we would like to interpret the activities of engineers in different departments in terms of practices. The philosopher Alisdair MacIntyre (1984) has paid a lot of effort to understand the moral behavior of humans in different fields. He introduces the word 'practice' to distinguish the various activities in which humans act. In his view, practices are characterized by four aspects. Firstly, a practice is a 'cooperative human activity'. That means, practices are not about individuals but are about people that work together. This characteristic typically applies to the work of engineers in the departments of Research & Development (R&D), Marketing & Sales (M&S), and Operations (OPS): Engineers always work together in groups to realize their objectives. Secondly, a practice is 'socially established'. That means, practices are not casual partnerships but refer to activities that are related to or are rooted in a community. In this case, the practices of R&D, M&S, and OPS are well-established in the industrial community. Most companies have organized their activities along with these disciplines. Thirdly, a practice realizes 'goods internal to that form of activity'. That means that practices produce goods that are characteristic of that practice. For example, R&D 'produces' innovations, M&S takes care of the sales of products, and OPS is responsible for the production of goods. Finally, a practice operates to 'standards of excellence'. That means, the activities in a practice have to meet certain standards of quality. This also holds for practices like R&D, M&S, and OPS. Each of these practices has its standards of quality, e.g., standards defined by ISO9000.

4.2 Different Types of Practices

MacIntyre would argue that the departments R&D, M&S, and OPS have to be interpreted as different practices. The main reason is that each of these departments produces their 'goods' according to their 'standards of excellence'. After all, each practice has its own type of knowledge, its own methods, and its own ways of thinking.

The goods and standards of excellence of the R&D department have to do with conducting research, developing new processes, and designing new equipment. The goods and standards of excellence of the M&S refer to understanding the needs of customers, recognizing the developments in the market, and to sell the products with a certain profit. The goods and standards of excellence of the OPS department are about reliable and controlled production of goods.

The idea that R&D, M&S, and OPS are different practices is key for understanding the process industry. On the one hand, it makes it understandable that there are often 'walls' between the different departments and that 'silo thinking' can develop. On the other hand, it shows that the success of industrial innovations strongly depends on the quality of the cooperation between R&D, M&S, and OPS departments. After all, successful innovation is an innovation that is developed by R&D, sold by M&S, and produced by OPS.

4.3 Industrial Innovation Practices

We have coined the idea of 'industrial innovation practices' to emphasize that innovation is not only a matter for the R&D department, but that also departments like M&S and OPS have to contribute actively. In other words, the idea of industrial innovation practices explains that successful innovation does not only require an innovative culture in R&D but also requires an innovative culture in M&S and OPS.

It cannot be taken for granted that departments like R&D, M&S, and OPS cooperate smoothly. In many companies, R&D, M&S, and OPS are not located at the same plant. As a result, there are 'natural walls' between these departments. Easily, these walls become barriers to innovate effectively. In particular, OPS has a 'conservative' culture. After all, the strength of operations is to produce the same product every day, every week, every month, and every year. Every change in the process can disturb the continuous production of the concerning product.

4.4 Soft Aspects of Innovation Practices

Nicolini (2012, 1–6) believes that practice approaches offer a 'radically new way of understanding and explaining social and organizational phenomena'. The reason is that these approaches are inherently relational. They focus on the relationships between people and the relationships between people and material things like feedstock and equipment. They also leave space for the initiative, creativity, and performance of individual actors. In addition, they challenge and transform our views of scientific knowledge and the meaning of technology. Finally, they emphasize the importance of power, conflict, and politics as constitutive elements of our social reality. Nicolini (2012, 221) stresses that the study of practices always should start in the middle of the action: 'Attention should be toward issues such as: what are people doing and saying? What are they trying to do when they speak? What is said and done? How do the patterns of doing and saying flow in time? What temporal sequences do they conjure? With what effect? Through which moves, strategies, methods, and discursive practical devices do practitioners accomplish their work?'.

Nicolini emphasizes the 'soft' aspects of innovation. He focuses on relationships, the initiative of individuals, innovative ideas, challenging traditional approaches, power, and politics. We would like to add, we also have to focus on phenomena like intrinsic values, interests, and ideals. With that, we are at the heart of the next section.

4.5 Industrial Innovation Practices at Eastman

Now, we come back to the questions asked at the beginning of this section 'How is it possible that the innovation at Eastman was developed in a relatively short time?' and 'Why did nobody in the management laid crosswise when the traditional design method was left behind and a new design approach was chosen?' Jeff Siirola of Eastman Chemical answered these questions in an interview with Jan Harmsen.

At Eastman, the R&D, M&S, and OPS departments were located at the same plant. The top manager, the department heads, and their engineers worked in the same building. They met each other at the coffee machine and used to have their lunch together in the canteen. All relevant decisions were informally prepared to facilitate consensus or were even taken informally. However, there is more. The manager of the engineering group became ill. Jeff Siirola, who was the manager of the R&D department, was asked to manage this group as an interim. He decided that a couple of engineers of this group had to be trained in the function design approach. Finally, the top manager of the Eastman Chemical plant was a chemical engineer. He understood the language of his department managers and their engineers. Half a word was enough for him. All these conditions and changes contributed to a culture in which there we no walls between R&D, M&S, OPS, and engineering. Also, silo thinking did not develop. As a result, all engineers and all disciplines were intensively together to develop an innovative process for methyl acetate.

5 Triple I Model

Jochemsen, Glas, Hoogland, and others have developed the so-called the normative practice approach (de Vries & Jochemsen, 2019). This approach is strongly inspired by the ideas of MacIntyre (1984) and focuses on professional practices. Originally, the normative practice approach was developed for health care, but later on, it was elaborated for technology, engineering, and management and organization (Verkerk et al., 2016). The key to this approach is that practices are not 'neutral structures' but

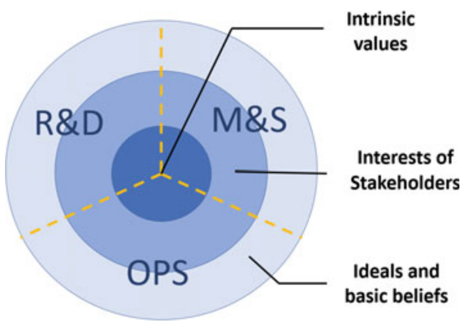


Fig. 4 Triple I model for industrial innovation practices

normative structures. The unique contribution of the normative practice approach is not that it prescribes certain norms but that it offers an approach to identify normative aspects of practices. After that, identified normative aspects can be affirmed or criticized.

5.1 *Intrinsic Values, Interests of Stakeholders, and Ideals and Basic Beliefs*

Verkerk (2014), Verkerk et al. (2017), and Verkerk and Vischer (2019) have developed an organizational variant of the normative practice approach for professional practices that consider organizations both as 'the site and the result of work activities' and as 'bundles of practices' and that understand 'management as a particular form of activity aimed at ensuring that these social and material activities work more or less in the same direction' (Nicolini, 2012, 2). This approach has been called the Triple I model.[1] It offers three different perspectives to understand engineering practices; to wit, intrinsic values, interests of stakeholders, and ideals and basic beliefs, see Fig. 4. We would like to note that the Triple I model has been developed in close cooperation with engineers (Verkerk, 2014). Additionally, Verkerk and Visscher (2019) and Harmsen and Verkerk (2020, 2021) showed that this model also holds for the process industry.

The first 'I' refers to the 'intrinsic values' of a practice. The intrinsic values express what is very important for engineers that work in a certain practice. Intrinsic values can be described as an 'invisible hand' that drives engineers in their daily activity. For example, the intrinsic values of an R&D department are creativity and innovative attitude. The intrinsic values of the M&S department are customer orientation, customer satisfaction, and profitability. The intrinsic values of the OPS department are values like process control, efficiency, safety, environmental, and health.

[1] In Harmsen and Verkerk (2020, 2021), this model was named the VIB model (Values, Interests, and Beliefs).

The second ‘I’ refers to the ‘interests of stakeholders’ of a practice. Industrial practices have their specific network of stakeholders. Important stakeholders are the customers, suppliers, shareholders, banks, and authorities. Every stakeholder has its own justified interests. For example, the justified interest of customers is the delivery of chemical products with a good quality and at a reasonable price. The justified interests of the local authorities are safety, environmental concerns, and employment opportunities. Generally, R&D, M&S, and OPS have partly overlapping sets of stakeholders.

The third ‘I’ refers to the ‘ideals and basic beliefs’ that are present in society and that have an influence on all engineers that work in a certain practice. At this moment, the most important ideals and basic beliefs in society that influence industrial innovation practices are the ideas of a circular economy, sustainability, and SDGs. It has to be noted that SDGs also include standards with respect to the circular economy and sustainability.

The Triple model can be used in two different ways. Firstly, it can be used in a descriptive way to analyze an existing practice. In that case, this model offers three perspectives or three pairs of glasses to analyze the status quo. Secondly, it can be used in a prescriptive way to guide the development of an existing practice. Then, this model offers three perspectives or three pairs of glasses to define future status. We would like to emphasize that the three ‘Is’ are not ‘sold separately’ but form an integral part of a specific practice.

5.2 Understanding the Eastman Case

Siirola and others have described the intensified process of methyl acetate in detail. That is remarkable because companies rarely report their innovation in detail. Siirola and his colleagues felt a strong need to share their knowledge about PI with the engineering community. The scientific articles of Siirola and others suggest that the development of this innovation was a ‘technological endeavor’. That means, it was all about functions, processes, simulations, and designs. After reading all relevant articles, we interviewed Siirola about this innovation. We asked him about the soft factors as specified by the Triple I model, especially because these factors were not made explicit in the publications about this innovation. We expected that Siirola would find the questions about intrinsic values, interests, and ideals difficult. To our surprise, however, this turned out not to be the case. After we asked the questions, he immediately started talking. He was, so to speak, unstoppable. It seemed he’d always wanted to tell that story but never got the chance.

Siirola reported that the engineers did not like the complex conventional design. They wanted to develop a superior process. He mentioned three values that drove the engineers at Eastman: developing innovative processes, designing reliable production processes resulting, and having an economical process. He also mentioned the importance of values like safety, health, environment, and social community.

Siirola told that Eastman Chemical was the main employer of the town Kingsport in Tennessee. Since its start in 1920, it had not fired any employee (till 1999). Every employee of Eastman Chemical knew the importance of the company for employment. By far, the local society was the most important stakeholder. The engineers took responsibility for the local society by developing new, innovative, reliable, and competitive production processes. But the interests of other stakeholders were not neglected. Design and development were also focused on a process that produced high purity methyl acetate for the clients. Maybe, also the interest of the process operators was in mind when striving for a simple and easy-to-control process.

Siirola also recounted that ideals and basic beliefs in the (local) society played a role. He stated that Eastman Chemical was the largest employer in the city. It provided as many as 13,500 jobs, and so, it provided a large income to the local city community. Eastman's importance comes even more sharply when you realize that Tennessee is a relatively poor state. In turn, the community highly valued the Eastman Chemical Company. In many ways, it was made clear to the company and its employees that they were important. This appreciation was a great motivator for engineers to advance the future of the company.

In summary, the interview of Jeff Siirola revealed that the engineers of Eastman Chemical were highly motivated to develop an innovative process that would highly competitive. They were driven by values, understood the importance of the social community, and motivated by the opinions of the local community.

6 Sustainable Development Goals

As noted earlier, the United Nations' SDGs are important ideals of basic beliefs in our society that exert an influence on process industries. For companies, it is impossible to do just window dressing. More and more, the stakeholders of the company expect something to happen. Investors in particular are making stronger demands.

The United Nations have defined seventeen Sustainable Development Goals. Each goal is elaborated in detail. The titles of these goals are quite self-explanatory:

SDG 1: End poverty in all its forms everywhere.

SDG 2: End hunger, achieve food security and improved nutrition and promote sustainable agriculture.

SDG 3: *Ensure healthy lives and promote well-being for all at all ages.*

SDG 4: *Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all.*

SDG 5: *Achieve gender equality and empower all women and girls.*

SDG 6: *Ensure availability and sustainable management of water and sanitation for all.*

SDG 7: *Ensure access to affordable, reliable, sustainable and modern energy for all.*

SDG 8: *Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.*

SDG 9: *Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.*

SDG 10: *Reduce inequality within and among countries.*

SDG 11: *Make cities and human settlements inclusive, safe, resilient and sustainable.*

SDG 12: *Ensure sustainable consumption and production patterns.*

SDG 13: *Take urgent action to combat climate change and its impacts.*

SDG 14: *Conserve and sustainably use the oceans, seas and marine resources for sustainable development.*

SDG 15: *Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.*

SDG 16: *Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.*

SDG 17: *Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development.*

Some SDGs are relevant for all process industries. For example, SDG 7 is about affordable, reliable, sustainable, and modern energy, SDG 8 is about inclusive and sustainable economic growth and decent work for all, SDG 9 is about a resilient infrastructure that promotes sustainable industrialization and fosters innovation, SDG 12 is about sustainable consumption and production patterns, and SDG is 13 about urgent action to combat climate change and its impacts. Others are relevant to specific process industries. For example, SDG 2 about ending hunger and achieving food security is important for industries in the field of food and agriculture, and SDG 3 about healthy lives and promoting well-being for all, challenges industries in the field of food, agriculture, water production, and pharmacy.

We would like to emphasize that innovations like PI strongly contribute to different SDGs. Take for example SDG 9. This goal requires a radical change in industrial innovation practices. It cannot be achieved by the traditional methods of continuous improvement. It involves nothing less than new concepts, new ways of cooperation, and new ways of acting. In other words, it requires innovation of industrial innovation practices itself. In addition, it also involves innovation in industrial infrastructures and networks. These radical changes in industrial innovation practices are promoted by PI. Another example is SDG 12. PI strongly contribute to sustainable production patterns because its processes have a material and/or energy efficiency that is an order of magnitude better than conventional processes. PI also will contribute to sustainable consumption patterns when PI will be combined with the principles of a circular economy. The last example is SDG 13. PI contributes strongly to combat climate change by developing processes with higher energy efficiency than conventional processes.

7 Conclusion

In this chapter, we have presented PI as an example of a method to realize breakthrough innovations in the process industry. Case studies and philosophical reflections revealed the conditions to develop breakthrough innovations. Especially, the nature of industrial innovation practices was discussed.

The insights obtained in this case study can be generalized. Our main conclusion is that breakthrough innovations in the process industry only will be realized by combining hard factors (design, modeling, validation, and so on) with soft factors (cooperation, intrinsic values, interests, ideals and basic beliefs, and infrastructures).

This main conclusion can be specified by focusing on particular factors as follows:

1. Breakthrough innovations require a critical evaluation of present approaches in designing and managing innovations. Existing hard factors have to be questioned to support the development of radical innovations.
2. Breakthrough innovations only will be realized when innovative cultures are present in R&D, M&S, and OPS. These departments have to cooperate intensively, and the specific knowledge of each of these departments has to be integrated into the innovation process.
3. Breakthrough innovations are strongly driven and supported by soft factors like intrinsic values of engineers, interests of stakeholders, and ideals and basis beliefs in society. These factors contribute to a culture and infrastructure in which radical innovations will thrive.
4. Finally, breakthrough innovations are seldom the result of one specific actor. An analysis of case studies in PI (Harmsen & Verkerk, 2020) showed that local infrastructures of process industries, universities, customers, construction companies, and so on are required to realize breakthrough innovations.

Our conclusion is that breakthrough innovations in the process industry require innovations in hard and soft factors of industrial innovation practices. The entirety of these innovations can only be described as a paradigmatic change. The reason is that breakthrough innovations in the process industry not only refers to innovation in products, processes or equipment, but also refers to innovation in design methods, cooperation patterns within the company, moral considerations, infrastructures, and ways of thinking.

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Sustainability and the Responsibility of Engineers

Luis Vargas

1 Introduction

In this chapter, some topics related to the social implications of engineering practices are presented. Here the word "social" is used in a broad meaning, where the "social" encompasses different aspects, e.g., moral, justice, trust, and "social" in a narrower meaning. Furthermore, the broad meaning of the "social" encompasses different types of normativity as defined in Sects. 2, Chap. "Engineering Practices: Complexity—Diversity—Coherence—Meaningfulness" and Chap. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures" of this book.

The chapter starts with a revision of the concept of sustainability in connection with the engineering practice and the role of higher education institutions in the transformational process. Indeed universities are key actors in the transformation toward a sustainable world as they are responsible for engineering education. Then, reflections on sustainability as a value and the moral responsibility of engineers are presented. Those reflections are linked to some ideas on renewable generation and its sustainable effects, as well as sustainable habits in society and the effects in waste and residual generation. The challenges associated with energy access and its implications on energy poverty are revised in cities, peripheral urbanization and rural communities. Also, the main drivers for the acceptance and opposition to renewable energy projects are revised. At the end, conclusions with the main message of this chapter are presented.

Overall, this chapter speaks about the different responsibilities of the engineer. Each responsibly of the engineer leads to a normativity with respect to the technological device or process that are being created. In that line, social responsibility of

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the engineer leads to a new approach for designing artifacts, which must support sustainability and also function properly in the community.

1.1 General Aspects of Sustainability in Society and the Role of Universities in Engineering Education

The concept of sustainability has changed over the years, although the basic intuition of its content remains the same as that enunciated by the Bruntland Commission in 1987: "meeting the needs of the present without compromising the ability of future generations to meet their own needs" (Bruntland Commission, 1987).

As engineering has tried to put this principle into practice, various interpretations have appeared about its content and scope. A more recent conceptualization (Griggs et al., 2013) sees sustainability (or sustainable development) as "development that meets the needs of the present while safeguarding Earth's life-support system, on which the welfare of current and future generations depends".

Nowadays, there is a consensus that sustainable engineering consists of using resources in a way that does not compromise the environment or deplete the materials for future generations. This definition encompasses all engineering fields, which must incorporate sustainability into their practice in order to ensure that the outcomes of engineering projects and inventions improve the quality of life for all.

Historically, engineers have devoted their efforts toward the developments of machines, devices, infrastructure and systems to solve specific problems. Those efforts were unanimously welcomed in the past, where celebrations took place to commemorate the inauguration of highways, railroads, new telephones, etc. Yes, people used to celebrate infrastructure everywhere.

With the awareness of climate change and the understanding of the capacity of humans for altering the planet at an increasing rate, we are living now in a new era, the Anthropocene epoch (Waters et al, 2016). Some researchers maintain that this new era started with the spread of agriculture and deforestation, and including later the Columbian Exchange of Old World and New World species, the Industrial Revolution and the mid-twentieth century "Great Acceleration" of population growth and industrialization (Ruddiman, 2017). In other words, humans now can endanger Earth's life-support systems. Today, there is a mature and well-documented awareness about the impact of engineering on the environment and life systems on the planet. This imposes a moral duty to all inhabitants of the earth, and especially to engineers (Waelbers, 2011): We must act and live in a sustainable way.

A standard and comprehensive summary of the main challenges for achieving a sustainable world is found in the 17 Sustainable Development Goals (SDGs) (UN, 2015), which set a call for action by all countries—developed and developing—in a global partnership.

It is now worldwide recognized that to protect future sustainability, we must limit global warming to an average of 1.5 °C. This requires roughly to reduce by half all-carbon emissions each decade through 2050. All sectors must play a role in the necessary transition, but the energy sector has a paramount responsibility as, according to the World Resources Institute (WRI), it is estimated that energy is the largest source of greenhouse gases (GHGs), accounting for around 65% of all GHGs. Specifically, the power sector (electricity generation) produced 30% of global greenhouse gas emissions (or 15.6 $GtCO_2e$) in 2016 (Lebling et al., 2020).

Now there is a consensus that an energy transition is required, from the current state to a zero-emission state, which will use a blend of alternative fuels, such as hydrogen, and electrification with renewable resources in all human activities. A similar process is underway in all engineering sectors, where new materials and processes are used in a sustainable way.

It is common to find praise for engineering on the technological advances that have brought development to humanity and improvement to the quality of life, but this development has also had a negative aspect for which we engineers are also responsible. In fact, it must be stressed that as engineers, we have a great responsibility in the state of the sustainability of the planet, since behind any major transformation of the landscape in nature there is an engineering project, i.e., we have a great share of responsibility in all artificial installations built by man: Engineers have built the fossil fuel plants, industrial complexes and all the infrastructure that have caused ecological damage.

Therefore, we must become aware of our role in society and correct the mistakes we have made in the past. This means rethinking the work of engineering and adding new values to the training of new generations of engineers.

Universities play a significant role in promoting the concepts and values of sustainability as they pose a wide variety of areas, such as new educational programs, sustainability research, cooperation with other entities and the use of sustainability demonstration projects in real-life applications (Vargas, & Jimenez-Esteves, 2013).

In the case of education, there is a need for new courses that prepare engineers to work with renewable resources for producing sustainable energy generation systems (Jennings, 2009). This involves the teaching of didactic competencies in the field of renewable energies not only to students but also to educators, trainers, lecturers and faculty (Acikgoz, 2011). Research can be fostered in centers oriented toward education for sustainable development (Itoh et al., 2008), where professors play the roles of the academic-practitioner, as teachers, and in research projects, as investigators are brought together to integrate educational practice and research (Tormey et al., 2008). These centers are characterized by an integrated approach where different target groups are involved (e.g., schools, NGOs and industry) and where a local university plays a key role (Leal Filho & Schwartz, 2008). Overall, universities are forming future generations, which must embrace the responsibility of building a sustainable society (Axelsson et al., 2008; Mochizuki & Fadeeva, 2010).

Another line of action is the promotion of demonstration sustainable projects on campus (Krizek et al., 2012). These works target to increase the level of awareness about environmental issues and have received enormous interest among the students (Ghosh, 2011).

Finally, an aspect that sometimes is neglected is that sustainability is very important in bringing people together. Indeed, sustainability helps to attract more students in an increasingly competitive higher education scenario. Moreover, as a result of sustainability change processes, unexpected associations can emerge on campus among professors, students, staff and other higher education members (Vargas et al., 2019), and also with the neighboring community and the society.

1.2 Sustainability as a Value, Renewable Generation and Its Sustainable Effects

Ethics or morality has to do with the rules and norms of conduct within a society, which are necessary to make cooperation possible in a framework of justice and freedom. So, ethics is at the base of all decisions that an engineer (and any person) has to make before any project starts. For instance, we have to ask what are the intentions, the impact and the consequences (benefits or harms) that are brought about by projects, both to the environment and the society as a whole. This questioning must be at the very beginning of all engineering projects hereinafter.

In the area of energy, this moral imperative along with the sustainability definition of the Bruntland Commission translates into proposing a system that meets society's current energy demand without compromising the ability to meet future energy needs. This interpretation leads directly toward renewable energies since they are the only energy sources that do not depend on primary energy with finite inputs, as occurs with fossil fuels or nuclear energy. Thus, thermal solar energy, photovoltaic energy, wind energy, hydro energy, geothermal energy, biomass and those from the sea (tides, kinetics, etc.) appear on the scene in different forms. The challenge of achieving sustainability in energy would be solved by the replacement of all traditional energies with renewable ones.

This change brings the benefit that renewable energies have zero or very low greenhouse gas emissions, so they help mitigate climate change. Fortunately, the spread of renewable energies is underway, they are growing everywhere, and now the discussion is focused on the speed of the rate of the transition. In the case of Latin American countries, a good indicator regarding the future of energy is the annual growth rate, which shows that renewable energy is the fastest-growing energy with more than 50% of all the total growth.

In a wider view of human activity, we realize that a common paradigm crosses all productivity sectors, the take-make-waste extractive industrial model, which at the end of the pipeline leaves residuals and waste, usually harming and endangering the environment. This paradigm is now being replaced by a new concept that redefines growth: the circular economy. The main objectives of this emerging paradigm are to eliminate the idea of waste or residuals and to decouple economic activity from the consumption of finite resources. In order to achieve those objectives, the design of any device, machine or process must rule out waste and pollution, Thus, once their useful life cycle has been accomplished all products and materials are reused in other processes. In other words, engineers now not only must think about designing machines to run, but also in the shutdown process, which must leave no waste to be piled up anywhere.

The main drawback of landfills for waste disposal is that they produce methane gas emissions, which positioned municipal solid waste landfills as a main source of human related methane emissions along with enteric fermentation and natural gas and petroleum systems.

In the energy arena, it has been a while since the incineration plants transform waste to energy. In fact, the first incinerators were built in the second half of the nineteen century. The basic idea is to use the material contained in the waste, which is combusted in the presence of oxygen at high pressure in a boiler or furnace. One of the problems of these plants is that the products formed in the combustion process include hot combustion gas, which consists of N_2, CO_2, H_2O, flue gas, oxygen and noncombustible residues. In other words, they require proper abatement measures in order to confine the GHG and also to treat the solid residuals. Besides direct incineration, newer versions include more complex combined heat and power systems, such as anaerobic digestion, pyrolysis, gasification, fermentation, etc. In order to facilitate social acceptance, these new plants may incorporate also recreational and sociocultural centers (Kumar & Ankaram, 2019). Overall, they operate under the objective of energy generation and, at the same time, waste reduction, limiting emissions, avoiding the use of land for landfill and also providing additional social services to the communities.

Another promising area is the use of food waste into energy, both at industrial and local levels (homes). The idea here is to capture nearly all of the energy in a food waste product, leaving little behind to be disposed of at a landfill. New companies are flourishing around the world installing waste treatment plants, capable of converting biogas from household waste into biomethane. Many of these systems are designed for domestic use and can be installed in gardens, so at home biogas is produced out of the food leftovers. In turn, the biogas can be used for cooking, heating and even lighting.

If we contemplate the reality around us, we see that every living being has a cycle: birth, growth to maturity, old age and death. In this last stage, all organic components of the body fusion into new systems and the cycle goes on. The new paradigm of circular economy aims to mimic the same cycle for all human activity and artificial inventions. So, now in universities, we must teach engineers to build, shutdown, disassemble and reuse. Reuse means that each part will migrate to other constructions or processes.

But what are the reasons that brought us to this current state? In order to answer that question, it is useful to retrieve the case of the first development of nuclear technology. In fact, the first harmful effects on the human body produced by radioactive material were discovered because the personnel involved in those experiments became seriously ill and died *en masse*. No one asked first the elemental question of whether that radioactive material was harmful to human life, no technician wondered what would be the effect of handling that material. This example shows that the working task forces were completely devoted to the problem-solving issues of nuclear energy, and there was not in their mind any other concern. Then, in other areas, the world knew controversies over the toxic effects of the chemical industry, the contamination of groundwater, etc. Here again, the harmful effects were known not because from the beginning someone wondered what was the effect of the residuals. It was the death of animals and flora that brought about the bad news.

Much is said about the economic interest of large industrial consortia, or even about human evil. But perhaps the origin of everything was simply that engineers (and the system) did not have in their consciousness the basic questions: What I am creating is harmful to the health of flora and fauna? Is it harmful to the environment? On the contrary, everyone operated on the conviction that the environment, the outside, was vast and infinite and nothing we could do would alter the order of the earth. Now we know that this is not the case.

1.3 Sustainable Habits in Society and the Effects in Garbage Generation

As was pointed out in the context of circular economy, one of the front-line slogans nowadays is no more waste, no more garbage. That new concept crosses from the multinational companies to the behavior of individuals, to build a reality where all machines and devices have components that can be reused and transformed, that at the end of its useful life, the device is dismantled in parts that are integrated into another device or processes.

At an individual level, the concept of Sustainability Citizenship is defined as a person who believes (Dobson, 2011) that sustainability is a common good shared by the society; that ethical and moral knowledge is as important as technoscientific knowledge in the context of pro-sustainability behavior change; that these responsibilities are due not only to one's neighbors or fellow nationals but also to distant strangers (distant in space and even in time); that has an awareness that private environment-related actions can have public environment-related impacts. The sustainability citizen will therefore engage in social and public action.

There is an enormous need to implement innovative ideas that help accelerate the transition toward low-carbon sustainable lifestyles, promoting sustainable lifestyles to climate change mitigation, while contributing to the delivery of sustainable lifestyles and education to society. Here engineers have a huge challenge ahead.

1.4 Access to Energy and Its Implications: Energy Poverty

Key consumption and lifestyle domains with high climate impact, such as mobility, food, housing, tourism, energy, water, are encouraged to migrate to new sustainable habits. This is a major need everywhere human beings live: big cities, peripheral urbanizations and rural settlements. In order to have a clear picture of the energy needs, it is necessary to include energy services, which support activities such as agriculture, trade, small-scale manufacturing and industry (Strydom et al., 2019).

The issue of sustainable cities has been addressed extensively in the literature, with research aimed at designing, understanding and promoting environmentally sustainable cities. By following the spirit of the original definition of the Bruntland Commission, a sustainable city is a city designed with consideration for social, economic, environmental impact and resilient habitat for existing populations, without compromising the ability of future generations to experience the same living conditions.

It is important to identify significant risks affecting a major city. For instance, on the energy system, a detailed sustainability analysis of the energy sector of the city must be conducted, using selected energy indicators (Simon et al., 2012). With this approach, risks for the sustainable development of the energy sector are detected, such as increasing concentration in the energy sector, import dependency for fossil fuels, and increasing CO_2 emissions from energy production. Then, scenario construction with options toward more sustainable development of the city within the national energy system is assessed, such as the enhancement of energy efficiency and increased use of renewable energies.

The situation of peripheral urbanizations, especially those with a significant share of poverty, has received less attention. The World Economic Forum defines energy poverty as the lack of access to sustainable modern energy services and products to support development. It can be said that energy poverty is one of the major challenges that face the energy sector worldwide (Gonzalez-Eguino, 2015).

One of the most critical areas of energy poverty is sub-Saharan Africa, where it is estimated that approximately 600 million people—57% of the population—live without electricity. In developing Asia, around 350 million people—representing 9% of the population—lack access as well (IEA, 2018).

Recent studies indicate that there is still an enormous gap in Latin American countries, where the energy poverty (EP) indicator (percentage of people living in energy poverty conditions) in some countries are as follows: Colombia 29%, Dominican Republic 32%, Guatemala 76%, Haiti 98%, Honduras 72%, Mexico 30% and Peru 65% (Santillan et al., 2020).

Energy poverty has several drivers, among the most important are rising energy prices, rising shared energy costs in the incomes, low incomes, energy-inefficient housing, high energy losses and finally market and regulatory failures.

Energy poverty is usually expressed in relation to two groups of needs: "fundamental" and "basic." The fundamental needs are those that imply direct impacts on human health, whose satisfaction is considered critical, independent of the territorial context.

A quick list of fundamental needs includes The cooking and preservation of food, healthy minimum (winter) and maximum (summer) in-house temperatures, access to water and the availability of continuous electricity supply for people electro dependents in health. On the other hand, basic needs correspond to those requirements whose relevance depends on the socioecological (biophysical, geographical and climatic), sociotechnical (technological and infrastructural) and sociocultural (norms, markets, customs and expectations related to the quality of life and human development), characteristics typical of a certain territory. In this group are the thermal comfort, domestic hot water, lighting, home appliances and technological devices for education. This last item has been particularly relevant during the Covid-19 pandemic, which showed the paramount relevance of communication connectivity and proper Internet access worldwide.

The 17 SDG of the United Nations recognizes that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality and spur economic growth—all while tackling climate change and working to preserve our oceans and forests.

The energy access of isolated populations is another enormous challenge, due to difficult access and means to build, operate and maintain energy infrastructure where those communities live, usually very far from urban centers. Even when it is possible to assemble a technical team and acquire equipment to install renewable energies in remote places, an efficient maintenance and repair system has to be created for the project to be sustainable in time. An interesting idea in this perspective is to teach communities to solve the most recurrent problems, where a chosen person or persons are trained to deal with those problems. This in turn may create distortions or alter the natural order of these communities. Therefore, in addition to the technological solution, usually based on microgrids technology, projects also include a proposal for community-based operation and maintenance schemes, in order to pursue social acceptance of the project as well as its long-term sustainability.

Thus, there must be a joint community intervention program that goes on in parallel with the technical solution (Palma-Benhke et al., 2011). This community intervention process plays a key role when developing this kind of projects, allowing the creation of trust between project developers and the community, working in a "co-construction" way (the community participates in the decision-making process) and providing enough tools to endow the community itself to take care of the operation and maintenance of the microgrid, which finally ensures the sustainability of the project in the long term. In order to achieve these goals, several meetings with local persons must be undertaken, i.e., engineers and technicians must engage in social contact with the communities.

Based on reported experiences (Jiménez-Estevez et al., 2014), a good community intervention program must include at least three stages: building trust, co-construction and ensuring sustainability.

The objective of the first stage is to generate a preliminary vision of the locality to intervene, as well as to identify the main stakeholders of the systems and their visions and narratives. The second objective is to understand the social structure of the community, in order to understand the power structures and organization where the participatory process is to be developed. The third objective is to build trust between stakeholders, especially the community. It is also in this stage where the viability of the project is defined, considering technical, environmental, social and financial constraints. During this stage, a set of different meetings is arranged in order to perceive the community visions.

The co-construction stage is aimed to discuss the different visions and narratives previously identified among relevant stakeholders, and from these discussions, to build consensus and guidelines that encompass the complexity of multiple visions and objectives that each stakeholder brings to the project. This is a crucial stage since it allows generating a long-term action plan for the project. It is expected that this stage also comprises the capacity building tasks, which are aimed to provide the necessary knowledge and abilities to the people so they can perform maintenance and small repair tasks when they are needed. Major maintenance and repairs are performed by a crew of technicians from the nearest and most suitable city.

Finally, the ensuring sustainability stage has the objective of identifying socioenvironmental components that could be affected by the project (positive and negative impacts); and creating a monitoring system to identify impacts and potential conflict and problems.

In all the challenges presented above, do engineers have a share of responsibility? Is there a moral obligation to commit engineers to the solution of energy access and energy poverty? To answer those questions, we must realize that while engineers are responsible for carrying out their work competently and skillfully, they are also involved as world citizens; therefore, they certainly are connected with broader ethical and social implications of engineering.

Some engineers have felt the call for improving the living conditions of communities worldwide. A good example is the movement *Engineers Without Borders* who aim to alleviate basic human needs in vulnerable communities around the world. They install solar panels to bring electricity to rural communities, they promote projects to facilitate access to water, etc. This is an inspiring example that is being emulated in many countries.

It is now widely accepted that this awareness should be cultivated early on in the education of prospective engineers (Murphy et al., 2015a, 2015b), but teaching in the field of engineering ethics can be challenging. First of all, there is no unanimous conviction across faculty in the engineering disciplines to teach classes in professional ethics. Additional complexity is encountered when delivering that content to an international context. Nonetheless, today there is plenty of instructional material available to assist with the process of teaching engineering ethics.

1.5 Acceptance and Opposition to Renewable Energies

Although technically and environmentally renewable energy projects fulfill many requirements, from a social perspective they may experience opposition and barriers (Wustenhagen et al., 2007). Indeed, social acceptance as a part of renewable energy technology implementation is a crucial aspect that must be addressed carefully.

Social acceptance relates to three dimensions, namely sociopolitical acceptance, community acceptance and market acceptance. The first dimension points out the general level of sociopolitical acceptance, which is largely related to key stakeholders and policy actors of effective policies. Those policies require to foster and enhance market and community acceptance, for instance, the establishment of a reliable financial framework that creates options for new investors, and spatial planning systems that stimulate collaborative decision making.

The community acceptance is influenced by the distributional justice of how costs and benefits are shared, a fair decision-making process allowing all relevant stakeholders an opportunity to participate, and building local community trust in the intentions of the investors and actors from outside the community.

The third aspect of interest connects with the process of market adoption of technology. Here it is important the early adoption of innovative products by communities through a communication process. Energy technologies are bound to infrastructures that make them more complex for the diffusion of innovation than other products. For instance, the experience of green power marketing, where consumers can switch to renewable energy supply, is probably the area where market adoption can attain social acceptance and experience reduced barriers to diffusion.

So any intervention or project must first have contact with the surrounding community in order to minimize social opposition, this is also a requirement before any stone is moved in the soil.

2 Conclusion

The starting point to improve the sustainability conditions of society is to recognize our share of responsibility in the present state, not to deny or criticize the overwhelming proof of global warming, nor to object that the only possible, stable and developed world is a sustainable world.

In order to transform the current state of the planet, we must start from the right place: ourselves. We must first experience a personal transformation, a genuine and lasting shift in the way we see and perceive the world around us. As engineers we have worked to produce significant technological breakthroughs, and equally, we are also responsible for the consequences on the deterioration of the Earth's life-support systems.

After we have accepted our quota of responsibility, we can commit ourselves to the enormous task of providing a sustainable future for all. A task requires a profound conviction and commitment, and also a clear understanding of all the effects that our actions produce in the environment. Indeed, engineering must embrace the sustainable path as the only path that will lead us to a better world.

Note that this chapter is somehow connected to other parts of this book. In this sense, sustainable energy plays a crucial role in the inclusion of people with no access to electricity, as pointed out in Chap. "Microgrid Operation and the Social Impact of its Deployment". The social implications also affect the social modeling presented in Chap. "A Multi-Aspect Dynamic System Model to Assess Poverty Traps" and affect the health of people addressed in Chap. "The Engineer in the Face of Social

Changes: The Cases of Health and Sustainability at Work". These are transversal effects, but note that the technical issues discussed in Chaps. "Industrial Innovation Practices Breakthrough by Process Intensification", "Social and Economic Implications of Electricity Generation Sources" and "Amazon Region Power Plants and Social Impacts" are also impacted by the concepts discussed here.

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Economics, Regulatory Aspects, and Public Policies

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Keywords Economics · Regulatory aspects · Public policies · Business · Stakeholders · Return · Risk · Markowitz risk-return plan · Optimized Tariff model · TAROT · Socioeconomic welfare · Economic financial equilibrium · EVA · Smart electricity market · Stochastic model · Democracy · Energy poverty · Prosumers · Low-income consumers · Measure of inequality · GINI index · Consumer behavior · Non-technical losses · Energy theft · Sustainable society · Environmental sustainability · Social justice · Cultural issues

1 Introduction

The distribution segment of the electric sector is usually regulated by the government as a way to protect final consumers by avoiding excessively high tariffs, which would probably occur in a natural monopoly context. Therefore, the regulation of the sector must be effectively planned to guarantee social and economic development (since electricity is an essential and irreplaceable commodity). Although regulatory agencies worldwide have considerable experience, in the short-term several challenges are anticipated in the task of regulating the electricity market effectively. Among such difficulties, stand out the philosophic dimensions or normative aspects presented in Fig. 1, which illustrates the relation between this chapter and the general idea of the book, which is highlighting holistic engineering and technology concepts. Figure 2 also presents fundamental questions on holistic engineering, economics, and regulatory issues.

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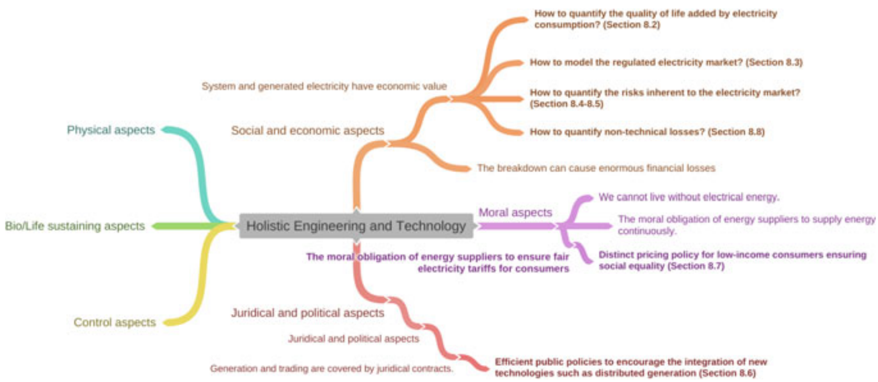


Fig. 1 Relation between this chapter and the general idea of the book, which is highlighting holistic engineering and technology concepts

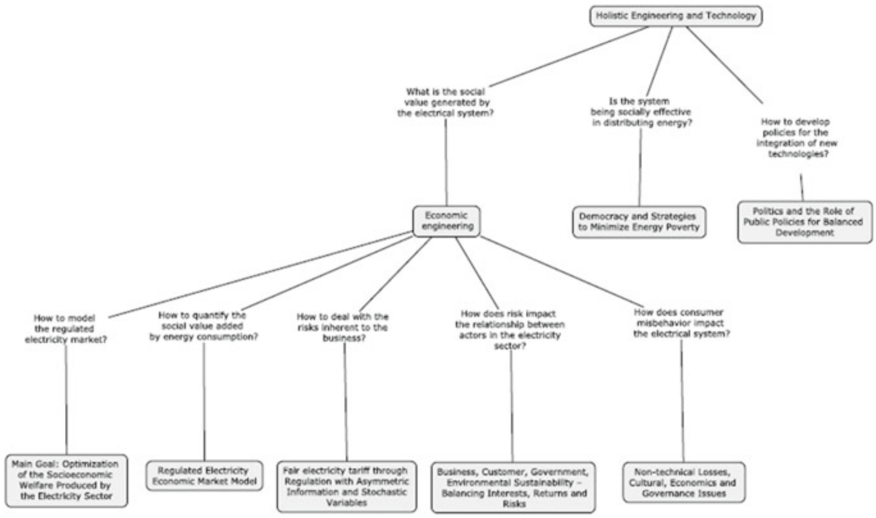


Fig. 2 Fundamental questions on holistic engineering, economics, and regulatory issues

The sentences in bold in Fig. 1 regard the topics discussed in this chapter, whereas the regular sentences regard the topics discussed in the introductory chapter. Therefore, this mind map illustrates the holistic challenges of economics, regulatory aspects, and public policies for overall sustainability.

The integration of new technologies into the electric grid such as renewable distributed generation (DG), energy storage systems (ESS), and smart grids add more complexity to the challenges. In this context, ancillary services must be accurately quantified (e.g., frequency/voltage regulation, energy loss reduction) in order to remunerate prosumers properly. This is particularly difficult due to the variability of the load curve and the generation curve, i.e., the impact of new technologies on the grid is dynamic.

Moreover, there is a growing concern with the potential increase in social inequality, environmental problems, etc., due to the deployment of new technologies, which can be a serious problem if regulation is ineffective. For example, the remuneration of prosumers might lead to a tariff increase by the regulatory agency (in a scenario of poor regulation), which is likely to heavily harm low-income consumers, resulting in extensive social impacts. Besides the above-mentioned issues, regulatory agencies must responsibly encourage the integration of new technologies through effective and balancing public policies, which is highly challenging.

Unforeseen events, such as the COVID-19 pandemic scenario, which drastically reduced electricity demand worldwide and also transformed consumption habits, pose even more challenges. It is undeniable that the world is currently dealing with a high risk scenario. While the pandemic is expected to be over in the midterm, some behavioral changes are permanent and it is fair to affirm that regulatory agencies lack framework and experience on the subject. Moreover, regulatory agencies must develop efficient public policies for potential future pandemics/crises in order to mitigate their impact and ensure better environmental, social, and economic development.

Due to the challenges faced by regulatory agencies, electricity market models are essential to assist them and ensure more efficient regulation, leading to responsible technology integration, social equality, and economic progress, but with environmental equilibrium, since drastic climate changes might result in human extinction on Earth. In this context, the economic model of the electricity market which will be presented and used throughout this chapter, in order to assist decision making by regulatory agencies, is the Optimized Tariff Model (TAROT®). This model is characterized by a simple but faithful representation of the electricity distribution market as a whole, representing not only the parameters of the concessionaires, but also consumers, investors, and society in general.

The highlight of the analyzes using TAROT is the verification by the policymakers, before making a decision, if a certain action will add or deteriorate the value of socioeconomic welfare. Thus, if a public policy generates an added value for society less than the current one, it means that this policy will actually be destroying value instead of generating value, and therefore, it must be rethought in order to achieve the primary objective of the regulatory agent: the maximization of socioeconomic welfare, that is, the surplus of society.

The concepts and applications of the model will be presented in this chapter in the following sections. As will be seen, the applications are varied, and range from the calculation of fair rates, risk and return analysis, to the evaluation of public policies to encourage micro- and mini-generation and strategies to minimize energy poverty. Thus, it is expected that the model will assist regulators in decision making seeking sustainable growth in the sector through policies that generate a balance between attracting investments, guaranteeing revenue for the operation of the network and a fair tariff for consumers.

2 Main Goal: Optimization of the Socioeconomic Welfare Produced by the Electricity Sector

When a consumer purchases goods, whether it is electricity or not, he or she seeks a quality of life increase. The economic utility function is defined with the purpose of monetarily quantifying the quality of life added. In economics, the utility function is extremely important, since it can be used to calculate the optimal price of the product or the quantity of purchased products. In (Kobayashi 2016; Ma et al. 2017; Mamounakis et al. 2019; Samadi et al. 2010; Song and Qu 2014; Taniguchi et al. 2015), the economic utility function is defined as either (1) or (2):

$$U(E) = aE - \frac{b}{2}E^2 \tag{1}$$

where
the parameter a is the avidity (desire to consume or willingness to pay);
the parameter b is the satiety (degree of satisfaction with the consumed energy);
The variable E is the consumed energy.

$$U(E) = w.ln(E) + d \tag{2}$$

where
the parameter w is the avidity;
d is a predetermined parameter.

In the context of regulated electricity markets, the utility function is used for socioeconomic welfare maximization, which is the main goal of regulatory agencies, at least in theory. The maximization of the socioeconomic welfare is obtained by calculating the optimal energy tariff, which can then be homologated by the regulatory agency. This concept will be presented in detail in Sect. 2. In summary, the socioeconomic welfare (Economic Welfare Added—EWA) is defined as:

$$EWA = U(E) - C(E) \tag{3}$$

where
U(E) is the economic utility function;
C(E) is the energy cost function.

Hence, the economic utility function assists regulatory agencies in the task of optimizing the socioeconomic welfare produced by the electricity sector. The economic utility function is applied in Sect. 2 in the context of an economic market model.

3 Regulated Electricity Economic Market Model

The Optimized Tariff Model (TAROT®) is widely used for regulated electricity market modeling due to its simplicity and accuracy (Arango et al. 2008a, b, 2010, 2017, 2019; Cortez 2018; Cortez et al. 2018, 2020; Costa et al. 2018; Domingues et al. 2002; Pereira et al. 2013, 2015). The TAROT® represents an economic flow diagram of the market, as presented in Fig. 3, which shows the structure of transactions carried out among the main agents of the electricity market: power distribution company, the government, and consumers. The main goal of the model is to enable the obtention of the optimal tariff (tariff that maximizes the socioeconomic welfare). This concept is essential to guarantee a sustainable electricity market, fair electricity tariff, and broad society access to electricity. To put things into perspective, nearly eleven million Brazilians do not have access to electricity, thus, to overcome this issue, optimal tariff homologation is essential (one of the reasons for the lack of access is the high tariff). It should be emphasized, however, that public policies Sects. (6 and 7) are also essential to increase access to electricity/minimize energy poverty and should be proposed alongside optimal tariff homologation.

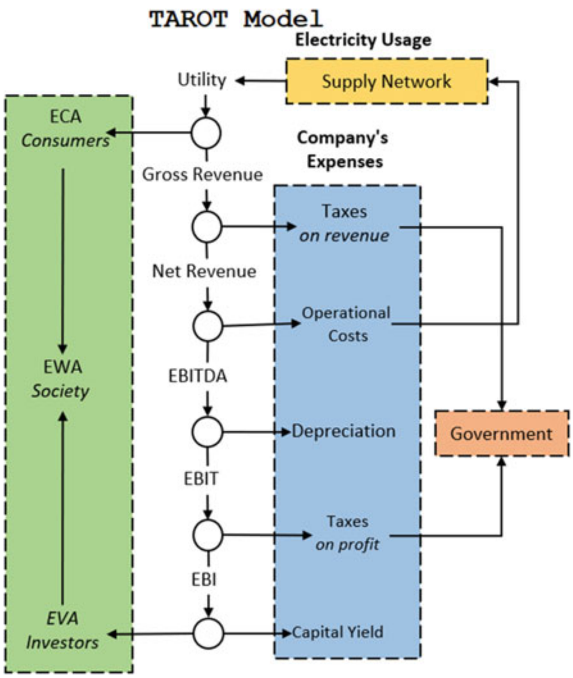


Fig. 3 Economic flow diagram of the TAROT® model (Cortez 2018)

3.1 Consumer's Model

The utility function represented in (4) is usually applied in the TAROT model context due to its linear marginal utility function.

$$U(E) = aE - \frac{b}{2}E^2 \tag{4}$$

The gross revenue (R) is given by (5):

$$R = TE \tag{5}$$

where
T is the tariff;
E is the consumed energy.

From the consumer's point of view, the gross revenue paid to the power distribution company is characterized as an economic sacrifice. Hence, the consumer's surplus (*ECA*—Economic Consumer Added) is given by:

$$ECA = U(E) - R \tag{6}$$

Based on (4) and (5), (6) can be rewritten as:

$$ECA = aE - \frac{b}{2}E^2 - TE \tag{7}$$

3.2 Power Distribution Company's Model

The perspective from which the power distribution company is evaluated is its generated economic value. Mathematically:

$$EVA = R - C \tag{8}$$

where
R is the gross revenue;
C is the overall cost (sum of cost components).

3.2.1 The Cost Structure

The operational costs (G) are modeled by (9):

$$G = eE + p\frac{E^2}{B} \tag{9}$$

where
e and p are adjustable parameters;
B is the grid investment;
eE models the operating costs of energy, management, maintenance and operation;
pE^2/B models the cost related to energy loss.

The grid depreciation cost (D) is modeled by (10):

$$D = dB \tag{10}$$

The taxes on revenue (Taxes_R) are given by (11):

$$\text{Taxes}_R = \mu R \tag{11}$$

where
μ is the sales tax or tax on revenue;
R is the gross revenue.

The taxes on profit (Taxes_P) are given by (9.17):

$$\text{Taxes}_P = t(R - G - \mu R) \tag{12}$$

where
t is the tax fee;
R is the gross revenue;
G is equated in (9);

The capital yield is modeled by (13):

$$Y = r_w B \tag{13}$$

where
r_w is the WACC—weighted average capital cost, which considers both third-party capital interest and shareholder remuneration.

Finally, the overall cost is calculated by the sum of (9), (10), (11), (12), and (13):

$$\begin{aligned} C &= eE + \frac{pE^2}{B} + dB + \mu R + t(R - G - \mu R) + r_w B \\ \Rightarrow C &= tR + (1-t)\left(eE + \frac{pE^2}{B} + \mu R + kB\right) \end{aligned} \tag{14}$$

where the parameter k is the hurdle rate for aggregation of value to the regulated company, equated by (15):

$$k = d + \frac{r_w}{1-t} \tag{15}$$

From (8) and (15), the power distribution company's surplus is expressed by (16):

$$EVA = (1-t)\left[R - \left(eE + \frac{pE^2}{B} + \mu R + kB\right)\right] \tag{16}$$

3.3 Overall Socioeconomic Model

Both consumers and the power distribution company benefit from the economic transaction. As a way of analyzing society as a whole, the socioeconomic welfare (*EWA*—Economic Wealth Added) is defined, which is given by the overall market surplus:

$$EWA = ECA + EVA \tag{17}$$

where
ECA is the consumer's surplus equated in (7);
EVA is the power distribution company's surplus equated in (16) or (18) if minimum costs are considered. The maximization of the socioeconomic welfare, which is ideally the main goal of regulatory agencies, is given by (18):

$$EVA = 0 \Rightarrow R - \left(eE + p\frac{E^2}{B} + \mu R + kB\right) = 0 \tag{18}$$

Equation (18) guarantees a state of invested capital is remunerated at the WACC rate and financial economical equilibrium (FEE) for the power distribution company, since all its costs can be paid; hence, (18) implies in a sustainable electricity market. Simultaneously, the maximum affordability for the consumers is ensured.

4 Fair Electricity Tariff Through Regulation with Asymmetric Information and Stochastic Variables

In this section, the TAROT® model presented in Sect. 2 is applied in the context of risk assessment. The inherent uncertainties of the electric system, the restructuring process of companies in the sector and the penetration of new technologies create the expectation of a future full of challenges. In this context, risk analysis becomes a powerful tool to assist companies in decision making in the face of possible economic problems caused by stochastic scenarios.

The TAROT® model typically considers the following risk categories:

- Hydrological risk (or risks associated with other inputs, e.g., coal), which directly impacts the energy supply and supply costs;
- Country's economic risk, which directly impacts the demand of electricity, affecting the company's revenue.

These two essential risk categories will be inserted into the TAROT® model, respectively, through the stochastic modeling of the following parameters:

- Parameter of grid operating costs (e) defined in (9);
- Consumer's avidity parameter (a) defined in (1).

In general, e is impacted by the hydrological risk and a is impacted by the country's economic risk. Naturally, historical data are required to obtain the stochastic parameters.

Figure 4 exhibits the annual Brazilian electricity consumption from 1995 to 2015.

Observing the behavior of energy consumption over the years, a trend component and a random component can be verified. Hence, a future point will be associated in part with the present point and in part with a random unpredictability. This behavior is known as random walk and (19) is used to model the stochastic avidity parameter.

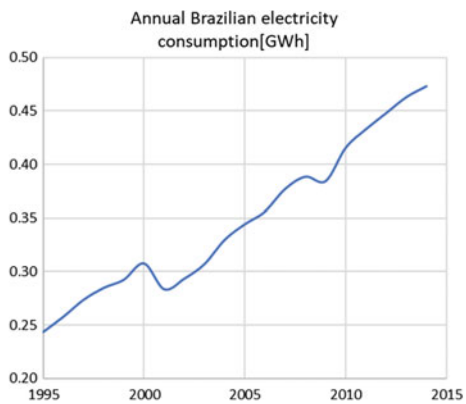


Fig. 4 Annual Brazilian electricity consumption (Cortez 2018)

Table 1 Input data for stochastic modeling of parameters for a typical Brazilian power distribution company

Parameter	Unit	Value
Stochastic parameters for modeling the avidity		
g	(%)	5
$\mu\tilde{a}$	(MR$/TWh)	0
$\sigma\tilde{a}$	(MR$/TWh)	23
Stochastic parameters for modeling the costs		
γ	(%)	−0.5
$\mu\tilde{e}$	(MR$/TWh)	0
$\sigma\tilde{e}$	(MR$/TWh)	2

$$\tilde{a} = ae^{g} + \tilde{\text{error}}_a \tag{19}$$

where
a is the deterministic value of the avidity;
e is the Neperian number;
g represents the growth trend of energy consumption;
$\tilde{\text{error}}_a$ is known as random noise with zero mean and finite standard deviation. The standard deviation is calculated based on historical data.

Similarly to the avidity, the grid effective operating costs parameter can also be modeled by the random walk concept. However, an effective incentive regulation is assumed; thus, the cost parameter has a natural tendency to decrease. Mathematically, (20) exhibits the stochastic grid operating costs parameter:

$$\tilde{e} = e\boldsymbol{e}^{\gamma} + \tilde{\text{error}}_e \tag{20}$$

where
e is the deterministic value of the parameter;
e is the Neperian number (represented in bold to avoid confusion);
γ represents the trend of cost reduction over time due to incentive regulation;
$\tilde{\text{error}}_e$ is known as random noise with zero mean and finite standard deviation. The standard deviation is calculated based on historical data.

Based on the stochastic parameters, a Monte Carlo simulation can be performed in order to analyze the electricity market in the context of risks/uncertainties. Table 1 presents typical values of the stochastic parameters in Brazil. It should be emphasized that

here
μ represents the mean value of the random noise and
σ the standard deviation.

Table 2 Typical values of a Brazilian power distribution company

Parameter	Unit	Value
a	(MR$/TWh)	1600
b	(MR$/TWh^2)	40
e	(MR$/TWh)	200
p	(MR$/TWh^2)	200
μ	(%)	22.00
t	(%)	34.00
d	(%)	4.00
r_w	(%)	7.50
k	(%)	15.12

Table 3 Optimized parameters

Parameter	Unit	Value
E^*	(TWh)	32.22
T^*	(MR$/TWh)	311.02
B^*	(MR$)	4,539.11

Naturally, besides the stochastic parameters $\tilde{a}$ and $\tilde{e}$, the parameters of the deterministic TAROT® mentioned in Sect. 2 are also necessary to perform a Monte Carlo simulation. Tables 2 and 3 present typical values of the deterministic parameters in Brazil.

Finally, a Monte Carlo simulation can be performed (using the software Crystal Ball®). From the simulation, it was possible to verify that the power distribution company's *EVA* presents a 67.63% chance of being positive. Thus, the company exhibits a considerable economic risk and this result justify the importance of the stochastic TAROT® model, since the deterministic TAROT® would not be able to assess the company's performance realistically.

For a more comprehensive stochastic analysis of the Brazilian market, the concept of return over investment (ROI) can be used, which is an economic indicator equated by (21):

$$ROI = \frac{EBITDA}{B} \tag{21}$$

where

EBITDA are the earnings before interests, taxes, depreciation and amortization;

B is the grid investment.

The use of ROI for economic comparison of companies is beneficial since it levels big and small companies by considering the grid investment. Figure 5 presents the Markowitz portfolio of Brazilian power distribution companies, where the y-axis

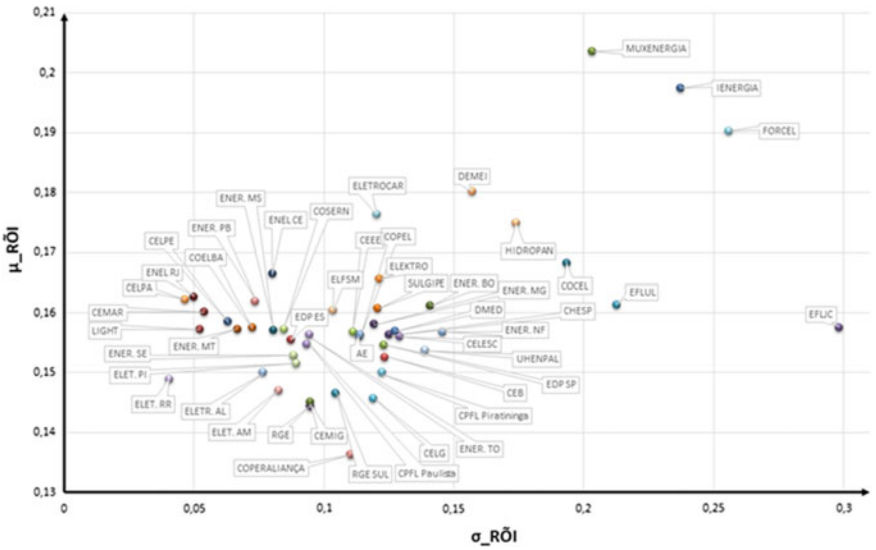


Fig. 5 Markowitz portfolio for ROI risk–return of Brazilian power distribution companies (Cortez 2018)

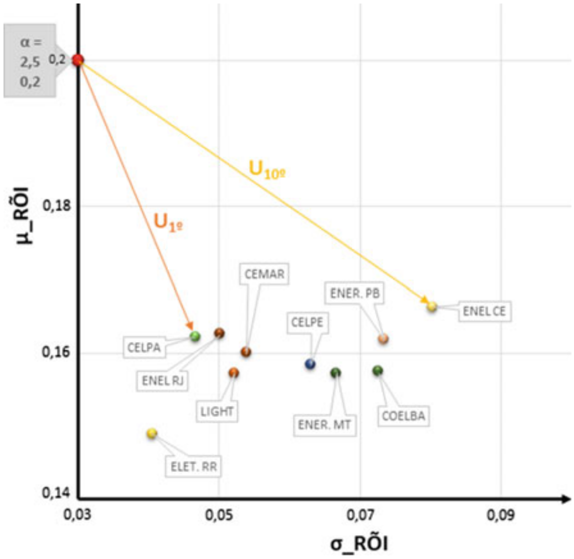
regards the mean value of ROI, i.e., the return, whereas the x-axis regards the standard deviation of ROI, i.e., the risk.

The investor profile is measured by the α parameter (considering that the risk aversion increases with the α parameter). It is widely known in economics that the company with an expected return μ and standard deviation σ that is closest to the center of the circumference P(0, $1/2\alpha$) in the Markowitz portfolio will be the company chosen by the investor. Figure 6 exhibits a comparison assuming a typical moderate investor with $\alpha = 2.5$. In this case, CELPA was the preferred company, as its location is the closest to the center of the circumference P(0, 0.2).

5 Business, Customer, Government, Environmental Sustainability—Balancing Interests, Returns and Risks

This section has the purpose of further developing the theory presented in Sect. 4, focusing on numerical multi-scenario examples.

Fig. 6 Economic comparison of Brazilian power distribution companies (Cortez 2018)



5.1 *Risk–Return Methodology*

The theory of risk combined with return arises from the need to analyze investments or projects in which decision making is not trivial. Evidently, when comparing two projects in which the first presents less risk and greater return than the second, then the first project is chosen in a trivial way. However, the decision is not trivial when a project appears that presents greater risk and greater return than another. Under these conditions, which project to choose? Now, this question cannot be answered in a generic way. However, it can be answered by knowing the investor's profile when faced with risk. For this, a knowledge based on the utility theory of (Von Neumann and Morgenstern 1944) was developed, in which the return of a project does not present an absolute value but a relative value. With this proposal, it was possible to prove that the return on an investment depends, among other factors, on the profile of the investor in view of the risk. Mathematically, one of the ways to represent the utility function is:

$$U = \mathrm{ROI} - \alpha \mathrm{ROI}^2 \tag{22}$$

being:
α: Risk aversion coefficient.
U: Company utility function.
ROI: Company Return on Investment.

Equation (22) suggests that the economic utility of that project falls in proportion to the degree of risk aversion of the investor. Now, when one is sure of the return values of the projects, which they suggest in risk-free projects (they hardly exists in practice), then the most returnable project is chosen in a trivial way. However, the return on projects is calculated based on hypotheses and estimates, which leads to the variable return for a stochastic character. This way, the return variable starts to obey a probability distribution function with an average and a standard deviation. Thus, Eq. (22) can be improved:

$$E(U) = E(\text{ROI}) - \alpha E(\text{ROI}^2) \tag{23}$$

It is known that:

$$E(\text{ROI}^2) = E^2(\text{ROI}) + \sigma^2 \tag{24}$$

Which can best be written by:

$$E(U) = E(\text{ROI}) - \alpha E^2(\text{ROI}) - \alpha\sigma^2 \tag{25}$$

Developing, it reaches Eq. (26):

$$\left(E(\text{ROI}) - \frac{1}{2\alpha}\right)^2 + \sigma^2 = \frac{-E(U)}{\alpha} + \frac{1}{4\alpha^2} \tag{26}$$

In the Markowitz plan (Danthine and Donaldson 2005; Fabozzi et al. 2007; Markowitz 1952), the E(U) function represents a circle with center at the point of Risk Aversion of Company H: (0; 1/2α) and radius with the value of $sqrt[1/4a2 - E(U)/a]$. The radius value represents the distance from the risk aversion point to the risk–return point of the project. Thus, the lower the radius value the better the project is from the perspective of the company or investor.

Now, isolating E(ROI) results on (27):

$$E(\text{ROI}) = \frac{1}{2\alpha} + -\sqrt{\frac{-E(U)}{\alpha} + \frac{1}{4\alpha^2} - \sigma^2} \tag{27}$$

By varying the risk in Eq. (27), the utility curves that represent semicircles in the Markowitz plan are reached for the projects considering the company's degree of risk aversion. Figure 7 shows this graphically.

The value of the semicircle radius, that is, the value of the distance from the utility curve to the risk aversion point can be calculated by (28):

$$d = \sqrt{\frac{-E(U)}{\alpha} + \frac{1}{4\alpha^2}} \tag{28}$$

Knowing from statistic that:

$$E(\text{ROI}) = \sum_{i=1}^{n} \pi_i ROI_i \tag{29}$$

$$\sigma = \sqrt{\sum_{i=1}^{n} \pi_i (ROI_i - E(\mathrm{ROI}))^2} \tag{30}$$

$$E(U) = \sum_{i=1}^{n} \pi_i U(\mathrm{ROI}_i) \tag{31}$$

being:
$E(\mathrm{ROI})$: Corresponds to the expected return on investment.
σ: Corresponds to the project's risk.
π_i: Probability of occurrence of scenario i.
i: Scenarios considered.
$E(U)$: Expected value of the project's economic utility.
$U(\mathrm{ROI})_i$: Project economic utility in scenario i.

5.2 Electricity Company Model in a Regulated Scenario

The model of the electricity company proposed throughout this work corresponds to the TAROT model (Arango et al. 2008a, 2010, 2017; Domingues et al. 2002. This model was chosen because, much more than an economic model, it represents a socioeconomic model, detailing the interaction of the electricity company with the consumer through the commercialization of energy. The model works well for teaching purposes and is based on the theory of value-based management (Martin and Petty 2000). Figure 7 represents the TAROT model,

being:

U: Consumers' economic utility. S: Consumers' Surplus. R: Electricity Company Revenue. E: System energy. $e * E$: Variable Costs.$p * E^2/B$: costs related to technical losses. dB: grid depreciation or portion of investment. p, e, d: are adjustable coefficients intended to approximate the costs to real situations. B: Investment in physical grid or network. EBITDA: Earnings before Interest, Taxes, Depreciation, and Amortization. EBIT: Earnings Before Interest and Taxes. t: tax aliquot over EBIT. NOPAT: Net Operating Profit after Taxes. rw: coefficient of return on capital invested. $r_w B$: Investor's capital remuneration. C: Electricity Company Costs. V: Economic Value Added. W: Socioeconomic Value Added or Social Welfare.

The model equations are well-described throughout this chapter, but some main ones are worth mentioning. Equation (32) represents the company's return on the investment done:

$$\mathrm{ROI} = \frac{EBTIDA}{B} \tag{32}$$

Equation (33) represents the company's revenue from the sale of energy:

$$R = TE \tag{33}$$

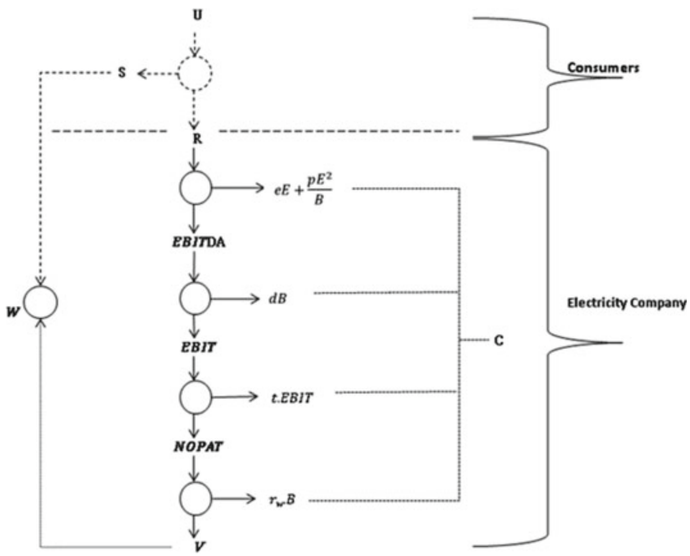


Fig. 7 TAROT socioeconomic market model

Expression (34) represents the total costs of the electricity company:

$$C = eE + \frac{pE^2}{B} + B(d + r_w) + tEBIT \tag{34}$$

The company's economic added value can be represented through Equation (35):

$$V = R - C \tag{35}$$

A regulated electricity company means that the total value of its costs must be equal to its revenue. In other words, the company is considered regulated, when its economic added value is zero and it is in economic–financial balance.

5.3 *Application of a Regulated Electricity Company Model*

Using the model of the regulated electricity company as described in the section before, a hypothetical regulated electricity company is considered whose parameters of the company and its consumers are represented through Tables 4 and 5 (Fig. 8).

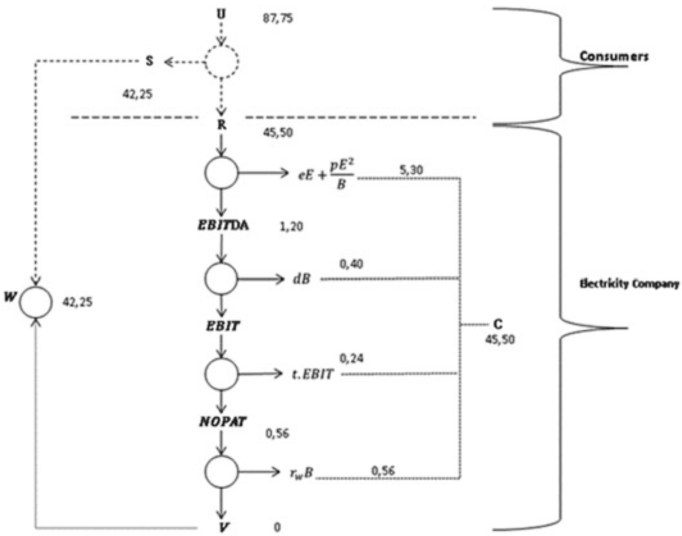


Fig. 8 Application of the TAROT model for a hypothetical electricity company

5.4 Application of Risk and Return Theory for Project Evaluation in the Regulated Company

In order to test the risk and return theory to evaluate projects, a hypothetical electricity company will decide between two technology projects that have the function of

Table 4 Consumer data

Parameters and variables	Meaning	Value
a	Avidity	20 (R\$/MWh)
b	Satiety	2 (R\$/MWh^2)
T	Regulated tariff	7 (R\$/MWh)

Table 5 Hypothetical electricity company data

Parameters	Meaning	Value
e	Variable costs coefficient	6 (R\$/MWh)
p	Technical losses coefficient	1.00355 ($R\$^2$/MWh^2)
B	Investment in the electricity grid	8 (MR\$)
d	Depreciation coefficient	5%
r_w	Investor remmuneration coefficient	7%
t	Tax rate over EBIT	30%

Table 6 Expected values of the company's variable costs (e) with the implementation of the projects

Variable	Scenario	Value (Project A)	Value (Project B)	Probability of occurrence (%)
e1	Modest	5.6	5.9	25
e2	Intermediate	5.5	5.5	25
e3	Semi-aggressive	5.4	5.2	25
e4	Aggressive	5.3	5	25

Table 7 Project return on investment values (ROI) for each scenario

Scenario	Probability of occurrence (%)	ROI (A) (%)	ROI (B) (%)
Modest	25	47.50	23.13
Intermediate	25	55.63	55.63
Semi-aggressive	25	63.75	80.00
Aggressive	25	71.88	96.25

Table 8 Projects risk–return results

	Project A (%)	Project B (%)
E(ROI)	59.69	63.75
σ	9.085	27.551
$E(U)$	41.463	39.635

reducing the company's costs. It is known that the projects produce benefits such as cost reduction, but a consultancy was hired to estimate the cost reduction values for both projects. After analysis and study by the consultant, it was reached the cost values after reduction, for the projects according to Table 6.

With the cost values for the four scenarios considered in Table 7, the ROI values are calculated according to Eq. (32) for each scenario and the results are described in Table 7.

Using a risk aversion coefficient ($\alpha = 0.5$) for the company and using Eqs. (29)–(31), the values of the risk–return indicators for the analyzed projects result in Table 8.

These results described in Table 8 for projects A and B can be plotted in the Markowitz risk–return plan, as shown in Fig. 9:

Analyzing Fig. 9, it is possible to verify through the economic utility curves of projects A and B, that project A is better than B. However, one way to see graphically is through the distance between the point of the project and the point of aversion to risk that corresponds to the radius. Thus, the project with the smallest radius is the best. Through Fig. 9, it is possible to verify that project A has a smaller radius, so it is the favorite in relation to project B from the company's perspective in relation

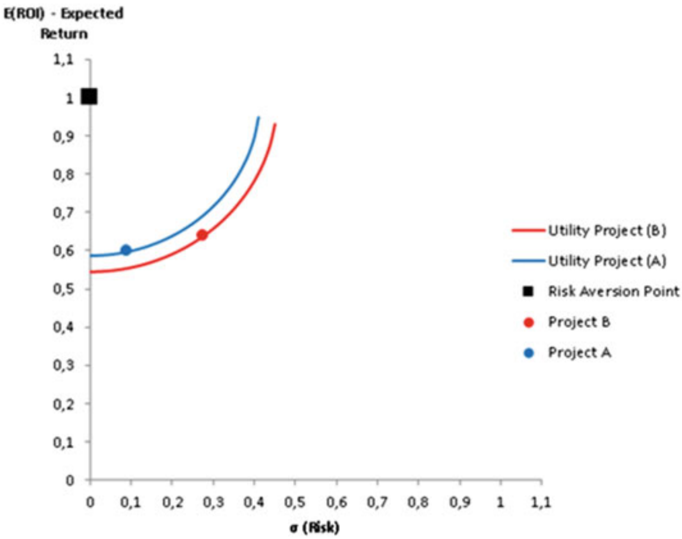


Fig. 9 Projects evaluation in the Markowitz plan ($\alpha = 0.5$)

Table 9 Value of the distance of the projects to the risk aversion point ($\alpha = 0.5$)

Projects	Project A	Project B
Radius value or distance	0.41321132	0.455295407

Table 10 Value of the distance of the projects to the risk aversion point ($\alpha = 0.5$)

Projects	Project A	Project B
Radius value or distance	1.406038262	1.390051764

to its risk profile, quantitatively and through the numerical calculation of the radius according to Eq. (28) and represented through Table 9.

However, Project A will not always be better than Project B. It is now assumed that the value of the company's risk aversion coefficient becomes ($\alpha = 0.25$). The projects in the Markowitz plan can be represented through Fig. 10:

Quantitatively, Table 10 can represent the value of the utility curves for the risk aversion point,

that is, it can be said that the choice between projects with non-trivial risk–return depends on the investor or company risk profile.

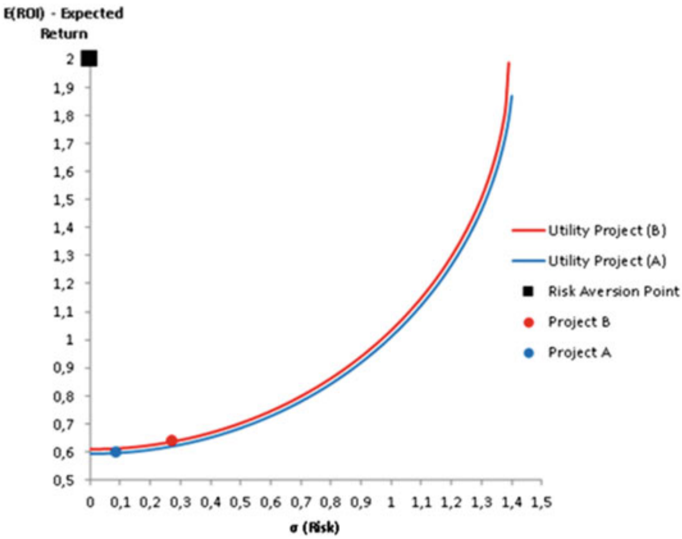


Fig. 10 Projects evaluation in the Markowitz plan ($\alpha = 0.25$)

6 Politics and the Role of Public Policies for Balanced Development

6.1 Formulation of Public Policies

Evaluating the effectiveness of public policies is just as important as the assessment of market risks performed in Sects. 4 and 5. Public policies can be understood as a set of measures and actions taken by the government with the objective of influencing or controlling the behavior of stakeholders. The formulation of these policies is a complex process, and understanding the type of policy to be adopted is important to obtain a better perspective of the possibilities of contributions as well as their possible limitations (Friedman 2002). The analysis of public policies aims to define the problem and identify new proposals, as well as their consequences and impacts for society as a whole. This study is part of the government's decision-making process. It is noteworthy that the social objectives of these policies can often be easily perceived; however, often quantifying their costs and benefits may not be a simple task (Friedman 2002). For example, to encourage the production of energy from renewable sources, it is necessary to make a comprehensive analysis of the costs and benefits associated with this new form of generation. The analyzes must consider all the costs involved and devise policies that allow reaching common goals with the lowest possible total cost, thus maximizing socioeconomic welfare.

Some points are important to be analyzed by public policymakers:

1. The costs involved to implement a specific public policy should not be higher than the accrued benefits;
2. In order to promote sustainable and efficient development, the incentive public policy must maximize socioeconomic welfare;
3. The same public policy can have different impacts on society, especially in a country as large and with so much inequality as Brazil (this aspect will be discussed further in Sect. 7 of this chapter);
4. In order to effectively obtain a smart market, the public policy must aim fare tariffs and remuneration, for all the stakeholders involved; otherwise, it will not be a smart and efficient market.

6.2 Public Policies to Encourage Micro- and Mini-Generation in Brazil

Following the global trend of promoting energy generation from small- and medium-sized consumer units through renewable sources, the Brazilian Electricity Regulatory Agency (ANEEL) published the Normative Resolution No. 482 of April 17, 2012, ANEEL 2012) establishing the general conditions for access from micro- and mini-generation to the distribution network, in order to regulate this new market.

The application of public policies as an incentive mechanism is important to establish favorable conditions for the use of alternative sources of energy, and there are several mechanisms currently used worldwide, each with its different characteristics, which can also be classified as direct or indirect mechanisms.

In the case of directs, they are those whose main objective is to promote the dissemination of renewable energy sources. Those already called indirect are characterized by the advancement of certain sectors that positively influence the spread of these sources, such as emission rates of the industries that encourage the efficient use of energy and use of new sources (Pereira et al. 2017). Thus, policymakers from governments intervene by using different incentive mechanisms in order to encourage the distributed generation market.

The ANEEL's Resolution Nr. 482 defined the mechanism for encouraging distributed generation: the energy compensation system, also known as net metering. In this system, the energy-producing consumer (prosumer) is allowed to inject the surplus energy generated in the distributor's system, generating energy credits that are later used to reduce their monthly consumption. Thus, the billing of the consumer unit is the difference between the amount of energy consumed and the amount of energy injected into the grid. Thus, the energy generated and injected into the grid is fully deducted from the energy bill, that is, considering all components involved in the tariff.

Net metering is characterized by being an important mechanism in the promotion of small generation systems, also used in the USA and its function is to allow consumers to generate their own energy, and not to stimulate the creation of micro

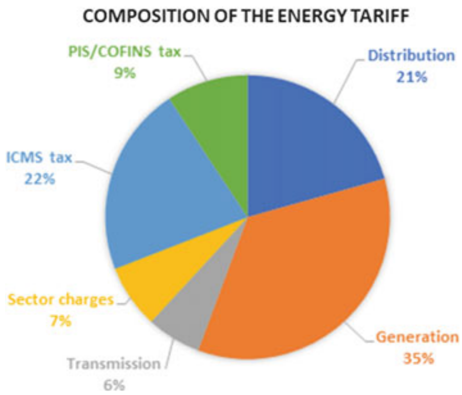


Fig. 11 Composition of the monomial energy tariff (ONS)

plants (G. Aquila et al. 2015). This system is most effective in regions where the electricity tariff is the highest. This is because the sale of energy is not foreseen, but the creation of energy credits for the energy that is injected into the network, in order to be offset later in the account.

Since 2012, with the publication of REN 482 (ANEEL 2012), the Brazilian government has shown an interest in encouraging consumers to adhere to the distributed micro- and mini-generation model from renewable energy sources. But for this to happen in a smart and efficient way, incentive policies are needed that seek a balance between all the agents involved. That is, there must be benefits for both consumers and the State, as well as for the concessionaire. It is necessary to note that the incentive policy must generate greater socioeconomic well-being in the energy market than previously. Otherwise, if the gains for society in general are smaller, it is not worthwhile to implement this policy.

Since it was implemented, ANEEL's Resolution already provided for a future revision of its guidelines. This review is ongoing and had public hearings and consultations so that all agents involved in the sector could make their contribution to improvements. The main discussion is about the cross-subsidy that net metering provides. This subsidy is embedded in the tariff structure itself.

Due to the Brazilian tariff model, the energy tariff is also comprised of distribution, transmission, generation, charges, and taxes, in addition to the cost of energy (SECAP 2019). Figure 11 shows the components included when consuming energy from the distributor.

Thus, the prosumer who injects the surplus energy into the distributor's grid, when his energy credits are offset in the account, due to the low-voltage residential consumers' tariff being monomial, he is remunerated for all components included in the tariff. Thus, what happens is that the consumer who generates his own energy and injects the surplus into the grid, receives more for it than a conventional generator (SECAP 2019).

This cross-subsidy, when implemented, was seen as a necessary stimulus for distributed micro- and mini-generation. But the greater the penetration of DG in the Brazilian energy matrix, the lower the revenue earned by the distributor, which passes on its costs to other customers, resulting in an increase in electricity tariffs. Consequently, the higher the energy tariff, the more incentive and advantage the consumer obtains in becoming a prosumer, which ends up generating a vicious circle, which becomes increasingly inefficient. In addition to burdening other grid users, it is noteworthy that the most impacted are mainly consumers with less purchasing power, who are unlikely to be able to install DG.

Another problem that the compensation system provides is that it does not consider the moments of injection and energy consumption in the network. Generally, the consumer who has a photovoltaic system injects energy into the grid at off-peak times, when the grid's energy demand is low, while consuming at peak times. The main point of discussion regarding the non-consideration of injection and consumption schedules is that in this case the postponement of investments in the concessionaire's network is not verified (Pereira et al. 2017), since it needs to dimension its network to meet all demand at the end, and distributed generation is not relieving the load at this time of greater network overload.

A difficulty faced in other countries like Germany (Pereira et al. 2017) is to clearly quantify the benefits and positive impacts associated with the dissemination of renewable sources, such as reducing carbon emissions, generating jobs, and energy security. The costs in general are easily calculated, while the benefits are not easy to verify, as also presented in ANEEL's Regulatory Impact Analysis No. 003 of 2019 (ANEEL 2019).

The main modification suggested by ANEEL for REN 482 refers to the payment for the use of the network by consumers who generate and consume electricity. Some solutions suggested by the other stakeholders to the problems previously verified are the migration to the binomial tariff for low-voltage consumers and hourly tariffs, such as the white tariff.

It is expected that the revision of REN 482 will be carried out and that it will result in an increase in the payback of projects. However, given the high electricity tariffs and their steady growth, the number of adhesions should continue to grow, despite the slowdown in growth. Another consequence of the possible change in the regulatory issue is the incentive to projects that consider the use of an energy storage system aimed at managing consumption and generation.

The use of distributed batteries in conjunction with distributed intermittent systems, such as the solar photovoltaic source, may have a strategic role in the future, helping to smooth the problems caused in the operation of these systems in parallel with the National Interconnected System, such as, for example, the displacement of demand and the reduction in peak demand.

Given the current Brazilian scenario, it is clear that the great challenge for the regulatory agent is to reduce existing subsidies while recognizing the positive externalities of micro- and mini-generation in the energy tariff, in addition to not transferring resources from the least favored to the most favored (Federal Senate 2019). It is important to have a clear objective in the implementation of one or the other public policy, and the evolution of distributed energy storage systems in the long term must also be considered, in order to allow an adequate modernization of the electricity sector.

Public policies should not burden or benefit any stakeholder sector too much, thus causing a social, economical, and environmental imbalance. In the current rules, energy concessionaires feel penalized since there is a decrease in revenue verified with the increase of distributed generation, coupled with the increased degree of complexity of the system's operation due to the intermittency of the photovoltaic solar source, which is the source most used by residential and commercial prosumers.

Therefore, the current question in relation to distributed generation in Brazil, and consequently of public policymakers, is whether the growth of this generation modality needs incentives to continue expanding. And if it is still necessary, what is the most sustainable, efficient, and fair way to promote this stimulus, so that the costs involved are not greater than the social, economical, and environmental benefits provided by renewable sources (SECAP 2019). It is noteworthy that these challenges are not exclusive to Brazil, since worldwide public policymakers are looking for the best way to promote socioeconomic welfare, given the current condition of each country in the issue of advancing the adoption of renewable sources in their energy matrices.

New policies and market reforms are needed to strike a balance between the conflicting interests of DG facility owners, distribution companies and energy consumers in general, and the government, since historically the energy tariff has been used as a major collector of taxes and charges for the State. These policies should allow an environment of healthy growth and maturation of the sector, in a sustainable manner, in order to reduce energy poverty and add more value to society as a whole. However, this is not an easy task, and the use of an Economic Model of the Regulated Electric Market, which represents the sector in an appropriate, simple and faithful way, can help policymakers to understand the effects of the adoption of certain public policies for all sector agents.

6.3 Evaluation of Public Policies Through the Economic Model of the Electric Market

To evaluate incentive public policies, in this section the economic model of the electricity market, previously presented and known as TAROT—Optimized Tariff, is applied. By using this model, the maximization of socioeconomic welfare produced by one or the other policy can be assessed, as well as its impacts on the energy distributor, consumers, and the government (through taxes).

The parameters values of the distribution company of the State of Minas Gerais, CEMIG, which is the company that has the largest number of distributed generation connections in its network currently in Brazil, will be used. The data used for the optimized TAROT model, as shown in Fig. 3, are also presented in Table 11. The parameters of the consumer, avidity, and satiety are shown in Table 12.

Table 11 Concessionaire parameters

Parameter	Unit	Value
Optimized tariff (T^*)	(MR$)	533.17
Amount of energy (E^*)	(TWh)	44.35
Optimized remuneration base (B^*)	(MR$)	10,355.89
Operating cost factor (e)	(MR$/TWh)	307.68
Loss factor (p)	(MR$^{2}/TWh^2)	8777.74
Depreciation factor (d)	(%)	3.84
Weighted average cost of capital (r_w)	(%)	8.09
Tax on net income (t)	(%)	34.00
Tax on gross revenue (μ)	(%)	28.19

Table 12 Consumption parameters

Parameter	Unit	Value
Avidity (a)	(MR$/TWh)	4,204.64
Satiety (b)	(MR$/TWh^2)	82.78

With the parameters being optimized, the model results for the concessionaire in Economic Financial Equilibrium (EFE) are obtained, after the tariff review by ANEEL. In this way, its Economic Value Added (EVA) is close to zero. This means that, with the optimum tariff determined by ANEEL, the concessionaire is able to bear all its costs, pay taxes and properly remunerate shareholders. In this scenario of Economic Financial Equilibrium, the surplus of the society is practically only given by the surplus of the consumer, as can be seen in Fig. 12. To obtain an EVA higher than zero, the company must work in order to be more efficient in its operation, reducing its costs and earning a higher profit after assuming all its commitments. According to the present regulation (Factor X), the company can keep extra gains but also share part of its efficiency gains in order to reduce electricity tariffs for customers, aiming at fair tariffs.

Considering now one of the main discussions of policymakers and industry regulators today, it will assess the impact of a 20% reduction in the collection of the concessionaire due to increased generation of distributed connections in your network. Due to the growth in the number of prosumers, they will pay the concessionaire only the cost of availability, that is, the minimum amount to remain connected to the system.

As already discussed, due to the non-use of hourly rates, there is a disregard for the periods in which energy is injected and consumed. As the most widely used source in DG is photovoltaic, when comparing the solar generation curve with the system consumption curve, it is observed that there is no reduction in peak demand,

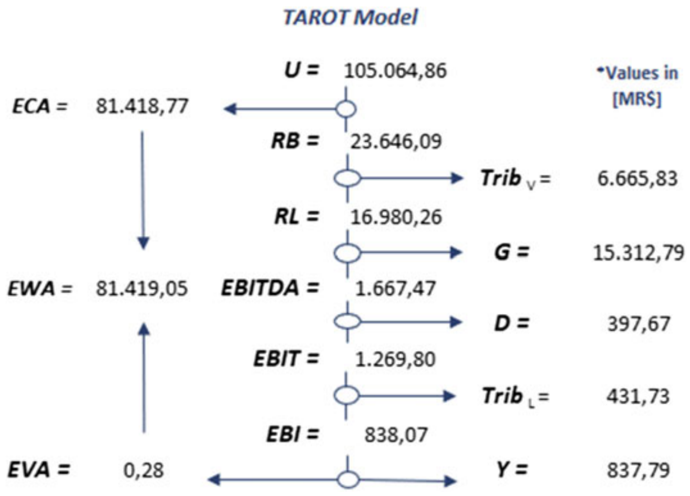


Fig. 12 Result for the TAROT optimized with CEMIG data

which does not reduce the investments needed by the concessionaire to meet and supply the energy required in times of greatest demand. Then, CEMIG's costs will be maintained in the analysis of this scenario, even with a 20% reduction in revenue.

Recalculating the variables of the TAROT model with these new premises, it is possible to verify in this scenario that if companies do not change their business models and explore the new possibilities that GD can provide, the distributor's EVA in analysis is negative, in the amount of 43.77 MR$ (Mega Reais). This deficit in the concessionaire's accounts will be passed on and shared with ordinary consumers in the next tariff review. In addition, it is observed that the surplus of society in general is not maximized in this scenario, when compared with the scenario of Economic Financial Equilibrium. In other words, in this situation the majority of stakeholders are affected: the average consumer will have an increase in the tariff in the next review cycle, the distributor is unable to meet all its commitments, and the government is collecting less taxes. This scenario would be advantageous only to prosumers indicating that the regulatory agency, the power utility company, the government and other stakeholds need to search for a new sustainable business model.

Therefore, it appears that the current Brazilian rules of net metering, will not promote a long-term development of a sustainable, and efficient and market, and that is why any discussion involving the revision of REN 482 is justified. Through the Economic Model of the Electricity Market TAROT used, it is simpler to visualize the impacts caused for different scenarios, becoming a powerful tool to assist decision makers in the development and implementation of public policies to encourage the sector, considering the balance among all the agents involved.

One of the core issues that must be analyzed in the formulation of incentive policies is the tax issue. The reduction of taxes stimulates any type of consumption and reflects a reduction in the return on investment. Generally, the taxes charged in the country that impact the energy sector are diverse. Among them, the state ICMS tax, and the federal PIS and COFINS taxes, which are levied on gross revenue, can be highlighted. In the state of Minas Gerais, where CEMIG is located, ICMS is approximately 23%. Considering that, instead of changing the net metering tariff, the state government decides to reduce 10% of the state gross revenue tax, the ICMS. What would be the impact of that decision?

This answer can be obtained by recalculating the variables in the TAROT model, considering this exemption. It will be verified that, with only a 10% reduction in the ICMS collected by the state of Minas Gerais, it would be enough for the distribution company, even with the reduction in its collection due to the sale of energy, to be able to bear all its costs and generate an EVA equal to or greater than zero.

From the TAROT model, which allows the representation of both the concessionaire, government taxes and consumer parameters and the gains of society in general, it is possible to observe for each scenario, whether a given action is beneficial to all agents involved, in addition to generating greater socioeconomic welfare in the energy market than previously. If, when carrying out the analysis, the gains for society in general were smaller, it is not worthwhile to implement this policy. Thus, with this model, which faithfully reflects various aspects of the electricity market, it is possible to assess the impact that a given government public policy can have on socioeconomic welfare, such as, for example, reducing tax.

7 Democracy and Strategies to Minimize Energy Poverty

It is essential that public policies are applied with the purpose of minimizing energy poverty. While Sect. 6 focuses on the general context of public policies, this section addresses its application in the context of social justice and universal access to electricity.

7.1 The Distribution Company, Prosumers, and Low-Income Consumers

There are many works in the literature that discuss energy policies, economics, and technological approaches as (Benso et al. 2018; Bodach and Hamhaber 2010; Primc and Slabe-Erker 2020; Primc et al. 2019; Romero et al. 2018; Sovacool 2012) and show concern for the less fortunate people who cannot benefit from electricity because of their socioeconomic conditions, a phenomenon known as energy poverty (Bouzarovski et al. 2012; Dobbins et al. 2019; González-Eguino 2015; Marchand et al. 2019; Middlemiss et al. 2019; Scarpellini et al. 2019; Schleich 2019; Walker et al. 2013). In addition, there is also an electrical energy social tariff (TSEE) program for the low-income population. However, socioeconomic characteristics are quite

Table 13 Socioeconomic characteristics of Brazil in 2019 (ANEEL 2015b; IBGE 2017)

	Gini index	Population distribution (%)	Average income (R$)	Average consumption of electrical energy (TWh)	Average energy Tariff (R$/MWh)
Midwestern	0.507	7.60	2,506.00	29.18	526.96
Southern	0.467	14.30	2,549.00	57.61	488.25
Southeastern	0.527	42.00	2,650.00	146.92	521.55
Northeastern	0.559	27.60	1,588.00	62.76	478.07
Northern	0.537	8.50	1,687.00	20.16	586.31
Brazil	0.543	100.00	2,308.00	316.48	511.49

different in each region of Brazil, as can be seen in Table 13, and because of this, the present public policies, which are a cross-subsidized and are the same for all country, do not cause the same impact on all consumers (especially for the ones living in poor regions.

Reducing energy poverty has to consider how this policy contributes for improving the income distribution in each region. With the smart grids scenario being globally promoted, a truly smart market should also care about minimizing energy poverty and promoting socioeconomic justice. In Brazil, there are both cases of energy poverty, since for the average income of families, electricity is still too expensive. According to the Brazilian Institute of Geography and Statistics (IBGE 2019) 0.2% of the Brazilian residences have no access to electrical energy. That corresponds to about 140,000 homes without any access to electrical energy at all. According to public data from ANEEL (ANEEL 2012), about 12% of energy consumers are considered low-income consumers and, therefore, are getting discounts on their energy bills.

The Electrical Energy Social Tariff (TSEE) is a public policy aimed at favoring the low-income population and providing better access for this population to the benefits of electricity. There is no doubt that with electrification, income growth, and socioeconomic developments follow up. But it is relevant to adjust the energy policies to be less bureaucratic, less costly, and more effective for the people in need. Currently in Brazil, the Electrical Energy Social Tariff (TSEE) is regulated by Law Nr. 12,212 of 2010 and by Decree Nr. 7,583 of 2013. It covers the Group B consumers, more specifically the group B1-Low Income, Indigenous, and Quilombola. It consists of tariff discounts incident over the conventional residential tariff. The application of discount is the same all over the country, despised the differences of socioeconomic situation in each region of Brazil. With this in mind, the question of how the discounts offered to the poorest affects the rest of the population is born. In order to assess the income distribution, it is used the Gini index, since this is a widely used method for evaluating inequality in income distribution.

7.2 The Measure of Inequality: Gini Index

To measure social effects, it is necessary to study the aggregates of individuals in their statistical composition, such as income, age, and other collective variables. The objective is to explain the basic principles of this approach.

Economic engineering deals with projects, especially those that are inserted in corporations in order to make them more efficient and beneficial, both internally and in their social role.

But how to express the company's effect on society? For this, first of all, it is essential to study the composition of individual aggregates; that is, how they are distributed in the social environment to which they belong.

Starting with the composition of a group of individuals in terms of their income, in general, these groups involve a large number of them, so it is convenient to define a continuous variable (v) that goes from zero to the total number of members. Thus, the income of the nth individual can be expressed as:

$$\int_{n-1}^{n} y(v)\mathrm{d}v \tag{36}$$

$y(v)$ being the group's income distribution. And still,

$$z = \int_{0}^{n} y(v)\mathrm{d}v \tag{37}$$

such as total group income or accumulated income.

If all y_n incomes are equal, the income distribution is perfectly uniform. As the y_n incomes differ, the distributions will be less uniform, until the extreme case of having a single individual or family holding the total disposable income (Romero et al. 2018). When the accumulated proportion of income (z) varies as a function of the cumulative proportion of the population (p), with individuals being ordered by increasing values of income, there is the Lorenz curve (Samadi et al. 2010), as shown in Fig. 13.

By definition, Gini's index (or coefficient) is a relationship between the area of inequality, indicated by α and the area of the triangle. Therefore,

$$\text{Gini} = \frac{\alpha}{\alpha + \beta} \tag{38}$$

Figure 14 represents the difference in Gini index when the population receive some income benefit.

$$G = \frac{OAB}{OBM} \tag{39}$$

$$G' = \frac{OA'B}{OBM} \tag{40}$$

$$\Delta G = G - G' = \frac{OA'BA}{OBM} \tag{41}$$

Note that perfect equality implies that the area of 45° is the Lorenz curve itself, and in the case of maximum inequality, the Lorenz curve is superimposed on the horizontal axis until the last element that has positive income. Thus, the limits of the Gini index are $0 \leq G \leq 1$, with 0 being the maximum equality and 1 the maximum inequality.

For example, a perfectly equal income distribution has Gini index of zero, whereas a total unequal distribution has Gini index equal to one, as shown in Fig. 15. Figure 16 shows how the simplify Gini index was calculated.

When the tariff value is increased for a large part of the population favoring another part, the socioeconomic value tends to fall, as it increases the sacrifice of consumers to obtain the same amount of energy. However, this difference ends up providing an increase in the income of the less favored, since they have in the reduction of the tariff the increase in their income because, if before they used to spend X with the

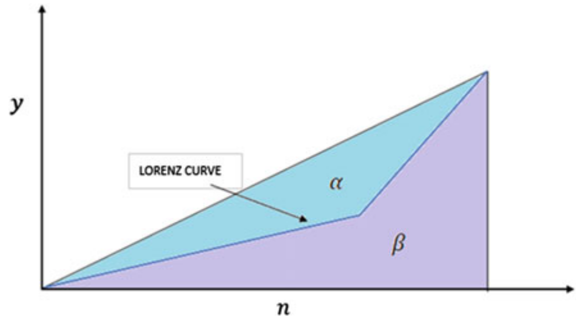


Fig. 13 Lorenz curve illustration

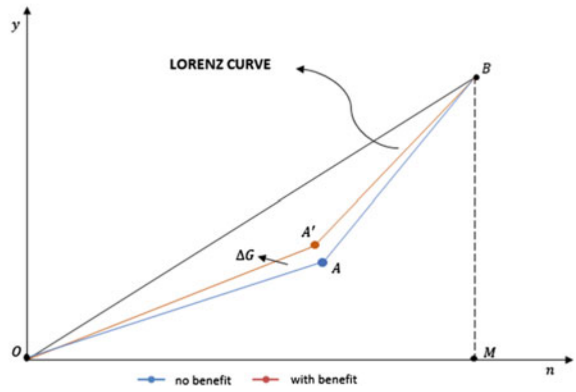


Fig. 14 Lorenz curve illustration

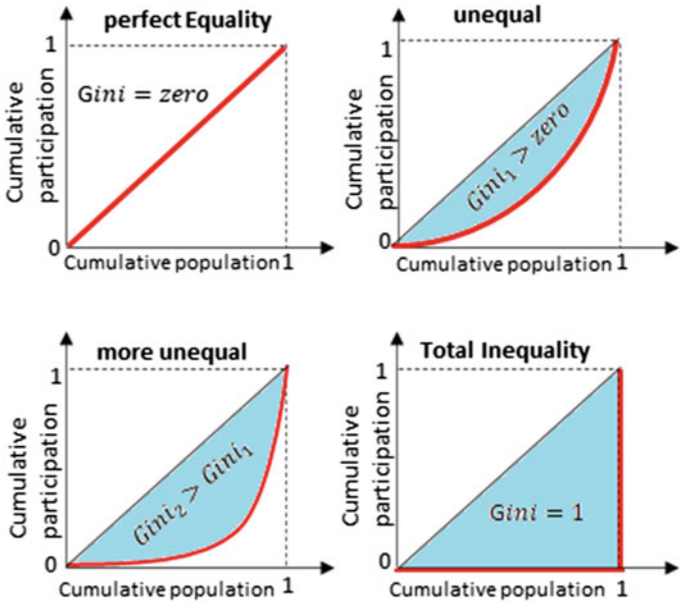


Fig. 15 Gini index expressing income inequality distribution

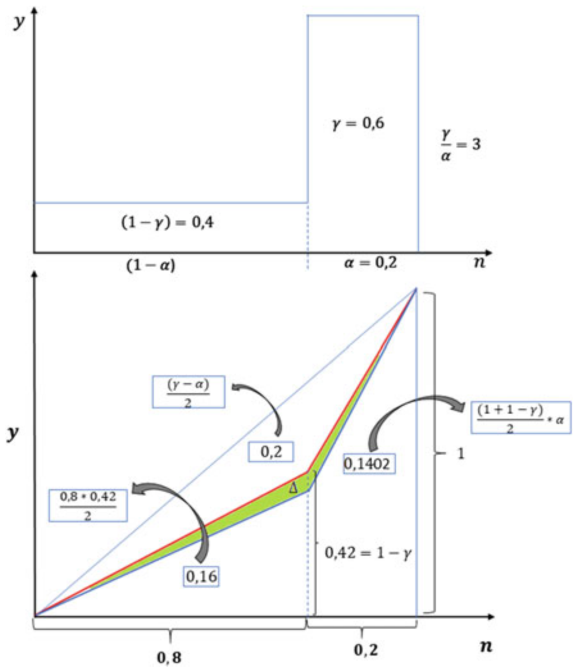


Fig. 16 Simplified Gini index calculation

electric bill, now they will spend $X - \Delta X$. In addition to the possibility of having more access to electricity and all the conveniences it provides. Then, it can be said that there was a relative transfer of income from the richest to the poorest, and this indicates a reduction in the inequality. For this study, the distribution of income was based on (IBGE 2017) and it was assumed that only 10% (Okushima 2017) of their income was spent on electricity bills.

7.3 Impacts of Social Benefit on Consumer Behavior

Applying a subsidized rate for a group of consumers can generate a change in consumer behavior. The first expected behavior change is an increase in consumption by the beneficiary group. The reduction in rate allows the consumer to increase their energy consumption and thus also increase the utility obtained by the electrical system. As the consumer is a maximizer of his utility and is restricted by his disposable income (mainly low-income consumers), a portion of the income made available through the tariff reduction can also go to the consumption of other goods. This diversion of income for the consumption of other goods can be beneficial for the consumer and for the other sectors of the economy that receive this extra income, but it can be problematic for the electricity sector if it is not properly balanced by other gains.

Because it typically has a discrete limit (the incentive applies to consumers with up to X kWh/month of consumption), some different behaviors can happen in the vicinity of the incentive limit. Consumers who are close to the limit and receive the incentive can make an effort not to increase consumption so that they do not run the risk of leaving the group receiving the benefit. This makes the income released as a result of the incentive go directly to the consumption of other goods. Consumers with consumption slightly above the incentive limit may feel compelled to save energy in order to benefit from the incentive. This reduction in sales in the vicinity of the incentive limit must be assessed so that the cost transferred to other consumers is not too high.

Some consumers who are close to the incentive threshold may find it difficult to reduce their consumption until they are below the incentive threshold. However, being able to enter the incentive range, the return of an energy theft is greater, being able to overcome what is necessary for the latter to make the decision to steal energy. Considering only the rational factors of the decision to steal energy, it is possible to make an assessment of how this benefit can impact the decision of the consumer to steal energy.

8 Non-technical Losses, Cultural, Economics, and Governance Issues

Non-technical losses are a recurring problem in countries with high social inequality, as energy theft is likely to affect the power distribution company and the market as a whole. Thus, it is particularly important to adapt the TAROT model presented in Sect. 2 to the context of energy theft.

8.1 Characterization of Energy Theft

In an electrical system, not all the energy generated can reach the consumer. This difference between the energy injected into the system and the invoiced energy is called globally loss (ANEEL 2018). This loss occurs for different reasons. If it occurs due to the means necessary for the distribution system (such as by the Joule effect on the conductors or by hysteresis in the core of the transformers), this loss is called a technical loss (ANEEL 2015a). If these losses occur due to collection failures, defaults, or energy diversion, these losses are called non-technical losses. Non-technical losses can have several reasons (Smith 2004) and it is necessary to understand whether or not this loss is a consensus of society.

One difficulty with a more objective approach to non-technical losses is that this is not a quantity that can be directly measured. The overall loss is measured as the difference between the energy injected into the system and the energy billed. The injected energy can be measured from meters installed at the borders of the system. Distributed generation makes it difficult to manage the measurement of the injected energy by increasing the number of reading points required, but the automated measurement infrastructure (AMI) compensates for this extra work. Technical losses are estimated in terms of the energy that passes through the network elements. It is not a simple procedure, because although the loss behavior in the network elements is well known, some plots are nonlinear (such as the losses due to the joule effect on the conductors). Furthermore, the power that passes through each element of the network is not known at all times. So the estimate of technical losses is a sum of estimates (which are random variables). As the technical loss is the sum of several independent random variables (or with little dependence), it turns out that the total sum converges to a result with a standard deviation less than the sum of the standard deviations (central limit theorem). So the estimate of technical loss is well-accepted within the electricity sector. Non-technical loss is defined as the difference between a measured quantity (total loss) and an estimated quantity (technical loss). This non-technical loss characteristic makes an effort to modify the technical loss estimate and reduce the non-technical loss (Anicio et al. 2009; Madrigal et al. 2017; Porto 2010; Vilela 2004).

Understanding the consumer reasons to steal energy is of no consensus. A more direct approach is that consumers steal energy because they do not have the money to pay the bill. So poverty is a key factor in the decision to steal energy (de Araujo et al. 2004). Non-technical loss data is treated as sensitive information by the distributors, which makes it difficult to make more emphatic statements, but information on technical losses by customer groups (residential, commercial, and industrial) indicates that industrial and commercial consumers (who should not have the same problem of low-income consumers) also steal energy.

In order to better plan the actions to combat theft, the energy theft mechanisms are classified (Brazil 1940). The energy diversion is when the consumer is directly connected to the distribution network without going through a meter and the supply contract is not by estimate. Measurement fraud occurs when the meter is manipulated so that the reading is less than the actual consumption. The two ways of stealing energy are different for different reasons. The diversion of energy is simpler to implement and generally of lower cost to implement. Measurement fraud, on the other hand, requires more knowledge and tends to have a higher cost. The law also treats differently the two cases. The penalty for deviation is less than that for fraud. But in terms of impact for the distributor and other consumers, the difference is very small, because it is caused mainly by the non-revenue of energy.

8.2 Actors Involved

The issue of energy theft goes far beyond the relationship between consumers and distributor. There are other actors who are impacted by this issue and who influence the distributor's decisions. The actors most directly affected are:

- Consumers
- Theft installers
- Managers
- Generators
- Administration
- Investors
- Lenders.

Each of these actors has a different goal. Figure 17 shows the different actors with their questions of interest. Keep in mind that these differences exist and what each actor's goals are can help to understand each other's position when discussing at the negotiating table.

8.3 The Decision to Steal Electricity

Understanding the real motivations of consumers for stealing energy is a complex task. Several factors can influence this decision.

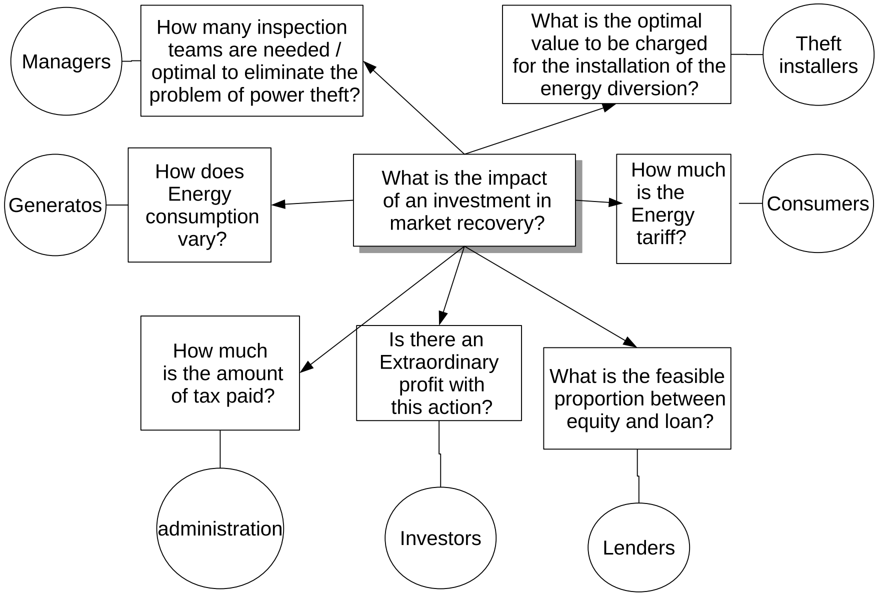


Fig. 17 Actors related to NTL and their objectives

One of the lines is to consider cultural factors (de Araujo et al. 2004; Parente and Pinho 2008). The cultural approach attempts to identify common characteristics among consumers who steal energy. This approach is not deterministic because even consumers with a stealing energy profile do not necessarily steal, nor does it indicate a line of action to address the energy stealing problem.

Another approach is to identify which consumers steal energy from their energy consumption behavior (Leite and Mantovani 2018; Sánchez-Zuleta et al. 2017). This approach employs different techniques to identify consumers most likely to steal energy. From this, a priority is given to the consumers to be inspected.

A third approach is to try to model the consumer decision-making process based on rational behavior and communication with neighbors (Deccache 2019). This line of investigation is able to assess the effect of the distributor's market recovery actions and assess how non-technical losses evolve.

8.4 Impacts on Society

8.4.1 Power Supply Quality

Increased electricity consumption due to energy theft impacts neighboring consumers due to increased technical losses (Arango et al. 2016). As the distributor is obliged to maintain quality standards of energy supply it may be required to make investments to increase the power supply capacity of the grid because of a consumption for which it is not remunerated.

On the economic side, non-technical losses create other problems. By operating in a regulated market the distributor passes on, at least in part, the damage caused by consumers stealing energy to other consumers (Arango et al. 2017). This redistribution of energy costs provides some distortions such as:

- It overcharge the regular consumer.
- Creates an undue competitive advantage for the theft consumer.
- Artificially increases energy demand, which opens up new business opportunities for power generators.
- Creates a black market for theft installation.

Some of these impacts can be better evaluated when a simulation of the energy market is made to evaluate the performance of each actor (Deccache 2019). With simulations, it is possible to vary several parameters to understand what is happening to each actor. One of the parameters that is difficult to vary because of the little experience that there is in varying it is the amount of inspections that the distributor does monthly.

8.4.2 Concentration of Energy Consumption

To assess how the imbalance of opportunities between consumers who steal and those who do not steal impacts society can be used the Gini index on the energy consumption of a certain market. Observing the Gini index on a monthly basis it is possible to observe how the phenomena of a distributor impact on the distribution of energy consumption.

For the comparison to be more direct, a simulated market was observed (Deccache 2019). In this way, it is possible to compare two initially identical markets which differ only by the number of inspections carried out monthly. Both markets have 100 consumers, inflation of 5% per year, same energy value purchased by the distributor, taxes, etc. The difference is that in one market 4 inspections are carried out per month (Fig. 18) and in the other are 20 inspections per month (Fig. 19). For both markets, rents were simultaneously adjusted annually for inflation. This causes the income dispersion to be constant over time for the two simulations. In this case, the Gini index for consumer income was 0.13408.

The difference in the evolution of the Gini index in both cases is observable. In the case of 4 inspections per month, the Gini index reaches close to 1 at the end of the 120-month period. In the case of 20 inspections per month, the Gini index stood at about 0.7 at the end of the 120-month period. Tariff revisions occur every 48 months from the 6th month. These moments present a sudden variation in the distribution of energy consumption because the energy rate may vary in a way not equal to other products, but according to the very variation of costs in the electricity sector. Moreover, in the simulation, the demand is in a form that represents competition between electricity and other goods (Deccache 2019), but one in which consumption is limited by the disposable income for the consumption of all goods.

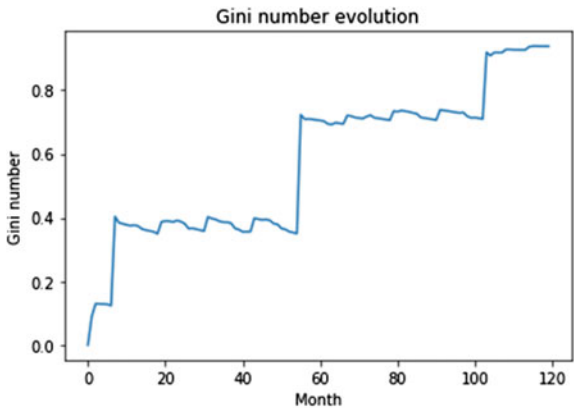


Fig. 18 Evolution of the Gini index in the simulated market with 4 inspections per month

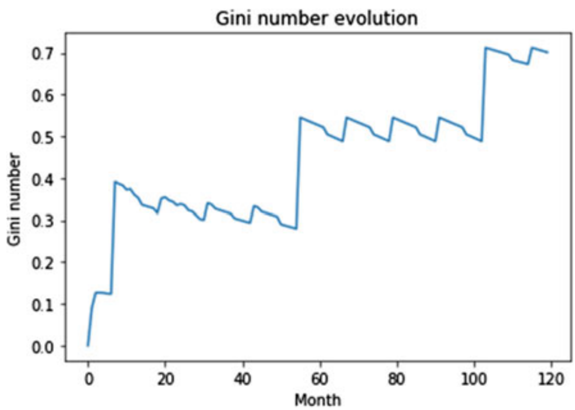


Fig. 19 Evolution of the Gini index in the simulated market with 20 inspections per month

Rate revisions (ANEEL 2019) are special moments of the effect of increases in inequality in the distribution of energy consumption because the increase in the price of energy does not accompany the increase in other goods, but follows a logic of its own. And when there is an increase in energy theft the tariff increase is greater. Because of the increase in the tariff, the concentration of consumption is even higher.

9 Conclusions

Under the assumptions that the main goal of a regulatory agency is the optimization of the socioeconomic welfare added to society by the electricity sector, developing a regulatory, economic market model of such market is fundamental. Then, it becomes possible to: evaluate the economic flows among the market agents; calculate the optimal capital investment's, minimal costs, and optimal tariffs yet preserving the capital yield to investors; simulate actions using agent-based models to reduce energy and financial losses due to energy theft; identify the most effective public policies to reduce energy poverty and inequalities and their impacts on the Gini index, and more. A stochastic regulatory economic model of the smart electricity market can predict returns and risks to a more fare, free, and sustainable society.

Therefore, this chapter presented the Optimized Tariff Model (TAROT®) in the context of smart renewable electricity markets and relevant philosophical discussions regarding broad electricity access, social justice, and cultural issues. As demonstrated, the TAROT® model is extremely flexible since it can be applied under several circumstances (risk assessment, public policies, energy poverty, and non-technical losses). Hence, the TAROT® model is a valuable tool for analyzing the electricity market holistically.

However, there is still no definitive answer regarding smart electricity markets, since it is an extremely complex topic. Efforts should focus on how to make present markets smarter rather than attempting to propose an ideal democratic market in such an early stage. In conclusion, more work is required to further develop the concept of smart markets, and such work must assess environmental, economic, social, political, and philosophical aspects holistically.

The contents of this book may help one to take decisions discussed in Chapters 'Industrial Innovation Practices Breakthrough by Process Intensification', 'The Socio-economic Implications of the Coronavirus Pandemic: A Brazilian Electric Sector Analysis', 'The Need of Normative Technologies for Smart Living Cities' and 'Amazon Region Power Plants and Social Impacts', when the economic impacts of decisions are necessary. Note, however, that the concepts of social inclusion discussed here enables one to better understand Chapter 'The Engineer in the Face of Social Changes: The Cases of Health and Sustainability at Work', since the good health of workers may bring some economic consequences to people and companies in general. Social modeling of Chapter 'A Multi-aspect Dynamic System Model to Assess Poverty Traps' is strongly linked to this chapter and the benefits of providing electricity with quality to people, as discussed in Chapter 'Microgrid Operation and the Social Impact of its Deployment', may change their consumption profile, creating new habits, and positively impacting the economy.

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Statistics and Engineering

Pedro Paulo Balestrassi and Estevão Luiz Romão

Keywords Statistical engineering · Cause and effect · Variability reduction · Statistical thinking

1 Introduction

The use of statistical tools and statistical thinking in decision making is fundamental to the practice of engineering, in most areas. The recently coined term, *Statistical Engineering*, has shown that an engineer, in its two main functions of (i) improving processes or products and (ii) developing new processes or products, depends on data analysis, experimental planning, and many tools related to the natural variability of processes and products and the presence of a large number of variables and models.

This chapter seeks to synthesize the statistical engineering approach and the possible social implications of this knowledge. Furthermore, this chapter is intimately related to other chapters, for instance, in Chapter 'Key Concepts For Frameworks: Values, Aspects Normativity and Enkaptic Structures' where the authors discuss about the responsibility of the engineer from a technological control point of view, showing that control has its own normativity, in a context of transition to the energy infrastructure of the future. The Triple I model depicts coherent strategies to ensure this transition. Then, technological control can be considered a sine qua non, in view of the important role of technology in modern society. From this perspective, a moral responsibility of the engineer must also be considered, and complying with

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both economic and moral norms is crucial. In addition, Chapter 'Towards a Holistic Normative Design' mentions some relevant concepts as it calls attention to the normative of controlling processes, highlighting the importance of holistic design process in a context of power generation that is also encompassed in the present chapter.

1.1 Decision in the Presence of Variability

Statistics is a science that helps us make decisions and draw conclusions in the presence of variability. Related to variability are numerous terms and concepts: fluctuation, uncertainty, volatility, changeability, inconsistency, irregularity, mutability, oscillation, transience, unpredictability, irregularity, variation, risk, probability, unsteadiness, unfixedness, etc. These terms are closely related to complex decisions. The Nobel Prize in economics, Daniel Kanheman, in his famous "Thinking Fast and Slow" book, was precise in saying that humans are not very good at decision making in the presence of variability.

One simple example where a manager acts in the presence of variability in a typical industrial world is depicted in the following time series plots. The manager here wants to control the in-process inventory at the lowest possible level. In April 2019, he was extremely happy with the obtained results of 15, a record for the last three years. The manager delivers an award to his department in view of the achievements with a ceremony at the company cafeteria with pizza and refreshments for everyone. He says everyone should be proud of such an achievement (Fig. 1).

In July, after three consecutive months of inventory increase, the manager would like to be able to withdraw the prize. He says: "The recognition seems to have given no result. Instead of keeping the gain, the department seems to have become complacent, allowing inventory to return to its original position (Fig. 2).

In November, the in-process inventory reaches 26! The manager decides to fire some employees, and he takes note of some names. "This group needs a tough manager. No more Mr. Nice Guy!". He talks to everyone and demands that something

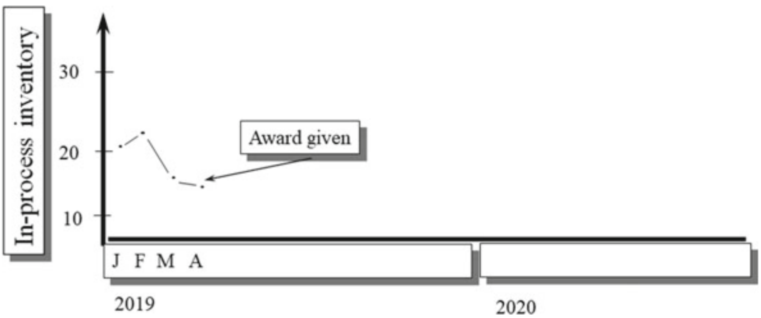

Fig. 1 Time series plot for an in-process control inventory. A case of success!

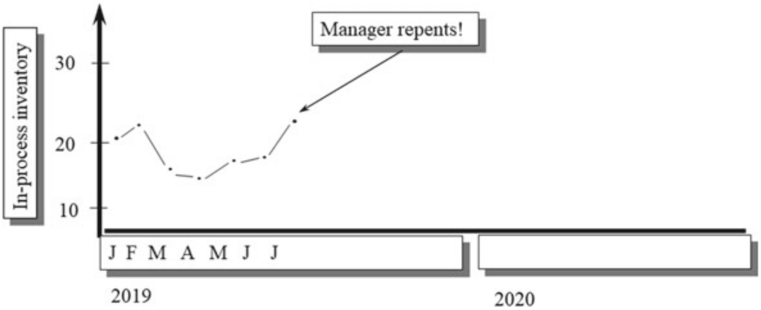

Fig. 2 Case of success is now in check

needs to be done to keep inventory levels down. After this reaction, all proceed cautiously. Some begin to hide material in dark corners in the factory. No one knows what to do. Everyone waits in hope that inventory will fall (Fig. 3).

In June 2020, the manager concludes that things are getting better. He notices a reduced inventory since the end of last year. What he learned (since little was done to change the system) is that tough management works (Fig. 4).

Not knowing how to interpret variation is one of the most common problems in all production processes. The manager here, in the presence of variability, makes the classical mistake of interpreting some high and low points as indicators of the state of the process. He does not comprehend that typical causes of variation are present in the process and do not know how to minimize it. This is a very common error in many fields. The systematic purchase of materials with low quality, the lack of training, and the lack of standardization of operations are, among many other factors, likely to generate variability in the process. To solve a problem like this, the manager should use scientific methods and adequate tools.

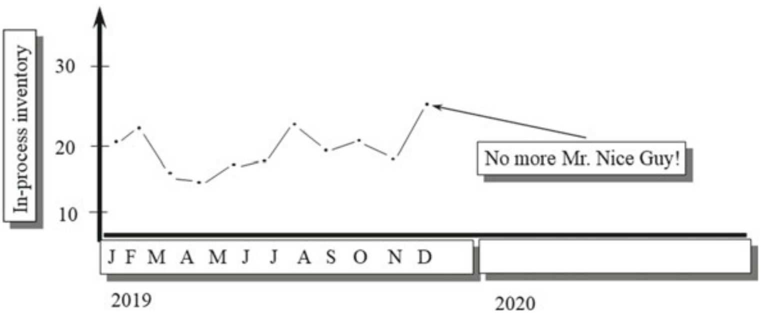

Fig. 3 Case of unsuccess!

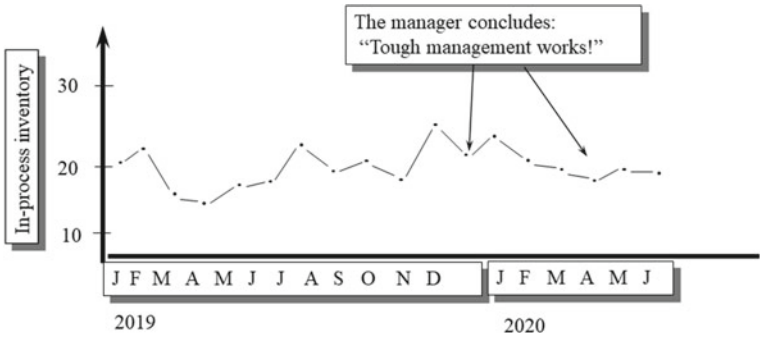

Fig. 4 Graphical history of bad management

1.2 Statistics and Concepts

Statistical thinking is a concept that has been discussed in the literature as principles and concepts disseminated in companies to conduct a statistical approach, and it is often associated with using continuous improvement programs, such as Six Sigma and Lean Six Sigma, since the 1990s (Lisarelli et al., 2020). Currently, statistical tools are available to professionals through just a few mouse clicks. A simple example: Suppose that a manufacturing process has a production loss of around 10% and that an engineer has made a modification to the process to improve it. He then collects 100 pieces and finds only 5 defectives, that is, 5% defective. Can it be said that the process has improved?

With just had a simple command in the popular Minitab software (widely used in companies around the world (Hoerl & Snee, 2010)) he gets the following screen of results of a hypothesis test of two proportions and concludes that the change from 10 to 5% does not represent a statistically significant improvement due to the high values of P_value above a level of significance (usually 5%). These calculations would take a long time to be computed manually. Another conclusion is that the sample is not significant to establish this difference. So, he gets a sample of a thousand pieces and finds 50 of them defective. In this second case, the new hypothesis test reveals a significant difference, where the P-Value is zero. Figure 5 shows the results of the two hypothesis tests.

Tools like these are abundant in most statistical computer programs and greatly assist professionals in all areas of decision making. What was once a specific resource for academics and researchers is now available to everyone. There is also an abundant source of videos, podcasts, etc., that assist in its use.

Figure 6 depicts some statistical tools that can be applied in various engineering problems and are present in most statistical packages. Part A presents different ways to graph the observations that one might have. Through this analysis, it is possible to understand the behavior of the data and pursue future analysis. The hypothesis tests presented in Part B are commonly used, for instance, in an industrial context when a

Test and CI for Two Proportions

Method

p_1: proportion where Sample 1 = Event
p_2: proportion where Sample 2 = Event
Difference: $p_1 - p_2$

Descriptive Statistics

Sample	N	Event	Sample p
Sample 1	100	10	0,100000
Sample 2	100	5	0,050000

Estimation for Difference

Difference	95% CI for Difference
0,05	(-0,022677; 0,122677)

CI based on normal approximation

Test

Null hypothesis H_0: $p_1 - p_2 = 0$
Alternative hypothesis H_1: $p_1 - p_2 \neq 0$

Method	Z-Value	P-Value
Normal approximation	1,35	0,178
Fisher's exact		0,283

Test and CI for Two Proportions

Method

p_1: proportion where Sample 1 = Event
p_2: proportion where Sample 2 = Event
Difference: $p_1 - p_2$

Descriptive Statistics

Sample	N	Event	Sample p
Sample 1	1000	100	0,100000
Sample 2	1000	50	0,050000

Estimation for Difference

Difference	95% CI for Difference
0,05	(0,027017; 0,072983)

CI based on normal approximation

Test

Null hypothesis H_0: $p_1 - p_2 = 0$
Alternative hypothesis H_1: $p_1 - p_2 \neq 0$

Method	Z-Value	P-Value
Normal approximation	4,26	0,000
Fisher's exact		0,000

Fig. 5 Minitab session analysis of a hypothesis test with P_Value

team of workers takes actions to improve certain processes and the manager wants to know whether the actions were effective. Capability analysis, in Part C, is performed to determine how well the process can reach customer requirements as previously exemplified in the manager in-process inventory example. Regression techniques, in Part D, are very useful when data are available and practitioners cannot interfere in the process parameters. In many cases, regression provides a good model for the process output and it may also be useful to make predictions. On the other hand, when existing the possibility to make purposeful changes in the process inputs, it is recommended to carry out designed experiments applying the techniques in Part E.

When the data are collected over time, techniques such as control charts, in Part F, can be used to identify whether the process is under statistical control or not. Moreover, time series modeling techniques, in Part G, are applied to describe the behavior of the data over time and to make predictions. Some considerations about seasonality and trend must be made before choosing the best model for the data.

The abundance of resources can create confusion. See for example the two graphs below trying to describe the same data. The Pie Chart, despite being appealing, is colorful, confusing, and impractical to conclude something. The second graph is simple and says what needs to be said. The site https://www.kaiserfung.com, where this example was taken, has tons of similar examples (Figs. 7 and 8).

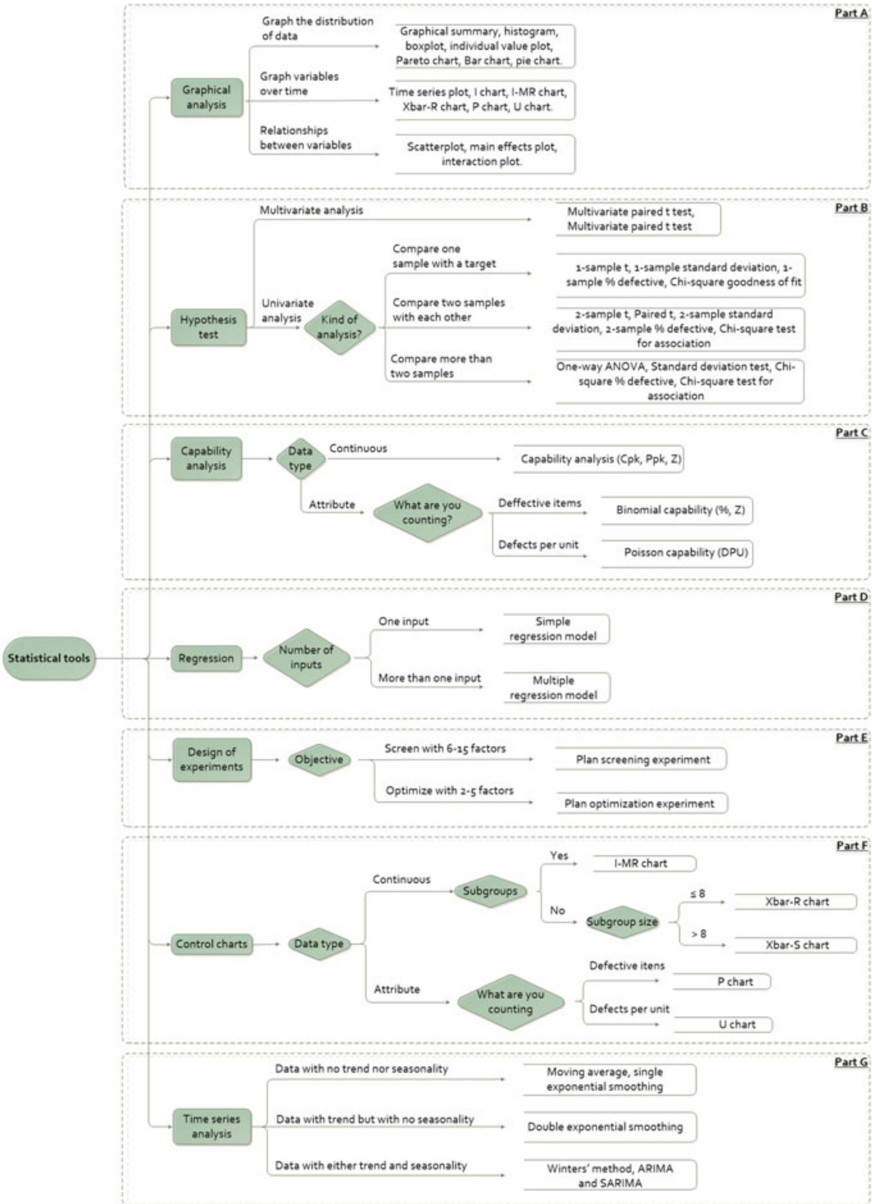

Fig. 6 Statistical tools

Fig. 7 Example of graphical output using a colorful pie chart

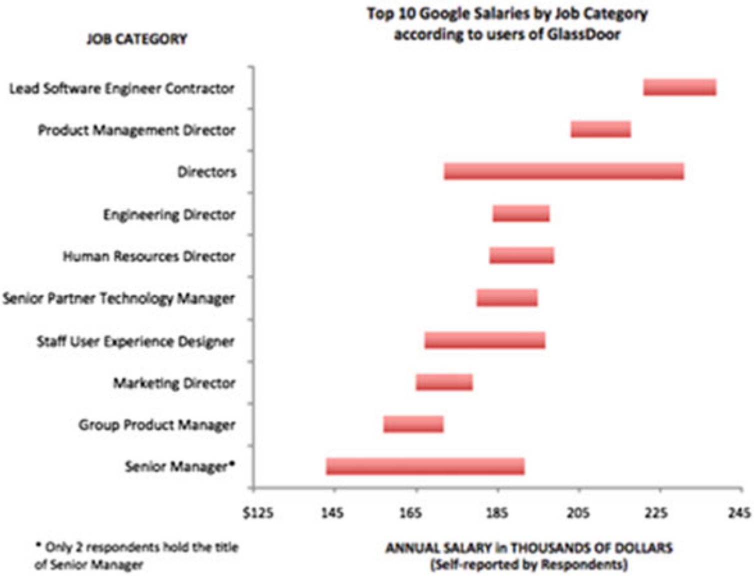

Fig. 8 Example of better graphical output from the previous example

1.3 Statistical Engineering

An engineer is someone who solves problems of interest to society by the efficient application of scientific principles. *Engineers accomplish this either by refining an existing product or process or by designing a new product or process that meets customers' needs.* The engineering, or scientific, method is the approach to formulating and solving these problems.

The engineering method features a strong interplay among the problem, the factors that may influence its solution, a model of the phenomenon, and experimentation to verify the adequacy of the model, and the proposed solution to the problem. Consequently, engineers must know how to efficiently plan experiments, collect data, analyze, and interpret the data, and understand how the observed data are related to the model they have proposed for the problem under study.

The concept of statistical engineering appears in a context where it is necessary to identify how to best use statistical concepts, methods, and tools, integrating them with relevant disciplines, including information technology, in order to obtain improved results. It means that instead of focusing on advancing fundamental science laws, it is mainly concerned with how to utilize them aiming to reach practical benefits (Hoerl & Snee, 2010).

Nevertheless, it is important to distinguish statistical engineering from applied statistics and theoretical statistics, since both of them are parts of statistical engineering. Moreover, in statistical engineering, a whole system, which is more than the sum of the parts, is created, and a good example of statistical engineering is the Lean Six Sigma (LSS) methodology (Scinto, 2011).

Statistical engineering may be understood as a discipline aiming to drive greater practical improvement from statistical theory. Therefore, there must be a strong connection between statistical theory and statistical practice, as shown in Fig. 9.

Scinto (2011) presents some items to verify whether an activity falls under the concept of statistical engineering or not: (i) meets high level of an organization; (ii) work/study for the greater good; (iii) use of statistical concepts and tools; (iv) collaborative effort with other sciences; (v) integrated with other sciences; (vi) documented protocol; (vii) activity continuous with sustainable life; (viii) improved results. However, not all the items need to be presented in one single activity, but presenting them is useful to elucidate the concepts of statistical engineering.

A problem which requires a statistical engineering solution has a high degree of complexity. Technical and nontechnical challenges must be considered, since the problem represents a high-level need of the organization. The solution for it is still unknown, but when it has been solved, the same procedure can be leveraged to similar problems elsewhere (Snee & Hoerl, 2010). For instance, a statistical engineering approach was applied in a problem involving variability reduction aiming to increase manufacturing productivity (Schall, 2012). The author explains that the developed methodology could also be extended into other parts of the company such as logistics, customer service, and finance operations.

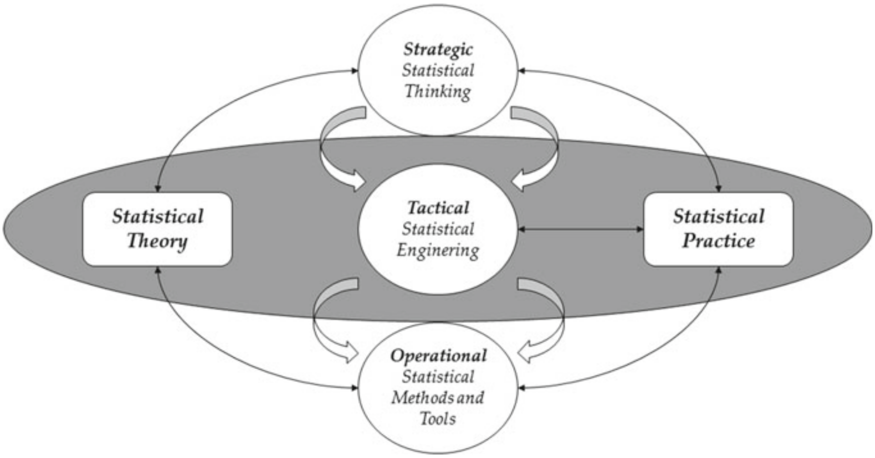

Fig. 9 Statistical engineering in the context of statistics discipline adapted from (Snee & Hoerl, 2010)

Another relevant aspect of this topic is the importance of leadership to the success of an organization when using statistical engineering to solve complex and unstructured problems. As mentioned in (Snee & Hoerl, 2012), enhanced leadership skills are important in this context, since significant changes are implemented in the company. Moreover, statisticians and quality professionals have a greater impact on the company when they become strong leaders, also helping the reputation of their professions.

Hence, statistical engineering is a way for statisticians and engineers to produce results that they would never have produced singly or without applying statistical methods and statistical thinking (Hare, 2012).

Consider an example where the thickness of a metal part is an important parameter of quality for a company. Parts are produced continuously during the day. In the past, one engineer suggested that for each hour five parts should be inspected and put in a table, as shown in Fig. 10. The engineer left the company but the procedure has continued. A new engineer was hired, and he is asked to check the data on the table to respond to two main questions: (i) Is the process under control? Do the parts meet the client's specification? Immediately the new engineer realizes that just looking at the numbers as it is, it will be extremely complex to see some patterns in the data.

The first ideas are generally to compute some basic statistics like mean and standard deviation and plot some graphs, as in Fig. 11.

In these graphs, the mean and the standard deviation are plotted in a control chart and some control lines indicate that the process is under control. The first graph shows the variation of means along the day and the second graph the standard deviation. This simple idea of controlling the process was developed by Shewhart in 1924, and it is still relevant in the present days. An indicative of the out of control would be

	x1	x2	x3	x4	x5
1	0,0653831	0,0625766	0,0599464	0,0606617	0,0584120
2	0,0599487	0,0607271	0,0649285	0,0664641	0,0575935
3	0,0600097	0,0660410	0,0658346	0,0634289	0,0562083
4	0,0610816	0,0629744	0,0631675	0,0607705	0,0630259
5	0,0592186	0,0667025	0,0637761	0,0633521	0,0608858
6	0,0623355	0,0653792	0,0583681	0,0639481	0,0635011
7	0,0651071	0,0608500	0,0633819	0,0657101	0,0638186
8	0,0647682	0,0602126	0,0621196	0,0640625	0,0620575
9	0,0642601	0,0677436	0,0623629	0,0654706	0,0628174
10	0,0638378	0,0616585	0,0627352	0,0633092	0,0665288
11	0,0594095	0,0634129	0,0630928	0,0620714	0,0590266
12	0,0620712	0,0616334	0,0668799	0,0642109	0,0622513
13	0,0606462	0,0701766	0,0687894	0,0646402	0,0615405
14	0,0643669	0,0648384	0,0646254	0,0628685	0,0599025
15	0,0625701	0,0609542	0,0643833	0,0649941	0,0579872
16	0,0624939	0,0609021	0,0638271	0,0611223	0,0626520
17	0,0624381	0,0598948	0,0596671	0,0610823	0,0620102
18	0,0610827	0,0653447	0,0639946	0,0628698	0,0628430
19	0,0567423	0,0628061	0,0609729	0,0644117	0,0657474
20	0,0644298	0,0647190	0,0641582	0,0640028	0,0635899
21	0,0622056	0,0594741	0,0631619	0,0639504	0,0615529
22	0,0621588	0,0673611	0,0642042	0,0653118	0,0653660
23	0,0647934	0,0637153	0,0622381	0,0659411	0,0628547
24	0,0627936	0,0604551	0,0600925	0,0652968	0,0622902

Fig. 10 Data collection of a parameter process. Each hour a subgroup of five parts is collected

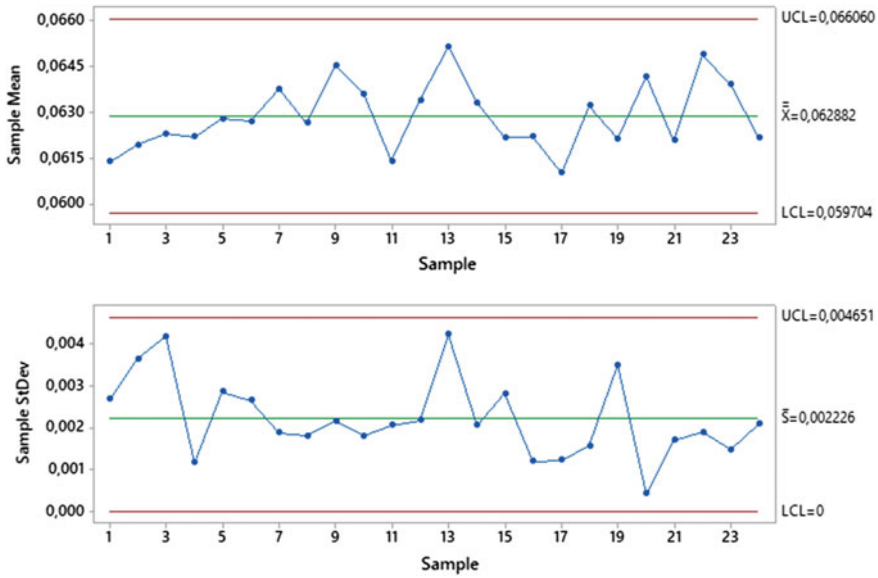

Fig. 11 Statistical control charts for the process

a point outside the control lines or a non-random pattern of points inside the lines. This is called statistical process control.

To see if the process attends the client specification, the new engineer checks the desired tolerance defined by the client between the values of 0.060″ and 0.066,” and he realizes that the graph of the mean is fine, but in the table, some values are outside the specification limits. This is obvious because the mean presented in the graph contains some values outside the specification limits. How many parts are outside the specification is the natural question to ask. Inspecting the table is not a reliable way to do this so the new engineer plots a new graph that shows the capability of the process in attending the client specification, as in Fig. 12.

In this graph, it is easy to see that the estimated amount of parts out of specification limits is about 22% (or ~21,693 ppm). This represents a huge amount of parts being out of specification!

How to solve such a problem is the next natural question. What about hiding the bad points or to enlarge the specification limits? Bad idea, of course. This is for someone incompetent to find the solution. Inspecting the graph, it is easy to see that the statistical solution is to decrease the variability of the process by making the normal curve between the specification lines. Variability is the problem!

The new engineer needs to improve the process by reducing the variability. But how to do that? What is the practical solution?

One modern way to do that is to have a scientific method to explore cause and effect. The Six Sigma methodology has been used for most of the top companies in the world as a way to do this (Vinod et al., 2015). From the middle of the 1980s, the Six

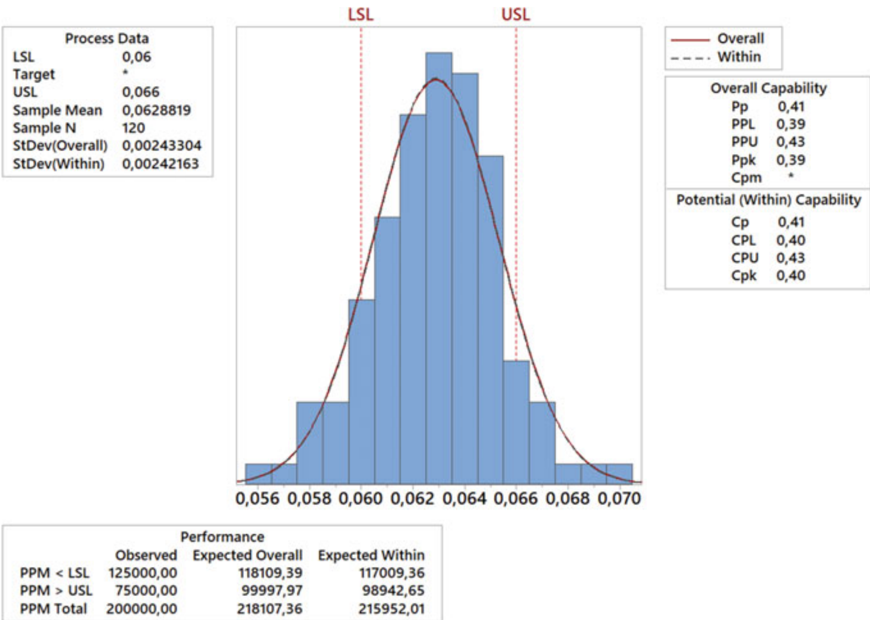

Fig. 12 Capability analysis of the process

Sigma concept emerged in Motorola. Because Six Sigma implementation facilitated the companies to achieve profitability, it was implemented subsequently in many parts of the world. Six Sigma is implemented by the majority of the companies situated in the world by applying DMAIC (stands for define, measure, analyze, improve and control) phases. Figure 13 presents a DMAIC roadmap that lots of companies employ as a systematic way to solve engineering problems such as the presented one. The main idea of the roadmap is to transform the engineering problem into a statistical problem. With convenient tools, the statistical problem delivers a practical solution using scientific principles. In case the process is unable to improve, a Design for Six Sigma (DFSS) approach, as depicted by Fig. 14, can be used to create a new process or product.

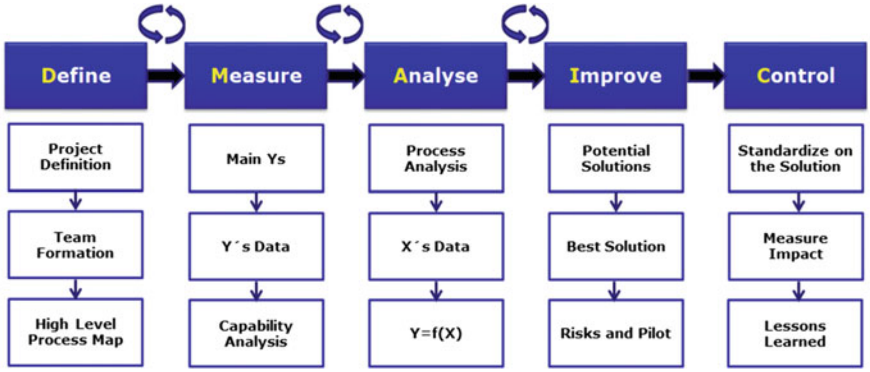

Fig. 13 Six Sigma DMAIC roadmap for process improvement

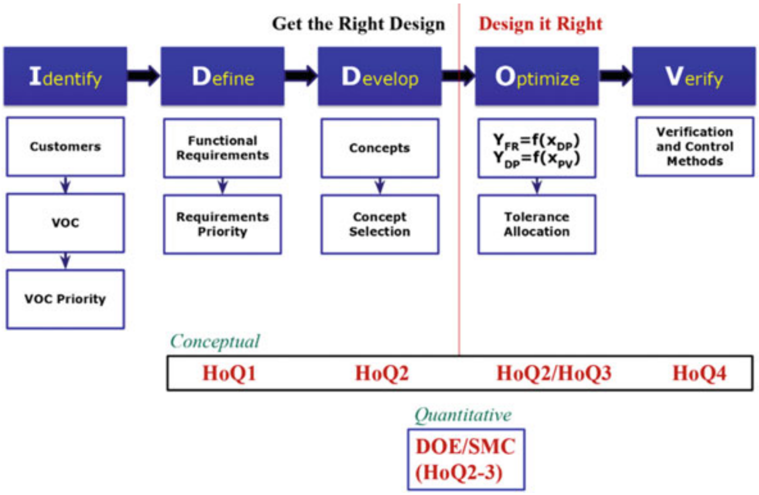

Fig. 14 Design for Six Sigma IDDOV roadmap for new process development

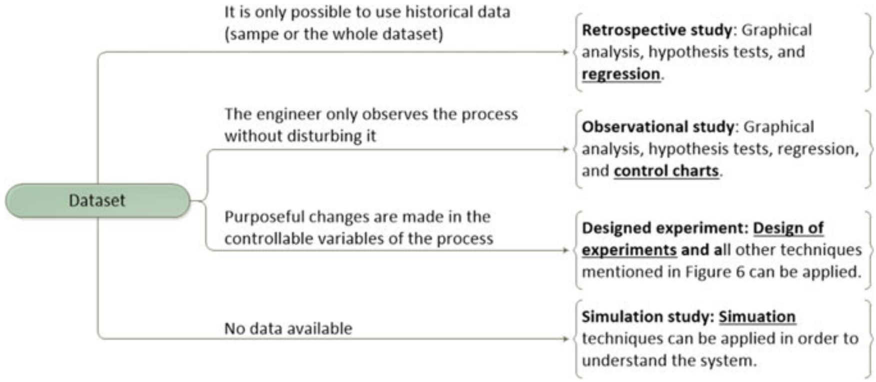

Fig. 15 Guideline to four types of studies based on the dataset features

In order to summarize the possible techniques that can be used in different types of datasets, Fig. 15 depicts four distinct strategies to be applied according to the nature of the data. When only past data are available, it is recommended, among others, to apply regression techniques, which characterizes a retrospective study. An observational study is developed when data can be collected in real time. In this case, control charts and regression are conveniently applied. Designed experiments should be performed when the experimenter can make purposeful changes in the inputs to observe the effect of these changes in the process outputs. Finally, when no data are available, it is still possible to simulate a dataset considering the range of possibilities in which the process may occur and draw conclusions from a simulation study.

2 Cause and Effect

Conducting an experimental process correctly is something that engineers, managers, administrators, technicians from the most different areas, and people with common sense generally think they know how to do, but the vast majority truly do not know. Let us look at a typical case.

A biomedical researcher wants to discover the effect of several factors that can increase brain electrical activity in rats. Sensors are placed on the rat's scalp, and an electroencephalography device records the electrical voltage in its brain. The researcher first realizes that in a normal condition, without changing the factors, the electrical activity behaves in a certain way and intensity. Then, it varies one of the factors, for example, introducing visual stimuli and observing the new response of electrical activity. New factors are now being modified, for example, by injecting a stimulating drug that can even kill the rat (destructive test), and again the response is analyzed. This method of varying the factors and observing the response happens repeatedly until the experimental conclusion is reached. Finally, statistics are presented, mainly using graphical methods and a conclusion can be reached; such as, light stimuli causes an increase in electrical activity in rats.

This could be a great contribution, if, for example, the same conclusion could be extended to human beings and aid in the discovery of new epileptic drugs or solutions that would improve our quality of life. That way, unfortunately, certain people would be banned from nightclubs with strobe lights and would also be banned from driving at night where the headlights of other cars could cause undesirable effects. Pharmaceutical companies could make a lot of money selling a new drug that would alleviate epileptic effects and an unfolding of facts would follow from that. The experimental mouse would be an achievement for science.

Despite the spectacular results and the fantastic development of the facts, in the mind of the initial researcher, some doubts could still exist: Could other factors not considered in the experiment also increase the electrical activity in the same way as the luminous effect? Could a combined effect of several other factors also increase electrical activity? Was the number of rats sufficient for the conclusions? Was this generalization to humans done correctly? Was the electroencephalography equipment working correctly, due to some *strange* results? Did … well, never mind! The important thing is that it is working in most cases (*or not?*).

In the medical field, some absolute truths are often conveyed and even radically change a society. Remember that coffee was the great enemy of all human beings and everyone felt guilty about delighting it during breaks from any job or event. Now, in an important work published in the Journal of Alzheimer's Disease, coffee is associated with a decrease in degenerative diseases such as Parkinson's and Alzheimer's (Eskelinen & Kivipelto, 2010). For those fearful of this disease, the advice now is: have coffee but without sugar. It is also important that it is taken 15 min after boiling. How about the abominable meat? In Dr. Atkins' diet or South Beach´s diet, fat people have an answer to their discomfort that in a way banishes carbohydrates and does not leave the meat in bad shape. Unfortunately, the export of oranges in many countries, rich in carbohydrates, suffered a huge drop in the American market.

The objective here is not to make any apology for tobacco, coffee or meat. The point to note is that the relationship between cause and effect is not at all easy to investigate even for the most brilliant minds. How to determine that the coffee after 15 min of boiling and without sugar will have the desired effect in the long run? How do you know if sugar is the villain in the story? Normally, our common sense has a tendency, and goes easy, to assess a one-to-one cause and effect relationship. Example: Mango with milk is bad, if you do not go to mass every Sunday you go to hell, etc.

In a company, the cause and effect relationship is not very different either. Generally, an empirical cause is always sought for any error or problem that may exist. Typical examples are: the increase in the number of invoices issued is the factor that most affects our loss of quality with the customer. The lack of training is what impacts our production. Removal problems are always caused by a repetitive strain injury. The intern is to blame for the delay…

Figures 16 and 17 show two types of strategies that researchers often use to conduct an experimental study. Here, the objective is to have a result Y that is the highest possible value where seven binary X variables (represented by $-$ and $+$) are considered. In Fig. 16, in a first experiment, all variables X are fixed at level, and the answer Y $= 2.1$ is obtained. Such an experiment serves as the basis for the next experiment, varying X1 to level+, obtaining an improvement in the value of Y to 2.6. X1 is then fixed+, and variable X2 is then changed to a positive level. As the answer Y $= 2.4$ represents a result inferior to the previous one, the variable X2 is modified to the previous level of X2 $= -$, and the new variable X3 is then modified. This process is followed until the 7 variables are modified and the last line is supposed to represent an optimal situation in the experimental study. Moreover, Fig. 17 represents a similar study where variables X1–X7 are compared only with the first line, where all values of X are negative and the response Y $= 2.1$. The final result, in the last line, summarizes the levels of X where the answer Y obtained a value higher than the value of the first line.

Both strategies are of the stick-a-winner strategy type and are considered as an example of common sense by researchers. In reality, however, such strategies are

Experiment	X1	X2	X3	X4	X5	X6	X7	Results ⇧
1.	–	–	–	–	–	–	–	2.1
2.	+	–	–	–	–	–	–	2.6
3.	+	+	–	–	–	–	–	2.4
4.	+	–	+	–	–	–	–	2.5
5.	+	–	–	+	–	–	–	2.8
6.	+	–	–	+	+	–	–	2.9
7.	+	–	–	+	+	+	–	2.7
8.	+	–	–	+	+	–	+	3.2
Final	+	–	–	+	+	–	+	

Fig. 16 Stick-a-winner experimental strategy (each result is compared to the previous one)

Experiment	X1	X2	X3	X4	X5	X6	X7	Results ⇧
1.	–	–	–	–	–	–	–	2.1
2.	+	–	–	–	–	–	–	2.5
3.	–	+	–	–	–	–	–	1.9
4.	–	–	+	–	–	–	–	1.9
5.	–	–	–	+	–	–	–	2.2
6.	–	–	–	–	+	–	–	2.3
7.	–	–	–	–	–	+	–	2.5
8.	–	–	–	–	–	–	+	2.3
Final	+	–	–	+	+	+	+	

Fig. 17 Stick-a-winner experimental strategy (each result is compared to the first row)

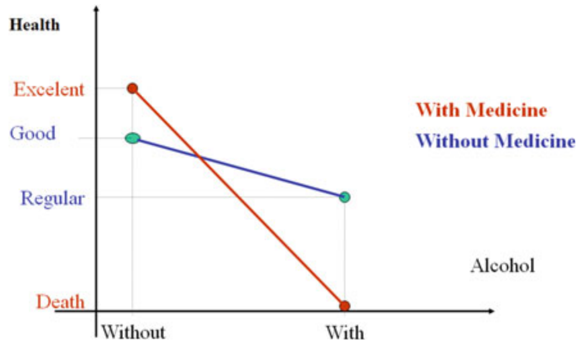

Fig. 18 Interaction plot

just common sense and carry basic errors in terms of statistical reasoning. First, the experiments are not balanced in relation to the adopted levels. The number of negative levels is much higher in both of them. In the second case, for example, all errors in the positive levels in all variables X cannot be estimated because there is only one answer Y. Interaction between two or more variables X is another aspect completely neglected in such strategies. The concept of interaction (usually confused with correlation) is illustrated in Fig. 18.

The effect of alcohol consumption (X1) and medication use (X2) can impact an individual's health (Y). The simultaneous use of alcohol and medicine generates an unexpected effect on the Y response. In the case of non-interaction, the two lines would be parallel. Interactions of an order greater than two, when existing, are difficult to be observed and they escape the eyes of specialists.

The idea of the process, represented in Fig. 19, is essential in engineering. W. Edwards Deming, the great guru of quality control, quotes: "If you can't describe what you are doing as a process, you don't know what you're doing." Here the inputs, coming from different sources are processed and controlled by X variables, under the influence of uncontrollable variables (Z) where multiple outputs (Y) must be simultaneously optimized to meet a particular client.

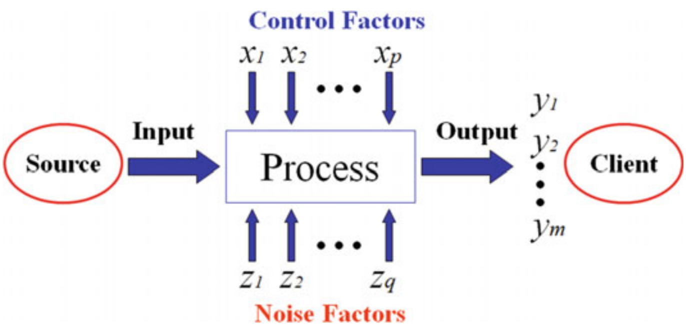

Fig. 19 Variables of a process

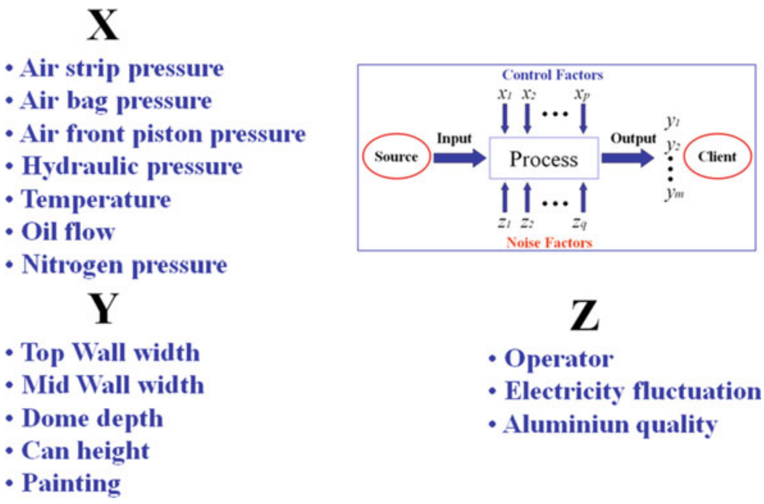

Fig. 20 Variables of the bodymaker process of can making

Establishing a cause and effect relationship in scenarios with many variables is extremely complex without the use of statistical methods. In the example in Fig. 20, the bodymaker manufacturing process has an excessive number of variables to consider.

Some questions could be asked in this context:

- Which factors influence Y the most?
- How to adjust X to get the desired value for Y?
- How to adjust X to achieve minimal variation for Y?
- How to adjust X so that the effect of Z on Y is minimal?

In this multiple, multivariate problem with numerous existing interactions, the knowledge of appropriate statistical methods becomes essential for an engineer to deal with such issues. Design of Experiments (DOE), in this case, presents itself as the natural tool to be used and a range of friendly computer programs are available to assist the researcher. Among many, the following stand out: Minitab, JMP, DOE Kiss for Excel, DOE Wisdom, Q-Edge, SPSS, DOE-PC, Design-Expert/Design Ease, Statistica, Strategy4DOE, Quality Edge, SAS, …

Within Minitab's DOE module, for example, there is a range of experimental designs available (as in Fig. 21), with an extensive library of statistical analysis, which makes the work of Sir Ronald Aylmer Fisher (the great British statistician, considered the creator of DOE) something extremely accessible to today's engineers. The use of computational resources made the calculations easy activities allowing a greater emphasis on understanding and interpreting the results.

Available Factorial Designs (with Resolution)

Run	Factors 2	3	4	5	6	7	8	9	10	11	12	13	14	15
4	Full	III												
8		Full	IV	III	III	III								
16			Full	V	IV	IV	IV	III	III	III	III	III	III	III
32				Full	VI	IV	IV	IV	IV	IV	IV	IV	IV	IV
64					Full	VII	V	IV	IV	IV	IV	IV	IV	IV
128						Full	VIII	VI	V	V	IV	IV	IV	IV

Available Resolution III Plackett-Burman Designs

Factors	Runs	Factors	Runs	Factors	Runs
2-7	12,20,24,28,...,48	20-23	24,28,32,36,...,48	36-39	40,44,48
8-11	12,20,24,28,...,48	24-27	28,32,36,40,44,48	40-43	44,48
12-15	20,24,28,36,...,48	28-31	32,36,40,44,48	44-47	48
16-19	20,24,28,32,...,48	32-35	36,40,44,48		

Fig. 21 Factorial designs guideline from Minitab. The colors and roman letters represent the experimental design resolution. Plackett–Burman screening designs, Taguchi robust designs, response surface methodology and many other designs are also available.

3 Final Thoughts

The work carried out by statisticians and engineers is often seen as purely technical and does not have strong social implications. However, these professionals often contribute to improving the population's life in different ways and in different areas.

In order to exemplify, consider a topic widely commented nowadays that is the spread of fake news. This information spreads quickly through social networks and can encourage readers to make the wrong decisions and attitudes, as this news can influence consumers when choosing a certain product to more complex decisions related even to health and politics. In this context, artificial intelligence has stood out as an important tool in the recognition of fake news. Several input variables can be considered in the analysis, such as the number of typing errors present in the message, the number of characters, whether the message is more emotional or not, among several others. In view of this, this information will be useful during the training of an artificial neural network that will be able to generalize the learning, classifying certain news as true or not with a high level of confidence.

On the other hand, some practices still need to be disseminated and incorporated into the work of an engineer. Generally, when trying to find the best configuration for a given process or the best materials for the development of a new product, approaches such as trial-and-error are used. The drawback of this approach is that it requires running a large number of experiments, besides the difficulty in obtaining an optimal result. It involves high costs and a long time to obtain a solution to the problem. As presented in this chapter, designed experiments represent a great alternative to trial-and-error approaches, because, with the least number of experiments, it is possible to extract a large amount of information on a given topic. In addition to factorial designs, there are also fractional factorial designs, central composite designs, Box–Behnken design, Taguchi design, mixture design, among others. Each one is used for a distinct purpose, therefore, more suitable for a specific type of problem. Thus, engineers must have sufficient statistical knowledge to plan the experiments, collect the necessary information, analyze and interpret the data, as well as understand how the collected data relate to the proposed models. Readers who feel the need to go a little deeper in this area can consult Montgomery (2013).

Another important concept discussed in this chapter is variability and how it affects a given process, even when it is under statistical control. In this context, it is worth noting that many products acquired today have their parts produced in different units of a company or even different companies. All these parts follow different specifications; that is, they have target values, as well as lower and upper specification limits for their measurements. However, the presence of variability is intrinsic to the entire production process, and as a result, the parts may not meet pre-established specifications, leading to the risk of the final equipment not being assembled. This risk is closely related to the standard deviation or the variability associated with manufactured parts.

These discussions highlight the importance of a production process being able to meet its specifications. Otherwise, there may be large amounts of scrap or rework to be carried out at the end of the process, which represents significant losses of time and money for the organization. In addition, this is also related to the responsibility of the engineers in delivering a safe product to the costumers. This has to do with moral responsibility, since the damages related to an out of specification product, depending on its use and the public to whom it is destinated, may range from simple inconvenient to death.

Another theme that has become a strong trend today is the use of artificial intelligence techniques in companies, mainly with the advent of industry 4.0 and the process of digital transformation. Tools such as artificial neural networks have been increasingly used in highly complex problems in which a huge number of variables are considered possible predictors for the responses under investigation. Concomitantly, this large amount of data must initially undergo statistical treatments such as correlation analysis, principal component analysis, factor analysis, hypothesis tests with respect to normality, heteroscedasticity, and several others. This initial treatment of data is essential for a better performance of artificial intelligence techniques, showing that statistical and machine learning tools become much more powerful when used together.

Box, Hunter, & Hunter (2005) comment that each problem has its methods and must be treated differently from the others. However, they also indicate some good practices to be followed when solving any problem. Initially, it is extremely important to understand deeply what is the problem being solved as well as what are the necessary resources for the work. Non-statistical knowledge should never be neglected, since statistical tools are useless, unless they are applied together with the appropriate experience and knowledge on the subject. Furthermore, all goals and objectives must be clearly established, as well as the metrics used to measure them. There must be an interaction between theory and practice. The success of many scientists, such as Sir Ronald Fisher and Willian S. Gosset (the famous *Student*), is certainly directly related to the participation in various experimental works, improving their ability to develop powerful statistical techniques.

All of the analyzes mentioned in this chapter can be developed with software support. They feature modules for carrying out designed experiments, time series analysis, regression, multivariate analysis, among others. Besides, program languages such as R and Python are widely used in academic research due to a large number of available libraries, presenting great utility in the statistical treatment of data as well as in the training of artificial intelligence techniques. Through these languages, recently discovered methods are implemented in the form of new packages and libraries, so that knowledge can be shared among all the data scientists communities.

This chapter may help one to understand other chapters of this book. Decision making on innovations, discussed in Chapter 'Industrial Innovation Practices Breakthrough by Process Intensification', economic and regulatory aspects in Chapter 'Economics, Regulatory Aspects and Public Policies and energy planning explained in Chapters 'Social and Economic Implications of Electricity Generation Sources' and 'Amazon Region Power Plants and Social Impacts' may benefit from the concepts explained here. Note, however, that societal modeling described in Chapter 'A Multi-Aspect Dynamic System Model to Assess Poverty Traps' and pandemic issues related in Chapter 'The Socio-Economic Implications of the Coronavirus Pandemic: A Brazilian Electric Sector Analysis' depend strongly on statistics concepts. Thus, this chapter may help one to cement the concepts of other chapters.

Finally, considering the complexity of engineering problems within a social and environmental context requires careful interpretation of statistical results. The engineer needs to be sensitive and to take into account a comprehensive systems engineering perspective of the problem being investigated.

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Suggested Reading: (A List of Popular Books that Explores Statistical Thinking)

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Gladwell, M. (2008). *Outliers: The story of success*. Little, Brown and Company.

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Technologies

Smart Telecommunications: The Catalyst of a Social Revolution

Paulo Coelho, Mário Gomes, Filipe Bandeiras, and Antonio Carlos Zambroni de Souza

Keywords Telecommunications · Information and communication technologies · Computer networks · Social networking services · Distance education · Virtual reality

1 Introduction

For quite some time, the work performed by engineers has often been viewed as purely technical and without social implications. This is not only common among people outside of engineering, but also among engineers themselves. The work of engineers in modern society has major implications and effects at the social, economic, and environmental levels.

As a starting point, it is important to address how the imagination of engineers is influenced by the society they are part of. The imagination of engineers functions the same way social imagination does, being a factor of change and stabilization. Essentially, social imagination plays the role of justifying the present state of society and exploring a better future state for that same society. In engineering, the best ideas and

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solutions to problems are inspired by representations of what is efficient and effective in the real world. This can be fundamentally ethical and social, because it represents what is good and productive in society (Picon, 2004). Engineers work actively with customers and communities in order to provide solutions to complex and demanding problems of social, economic, and environmental nature. Also, engineers also have the social responsibility to ensure human safety and environmental protection by mitigating the harmful and negative impacts of the technology they produce. The approaches and technological innovations of engineering are crucial to improve and maintain the quality of life, being the key drivers that positively influence and shape society.

In developing countries, the work of engineers contributes to the development of healthcare and information services in poor communities, as well as appropriate and affordable infrastructures for the delivery of clean water, sanitation, power, and communication (Lawlor, 2016). However, most engineering studies are likely to focus on technical aspects rather than on social implications associated with the interaction between technology and society. Therefore, it is important to find ways of promoting the social responsibility commitment among engineers (Bielefeldt, 2018).

Economic development shows major importance in the process of creating the conditions essential to gain economic growth in the long run, especially in developing countries. As economic theory suggests, the growth in the economy depends on the quality and quantities of the factors of production, namely labor and capital, and the efficient and innovative way in which those quantities are used. Growth can be sustained by an increase in the amounts of labor and capital "invested" and by increasing the efficiency in which these factors are used, both individually and combined to produce the expected output. The quality of education of the overall population and the average number of years of education, or even the investment in research and development (R&D) are also important factors that cannot be overlooked (CEBR, 2016).

Over the time, engineers have played a very important role in the major process of global economic development, and as a positive consequence of their actions, they contributed to the eradication of poverty. Their contribution to the development of new products and infrastructures allows them to reinforce the development process and drives economic growth. This development process increases the possibility and opportunity to have access to better education, and thus, it encourages labor mobility. It must not be forgotten that the investment in communications networks, Internet, and mobile phones, aiming to enable access to information, also play a key role in economic development and growth (CEBR, 2016).

Telecommunications is one of the most dynamic areas of engineering. "Engineers make things, make things work and make things work better". Engineers use their skills and creativity to design and propose solutions to the world's problems, helping to "build the future" (CEBR, 2016). But what costs can this have on society and the world of labor? Is it possible that with the evolution of telecommunications the world could enter an era of increasing technological unemployment? Is it possible to predict the implications on society, people, and systems? What will happen if the outermost predictions regarding technological unemployment are attained? What if human labor, in almost all forms suffers a takeover from ICTs, robotic, and automation technologies?!

This chapter addresses the importance of telecommunications in this paradigm shift and the concerns regarding the impacts of technology on society, as well as the reasons for an optimistic view when the development of technology is done properly to maximize potential benefits and minimize harmful effects while taking into consideration the implications at the social, economic and environmental level. We try to be consistent with the idea of normativity developed in Chapters 'Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures' and 'Towards a Holistic Normative Design'. We also understand that the challenge of engineers is not primarily to balance between different normativities but to develop products in which all normativities are met.

2 Principles of Telecommunication Technologies

2.1 Brief Historical Overview of Telecommunications

An important part of the overall history of communication is the history of telecommunications. Telecommunication can be defined as the science and technology of communication over a distance. The ability to, in a quick, accurate, and efficient manner, be able to transmit information, through sounds, words or visuals has been one of the main propellers of human innovation. Communication has always been the milestone for survival and success, ever since the prehistoric man who used signal fires until nowadays, with the high-powered executives wielding a smartphone. There are various ways to make a voice call, starting with the landline phone at the work desk or home, the cell phone, and also several computer software options such as Skype, WhatsApp, Google Hangouts, and many others.

The evolution of telecommunication illustrates the never-ending leap in progress. Telecommunications became more widespread and efficient with the development of modern civilization because it comes in parallel with human development. The history of telecommunications began with man's first attempt to perform distance communication using fires, beacons, smoke signals, and drums to encode information. The first attempts at distance communication were extremely limited. Natives in Africa, New Guinea, and South America used drums to communicate. In North America and China, smoke signals were commonly used for the same purpose (Mitel, 2020; TechnoFunc, 2012).

In 1672, Robert Hooke created the first experimental acoustic (mechanical) telephone. Hooke found out that sound could be transmitted over a wire or a string into an earpiece or mouthpiece, attached to it. The worldwide future impact of this discovery was not something that Hooke was aware of at the time (Mitel, 2020).

More than one hundred years later, in the 1790s, the French engineer Claude Chappe presented in Europe the first visual telegraphy (or semaphore lines). The visual telegraph was a system of pendulums set up somewhere high, like for example on a tower. The mechanical arms of the telegraph had to swing around to sign messages from one tower to the following tower. This was the first telecommunications system in Europe. However, it needed skilled operators, the towers were very expensive, and they often needed to be placed at intervals of ten to thirty kilometers (Mitel, 2020; TechnoFunc, 2012).

The beginning of the telecommunications era was in 1844, with the successful innovation of Samuel Morse, the electrical telegraph. Morse discovered that if he connected two model telegraphs along with running electricity through a wire, he was able to send messages using a more or less simple process of holding or releasing the buttons in a series of intervals. This process was named after its author and became known as Morse code. This was the milestone for modern landline phones. The expansion of the telegraph paralleled and aided the development of the network of railroads in the USA.

In 1862, the first coast-to-coast telegraph line opened, and it was immediately economically successful, proving the value of telecommunications over great distances (Mitel, 2020; TechnoFunc, 2012). Initially, the telegraph systems served only land routes, and inventors assumed that it was not possible to lay lines underwater. However, in August of 1858, after several experiments running insulated telegraph lines under lakes and across rivers, a consortium led by the American Cyrus Field, successfully fulfilled the task of launching the first transatlantic cable connecting the UK and the USA. The possibility of almost "instantly" communicate showed a great positive impact on business and many other human aspects of daily life (Mitel, 2020; TechnoFunc, 2012).

The success of the telegraph industry and the developments in electrical manufacturing businesses provided the background for the birth of the telephone. The creation of the telephone was associated with Graham Bell, who register its patent in March of 1876. In 1878 and 1879, the first commercial telephone services were set up in the cities of New Haven and London (TechnoFunc, 2012).

The wireless telegraphy was developed in 1893, being Nikolai Tesla the first to successfully transmit radio waves wirelessly through a transmitter and to register the patent of this accomplishment. Shortly after, another inventor, Guglielmo Marconi, contemporary of Tesla, claimed that Tesla had copied his work. It was proven to not be true during the legal battle that ensued (Mitel, 2020). Despite being defeated in the US courts, Marconi continued his work and created new versions of wireless sound transmission. After a few years, in 1896, he was able to perform his first long-distance wireless transmission, over a distance of 2 km. This achievement placed Marconi in the history books as the man who created the first radio in 1896 (Mitel, 2020).

Another important milestone was the First North American coast-to-coast telephone calling that was made by Alexander Graham Bell in January of 1915, to his assistant. This long-distance call was the first in history to be made from a landline. This had a great meaning because it made long-distance communication in the USA a reality (Mitel, 2020).

All these developments were very important; however, transatlantic communications by voice remained unavailable for customers until January of 1927. At that time, it was established a connection between the UK and the USA using a radiotelephone service. Initially, all the phones were radio phones, and therefore they presented some problems like fading and interference. In the beginning, there was only one circuit that received around 2000 calls per year. In September of 1956, the first cable connection TAT-1 was inaugurated, and it provided 36 telephone circuits. Nevertheless, transcontinental telephone service was not available until around 1915, when amplifiers based on Lee De Forest's "Audion" vacuum tube started to be used (Mitel, 2020; TechnoFunc, 2012).

After 1945, improved technology started to bring about changes in telecommunications. The times of war boosted Bell Labs, among other researchers, to produce coaxial cable and microwave links that started to be used commercially during the years after the war. With this technology, it was no longer necessary to build expensive telecommunication networks using copper wires. These microwave links needed to use several antenna towers, and a license to use the high-frequency spectrum was also required. However, the traditional wired network was still more expensive. The new coaxial cable was able to offer the broadband capacity needed to transmit a large number of telephone calls or even full-motion video (TechnoFunc, 2012).

The first telephone call that was ever made from a mobile phone was in June of 1946. The project was developed by Southwestern Bell, and it was not a very extensive mobile network, because the cost of installation was high, and the volume of calls was small (Mitel, 2020).

The cold war missile race boosted the development of satellite communication. The world's first artificial satellite was put in orbit in October 1957, when the Soviet Union launched Sputnik into a low Earth orbit. This low orbit path was used early in military satellite communications until the 1970s, when the first commercial geostationary satellites appeared. The commercial telecommunications satellite, "Communications Satellite Act", was officially approved in 1962 and allowed telecommunications to finally go into space. AT&T "built" their satellites, and two years later, six of their telecommunications satellites were put into orbit (Mitel, 2020; TechnoFunc, 2012).

The beginning of fiber-optic telecommunications started in 1964 when Charles Kao and George Hockman published a scientific paper stating that fiber-optic communication could be possible because the fibers used to transmit information were free of impurities (Kao & Hockman, 1966; Mitel, 2020). This discovery created opportunities for success, allowing the transmission of sound over beams of light.

In 1965, in North America, the first trials of the picturephone service, by Union Carbide Corporation, began. These were called "Mod I" picturephone sets (Mitel, 2020).

Charley Kline and Bill Duvall created in 1969 the first computer network. The first data, based in packet switching "traveled" in 1969, between nodes of the ARPANET, a precursor of the Internet. At that time, ARPANET consisted of a four-node network between the University of California in Los Angeles, the Stanford Research Institute, the University of Utah, and the University of California in Santa Barbara. By 1981, it consisted of 213 nodes (Mitel, 2020; TechnoFunc, 2012).

The history of mobile phones is associated with the evolution of the existing two-way radios that were permanently installed in vehicles such as police cruisers, taxicabs, fire trucks, etc. The later versions, the so-called bag phones, were transportable and could be used as mobile two-way radios as well as portable phones since they were equipped with a cigarette lighter plug that allowed them to be carried anywhere. The Motorola manager, the Inventor Martin Cooper, made the first cellular mobile call in April 1973 to his rival Joel Engel, head of research at AT&T's Bell Labs. The first mobile phone had a maximum talk time of 30 min and would eventually be a prototype for Motorola's first mobile phones (Mitel, 2020; TechnoFunc, 2012). This was the beginning of the era of the handheld cellular mobile phone.

In 1979, there was a huge improvement in maritime communications: INMARSAT ship-to-shore satellite communications. The International Maritime Satellite Organization (INMARSAT) was created so that marine vessel could have reliable communication to increase safety and communication for sailors and passengers who needed to communicate with the shore (Mitel, 2020).

In 1981, the first commercially automated cellular network was launched in Japan, initially only in Tokyo (in 1979) and expanded afterward. At the same time, the Nordic Mobile Telephone system was established in Denmark, Finland, Norway, and Sweden (Mitel, 2020).

In the USA, digital technology was used for the first time in telecommunications, in 1962, when AT&T developed its T1 Carrier System, a line that offered more capacity and a cleaner signal, i.e., with less noise. Shortly after that, digital telephone switches appeared and allowed a more flexible network design and operation. However, the most radical change came with the installation of fiber-optic cables to allow the use of voice, data, and video signals. Due to the large carrying capacity of fiber, telecommunications networks presented an expansion well above the projected growth (TechnoFunc, 2012).

The Internet's official "date of birth" is January 1 of 1983, as the transmission control protocol/Internet protocol (TCP/IP) became standard, because ARPANET officially changed its old network control protocols (NCP). Before 1982, the Internet was a network restricted to limited network groups such as government, military, corporate, and university research networks, being highly secure. The "Simple Mail Transfer Protocol" written by Jonathan Postel in 1982 changed the focus of the Internet from security to reliability, and this was achieved using networks as relay stations in order to be able to send electronic mail, through cooperative hosts, to the recipient. Internet access using the old telephone and television networks allowed its widespread, late in the century. The general "World Wide Web" and the development of the graphical user interface allowed the common use of an immensity of information resources and an increasing acceptance and use by the public. Many homes around the world already had an Internet connection in the early 2000s, and the number of broadband connections was growing. The growth projections of the Internet generated optimistic plans for the underlying telecommunication services.

In 2003, a service based on the Internet protocol (IP) the telephony appeared, and it was known as Internet telephony. It was a service based on the voice over IP communication protocol (VoIP). IP telephony uses a broadband Internet connection to send information (conversations) as data packets. IP telephony is also competing with mobile networks because in addition to replacing the traditional plain old telephone service (POTS) system, it is offering free or low-cost connections by means of Wi-Fi hotspots. This allowed phone calls to be transmitted over a computer through IPs, and therefore long-distance charges were no longer applicable since callers would use already-established computer networks. VoIP could also be used on private wireless networks where the connection to the outside telephone network may or may not exist (Mitel, 2020; TechnoFunc, 2012).

The first mobile satellite handheld phones appeared in 1998. At that time, a company called Iridium put into place the first canopy of 64 satellites and produced the first handheld satellite phones. This new phone was smaller and less heavy and uncomfortable than the previous “bag” phones; therefore, it revolutionized mobile telecommunications and led to the modern smartphone in 2001 (Mitel, 2020). The original purpose was to encircle the world through the telephone network, independently of the technology used.

People start to look at telecommunications as just another easy-to-use interface. In the same way that Bell created his original telephone using ideas from the telegraphy of his time, nowadays software developers put together existing tools and infrastructure to create something new. With the cloud revolution over the last 15 years, there has been a culture change, and companies started to provide services that were designed to be combined into new apps and services. They provided APIs. Need to send an email from your app? There is an API for that. Need to check a customer’s credit score? There is an API for that. Need to send an SMS? There is an API for that. With this evolution, telecommunications went from an expensive and restrictive service to a commodity that allowed anyone to create applications. Society is about to go through a new revolution in the way people think about telecommunications, whether they use chat, voice, or SMS.

The cloud communication APIs have made innovations in telecommunications accessible to everyone and that will become even more evident with innovations from the fifth-generation (5G) technology. The 5G telecommunications networks hit the market in late 2018, and it is a fact that they will continue to expand worldwide. 5G is expected to bring a speed improvement, and beyond that to unleash a massive Internet of Things (IoT) ecosystem so that networks can fulfill communication needs for a massive number of connected devices, with the right trade-offs between speed (tops out at 10 gigabits per second), ultra-low latency, more reliability, massive network capacity, increased availability, and a more uniform user experience to more users. The 5G networks represent a sign of the future of telecommunications because they enable a new kind of network designed to connect almost everyone and everything, and that includes machines, objects, and devices. Welcome to the future of telecommunications.

2.2 *Transmitting and Receiving Signals*

A signal transmission system can be defined as the electrical channel between an information source and a destination. The complexity range of these systems can go from a simple pair of wires to a sophisticated laser-optics link. Therefore, signal transmission is the process by which an electrical waveform goes from one location to another, and ideally, it arrives without distortion. The signal reception corresponds to the reception of an electrical waveform and the conversion of the information into a usable form. A communication system transports information from its origin to its destination, which can be at any distance. A typical system involves several components that cover the entire "range" of electrical engineering (Carlson et al., 2010).

2.2.1 Elements of a Communication System

In Fig. 1, the elements of a communication system are shown, including disturbances (unwanted contaminations). The communication system consists of three essential parts: the transmitter, transmission channel, and receiver. Each part plays a specific role in signal transmission, as follows.

As described in (Carlson et al., 2010), the transmitter processes the input signal to produce a transmitted signal that is adjusted to the characteristics of the channel. Signal processing usually involves modulation and may include coding. Thus, in the process of modulation, the transmitter combines the information signal that must be carried with the radio frequency signal (that generates radio waves), called the carrier signal. For different types of transmitters, the information is added to the carrier in different ways. For instance, information is added to the radio signal by varying its amplitude in the case of amplitude modulation (AM) transmitter, or by varying its frequency in the case of a frequency modulation (FM) transmitter.

A one-way, simplex (SX), the transmission is represented in Fig. 1. Two-way communication requires a transmitter and a receiver at each end. A full-duplex (FDX) system presents a channel that enables simultaneous transmission in both directions.

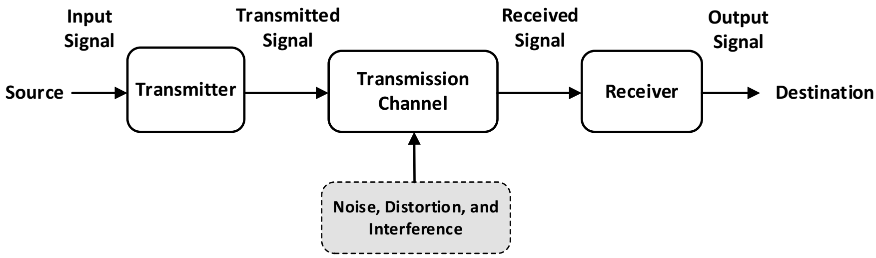

Fig. 1 Communication system elements

A half-duplex (HDX) system enables the transmission in either direction, however not at the same time (Carlson et al., 2010).

2.3 Analog and Digital Communication

The concept of information and message is central to communication. Whatever form the message takes, the goal of a communication system is to reproduce at the destination an acceptable replica of the source message. There are many kinds of information sources and messages appearing in various forms. Nonetheless, two distinct message categories can be identified: analog and digital.

Messages transmitted can be analog or digital. An analog message can be defined as a physical quantity that varies with time smoothly and continuously (Carlson et al., 2010). An example of an analog message is the acoustic pressure produced when a person speaks, or the angular position of an aircraft gyro. As the information is laid in a waveform that varies with time, an analog communication system should provide this waveform with a certain degree of fidelity. A digital message is an ordered sequence of symbols that were selected from a finite set of discrete elements (Carlson et al., 2010). An example of a digital message is a listing of hourly temperature readings or the keys pressed on a computer keyboard. As the information is transmitted in discrete symbols, a digital communication system should provide these symbols with a certain degree of accuracy in a certain amount of time.

2.3.1 Analog Communication vs Digital Communication

This subsection presents a brief comparison between digital and analog communications and describes the advantages of digital systems over analog systems. Then, it focuses on the problems of digital communications and presents the differences between digital and analog transmission.

Despite the apparent increase in hardware complexity, a digital system can provide the following advantages (Carlson et al., 2010):

1. **Stability**. Because digital systems are inherently time-invariant, the most important system parameters are embedded in algorithms that change only when reprogrammed, providing greater accuracy in signal reproduction. In analog hardware, the signal and its parameters suffer changes with environmental factors such as component aging and external temperatures.
2. **Flexibility**. Because the digital hardware is in place, it allows enough flexibility to change the system, thus enabling a multiplicity of signal processing algorithms to allow to more efficiently: (a) improve signal fidelity; (b) perform error correction/detection to improve data accuracy; (c) perform encryption to enable privacy and security; (d) use compression algorithms to remove redundancies;

and (e) allow for multiplexing of different types of signals such as voice, image, video, and text. Moreover, an algorithm can be easily and remotely modified.

3. **Reliable reproduction**. An analog message is corrupted by noise and distortion when traveling through a channel. Amplifiers or repeaters can be used to boost the signal. However, they amplify both the noise and the signal, increasing distortion that becomes accumulative. In digital communication, signal reproduction is extremely reliable whether copies of digital audio recordings are created, or regenerative repeaters are used for a long-distance digital channel.

2.3.2 Types of Analog and Digital Communication Systems

Depending on the modulation, analog communication systems can include amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM). Similarly, digital communication systems can include amplitude shift keying (ASK), frequency-shift keying (FSK), minimum shift keying (MSK), phase-shift keying (PSK), and quadrature amplitude modulation (QAM).

2.4 Differences Between Communication Channels

There are certain types and channels of communication that may be the preferred methods for communication in a certain activity or application. Communication can be classified into three basic types, including verbal communication, which is the most common form of communication that involves listening to a person to understand the meaning of the content of the message; written communication, which involves reading the message; and nonverbal communication, which involves observing a person and deducing the meaning of the message (Bauer et al., 2013; Commbox, 2020).

Verbal Communication—This type of communication takes place in person, or over the phone. The medium where this communication takes place is oral, and the message is being sent in both ways from the sender to the receiver and vice versa. A change in tone can modify the way the meaning of a message is understood. Most of the time, oral is a synchronous communication, but there are a few exceptions. For instance, voice mail is an oral message that is asynchronous (Bauer et al., 2013).

Written Communication—This type of communication involves printed messages, such as letters, e-mails, and proposals. These messages can be printed on paper or appear on the screen. Most of the time, written communication is asynchronous, because the sender may write a message that can be read by the receiver at any time and by many people.

Verbal communication usually takes place in real-time, while written communication can be carried out over a longer period. Written communication can also be collaborative because multiple people can collaborate in writing the content of a document before it can be sent to the intended audience.

Nonverbal Communication—It is known that what is said is a vital part of any communication. However, what is not said can be even more important. Studies are showing that nonverbal communication can influence the decision of getting a job offer or not. There are clues such as the rate of gesturing, the amount of time spent talking, and the formality of dress that can determine which candidates would be the most socially successful on the job (Bauer et al., 2013; Gifford et al., 1985). In order for communication to be effective, the body language of the communicator, its appearance, and tone of voice must align with the words being transmitted.

2.4.1 Communication Channels

When entities communicate with each other, the medium by which they communicate is the communication channel. This includes email, phone, or social media channels such as WhatsApp. The question is which ones should be used and how to include them in various applications. Then there must be some kind of balance. As society moves in the twenty-first century, more diverse approaches of communication channels must be adopted. This will become more and more important to provide a diverse and appropriate mix of communication levels to the audience. Several generations use or prefer different communication channels. For instance, older generations tend to access social media less than newer generations (Commbox, 2020). Generation Z, those born after 1997 are the customers of the future that technology needs to appeal to. The members of Generation Z can be seen as "digital natives" who do not know what it is like to not have Internet access: "no matter when, no matter what, no matter where" (Shay, 2017). Therefore, the methods they choose to communicate with their preferred brands, matter to both society and the economy. Generation Z is the main user of the most recent social media channels (Commbox, 2020).

Communication travels in many different directions. External communication in a web page can blend elements of public relations, marketing, and editorial content, reaching receivers at several levels and in several ways (Bauer et al., 2013). There are a lot of elements like banner ads, blogs, and advertiser-driven "click-through" areas, which allow businesses to send messages to a receiver online. Because online communications have great flexibility, they tend to be less formal and convey more reliability in external communication. For instance, when a message is relayed in a daily blog post, it will reach a receiver differently as if it was delivered in an annual report. The quality of web communications in "real time" may represent a more important appeal to receivers than traditional ads and public relations messages. Online pages can be revisited countless times in a single day, and for this reason, the external communications must be clear and accurate since this is as vital for online use as it is in traditional media.

3 Role of Telecommunications in Engineering Systems

3.1 Communication and Communication Protocols

As communication networks use digital technologies, modern computers are required. Computers need to communicate with various peripheral devices (e.g., mouse, keyboard, a monitor), or send messages to other computers (connected across a local area network, a mobile phone cellular network, or the Internet). The communication network requires a set of predefined rules to correctly manage how communication takes place. These rules are known as communication protocols, which are standard rules for data representation and data transfer over a communication channel (Kim et al., 2019; Coelho et al., 2019). The protocols allow messages to be transmitted in a structured and organized manner. Therefore, receivers can process the data sent from the senders. Communication protocols make sure that communication between any devices is successful. Moreover, different protocols exist to specify rules for different types of communication.

With the shift to digital technologies, large amounts of analog and digital information are concentrated in a single intelligent electronic device (IED), which is widely used in electrical power systems and smart grid (SG) applications. An SG involves many smart devices at all levels of the energy supply chain such as smart meters, phasor measurement units (PMU), supervisory control and data acquisition (SCADA), energy management system (EMS), and demand management system (DMS) (Kim et al. 2019; Kirpes et al., 2019; Coelho et al., 2019). SG communication standards are designed to meet different requirements at various layers (Adamiak et al., 2009, Kim et al., 2019, Coelho et al., 2019). Two reference models commonly used to describe these layers are the International Organization for Standardization (ISO) or Open Systems Interconnection (OSI) and the GridWise Architecture Council (GWAC). Concerning the objectives of various SG standards, some standards address the use of wireless media, fiber-optic cables, or powerline carrier (Kim et al., 2019; Coelho et al., 2019). Other standards address the transport layers for transmitting information from one location to another or the application layers for semantic data structures as information is transmitted between software applications. The communication layer accommodates various communication protocols that are responsible for the interaction between distinct layers. The reliability, scalability, security, power consumption levels, and economic viability of the communication technologies and protocols are essential to allow efficient interoperability of power systems, especially in SG applications (Cali & Fifield, 2019). Table 1 presents some communication protocols used in energy systems and their respective application (Kim et al., 2019; Perera, 2015; Czechowski et al., 2015; Adamiak et al., 2009; Musleh et al., 2019; Kirpes et al., 2019).

Table 1 Communication protocols and their application in energy systems

Application	Protocol
Supervisory control and data acquisition (SCADA) systems	IEC60870, DNP3 and IEC61850
Connection between substation devices	DNP3 and IEC60870
Generic object-oriented substation event (GOOSE) messaging	IEC61850
Energy management system (EMS)	IEEE 2030.5
Smart metering and grid management	IEC 62056 xDLMS/COSEM and CLC/prTS 5068-5
Energy markets	IEC 61968-100
Marketplaces	EN82325-450/451
Communication between electric vehicle (EV) and charging stations	IEC61851-1 (SAE J1772) and ISO/IEC 15118-2 XML (EXI) TCP/IP

3.2 Local Area Networks and Wide Area Networks

A computer network consists of at least two computers connected through wired or wireless connections that can communicate with one another (i.e., exchange data). There are many reasons for connecting computers into a network and some of them include (Celebic & Rendulic, 2011): (i) exchange of data among users with access to the network, (ii) share of connected devices in the network, and (iii) increase of user communication and socialization. In a simplified and comprehensive way, the types of networks according to their size are (Celebic & Rendulic, 2011; Coelho et al., 2019):

- Local area network (LAN). This type of network covers a relatively small geographical area. LAN connects generally computers within a building (firm or household) through wired connections. A wireless local area network (WLAN) is like a LAN, but it is achieved wirelessly.
- Wide area network (WAN). This type of network covers a relatively large geographical area. WAN connects a much greater number of computers and local networks.

In the early beginning of broadband Internet access, Internet providers charged a fee based on data traffic due to underdeveloped communication infrastructures. With dial-up Internet access, users are charged based on time spent on the Internet. Today, with developed telecommunication infrastructures, Internet providers do not charge based on the time spent on the Internet or the amount of transferred data; however, they charge users according to their access speed. The main methods to connect to the Internet are (Celebic & Rendulic, 2011): (i) mobile (using mobile networks such as GPRS, EDGE, UMTS, HSPA), (ii) satellite (commonly used in locations without proper infrastructure), (iii) wireless (using mostly radio frequencies of 2.4 GHz), (iv) wired (connecting to the Internet through telephone lines using a modem), and

(v) broadband over powerline (using the existing low and medium-voltage electric power distribution network). Broadband over powerlines is an emerging technology with substantial potential because powerlines are generally installed everywhere, mitigating the need to build new broadband facilities for every customer.

3.3 Electric Power Systems and Smart Grids

Communication has always played an important role in the real-time operation of electric power systems (Adamiak et al., 2009; Yousuf & Vajuhudeen, 2017). In the beginning, the telephone was used to communicate powerline data back to the control center to dispatch operators to perform switching operations at substations. Telephone-switching-based remote-control units became available in the 1930s, which provided the ability to command and control sections of the electric power system. As digital communications became a viable option in the 1960s, data acquisition systems (DAS) were installed to automatically collect measurement data from substations (Adamiak et al., 2009). Because bandwidth was relatively limited, DAS communication protocols were optimized to operate in low-bandwidth communication channels.

According to IEA and ISGAN (2016), flexibility is the ability of power systems to maintain reliability and continuous service in the event of rapid and large swings in supply or demand. In this scope, demand response (DR) is emerging as a crucial component for system operators. This allows greater flexibility regarding when and where loads consume power on the grid while allowing consumers to use power when costs are lower. DR programs are often designed and deployed by third parties rather than utility companies and often use communications and control systems outside of the utility system. Measurement and verification enabled by AMI offer the opportunity for all energy market participants, and especially system operators, to recognize the value of DR programs. Communications systems that support SG deployment, such as PLC technology, as well as the communication capabilities of AMI systems, may help control devices for DR on a distribution feeder (Binz et al., 2019; Coelho et al., 2019).

4 Computer Networks and Social Networks

After four generations of various computing devices and the integration of Information and Communications Technologies (ICTs), modern society has been completely arranged and shaped in a way that became nearly impossible for humans to perform some tasks or even think about living without the benefits provided by these devices in our daily lives. When computer networks start connecting people and organizations, forming vast and diverse communities, they become social networks or computer-supported social networks (CSSN) (Wellman, 2001; Wellman et al., 1996). Initially, CSSNs provided benefits to organizations by enabling people to work, cooperate, and interact with one another from home. This form of CSSN known as computer-supported cooperative work (CSCW) allowed organizations to connect and coordinate complex work structures and reduce travel costs and time (Wellman et al., 1996).

With the introduction of social networking services (SNS), the use of CSSNs and access to the Internet has proliferated and became a widespread practice among people of all ages around the world. According to Boyd and Ellison (2007), an SNS can be defined as a web-based service that allows individuals to create a semi-public profile, articulate a list of users with whom they share a connection, and navigate their list of connections and lists made by other users within a bounded system. Essentially, SNSs provide virtual places for people to connect, allowing information and media content (i.e., images, music, videos) to be created, shared, and consumed by millions of network users. In the last two decades, hundreds of web-based services have been created with distinct features, but they all share the same key characteristics that define them as SNSs. The first recognized SNS was SixDegrees launched in 1997. Even with millions of users, SixDegrees failed to be a sustainable business and closed in 2000. During this time, several tools were created to support both personal and professional connections.

The next wave of early SNSs started with the launch of Ryze in 2001 and then with LinkedIn and Friendster. LinkedIn ended up becoming a powerful business service, but the other SNSs were left behind either due to technical and social difficulties or lack of popularity. The proliferation of SNSs started significantly after 2003 with many new services being created in the form of profile-centric sites such as Facebook, Twitter, MySpace, Orkut, and Hi5. Other services such as Flickr, Last.FM, and YouTube implemented several features commonly found in SNSs to focus on media sharing (e.g., photos, music, and video sharing). These SNSs quickly grew in popularity and became a global phenomenon, attracting the attention of people of all ages around the world (Boyd & Ellison, 2007). The exponential growth of the ICT sector, along with the increased adoption of mobile devices and Internet access, has been the major contributor to the tremendous proliferation of SNSs in many societies around the world.

A wide range of benefits associated with the use of SNSs by young people has been identified and summarized by Collin et al. (2011). The correct use of SNSs mainly supports the development of media literacy, improvement of formal education, enhancement of creativity, the formation of individual and collective identity, sense of belonging, creation of social relationships and communities, participation in civil and political activities, and promotion of well-being and self-efficacy (Collin et al., 2011). More specifically, the media and digital literacy of users are developed by improving their critical thinking capabilities and increasing their technical knowledge and skills required to create content and effectively use SNSs. Using SNSs provides an additional place to perform learning discussions outside of the traditional classroom, enabling students to join or form online communities of people with similar interests and improve upon or complement formal education. SNSs enhance the creativity and self-expression of users by allowing them to generate completely new content and edit existing content. Sharing content with a broader audience in online communities can empower young people and help them develop their sense of belonging and their individual and collective identity. Young people can use the various features provided by SNSs such as instant messaging and media sharing to strengthen their existing social relationships and establish new ones. In this sense, SNSs also provide the ability for individuals to find and renew relationships with old acquaintances by navigating their network of connections. Moreover, young people can effectively use SNSs as a place to engage in civil and political activities, increasing youth participation in community decision-making and governance processes. Political candidates and advocacy have also been using SNSs for campaigning and political discussion. All this contributes positively to the well-being of young people and promotes their self-efficacy by preparing them to successfully adapt to change, new tasks, and stressful situations (Collin et al., 2011). Nevertheless, online interactions in SNSs may come with potential risks to the user such as addiction disorders, depression symptoms, data security issues, privacy violations, predation, or even cyberbullying (Collin et al., 2011; Pantic, 2014).

4.1 Socioeconomic and Environmental Impacts of ICTs

The introduction of ICTs plays an important role in achieving sustainable development in modern society. ICTs are, without a doubt, changing the quality of life for individuals and communities around the world and providing numerous benefits and opportunities for business, government, and environment (UNCTAD, 2011). It is known that the high penetration of ICTs has positive and negative impacts, which can affect society both directly and indirectly. However, measuring and characterizing the effect of ICTs can be a difficult and demanding task, because these impacts manifest differently in developing countries than they do in developed countries. Besides, the ICT sector mostly encompasses a panoply of general-purpose devices and services constantly involving and spreading to multiple areas of application, meaning that their use and impact are mainly indirect and difficult to measure (OECD, 2008). In 2007, OECD used a comprehensive conceptual model for information society statistics to assist with the measurement of ICT impacts. This conceptual model included the impacts of ICT use and production, impacts of trade in ICT products, impacts of both use and production of electronic and digital content, and influence of skills, innovation, regulation, and ICT infrastructure (OECD, 2008; UNCTAD, 2011).

The literature categorizes the positive and negative impacts of ICTs as social, economic, and environmental (EITO, 2002). The adoption of ICTs can have many social impacts and create numerous opportunities for society. For instance, ICTs grant access to free information and online services regarding health and government. Access to health information and online services has the potential to improve remote healthcare services and promote individual well-being and self-efficacy, while access to government information and online services can increase government transparency and legitimacy. The design, production, and operation of ICT equipment create new jobs and opportunities for qualified individuals, but this may threaten unqualified personnel and low-skilled workers resulting in some popular dissatisfaction and social exclusion. ICTs can also promote local communities and introduce new types of online communities. However, online communities and services are vulnerable to data security threats and privacy invasion and can be used to spread misinformation and crime (EITO, 2002). ICTs greatly impact the economy and can provide benefits for financial markets and businesses. Some of these benefits include the introduction of new financial markets and the growth of on-going investments in researching and developing ICT equipment. This has the potential to promote and open the financial markets to more participants. Small- and medium-size enterprises (SME) can also take advantage of ICTs to increase efficiency and improve productivity. There are, although, high-cost requirements associated with the implementation and maintenance of ICT equipment, and certain SMEs may be subjected to financial stress due to their financial limitations. Also, the adoption of ICTs may also strengthen the patterns of wealth inequality in populations (EITO, 2002).

For some time, authors have only characterized the social and economic impacts of ICTs, while the impacts on the environment were usually overlooked. This is mostly because the impact ICTs have on the environment is often considered insignificant when compared to the impact they have on society and the economy. Moreover, many authors consider the environmental impacts of ICTs to be entirely indirect, in contrast to social and economic impacts which are often described as direct impacts (EITO, 2002; OECD, 2008). Nonetheless, the environmental impacts of ICTs have recently become a much more frequent topic of discussion and research. The use of ICTs can positively impact the environment by increasing energy efficiency in both manufacturing and recycling processes and by reducing travel times, traffic, and congestions through telework and telematics. This may result in a significant decrease in greenhouse gas (GHG) emissions. However, the manufacture and operation of ICTs account for large shares of electricity generation, and these processes usually involve substances that are toxic and hazardous to both humans and the environment such as lithium or cadmium, which makes the disposal of ICT equipment problematic. On the positive side, the introduction of electronic commerce and online exchanges has the potential to extend the lifetime of used products, and therefore, can help to reduce electronic waste and over-production of products. Table 2 summarizes some of the social, economic, and environmental impacts associated with ICTs (EITO, 2002).

The integration of ICTs and SNSs into the educational system offered the opportunity to reshape the learning process of students, provide new ways to access information and significantly improve the quality of education and acquisition of basic skills. Because of economic, social, and cultural constraints, certain groups such as ethnic minorities, rural communities, and people with disabilities are often excluded from any form of formal and non-formal education. ICTs can provide these groups with various learning tools and resources, as well as free and quick access to both formal and nonformal education (Tinio, 2003). It cannot be denied that ICTs have revolutionized the educational system in the last two decades, but for some time the empirical literature showed mixed results regarding the impacts of ICT usage in

Table 2 Social, economic, and environmental impacts of ICTs

	Positive impacts	Negative impacts
Social	• Creation of new jobs and opportunities for qualified individuals • Quick access to free information and numerous online services regarding health and government • Promotion of local communities and introduction of new types of community	• Demotion of unqualified workers resulting in popular dissatisfaction • Invasion of user privacy and increased vulnerability to data security threats • Mass spread of misinformation and risk of social exclusion or digital divide regarding access to ICTs
Economic	• Growth of financial markets and ongoing investments in researching and developing ICTs • Introduction of new financial markets enabling more market participants • Modernization of industries and SMEs resulting in increased efficiency and productivity	• Rapid inflation and collapse of ICT stocks jeopardize market stability • Risk of strengthening patterns of wealth inequality in populations • Risk of financial stress for SMEs due to high costs in implementing and maintaining ICTs
Environmental	• Use of ICTs for telework and telematics reduces travel times, traffic, and congestions resulting in less GHG emissions • Use of ICTs contributes to increased energy efficiency in manufacturing and recycling processes • Introduction of electronic commerce extends lifetimes of used products	• Use of toxic and hazardous materials to manufacture and operate ICTs • Risk of increased electronic waste and problematic disposal of some ICT equipment • Operation of ICT equipment accounts for large shares of electricity generation

the academic performance of students. Many studies showed the effects of ICTs in student achievement, while other studies showed no evidence of a key role for ICTs in student achievement. This is mainly because it is difficult to isolate the effects of ICTs in educational environments and observe the performance of students (Youssef & Dahmani, 2008). However, more recent studies revealed that the use of ICTs positively impacts the academic performance of students (Basri et al., 2018; Hussain et al., 2017). The study carried out by Castillo-Merino and Serradell-López (2014) concludes that motivation constitutes a major factor that affects the academic performance of online students, being a key driver for the positive and significant impact of ICTs.

4.1.1 Impacts of Mobile Phones

In the last decade, smartphones have become the dominant personal computers, integrating various technologies such as capacitive touchscreens, flexible displays, facial recognition, fingerprint scanners, multiple high-resolution cameras, virtual reality, and many more. A smartphone can now do about anything using the features of mobile applications (i.e., mobile apps) installed on the operating system. Developing a mobile application has become simple, profitable and anyone can do it with the right set of tools and skills. These incredible developments have turned smartphones into a necessity and constant companions in our daily lives, especially among young people. Moreover, the use of mobile broadband made it incredibly easy for mobile phone users to quickly communicate with one another, and access information at any time and almost anywhere.

The widespread use of mobile phones and mobile broadband, like any other technology, has some positive and negative impacts on society, economy, and environment. According to the literature, these impacts seem to be more pronounced in low- and middle-income countries. In general, the environmental impacts of mobile phones and other ICT equipment are mostly negative and usually associated with their problematic disposal and use of toxic and hazardous materials during production and operation. However, mobile phones can also positively impact the environment by reducing travel times, traffic, and congestions through a variety of mobile applications and tools. The economic impacts seem to be positive contributions to the gross domestic product (GDP) growth. This is based on the correlation between the rates of mobile service penetration and the rates of GDP growth (Miller et al., 2014). An increase in mobile service penetration increases the GDP growth of a country. In low-income or developing countries, the impact on GDP growth can be significantly larger. Studies find that the penetration of mobile phones generates a positive impact on worker and business productivity, and consequently on total factor productivity (TFP). Because TFP is considered the primary contributor to GDP growth, an increase in TFP leads to an increase in GDP rates (Deloitte, 2012). Moreover, well-established mobile services and communication infrastructures can also improve the flow of foreign direct investment (FDI). Increases in mobile service penetration cause FDI to increase as a proportion of GDP (Lane et al., 2006). The use of mobile phones has the potential to reduce travel times and costs, increase worker efficiency, enhance information flow, promote entrepreneurship, and improve job creation and search (Deloitte, 2012). The social impacts of mobile phones are related to effects on social well-being and quality of life. Mobile phones can improve the quality of education, governance, and health care by granting active participation and by providing quick access to free information and online services (Miller et al., 2014). This can be particularly important in low-income or developing countries to mitigate the risk of social exclusion. Poor and rural populations can benefit from the use of mobile phones and services in order to promote social cohesion in families and society, extend communication to people with low education and literacy, and provide information and assistance on health and natural disasters (Lane et al., 2006). According to Silver et al. (2019), a large majority, mostly younger and more educated adults in middle-income countries, say mobile phones have been positive for society and good for them personally. However, some of them say mobile phones have a negative impact on children, health, and morality.

4.1.2 Impacts of Internet Access

The Internet is the largest computer network that grants the ability for any individual or organization to quickly access large amounts of information and resources at any time and any given location. This can be extremely important for the development of knowledge and skills among young people and the general population. In 1995, only less than 1% of the world population had Internet access. According to ITU (2019), the number of Internet users was around 1.1 billion or 16.8% of the world population in 2005, and it increased significantly to around 3 billion or 41.5% of the world population in 2015. The proliferation of Internet cafés (i.e., cybercafés) in the late 1990s and the continuous widespread of computers and smartphones after the late 2000s contributed to the significant increase of Internet users. At the end of 2019, it was estimated by ITU that the number of Internet users was around 4.1 billion or 53.6% of the world population (ITU, 2019). This means that 46.4% of the world population, mostly in low-income and developing countries, lacks Internet access and has no access to the social, economic, and civic benefits provided by this type of connectivity (West, 2015). Even in some industrialized and developed countries, a large percentage of children in poor communities, ethnic minorities, and people with disabilities have no access to the Internet at home. This digital divide tends to further deepen and spread within countries as technology grows and Internet becomes much more integrated into fundamental services of society and economy (Huizer et al., 2017; UNICEF, 2017). It is estimated that over 90% of jobs created in the next decade will require technical and digital skills, making Africa the youngest continent in demographic terms. Without the development of relevant digital skills and access to proper education, a vast majority of children lacking digital literacy will be left further behind (Huizer et al., 2017). The integration of ICTs plays a key role in mitigating the digital divide by enabling Internet access and basic online services for all children to improve their education and digital literacy (UNICEF, 2017).

Internet access has major socioeconomic impacts and the potential to unlock numerous economic benefits, especially in developing countries. These benefits are usually provided through the widespread adoption of mobile phones and other portable devices, which enable numerous Internet-based services (Deloitte, 2014; OECD, 2016). One major economic impact of Internet access is the ability to significantly increase productivity and efficiency across a variety of sectors, promoting GDP growth. For instance, the agricultural sector can benefit from the extended connectivity by providing farmers valuable information regarding weather conditions, crop yield, pest control, market pricing, and livestock tracking. The extended connectivity facilitates and accelerates the spread of information and ideas, which can be useful to develop solutions and overcome problems. Furthermore, the efficiency of economic markets can be increased by reducing transaction costs, increasing transparency, and removing entry barriers (Deloitte, 2014). Several SMEs can grow by taking advantage of these benefits, allowing them to potentially reach a broader market. Increasing Internet penetration will encourage entrepreneurship and innovation, resulting in a significant increase in the number of new businesses and the growth of existing businesses. Internet access not only offers the opportunity for the creation of additional jobs and new businesses, but it also enables the shift to higher-skilled labor and knowledge-based economy. The extended access to information and increased employment opportunities can be key factors to eventually reduce extreme poverty in developing countries (Deloitte, 2014). The social impacts of Internet access can offer a panoply of social benefits, leading to significant improvements in quality of life and skills. These social benefits mostly range across health, education, and social inclusion (Deloitte, 2014; Huizer et al., 2017). In developing countries, hundreds of thousands of deaths occur every year due to the lack of access to basic health information and healthcare services. Internet access has the potential to avoid a large proportion of these deaths by simply providing health information and healthcare services to the population, increasing life expectancy. In addition, increasing Internet penetration can also offer the opportunity to extend medical services and assistance through remote diagnosis to rural and isolated regions, which often lack health infrastructures. Mobile devices can significantly improve the medical behaviors of both patients and healthcare professionals by reducing travel times for doctors, delivering assistance with medications or treatments, providing easy access to information, and enabling connectivity among patients and doctors regardless of the location (Deloitte, 2014). Most children in developing countries are excluded from any form of formal and nonformal education. Internet access can provide effective means to extend access to education and improve the outcomes of collaborative learning among children and young people. Both students and teachers can benefit from increased Internet penetration by using a variety of online resources and services to aid their learning and teaching processes (Deloitte, 2014). It is undeniable that the social benefits associated with the Internet have a strong impact on the personal and community level. Internet access increases the efficiency of public services, promotes active civic engagement through online voting and citizen services, provides spaces for self-expression, and enables individuals to easily connect with friends and family through various SNSs. This is particularly important in developing countries to encourage social inclusion and achieve a cohesive society where individuals engage and connect without a sense of isolation (Deloitte, 2014).

4.1.3 Impacts of Media

Media are the communication channel or outlet used to deliver and spread various forms of information and entertainment to collective groups of people. This can be achieved through Internet, television, radio, newspapers, and magazines. Even though the term “media” only began to be used around the 1920s with the introduction of radio and television, it can be traced back to the old ways of communication such as cave painting, writing, and early printing. In 1948, the access to information through any media was declared in the Universal Declaration of Human Rights (UDHR) as a fundamental right of freedom of expression. The media have become a necessity and particularly important for certain types of audiences that do not possess the knowledge or means to be informed about the events happening in the world around them (Happer & Philo, 2013).

The use of media has significant impacts on society and plays a critical role in the development path of individuals. Media can empower people and influence the way they think and act, not just individually, but also collectively. When used correctly as an independent and transparent outlet for information, the media have the potential to provide many social, economic, and governance benefits (DellaVigna & La Ferrara, 2015; MDIF, 2014). Governance can be improved by directly and indirectly reducing corruption through a free and independent press, which delivers accurate information to expose government officials and increase voter knowledge. The media can also give an impactful voice to the poor and most vulnerable individuals, which are often ignored by government officials. Bringing this information to the public eye creates more informed citizens, impacts their voting decisions, and helps them hold their government accountable (MDIF, 2014). Providing better and more accurate information can lead to better decisions, as well as improved economic stability and progress. The media can be a strong mechanism to enhance political coordination in the development of safe and sound economic policies. In addition, free media and greater information access can reduce political risk, resulting in increased stability for countries with high political risk (MDIF, 2014). Media can also affect and impose positive changes in society by providing specific information to reach certain audiences. This information can effectively influence public opinion, leading to increased awareness and changes in behavior toward social issues such as public health, social inequality, and climate change (MDIF, 2014).

4.2 Distance Education

The ability for humans and animals to learn starts at birth and it is developed from the interactions and experiences with the surrounding environment and between individuals. Some basic forms of learning can be as simple as an attenuation in the strength of the behavioral responses to a sensory stimulus upon repeated exposure to that same stimulus (i.e., nonassociative learning) or an adaptation of the behavioral responses due to the association between distinct stimuli (i.e., associative learning) (Jozefowiez, 2012; Poon & Schmid, 2012). The act of playing is also considered a form of learning commonly seen in children and young animals. Learning through play helps the development and improvement of a wide variety of skills and behavioral responses to situations and challenges. By interacting with others, humans can effectively perform active learning, in which they actively participate and control their learning process through analysis, synthesis, and evaluation (Gogus, 2012). This differentiates from passive learning, which involves the individual quietly acquire and retain the information without any interaction with others or participation in the learning process. Furthermore, the learning process can either take place within a formally organized educational institution with specified objectives (i.e., formal learning) or outside of it (i.e., nonformal learning) (Hager, 2012). Formal learning is done in a teacher-student fashion, and students receive formal recognition in the form of a certificate or diploma upon completing the learning course (Punie et al., 2006).

Several SNSs (e.g., Facebook, Twitter, and YouTube) provide places to perform social learning, in which a collaborative community of individuals with similar interests and goals can share ideas to find solutions (Liccardi et al., 2007). Social learning helps to motivate students to complete educational tasks and offers a quick way for students to connect and collaborate by sharing information and ideas (Zaidieh, 2012). The use of learning management systems (LMS) and virtual learning environments (VTE) became widely popular in higher education institutions around the 1990s and still is today to some degree. These systems provided the tools required to increase the interaction among students and facilitate the distribution of educational material and information. However, the tools used in LMSs and VTEs provided less communication than traditional classrooms and often failed at motivating the students, tending to be somewhat teacher-centered from the perspective of students (Özmen & Atici, 2014). For this reason, the use of SNSs in education has been getting a lot of attention from researchers. SNSs can overcome certain limitations of LMSs and VTEs such as Moodle, Blackboard, and WebCT by promoting student engagement, motivation, interaction, and communication. While the use of SNSs in higher education seemed highly beneficial for students, some researchers had not recommended its use because of personal data security concerns and potential distractions within the learning environment. Some have also suggested merging SNSs with LMSs and VTEs to improve the quality of the learning process (Özmen & Atici, 2014).

The new developments in the educational system and the wide use of SNSs for educational purposes allowed distance education to become an efficient and effective form of learning among students. Distance learning does not require the individual to be physically present at a school or classroom, meaning that teachers and students are separated by either geographical or temporal distance (Wheeler, 2012). Depending on the time discrepancy, distance learning can be either synchronous or asynchronous. Synchronous distance learning occurs in real time for all participants, whereas asynchronous distance learning occurs without any real-time interaction from the participants (Hrastinski, 2008). A synchronous learning method can mitigate the sense of isolation and provide many social benefits to both teachers and students as they are actively participating and receiving feedback in real time. An asynchronous learning method usually provides a flexible way for teachers and students to collaborate on their schedule without being online at the same time (Midkiff & DaSilva, 2000; Murphy et al., 2011; Perveen, 2016). Table 3 presents some of the advantages and disadvantages of using synchronous and asynchronous distance learning. Both types of distance learning have their own merits and applications, thus educational institutions are likely to use hybrid learning methods in order to improve efficiency and provide flexibility. The earliest form of distance learning was achieved through correspondence courses in the nineteenth century and saw its popularity grow in the early part of the twentieth century. Throughout the next decades, the technological advances in radio, television, computers, and Internet became the key enablers of distance learning (Sumner, 2000).

Table 3 Advantages and disadvantages of synchronous and asynchronous distance learning

	Advantages	Disadvantages
Synchronous	• Enables real-time interaction and collaboration among all participants • Allows students to receive instant feedback and troubleshooting assistance • Mitigates sense of isolation due to increased connectivity between participants	• Restricts access to certain students due to technical and economic difficulties • Reduces cognitive effort of students due to short reflection time • Requires predetermined and rigid schedules
Asynchronous	• Enables interaction and collaboration without time barriers • Allows participants to learn and work on their own pace and schedule • Provides flexible and affordable access to distance education for all kinds of students	• Suffers from delayed feedback and nonimmediate assistance • Requires strategies to keep students motivated and engaged in learning activities • Requires self-discipline and maturity to guarantee effective learning

So, how does distance learning compare to traditional institutional learning? The answer is not clear or simple. Providing students the ability to do work on their schedule is not always a benefit and may subject students to heavier time constraints. According to some studies, traditional institutional learning was shown to be more effective and favored among students than distance learning (Hrastinski, 2008). The study by Stack (2015) showed evidence of no significant difference in the final exam scores of students during distance learning and traditional institutional learning. However, distance learning students were more prone to cheating due to increased availability of resources.

In early 2020, the closure of schools due to the COVID-19 pandemic forced thousands of educational establishments and educational agents to quickly transition to the digital age in an unplanned manner. This large disruption in the educational system impacted 94% of the world student population and up to 99% in low- and middle-income countries, reducing even further the learning opportunities for the poorer and most vulnerable population (United Nations, 2020). With the support of various central services and partner entities, schools and other learning institutions implemented forms of distance learning in order to guarantee student monitoring in classes and provide equal access to education. This led to a digital transformation of the educational system with completely new methodologies and strategies. While distance learning stimulates innovation within the educational system, it also highlights the challenges of delivering quality education and the need to not leave anyone behind (United Nations, 2020). During this time, the process of teaching was developed in an environment of great complexity and uncertainty, where more extensive and specialized knowledge was required to overcome the technological and social challenges associated with distance learning. This resulted in a need for training sessions and courses on the operation of ICTs and the use of video-conferencing software (e.g., Microsoft Teams, Google Meet, and Zoom) to deal with the difficulties faced by both students and teachers. Moreover, despite the efforts made to minimize economic and social inequalities, there was the need to provide the technical means capable of responding to the demands of this type of education. In some cases, students also manifest the lack of digital skills to effectively use the tools for distance learning. This is far more common among the poorer and most vulnerable students (United Nations, 2020).

With the widespread of distance learning, an important and pertinent question arises. What are the medium- and long-term consequences of distance learning in the psychological health and social development of young students? There is no concrete answer, and it is difficult to fully anticipate the problems and impacts that may arise. Perhaps the greatest impact is on the social level of young students because schools are places for the development of social skills based on interpersonal relationships. On the other hand, it is also possible to take advantage of distance learning. The digital transformation of the educational system brought new professional demands and led to the development of new cognitive skills in students. This can also provide students with the opportunity to improve their autonomy and organization skills while learning to be flexible and creative in the tasks they carry out.

4.2.1 Distance Learning in Engineering

During the last two decades, the adoption of distance education for both formal and nonformal learning activities has grown and quickly become popular among educational institutions and other professional bodies. While distance learning has been relatively effective in certain disciplines and fields of study, it may be considered not ideal for engineering at first glance. Some educational institutions use distance learning in less technical disciplines and completely avoid its use in engineering, resulting in much slower progress toward distance engineering education (Bilham & Gilmour, 1995; Gudimetla & Iyer, 2006). This is mostly because engineering education distinguishes from other disciplines due to being heavily based on science and mathematics, requiring the acquisition of technical and practical skills. Engineering disciplines can be difficult to teach through distance learning methodologies because of the need for a practical hands-on component and physical laboratory work (Banday et al., 2014; Bilham & Gilmour, 1995). Implementing distance learning in engineering education can also be a challenging task due to difficulties in identifying the skills required by students, evaluating the progress of students, identifying the appropriate teaching methods, and managing the teaching schedules of teachers (Anis, 2011). Also, some students may quickly lose motivation and interest in carrying out their tasks or may face difficulties due to limited digital skills when using computers and specific software. Other students may not be able to successfully retrieve and access the information, being unable to fully comprehend the tasks at hand. Therefore, distance learning resources must be not only informative but also both visually captivating and interactive enough to capture the interest of students and enable a further desire to learn (Gudimetla & Iyer, 2006). Several options have been introduced for distance learning programs to partially overcome the practical requirements of engineering education. Some of these options included the use of residential schools, weekend workshops, practical home experimental kits, on-the-job practical skills training programs, videos, and simulators (Bilham & Gilmour, 1995).

Advances in the development of ICTs allowed distance learning to be much more efficient and effective, enabling it to be implemented in engineering education. For instance, some institutions have developed their own virtual and remote-control laboratories that can be accessed by students to support their distance learning activities in various disciplines such as power electronics and electrical drives, control and automation, physics, and chemistry (Banday et al., 2014). Virtual laboratories allow students to perform interactive laboratory experiments using simulations on a computer, providing a cost-effective solution for real-time distance learning in engineering education. This can also include the use of virtual reality and augmented reality. On the other hand, remote-control laboratories enable students to remotely access and use physical laboratory equipment to perform experiments (Anis, 2011). The adoption of distance learning can provide numerous benefits to both engineering students and educational institutions. It has the potential to facilitate the reconciliation of work and study, reduce the costs of education services, enable the development of digital skills, and mitigate the overcrowding problem in public educational institutions (Anis, 2011). In developing countries, distance learning can extend engineering education to a much larger population including ethnic minorities, rural communities, and people with disabilities. According to Banday et al. (2014), a study has shown that distance learning resources and methods improved the performance of students in engineering education and most students considered them to be more productive than traditional classroom learning methods.

4.2.2 Distance Learning in Healthcare

For over four decades, distance education has been widely adopted in various healthcare areas, but its use has been mostly limited to health education and medical training (Knebel, 2001). It is involved as an effective way to provide accessible education and training to students in rural areas and allow students with disabilities and limited financial resources to complete their studies. This has been particularly important in developing countries to offer affordable healthcare services and extend health education to the population excluded from any forms of education and information due to economic, social, and cultural constraints. Often students in low-income and developing countries have no means of obtaining additional continuing education in traditional educational institutions due to problems such as overcrowding, poor infrastructures and high costs. Distance learning also provides health education and information to certain ethnic minorities and women with childcare obligations or undergoing pregnancy (Knebel, 2001). The applications of distance learning in health education can be found at the undergraduate level and postgraduate level. Distance learning at the undergraduate level is mainly introduced in the traditional curriculum or in extracurricular applications, while distance learning at the postgraduate level is usually applied to various applications of advanced education, specialist education and credited or noncredited continuing education (Mattheos et al., 2001).

Traditional training may present some temporal and spatial barriers to the development of well-trained and competent healthcare professionals. Trainees are often forced to reconcile work and training or go to specific locations for extended periods to perform training procedures, resulting in fatigue and a decrease in performance. These issues can be successfully addressed when using distance learning programs for healthcare training purposes, because it allows trainees to learn at their own pace and at their preferred schedule and location, potentially reducing instructional time and increasing their motivation and performance (Knebel, 2001). According to Gormley et al. (2009), undergraduate medical students value the use of distance learning resources in the acquisition of basic clinical skills and appear to have the digital skills necessary to effectively benefit from this type of resource. However, like distance engineering education, implementing distance learning programs in health education can be a challenging task, especially when used to train specific clinical procedures. These procedures are extremely skill-oriented and require intensive practical and supervised training (Knebel, 2001). Innovations in ICTs allowed major positive changes in distance learning methodologies for health education. The last generation of distance learning in health education was mostly characterized by VTEs, which allow total student interaction and participation (Mattheos et al., 2001). These VTEs are combinations of systems with numerous functionalities and services in the form of either proprietary software or open-source software (e.g., Moodle, Blackboard and WebCT). Computer simulations, more specifically the use of virtual reality and augmented reality, can further enhance the learning experience and enable students to practice their manipulation and dexterity skills using virtual patients (Ellaway & Masters, 2008).

4.3 Virtual Reality

The concept of virtual reality consists of a three-dimensional virtual environment generated using complex computer simulations, which allows the user to be completely immersed in the virtual environment (Christensen et al., 2016; Martín-Gutiérrez et al., 2017). Immersion is created and enhanced through various sensors and devices to successfully track head, body, and hand position (e.g., headset, goggles, and gloves), enabling the user to actively interact with the virtual environment and receive sensory stimuli in real time. This allows the virtual reality system to simulate the physical presence of the user in the virtual environment while covering the sensory, motoric, cognitive, and emotional domains (Martín-Gutiérrez et al., 2017). Virtual reality originated in the 1950s and its popularity grew in the late 1980s and 1990s is mostly used for educational and training purposes in healthcare and military applications. Other common applications include marketing and entertainment (Christensen et al., 2016; Trahan et al., 2019).

Early applications of virtual reality in healthcare were focused on the psychological health and well-being of patients, being extensively used as a therapy to address post-traumatic stress disorder (PTSD) and treat social anxiety or simple phobias such as agoraphobia, claustrophobia, acrophobia, and aviophobia. This can be achieved by exposing patients to realistic and life-like virtual emergency situations to reduce their psychological stress during a real emergency and improve their decision-making and problem-solving capabilities (Mandal, 2013; Trahan et al., 2019). Most of these applications have been successful at addressing the psychological health and well-being of patients, extending the use of virtual reality for training in a wide variety of fields (Trahan et al., 2019). However, despite the positive outcomes, there have been some concerns regarding social and psychological effects on users because of the addictive immersion obtained from virtual environments. Moreover, the continuous use of virtual reality devices for long periods can cause the user to feel disoriented and nauseated (Mandal, 2013). At present, technological advances in ICTs and affordable releases of commercially available virtual reality devices (e.g., Oculus Rift, HTC Vive, Valve Index) allowed virtual reality to quickly spread in the entertainment sector, more specifically in video gaming applications. This also provided new ways for the marketing and tourism sector to advertise and present products, brands, and destinations. Virtual reality in marketing and tourism offers much more interactivity and vividness than traditional media. The level of interest and loyalty of customers is increased by enabling them to virtually test products, experience lifestyles, and visit destinations (Grudzewski et al., 2018). According to Flavián et al. (2019), the use of virtual reality and augmented reality technologies can add significant value throughout the different stages of the customer experience (i.e., pre-experience, experience, and post-experience stages). For instance, these technologies help customers making better decisions in the pre-experience stage, provide customers a sense of enjoyment and engagement during the experience stage, and encourage customers to spread product recommendations through SNSs in the post-experience stage (Flavián et al., 2019). In education, the use of virtual reality can be considered as a natural evolution of computer-assisted instruction and provides similar benefits (Martín-Gutiérrez et al., 2017; Pantelidis, 2009). Like computer-assisted instruction, one of the main advantages of using virtual reality in education is its ability to motivate students and capture their attention. Most students hold a positive attitude toward the use of virtual reality in their learning process because it allows them to engage and interact with immersive virtual environments in exciting and challenging ways. This encourages students to be active learners and helps them visualize abstract ideas in detail and obtain results in real-time, improving their performance and cognitive skills, as well as their decision-making and problem-solving capabilities. Since virtual reality technology became much more accessible and affordable, it can offer new learning opportunities for students with disabilities and enable them to experience certain situations in ways that would be otherwise impossible without this technology (Martín-Gutiérrez et al., 2017). The use of virtual reality may not be appropriate in every discipline or teaching scenario (Pantelidis, 2009). For instance, it should be only considered when real-world training is dangerous or difficult to teach and when the interactions with the virtual objects are as motivating or more motivating than the interactions with the real objects. On the other hand, it should not be considered when the use of virtual environments can cause physical or emotional damage to the student when the interaction with real humans or objects is necessary, and when the use of virtual reality is too difficult or expensive considering the expected outcome (Pantelidis, 2009). Virtual reality with high interactivity and immersion has shown to be more effective in improving post-intervention knowledge and skills when compared to traditional education or even distance education (Kyaw et al., 2019).

There have been clear indications of increasing convergence between virtual reality and SNSs (O'Brolcháin et al., 2016). Video games have already taken aspects of SNSs in the sense that they provide means for communication and a virtual space for social interactions. Not only that, but SNSs are also taking on aspects of video games by quantifying normal activities and rewarding users for tasks they complete in their everyday life (i.e., gamification). As this convergence increases and virtual reality takes the role of SNSs by providing real-time communication and social interaction in immersive virtual environments using virtual avatars, some ethical issues of privacy and autonomy may arise (O'Brolcháin et al., 2016). Threats to user privacy are further aggravated because people leave a much larger digital footprint by carrying out more tasks and activities online with the increased convergence between virtual reality and SNSs. This can compromise user information as data can easily be accessed by a large group of unauthorized and malicious people, including government agencies, organizations, and hackers. Sometimes users are completely unaware of the amount of personal information they are revealing and making available online. Sound and video recordings captured by mobile devices for the creation of realistic virtual avatars can be easily shared and made public without the consent of the user. Moreover, even people outside of any social network may end up having their privacy compromised via experiences shared with friends or family members. The loss of informational, physical, and associational privacy can have serious issues in the mental health and social life of users, often resulting in isolation, discrimination, and reduction of job opportunities (O'Brolcháin et al., 2016). Threats to user autonomy are centered on the ability of users to access relevant information and make decisions according to their values and beliefs. The content displayed to the user in SNSs is often personalized according to perceived personal preferences or purely based on the interests and recommendations of friends. This content filter significantly restricts the range of information available to the user. Large-scale companies have the means to manipulate or select the information being presented to the user in SNSs, influencing the behavior and emotional state of users, as well as the public opinion toward adopting certain attitudes. Also, some users may also be unable to act as their authentic selves and feel pressured to conform with the social norms and popular trends. These norms and trends are set by individuals who spend large amounts of time in SNSs and can easily influence and manipulate others with illusions of perfect lifestyles (e.g., the so-called influencers). Both concepts of virtual reality and social networks are known to be potentially very addictive to the user. Therefore, it is safe to assume that the increased convergence between virtual reality and SNSs will only further increase the risk of addiction. The addictive nature of the virtual environment forces the development of bad habits and behaviors (e.g., violence and gambling), which may carry over to the real world (O'Brolcháin et al., 2016). It is worth mentioning that the convergence of virtual reality and SNSs has the potential to provide benefits to autonomy by enabling users to act freely online as their authentic selves. The providers of virtual and SNSs need to ensure data protection and transparency in order to mitigate the threats to privacy and autonomy (O'Brolcháin et al., 2016).

Mixed reality is seen as the process of merging real environments and virtual environments. To put this into perspective, it is essentially the middle ground between reality and virtual reality, encompassing the concepts of augmented reality and augmented virtuality (Flavián et al., 2019). The less explored and known concept is augmented virtuality, which integrates real objects in the virtual environment and allows them to interact with the virtual elements in real time. On the other hand, augmented reality overlays the real environment with virtual objects and additional information in precise positions. The virtual objects are embedded into the real environment and can interact with it, forming a mixed reality environment. It is designed to enhance the user perception of the real environment in real time and does not generate a functional three-dimensional virtual environment. Unlike virtual reality, users can easily distinguish between the real environment and virtual elements (Christensen et al., 2016; Martín-Gutiérrez et al., 2017). Besides, the user does not need to use a specific device or wear special gear, instead, augmented reality can be achieved by using mobile devices such as smartphones and tablets. As represented in Fig. 2, the reality-virtuality continuum is a continuous scale that shows the variations between mixed environments and completely real and virtual environments, encompassing augmented reality, augmented virtuality, and virtual reality. The concept of the reality–virtuality continuum was originally introduced by Paul Milgram and Fumio Kishino in 1994 to represent classes of real and virtual objects in any display situation. Environments consisting entirely of real objects are displayed at one end of the continuum, while purely virtual environments are displayed at the other end. Any

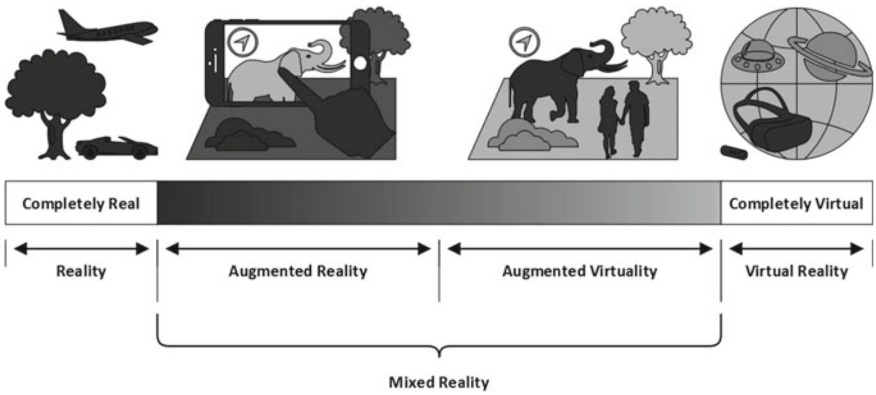

Fig. 2 Reality–virtuality continuum showing variations of real, mixed, and virtual environments

environment containing a combination of both real and virtual objects is displayed between the two ends of the continuum (Milgram & Kishino, 1994).

Augmented reality started to be applied in healthcare applications to enhance clinical procedures and in military applications to display aircraft instrumentation or provide three-dimensional information to soldiers on the battlefield. The educational sector may benefit the most from the use of augmented reality as it allows students to visualize abstract ideas and virtual objects coexisting with the real environment, providing new opportunities to improve teaching and learning processes (Martín-Gutiérrez et al., 2017; Mekni & Lemieux, 2014). Augmented reality has also been widely used in entertainment and marketing to create video games and as an engaging and appealing way to provide additional information to the user in real-time and improve the shopping experience. A simple example of its use in marketing is the well-known QR-Code, which can provide additional information about a product upon being analyzed using the camera of a mobile device (Mekni & Lemieux, 2014). In manufacturing applications, augmented reality can be used to enhance the perception of employees in a product assembly line and aid them with various assembly tasks through detailed instructions and three-dimensional animations. This can significantly reduce the amount of training required for assembly line personnel and contribute to reductions in product assembly time and product lead time. Navigation can be enhanced with augmented reality by integrating an overlay with useful GPS information into phone cameras (Christensen et al., 2016). It can be used in car heads-up displays to warn drivers about potential dangers and provide information about routes and landmarks. This can be applied in tourism to enhance the visitor experience in guided tours. Augmented reality can also have applications in urban planning and civil engineering to assist the methodologies used for construction, inspection, and renovation of buildings and structures (Mekni & Lemieux, 2014).

The virtual reality and augmented reality industries are going through an exciting stage and technology have become accessible to both customers and industry, allowing the creation of new start-ups, projects, and business ideas. These industries spread across Europe, Asia, and the USA, focusing on activities ranging from R&D to hardware manufacturing and software creation (Bezegová et al., 2017). European countries are mainly invested in academic virtual and augmented reality research, which plays an important role in the development of new technologies and the creation of software for a wide variety of applications. The Asian market has been growing at high rates by being active in the mass manufacturing of virtual and augmented reality hardware as it benefits from competitively priced labor. The USA currently leads the global virtual and augmented reality market in terms of R&D for hardware and software with the most active venture capital funds to invest in early start-ups (Bezegová et al., 2017). Furthermore, the economic activity associated with the commercial revenues obtained from selling virtual and augmented reality technology contributes to the GDP growth (Christensen et al., 2016).

5 Conclusion

The work carried out by engineers is often viewed as purely technical and without any social implications, when in fact, their work has major impacts on society, economy, and environment. Engineers are responsible for creating and designing solutions to complex problems of society. The various tools and devices developed by various engineering fields have the potential to significantly shape societies around the world by improving the quality of life, contributing to economic growth, and transforming the environment. These achievements and accomplishments are motivated by representations of what is efficient and effective in the real world, which essentially translates to what is good and productive in society. This means that the responsibility of engineers is fundamentally ethical and social.

A major achievement of engineering was in the field of telecommunications, which revolutionized the way individuals and distinct systems communicate with one another. Throughout history, the applications of telecommunications have been immense, especially in electric power systems and SGs. Therefore, the contents of this chapter started by briefly introducing the history and principles of telecommunications, as well as various aspects of signal transmission, analog and digital communication, signal modulation, and communication channels. Also, this chapter has also addressed the importance of telecommunications on engineering systems and provided a brief overview of communication protocols and types of networks.

With the widespread of various ICTs in modern society, it became nearly impossible for humans to perform some tasks or even think about a life without the benefits provided by these tools and devices. Moreover, their integration into the educational system also offered the opportunity to improve the quality of education, acquisition of basic skills. The role and social implications of computer networks and social networks have been addressed in this chapter with a special focus on the most evident social, economic, and environmental impacts of ICTs. As expected, the transition to the digital era using ICTs does not occur at the same pace everywhere and for everyone around the world, meaning that low- and middle-income countries and certain groups such as ethnic minorities, rural communities, and people with disabilities are often left behind. Because of this, the impacts of ICTs in developing countries have been addressed throughout the chapter. The combination of ICTs with SNSs for educational purposes allowed distance education to finally become an efficient and effective form of learning among students, especially in the fields of engineering and healthcare. The concept of distance education has been introduced and discussed comprehensively, providing a brief comparison between synchronous and asynchronous distance learning. This form of education has been crucial in developing countries to provide affordable healthcare services and extend health education to the population. Distance education has been viewed as being unsuitable for engineering education because of the need for practical hands-on component and physical laboratory work. However, the advances in ICTs allowed educational institutions to effectively develop virtual and remote-control laboratories and rely on virtual reality and augmented reality technologies in order to enable real-time distance learning.

The concept of virtual reality and the variations of mixed reality in the reality–virtuality continuum have been introduced in detail, while providing an overview of the numerous applications of virtual and augmented reality and addressing the increasing convergence between virtual reality and SNSs.

In conclusion, the numerous impacts of telecommunications and ICTs comprehensively addressed and discussed in this chapter show that the work performed by engineers has major implications in societies at the social, economic, and environmental levels. The social impacts are worldwide, but are much more pronounced in developing countries. Therefore, engineers must not view their work as purely technical. The introduction of new and more effective ways of promoting the social responsibility of engineers is important to mitigate the harmful effects of technology and guarantee a positive influence on society.

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Analytical Optimization Applied to Social Aspects and Public Policies

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Abstract System engineering has been gaining attention around the world due to its interdisciplinary/interface approach in dealing with complex system design, modeling, and optimization. In this chapter, the basics of system optimization are presented and discussed. Furthermore, some applications on public services and policies are explored, showing how system optimization may have social implications in human life.

1 Introduction

The idea of doing things more efficiently is probably closed linked to human, society and economic evolution. Millions years ago, in the prehistory, the *homo-sapiens* have already been seeking a more efficient way to hunt, to farm, to build and to protect home. The experience and findings of these prehistoric humans led to the agriculture, civilization and societies. Furthermore, as individual and society do not have free disposal and unlimited resources, they should also be allocated in such a way to increase social welfare.

Optimization started from the earliest stages of human civilization, Du et al. (2009) have stated in their *History of Optimization* paper. Indeed, optimization may be understood as finding a new operation point that is better than the actual one. During much time in history, the mathematical formulation was not employed to model systems behavior, and decisions were usually made based on observation and simulation, as well as trial and error.

The Merriam-Webster dictionary[1] generally defines optimization as *an act, process, or methodology of making something (such as a design, system, or decision)*

[1] https://www.merriam-webster.com/.

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as fully perfect, functional, or effective as possible. In a more specifically definition, it states optimization as *the mathematical procedures (such as finding the maximum of a function) involved in this* act, process, or methodology of making something as fully perfect, functional, or effective as possible.

In this chapter, we will review the mathematical concepts of optimization, as well few applications of such methodologies on public services and policy. This chapter has two main goals here: (i) present general and introductory formulation of mathematical optimization; and (ii) show that these approaches, although usually linked to hard sciences, might have numerous applications onto soft sciences, which may help social sciences researchers and practitioners to understand the relationships that drives to decision seeking social welfare.

1.1 Mathematical Optimization

Optimize usually drives to better decisions that may save resources and/or maximize the impact on individuals' life. While optimization has been empirical during most of human history, the series of abstractions that led to mathematical sciences sometime between 1000 and 3000 B.C., have been used by physical, biological, and social scientists to describe the behavior of nature and animal relationships. Such abstractions, written down as axioms and equations relationships, allow scientists and practitioners to understand systems' dynamics, looking for optimizing their operations. That is, the use of applied mathematics in systems modeling and its dynamics investigation has been increasing in the last centuries, which allowed a great advance in mathematical optimization.

The establishment of modern calculus by Gottfried Wilhelm von Leibniz and Isaac Newton in the late 17th century may be seen as the first mathematical optimization approach, where a point on a function with its first derivative equal to zero may give either a maximum or minimum of such function. This idea of optimization has evolved over and time lots of mathematical theorems and demonstrations have led to sophisticated formulations for the necessary and sufficient conditions of an optimal solution. However, when dealing with problems with many (decision) variables, one is often able to find out only numerical solutions, instead a closed formula that solves all problems with similar characteristics.

Early iterative methods have been proposed in 18th century by Isaac Newton and Johann C.F. Gauss, practical usage of such an approach felt on the computational limitation power. Over the years, numerous contributions to numerical optimization techniques have been offered in the literature. From the steepest descent method discussed by Cauchy (1847) to Newton's method and its simplification to quasi-Newton approaches Gill et al. (1981). With the advance of computational power since the mid 20th century, researching in optimization techniques have attracted increasing attention from practitioners and researchers around the world, leading to numerous methods and approaches for seeking optimal solution, such as linear and quadratic programming, penalty and interior-point methods, as well as heuristics and evolutionary approaches, among many others.

The advance of optimization approaches and their applications opened a great opportunity of applying such techniques in problems that may impact social welfare. Maybe, its most prominent use in social applications refers to economics, where optimization is applied to estimate statistics economic models and econometric parameters in applied social sciences, so that economists may study social distributions and propose policies that may improve human welfare. Nevertheless, other applications also impact social life, such as logistics, scheduling, and costs optimization, among many others.

Next, we briefly review the basic concepts of continuous optimization theory, as well as some numerical approaches to search for numerical optimal solutions. Far from the present a deep discussion on optimization theory, the aim here is to discuss a general view of optimization techniques and how they can be used for the benefit of humankind. As an introductory discussion, hot topics such as stochastic and discrete optimization are not covered here, as well as evolutionary approaches.

2 Optimization Basics

Mathematical optimization has three main characters: the objective function f, the decision variables x and, eventually, system and/or operational constraints g and h, respectively.

Here, we consider the objective function f as map that, when applied to an decision variables x results in a scalar $f(x)$. The general optimization problem refers to looking for the value x_* that makes $f(x_*)$ reach it minimum value.[2] Sometimes, the problem under analysis may have physical constraints g and/or operational constraints h. Similarly to f, constraints g and h maps the decision variables x onto $g(x)$ and $h(x)$. These numbers can then be compared to physical and operational constraints so that the solution x_* makes sense in practice, or, in mathematical jargon, is feasible.

In what follows, we briefly discuss the mathematical concepts of unconstrained and constrained optimization. The approach we explore here is based on the Taylor series approximation of a continuous function (at least) twice differentiable. Although there exist many approaches for discussing optimization theory, considering Taylor series expansion in a sufficiently small interval, we may have a fair (good) representation of the function to be optimized with terms up to the second order. It makes the understanding of optimization conditions easier, and we can link it directly to numerical solutions through Newton's method.

[2] Throughout this chapter, optimization is always considered to minimize an objective function. If one wants to work with a maximization problem, one must change the sign of the objective function, and all discussion presented in this section holds true.

Readers not aware of Taylor expansion definitions is also able to follow the discussion presented in this section. Note, however, that there are an enormous amount of references in the literature presenting and discussing Taylor series expansion.

Although we tried to keep formal mathematical concepts and notation to the minimum, prior concepts of algebra and numerical methods will help the readers to follow the content presented here. If the reader do not feel comfortable in following the mathematical discussion, one may skip this chapter.

2.1 Unconstrained Optimization Basics

We start the discussion by considering an univariate function $f(x) : \mathbb{R} \mapsto \mathbb{R}$, which we aim to find the value of the *decision variable* x_* inside a $[a, b] = \{x \in \mathbb{R} | a \leq x \leq b\}$ that minimizes $f(x)$. Such an point x_*, if exists, is defined as the *minimizer* of $f(x)$. Furthermore, $f(x)$ is usually named *objective function*.

In seeking such a point, one may look into the Taylor series expansion of $f(x)$. Taylor series expansion is defined as an infinite sum of terms that are expressed based on the function's derivatives at a single point. Such an expansion is able to represent any continuously differentiable function as an polynomial function.

Consider the univariate objective function $f(x) : \mathbb{R} \mapsto \mathbb{R}$ (at least) twice differentiable in a small (enough) interval $[a, b] = \{x \in \mathbb{R} | a \leq x \leq b\}$. If x_* and x are inside such an interval, $f(x)$ may be written (at least) by its second order Taylor series expansion as[3]:

$$f(x) = f(x_*) + f'(x_*)(x_* - x) + \frac{1}{2} f''(x_*)(x_* - x)^2 \tag{1}$$

Furthermore, if the first derivative $f'(x_*) = 0$, and the second derivative $f''(x_*) > 0$, for all $x \neq x_*$, Eq. (1) becomes:

$$f(x) = f(x_*) + 0 + \text{positive number} \tag{2}$$

From Eq. (2), one can see that $x = x_*$ defines a minimizer of $f(x)$. Based on the second order Taylor series expansion and the assumptions stated above, we can define the nature of a point in an interval in more formal way. That is, a point x in the interval I is:

- a ***critical (or stationary) point*** of $f(x)$ if there exist $f'(x)$ and it is equal to zero.
- a ***global minimum*** of $f(x)$ over I if $f(x) \leq f(x)$ for all $x \in I$;
- a ***local minimum*** of $f(x)$ if there exist a positive number δ, so that $f(x_*) \leq f(x)$ for all $x \in I$, and $x_* - \delta \leq x \leq x_* + \delta$;

[3] In such an approximation, high order terms of Taylor series expansion is considered negligible residual due to the small (enough) interval $[a, b] = \{x \in \mathbb{R} | a \leq x \leq b\}$.

- a ***strict local minimum*** of $f(x)$ if there exist a positive number δ, such that $f(x_*) < f(x)$ for all $x \in I$, and $x_* - \delta \leq x \leq x_* + \delta$ e $x \neq x_*$;

The statements above defines that a necessary condition for a minimizer refers to a vanishing first derivative of the objective function, i.e., $f'(x_*) = 0$. This condition is important as it is equivalent to find the root(s) of $f'(x_*)$, enabling the use (and improve) the well known numerical methods for doing so, as we will further discuss.

Note, however, that $f'(x_*) = 0$ does not guarantee a minimum of $f(x)$. For understanding the nature of x, one must look at its second derivative, so that $f''(x_*) >= 0$ is a sufficient condition to make x_* a minimizer of $f(x)$. Again, considering statements above, a point x_* in the interval I is:

- a ***global minimum*** of $f(x)$ over I if $f'(x_*) = 0$ and $f''(x) \geq 0$ for all $x \in I$;
- a ***local minimum*** of $f(x)$ if there exist a positive number δ, so that $f'(x_*) = 0$ and $f''(x) >= 0$ for all $x \in I$, and $x_* - \delta \leq x \leq x_* + \delta$;
- a ***strict local minimum*** of $f(x)$ if there exist a positive number δ, such that $f'(x_*) = 0$ and $f''(x) > 0$ for all $x \in I$, and $x_* - \delta \leq x \leq x_* + \delta$ e $x \neq x_*$;

The univariate minimization case above may be easily extended to the multivariate function $f(x) : \mathbb{R}^n \mapsto \mathbb{R}$ by introducing the gradient (∇f) and Hessian ($\nabla^2 f$) of $f(x)$. Considering the vector of decision variables $x^T = [x_1, x_2, \ldots, x_n]$, the gradient of $f(x_0)$ is defined by a vector of first order derivative related to each component $x_i \in x$. That is:

$$\nabla f(x)^T = \begin{bmatrix} \frac{\partial f}{\partial x_1} & \frac{\partial f}{\partial x_2} & \cdots & \frac{\partial f}{\partial x_n} \end{bmatrix} \tag{3}$$

As for the Hessian, it is defined as the second derivative of the objective function related to decision variables. That is:

$$\nabla^2 f(x) = \begin{bmatrix} \frac{\partial^2 f}{\partial x_1^2} & \frac{\partial^2 f}{\partial x_1 \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_1 \partial x_n} \\ \frac{\partial^2 f}{\partial x_2 \partial x_1} & \frac{\partial^2 f}{\partial x_2^2} & \cdots & \frac{\partial^2 f}{\partial x_2 \partial x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial^2 f}{\partial x_n \partial x_1} & \frac{\partial^2 f}{\partial x_n \partial x_2} & \cdots & \frac{\partial^2 f}{\partial x_n^2} \end{bmatrix} \tag{4}$$

Thus, if an multivariate function $f(x) : \mathbb{R}^n \mapsto \mathbb{R}$ (at least) twice differentiable in a small (enough) interval $[a, b] = \{x \in \mathbb{R} | a \leq x \leq b\}$. If x_* and x are inside such an interval, such that $\Delta x = x_* - x$, $f(x)$ may be written (at least) by its second-order Taylor series expansion as:

$$f(x) = f(x_*) + \nabla f(x_*)^T \Delta x + \frac{1}{2} \Delta x^T \nabla^2 f(x_*) \Delta x \tag{5}$$

Considering Eq. (5), the cost of first-order approximation is

$$f(x + \Delta x) - f(x_*) \approx \nabla f(x_*)^T \Delta x \tag{6}$$

If x_* is a local minimum of $f(x)$, a noise in Δx results in $\nabla f(x_*)^T \Delta x \geq 0$. Thus, $\nabla f(x_*) = 0$ is the *first-order necessary condition* for x_* defining a local minimum of $f(x)$.

When looking to the cost of second-order approximation, one has:

$$f(x + \Delta x) - f(x_*) \approx \nabla f(x_*)^T \Delta x + \frac{1}{2} \Delta x^T \nabla^2 f(x_*) \Delta x \tag{7}$$

If x_* is a local minimum of $f(x)$, $\nabla f(x_*) = 0$ and a noise in Δx results in $\frac{1}{2} \Delta x^T \nabla^2 f(x_*) \Delta x \geq 0$. Thus, $\Delta x^T \nabla^2 f(x_*) \Delta x \geq 0$ is the *second-order necessary condition* for x_* defining a local minimum of $f(x)$.

Interestingly, if the first-order necessary condition $\nabla f(x_*) = 0$ is satisfied, having a positive-definite Hessian is a *sufficient condition* for x_* defining a local minimum of $f(x)$. That is, $f(x_*)$ strictly increases with small variations from x_* when $\Delta x^T \nabla^2 f(x_*) \Delta x > 0$.

A special case where necessary condition defines global minimum refers to the convex functions. A function $f(x) : \mathbb{R}^n \mapsto \mathbb{R}$ is defined as convex if the line segment between any two points on the graph of such function lies above the graph between the two points. Mathematically, for two points $x_1 \neq x_2$ and a scalar α:

$$f\left(\alpha x_1 + (1 - \alpha) x_2\right) \leq \alpha f(x_1) + (1 - \alpha) f(x_2) \tag{8}$$

For a convex function, such as Eq. (8), the Hessian of the objective function is always positive-definite, so that local minimum is also global. Thus, in this case, $\nabla f(x_*) = 0$ is both necessary and sufficient conditions.

The necessary and sufficient conditions are, indeed, the basics of optimization theory and many of numerical optimization algorithms, such as line-search and trust-region numerical approaches. Departing from these, we can establish the basics for constrained optimization, as I discuss next.

2.2 Constrained Optimization—Part 1: Equality Constraints

In the previous section, we have discussed the basics of unconstrained optimization theory based on derivative approach. In analyzing real world problems, however, restrictions may arise based on modeling assumptions. In these cases, searching for a minimum of the objective function is usually constrained by a feasible region usually defined by a set of equations.[4] Thus, the optimization problem may be generally written as:

$$\begin{aligned} \min \quad & f(x) \\ \text{subject to} \quad & g_i(x) = 0, \quad i = 1, 2, \ldots, m \end{aligned} \tag{9}$$

[4] Such equations may represent equality and inequality constraints.

When dealing with a problem like one of Eq. (9), one of the usual approach is the use of Lagrange multipliers λ_j, one for each constraint. Indeed, Joseph-Louis Lagrange have shown that, considering $\nabla g(x)^T = \left[\nabla g_1(x)\ \nabla g_2(x)\ \cdots\ \nabla g_m(x)\right]$, there exist unique Lagrange multipliers $\lambda^T = \left[\lambda_1\ \lambda_2\ \cdots\ \lambda_m\right]$ so that:

$$\nabla f(x) = \lambda^T \nabla g(x) \tag{10}$$

Lagrange multipliers are easier understandable considering feasible variation overview, as shown by RAO (2019). Consider, for instance, the problem with $n = 2$ decision variable and $m = 1$ constraint:

$$\begin{aligned} \min \quad & f(x_1, x_2) \\ \text{subject to} \quad & g(x_1, x_2) = 0 \end{aligned} \tag{11}$$

The first order necessary condition for a minimizer (x_{1*}, x_{2*}) may be written as $\nabla f^T df = 0$, i.e.:

$$\frac{\partial f}{\partial x_1} dx_1 + \frac{\partial f}{\partial x_2} dx_2 = 0 \tag{12}$$

At the minimizer, $g(x_{1*}, x_{2*}) = 0$, so that its first order Taylor series expansion, given by:

$$g(x_{1*} + \Delta x_1, x_{2*} + \Delta x_2) \approx \frac{\partial g}{\partial x_1} dx_1 + \frac{\partial g}{\partial x_2} dx_2 = 0 \tag{13}$$

defines the feasible variation of decision variables considering the constraint $g(x_1, x_2) = 0$. That is, a small step dx_1 must be followed by a step:

$$dx_2 = -\frac{\partial g / \partial x_1}{\partial g / \partial x_2} dx_1 \tag{14}$$

to keep $g(x_1, x_2) = 0$. Thus, by plugging Eq. (14) into the first order necessary condition (12) at (x_{1*}, x_{2*}), one has:

$$\left(\frac{\partial f}{\partial x_1} - \lambda \frac{\partial g}{\partial x_1} \right) dx_1 = 0 \tag{15}$$

with

$$\lambda = \frac{\partial f / \partial x_2}{\partial g / \partial x_2} \tag{16}$$

Thus, for the example of $n = 2$ and $m = 1$, the first order necessary conditions for a minimizer (x_{1*}, x_{2*}) are:

$$
\begin{aligned}
\frac{\partial f}{\partial x_1} - \lambda \frac{\partial g}{\partial x_1} &= 0 \\
\frac{\partial f}{\partial x_2} - \lambda \frac{\partial g}{\partial x_2} &= 0 \\
g(x_1, x_2) &= 0
\end{aligned}
\tag{17}
$$

In more general terms, given the optimization problem (9) with $x \in \mathbb{R}^n$ and $\lambda \in \mathbb{R}^m$, we can define the Lagrange function $L(x) : \mathbb{R}^{n+m} \mapsto \mathbb{R}$, such that:

$$
L\,(x, \lambda) = f(x) - \lambda^T g(x) \tag{18}
$$

and the first order necessary conditions is given by $\nabla_{(x,\lambda)} L = 0$, where the subscripts $\nabla_{(x,\lambda)}$ refers to the derivative of Lagrange function (18) related to x and λ. As for the second order necessary condition, it is given by $y^T \nabla^2_{xx} L y \geq 0$ for any y, i.e., the second derivative of the Lagrange function related to the decision variable x is positive-semidefinite. As in the unconstrained case, if $y^T \nabla^2_{xx} L y > 0$ for any y, the Hessian is positive-definite and x_* defines a local minimum of the problem (9).

2.2.1 The Lagrange Multiplier

In the previous Section, the first and second-order conditions of equality constrained optimization problem of Eq. (9) was discussed with the help of the Lagrange function and multipliers. We could interpret the Lagrange multipliers λ_i as a penalty on the objective function when constraints fails to become $g_i(x) = 0$. Thus, intuitively, these scalars define a "*price*" to either pay or reward on changing the bounds of equality constraints.

To make the discussion simple, consider a equality constrained optimization problem with only one constraint, i.e., $m = 1$. Consider also a translational variable y, such that $g(x) = \hat{g}(x) - y = 0$, Thus, equation (9) may be rewritten as:

$$
\begin{aligned}
\min \quad & f(x) \\
\text{subject to} \quad & \hat{g}(x) - y = 0
\end{aligned}
\tag{19}
$$

The first-order necessary condition of the problem (20) are:

$$
\begin{aligned}
\frac{\partial f}{\partial x_i} - \lambda \frac{\partial \hat{g}}{\partial x_i} &= 0, \quad i = 1, 2, ..., n \\
g(x) &= 0
\end{aligned}
\tag{20}
$$

If one wants to quantify the "*price*" to pay/reward in slightly changing the boundary of constraint $\hat{g}(x)$, one has $dy - d\hat{g} = 0$, or $dy = \nabla \hat{g}^T dx$. Substituting the first-order optimally condition, we have:

$$\frac{\partial \hat{g}}{\partial x_i} = \frac{1}{\lambda}\frac{\partial f}{\partial x_i} \quad i = 1, 2, ..., n \tag{21}$$

With Eq. (21), dy may be written as:

$$dy = \frac{1}{\lambda}\sum_{i=1}^{n}\frac{\partial f}{\partial x_i}dx = \frac{df}{\lambda} \tag{22}$$

Equation (22) states that, at optimum, $\lambda_* = df_*/dy$, or alternatively, $df_* = \lambda_* dy$, so that λ_* is the price to pay/reward for relaxing the boundary of $\hat{g}$ through y. In other words, if $\lambda_* > 0$, relaxing the $\hat{g}$ by a small dy worsens the objective function; if $\lambda_* < 0$, relaxing the $\hat{g}$ by a small dy improves the objective function; finally, if $\lambda_* = 0$, relaxing the $\hat{g}$ by a small dy does not impact the objective function. This is why the Lagrange multipliers are often referred as marginal cost, and widely used in sensitivity analysis of constrained optimization problems.

2.3 Constrained Optimization—Part 2: Inequality Constraints

In the previous section, we have discussed the basics of equality constrained optimization was discussed which is usually considered for system modeling constraints. In real world applications, however, practical restrictions may arise based on operational requirements, which is usually represented by inequality constraints. In this case, the optimization problem may be generally written as:

$$\begin{aligned} \min \quad & f(x) \\ \text{subject to} \quad & g_i(x) = 0, \quad i = 1, 2, ..., m \\ & h_j(x) \geq 0, \quad j = 1, 2, ..., p \end{aligned} \tag{23}$$

We stick with RAO (2019) to explore the features of the inequality constraints by defining the variables $z^T = \left[z_1\ z_2\ \cdots\ z_p\right]$, so that problem (23) may be rewritten as:

$$\begin{aligned} \min \quad & f(x) \\ \text{subject to} \quad & g_i(x) = 0, \quad i = 1, 2, ..., m \\ & h_j(x) - z_j^2 = 0, \quad j = 1, 2, ..., p \end{aligned} \tag{24}$$

Note that problem (24) is similar to the problem (9), except for the variable z. Thus, the Lagrange function for the problem (24) is given by:

$$L(x, \lambda, \mu, z) = f(x) - \lambda^T g(x) - \mu^T \left[h(x) - z^2\right] \tag{25}$$

where $\mu^T = \left[\mu_1\ \mu_2\ \cdots\ \mu_p\right]$ and $z.^2$ refers to the element-wise square the vector z.

Following the constrained approach discussed in the previous section,[5] the first-order necessary conditions for the problem (23) are given by:

$$\begin{aligned}
\nabla_x L &= \nabla f(x) - \lambda^T \nabla g(x) - \mu^T \nabla h(x) = 0 \\
\nabla_\lambda L &= g(x) = 0 \\
\nabla_\mu L &= h(x) - z.^2 = 0 \\
\nabla_z L &= \mu_j z_j = 0, \quad j = 1, 2, ..., p
\end{aligned} \tag{26}$$

First-order necessary conditions (26) for inequality constraints problem (23) states that, at an optimal solution, either z_j or μ_j is zero, so that they define the sets of active and inactive inequality constraints. That is, if $z_j = 0$, there is no slack on the j-th inequality constraint, so that $h_j(x) = 0$, $\mu_j \geq 0$ and such a constraint is said active. Nevertheless, if $z_j > 0$, the j-th inequality constraint in not at its boundary, so that $h_j(x) > 0$, $\mu_j = 0$ and such a constraint is said inactive.

Based on this concept, Karush (1939) and Kuhn and Tucker (1951) extended the necessary conditions of equality constraints optimization problem to plugin inequality constraints, generalizing the method of Lagrange multipliers. By substituting $s_j = z_j^2$ and defining the set of active inequality constraint at a x as $W(x)$, the Karush-Kuhn-Tucker (KKT) first order conditions my be written as:

$$\begin{aligned}
\nabla f(x) - \lambda^T \nabla g(x) - \mu^T \nabla h(x) = 0 & \\
g_i(x) = 0, &\quad i = 1, 2, ..., m \\
h_j(x) = 0, &\quad j \in W(x) \\
\mu_j \geq 0, &\quad j \in W(x) \\
\mu_j = 0, &\quad j \notin W(x) \\
\mu_j z_j = 0, &\quad j = 1, 2, ..., p
\end{aligned} \tag{27}$$

As in the equality constraint case, the the second-order necessary condition is given by $y^T \nabla_{xx}^2 L y \geq 0$ for any y, i.e., the second derivative of the Lagrange function related to the decision variable x is positive-semidefinite. Again, if $y^T \nabla_{xx}^2 L y > 0$ for any y, the Hessian is positive-definite and x_* defines a local minimum of the problem (23).

2.4 Duality

The constrained optimization problem discussed in Sect. 2.2, known as the primal, has an complementary constrained extremum problem known as dual problem. That is, given the problem (9), we can write a maximization problem with the same data based

[5] Taking the derivative of the Lagrangian function related to decision variables x, as well as λ, μ and z.

on Lagrangian function (18). By defining the dual function $q(\lambda) = \inf_x L(x, \lambda)$, the dual of the problem (9) is given by:

$$\max \quad q(\lambda) = \inf_x L(x, \lambda) \tag{28}$$

In Eq. (28), $\inf_x$ refers to the global minimum of Lagrange function over decision variables x. If such an global minimum exists, $q(\lambda) > -\infty$, and the dual problem (28) is a lower bound for the primal problem (9). Indeed, we can show that for any $\bar{x}$ and $\bar{\lambda}$, we have;

$$q(\bar{\lambda}) = f(x) - \bar{\lambda}^T g(x) \leq f(\bar{x}) - \lambda^T g(\bar{x}) \leq f(\bar{x}) \tag{29}$$

In some special cases, such as convex problems, if x_* and λ_* are solutions for the problems (9) and (28), respectively, $q(\lambda_*) = f(x_*)$. The features of the primal-dual relationship has been extensively used to develop and improve numerical algorithms to search for optimal solutions of constrained problems. A deeper discussion on duality theory are extensively provided in the traditional optimization literature, as the ones suggested in this chapter.

3 Optimization Applications on Public Services and Policy

With the evolution of numerical optimization methods—which we will introduce in the Appendix—and the advance of computational power since the mid 20th century, optimization has been gaining a vast field of social applications. Such applications might be either direct use of optimization algorithms in system optimization, or indirect consideration of optimal solutions in decision making.

Direct applications usually refers to engineering problems, such as routes optimization to minimize fuel consumption, traffic (lights) control to minimize congestion, electrical power grid minimize energy prices, material development to minimize aircraft weight, supply chain analysis to minimize delivery delays, among many many other applications.

As for indirect use of optimization, we refer to methods that are usually used to help decisions such as data analysis and policymaking. In what follows, the use of optimization in social statistics, efficiency analysis for utility companies, as well as some machine learning models for classification and prediction are briefly discussed to illustrate optimization applied in social aspects and public policies.

3.1 Social Statistics

Data analysis plays a crucial role in understanding society. Since 19th century, when statistics started to be applied in practice, data have been collected, stored, and processed so one can extract meaningful information for decision making. With the advance of statistical tools and computational power, we are now able to store and process a massive quantity of data and model a system with a bunch of statistical approaches available.

Statistical theory is a topic of applied mathematics used to model and analyze random variables. Roughly, in statistical modeling, the data is considered to have a probability density function (PDF) that is able to describe regions of the function domain that the variable is observed more or less often. Theoretically, such an PDF contains all information about the random variable, so that one is able to estimate its location and spread, enabling good decisions in, for instance, policy and public services. Applied in social sciences, statistics is usually refereed as *social statistics*. Indeed, Maravelakis (2019) states that "*social statistics deal with the application of statistical methodology in areas like survey methodology, official statistics, sociology, psychology, political science, criminology, public policy, marketing research, demography, education, economics and others*".

As all science models, statistical models are based in assumptions that, given the observable data, one is able to estimate model parameters. There exists different approaches used in estimating model parameters, where the optimization methods discussed above being useful on many of them, but many of the social statistics methods are based in likelihood theory and its use to estimate model parameters.

Consider a random variable that might be represented by a PDF $p_x(y_j)$, where y_j is a observable variable and x is a vector of the parameters that define such PDF. In a common problem in statistics, one must decide the value on x that results in the best fit of a PDF onto the observed data. If one deals with several observations $y_1, y_2, \ldots, y_T$ drawn from an independent and identically distributed (iid) random variable, search for x may be done by defining the *likelihood function*, which is the PDF as a function of x and fixed y_j as:

$$l(x) = \prod_{j=1}^{T} p_x(y_j) \tag{30}$$

In general, it is more convenient to work with the logarithm of Eq. (30), widely known as *log-likelihood function*, so the we can apply the methods discussed in Sect. 5.1 to solve the problem:

$$\min \quad f(x) = -\sum_{j=1}^{T} \log \left[p_x(y_j) \right] \tag{31}$$

Solving (31), one finds the vector x_* which is the best estimator for PDF parameters, given the assumptions made and observed data. That is, x_* maximizes the likelihood of assumed PDF generate a sample with the characteristics of observed data. In statistics, this approach is known as Maximum Likelihood Estimation (MLE) and is widely used in analyzing social data and time series to help the improvement of social policies.[6]

The reader might be asking where MLE is used in practice. This is generally considered in problems which use parametric models and multivariate statistics, where mathematical model for the data under analysis is expressed on the likelihood function $p_x(y_j)$. For instance, one may assume that the population is normally distributed, and use MLE to estimate its mean and variance.[7]

On pandemic scenario observed in 2020–2021, MLE could be used to estimate the distribution parameters of cases and deaths, as the basic reproductive number R_0.[8] For instance, considering the secondary cases produced by an ill person follows the Poisson distribution,[9] with expected value R_0 and a serial interval described by a multinomial distribution, one may use the series of daily confirmed cases N_1, N_2, ..., N_T to estimate the MLE by Forsberg White and Pagano (2008):

$$\min \quad f(x) = -\sum_{t=1}^{T} \log \left[\frac{e^{\mu_t} \mu_t^{N_t}}{N_t!} \right] \tag{32}$$

with $\mu_t = R_0 \sum_{j=1}^{k} p_j N_{t-1}$. The decision variables of Eq. (32) refers to R_0 and p_j, and its solution of yields basic reproductive number R_0. Figure 1 shows the basic reproductive number estimated for world Covid cases,[10] whereas Fig. 2 depicts the estimated rate for six countries.

Figure 2 suggests that, by March 2021, United States, United Kingdom and Israel are getting advantage on pandemic situation as a result of massive vaccination, whereas Germany, Italy and Brazil may be slipping in vaccination by such date.

Certainly, the estimates of the reproduction rate help scientists and policymakers in analyzing the pandemic evolution. For instance, R_0 greater than 1.0 indicates that the disease is spreading and actions might be taken, either to content the virus or to optimize resources for patients' treatments. Important to mention that estimates based on MLE, although not an exact value, are reliable estimates for decision making.

MLE is also often used in multivariate statistics, where multiple variables are analyzed altogether. In this case, MLE is used to estimate parameters of what is

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[6] For deep discussion in likelihood theory, readers are referred to Morris (2002) and Ward and Ahlquist (2018).

[7] The well know formulas for sample mean $\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$ and $s^2 = \frac{1}{n} \sum_{i=1}^{n} (x_i - \bar{x})^2$ of normal distribution are obtained from MLE indeed.

[8] The basic reproductive number R_0 is the number secondary cases produced by an infected individual.

[9] The Poisson distribution is a discrete probability distribution expressing the probability of a given number of events occurring in a fixed interval of time with constant expected rate and no time dependence Rice (2006).

[10] The data used was obtained from Roser et al. (2020). Here, the basic reproductive number is estimated in a weekly frequency, with a sample size of 60 d and a serial interval of four days. As this is rather an illustrative example, these parameters were chosen arbitrarily.

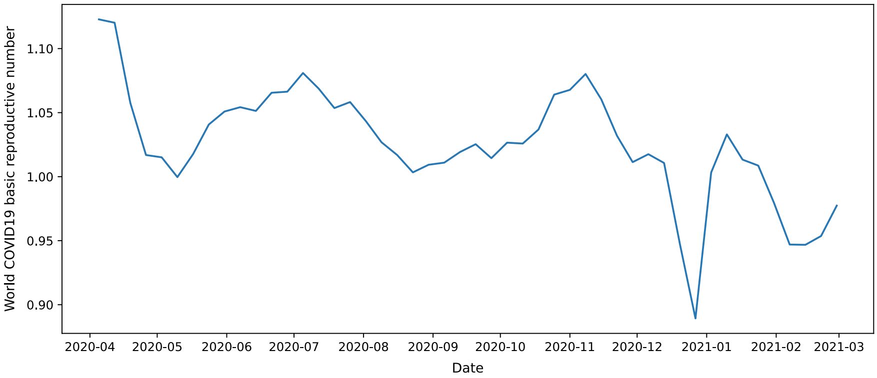

Fig. 1 Basic reproductive number estimation for COVID pandemic

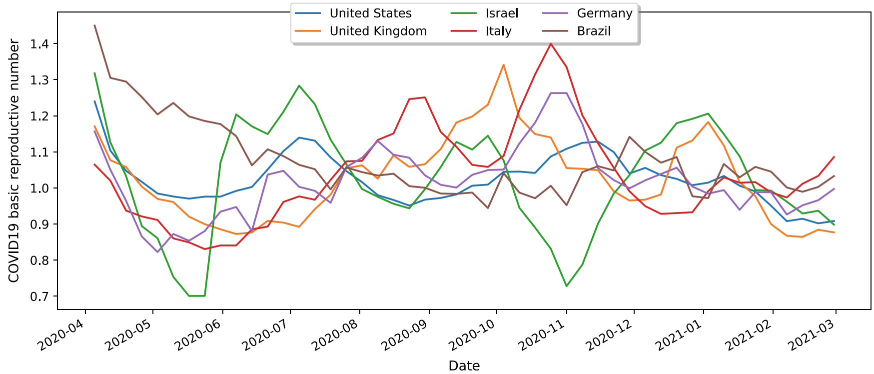

Fig. 2 Basic reproductive number estimation for COVID pandemic by country

known as joint probability distribution functions, which is often considered in cluster analysis, principal component analysis and factor analysis.

Besides MLE, optimization plays important role on other areas of social statistics, such as sampling and design of the experiments, where optimal sample size and optimal design are often considered in applied research. Indeed, optimization is being used in many different areas of statistics in general, and social statistics in particular.

3.2 Efficiency Analysis

Performance evaluation is of interest to almost all activities. Often, productivity and efficiency are related to the input/output and observed/optimum ratios of a process, respectively. As time progresses, better performance is expected. Thus, performance evaluation may be used to identify drawbacks and design improvements.

One of the measures of performance evaluation is efficiency, which is measured by comparing outputs to inputs. By output, we refer to a variable that is defined as greater is better. As for input, it is defined as lower is better variable. Thus, the greater is the ratio output/input, the greater is the efficiency of a decision-making unit (DMU).

Indeed, efficiency is technical or economic. Fried et al. (2008) states that the former regards to the comparison of observed input to minimum potential input required to produce a given amount of output (or observed output to maximum potential output obtainable from a given amount of input), while the latter extend the comparison to optimum cost, revenue, profit, etc.

Efficiency analysis is commonly used in regulated utility services. Consider the case of natural monopolies, an industry in which either the high start-up costs or powerful economies of scale define a barrier for new companies to enter the market. This is the case of the utility sector, such as the electricity or gas distribution grid. That is, the company that holds the electricity distribution network or gas pipes has no competitor within its market. In cases like, the government oversees the company performance by regulating the sector guaranteeing the quality standards and fair pricing.

Efficiency analysis is also known as benchmarking. Among benchmark techniques, the most widely used by operator are corrected ordinary least squares (COLS), stochastic frontier analysis (SFA) and data envelopment analysis (DEA). The first two approaches select an equation defining the relationship between explanatory variables and dependent variables. They are defined as parametric approaches. Dependent variables are usually considered as costs and explanatory variables of services to be analyzed. Then, the error between the selected equation and the actual value of costs defines the efficiency gap to be closed, and parameters are estimated with tools like MLE discussed in the previous section.

On the other hand, the DEA, firstly proposed by Charnes et al. (1978), is a non-parametric technique that defines an envelope around observations. The frontier is defined by the efficient firms that envelop the less efficient firms. The distance of inefficient firms to the frontier defines the efficiency gap. The advantage in using this analysis in economic regulator refers to the performance comparison within companies with different markets, as well as the less assumptions that have to be considered when compared to parametric approaches.

Indeed, an utility company charges tariffs from costumers up to an allowed revenue and, at the same time, can allocate its resource as a decision making unity (DMU). Such company technical efficiency compared to the companies on other markets may be estimated by using data from input (operational and/or capital expenditures) and output (energy delivered and number of consumers) to estimate the cost efficiency frontier.

Take the simplified example of Fig. 3, where each dot represents a utility that consumes operational expenditures (OPEX) to serve their customers.[11] For instance,

[11] In general, this OPEX (and other utility's cost) are recovered through tariffs and fees charged from their consumers. These tariff are usually regulated and defined by an independent Regulator.

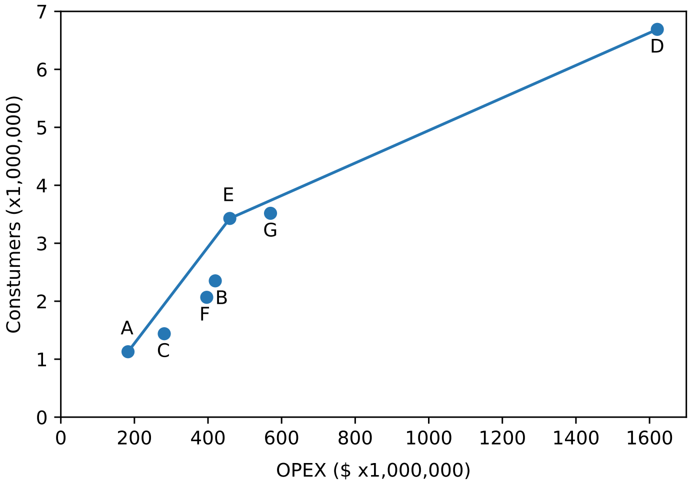

Fig. 3 Utility data

Fig. 3 shows that Utility A consumes less than \$200M to serve more than 1 million costumers, Utility B uses more than \$400M to attend over 2 million costumers, and so on.

It is easy to comprehend that utilities A, D, and E are the most efficient ones, as, compared to others, they consume less OPEX to serve their customers. Thus, the lines joining these utilities envelops all DMUs and may be named as benchmark line of efficiency, or efficiency frontier. The gap of other utilities from these frontiers defines their (in)efficiency score.

The efficiency scores of each utility may calculated as a distance from the efficient frontier. Assuming constant variable to scale, an input oriented version of DEA optimization problem could be written as:

$$\max \quad \theta_o \tag{33a}$$

$$\text{subject to} \quad \sum_{k=1}^{n} x_{ik}\lambda_k \leq \theta_o x_{io}, \quad i = 1, \dots, \tag{33b}$$

$$\sum_{k=1}^{n} y_{jk}\lambda_k \geq y_{jo}, \quad j = 1, \dots, s \tag{33c}$$

$$\sum_{k=1}^{n} \lambda_k = 1 \tag{33d}$$

$$\lambda_k \geq 0, \quad k = 1, 2, ..., n \tag{33e}$$

where, respectively, to number of DMUs, inputs and outputs of the model. Furthermore, x_{ik} is the i-th input of k-th DMU and y_{ik} is the j-th output of k-th DMU. The

Table 1 Electricity utilities data and efficiency

DMU	OPEX ($M)	NC (x10^6)	Efficiency
A	182.63	1.128	1.000
B	419.79	2.351	0.786
C	281.13	1.439	0.783
D	1621.13	6.690	1.000
E	459.28	3.428	1.000
F	396.56	2.067	0.745
G	569.93	3.517	0.862

decision variables λ_k defines the efficient reference of DMU o, and θ_o the efficiency score. Equations (33b) and (33c) ensures the benchmark model, stating that at least one DMU lies at the efficient frontier. For the problem of Fig. 3, the efficiency scores obtained with (33) are given in Table 1.

Table 1 tell us that Utility B, compared to pairs, would be able to reduce its OPEX to 78.6% of the observed level to serve the same number of clients so that such amount could be cutoff of consumers' tariffs. Similarly for Utilities C, F, G, the OPEX could be reduced, respectively, to 78.3, 74.5, and 86.2% of their observed level, promoting eventual tariff reductions.

Note that the benchmark model of Eq. (33) is an linear-programming approach discussed in Sect. 5.3.1. When the number of DMUs increases, the interior-point methods may be used to solve the efficiency analysis.

Briefly described above, the efficiency analysis by using data envelopment analysis has many other applications in public service and policy. Indeed, Charnes et al. (1978) proposed DEA for analyzing public secondary schools, and has numerous research in education sector Johnes et al. (2017). Other applications of this optimization approach refers to social economical analysis Rabar (2017), healthcare Kohl et al. (2019), Zakowska and Godycki-Cwirko (2019), and many other areas of public policy.

3.3 *Classification and Prediction*

Many policy problems rely on classification and prediction. For instance, classify people wealth using indirect data Blumenstock et al. (2015), predict health risks so that intervention by the public office can take place before that happens Potash et al. (2015), or defining hiring decisions on public positions Chalfin et al. (2016) are few examples of a bunch of problems faced by policymakers. In cases like these, machine learning (ML) tools may very useful to extract information of available data.

Indeed, ML is the definition coined for the processes of dealing with large datasets to learn and estimate relationships among inputs and outputs. In learning such relationships, ML seeks to formulate predictions on new data, helping humans to make better decisions. These concepts usually appear as hot topics that are usually linked to computer science and engineering. However, the application in social sciences and day-to-day life has been increasing a lot lately.

There exist different approaches and tools under ML, from well-known linear regression (LR) to the robust support vector machines (SVM), among many others as artificial neural networks. Most methods rely on optimization problems for a model estimate.

LR, considering the available data, seeks to minimize out-of-sample predictions. This is a slightly different concept from the traditional regression method which makes LR a more powerful ML method. That is, in traditional regression one seeks to minimize the mean square error (MSE) of in-sample data between the observed response y_j and the estimated function $f(x_j)$, by assuming zero bias in the model:

$$\min \quad \sum_{j=1}^{N} \left(y_j - f(x_j)\right)^2 \tag{34}$$

The solution of Eq. (34) by one of the methods discussed above results in an estimated function $\hat{f}$ that map the predictors x_j to response y_j based solely on the data presented to the algorithm and completely ignoring eventual new data. Indeed, when new data is presented to the model, the MSE can be decomposed in two terms: variance and (squared) bias:

$$\left(\hat{f}(x_n) - E(y_n)\right)^2 + (E(y_n) - y_n)^2 \text{ Variance} + \text{(squared) Bias} \tag{35}$$

Equation (35) makes clear that forcing Bias = 0, only in-sample information is presented in traditional regression approach. Thus, ML techniques have been developed to allow trade-offs between variance and bias while adjusting the regression model. This is done by inserting a regularizer term ρ in the traditional regression that penalizes functions that increase the variance. That is

$$\min \quad \sum_{j=1}^{N} \left(y_j - f(x_j)\right)^2 + \lambda\rho(f) \tag{36}$$

The LR of Eq. (36) is then solved by using the available data, and the parameter λ may be set with the help of the cross-validation technique. That is, one may split the data set in M subsamples of size N/M, and use $M - 1$ samples to solve Eq. (36), and the M-th sample to evaluate the model prediction, repeating the procedure iteratively until finding the best λ for the problem. This approach is known in the literature as the train-test procedure, where the $M - 1$ subsample plays the role of the training set, and the M-th subsample is the testing set.

This ML tool has been used in different social applications. For instance, McNeish (2015) have explored LASSO onto behavioral science, so that the features of behav-

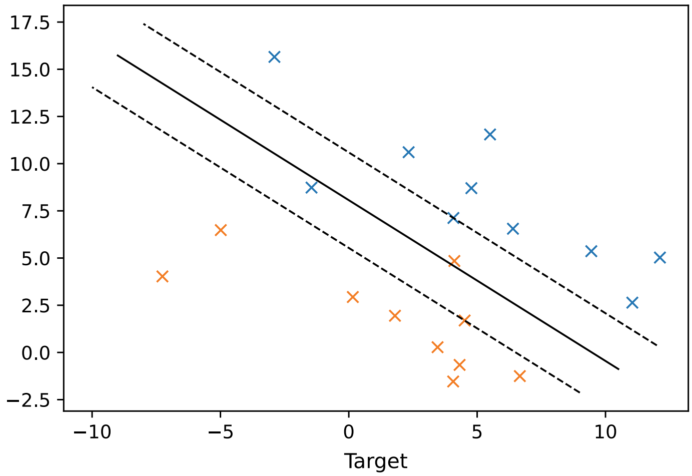

Fig. 4 Support vector machine illustration

ioral science research could be more accurately understood. Shi et al. (2020) proposes the use of LASSO to analyze factors of household carbon emissions. Indeed, machine learning, which depends on the optimization of regularized MSE, also has its place in healthcare Algamal et al. (2018) and many other social applications.

Other ML technique that uses the concept of regularization refers to SVM Vapnik (1998). SVMs was originally proposed for solving binary classification throughout a convex optimization problems, which seeks in finding the maximum margin separating the hyperplane, while correctly classifying as many training points as possible. Although it seems technically complicated, the concept is simple, and is illustrated in Fig. 4.

SVM seeks to find out the dashed lines (support vectors) in Fig. 4, so that the line in the middle (the solid line) classify the groups. Considering y_i, x_i and λ as defined above, and the group prediction given by $\text{sign}\big(\omega^T\phi(x_i) + b\big)$, SVM may be solved by minimizing the risk of misclassification through the following optimization problem:

$$\min \quad \frac{1}{2}\omega^T\omega + \lambda\sum_{i=1}^{n}\zeta_i \tag{37a}$$

$$\text{subject to} \quad y_i\left(\omega^T\phi(x_i) + b\right) \geq \zeta_i, \quad i = 1, 2, ..., n \tag{37b}$$

$$\zeta_i \geq 0, \quad i = 1, 2, ..., n \tag{37c}$$

Decision variable of Eq. (37) refers to ω, ζ and b. Notice that (37) is a constrained nonlinear optimization problem, and solving such an problem was discussed in Sects. 2 and 5. Interesting, one can show that (37) is convex, so that, if exists, the solution is unique. Thus, due to big data sets applications, it is usually solved by considering the dual formulation[12]:

$$\min \quad \frac{1}{2}\alpha^T Q\alpha - e^T\alpha \tag{38a}$$

$$\text{subject to} \quad y^T\alpha = 0 \tag{38b}$$

$$0 \leq \alpha_i \geq \lambda, \quad i = 1, 2, ..., n \tag{38c}$$

where Q is a nxn matrix with $Q_{ij} = y_i y_j K\left(x_i, x_j\right)$, $K\left(x_i, x_j\right) = \phi(x_i)\phi(x_j)$ is the kernel.[13]

Due its robustness and ability to implicitly map into a higher (eventually infinite) dimensional space Bishop (2006), the use of SVM has been increasing in the last years, especially in healthcare researches. For instance, Capriotti et al. (2006) used SVM for predicting the insurgence of human genetic diseases; Barakat et al. (2010) considered this ML technique to enhance diabetes mellitus diagnosis; Sansone et al. (2013) seeks pattern recognition in electrocardiogram; Pradeep and Naveen (2018) considers the prediction of lung cancer survivability and Xing et al. (2020) used SVM for classify social anxiety disorder, among surely numerous other researches in this area.

SVM is one of the most powerful supervised ML tools available, and may also be used as a regression approach Bishop (2006). Indeed, its applications are popping in all areas related to data science, so the reader is stimulated to search for SVM applications in your area of interest.

4 Remarks

The search for better decisions probably is part of humankind since prehistory. While in the far past most decisions were made either on trial-and-error or experience approach, the mathematical sciences abstractions enabled humankind formal approaches to write down the practical, social, and philosophical problems and seek optimal solutions.

The optimization theory and numerical optimization have evolved recently since the 19th century with the advances of calculus, and in the 20th century with the computational power of digital computers. Although viewed as a hard science, optimization techniques have a vast application that impacts civilization and social life, including public policy, system automation, and healthcare.

In this chapter, we briefly introduce the basics of mathematical concepts of smooth optimization, as well as offered an introductory discussion on numerical optimization methods. Furthermore, we discussed three topics where optimization is used on public policy: (i) statistical maximum likelihood estimation, (ii) efficiency assess-

[12] Duality is discussed in Sect. 2.4.

[13] For further discussion on SVM, the reader may look at Bishop (2006).

ment through data envelopment analysis, and (iii) application of machine learning such as regression and support vector machines.

This chapter is, indeed, a pill on optimization applications for social welfare, where such topic is becoming more evident with the advance of computational power, artificial intelligence techniques, and big data analysis. The reader is thus invited to abstract about the impact that optimization and its applications are having (and continues to have) in our lives, compelling to understand how it works and what it can offer us to increase social welfare and quality of life.

5 Appendix—Brief Introduction to Numerical Optimization Methods

In this section, the basics of smooth optimization methods are briefly reviewed. We cover general gradient approaches features that led to most used numerical optimization algorithms used nowadays. Such approaches has been improved through time resulting in robust and efficient algorithms which is also used alongside new machine learning approaches. Although we will not cover machine learning in this chapter, understanding how optimization methods may help one to analyze and tune models, as well as general optimization problems. Furthermore, we will also not cover convergence features of the methods discussed in this section as our intention is to show general information about such methods, not going deep in their characteristics.

The general idea of numerical optimization is to build up a iterative approach that, at each step, the objective function is improved. That is, considering a counter k, we seek to update the decision variable x_k in direction d_k so that $x_{k+1} = x_k + \alpha d_k$ and $f(x_{k+1}) < f(x_k)$ as $k \to \infty$.[14] In doing so, we are able to approach the minimizer x_* as much as we accept a (small) error ϵ. Mathematically, we can write:

$$\lim_{k \to \infty} f(x_k) = f(x_*) \tag{39}$$

In what follows, we discuss how the gradient of the objective function $\nabla f(x)$ (and Lagrangian $\nabla L(x)$) may be used to seek a descent direction d_k. Starting from unconstrained optimization, we also explore such concepts to constrained optimization problems through Quadratic Programming, Sequential Quadratic Programming (SQP) and Logarithm barrier approach.

[14] To make notation simpler, from this section on, the subscript of the variables refers to the state of the variable in the iterative process instead of the entry in the variable vector, unless explicitly stated the contrary. For instance, the subscript k refers to the variable ate k-th iterate, not the x_k entry in $x^T = [x_1, x_2, \ldots, x_n]$.

5.1 Gradient Direction

Consider $x_{k+1} = x_k + \alpha d_k$ with $\alpha \in (0, 1]$ such that $d_k \in \mathbb{R}^n$. The first-order Taylor series expansion of the objective function $f(x)$ is:

$$f(x_{k+1}) = f(x_k) + \alpha \nabla f(x_k)^T d_k \tag{40}$$

If the angle between d_k and $\nabla f(x_k)$ greater than $\pi/2$, i.e., $\nabla f(x_k)^T d_k < 0$, we guarantee $f(x_k + \alpha d_k) < f(x_k)$. If we choose $d_k = -\nabla f(x_k)$ at iterate k with $\nabla f(x_k) \neq 0$, the first-order Taylor series expansion becomes

$$f(x_{k+1}) = f(x_k) - \alpha \nabla f(x_k)^T \nabla f(x_k) = f(x_k) - \alpha \|\nabla f(x_k)\|^2 \tag{41}$$

Thus, we may be able to choose an step $\alpha \in (0, 1]$ so that $f(x_{k+1}) < f(x_k)$. Indeed, this step choice is known as steepest-descent, and is the general concept of all gradient methods. One can then search for a step size $\alpha \in (0, 1]$ that guarantees $f(x_{k+1}) < f(x_k)$ in many different ways, such as extensive interval search, Wolfe conditions, and other available in the literature. The algorithm for steepest-descent approach may be written as:

procedure MAXDECL(x_0, ∇f, k_{max})
  $k \leftarrow 0$
  while $|\nabla f(x_k)| > \epsilon_f$ and $|x_k - x_{k-1}| > \epsilon_x$ and $k < k_{max}$ **do**
    $k \leftarrow k + 1$
    $\alpha_k \leftarrow \alpha \in (0, 1]$ so that $f(x_{k+1}) < f(x_k)$
    $x_{k+1} \leftarrow x_k - \alpha_k \nabla f(x_k)$
  return x_k

An extension in the steepest-descent method, one can consider an additional information in the direction $d_k = -D_k \nabla f(x_k)$. Usually, D_k is obtained by the quadratic approximation of objective function. Consider, for instance, the first-order necessary condition. Applying the well known Newton method to seek for $\nabla f(x_*) = 0$, we have:

$$x_{k+1} = x_k - \nabla^2 f(x_k)^{-1} \nabla f(x_k) \tag{42}$$

so that $D_k = \nabla^2 f(x_k)^{-1}$ e $\alpha_k = 1$. As in the steepest-descent, one may look for a more favorable step size $\alpha \in (0, 1]$ leading to Quasi-Newton methods. Furthermore, it might be hard to compute and factor the Hessian, so that a number of numerical estimates for $\nabla^2 f(x_k)$ available in the literature. Finally, to obtain a descent direction, the Hessian $\nabla^2 f(x_k)$ should be positive-definite.[15] Thus, some of the numerical estimates of $\nabla^2 f(x_k)$ also guarantees an descent direction for quasi-Newton methods. The algorithm for Quasi-Newton approach may be written as:

procedure NEWTON(x_0, ∇f, $\nabla^2 f$, k_{max})
  $k \leftarrow 0$

[15] Check why at Sect. 2.1, Eq. (2).

while $|\nabla f(x_k)| > \epsilon_f$ and $|x_k - x_{k-1}| > \epsilon_x$ and $k < k_{max}$ **do**
  $k \leftarrow k + 1$
  Define D_k with second-order information
  $\alpha_k \leftarrow \alpha \in (0, 1]$ so that $f(x_{k+1}) < f(x_k)$
  $x_{k+1} \leftarrow x_k - \alpha_k D_k \nabla f(x_k)$
return x_k

Indeed, there exist other numerical methods that use gradient information on optimization problems as the conjugate gradient methods. Readers seeking for more information about such methods are refereed to suggested literature. In what follows, we extend the gradient approach to constrained optimizations problems through Sequential Quadratic Programming and Logarithm barrier approach.

5.2 Gradient Direction for Constrained Optimization Problems

The gradient approach discussed in the previous section may be extended for constrained optimization problem. In doing so, instead of focusing on objective function, we look at the Lagrangian function to derive the features of numerical optimization approach. We start by discussing Quadratic Programing (QP), which leads us to Sequential Quadratic Programing (SQP) for more general optimization problems.

5.2.1 Quadratic Programming

Consider a $n \times n$ positive-definite matrix Q, a $n \times m$ space matrix A, and vectors b and c with dimensions $m \times 1$ and $n \times 1$, respectively. We can define a Quadratic Programming as:

$$\begin{aligned} \min \quad & \frac{1}{2} x^T Q x + c^T x \\ \text{subject to} \quad & Ax = b \end{aligned} \tag{43}$$

The QP of Eq. (43) is widely studied in optimization literature, as its equations may be referred to Taylor series expansion approximation, as we will further discuss. Thus, studying its fundamentals is important to understand the Sequential Quadratic Programming.

The Lagrangian function of problem (43) is given by:

$$L(x, \lambda) = \frac{1}{2} x^T Q x + c^T c - \lambda^T (Ax - b) \tag{44}$$

And the KKT conditions for Eq. (44) is:

$$\begin{aligned} Qx_* + c - A^T\lambda_* &= 0 \\ Ax_* - b &= 0 \end{aligned} \tag{45}$$

Considering $x_* = x + \Delta x$, Eq. (45) becomes:

$$\begin{aligned} Q\Delta x - A^T\lambda_* =&Qx + c \\ -A\Delta x =& - Ax + b \end{aligned} \tag{46}$$

Note that (46) is a set of linear equation, and if the matrix A has rank m and Q is positive-definite, Eq. (46) has a unique solution at the minimizer (x_*, λ_*). That is, if the conditions above holds, the QP of Eq. (43) is positive-definite is convex.

QP is important because many system modeling are approximated by the quadratic model, specially in experimental analysis. Thus, one can use a QP to find out the minimizer of such problem by solving Eq. (46) with the help of any numerical method available in the literature. By choosing Newton method to solve (46), one reaches the solution in only one iteration. Indeed, this is the base of Sequential Quadratic Programming, that we discuss in the next section.

Importantly, we only consider the equality constraint approach here. However, inequality constraint may be easily considered by using the concept of active constraints and Lagrange multiplier (cost) information discussed in previous sections, leading to active-set method. For detailed information on such an approach, readers are referred to Nocedal and Wright (2006).

5.2.2 Sequential Quadratic Programming

Consider the problem (9) and the corresponding Lagrange function (18). The KKT for this problem is given by:

$$F(x,\lambda) = \begin{bmatrix} \nabla f(x) - \nabla g(x)^T\lambda \\ g(x) \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix} \tag{47}$$

By using the Newton method to search $F(x, \lambda) = 0$, the variables are updated as:

$$\begin{bmatrix} x_{k+1} \\ \lambda_{k+1} \end{bmatrix} = \begin{bmatrix} x_k \\ \lambda_k \end{bmatrix} + \begin{bmatrix} \nabla^2_{xx} L(x_k, \lambda_k) & -\nabla g(x_k)^T \\ \nabla g(x_k)^T & 0 \end{bmatrix}^{-1} \begin{bmatrix} \nabla f(x_k) - \nabla g(x_k)^T\lambda \\ g(x_k) \end{bmatrix} \tag{48}$$

From Eq. (48) that the Newton step $\begin{bmatrix} \Delta x_k & \Delta\lambda_k \end{bmatrix}^T$ is obtained by solving the following linear problems:

$$\begin{bmatrix} \nabla^2_{xx} L(x_k, \lambda_k) & -\nabla g(x_k)^T \\ \nabla g(x_k)^T & 0 \end{bmatrix} \begin{bmatrix} \Delta x_k \\ \Delta\lambda_k \end{bmatrix} = \begin{bmatrix} -\nabla f(x_k) + \nabla g(x_k)^T\lambda_k \\ -g(x_k) \end{bmatrix} \tag{49}$$

or similarly:

$$\begin{aligned} \nabla^2_{xx} L(x_k, \lambda_k)\Delta x_k - \nabla g(x_k)^T \Delta\lambda_k &= -\nabla f(x_k) + \nabla g(x_k)^T \lambda_k \\ \nabla g(x_k)^T \Delta x_k &= -g(x_k) \end{aligned} \tag{50}$$

Note that Eq. (49) is similar to Eq. (45) if $\lambda_* = \lambda + \Delta\lambda$. That is, using Newton method so find the stationary point in the first-order necessary conditions is similar of solving a sequence of Quadratic Programming approximation of general problem (9). If

$$\nabla^2_{xx} L(x_k)$$

is positive-definite and $\nabla g(x_k)$ has full rank, Eq. (49) is well defined and $\lim_{k\to\infty} f(x_k) = f(x_*)$

The discussion above reveals the close link between Newton method and Quadratic Programming. Nevertheless, Quasi-Newton approaches are usually used in practice, as discussed in Sect. 5.1. In this case, $\nabla^2_{xx} L(x_k, \lambda_k)$ is usually replaced by D_k which is estimated throughout the iterative process, and a step size in considered in variable updates, so that:

$$\begin{bmatrix} x_{k+1} \\ \lambda_{k+1} \end{bmatrix} = \begin{bmatrix} x_k \\ \lambda_k \end{bmatrix} + \alpha_k \begin{bmatrix} \Delta x_k \\ \Delta\lambda_k \end{bmatrix} \tag{51}$$

An general algorithm for SQP is given by:

1: **procedure** SQP(x_0, λ_0, k_{max})
2: $k \leftarrow 0$
3: Define D_k
4: **while** $|\nabla F(x_k, \lambda_k)| > \epsilon_f$ and $|x_k - x_{k-1}| > \epsilon_x$ and $k < k_{max}$ **do**
5: $k \leftarrow k + 1$
6: Solve $D_k \left[\Delta x_k \;\; \Delta\lambda_k\right]^T = F(x_k, \lambda_k)$
7: $\alpha_k \leftarrow \alpha \in (0, 1]$
8: Update variables with equation (51)
9: **return** x_k

The SQP discussed above proves to be an good algorithm for solving equality constraint problems, specially when positive-definiteness of the Hessian $\nabla^2_{xx} L(x_k, \lambda_k)$ holds. When inequality constraints are present, although successful algorithm, the computational cost of SQP increases, as active set may be updated many times until reach optimal solution. An approach that deals with inequality constraint direct refers to logarithm barrier approach, which is discussed next.

5.3 Logarithm Barrier Approach

In this section, we explore the basics of logarithm barrier approach to deal with inequality constraints. Such approach, also know as interior-point method, has been shown very robust to deal with general optimization problems, even when initial guess is not feasible. Of course, such robustness comes with the price of some computational effort.

We review interior-point methods on Linear Programming. However, such method also succeed when applied to nonlinear programming. Thus, we also show logarithm barrier approach formulation for this later case.

5.3.1 Linear Programming

Consider the problem of finding the value of non-negative decision variables $x \geq 0$ that minimizes a linear objective function $f(x) = c^T x$ restricted bu linear constraints $Ax = b$. Such an optimization problem may be written as:

$$\begin{aligned} \min \quad & c^T x \\ \text{subject to} \quad & Ax = b \\ & x - s = 0 \end{aligned} \tag{52}$$

The problem (52) is widely known as Linear Programming, where c and x has dimension of $n \times 1$, A is the space matrix with $n \times m$, b is $m \times 1$, and the slack variable $s = x$. Based on discussion of Sect. 2, the Lagrange function of the LP may be written as:

$$L(x, \lambda) = c^T x - \lambda^T (Ax - b) - \mu^T x \tag{53}$$

and the KKT conditions are given by:

$$\begin{aligned} c - A^T \lambda_* - \mu = 0 \\ Ax_* - b = 0 \\ x^T \mu = 0 \\ x \geq 0, \quad \mu \geq 0 \end{aligned} \tag{54}$$

Solving the system of Eq. (54) leads to the solution of LP, but the non-linear first-order necessary condition $x^T \mu = 0$ plays a drawback for numerical algorithms based in gradient information: if, at a iteration, either x or μ assumes a value of 0, no algorithm based on gradient direction will be able to step out such value, which may lead to a spurious solution.

An alternative to such a problem has been proposed by Karmarkar (1984), which is equivalent to plugin a logarithm barrier on the slack variables, so that the inequality constraints $x \geq 0$ and $\mu \geq 0$ are satisfied strictly. Thus, considering a scalar δ_k, the

LP may be rewritten as:

$$\begin{aligned} \min \quad & c^T x - \delta_k \sum_{i=1}^{n} \ln x_i \\ \text{subject to} \quad & Ax = b \end{aligned} \tag{55}$$

Defining the diagonal matrix $X = diag(x)$ and $M = diag(\mu)$, and an $n \times 1$ vector e with all entries equal 1, the KKT conditions becomes by:

$$\begin{aligned} c - A^T \lambda_* - \mu_* = 0 \\ Ax_* - b = 0 \\ X_* M_* - \delta_k e = 0 \end{aligned} \tag{56}$$

Equation (56) is easy to solve by gradient approaches, such as Quasi-Newton methods. The choice of barrier scalar, which defines the desirability of the current solution, plays a crucial role in algorithm performance. In LP, the barrier scalar are usually chosen based in duality gap of current solution. Based on Eq. (53) and discussion of Sect. 2.4, it is easy to show that the LP dual may also be written as a LP as:

$$\begin{aligned} \min \quad & b^T \lambda \\ \text{subject to} \quad & A^T \lambda \leq c \end{aligned} \tag{57}$$

where $b^T \lambda \leq c^T x$. Furthermore, as LP is a convex problem if the solution exists, $b^T \lambda_* = c^T x_*$. Thus, a usual choice for δ_k is given by $\delta_k = \mu_k^T x_k / n$ so that $\delta_k \to 0$ as $k \to \infty$. The variable updates may be obtaining by solving:

$$\begin{bmatrix} 0 & A^T & 0 \\ A & 0 & 0 \\ M & 0 & X \end{bmatrix} \begin{bmatrix} \Delta x_k \\ \Delta \lambda_k \\ \Delta \mu_k \end{bmatrix} = \begin{bmatrix} A^T \lambda_k + \mu_k - c \\ -Ax_k + b \\ -X_k M_k + \delta_k e \end{bmatrix} \tag{58}$$

By defining, respectively, a primal and dual step size ${}_k^P$ and ${}_k^D$ that guarantees $x > 0$ and $\mu > 0$, the variables may be updated as:

$$\begin{aligned} x_{k+1} =& x_k +_k^P \Delta x_k \\ \lambda_{k+1} =& \lambda_k +_k^D \Delta \lambda_k \\ \mu_{k+1} =& \mu_k +_k^D \Delta \mu_k \end{aligned} \tag{59}$$

The approach above is widely known as Primal-Dual Interior Points method, and a basic algorithm may be stated as:

procedure PDPI(x_0, λ_0, μ_0, $k_{\max}$)
    $k \leftarrow 0$
    Compute $\delta_k = \mu_k^T x_k / n$

while $\delta_k > \epsilon_x$ and $k < k_{\max}$ **do**
  $k \leftarrow k + 1$
  Solve equation (58)
  Choose ${}^{P}_{k}$ and ${}^{D}_{k}$ that guarantees $x > 0$ and $\mu > 0$
  Update variables with equation (59)
  Compute $\delta_k = \mu_k^T x_k / n$
return x_k

Primal-Dual Interior Points method is often used when the LP dimension is high, so that the logarithm barrier allows to seek the optimal solution through a central path, instead of feasible region vertex as traditional Simplex approach.

Initially proposed for LP, the logarithm barrier approach has been shown valuable in solving general optimization problems. For instance, consider the problem:

$$\begin{aligned} \min \quad & f(x) \\ \text{subject to} \quad & g(x) = 0 \\ & \underline{h} \leq h(x) \leq \overline{h} \end{aligned} \tag{60}$$

We can rewrite Eq. (60) with a logarithm barrier as:

$$\begin{aligned} \min \quad & f(x) - \delta_k \sum_{i=1}^{n} (\ln s_i + \ln z_i) \\ \text{subject to} \quad & g(x) = 0 \\ & -s - z + \overline{h} - \underline{h} = 0 \\ & -h(x) - z + \overline{h} = 0 \end{aligned} \tag{61}$$

so that the Lagrange function and the KKT conditions are given by:

$$\begin{aligned} L\,(x, \lambda, \mu, \pi,) = & f(x) - \delta_k \sum_{i=1}^{n} (\ln s_i + \ln z_i) - \lambda^T g(x) \\ & - \mu^T \left(-s - z + \overline{h} - \underline{h}\right) - \pi^T \left(-h(x) - z + \overline{h}\right) \end{aligned} \tag{62}$$

$$\begin{aligned} \nabla f(x_*) - \nabla g(x_*)^T \lambda_* - \nabla h(x_*)\mu_* &= 0 \\ -g(x_*) &= 0 \\ -s_* - z_* + \overline{h} - \underline{h} &= 0 \\ -h(x_*) - z_* + \overline{h} &= 0 \\ S_* M_* - \delta_k e &= 0 \\ diag(\mu_* + \pi_*) M_* - \delta_k e &= 0 \\ \mu_*, s_*, \pi_*, z_* &\geq 0 \end{aligned} \tag{63}$$

Different variations of Primal-Dual algorithms are based in solving equation like (62). For detailed discussion on logarithm barrier approaches for nonlinear optimization problems are referred to Wright (1997).

Indeed, for a deep understanding of optimization, the reader is referred to more detailed references such as Gill et al. (1981) and Nocedal and Wright (2006), which covers optimization theories and algorithms. Yet, there is many other books on optimization. One may also find online a lot of resource on optimization and quantitative methods online.

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The Socio-Economic Implications of the Coronavirus Pandemic: A Brazilian Electric Sector Analysis

Pedro H. Camargos and Jansen Villibor

1 Introduction

In epidemiology studies, the infectious pathogen is referred to as an agent (Merrill, 2017). The disease level measures the evolution of an infection in a community. Frequently, if the infection level rises above a standard level, the phenomenon is considered an epidemic. Agent growth changes in the host's sensitivity or the introduction of the agent into a new place are generally responsible for starting an epidemic. A pandemic event occurs when an outbreak of disease affects multiple countries or continents.

Caused by the bacteria Yersinia pestis, the bubonic plague drastically affected the Byzantine Empire between 541 and 750, causing 30 to 50 million deaths (LeMay, 2016; Little, 2007; Rosen, 2007). The economic crisis took hold over the Byzantine empire, including Constantinople (Ortiz, 2020), causing political instability and invasions by Germanic tribes.

Between 1347 and 1351, the black plague spread across the Mediterranean, Alexandria, Middle East, and North Africa (Bramanti et al., 2019; Harmanjot, 2020; Jedwab et al. 2020). Black plague brings socio-economic impacts. Agricultural production declines dramatically due to the large number of people killed by the plague. Black plague brings socio-economic impacts. Agricultural production declines dramatically due to the large number of people killed by the plague.

In second decade of the twenty-first century, humanity was surprised by the discovery of a new disease: COVID-19. The illnesses is caused by infection with a new coronavirus (called SARS-CoV-2) with symptoms similar to those produced by the influenza virus. The COVID-19 pandemic spreading rapidly throughout the world, infecting millions of people and causing the death of thousands more (World Health

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Organization (WHO), 2020). COVID-19 is causing the largest global crisis of the 21st century (Chakraborty and Maity, 2020), affecting health care systems, economies and societies worldwide (International EnergyAgency (IEA), 2020; Nicola et al., 2020; Recovering fast and slow, 2021).

The electricity sector of many countries is being affected by an exogenous factor called COVID-19. Governments should adopt strategies to improve the infrastructure of the electricity sector, adapting energy sector policies in order to minimize the impact of the pandemic.

A detailed analysis of how confinement measures have modified the electricity consumption in Spain is presented in Santiago et al. (2020). Early pandemic impacts (March and April 2020) were analyzed, generating a more significant uncertainty for the Spain System Operator when making demand forecasts. Authors mention the use of random production of renewable plants can provide the network flexibility against unforeseen variations in demand, as has occurred during the Spain lockdown.

The measures of containment of the advancement of the new coronavirus also reached the electricity sector of North America countries. The overall electricity demand of the Ontario Canadian province for April 2020 declined 14% if compared to the same period in 2019. The socio-economic consequences of the pandemic were responsible for this reduction. Social distancing measures obligated the Canadian population to work remotely, influencing energy consumption changing demand patterns: higher energy demand in the earlier part of the week and lower demand in the latter part of the week (Abu-Rayash and Dincer, 2020).

In Brazil, containment measures have drastically affected the electricity sector. Changes in electricity consumption patterns reflect the drop in economic activity. Mainly industrial production demonstrates the need to analyze the impact of the global pandemic on the Brazilian electricity sector. This is important to prepare the agents of the Brazilian electric sector in the decision-making of future pandemics.

This chapter is divided as follows: Section 2 provides a brief description of the evolution of the pandemic around the world, trying to answer the following questions: What measures have the countries adopted to contain the spread of the virus? Which regions of the world are most affected by the disease? The main impacts of the pandemic on the Brazilian electricity sector are described in Sect. 3. The patterns of electricity consumption during the first half of 2020 are presented. The reader is led to a comparative study on the variation of the marginal cost and how the economic crisis affected the Brazilian electricity market. Section 4 compares the reduction in electricity consumption in Brazil with Italy.

2 Pandemic Evolution

In December 2019, Wuhan Center for Disease Control and Prevention (CDC) diagnosed four people with unusual pneumonia. Accordingly to the CDC, these patients used to work at Huanan Seafood Wholesale Market in Wuhan, which harbors a variety of exotic wildlife.

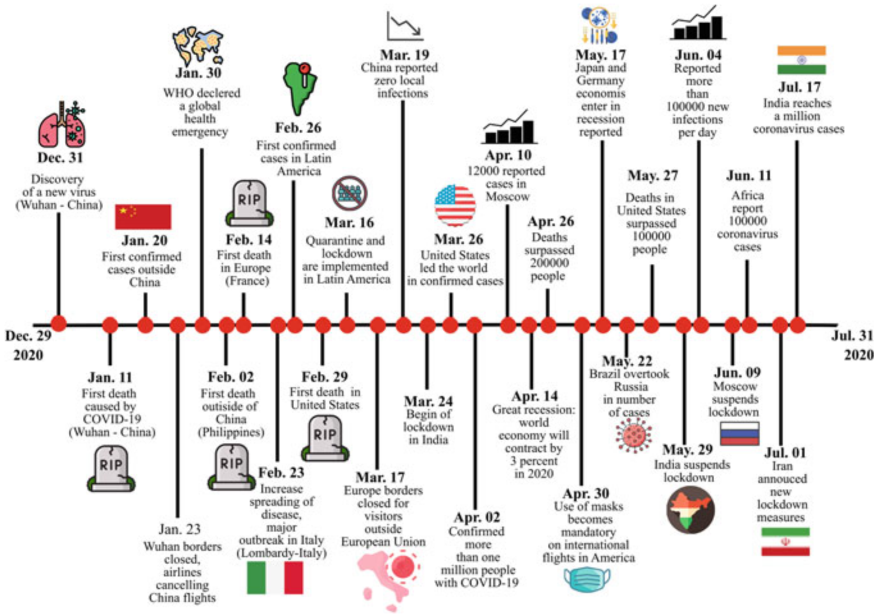


Fig. 1 Early COVID-19 outbreak timeline

On January 7th, 2020, Chinese scientists announced that the pneumonia outbreak is due to a novel virus (SARS-CoV-2) belonging to the Coronaviridae, a family of viruses that can infect animals (including camels, cats, and bats) and humans (Peng et al., 2020; Wang et al., 2020; Wu et al., 2020; Zhu, 2020).

The first case of COVID-19 reported outside China was on January 13th, in a woman in Thailand. On the same day, Japan announces the first case. Seven days later, South Korea and the USA. On January 25th, Australia, and France. By the end of January, the COVID-19 global cases are almost ten thousand. In just one month, the disease reached four continents (Asia, Europe, America, and Oceania). The first COVID-19 case diagnosed in Latin America was in Brazil on February 26th. On March 12th, WHO declared the novel coronavirus (COVID-19) outbreak a global pandemic, and by April 17th, the world reaches more than 2 million cases. The early COVID-19 outbreak timeline is in Fig. 1.

The COVID-19 pandemic led to a massive global health public campaign to slow down the virus spread by increasing handwashing, reducing face touching, wearing masks in public places, and physical distancing. Most of the countries adopted strict measures on transportation, commerce, cultural activities; schools and universities were closed, social distancing was imposed (quarantine), and in some cases, lockdown. In this scenario, it is necessary to analyze the disease evolution to assess what measures can be more effective. This analysis generally uses the application of mathematical and epidemiological models.

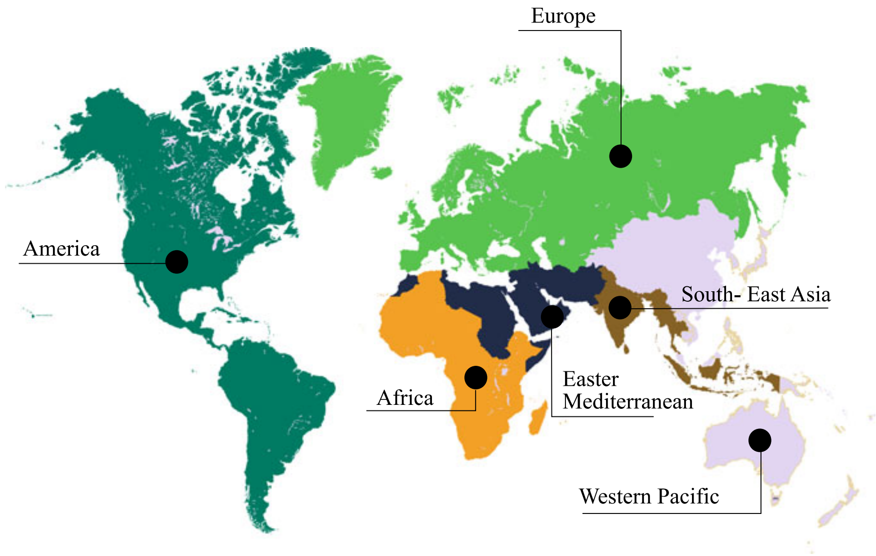


Fig. 2 WHO regions

The WHO is a specialized United Nations agency responsible for international health coordination. The WHO was founded on April 07th, 1948, and provides technical support to more than 100 countries. WHO members are grouped into six regions, as in Fig. 2: Americas, South-East Asia, Europe, Eastern Mediterranean, Africa, and Western Pacific.

During the COVID-19 pandemic, WHO integrated a global response strategy. WHO technical and operational support scale-up the countries preparedness and response, given priority to control the transmission in regions more affected by the disease. WHO teams analyze the countries with a high transmission rate and risk of imported cases. Then, the number of deaths and infections per country is grouped according to the six WHO regions. Figure 3 presents the number of confirmed cases and deaths per each WHO region.

From July to September of 2020, the regions of America and South East Asia reported the highest number of infections by the SARS-CoV-2, with the highest infection numbers in the USA (North America), India (South East Asia), and Brazil (South America). The world had more than 35 million peoples infected by October 7th. According to World Health Organization (WHO) (2020) and CCSE (2020), approximately 13.8% of the cases were in Brazil. In this scenario, the Brazilian government adopted sanitary control measures, implementing health policies, social distancing, and in some cases, lockdown to contain the virus. These measures harm all economic activities, also impacting the Brazilian electricity sector.

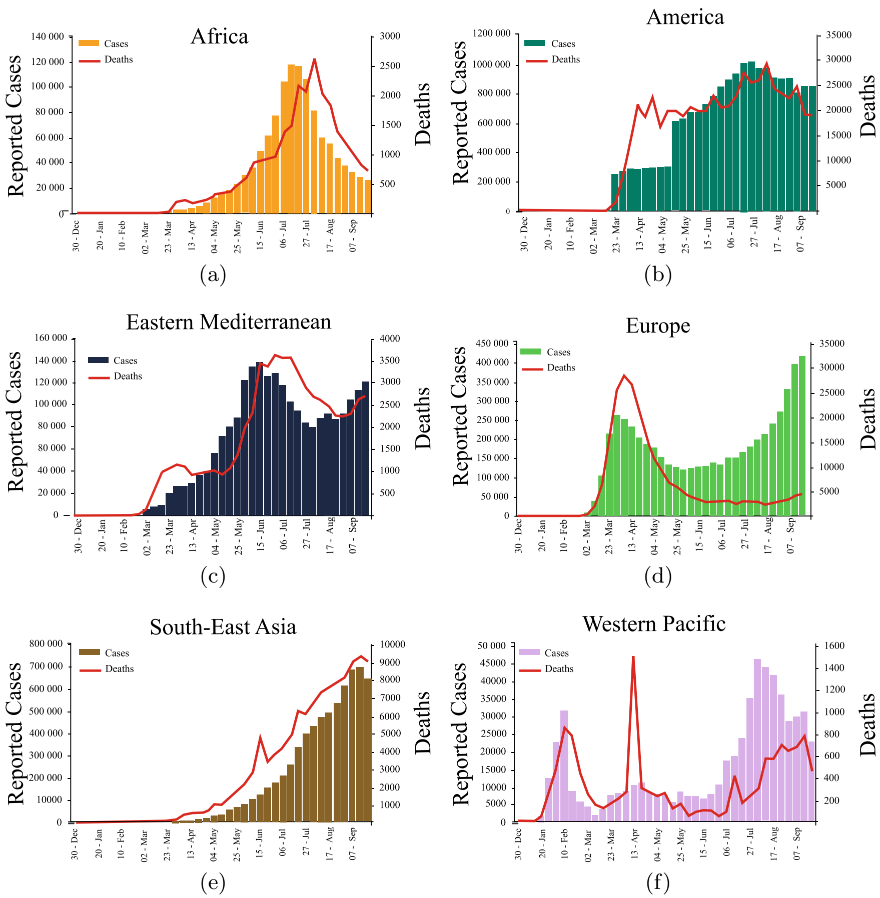


Fig. 3 Cases reported per WHO region **a** Africa, **b** America, **c** Eastern Mediterranean, **d** Europe, **e** South East Asia, **f** Western Pacific (World Health Organization (WHO), 2019)

3 Influence of COVID-19 Pandemic on the Brazilian Electricity Sector

The Brazilian electricity sector is composed of public and private agents. The Energy Research Company Monitoring Committee (EPE), Ministry of Mines and Energy (MME), and the National Electric Energy Agency (ANEEL) are the public agents of the sector. The Brazilian National Electric System Operator (ISO) controls and coordinates the generation and transmission activities inside the Brazilian National Interconnected System (SIN). The SIN interconnects the Brazilian regions classified in four subsystems: South, Southeast/Midwest, Northeast, and North, as shown in Fig. 4.

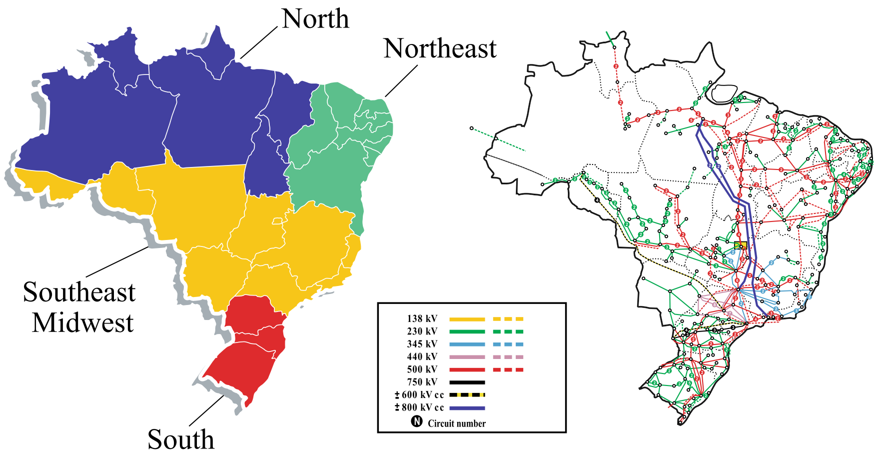


Fig. 4 Representation of SIN, Brazilian subsystems (Operador Nacional doSistemaEletrico (ONS), 2020)

The COVID-19 reported cases per subsystem from March to late September is in Fig. 5. The last seven days moving average was calculated to reduce the data oscillation caused by the irregular government data collection process.

The Southeast/Midwest moving average curve indicates a more accelerated growth in the number of infected people than the other subsystems, but all the subsystems moving average curves show an expressive rise in the number of infected people. The South subsystem recorded the lowest number of infected people until the middle of July 2020. In the Southeast/Midwest and Northeast, the number of reported cases decreased only in August.

On March 22th, campaigns to raise population awareness, suggesting social distance and the close of non-essential services (lockdown), start in Brazilian municipalities. However, such measures were insufficient to contain the disease spread in Brazilian cities from March to June and impacted the Brazilian electricity sector. There was a significant drop in energy consumption at the SIN in this period, an increase in the marginal operating cost, bringing economic impacts for the Brazilian electricity market related to energy trade.

To monitoring the social distancing levels in Brazil, the social distancing index was developed (Inloco, 2021). On March 22th, Brazil reached the highest social distancing level, where approximately 62.2% of the Brazilian population stayed at home. There was a relative decrease in the index from April to June, with a maximum of 59.9% in social distancing. However, from July to September, the average index drop due to the gradual reopening of nonessential services. Figure 7 presents the social distancing index between April and October.

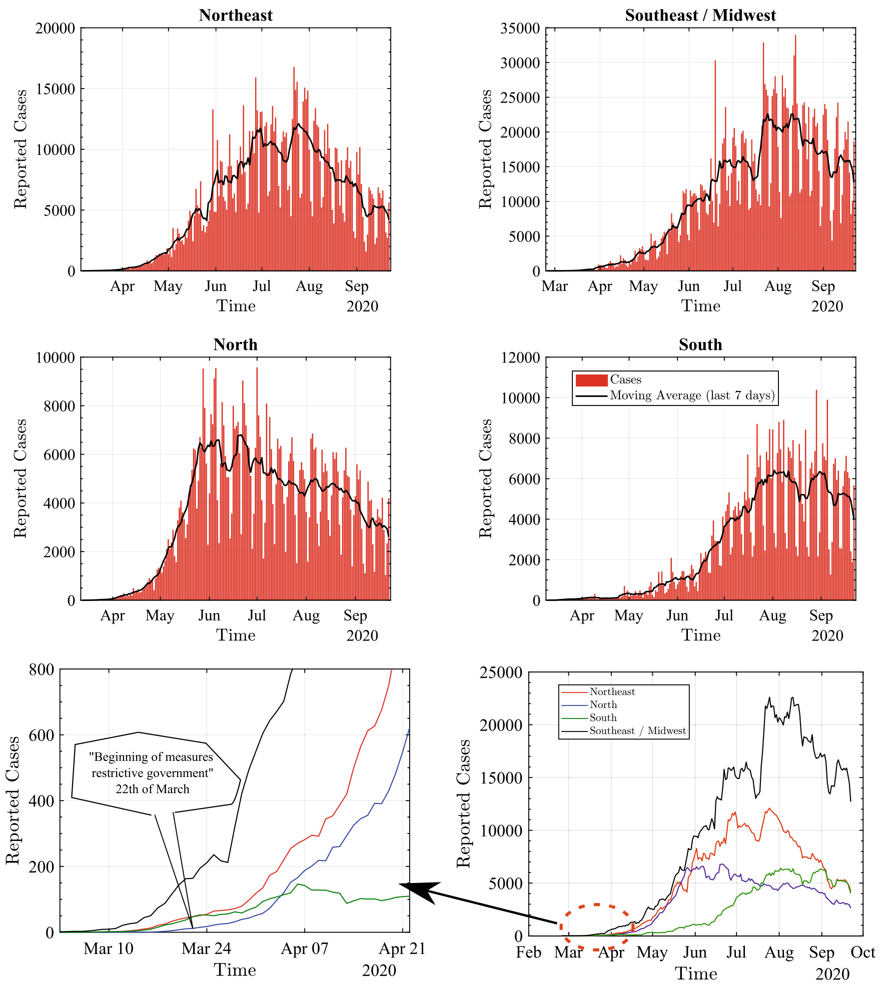


Fig. 5 COVID-19 Brazilian reported cases (Cota, 2021)

3.1 *Energy Consumption*

In Brazil, the measures to contain the spread of novel coronavirus began to take effect in the first weeks of March by adopting social distancing and paralyzing several industry segments. In Machado (2020), the authors estimated a 5.3% drop in the Brazilian Gross Domestic Product (GDP) in 2020. These economic impacts reflect in the Brazilian electricity sector.

It is possible to notice a change in the consumption profile in the first quarter of 2020. A preliminary survey compared the consumption pattern between the first two weeks of March and the first weeks of April and showed that the Southeast/Center-

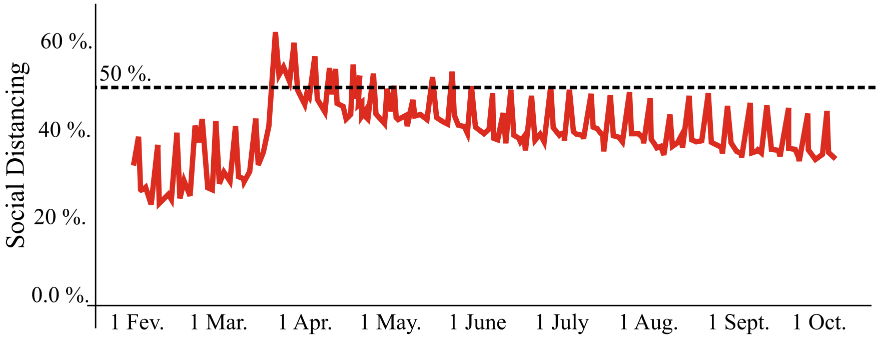


Fig. 6 Brazil social distancing index (Inloco, 2021)

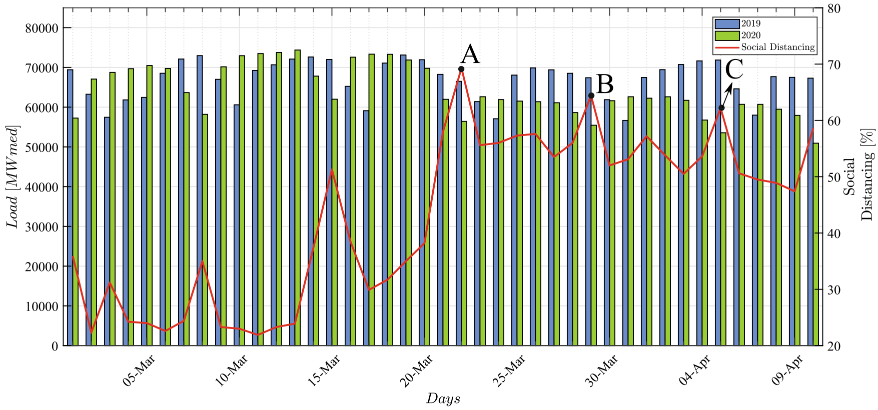


Fig. 7 Load in March, March–April 2019–2020 and social distancing curve

West region registered a reduction in electricity consumption of 9%, while the Northeast region falls by 10% and North by 4%. The drop was steeper in the South, with an 18% drop (CCEE-Camâra, 2021).

Figure 7 shows the average load for 2019 and 2020 and the 2020 social distancing index from 03/01/2020 to 04/04/2020. Points A, B, and C are days with a social distance greater than 60%, where they fall on the average daily load between 2020 and 2019 was 15%, 17%, and 25%, respectively. Therefore, the increase in social distancing contributed to the drop in demand.

The impacts of the pandemic were also reflected on the SIN load demanded by the SIN from 03/01/2020 to 04/09/2020 as showed in Fig. 8. The percentage difference was calculated for every ten days period in relation to the previous period. It was observed an average reduction of 16% in load for the period from 03/21/2020 to 04/09/2020 between 03/7/2020 to 03/20/2020 (ONS-Operador Nacional do Sistema, 2020). For the last two periods, a reduction above 15% was observed.

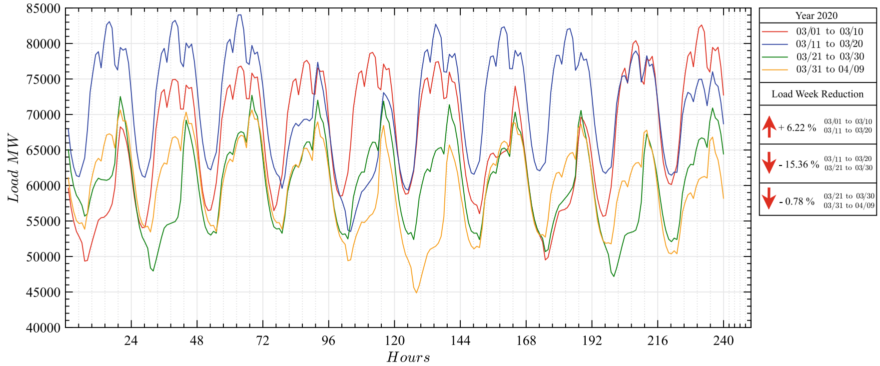


Fig. 8 Load in the SIN

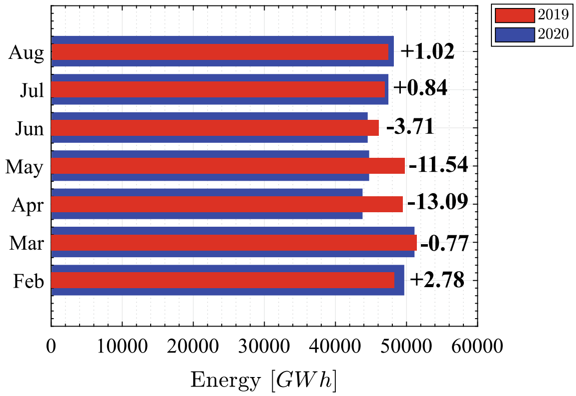


Fig. 9 Comparison energy consumption between 2019 and 2020

The drop in economic activities reflects on electricity demand as expected. The industry sector electricity consumption has been more seriously affected by the pandemic. Automotive, textile, and services sectors saw a drop of 45%, 34%, and 32%, respectively, comparing March 2020 and March 2019 (CCEE-Camâra, 2021).

Comparing the interval between February and August for the years 2020 and 2019, the maximum decrease in electricity consumption occurred in April (13.09%) and May (11.54%), as shown in Fig. 9. As in Fig. 6 the social distancing index in this period remained above 40%.

From June to August, occurred a decrease in social distancing, with indexes below 40%. The gradual return of industry activities and the end of lockdown in most Brazilian cities lead to an energy consumption increase. July and August consumed 0.84% and 1.02% more energy compared to 2019.

3.2 Marginal Cost of Operation

The approximate distribution of SIN installed generation capacity is 65.7% hydroelectric plants, 9.8% wind power plants, 12.8% thermonuclear, 8.3% biomass, 1.8% solar generation, and only 1.2% nuclear power plants (Operador Nacional do Sistema Eletrico (ONS), 2020). The predominance of hydraulic plants in Brazil creates the need for hydrological complementation and strong seasonality of generation in the SIN. The hydrological complementarity confers the supply of energy through hydraulic generation in periods of drought through the joint use of water resources in complementary basins. However, when the electricity demand is up the generation capacity of hydroelectric plants, thermoelectric plants start operating.

The marginal operating cost (MCO) is the cost to meet the additional demand using the system's available resources, from a thermal generation or energy deficit (Loureiro, 2009). If only hydropower plants are operating, this cost is lower. The operation of thermal plants can have high marginal operating costs. Therefore, the ISO decides how much energy is generated by hydroelectric and thermal plants, aiming at minimizing the MCO.

A thermoelectric plant generates electricity from thermal energy. A water volume is heated through burning fuel and turns into steam that spins a turbine that drives an electric generator. Most of the thermal plants use fossil fuels, which can be solids (coal), liquids (fuel or diesel oil), or gaseous (natural gas). The largest exporters of thermoelectric applications are Indonesia, Australia, Russia, USA, Colombia, South Africa, and Kazakhstan. Brazil imports 40% of the raw material from the USA Comex Stat (2020).

Figure 10 shows the coal price in 2020. The coal price reached the highest value on January 13th (point A), costing 75.33 USD/ton. Considering the analysis period in Fig. 11, the highest prices of this raw material occurred in the first quarter of 2020, represented by zone A. From March 27th, the coal cost starts to fall until reaching the lowest value in the first semester (approximately 52.1 USD/ton), represented by point B.

Figure 11 shows the MCO values for the Brazilian subsystems. As depicted in Fig. 12, the MCO depends on coal cost. In zone A (higher coal cost), CMO costs are higher than zone B in all subsystems. However, the CMO decrease (zone B) after the adoption of the pandemic policies.

The restrictive measures adopted by the Brazilian cities to contain the spread of Sars-Cov-2 began in many states in early March. On March 20th, eleven Brazilian states had already registered lockdown in at least one city. Therefore, at least one state located in each SIN subsystem had already implemented the lockdown (Brasil de Fato, 2020).

The energy generation in zone A was 50,928 GWh (Operador Nacional do Sistema Eletrico (ONS), 2020), while in zone B was 44,264 GWh, resulting in 6664 GWh of difference and leading the MCO to lower values.

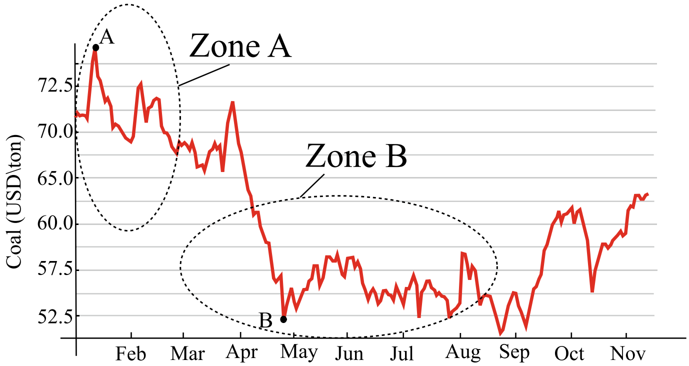
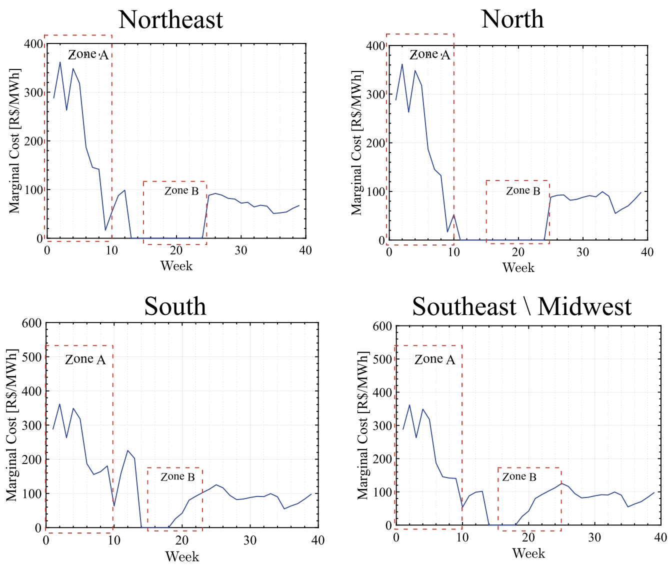


Fig. 10 Evolution of coal prices in 2020 (Trading Economics, 2020)



Week	Date
1	12/28/2019 to 01/03/2020
2	01/04/2020 to 01/10/2020
3	01/11/2020 to 01/17/2020
4	01/18/2020 to 01/24/2020
5	01/25/2020 to 01/31/2020
6	02/01/2020 to 02/07/2020
7	02/08/2020 to 02/14/2020
8	02/15/2020 to 02/21/2020
9	02/22/2020 to 02/28/2020
10	02/29/2020 to 03/06/2020
11	03/07/2020 to 03/13/2020
12	03/14/2020 to 03/20/2020
13	03/21/2020 to 03/27/2020
14	03/28/2020 to 04/03/2020
15	04/04/2020 to 04/10/2020
16	04/11/2020 to 04/17/2020
17	04/18/2020 to 04/24/2020
18	04/25/2020 to 05/01/2020
19	05/02/2020 to 05/08/2020
20	05/09/2020 to 05/15/2020
21	05/16/2020 to 05/22/2020
22	05/23/2020 to 05/29/2020
23	05/30/2020 to 06/05/2020
24	06/06/2020 to 06/12/2020
25	06/13/2020 to 06/19/2020
26	06/20/2020 to 06/26/2020
27	06/27/2020 to 07/03/2020
28	07/04/2020 to 07/10/2020
29	07/11/2020 to 07/17/2020
30	07/18/2020 to 07/24/2020
31	07/25/2020 to 07/31/2020
32	08/01/2020 to 08/07/2020
33	08/08/2020 to 08/14/2020
34	08/15/2020 to 08/21/2020
35	08/22/2020 to 08/28/2020
36	08/29/2020 to 09/04/2020
37	09/05/2020 to 09/11/2020
38	09/12/2020 to 09/18/2020
39	09/19/2020 to 09/25/2020

Fig. 11 Evolution of operational marginal cost in 2020

3.3 Brazil Energy Market

Energy trading in Brazil occurs in two trading environments: the Regulated Contracting Environment (ACR) and the Free Contracting Environment (ACL), also called the Free Energy Market. Energy generation and trading companies participate in the commercialization of energy in Brazil. In the ACR, sales occur through auctions promoted by CCEE. In the ACL, trade-in purchases and sales occur through negotiation with freely negotiated bilateral contracts between buyers and sellers.

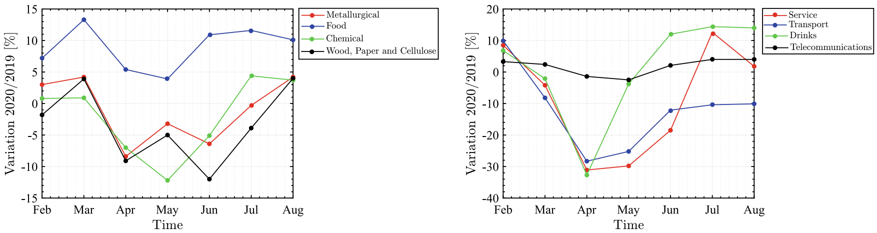


Fig. 12 Monthly evolution of electricity consumption in ACL per each industrial sector in 2020

CCEE provides monthly reports evaluating the electricity purchase and sale operations at SIN. According to these reports, it is possible to measure the pandemic impact on the Brazilian economy. Social distancing was intensified in the second half of April, impacting economic growth.

The monthly evolution of ACL electricity consumption of some industrial sectors in 2020 is in Fig. 12. In April, there was a drop in electricity consumption in all industry sectors analyzed. The most affected sectors were transportation (reduced people mobility), beverage manufacturing, and services. The food and telecommunications industry (both essential services) were the least impacted.

In June, the country started to loosen the social distancing in most parts of the country, which made the electricity consumption present a lower retraction than April and May. In July, consumption increased compared to the same period last year. In 2020, this was the first month that consumption shows a positive variation compared to the same period in 2019.

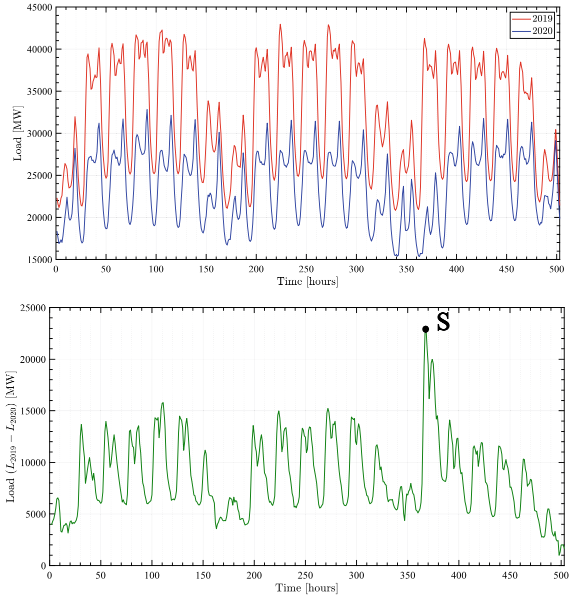
4 A Comparative Study: Brazil and Italy Electricity Consumption

Italy was the first country in Europe to impose social distancing measures and a lockdown to restrain the spread of novel coronavirus. The complete lockdown started on March 11th, eleven days before the intensification of the containing measures imposed in Brazil Electric Power Research Institute (2020). Due to the stop in industrial and commercial activities and people's circulation, electricity consumption was significantly reduced, mainly during the weekdays.

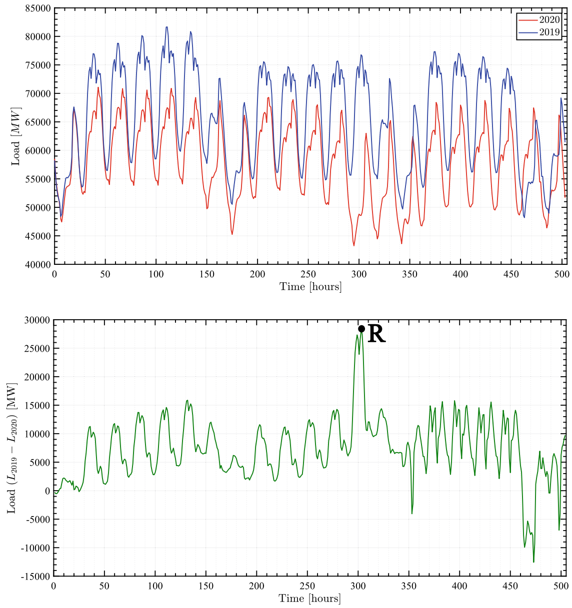
Figure 13a shows the load comparison in Italy, between three weeks of lockdown in 2020 (03/29–04/18) and the correspondent period in 2019 (03/31–04/20) and the difference between 2020 load (L_{2020}) and 2019 load L_{2019} The maximum load difference was approximately 22,901 MW (point S) on April 13th, 2020. The Brazilian load analysis is in Fig. 13b, where the maximum load difference was 28,208.5 MW (point R), also in April.

Figure 14 brings the percent difference between 2019 and 2020 for Italy and Brazil in the analysis period. The maximum percent difference in each country is highlighted

Fig. 13 **a** 2020 load versus 2019 load; **b** Instantaneous percent difference and their mean. *Data source* ENTSO-E (2020)



(a)



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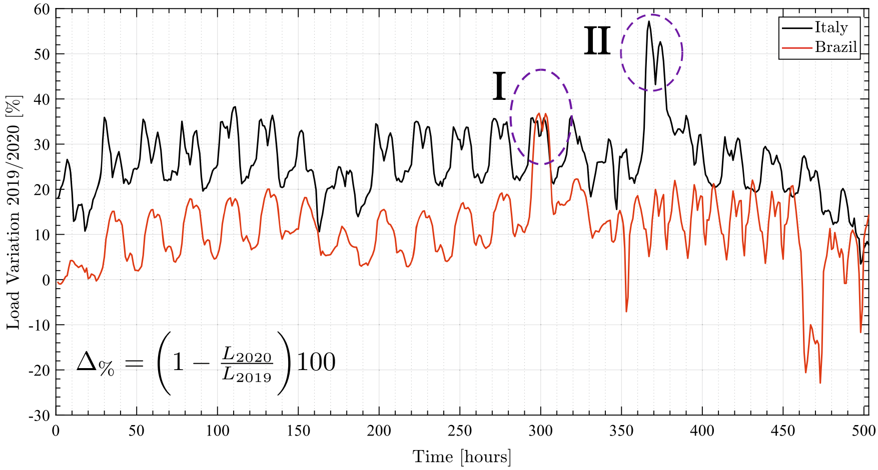

Fig. 14 Load percentage variation 2019/2020

inside the purple circles I and II. The maximum percentage difference was 37% for Brazil and 55% for Italy. The COVID-19 containment and monitoring measures adopted by Italy were more severe than the measures implemented in Brazil. That can indirectly explain the differences between the peaks in regions I and II.

5 General Implications for the Electricity Sector During and Post-Pandemic

The COVID-19 pandemic showed how a reliable, resilient, and low-cost electricity supply is necessary for society to deal with any crisis. The SIN requires continuous investments in network modernization to guarantee reliable electricity distribution.

In areas with high photovoltaic penetration, the load reduction creates unique challenges to manage high voltage and balance reactive power. In some cases, load shedding can be applied to adjust generation and load balance during potential interruptions. Improve the load forecast and coordination with large industrial could provide a more economical dispatch (Paaso et al., 2021).

The economic crisis caused by the pandemic in Brazil caused a contraction of the labor market, with many people losing their jobs. There was a worsening of social inequality in the country, culminating in an increase in energy poverty among the most impoverished population. Government officials encouraged specific measures and subsidies to utilities during the epidemic to combat this energy poverty. The most widespread intervention was to postpone any cut in supply in the event of non-payment. Such measures impacted the electricity sector's infrastructure, which had to readjust its medium and long-term expansion planning energetic.

Some measures have been taken during the crisis to reduce the impacts of changes in load patterns, for example, the implementation of automatic voltage control, capacitors, and reactors; coordination with generators and users for voltage adjustment; inspection of mission-critical circuits (Paaso et al., 2021).

To deal with the challenges imposed by the current pandemic, or even a new pandemic, the Brazilian electricity sector must reformulate the existing regulatory policy to maintain the Sector's structural balance. Besides, the power systems operating agencies need to keep attention to new behaviors in electricity consumption. This reduction in consumption patterns affected the pricing policy in the Brazilian electricity market. Electric Brazilian Sector should be aware that these price fluctuations could occur in future pandemics.

The formulation of public policies that consider all the electric sector structure, from generation to commercialization, could help the decision-making process of all the agents in the Brazilian electricity sector in case of a new economic and social crisis. The reduction in electricity consumption implies less revenue and brings financial instability for the electricity sector.

6 Conclusion

During the COVID-19 pandemic, health policies to control the virus spread cause impacts in the electricity sector, interfering in electricity consumption levels and patterns of electricity consumption. The drastic reductions in electricity consumption affected the energy trading market in Brazil.

Cultural and behavioral changes will be inevitable after the end of the pandemic. Some sectors will be more affected by these changes as the telecommunications sector, in which the large-scale utilization of home office practices during the pandemic crisis, increased Internet demand. Finally, Brazil must adopt strategies to improve the electricity sector infrastructure to meet changes in electricity consumption level and pattern during and after a pandemic.

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The Need of Normative Technologies for Smart Living Cities

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Keywords Critical infrastructures · Normative technologies · Smart cities · Social impacts · Systems engineering

1 Introduction

Cities must be increasingly connected, flexible, interactive, and sustainable to meet citizens' current needs for quality of life. In a world where the population is continually growing, resource consumption must be adequate and socially distributed. As a result, it also becomes an incentive for innovative and intelligent solutions that can somehow solve these problems.

In this context, the so-called smart cities emerge to solve urban problems, using technologies to integrate the most relevant social and environmental aspects, providing a better place for life in society. However, the development of these cities in a global context is still very recent. Thus, there is a need to implement monitoring and management tools to improve each city's energy efficiency and sustainability.

Eight infrastructures must be considered immediate and priority in society's context: communication systems, energy, food, health care, public safety, transportation systems, waste management, and water. These critical infrastructures can be

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viewed as the most basic and essential sectors for human welfare because they are vital for social well-being, poverty reduction, and sustainable development.

This article focuses precisely on these sectors, seeking technologies and solutions focused on smart communication, energy economy, proper food distribution, healthcare services, safety, smart mobility, waste management, and water supply. In the context of smart cities, the technologies addressed may help minimize some problems of these infrastructures.

First, an extensive database search was conducted to find articles citing technologies related to all eight essential sectors. After that, the selected material was reviewed, emphasizing each technology's benefit to the smart cities. With this information, a framework was prepared with all the technologies found, relating them to each corresponding sector.

1.1 Systems Engineering, Engineering, and Design Criteria

The starting point for understanding the impact of normative technologies on smart cities is systems thinking. Thus, it is possible to observe how a modern, sustainable, and people-centered city is a complex phenomenon that integrates diverse aspects, frameworks, and various subsystems. For this, some definitions and concepts must be highlighted so that it is possible to associate technologies and projects within the aspects discussed.

Systems thinking is the approach that enables better comprehension and designing of complex structures and projects. It includes some features, such as describing entities relation and complexity, model-based methods to illustrate real complex systems, and approaches that support holistic thinking (Haberfellner et al., 2019). This approach allows a broad look at the application or project under development, making it essential to consider the system's total behavior in the current scenario and the variations observed over time. With systems thinking, it is possible to move away from the reductionist view to generate complete and robust solutions instead of sub-solutions that can culminate in errors that are often not predicted.

Looking at the whole that involves the system, it is possible to analyze the effects in different aspects during the expected life cycle through stakeholders. In this way, systems engineering shapes this thinking to align the circumstances, ensuring good performance despite the uncertainties involved. It is the art and science of developing an operable system capable of meeting requirements within often opposed constraints (Griffin, 2007).

This concept has multidisciplinary as one of its prominent marks, and it has to do with complexity and all the relationships considered in the applications. Systems engineering is a holistic, integrative discipline, where contributions of different fields are evaluated and balanced to produce a coherent whole that is not dominated by a single discipline's perspective (Griffin, 2007). Thus, engineers from other areas can make a heterogeneous and consensual contribution. This project has space for electrical engineers, structural engineers, software engineers, mechanical engineers, control engineers, design engineers, and other professionals to work together. At NASA, "systems engineering" is defined as a systematic, multidisciplinary approach for the design, realization, technical management, operations, and retirement of a system (Hirshorn et al., 2017).

In the last few decades, there has been a growing application of systems thinking due to the increase in the systems' complexity and the search for an optimal, robust performance that considers the different knowledge fields. In this way, the academic programs have incorporated systems engineering into its curricula and form professionals specialized in the subject. In turn, engineers, researchers, and teachers attending to this knowledge are demanded more in projects and occupations in different areas, mainly in technology development. Systems engineers create the system architecture by configuring the system's elements to meet the performance requirements most satisfactorily and, in the process, incorporate a multitude of necessary technologies that must cohere in the final design (Booton & Ramo, 1984).

Projects that involve the development of normative technologies can benefit from the system-oriented approach. Systems engineering can also be viewed in terms of the depictions of the sequence of processes and methodologies used to execute the design, development, integration, and testing of a system (Kossiakoff & Sweet, 2002). Figure 1 shows a system engineering implementation workflow for project management.

The first step in this chain of processes is analyzing needs, where new ideas, requirements, and technological transformations arise. This stage is where the first steps of the project stage begin. Then, the concept sought is explored through research and evaluations and begins to consolidate the product or technology. After these initial steps, one of the essential steps arises, which is planning. The planning consists of organizing the project structures, price proposals, size, and execution definitions to be approved through a risk analysis. The product design and validation stage require

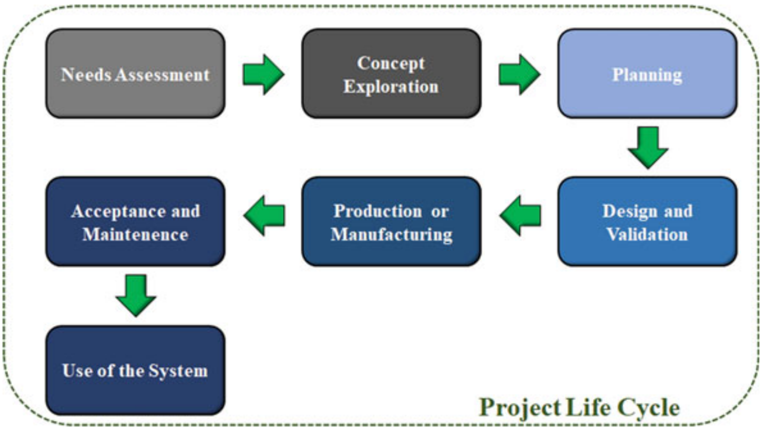

Fig. 1 System engineering implementation workflow for project management

constant monitoring and control of activities, from the prototype to testing. With this, the product can be manufactured and can undergo quality checks and tests to integrate the technology into the complete system. Finally, the project goes into use or execution in actual practice when it undergoes necessary maintenance. There must be a follow-up during the service period to investigate the continuity of what is being managed. This view shows the interweaving between management planning and the system engineering process.

The holistic engineering normative design makes up the side of systems engineering in the development of technologies. This chapter presents several normative technologies from a holistic view highlighting these applications' role in critical infrastructures. Therefore, this side of systems also relies on the engineering systems, design criteria, and philosophy of technology concepts. In Fig. 2, the different aspects approached by system engineering and engineering systems are highlighted.

Engineering systems are a field of study taking an integrative holistic view of large-scale, complex, technologically enabled systems with significant enterprise-level interactions and socio-technical interfaces (Rhodes & Hastings, 2004). This alignment incorporates and addresses systems engineering concepts, even experts already considered a topic within systems engineering. The main differences between the ideas are in the focus, scope, and role of these concepts. While systems engineering takes a complete look at the product or technology, engineering systems present a broad view that considers all stakeholders, not just those directly impacted. As a result, the role associated with systems engineering is more focused on design, integration, and performance. In contrast, engineering systems will act on different

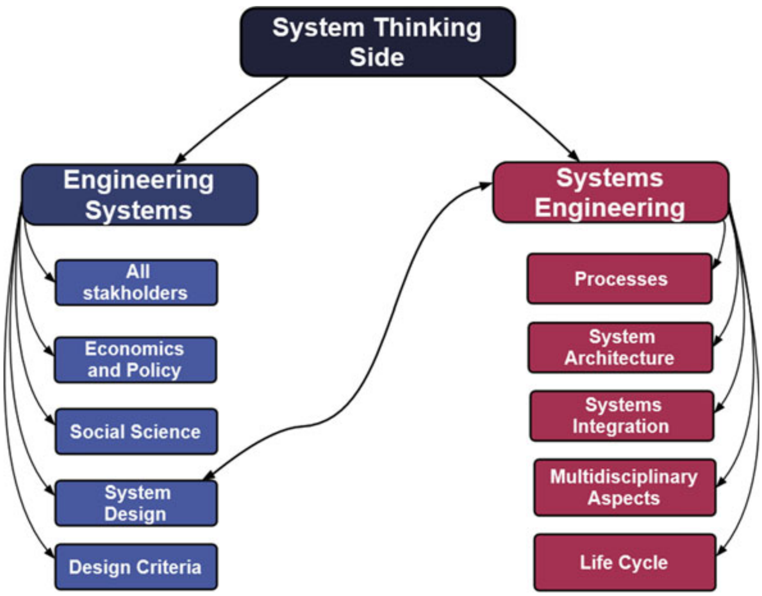

Fig. 2 System thinking side aspects

fronts besides design, such as economics, politics, and biology. It is possible to observe many similarities and a holistic tendency in the development and treatment of systems.

Through good engineering practice, it is possible to face the real and critical problems of society. From the supply of essential services such as power and water to life support machines in hospitals, engineering products are threaded through peoples' lives both individually and collectively (McCarthy, 2013). So, in addition to the professional obligation, the engineer has the opportunity to impact society positively.

Given these concepts, it is possible to understand the role and importance of systems engineering and the whole relationship with the holistic view on the systems side in dimensioning the impact of intervening in society through engineering.

1.2 Definition of Critical Infrastructures

Continuing the background conceptualization of the subjects that guide this chapter's proposal, critical infrastructures play a vital role within the scope of intelligent and complex systems such as smart cities.

Societal functions are highly dependent on networked systems, and even the most basic day-to-day operations involve interaction with various critical infrastructure systems (Murray & Grubesic, 2007). In smart cities, with technological advancement, sectors are becoming more connected through information and communication technologies (ICT's) and automation. Critical infrastructures ensure vital services to society, such as the potable water supply, electricity, or transportation (Bürgy, 2020). Any significant disruption of these services directly affects the security and the economic system of a society, public health and safety, or any combination of these pillars (Anderson & Fuloria, 2010).

From a system's perspective, it is possible to understand that interconnections between sectors and applications arise with increased intelligent systems' complexity. In a system-of-systems infrastructure, the overall structure escapes any single actor's control, and the different subsystems evolve autonomously (Gheorghe et al., 2006). Thus, based mainly on technology, these relationships increase vulnerability, create more critical infrastructures, or create challenges for existing ones. Normative technologies with a holistic approach can make significant contributions to critical infrastructure in the context of smart cities. In addition to bringing improvements and developments, essential solutions for society are also addressed.

To better understand the concept of critical infrastructures, it is necessary to know how the leading institutions and governments deal with the issue and define its scope. Some authors and norms present some exciting perspectives for understanding the subject, which can be seen below.

- "Infrastructures are critical because they provide services that are vital to one or more broad governmental or societal functions or attributes. It can be related to

citizens' survivability as far as their life's safety is concerned or to their quality of life" (Gheorghe et al., 2006);
- "The domain of critical infrastructures deals with engineering systems characterized by a high degree of technical complexity, social intricacy, and elaborate processes to fulfill essential functions in society" (Katina & Gheorghe, 2014);
- "… large-scale, human-made systems that function interdependently to produce and distribute essential goods (such as energy, water, and data) and services (such as transportation, banking, and health care). An infrastructure is termed critical if its incapacity or destruction has a significant impact on health, safety, security, economics, and social well-being" (Zio, 2016);
- "Organizations and facilities that are essential for the functioning of society and the economy as a whole" (ISO/IEC JTC 1/SC 27, 2013);
- "Critical Information Infrastructure: Those systems that are so vital to a nation that their incapacity or destruction would have a debilitating effect on national security, the economy, or public health and safety" (Shirey, 2007).

It is clear the points that these definitions address when talking about critical infrastructures and the importance of these sectors' vulnerability and how they are interconnected. Given that each country presents a particular vision, even if the central concept is shared.

Therefore, this chapter is in line with the definition approached and the scope of technologies too. With this alignment, it is possible to understand that in addition to these infrastructures without essentials for society's good functioning, these are also the pillars that directly impact social well-being within the city's transformations. In this way, it is possible to design and innovate technologies to guarantee smarter systems.

2 Life Sustaining and Critical Infrastructures

Smart living cities are a complex system with several interconnected aspects, as represented in Fig. 3. Critical infrastructures are among the most effective technical systems that influence any person's ordinary life or the normal operation of any industrial sector (Bagheri & Ghorbani, 2010). We classify these structures as the most basic and essential sectors for human welfare. Still, it is important to stress the modal aspects present in all activities mentioned, like justice, housing, labor access, equity, trust, and freedom.

The authors understand that a consistent and coherent balance between these life sustaining and critical infrastructures is necessary for society's fullness. One of these sectors' inefficiencies can cause a cascade effect, directly impacting another sector. The lack of secure and cost-effective provision of one of these essentials could result in a breakdown of supply, affordability, and accessibility of the other ones, especially for the most vulnerable in society (Machell et al., 2015).

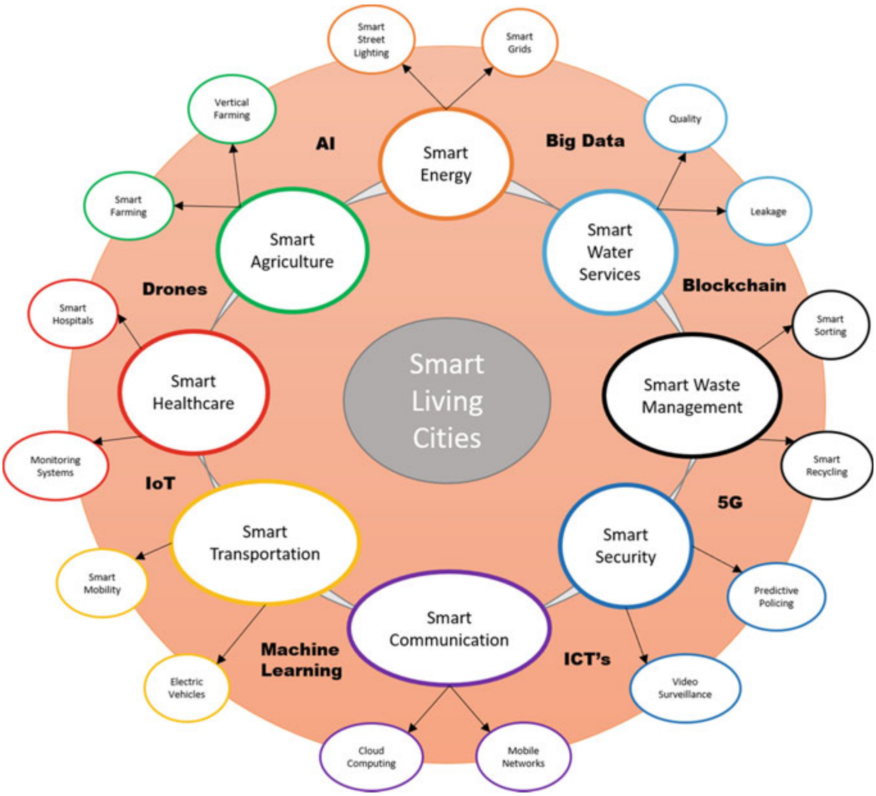

Fig. 3 Smart living cities and its interconnected aspects

2.1 Communication Systems

The communication systems are present in everything we touch. The cellphones at our hands, the televisions in our living rooms, the notebooks with access to the Internet in our offices and homes, and our newspapers are all capable of providing rapid communications from every corner of the globe (Haykin & Moher, 2008). These systems are essential because, as communication methods, they enable the transmission of any idea or information worldwide.

However, even with the digital revolution's global success in these cutting-edge technologies, a large part of the population still does not have access to these benefits. While more than half the world's population now has access to the Internet, the least developed countries' penetration rate was only 15% or one in seven individuals (The World Bank, 2019a).

Also, according to The World Bank, on a planet focused on the innovation of information and communication technologies, this persisting digital divide could exacerbate inequalities and create a new class of "digital poor." To avoid this scenario, developing countries need support to invest in deploying these digital infrastructures.

Only then will everyone be able to enjoy the benefits provided by these technologies. For example, China was one of the first countries globally to launch 5G technology with significant operator investment (Li et al., 2021). However, an even greater effort is needed for other countries to have equal access to these innovations.

2.2 Energy

Energy is at the heart of development. Energy enables the investments, innovations, and new industries that drive jobs, inclusive growth, and shared prosperity for entire economies (The World Bank, 2020c). It is also at the center of efforts to tackle climate change.

In 2018, the number of people without electricity access dropped to 860 million (IEA, 2018). Although this number is decreasing, a large part of the population still uses polluting fuels like wood or other biomass to cook and heat their homes. This use causes air pollution that results in widespread health impacts.

Energy consumption is expected to double until 2050 (McKinsey, 2019). By 2040, renewables will grow by 400% of its current amount (BP Energy Economics, 2018), followed by an even more constant electric vehicle presence. Lower costs for clean energy help with this transition, while disruptive technologies like smart grid and smart meters have upturned energy planning. So, a change in the energy sector is also needed to bring consumers closer to generation and monitor and manage its use.

Energy is used for multiple food system activities, including farm machinery and the processing, packaging, transporting, refrigerating, and preparing of food (Ingram, 2011). On the other hand, food is also used to generate energy. For example, certain commodity crops are grown for energy—corn, soy, and sugar are used to make biodiesel.

Energy also has an extreme connection with water. Specific forms of energy production require massive amounts of water. Too much water (alluvion period) or too little water (drought) can significantly impact electricity production.

Urban areas consume up to 80% of global electricity generation. By 2050, more than 70% of the population will live in cities (Curiale, 2014). With these numbers, it is essential for good energy planning and management in smart cities.

2.3 Food

Food systems encompass different activities: production, distribution, and consumption. These activities link people to the food they eat, as well as the system outcomes for society and the environment (Schipanski & Bennett, 2012). Therefore, this sector's development is one of the most powerful tools to end extreme poverty, generating, among other things, employment and food.

Food also involves climate change. Currently, the food sector accounts for more than 25% of greenhouse gases (GHG) emissions worldwide. The expected increase in meat and animal product consumption by 2050 would further increase GHG emissions by 80% (European Research & Innovation for Food & Nutrition Security, 2016).

Everyone has a role to play in reducing food loss and waste, not only for the sake of food but also for the other resources it uses. Smart cities must deal with this issue by creating measures to balance the food–waste nexus and even using the trash to generate energy, reaching the food–waste–energy nexus. Less food loss and waste would lead to more efficient land use and better water resources management with positive impacts on climate change and livelihoods (Food and Agriculture Organization of the United Nations (FAO), 2020).

One of the leading causes of death worldwide is risks associated with poor diets. Millions of people are either not eating enough or eating the wrong types of food, resulting in a double burden of malnutrition that can lead to illnesses and health crises (The World Bank, 2020a). According to the Food and Agriculture Organization of the United Nations (FAO), the number of people affected by hunger will surpass 840 million by 2030 (FAO, 2020). This study was carried out before the COVID-19 pandemic; however, it is already an alarming scenario.

Short- and medium-term policies should aim at achieving a pro-poor and inclusive transformation. It will require tackling existing inequalities at all levels through multi-sectoral policies that keep these inequalities as the central focus.

2.4 Health Care

With demographic growth and an aging global population, healthcare services are increasingly in need. Public health, which should be a universal right, is increasingly scrapped. Millions of people are pushed into extreme poverty every year because they cannot afford health service costs (The World Bank, 2020b). Even when these services are free, many people cannot be attended due to the lack of quality and affordability.

In developing countries, the situation is even worse. Each year, these countries' population pays over half a trillion dollars out of pocket for health care (World Health Organization and The World Bank, 2019). This reality only contributes to the increase of social inequality globally, where those who have financial conditions get better treatments and those who do not cannot even be treated.

Smart health care consists of multiple participants, such as doctors and patients, hospitals, and research institutions in an organic whole. The use of IoT, mobile Internet, cloud computing, big data and artificial intelligence, and modern biotechnology constitutes the cornerstone of smart health care (Tian et al., 2019).

New technology solutions can help health authorities and government agencies deliver the right service when and where it is needed. The patients need to play more active roles in managing their care at a lower cost.

2.5 Public Safety

Justice and security play a critical role in fostering a healthy business environment, enhancing growth, improving access to public services, curbing corruption, and restraining power abuse (World Bank Group, 2017). A safe city attracts tourists and investments, contributing to the smooth functioning of other essential infrastructures of society.

Facial recognition software can distinguish individuals in crowds and profiling based on location data so that individual households can be identified precisely. For such reasons, data practices like this have become subject to civil, political, and individual suspicion, constituting a highly volatile policy arena (van Zoonen, 2016).

For this reason, governments should be closer to their citizens and discuss ways to increase the security of their domains and, consequently, improve other aspects of society.

2.6 Transportation Systems

The transportation system can be defined as combining elements and interactions that produce the demand for travel within a given area to satisfy this demand (Cascetta, 2001). Transportation is also the essential means of connecting people, goods, and services.

The smooth operation of this sector can directly impact other sectors. It is possible to determine a given city's economic activity by analyzing its transport systems' quality and interconnection. This infrastructure can affect both the quality of life for citizens and the economic liveliness of a city.

Traditionally, cities have attempted to solve transportation challenges by expanding the infrastructure—building more roads, tunnels, and bridges. But for many cities today, poor financial conditions and land constraints make that approach impossible (IBM, 2011). It needs to focus on these cities, working on these infrastructures and focusing on reducing poverty and boosting prosperity as transport is at the heart of critical development changes.

This sector immensely impacts climate change. For example, transport accounts for about 64% of global oil consumption, 27% of all energy use, and 23% of the world's energy-related CO2 emissions (The World Bank, 2019b). With the ever-increasing rate of new vehicles on the market, the sector's environmental impact is expected to grow dramatically.

2.7 Waste Management

Waste is a fundamental factor in balancing the water–energy–food nexus that is often overlooked in the discussion. Every aspect of the nexus generates waste. Significant amounts of energy are embedded in the production, transportation, and storage of food, and much of this energy goes into the trash with unused food (Webber Energy Group, 2020). However, this misuse's ideal management can reduce the number of resources spent on some processes and sometimes return the lost energy.

In developing countries, roughly 45 million cubic meters of water are lost daily, with an economic value of over US$3 billion per year (The World Bank, 2016). About 20% of all freshwater resources treated for human consumption are lost through leakage mechanisms (The Guardian, 2017). To collect, manage, and distribute water, energy is needed, impacting the whole nexus.

Food loss and waste have, indeed, become an issue of great public concern. An estimated 1/3 of all food produced globally is lost or goes to waste every year (FAO, 2011). Visible food waste is accompanied by a less noticeable waste of both water and energy consumed during production, preparation, packaging, transport, sale, and disposal (Machell et al., 2015). Some of these wastes can be reused to produce electricity through different technologies and methods.

It is possible to create more sustainable water, energy, food supply, and consumption by addressing waste mechanisms. Some require approaches, including social factors, for example, simply consuming and wasting less.

2.8 Water

Water is at the center of economic and social development; it is vital to maintain health, grow food, manage the environment, and create jobs (The World Bank, 2017). It drives economic growth, supports healthy ecosystems, and is essential and fundamental for life itself.

About 2.1 billion people around the world do not have drinking water services, 4.2 billion people do not have safe sanitation services, and 3 billion do not have basic hand washing facilities (United Nations Children's Fund (UNICEF) and World Health Organization, 2019).

Water consumption for food production, including crops and livestock, accounts for about 86% of the total societal water consumption, though locally household and industrial uses can be predominant, particularly in major urban areas (D'Odorico et al., 2018). The growth rates can decline in some regions due to water-related losses in agriculture, health, income, and prosperity. This number shows the water–food nexus' significance and explains why water is essential for all the core economic growth drives.

3 Smart Cities

In this section, smart cities' overview will be raised as the adopted approach's essence is associated. Also discussed are how critical infrastructures are related and linked in the context of complex systems like smart cities. Finally, the role of innovative technologies is discussed.

3.1 Framework of Smart Cities

With the increasing number of international examples of smart cities emerging worldwide, this concept achieves an important role in recent urban challenges and gains more notoriety and importance. But what is a smart city? What qualities should a city possess to be considered smart?

The term "smart city" has recently attracted a lot of attention from policy-makers, business leaders, and citizenship in general. Although there is no unique definition of what a smart city is, the concept could be briefly described as cities that use information and communication technologies to increase their inhabitants' quality of life while contributing to sustainable development (Ignasi & Zarlenga, 2015).

Smart cities are often imagined with multiple sensors, cameras, and various other technologies, providing big continuous data. Cities, however, can only be smart if there are intelligence functions that can integrate and synthesize these data for some purpose, ways to improve the efficiency, equity, sustainability, and quality of life (Batty et al., 2012).

The indistinct nature of definition and approach of smart cities has resulted in the use of the term "smart" interchangeably with several other concepts of urban development, such as digital city (Yovanof & Hazapis, 2009), tech city (Foord, 2013), wired city (Batty, 2012), intelligent city (Komninos, 2002), information city (Sairamesh et al., 2004), knowledge city (Yigitcanlar et al., 2008), creative city (Florida, 2003), and sustainable city (Ahvenniemi et al., 2017). These different concepts share some similarities but focus on a particular aspect of using technology in urban environments (Macke et al., 2018).

The UK Department for Business, Innovation, and Skills (BIS) considers smart cities to be a process rather than a static one, in which increased citizen engagement, hard infrastructure, social capital, and digital technologies make cities more livable, resilient, and better qualified to respond to challenges (Department for Business Innovation & Skills, 2013). IBM defines a smart city as one that makes optimal use of all the interconnected information available to understand better and control its operations and optimize the use of limited resources (Crosgrove et al., 2011).

The Institute of Electrical and Electronics Engineers (IEEE) says that a smart city brings together technology, government, and society to enable the following characteristics: smart cities, a smart economy, smart mobility, a smart environment, smart people, smart living, and smart governance (IEEE, 2019). The European Commission defines a smart city as a place where traditional networks and services become more efficient with the use of digital and telecommunication technologies to benefit its inhabitants and business (European Comission, 2020).

These definitions collide positively in an issue of the good life that this system can provide. Technological development can always offer this type of delivery to society, but this is also linked to other social aspects, freedom, culture, moral, and even religious values. Therefore, we must take into account a complete view of how society interacts with these systems.

Reference (Yigitcanlar et al., 2019) presents a systematic review of smart and sustainable cities' literature to study whether cities can become smart without actually being sustainable. The answer based on their review is clear. After analyzing 35 recent articles published in journeys, they concluded that this is not possible. The authors also affirm that the smart city should not rely predominantly on technology as a savior to achieve sustainable outcomes.

Institutional, physical, social, and economic infrastructures are considered the four basic pillars of a smart city (Mohanty et al., 2016). It is possible to guarantee individual and collective freedoms by maintaining these aspects. Issues such as hunger, misery, energy poverty, and social inequality are massive breaks for development. There is no smartness in cities where there is social inequality and other associated problems (Salles et al., 2020).

Another critical point is the different norms and standards that have emerged to assist and guide development. A detailed review of international standards and projects involving smart cities is carried in (Lai et al., 2020). This type of reference is necessary because it helps new projects. For example, the IEEE has been influential in this respect, and several standards make contributions to the different fields of smart cities. Figure 4 illustrates the hall of the institution standards.

3.2 Integration of Infrastructures

The projects and works hardly deal with the interface between multiple critical infrastructures. In Sect. 1, the definitions were raised, and in Sect. 2, the details of each critical infrastructure were considered. At this point, it is reasonable to understand how these systems are then connected and directly and indirectly impact each other. It becomes more transparent and more understandable how this process occurs due to its complexity and relationships from a system's perspective.

The connections are almost limitless when we go to different levels of performance of each critical infrastructure. An example is essential to illustrate the concept. When moving toward a more complex social organization concept, such as smart cities, these conceptions become increasingly critical and sensitive. However, with the use of innovative technology and a systems approach, it is possible to create solutions that follow sustainable society goals. Figure 5 shows an integrated scope of these relationships with some examples.

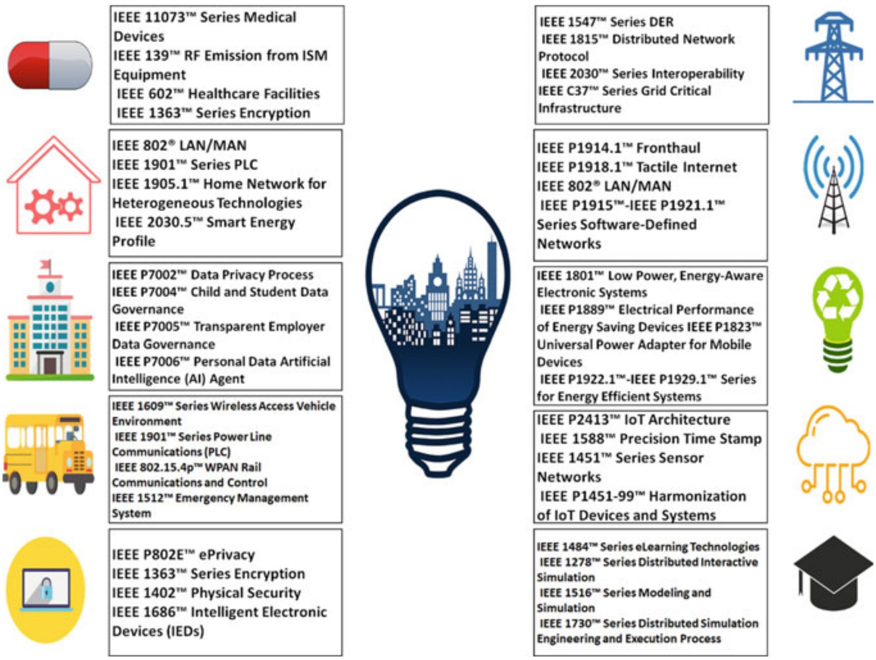

Fig. 4 IEEE standards for enabling smart cities. (Adapted from IEEE SA, 2017)

3.3 The Role of Innovative Technologies

It is necessary to highlight existing normativity definitions because these concepts are intertwined in developing new technologies to understand innovative technologies' roles. Below are some definitions collected with some philosophers and professionals in the area:

- *"Normativity (that there is right and wrong, good and bad, function and dysfunction) is a central concept in a good framework. This is because normativity is something we cannot escape if we take everyday life seriously. It is also a natural outcome of there being a law side to temporal reality."*, **Andrew Basden**.
- *"It's the "ought-ness" of things, isn't it? Distinctions ought to be made correctly; resources ought to be frugally harvested and saved or used. A painting ought to excite the imagination. Children ought to be loved by their parents. People ought to make themselves known to new neighbors and so on."*, **David Hanson**.
- *"As a human tool, the city which is not itself human has to satisfy the normed demands of the human community. It can function as a tool of liberation or oppression. But to be either liberating or oppressive, the city has TO EXIST & CHANGE. There are infrastructures involved. And therefore, for either end, its compliance with societal pillars is required (and, I think, unquestionable). The smart city can make no choices about its compliance with them. 'Smartness' necessitates that*

Fig. 5 Interconnection between the critical infrastructures

the sustainable cities demonstrate its unfailing subjection to society's pillars as it varies its performance according to cities' transformations. It hasn't the freedom to DECIDE whether to obey the rules or not, whether it OUGHT to turn up for work in the morning or stay in bed", **David Hanson (Adaptation for Smart Cities)**.

- *"Standard behavior that results in the proper working function—both individually and simultaneously with other entities."*, ***Charles Stomer***.
- *"Normativity is the state of being subject to norms which are rules that tell us what we should or should not do. As such we have the freedom to violate them or not. Norms guide our actions concerning a particular value so that it is protected and promoted. In HD's theory, that means there are norms for logical thought, formative progress, linguistic clarity, economic supply and demand, artistic success, justitial fairness, ethical love, and certitudinal trustworthiness."*, ***Roy Clouser***.
- *"Norms or principles are supposed to guide human conduct and therefore they immediately call forth the idea of norm-conformity and antinormativity (obedience and disobedience). This distinction, in turn, presupposes the (human) capacity to identify and distinguish the possible avenues of action and to choose between the available options freely. There are not many choices at any specific moment—just one choice amongst multiple options. Therefore freedom of choice presupposes an accountable agent to which the choice made and its consequences can be attributed."*, **Daniel Strauss**.

Technologies are inherently normative because their steady and reproducible realization in some space and time requires that the people associated with this context should behave in such a way as to enable the intended functioning of the technology (Radder, 2009). Despite this importance given to technological development in the last decades, mainly with the concept of smart discussed here, there are obstacles associated with the delay in developing several countries worldwide. It means that technologies are often limited because there is no interest or is unviable due to society's unsolved problems. But one must address the impacts that these innovative technologies can bring to society's critical infrastructures. Chaps. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures" and "Towards a Holistic Normative Design" address this view of normativity from an integrated view that relates to the position addressed in this text, mainly about the integration of complex systems.

4 Economic Accessibility of Each Technology

Table 1 shows the eight articles chosen, each one containing the infrastructure to which it refers, its technique and technology used. As discussed in Sect. 2, ICTs are powerfully present in these techniques, showing that the technology bias in a smart city can be used to manage the critical infrastructures. Although the authors' prototypes and simulations were satisfactory in small scale tests, they need to be tested in different environments with more robust components to meet a city or communities' demands. It is highly recommended to read the full articles for a better understanding of the proposed technologies and also as a way to give recognition and credit to the authors.

Table 1 Framework of normative technologies

Infrastructure	Reference	Technologies	Required country economy
Communication	Uribe-Pérez and Pous (2017)	Optical Fiber, ZigBee, and WiMAX	Developing economy
Energy	Mary et al. (2018)	LDR and Zigbee	Advanced economy
Food	Kyaw and Ng (2017)	Arduino and Raspberry Pi	Developing economy
Health care	Casino et al. (2017)	Bluetooth, Wi-Fi, and ZigBee	Advanced economy
Public safety	Isafiade and Bagula (2020)	Pattern mining	Developing economy
Transportation	Mrazovic et al. (2016)	Mobile App	Advanced economy
Waste	Maulana et al. (2018)	Arduino, RFID, and MQTT	Advanced economy
Water	Penteado et al. (2018)	Thermal Camera and MATLAB	Advanced economy

The technologies were chosen aiming at the possible applicability in all countries. However, on a large scale, there may be difficulties for some countries to implement these changes. Therefore, it is necessary to distinguish technologies that are accessible to places with different economic levels. It will be based on the country classification made by the World Economic Outlook (WEO), which divides the world into two major groups: advanced and developing economies (International Monetary Fund, 2018).

The authors of the technology that involves the communication infrastructure mentioned that cities that do not have a wide deployment of optical fiber could also use the system, as long as they use cheaper solutions like ZigBee. Thus, this technology can be implemented in developing countries. However, it is unlikely that a country with a developing economy will use the technology presented in the energy section. Unfortunately, some places in the world do not have a home light either street light.

For the same reasons, technologies involving the agriculture infrastructure can also be applied in countries with developing economies. They use controllers and sensors that can be purchased at an affordable price. Large-scale aquaponics systems can satisfy the hunger of millions at a low cost. The CIGO platform integrates different actors in its network. However, users need a smartphone and an Internet connection to use it, so this technology was limited to advanced economies.

RFID tags are not expensive, but they become unviable when thinking of a large-scale application due to the amount required. This technology can be used indoors in places that can afford this cost, but thinking about countries that do not have many resources makes it impossible. Table 5.1 shows the distinction and analysis between the chosen technologies and their required country economy. All technologies that can be implemented in developing economies can also be used in countries with advanced economies.

The researched technologies can be implemented in the two classifications, showing that a smart city does not exist exclusively in economically advanced countries with a high human development index. Quite the opposite, it is widely possible and viable to implement these technologies in developing economies with proper investments.

5 Social Impacts

Smart cities concepts are usually used referring to high-tech cities. The optimization of urban resources and efficiency is in the center of smart cities' projects and initiatives. The focus is on how technology can promote urban changes, using ICT's, ensuring socioeconomic improvements. Although the concepts are mainly related to innovation and technology, social aspects should be incorporated on studies. Once end users need and expectations must be considered, their engagement must prevent negative impacts or even make the city more efficient.

Despite its unique concept, smart cities presuppose a digital environment where the stakeholders are active and participative. However, the technological approach does not clarify if there are affordable electronic devices or fast Internet access for all users. Citizen training and autonomy on the use of technology, the understanding about big data, and the loss of privacy under safety are other aspects that should be discussed. Those insights are important to know what smart cities represent and how smart cities effectively change and improve citizens' lives. People are aware of how it works? Are they involved in the process of making a city smart/smarter?

Urban citizens' well-being is directly related to the critical infrastructures previously mentioned—food, water, energy, waste, transportation, communication, health care, and public safety. Kitchin (2014) draws attention to the growth of investments big companies are doing in smart cities technologies and services and how the high-tech approach seems to blur the end user role in smart cities conception and operation.

Social smart cities and human smart cities are terms that bring the end user to the center of the discussion. The social smart city is used in reference to social benefits and impacts smart grids can cause. Angelidou (2014) brings a literature review highlighting strategies to make a city become smarter, using two terms to characterize smart cities strategies: hard and soft infrastructures. The hard infrastructure systems focus on using technology as a resource for the development of the city's infrastructure. The city's soft infrastructure and people recommend beyond technology, human creativity, collective intelligence, and intellectual capital as resources for a more accurate and successful smart city.

On the other hand, human smart cities propose an approach where people get involved since smart systems' conception, having the power to design and create solutions. Studies put the citizen as the center of the discussion defending that the technologies are the mean that drives community's connection and motivates changes. This approach protects citizens' empowerment and collaboration. The solutions for community issues can be simple and local with digital technology as ally (Costa & Oliveira, 2017; Oliveira & Campolargo, 2015).

5.1 Smart City Governance

The interdependence of actors on smart grids can lead the system to break the boundaries between public and private. A smart administration or governance refers to using data and technologies to provide efficient public services. The government includes new ways of communication between the public administration and the community members. The ICTs are used for services optimization; data traffic in real time returns a city with better mobility and well prepared for hazards. The participation of the citizens has a fundamental role in this subject. The relationship between the citizen and the service provider gets closer and makes the end users more participative in the community. Cities that work well attract investments and visitors, increase job opportunities, and provide a better quality of life.

Despite the importance of citizens/companies engaging in their local communities, the governments must ensure the service provider reaches all the end users with the same quality. The autonomy that smart cities presume cannot raise community inequality. Each actor has a role in smart cities. The government cares about the citizens but are not prepared for innovative business models. The goal of the private sector is to increase profits and not always follow the public interests. The third sector, otherwise, can be prepared to deal with both, serve the public interests based on innovative business models, but in general do not have resources and ability to replicate success experiences. The challenge is to make a governance model mixing characteristics of different initiatives to make a smart city efficient (Gracia & García, 2018). According to Effing and Groot (2016), citizen participation in governance is what makes a city smart. The involvement of citizens, public administration, and companies together are more important than advanced technology.

Smart city governance must have democracy, efficiency, and transparency as values. Good management of resources allied to IoT improves service quality, uses data to provide information, improves emergency response, and facilitates decision making. The IoT for smart governance makes cities more efficient, innovative, democratic, and transparent (Mahmood, 2018).

5.2 End User Engagement and Connection

Smart cities expect and need citizens' engagement. The data flow going to and coming from the end users will drive the decision making on smart cities. Computers, smartphones, and tablets are the interfaces between the end user and the service provider in most cases. They expect robust services, with a friendly interface, easy access to data and an attractive layout. This stimulates the citizens to connect with each other and with the city, promoting better information exchange with the governance.

Being connected does not mean being engaged in the process. Despite having access to those technologies, not all users can convert the available data into information or knowledge. The active participation of citizens is essential because it makes the services provided more reliable once it is designed based on community expectations. Another challenge is to ensure citizens access to affordable digital devices, fast Internet access, and training for autonomous use. If the smart city focus is high tech, citizens will continue to be mere users (Mohseni, 2020; Murgante & Borruso, 2014).

To promote effective citizen engagement, the service providers must create mechanisms to listen to the community's opinions with a collaborative environment that stimulates mutual help. It is crucial to bring together people with different views, perspectives, and technology knowledge. For the last, giving directions for the individuals with a lack of technology knowledge ensures their effective participation (Batty et al., 2012). The citizens need to have a channel to enable mutual communication as an entity. This can be made between individuals who share the same needs and expectations, using ICTs to develop their technological skills and identify the social capital for developing the cities, taking into account local specificities. Granier and Kudo (2016) affirm that some social models' deep engagement can be not desired, even recognizing the importance of citizen participation for smart cities development.

5.3 *Privacy* Versus S*afety*

A smart city is considered a safer city. Advanced technology, even to reduce criminal activities or make services more efficient, gives this impression. Faster traffic, better routes for firefighting, and city monitoring centers help with this. End users give information for online sources networks (OSN) in return for services. That information became a business model, where the companies use for marketing purposes, not always being careful with protection and privacy issues. The data collected and transmitted may have sensitive information associated with it. The data can give tips about the user lifestyle or location, making them vulnerable to losing privacy. Although smart systems are related to the quality of life and well-being improvement, it is needed to pay attention to privacy threats since their implementation. Besides introducing data management systems for smart cities, for secure use of applications, security and privacy solutions need to be taken as studied in Al-Turjman et al. (2019).

From a public administration perspective, open data means transparency. That is, data freely available prevents the misapplication of public resources. Governments that provide free data channels appear to be more reliable and innovative and tend to attract business opportunities.

ONS are democratic tolls, allowing people of different ages, social positions, and ethnicities to be part of smart city development. Through these networks, the users provide enough data to governments, policy-makers, authorities, and companies to better understand people's behavior trends. The collected information can drive smart cities' success if the discussion about it considers the involved risks, threats, privacy, and security issues. For this sake, a balance should exist between safety, privacy, openness, and other socially desirable local values. As people are the center of this social issue, an appropriate digital education level for safe behavior should be provided (Moustaka et al., 2019).

6 Smart Living: An Integrated Perspective

As said before, smart cities approaches are mainly focused on technology. For an integrated perspective of smart cities, people must be considered as the center of the discussion once they interact with technology, having a proactive behavior for its conception. These people aim for a city founded on well-being once they assume technological innovation leadership, not the opposite. Thus, the social role presents an innovative connection between society, environment, services, and technology.

A smart city is a complex entity because it is formed by a mix of groups with different values, spread geographically and culturally. For this sake, it is impossible to generalize a smart city model or the technological apparatus used to figure out what is smart living for each citizen group. Culture determines behavior and people's needs. Even basic public services can be essentials for a group and not essential for others. For example, while ICTs and IoT can be used to improve and make efficient the water supply, water is culturally conditioned. It may need some adaptation if water conservation is aimed (Vinod Kumar, 2020). From an integrated perspective, IoT and ICTs are used in smart living technologies such as smart health care and smart housing. The services provided aim to be an inclusive promoting quality of life and well-being.

In IBM's smart home proposal, the sensors and monitoring instruments can connect with users and devices, responding to condition changes, making decisions based on the available data and reaching better results. These system abilities are used to deliver entertainment, energy management, safety, health, and wellness to people (Chard & Douglass, 2015). To address a smart healthcare system for cancer treatment, the study of Onasanya and Elshakankiri (2019) focuses on an IoT/wireless sensor network (WSN)-based system to offer more treatment options. The service provider takes action about patient treatment based on the exams and scans and the available information given by the WSN. The enhancement of treatment, diagnosis, and monitoring are reached through the IoT medical system. Otherwise, the WSN combines the information about available treatments from linked spatially distributed autonomous sensors, facilitating the medical service provider actions and increasing cancer treatment success.

The smart living role besides practical aspects of life, such as access to food, medication, housing, transportation, education, and entertainment, also addresses social values to convert a city through smart communities. Smart communities share values, history, and culture. For a good way of living, the citizens need to feel safe, have their privacy respected, and the public services should have high quality. However, to call a city smart is not as simple as can be the use of ICTs and IoT. What technology provides is a path for smart living.

7 Conclusions

This work presented the smart living cities concept, the differences between systems engineering from engineering systems and defined eight life sustaining and critical infrastructures. Definitions and smart cities' framework were also discussed, and the deep integration between the infrastructures was also explored. Finally, the researched normative technologies and the social impacts they may cause were presented.

With all definitions of smart cities discussed, it is possible to reach a commonplace and conclude that a smart city is a sustainable city in the first place, whether digital or not. It is also possible to affirm that a city where not everyone has access to energy, hungry people on the streets, lack of water, and unhygienic places to live cannot be considered a smart city.

The study shows that using normative technologies can improve efficiency, promote equality, increase resiliency, and reduce risks mitigating adverse impacts on social welfare and the environment of smart cities. The intensive use of ICT's aims to improve the quality of life of the citizens, proposing a real revolution in the way innovations are made.

Even though smart cities' primary role is technology, social aspects should be at the center of a smart discussion. The citizen's engagement helps the success of smart initiatives. For that, it is needed to ensure access to technologic education for autonomous and safer use. An integrated approach runs through people engagement respecting their community cultural specificities.

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Case Studies

Social and Economic Implications of Electricity Generation Sources

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Keywords Renewable electricity sources · Environmental studies · Social and economical aspects of power plants

1 Introduction

The Brazilian electricity sector is characterized by the intensive use of hydroelectricity. According to data from the International Energy Agency (IEA, 2015), just behind Canada and the USA, its share of renewables in electricity production in 2018 was 82% (Ibid.). The Brazilian energy matrix presents one of the highest shares of renewable energy in the world. According to the Energy Research Company (EPE, 2020), in 2019, 46.1% of Brazil's total energy supply was based on renewable sources. Among these, sugarcane held the first place, at 52.8%, followed by hydroelectricity, which represented 36.8%. Of the total energy produced in Brazil, sugarcane contributes 18%, followed by hydroelectric power with 12.4%.

Hence, Brazil has one of the cleanest energy matrices on the planet, mainly due to hydroelectric power. Hydroelectric plants (HPPs) produce renewable, low-cost energy with high profitability, and have a very low relative level of emissions.

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Nonetheless, there have been several increasing difficulties in planning, licensing, and building HPPs in Brazil, due to the perception that populations in regions where HPPs are developed bear the negative social and environmental impacts, while the largest beneficiaries are the big cities and electro-intensive industries. Indeed, the construction of large dams brings considerable social and environmental transformations. Over the last three decades, large hydroelectric reservoirs have displaced populations, flooded vast, often productive, areas, and changed the socioeconomic micro-regional systems and other preexisting structures of many areas, thereby causing major conflicts of interest (Furtado et al., 2013).

On the other hand, most hydroelectric plants have been a crucial factor in overcoming poverty in their areas of influence, particularly in regions with few alternatives for socioeconomic development. HPPs introduce new, highly significant dynamics to the local economy, due to aspects such as access to electricity, improvements in the quality of infrastructure, strong demographic dynamics, and the mobilization of resources, which were non-existent before the enterprise, including financial compensation for the municipalities. These factors are reflected in the well-being and quality of life of the population, working to induce local development.

The conflict of views regarding the impacts caused by large dams has become increasingly significant. Scientific research in this field is important to broaden understanding and to support appropriate decisions. With particular regard to Brazil, society needs to broaden this discussion, since there is still a huge hydraulic potential to be considered, which is not only essential for the economic and social development of the country but also the ecological sustainability of the Brazilian energy matrix.

This chapter presents a synopsis of planning in the Brazilian power sector, and the results of three research studies developed within the Research and Development Program of ANEEL (the National Agency of Electric Energy), which aimed to generate reliable information on the benefits brought by hydroelectric plants to their areas of influence, to create a tool to assess the regional integration of hydroelectric power plants, and, lastly, to create an index of sustainability for electric generation sources. This latter item encompassed renewable and non-renewable sources, enabling an informed, balanced debate on the choice of socially just, economically viable, and environmentally appropriate alternatives for the production of the energy needed to develop the country. In addition to this, one section examines the benefits of wind farms on local communities. There is a straight link between this chapter and some others of this book. Particularly, Chapter "Sustainability and the Responsibility of Engineers" deals with the problem of social inclusion and renewables but discussing also the problem of greenhouse emission, garbage processing, and the social acceptance of renewable sources. Here, we focus on the Brazilian characteristics of renewables, with special emphasis on hydroelectric-based sources, even though solar and wind-based sources are discussed. A link with Chapter "Economics, Regulatory Aspects and Public Policies" is also identifiable since economics is vital in planning an energy system.

2 The Brazilian Power Sector Planning

The power system expansion problem consists of determining a construction schedule for a given energy demand projection, which minimizes the present value of the investment and operating costs of the projected system. In the Brazilian power system, this is a complex problem due to a number of factors: size and characteristics of the system, institutional organization, the predominance of hydropower, a vast transmission system, many regional interconnections,[1] and excellent potential for developing thermal power plants.

In addition to the maturation periods of the projects and studies that precede their conception, these peculiarities also require an expansion planning framework in three-time horizons, which are as follows:

Long-term studies—with a time horizon of up to 30 years. They seek to analyze the development strategies of the electrical system, the future composition of the generating complex, the transmission systems, and establish a technical and industrial development program inventory of river basins. These studies define the guidelines for medium- and short-term planning and the marginal costs of long-term expansion.

Medium-term studies—with a time horizon of up to 15 years. At this stage, the studies establish generation and transmission expansion programs, estimate the investment requirements, and the demand for construction services: power plants, transmission lines, substations, and equipment—the same for power plant feasibility studies and the siting of thermoelectric projects.

Short-term studies—with a time horizon of up to 10 years. Decisions regarding the expansion of generation and transmission are presented, defining the projects and their time allocation, conducting analyses of supply conditions to the market, and calculating the marginal costs of expansion. Distribution programs are also established, with physical and financial goals, together with the global investment program for generation, transmission, distribution, and general installations. The conditioning factors of these studies are the market requirements of the various subsystems, the deadlines for implementing the projects, and the power sector's financial capacity. Private sector participation is considered as either independent producers, self-producers, or consortia for the construction of hydroelectric and thermoelectric plants. Its periodicity is annual with results in the ten-year power sector expansion plan. In general, studies in the ten-year plan consider two macroeconomic scenarios, one of which is chosen as a "reference scenario."

In recent years, reduced participation of hydroelectric plants with regularization reservoirs in the generation expansion has extended the spectrum of uncertainties within the system and, consequently, the complexity of its planning and operation. Similarly, the growing participation in the Brazilian energy mix of intermittent and uncontrollable sources (such as wind and solar), run-of-river hydroelectric plants, and inflexible thermoelectric plants has signaled the need to review the expansion planning process. This has brought challenges for the national interconnected system to operate.

[1] Mostly to take advantage of hydrological diversity among hydro basins.

The planning system in force in Brazil originated with the PDE 2006–2015 (also called PDE 2015). This document represented a resumption of effective planning practice in the power sector. With regard to the transmission expansion planning, Tolmasquim (2015) mentions that the PDE includes the regional interconnection works program based on system performance criteria and additional feasibility studies.

3 Energy Auctions: The Case of Renewable Electricity Sources

One of the goals of the ten-year energy plan is to define the tenders for power plants and transmission lines. These tenders aim at assuring the security of supply at a reasonable rate by way of mechanisms that support the generation and transmission capacity expansion. With this in mind, the government conducts public auctions to meet the growth of loads of the distributing companies (which supply captive consumers) in the regulated contracting environment—known in Brazil as ACR, by contracting new generation facilities.

The ACR represents nearly 70% of the market. In auctions, all sources compete, whereby the winner is the player that offers the lowest tariff for the energy generated from the underbid project. In the free contracting environment—ACL, which represents around 30% of the market, free consumers and generators freely negotiate bilateral power purchase agreements (PPA).

The PPA differences in the ACR and the ACL are accounted for and settled in the short-term market by the market operator—CCEE. In this segment, also known as the spot market, no trading takes place between the producers and consumers; the CCEE settles the PPA differences using the difference settlement price—PLD.

Hence, the PDE connects the needs of the consumption players to the generation sources through the indicative plan; the investors then decide (or not) to build new generation facilities through price proposals to sell energy at energy auctions. Such a decision depends on the rate of attractiveness, which depends on the expected evolution of the generation costs.

According to the CCEE database (2021), since 2005, new energy auctions have contracted more than 39,000 MW-year, most of which are hydroelectric projects. It should be emphasized that since 2009, there has been significant growth in contracting wind energy, due to (i) the creation of auctions for renewable sources, such as wind and solar power; (ii) auctions for energy reserve, specifically for contracting wind power, and (iii) the participation of wind power in regular energy auctions as of 2011.

Consequently, over the last few years, there has been a reduction in contracting energy from a hydraulic source. According to MME (2017), if, on the one hand, energy planning studies have guided decisions on auctions to expand the electric power generation matrix in Brazil, it is also confident that the results of the auctions feed back into planning studies. Some relevant aspects of the 2017 auctions for generation expansion should be mentioned.

- The planning agency—EPE and the prospective investors review the costs of the various sources and technologies that are candidates for development, in the light of the offers presented at these auctions, with emphasis on wind, solar, and natural gas, taking into account that some factors are cyclical.
- The results reveal the growing importance of proactive planning of the transmission expansion as a factor for the success of generation expansion. In specific cases, for larger projects or set of projects, the linked contracting of generation and transmission may prove to be a strategy to be explored.
- Given the diversity of renewable resources in Brazil and their complementarities in production and the competitiveness revealed at this auction, it is essential to study the participation of project portfolios as bidding entities at the auctions. The development of "hybrid" projects—for example, a blend of solar and wind—would be the first path. Moreover, the EPE and the prospective investors should consider new, more flexible, and generic arrangements.

4 Environmental Studies in Brazil

Since the last two decades of the twentieth century, the impacts caused to the environment by the production processes have been evaluated in much greater depth, including the generation of energy. This has become a growing concern also in the face of issues related to climate change and its serious consequences for the planet. Therefore, evaluating the socio-environmental impacts of the different sources of energy generation available in Brazil has become central for the decision-making process in the planning of the Brazilian electricity sector. Different sources of electricity generation have different socioeconomic and environmental impacts, and the evaluation of these impacts is fundamental to the project competitiveness analysis, in the search for sustainability and the best choices for society and the environment. This section presents the environmental studies involved in the planning and licensing processes for the expansion of the national interconnected system in Brazil.

In Brazil, the previous main studies developed for hydroelectric projects are (i) hydroelectric hydrographic basin inventory studies and (ii) feasibility project studies. The former are associated with the integrated environmental assessment (AAI); the feasibility studies are associated with the preparation of environmental impact studies (EIA) and environmental impact reports (RIMA).

4.1 Hydroelectric Hydrographic Basin Inventory

The first study for implementing a hydroelectric project is called the *hydroelectric potential estimates* of a hydrographic basin. It evaluates, in a preliminary manner, the aptitude of the basin for energy generation, focusing on its topographic, hydrological, geological, and environmental aspects. It is based on the available data and allows a first assessment of the potential and cost of the enterprise, defining its degree of priority for the next step.

The second is the *hydroelectric inventory study*, when a set of projects is produced, considering the various alternatives of fall division for the hydrographic basin. By comparing the many alternatives, it is possible to select the one that provides the best relationship between implementation costs, energy benefits, and social and environmental impacts. Secondary data are also used, complemented by field surveys. They are based on basic cartographic, hydro-meteorological, energy, geological and geotechnical, and socio-environmental and multiple water use studies. Thus, a set of uses, the main characteristics, cost/benefit indices, and socio-environmental indices are obtained. The socio-environmental studies of this phase use methodologies and procedures of an environmental impact assessment, identifying environmental weaknesses and socioeconomic potentialities.

4.2 Integrated Environmental Assessment (Avaliação Ambiental Integrada—AAI)

In Brazil, the instrument internationally known as the strategic environmental assessment (SEA) has earned the name of integrated environmental assessment (AAI), for political–strategic issues related to responsibility for its elaboration (Furtado, 2017).

In 2006, the Ministry of the Environment (MMA) published a document entitled *Integrated Environmental Assessment of Hydrographic Basin—AAI* (EPE, 2006), emphasizing the need to evaluate the cumulative and synergistic impacts of interventions in a given area, to the detriment of traditional, individualized treatments, which prevent an understanding of the interactions and dynamics of the most relevant processes that define or constitute the environment. As a consequence, in 2007, when the *manual of hydroelectric inventory of hydrographic basins* was revised, it became mandatory to prepare integrated environmental assessments (AAIs) in the context of UHEs inventory studies. Therefore, the AAI is the Brazilian correspondent of the strategic environmental assessment (SEA).

The IAA allows the participation of the many social actors to ensure agreements that contribute to sustainability. Its studies include relevant themes for the integrated management of the basin, considering its territorial extension, the diversity of its socio-environmental characteristics and the existing and planned hydroelectric uses, and their impacts.

4.3 Feasibility Studies

The feasibility studies of projects are more detailed and assess the technical, energy, economic, and socio-environmental feasibility of the alternatives, defining the optimal use that will go to the energy auction.

The EVA aims to present, analyze, and define the best locational alternatives of an enterprise, preceding and contributing to the EIA/RIMA and the design of the project. In electrical sector projects, such as the installation of new generation plants, it is extremely important to develop those studies before the acquisition of the land in which they will be installed, since it evaluates factors such as environmental and legal liabilities, surrounding communities, regional legislation, socioeconomic aspects, and environmental impediments, among others.

The environmental licensing process for hydroelectric projects covers three stages: (i) prior license, in which the environmental viability of the enterprise is attested; (ii) installation license, which approves the executive project and all environmental control, mitigation, and compensation measures to be conducted throughout the installation phase; and (iii) operation license, which grants the permission to operate the enterprise upon verification of compliance with the entire environmental control plan, as well as approves the controls to be conducted throughout the operation phase.

The environmental impact study (EIA) and the environmental impact report (RIMA) of a specific project are based on feasibility studies, such as EVA, and are central to obtain a prior license (Licença Prévia) from environmental agencies. The EIA is among the most widely used environmental impact assessment instruments. It presents a detailed environmental diagnosis of the physical, biotic, and socioeconomic aspects of the areas of direct and indirect influence of the project, as well as a prior analysis of all of its possible environmental impacts, their magnitudes, and the changes that can occur with the implementation and operation of the enterprise. It also contains environmental programs for the monitoring and control of its positive and negative impacts. The RIMA is its synthesis, briefly presenting the diagnosis, impacts, and programs, and should reflect the conclusions clearly and objectively, understandable to the general population.

The stage of obtaining the prior license is of fundamental importance for the licensing process to fulfill its purpose as an instrument of environmental policy and management. At this stage, the environmental viability of the enterprise is verified, and all the locational and constructive alternatives are presented, so that the impacts are minimized and effectively controlled throughout the installation and operation phases. Its technical studies are based on general legal guidelines and specific guidelines defined by the relevant environmental agency (Montaño & Souza, 2008).

Perhaps due to their importance, the EIAs/RIMAs have been strongly criticized, the main arguments are as follows:

(a) methodological deficiencies (Costa et al., 2010);
(b) an environmental adequacy perspective, using mechanisms capable of making legislation more flexible (Campos & Silva, 2012);

(c) problems in the terms of reference, documents that define the scope of the studies, as well as negligence in what these documents propose (Vulcanis, 2010; Banco Mundial, 2008);
(d) inconsistencies due to the lack of training and specialization of environmental agencies staff (Ibid.).

Lastly, there is a growing perception that the EIAs/RIMAs have been carried out only as fulfilments of formal stages, legitimizing already established political decisions.

5 Social and Economic Implications of Hydroelectric Power Projects in Brazil

This section presents some of the results from two researches developed by the Universidade Federal de Pernambuco—UFPE—and its Foundation for Development Support—FADE—within the scope of the ANEEL R&D Program. The first, developed from 2010 to 2012, within the ANEEL/CHESF R&D Program, is entitled "Evaluation of the effects of hydroelectric power plants on the socio-economic development of directly affected municipalities." The second, elaborated from 2013 to 2016, within the ANEEL/CEMIG R&D Program, further developed the subject and was entitled "Developing a tool to monitor and evaluate the economic, social and environmental sustainability in the areas of influence around dams" (Furtado & Furtado, 2016).

The following sections present the results of these two research studies, highlighting the importance of evaluating the social and economic benefits for local communities, setting out to maximize the positive impacts, and consequently, improve the acceptance of hydroelectric power projects.

5.1 The First Research

The objective of the first research was to assess the effects of hydroelectric power plants on the socioeconomic development of the affected municipalities. The study has assumed that HPPs bring significant contributions to the local development of the municipalities in the region where they are deployed. With this assumption, the following operational hypothesis was formulated: The levels of local development for municipalities directly influenced by the HPPs are higher than those for municipalities indirectly influenced, within their scope, in all regions of the country.

To achieve the objectives of the study, nationwide research was structured. The research assessed the development of a set of municipalities with areas flooded by five hydroelectric power reservoirs across the five Brazilian regions, enabling an analysis on the internalization level of socioeconomic benefits in the region affected by the reservoirs.

The criteria for selecting the hydroelectric power plant were to guarantee the validity and the possibility of being able to generalize the research findings and to cover the five regions of the country. By applying the criteria and considering the objective aspects of the research, the selected projects, with their respective installed capacities, were as follows: North Region: Tucuruí HPP (8375 MW); Northeast Region: Xingó HPP (3162 MW); Midwest Region: Serra da Mesa HPP (1275 MW); Southeast Region: Nova Ponte HPP (510 MW); Southern Region: Itá HPP (1450 MW).

5.1.1 Methodological Framework

To measure the sustainable local development of those municipalities, the study created a Sustainable Local Development Index (SLDI). To build the SLDI, the first step was to broaden the concept of sustainable local development, based fundamentally on the notion introduced by Buarque (2004) that local development may be understood as a process of changing reality, which promotes economic dynamism and an improvement in the quality of life of the population.

Four relevant dimensions were developed to indicate the SLD level of each municipality, based on the conceptual debate: quality of life; education; quality of management; and economic dynamism. Different themes composed each dimension. For each theme, the indicators were chosen based on their ability to model the reality, since they are the most relevant and they have the best levels of reliability, accessibility, and quality, considering not only the conditions of companies in the electricity sector, but also of the municipalities in the interior, non-governmental organizations, and organized communities, in general. Thus, a total of 73 indicators were defined for the composition of the SLDI (CHESF & UFPE, 2011; Furtado et al., 2011, 2018).

Based on the information gathered during the fieldwork, the levels of local development in the municipalities were assessed, which thereby enabled to infer the association between the presence of hydroelectric plants—and all the dynamics that occur within the region—with higher levels of local development.

5.1.2 Research Results

The main result of the research was the construction of the Sustainable Local Development Index—the SLDI, which enabled the hypothesis to be verified and the general and specific objectives to be attained. However, the creation of this index plays a further role since, in the evaluation of municipal development, it also introduces variables that do not appear in other existing indexes. It synthesizes a set of indicators structured in a broad base of dimensions.

Thus, the main innovations of the SLDI are as follows (Furtado et al., 2011, 2013):

(a) The theme of habitability was introduced to measure the quality of life, in addition to income and health.
(b) The income and health themes of the SLDI take into account more aspects and, consequently,
(c) A wider range of indicators, thereby making the assessment of the quality of life dimension more complete.
(d) In the education dimension, the SLDI considers more aspects and indicators, ensuring that the measurement of this dimension is very reliable; and
(e) Lastly, there is a fourth dimension in the SLDI, economic dynamism, which is fundamental to assessing the sustainability of local development.

Hence, it would seem that the SLDI is more representative, robust, and reliable than the HDI-M regarding its ability to reflect sustainable local development in all its dimensions.

The use of the SLDI demonstrated that in three hydroelectric power plants (HPPs)—Xingó, Tucuruí, and Itá—many socioeconomic benefits had been generated for the group of municipalities in which areas had been flooded by the reservoirs. However, in the case of two plants—Serra da Mesa and Nova Ponte—investments had not resulted in socioeconomic benefits for the municipalities with flooded areas.

Economic dynamism was the dimension that portrayed the most advantages of directly influenced municipalities over those municipalities outside this influence. While the different relationships between the dimensions allow us to infer which factors contributed to better local development, it is also valid to consider hypotheses related to the characteristics of the plants and the internal factors of the region in which they were implemented. The Itá HPP is the most recent of the five analyzed HPPs (1996/2000) and should have incorporated positive mechanisms to promote local development, which, to a certain extent, may explain its greater degree of regional insertion. In addition, it is located in a region of high social capital and entrepreneurial capacity and with a higher level of education, endogenous factors that must have contributed to the highest regional insertion. This is a contrary situation to the Serra da Mesa HPP, which is located in a region with lower social capital and entrepreneurial capacity. This lack of positive endogenous factors may have contributed to the poor performance presented and its modest regional insertion.

Additionally, the internalization level of the socioeconomic benefits in the regions directly affected by the reservoirs was also analyzed. Therefore, a scale of the degree of regional insertion of the plants was created by comparing the equivalent SLDI (weighted average of the SLDI) of the municipalities with flooded areas with the reference municipality, outside the direct influence of the hydroelectric plant. The scale was hierarchized by grades from 0 to 10 and grouped into different levels of regional insertion, i.e. very high, high, moderate, low, very low, and enclave.

5.2 *The Second Research*

This research aimed to develop a tool for monitoring and evaluating the level of regional integration of hydroelectric power plants. The issue of "regional insertion," a term first coined in the *"I Plano Diretor para Conservação e Recuperação Ambiental nas Obras e Serviços do Setor Elétrico"* (I Master Plan for the Conservation and Environmental Restoration in the Works and Services of the Power Sector) (Eletrobras, 1986), involves creating and maintaining alternatives for development opportunities on a regional level.

This level of integration, or "regional insertion", was measured by the level of sustainable local development of municipalities in the area of direct influence of the plants. The tool, named the Index of Sustainable Regional Integration (ISRI), contains a set of indicators that covers the four dimensions of local development: quality of life; economic development; quality of public management and environmental quality (Furtado et al., 2016; Furtado and Furtado, 2016; 2017).

The research produced the index of sustainable regional integration (ISRI), which is a tool for monitoring and assessing the regional integration of hydropower plants, based on a system of indicators that cover the four main dimensions of sustainable development: environmental quality, sociocultural quality, economic development, and quality of public management.

Besides building the ISRI, the fieldwork enabled the construction of a database that corresponded to the initial evaluation of the monitoring and evaluation process. The main criteria for selecting each indicator were its adequacy in relation to measuring the relevant aspects of sustainable local development, its feasibility, availability, and reliability, in order to produce a more accurate evaluation (Ibid).

The fieldwork involved 40 municipalities in the areas of direct influence (ADI) around six hydroelectric plants, located in the State of Minas Gerais, South-Eastern Brazil, namely Emborcação, Irapé, Nova Ponte, Queimado, Rosal, and Volta Grande.

5.2.1 Methodological Framework

The first step in the methodology adopted for the research consisted of a conceptual consolidation of the term "sustainable regional integration," based on the technical and scientific literature (Eletrobras, 1986). This was followed by constructing a preliminary matrix of indicators, consisting of dimensions, themes, aspects, and indicators, which represent everything involved in integrating a specific hydropower plant within its region, herein considered as the set of municipalities within its area of direct influence (ADI). The indicators were organized into four dimensions, all derived from the conceptual discussion: (i) quality of life, (ii) economic development, (iii) quality of public management, and (iv) environmental quality.

Secondly, a survey of data was developed, associating values to the indicators, and thus composed the baseline of the monitoring and evaluation process of the regional integration of the selected enterprises. Subsequently, these data were treated and consolidated in an electronic database, developed to provide support for processing the index of sustainable regional integration (ISRI). The indicators also underwent a process of standardization and parameterization, enabling their values to be expressed in units of comparable measures, using percentages, per capita, and density functions. The indicators were standardized on a scale of 0–1.

The consolidated index comprised 79 indicators distributed in the following dimensions: quality of life (34), economic development (18), quality of public management (17), and environmental quality (10).

To validate the results of the research, a triangulation of methods was employed, i.e., more than one method of research was used, aiming at results with a high level of reliability. In this research, the used methods were as follows: Delphi (main method), factor analysis (FA), a correlation between variables, and the ISRI analysis versus the reality of the municipalities (Furtado et al., 2015a, 2015b).

The factor analysis method was employed based on the need to summarize the large amount of information generated by the indicators. After using the FA, the final version of the index was consolidated. It was then possible to confirm the four dimensions: quality of life, economic development (ED), quality of public management, and environmental quality that make up the ISRI as an arithmetic mean.

Additionally, the ISRI results for each municipality were compared with the socioeconomic and environmental evaluations of the municipalities, which also enabled us to confirm the validity of the ISRI.

The internal consistency (reliability) of the ISRI was evaluated using Cronbach's alpha reliability analysis. The Cronbach's alpha coefficient (α) is a statistical tool to estimate the reliability of a questionnaire applied in a poll or reliability of the results obtained from questionnaires (Agresti & Finlay, 2012).

In order to qualify the results obtained for each index, a scale of analysis was formed with five classifications: very low, low, intermediate, high, and very high. These classifications together with ratings are as follows: very low ($0 \leq 0.30$), low (> 0.30 e ≤ 0.50), intermediate (> 0.50 e ≤ 0.70), high (> 0.70 e ≤ 0.90), and very high (> 0.90 e ≤ 1).

5.2.2 Research Results

To deal with the challenge of evaluating the integration of a hydroelectric power plant with the development of its region, the use of indicators has proven to be a good measure, provided they are comprehensive enough to cover the main dimensions of sustainable development, such as the quality of life and sociocultural aspects; economic development, the quality of public management, and environmental quality. Jointly, such indicators can reveal the most relevant aspects of sustainable local development and integration and are an important tool for monitoring the effects of actions implemented by the utilities, ensuring efficient allocation of resources and their effective management.

According to the results, the ISRIs of the hydropower plants ranged from 0.41 (Irapé HPP) to 0.47 (Volta Grande HPP), while the others fell between these two values. These results indicate a low degree of regional integration of the hydropower plants studied, all below 0.5 in the ISRI (Furtado et al., 2016; Furtado and Furtado, 2016; 2017).

These results may be explained due to the stage of the plants. As these hydroelectric power plants have been operating for a long period, some environmental programs have been concluded, and consequently, their results do not appear in the indicators. This demonstrates that these hydroelectric power plants did not present a sustainable regional integration.

Lastly, it may be stated that the municipalities captured by the ISRIs are compatible with the diagnosis of the municipalities in the areas directly affected by the reservoirs of hydroelectric power plants. This proves that the index, a tool for monitoring and evaluating sustainable regional integration, is correctly measuring what needs to be appraised.

6 Social and Economic Implications of Wind Power Projects in Brazil

Wind power projects have been implemented in various regions of Brazil, particularly in the Northeast of the country. After an intense level of installation along the Brazilian coastline, investors began to construct huge wind farms in the interior of this region. In a poor region, the local benefits have a crucial role in the socio-environmental viability of these projects.

Various environmental studies in these areas (Casa dos Ventos & Diversa Sustentabilidade, 2014a, 2014b, 2014c, 2015a, 2015b; ENEL & Diversa Sustentabilidade, 2018; Casaforte Eólica & Diversa Sustentabilidade, 2019) have assessed the positive impacts of the wind farms. The main benefits in these studies are usually presented by enterprise phases: planning; installation, and operation phase.

The mentioned studies (Ibid.) highlight the following positive impacts in the operation phase:

(a) The production of a clean energy supply for the National Interconnected System (NIS) by wind farms improves the quality of energy used throughout the country and is considered a positive impact of these generation sources. Moreover, if used to replace fossil fuel sources, it also helps to reduce the greenhouse effect;
(b) Land lease payment brings substantial benefits to landowners in the semiarid region of the Brazilian Northeast. Most of the companies that are erecting giant towers in the Northeast region have opted to lease the land in order to build wind farms. Considering a wind farm with 200 turbines in total and a medium payment of US$ 350 by month, for the lease of land for each wind turbine, the owners will be sharing a monthly sum of US$ 70,000, which will circulate within the region in the improvement of homes, acquisition of goods and food,

as well as resources for the technical improvement of agro-pastoral production, thereby favoring economic expansion.

(c) The low emission of CO_2 or pollutants into the atmosphere, using wind energy, is contained within the Brazilian strategies to meet the goals of achieving the CO_2 emission levels from the agreement established at the COP21 Paris Climate Conference, with the central objective of strengthening the global response to the threat of climate change. According to Miranda (2012), CO_2 emissions in the wind power generation life cycle occur, for the most part, still in the construction stage of components and equipment, which results in a relatively low emission factor, and is significantly lower when compared to other generation sources.

The experience in executing socio-environmental programs in the interior of the Brazilian Northeast region has confirmed these benefits (Casa dos Ventos & Diversa Sustentabilidade, 2014a, 2014b, 2014c, 2015a, 2015b).

Another important proven benefit is that implementing socio-environmental programs involving communities, such as social communication and environmental education programs, should contribute to promoting citizenship, socio-environmental education, social interaction, education, sociocultural belonging, and to the expansion of knowledge, among other relevant benefits for the population living in rural places.

A study developed by GO associates (Oliveira et al., 2020) for ABEEólica (Wind Energy Brazilian Association) used a methodology of regional input-product matrix (IPM), which considers that the economy constitutes an integrated system of several interdependent sectors, so the impacts suffered by one sector influence the other segments to a greater or lesser degree.

This study states that, in the period from 2011 to 2019, the Northeastern and Southern regions of Brazil received an investment of R$ 88.1 billion in. A percentage of 20% was destined for construction, and the rest was used on equipment, maintenance, and the machinery sectors. Within this context, the Brazilian wind sector implied a value gain in the economy of Northeast and South Brazil of R$ 66.95 billion.

The logic of the proposed methodology is that an investment expansion in the wind sector increases demand in the machinery and equipment sectors, including maintenance and repairs, and in construction (the direct effect), which increases production in other segments in order to face the expansion generated by the allocated resources. Sectors that provide inputs to these directly affected sectors will produce more to meet this new demand, so that a positive shock generates a chain effect, with a greater effect than the initial shock (the indirect effect). In turn, the initial shock, which occurred due to increased investments in the wind sector, has an impact on labor income and, consequently, on household consumption (the income effect), characterizing an impact of increased production on wages and, consequently, on consumption (Ibid.).

According to GO associates (Oliveira et al., 2020), the human development index (HDI) of municipalities showed that the installation of wind farms had a positive and significant effect on these indicators. The municipalities, where wind farms were installed between 2001 and 2010, revealed a greater increase in the HDI-M, on average, than in the control municipalities, where there are no wind farms.

These authors (Ibid.) also observed that the relationship between the GDP of municipalities, i.e., the economic activity, and the installation of wind farms in the municipalities, for the period between 1999 and 2017, indicated a positive and statistically significant relationship (21.15%). The municipalities with wind farms demonstrated, on average, a higher total and per capita real economic growth than the municipalities where there are no wind farms (19.69%).

Lastly, they realized that, for the period between 2000 and 2010, the results indicated a negative and significant relationship between the installation of wind farms in the municipalities and the Gini index, which signifies that in the municipalities where the farms had been installed there was a reduction in inequality, on average of 0.02%, when compared to the municipalities in the same state where there are no wind farms.

7 Sustainability of Electricity Generation Sources

This section presents the results from research entitled “Energy matrix and improving the systematics of environmental insertion into electric system expansion planning,” denominated the Sinapse project (Furtado et al., 2020). One of the main objectives of the research was to create a sustainability index to compare different electric power generation sources. The use of a sustainability indicator system enables a fairer comparison of environmental costs and benefits between technologies and developments. The research developed a fourfold methodology in order to build the SIGS. The dimensions of the SIGS are as follows: (i) environmental, (ii) social, (iii) economic (regional integration), and (iv) political–institutional. The results have indicated that, among the different sources of energy generation available in Brazil, all the renewable sources scored higher than non-renewable sources. The results also indicated that by using the SIGS, the planning process for the generation expansion of Brazil’s power sector may be considerably improved.

Thus, this research, considering the aspects and variables related to the various dimensions of sustainability—economic, social, environmental, cultural, and institutional, has determined the sustainability levels from different sources of generation, based on indicators that reflect the availability of resources, its environmental and socioeconomic impacts, and vulnerabilities in the face of climate change and land-use restrictions.

7.1 Background

Throughout the methodological process, it was essential to consider studies that have been elaborated over the past few years, bringing together a significant bibliographic survey—both national and international. Thus, armed with this knowledge, it has been possible to build the conceptual–methodological framework as a support to produce indications and recommendations capable of contributing to a new moment, with proposals for various social actors and economic agents involved, using an indicator system. Indicator systems are one of the most commonly used methods for this purpose, so that in this case, it can reflect, for each generation source, the medium- and long-term availability of resources, their environmental impacts, the socioeconomic aspects involved, and together with the vulnerabilities in the face of climate change and land-use restrictions.

Due to Brazil's major hydroelectric potential, and the growing criticisms of this type of expansion, which involves the construction of large reservoirs with the consequent environmental impacts, incorporating environmental issues into the planning process of the electric power sector has affected hydroelectric plants more heavily.

In Brazil, the use of sustainability indicators of electricity generation sources has been used with different levels of depth, depending on the type of the source. As expected, hydroelectric sources have a higher number of indicators, although there is a higher proportion of negative aspects than positive. The substantial participation of this source in national interconnected system (NIS) has provided much more knowledge on the environmental impacts and variables for its measurement. With regard to other sources, there is no comprehensive use of indicators within the Brazilian electricity sector, particularly when it comes to comparing the sustainability of these generation options in expansion planning. Since this is the objective of this research, this review provided relevant information for creating the sustainability index of energy generation sources.

In 1999, the International Atomic Energy Agency (IAEA) initiated a long-term program addressing indicators of sustainable development for energy (ISED), in cooperation with several other international organizations, including the International Energy Agency (IEA), UNDESA, and some IAEA Member States. The project was developed in two phases: In the first phase (1999–2001), 41 ISEDs were identified, and a conceptual tool was developed to classify and implement these indicators; the second phase began in 2002, with a three-year research project, to implement the set of indicators in seven countries. These indicators analyzed the existing energy policies and future strategies (IAEA, 2006).

7.2 Methodological Framework

According to Furtado and Furtado (2016), sustainability is based on two scientific disciplines: ecology and economics. In the first, the meaning, until the late 1970s, was associated with resilience, which is the ability of a system to face tensions and disorders without losing its functions and structures. In economic science, it is the term used to qualify development. The electricity sector grows through policies that are generally intended to demonstrate that investments aim at economic growth and improving the living conditions of the population. Both the social and environmental dimensions raise concerns, since both generation and transmission cause changes in the ecosystem in order to meet the basic demands of the population, thereby causing environmental impacts (Lugoboni, 2015).

Opting for an electricity generation source requires an appropriate assessment, which involves a study and negotiation of cost/benefit, in addition to obtaining a clear understanding of the impacts and adopting appropriate compensatory measures (Camargo et al., 2014). To evaluate the impacts of any enterprise on an environment, it is necessary to be fully aware of both the impactful action and the means that will receive it. Consequently, due to the complexity of the factors and variables involved in these evaluations, the use of indicators enables a comparison of the different options of generating sources.

7.2.1 Building the Indicators

Within the management context of a given territory, the objective of an indicator is to indicate the existence of risks, potentialities, and trends in its development, so that, together with the community, decisions may be taken more rationally (Tunstall, 1994). According to Gallopin (1996), the most desirable indicators are those that summarize and simplify the relevant information that makes real phenomena more apparent, legible, and identifiable. The main objective is to aggregate and quantify information, ensuring that its meaning is made clear.

According to Wong (2006), once the basic concepts and political context have been clarified, it is necessary to carry out additional work of conceptual consolidation to unfold the theoretical ideas that should become the basis for developing the indicators. Figure 1 illustrates this process.

This research used the null method, attributing the same importance to all dimensions, themes, aspects, and indicators. The arguments for taking this decision were as follows: (a) The technical method could bring relevant biases to the results since it is very dependent on subjectivity and the profile of the experts who assign the weights; (b) as the created index is a pioneering venture in Brazil, there is no bibliographic reference available for consultation; (c) in a complex context such as the sustainability of different sources of electricity generation, it would not be advisable to use weight assignment through public opinion research, and also, (d) the assignment of weights causes more problems than the use of the null method.

Thus, from the theoretical framework and national and international experiences, in addition to the knowledge brought by the research team, a system of sustainability indicators was proposed. The initial version of the indicator matrix represented an intermediate step for the construction of the sustainability index of electrical power

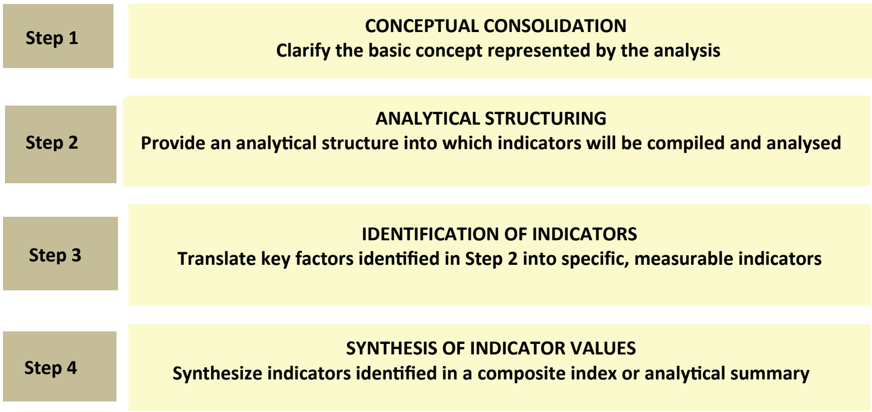

Fig. 1 Methodological steps for the construction of indicators (Wong, 2006)

generation sources (SIGS). In addition, the preliminary matrix was based on a questionnaire, answered by the participating researchers, composed of a question with multiple items, with the objective of understanding “what defines the sustainability of an electric power generation source.”

Based on this questionnaire, the experience of the researchers, and the literature review, it was possible to select the dimensions, themes, aspects, and indicators for the sustainability index of electrical power generation sources—SIGS. Four dimensions were adopted, all derived from the conceptual discussion on the term “sustainability”: (i) environmental, (ii) social, (iii) economic (regional insertion), and (iii) political–institutional.

The second step sought to achieve three main objectives in order to improve this matrix: (i) to obtain the data necessary for quantifying the indicators, (ii) not to take the limitations of the past and the present into the future, and (iii) to reduce the number of indicators.

Some of the indicator values were from secondary data sources, collected through an extensive literature review (national and international). Other indicators were quantified using a scale on which the values ranged from 1 to 5, where 5 was the value of higher sustainability and 1 the lowest.

Once the primary matrix and the data sources (primary and secondary) had been defined, the third step in constructing the indicator matrix is its validation and obtaining the values of the indicators proposed through the scale of the sustainability level of the energy generation source.

7.2.2 Validation and Obtaining Indicator Values: Applying the Delphi Method

Applying the Delphi method seemed the best solution for validating the indicators, as well as for obtaining the values of the sustainability levels of the energy generation source, per indicator. For this, 48 participants were selected. Thirty-seven were from the institutions and forums of the electricity sector, and 11 were specialists (independent consultants).

As for the questionnaires, we decided to use a composition of multiple choice and open questions. This was considered to be a possible combination that would generate more information without impairing the data tabulation. Thus, participants were able to add any comments they deemed necessary, thereby enriching the research. In the first part of the questionnaire, a scale presented five items to verify agreement (or not) as to whether the indicator should remain to represent the suggested aspect, according to the variation: *I agree, I am inclined to agree, I do not agree, I am inclined not to agree, and I do not know*. In the second part of the questionnaire, a scale presented five items, this time, so that the sustainability level of the energy source was indicated by the indicator analyzed, being: *very low, low, medium, high, and very high.*

In the first round of Delphi, the specialist answered 23 questionnaires from part I and 15 questionnaires from part II, thus representing a response percentage of 48 and 31%, respectively. These percentages are within the expected range, according to the literature surveyed, which suggests between 30 and 50% (Wright & Giovinazzo, 2000) and between 25 and 65% (Gordon, 1994).

For the description and analysis of the data obtained with the applied rounds, the research used central trend descriptive statistics (mean and median) and dispersion (interquartile amplitude). In the case of this research, it was decided to adopt the criterion suggested by Raskin (1994), which considers an interquartile amplitude less than or equal to a unit as an indicator of consensus.

The questionnaire prepared for the second round included 37 questions and maintained the same structure of two distinct, sequential sections, with the same objectives as the first round. In the first part, excluding questions that obtained convergence, the questions incorporated some of the suggestions presented by the experts in the first round. Thus, the survey resubmitted eight questions, again with the possibility of recording the comments deemed relevant.

For the items of part II of the questionnaire that presented convergence through the interquartile amplitude, the value adopted to represent the level of sustainability of the energy generation source per indicator is equivalent to the value of the arithmetic mean of the responses located within the interquartile interval. For those who did not present convergence through the analysis of the interquartile amplitude, a statistical analysis observed the behavior of data distribution in each case. If the answers presented a normal distribution, the value assumed as the sustainability level of the energy generation source analyzed was the average value of the given responses. If not, the analysis considered the median value, since in this type of distribution, the extreme responses influence the average, thereby distorting the result and leading to an unreal understanding.

7.3 Research Results

The results of the values of the sustainability indexes of electrical power generation sources (SIGSs) used the matrix and values resulting from the Delphi research conducted with the specialists. It should be noted that the final matrix of indicators is the same as that constructed by the researchers. However, some indicator designations and some units were changed due to suggestions by the specialists selected for the Delphi research.

As expected, renewable sources presented higher values of sustainability indices of electricity generation sources (SIGS) in comparison with non-renewable. The three sources that obtained the highest values were offshore wind (0.667), solar photovoltaic (0.634), and onshore wind (0.615). After this came run-of-river hydroelectric (0.608) and small hydroelectric (0.596). Biomass presented the worst result of renewable sources, with a SIGS of 0.506. The dimensions that most contributed to a high SIGS for the offshore wind source were environmental and social, respectively, 0.855 and 0.840. For solar photovoltaic, the environmental and social dimensions were, respectively, 0.890 and 0.578.

In the case of hydroelectric with reservoir (0.526), the dimension that contributed the most to its relatively low SIGS was social (0.334). On the other hand, the economic dimension presented one of the highest values (0.735) of all sources, which demonstrates the validity of the tool, considering that other research has already reported that hydroelectric plants contribute to local economic development.

For non-renewable sources, the highest SIGS was that of the nuclear source (0.459), followed by natural gas thermals with and without a combined cycle (0.450 and 0.447). The lowest SIGS among the non-renewables was that of fuel oil thermal source (0.404). The dimensions that increased the values of the SIGSs were environmental (0.694 for nuclear and 0.637 and 0.626 for natural gas thermals with and without combined cycle) and social (0.594 for nuclear and 0.503 and 0.503 for gas thermals). The economic dimension for gas thermals provides a low contribution to local economic development, and when compared to other sources, its value is 0.219, the lowest of this dimension among non-renewable sources. The political–institutional dimension for nuclear presented a very low value (0.183), which contributed to a reduction in the value of the SIGS of this source (Fig. 2).

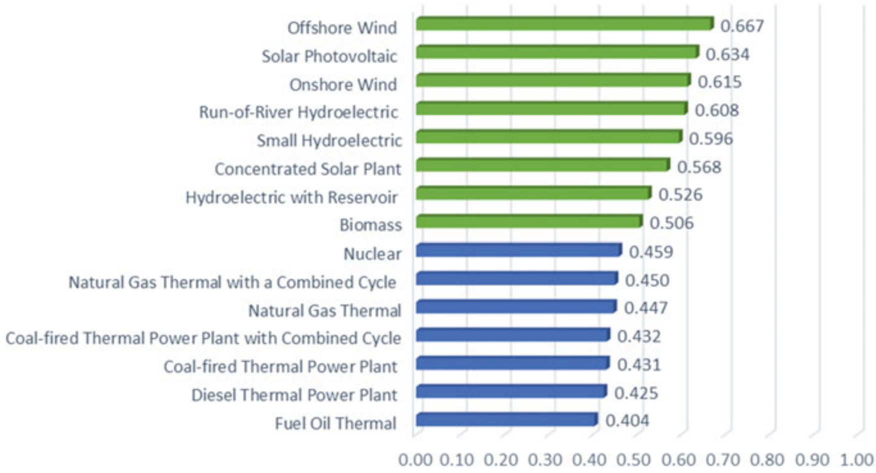

Fig. 2 Sustainability indices of electricity generation sources (SIGS) (Furtado et al., 2020; Ramos et al., 2020)

8 Concluding Remarks

This chapter has presented the results of three research studies from the ANEEL R&D Program. The first, denominated "Evaluation of the Effects of Hydroelectric Power Plants on the Socioeconomic Development of Directly Affected Municipalities," was developed by UFPE/FADE (Furtado et al., 2011, 2013). This research presented the socioeconomic benefits of hydroelectric power plants for the municipalities with areas affected by reservoirs.

The results of the abovementioned research demonstrated, by comparing the SLDIs of the municipalities with areas flooded by the reservoirs kinked to the plants with those of the unaffected municipalities (G2), that in three plants—Xingó, Tucuruí and Itá—there were different socioeconomic benefits for the directly affected municipalities (G1). In the case of two plants—Serra da Mesa and Nova Ponte—the investments did not result in higher socioeconomic benefits for the municipalities of G1—when faced with the municipalities of G2.

These results indicate that the socioeconomic programs of hydroelectric plants need to be better in municipalities that have flooded areas so that they are also able to receive the same benefits as the municipalities where the companies have their offices. Another relevant finding for the enhancement of the local HPP benefits is to improve municipal management, so that it may result in higher levels of quality of life and education and, consequently, higher levels of sustainable local development.

For a hydroelectric power plant to become a lever of local development, the responsible company must adopt an anticipatory and strategic stance in order to define the necessary and appropriate actions, projects, measures, and initiatives to promote the changes that lead to the development of the territory.

It is important to highlight that that public acceptance of electric power developments may be increased through the broad dissemination of one of the main findings of the research, namely that the contribution of hydroelectric power plants is highly significant to sustainable local development. Furthermore, the SLDI is an important tool for assessing, increasing, and communicating to the public the benefits brought about by installing an HPP in a region, and that this index may be applied to assess the socioeconomic benefits of plants using any source of energy or even of large enterprises in other sectors of the economy.

Besides the actions that involve the use of the SLDI, as a planning tool, other steps are also crucial for maximizing the socioeconomic benefits and for distributing them among the municipalities directly suitably affected by the HPPs. This involves changes in the current Brazilian laws and needs to be addressed through the political process.

In relation to the second research, denominated "Developing a tool to monitor and evaluate the economic, social and environmental sustainability of municipalities in the areas of influence around dams," the ISRI has proved to be a strong instrument for strategic planning in the electricity sector, supporting the decision-making process, ensuring the efficiency of resource allocation and the effective management of hydroelectric power plants. Since the system of indicators in which the ISRI is rooted has a national basis, it may be applied across the country, thus allowing comparisons between hydropower plants in different states and regions (Furtado et al., 2015a, 2015b, 2018).

The research has also revealed that strategic planning must go beyond mitigation and compensation of social demands, mostly practical or facile, indicating the expansion of regional integration and the long-term sustainable development of these regions. Some guidelines must be strengthened, such as improving the quality of life, diversifying local production bases, expanding economic competitiveness, developing public management, and improving conservation and environmental education. Seeking to define an instance responsible for regional planning is a valuable alternative for the utilities in implementing these guidelines, freeing them from the pressures of fragmented, specific demands by municipalities and society, and enabling the construction of instruments involving the main actors of the region.

Lastly, the creation of a matrix of sustainability indicators for electric energy generation sources is one of the most important results of the SINAPSE project. In addition to being an original result, it enables environmental variables to become a factor on the same level of importance as the technical and economic factors when planning the expansion of electricity generation, leaving behind the qualitative analysis of the environmental dimension in the expansion planning of SIN. Therefore, it is relevant to emphasize that a good design of a generation power project always should meet all different types of aspect'0-s, particularly economic, technological, social, and environmental (Furtado et al., 2020).

Finally, it is noteworthy that the values of the dimensions and the SIGSs may be used in the expansion generation model of SIN with total reliability, since the indicators have been validated and their primary values were obtained from specialists through a Delphi research and secondary specialized literature from an updated source.

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Amazon Region Power Plants and Social Impacts

José Ailton de Lima

Keywords Social impacts of power plants · Amazon · Brazilian electricity sector

1 Introduction

In 2003, when the labor party took over the federal executive command, Brazil had experienced electric energy rationing (Sauer et al., 2001). The power system shutdowns were frequent at the national level and often at regional and local scales. The outgoing government had invested in emergency programs based on natural gas and created a plan to stimulate wind-based generation, but the latter was not implemented at that time. The previous government had also initiated the privatization program for the Brazilian electricity system, but the new government removed the Eletrobras system from the privatization program (Batista, 1998).

At a historic meeting, the then Minister of Mines and Energy made a detailed panel on the electricity sector's situation. She stated that Brazil would need electricity at a 4000 to 5000 new MW of installed power per year for an economic recovery. The construction of new power plants had to be resumed. Then, her plan focused on ways to help the development of the country. However, the president commented at the end of the exhibition: "this plan is magnificent, but it remains to be said how we will bring electricity to the poor and regions deprived of this essential good." It was where the light for all program was born (Lula Institute, 2021).

There was factual criticism of the thermal installation program and a firm rejection of nuclear plants' installation in that context. On the other hand, Brazil had a hydroelectric potential that was one of the world's largest and had all the technical conditions to install hydroelectric plants of all sizes. There was an expectation of

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developing a program for installing small hydroelectric plants, and studies over this were carried out. The studies concluded that such small plants were not enough to support the needs of 4000 MW per year.

In that context, studies about large hydrographic basins already existed and had been interrupted. These studies could be retaken, mainly in the Eletrobras system. The previous government left the responsibility for investigations to the private sector.

It is possible to highlight that the large construction companies were part of the studies necessary for the large hydroelectric projects. Topographic surveys, geological studies, powerhouse location studies, dimensioning of generating units, and many technical studies were carried out. There was a difficulty that was environmental studies and the treatment of indigenous issues. In these two fields, the private sector could not move forward without the federal government's participation, and Eletrobras was placed in the center of the discussion, articulating all the effort and actions necessary to implement the plan (Silveira, 2016).

2 The Integration of the Brazilian Electricity Sector

The Brazilian electrical system works in an integrated manner. All electrical loads connected to the power grid are powered by the power plants, whether hydroelectric, nuclear, thermal, wind, or solar plants connected in a single set. If one load needs more electricity, this additional amount will be supplied by the power plant adequately placed in the system. If one load is disconnected or its need for electricity decreases, some power plants will have their generation reduced by the same proportion. The form described above is very simplified. What happens is that the electricity needs of a load and the respective possibilities for generating electricity from networked plants are managed by a nationwide algorithm that seeks to optimize the dispatch of each electricity generating plant from a set of previously established criteria. Under normal conditions, the electrical system operates without interference from human hands.

The entire Brazilian electric system's integration only occurred during the labor party government when Manaus and other capitals of northern states were integrated through extra high-voltage transmission lines (Pessanha & Leon, 2012).

The Brazilian electrical system grew and improved over decades of existence and experimentation to reach this technological stage. The expansion of the system, that is, the appearance of new loads and the consequent growth of the generating network, requires an intense and extensive planning effort in the short and long term. Annual, five-year, and ten-year planning are standard in the national electricity sector. One of the first measures taken by the labor government was to re-establish and re-adjust the planning instances of the electricity sector. The creation of the Energy Research Company—EPE came in this context. The restoration of the applied research capacity strengthened the Eletrobras System Research Center—CEPEL (Eletrobras CEPEL, 2021).

The daily operation of this gigantic electrical system is carried out by the National Electric System Operator—ONS (Electrical System National Operator (ONS), 2021), which optimizes the dispatches of the different types of generating plants and the electrical interconnections between the regions.

One of the national hydraulic system characteristics is the complementarity between the different hydrographic basins. The rivers in the northern region have their flood periods between May and October. The rivers in the southeastern part of Brazil, on the other hand, have their flood periods between November and April. While the northern region has its rivers in the filling phase, the rivers in the southeastern region are in shortage. From this complementarity, the concept of electrical interconnections between regions was born. In this way, the one that had water in its reservoirs supplied to those with low reservoirs. ONS also optimizes and operates the flow between regions. The interchange between geographic areas is one of the great strengths of the Brazilian electrical system. In short:

- Brazil has a tightly integrated electrical system;
- No region produces only for itself; the various ways of generating electric energy participate in this integrated system by making the generated power available to the national grid;
- The need for a nationwide planning system is inherent of the system nature;
- Whoever operates the system maintains control over the water sources and their uses and over the final prices of the economic good called electricity.

3 The Studies that Supported the Construction of Hydropower Plants in the Amazon

The first large hydroelectric plant to be built in the Amazon was Tucuruí. It was inaugurated in November 1984. It has a flooded area of 2850 km^2 with an installed capacity of 8370 MW. In the dry period, the Tocantins River flow, at the point where the dam is installed, can reach up to 4000 m^3/s, while in the flood period, the flow can reach almost 70,000 m^3/s. The Tucuruí reservoir's installation served to regulate the river's flow, making it more predictable and adapted to economic exploitation. There are many criticisms of the plant's installation process, particularly accentuated after the military dictatorship. Many reparations actions, mainly to indigenous communities, were carried out.

In Porto Velho, a distance of 2133 km from Tucuruí, the municipality sits where the plan installed two large hydroelectric plants on the Madeira River. The Madeira River's uses began to be studied by Eletronorte in the 1980s, at the end of the military dictatorship. New environmental standards were established and the first studies aimed at an alternative path between the optimum utilization recommended by engineering practices and the new demands of respect for indigenous peoples, minimizing the need for deforestation and having less impact on riverside populations' lives. The engineering companies studied the geological aspects, logistics, construction aspects, and machine models. Brazil had a long experience in installing hydroelectric power plants in high head waterfalls. Now there was a new situation where the waterfall was low, and the flow volume reached very high values. It required a little-used technology in Brazil. The Madeira River has a flow in the dry period that can reach just 700 m^3/s. In the wet period, the flow typically reaches 36,000m^3/s. In periods of flood, which has a strong recurrence in rivers in northern Brazil, the flow can get more than 80,000m^3/s.

When resuming studies on the Madeira River, the Eletrobras system had a protocol for studies on the viability of hydroelectric plants known as the "Manual and Guidelines for Studies and Projects," which was effectively inappropriate for the new situation presented. A new approach methodology needed to be developed. And it was designed from the old "manual" adapted to the new requirements, making the necessary adjustments to studies in full realization. An adjustable process in full swing is painful, costly, and conflicting. The situation of scarcity of electrical energy that was assumed, based on the possibilities of new electrical loads, ended up imposing this adaptive method.

Technical and environmental feasibility studies and water availability studies were carried out. In these studies, they presented two proposals for use: a plant on the São Francisco site, which, after the studies, realized that the Santo Antônio site was more viable, very close to the city of Porto Velho, and another on the Jirau site, about 100 km from Porto Velho. The total cost of these studies was over USD $18 million, in values at the time.

The Brazilian government had chosen to maintain how the power plants were being built under the 1995–2003 government but introducing some changes: the first change concerned the value of the energy offered to the consumer. Unlike the previous government, the labor party ran the auction, which offered the lowest tariff to the final consumer. For the public good, there was already a fixed amount before the auction. To win the auction in this new modality, the entrepreneur should charge the consumer a minimum tariff.

The second change was the permission for the Eletrobras system companies to participate in the auction as minority partners. With these measures, the labor government continued its privatizing policy, but only for new investments. The policy of selling assets that have been amortized or in a straightforward amortization process had been abolished. The projects resulting from the studies and which were put up for public auction is described in Table 1.

The labor party government decided to place the two projects in separate auctions, partly because it feared that a single company would control the entire Madeira River's total source and partially because it could open the possibility of diversifying investors in such large projects with two auctions.

The other great advantage in the government's focus was the Belo Monte site. This exploitation had been studied since the 1970s. In 1975, during the military dictatorship, studies of the Xingu river basin's hydroelectric inventory began. These studies were completed in 1980. In 1988, DNAEE authorized Eletronorte to carry out the feasibility studies for this use. The studies proceeded slowly but never completely stopped. In 1998, with ANEEL already created, Eletrobras requested authorization to

Table 1 Projects from the public auction and studies

	Santo Antônio power plant	Jirau power plant
Number of units	44	44
Rated power	3150 MW	3300 MW
Physical guarantee	2218 MWmed	2214 MWmed
Investment	R $9.5 billion	R $9.0 billion
Reservoir	350 m^2	351 m^2
Maximum tariff	R $122/MWh	R $91/MWh

carry out new technical feasibility studies for the exploitation, placing on the agenda a new alternative that would prevent the flooding of indigenous lands, which were concluded in 2002. In July 2005, the National Congress enacted Legislative Decree 788/2005, authorizing Eletrobras to complete environmental studies.

With the legislative authorization in hand, Eletrobras signed a Technical Cooperation Agreement with the construction companies Noberto Odebrecht, Camargo Corrêa, and Andrade Gutierrez, intending to conclude the technical, economic, and socio-environmental feasibility studies for the Belo Monte hydroelectric plant. In August 2007, IBAMA conducted a technical inspection and public meetings in the municipalities of Altamira and Vitória do Xingu to discuss the terms of reference for studies on environmental impact (Saracura, 2015).

Public audiences deserve to be highlighted in this account of the process. They brought together hundreds of people with the most diverse interests and qualifications. Ribeirinhos, indigenous people, fishers, miners, social scientists, members of national and international NGOs, and city dwellers of Porto Velho and Vitória do Xingu made up the group of people to be heard, and the authorities listened to all. A very long process, but it allowed IBAMA, after listening to everyone, to place in terms of reference of the environmental impact studies the most sensitive points to be studied by the entrepreneurs.

Public hearings with indigenous peoples were exclusive and conducted by Funai. There was an intense mobilization of indigenous communities. Some indigenous representations have traveled more than 700 km to place their claims. Here, too, everyone was heard. Their concerns were recorded by Funai and placed in terms of references in the impact studies on indigenous communities. In February 2010, IBAMA granted the Preliminary License 342/2010 to the project, and ANEEL approved the feasibility studies. In March 2010, ANEEL published Auction Notice No. 6/2010 for contracting electricity from HPP Belo Monte along with previous auctions.

Between mid-2009 and the auction date, there was an intense public debate about the maximum tariff established by ANEEL. The last auction held that the Jirau power plant had a ceiling rate of R $91/MWh, and the large construction companies involved in the Belo Monte studies considered this value insufficient. The ceiling amount placed by the government was R $83/MWh. The necessary information approved for the auction is described in Table 2.

Table 2 Projects from the public auction and studies—Belo Monte

	Belo Monte power plant	
	Primary power house	Secondary power house
Number of units	18	6
Rated power	11,000 MW	233 MW
Physical guarantee	4571 MWmed	
Investment	R $26 billion	
Reservoir	478 m^2	
Maximum tariff	R $83/MWh	

Since the beginning of the inventory studies, the project has met with strong resistance from environmentalists, local indigenous communities, and the Catholic Church. This systematic and organic resistance has led to successive reductions in the project's scope and, consequently, its flooding area. This opposition did not accept and does not take the project until today, although it has been concluded since November 2019. Part of today's criticism is that the guaranteed energy of 4571 MWmed is much smaller than the 11,233 MW of installed power, forgetting that this was the price to minimize environmental impacts.

Another constant criticism concerns the flooded area with statements that it could have supplied all this energy with wind or solar sources with a much smaller impact. It is necessary to remember that at the Belo Monte studies and auction, the largest commercial wind machine was 2 MW. For the same purpose, to place the same 11,000 MW from Belo Monte, the project would need 5650 units and with guaranteed energy as low as Belo Monte.

Here, it is also necessary to debate a technical aspect that involves the integrality of the Brazilian electrical system. A hybrid system such as hydraulic, thermal, nuclear, wind, and solar of the Brazilian size requires a specific capacity of inertia of the system in the moments of the significant load falls, exits of generating units, or falls of great transmission lines. The great advantage of an integrated system, like the Brazilian one, can become a significant weakness in episodes or large electrical events. It is necessary to ensure that transient imbalances do not become instabilities capable of bringing down the entire network.

The system, therefore, needs to have electromechanical robustness, in which the power grid can only achieve with large machines. Small machines, such as wind turbines with little inertia capacity or without any inertia component, such as solar plants, cannot hold and much less keep systemic instability during strong contingency events. Even if progress is made in expanding wind or solar plants, the Brazilian system will still need large machines to guarantee the system's dynamic stability. In the medium and long term, the system's morphology is expected to change with the expansion of these new generation sources. It will be necessary to carry out studies and experiments to determine system stability limits in each new configuration. Brazilian engineering can transform the electrical system's morphology, as it has done over the last 70–80 years. Over time, this morphological transformation will take place, always bearing in mind that the Brazilian system has its characteristics, particularly the social needs of a continental country and a large part of the population living under poverty conditions.

4 Cautions with the Construction Stage

The construction of hydroelectric projects on the scale of what we are discussing here requires simultaneous work on several fronts as follows:

- Techniques related to engineering design and practices related to the manufacturing aspects of electromechanical equipment and systems;
- Procedures related to construction aspects;
- Techniques related to aspects geological;
- Methods of environmental preservation and conservation;
- In negotiations with the communities directly or indirectly affected;
- In the commercial aspects of contracting services and goods;
- In the financial aspects of negotiation with banks and financing agencies;
- In the negotiations of guarantees and insurance as possible;
- From the supply of inputs such as steel and cement;
- And finally, from the entire governance structure to maintain and synchronize this whole range of activities.

There is no formula or recipe for making all this work in harmony, and due consideration will be given to this.

The first concern is with the governance structure. In general, the partners constitute a shareholders' meeting and a board of directors, with proportional votes that reflect each one's social participation in the project. The board of directors comprises an executive board, respecting the due reference term criteria for its construction.

The second recurring concern is the formatting of a basic project that needs to be delivered to ANEEL within a period already established in the auction notice. Here the question could arise: Why is the primary project not ready at the auction time? This is because no investor wants to advance thousands or even millions of dollars in formatting a basic project before the auction. If the investor loses the auction, competitors will not want to pay for the primary project. In summary, developing the basic design before the auction is a very high risk. Besides, after the auction, different engineering alternatives may emerge from the auction. As long as the auctioned project's basic parameters and indicators are respected, entrepreneurs are free to seek improvements in the final project to be approved.

The approach taken here is related to the Jirau and Belo Monte hydroelectric plants. The other major contemporary hydroelectric project of these two was the Santo Antônio hydroelectric project on the Madeira River. At the Santo Antônio hydroelectric auction, Chesf participated in the public dispute but was defeated by Furnas and Odebrecht. In the Jirau and Belo Monte projects, the companies made improvements to the primary project submitted to ANEEL.

In the case of the Jirau hydroelectric plant, the dam axis is moved upstream. As a result, the project was further removed from the border with Bolivia, and the project would guarantee that floods in the wet period would not cross the border between Brazil and Bolivia. Another significant change was the increase in the number of generating units to 50. In the Belo Monte hydroelectric project, the main change was transforming two supply channels into a single one, sufficient to meet the plant's load conditions. Each change of this required, in addition to reformatting the entire technical project, reviewing the environmental impact studies and their submission for approval by IBAMA.

In parallel with these project change measures, IBAMA continued with the project analysis to issue its Operation License. In general, in this phase that precedes the Operation License issuance, IBAMA makes a series of inquiries and new measurements about the project, particularly concerning the geological and geotechnical aspects.

Issuing the Operation License is very tense. The environmental impact studies require a significant financial effort from the entrepreneurs. An investment will only be recovered after the auction after an exhaustive audit by ANEEL on the amounts presented as study expenses. The issuance of the Operation License needs to be in accordance with the deadline for the works' beginning. If this period arrives and the Operation License is not issued, a great conflict front with the construction companies opens up. Neither in Jirau nor Belo Monte, the project obtained the Operating Licenses on the dates agreed with the construction companies. As issuing the Operation License is not structured, various actors involved created enormous pressure and blackmail environment. It is the most challenging part of project governance, as managers are trapped between the legitimate interests of those affected and those of shareholders, who can see the project's rate of return disappear with each delay in the work.

The contracting of goods and services assumes an astonishing volume in the first moments of the work. Services vary widely: hiring surveys and registering affected communities; negotiation of land and areas for implementation of the project with the proper notary records; vehicle fleets to meet the needs of the preparations and the work itself, food and accommodation for those first arriving at the work; surveying services for support buildings.

To guarantee the proper flow of the work, it is necessary to take care of the project's financing in the first moments. The National Bank for Social Development—BNDES financed the works mentioned above. All documentation delivered to IBAMA, ANEEL, ANA, FUNAI, and IPHAN, and all documentation that supports the partners' guarantee for the venture must also be sent to the bank. One of the most sophisticated steps in obtaining financing concerns the performance insurance for the work. For the Jirau and Belo Monte projects, contracting the construction insurance required an international union's format since no single insurer could afford the venture. The experience of Brazilian construction companies in similar projects, although smaller, weighed very positively, but the task required months of intense negotiations.

The contracting of steel and cement, precious inputs and required in large quantities, also required special treatment. For each of the works mentioned here, the need was equivalent to almost two years by the great Brazilian producers. For these inputs, the consortia that won the auctions made direct contracts with suppliers, leaving the task of managing the supply according to their needs for the construction companies.

In the two cases mentioned, Jirau and Belo Monte, the construction companies wanted a global contract responsible for purchasing large equipment such as turbines, generators, floodgates, and piping. In these two cases, the winning consortia of the auction chose to negotiate directly with suppliers. In Jirau, national suppliers made costly proposals for turbines and generators. Chinese companies offered the same equipment for 30% cheaper. The consortium understood that it would be a very risky bet to buy all the Chinese equipment, but it hinted at this possibility for Brazilian manufacturers. There were pressures and complaints that the Brazilian industry was being set aside. But a deal was closed with 18 Chinese machines and 32 national machines with prices very close to Chinese prices. In Belo Monte, something similar happened, not least because the consortium that manufactures the turbines was the same as Jirau. This time the proposals came from the Chinese and the Argentines. The negotiation ritual was very similar, and the conclusion was the purchase of four large machines from the Argentines and 14 from the Brazilian consortium. The prices obtained were very good for the consortium that won the auction. In both cases, to guarantee the quality of equipment purchased outside Brazil, technical teams for quality control and permanent manufacturing diligence were set up.

5 Social Issues

Social is used here as a vast concept because people's lives are affected both directly and indirectly by the implementation of the projects. Let us look at some examples of this concept: The people who lived on the banks of the Xingu River and many of its streams had to be removed and moved to other places. They received homes with basic sanitation, electricity, facilities in health care, and a sense of organization and hygiene that they did not have before. Many began to live in a community with neighbors, unlike the situation they lived in before. The daily work started to be done farther from their houses, which began to require commuting to work that did not exist before. The indigenous people who live on the banks of the Xingu and its streams have not had their land invaded by water and have demanded road linking their villages with the densest population centers. But this also made it easier for people from the densest population hubs to get closer to the indigenous people. Thus, both indigenous culture and its forms of political and economic relations have changed. As far as possible, the impacts of each of these changes in people's lives were foreseen, and palliative solutions were sought for each of them, with some impacts being irreversible. There is no way to compensate for the memory of people who had their loved ones buried in a cemetery that was covered by the waters. The ossuary was transferred, but the individuals' memories remain stuck in the original location. Thus, it becomes clear the broad social impact of these hydro projects in the Amazon region.

The electric system is a technical agent in the sense that it interacts with the environment (Simondon, 2018). Electricity is necessary for human activities in general. Specifically, in the case of large hydroelectric plants connected to large electricity transmission and distribution systems, this character takes on an exceptional meaning, as it carries with it very expressive contradictions or dualities:

- Meets the electricity needs of large population groups but directly harms those populations that are very close to the projects;
- The construction of the projects generates several technical and non-technical jobs on one hand but creates a situation of social disorder and overload on local infrastructures in nearby cities;
- The arrival of a large number of people in the cities close to the construction sites energizes the local economies but brings dependence on these new businesses that, for the most part, will not survive after construction;
- The industries that produce essential inputs to construction, such as iron, steel, and cement, take advantage of that tremendous temporary demand but are subject to the singularity of this moment, having to lay off thousands of employees after the end of a large contract.

It is characteristic of human beings' social nature to maintain a condition of stability, security, and social well-being. The beginning of the large project construction like the ones described here creates the requirements desired by the human being, but it also makes the exact opposite at the end of the construction. It is impossible to resolve all the contradictions in a process like this, just as it is impossible to imagine that projects can avoid conflicts simply by extending the initial conditions in time and space.

The way out or solution to these contradictions is constructing a walk constructed participative from the beginning of the process. Solving the problems generated by population displacement due to the creation of artificial reservoirs is not simple. It involves values such as symbolic memories, family ties, and local rituals associated with the place itself that cannot be measured. The project planners' first task is to demonstrate that the areas involved have been reduced to a minimum. The second task is to ensure that those who will be displaced will go to conditions suited to their needs. These negotiations sometimes take a long time and become incompatible with external energy needs. The process has to be thought out, negotiated, and legitimized long before construction begins.

Solving new population contingents arriving in cities also requires the same type of collective construction, now with representatives and leaders of the native community. In a region like the Brazilian Amazon, the arrival of a large-scale project like the ones described here is equivalent to the state's arrival for a large population that lived on its margins. One of the most significant issues is land tenure regularization. It is necessary to define areas for their facilities to allocate new population contingents, so one begins to deal with centuries-old land tenure problems, which are there as if asleep. The planning for the installation of new population contingents must also foresee their uninstallation.

The engineering projects must foresee all the issues listed and some more specific to each situation, studied, and have resolute conditions in the environmental impact studies—EIA and the resolution of environmental impacts—RIMA. These are basic reports. Additional studies and assessments may be necessary and are usually done. Those who will carry out the projects want to carry out the project at the lowest possible cost. On the other hand, the affected populations want the most expensive solutions or often solutions outside the scope of the project's entrepreneurs. The presence of a democratic state of law, strong, and legitimate is necessary for social solutions. It is illusory to think that this can be done despite legitimate power.

This democratic legitimacy is not just a figure of rhetoric. The construction of large hydroelectric dams, whether in the Amazon or elsewhere on the planet, involves universal social issues such as the rights of native peoples; meeting the electricity needs of large population groups under the poverty line; the generation of jobs and income for thousands of people; the technological mastery of the solutions adopted; the internalization of the technological domain for the national industry; and the continuity or not of certain production chains. The most elaborate social construction that human society has achieved to date to resolve the conflicts and contradictions of such a process is still the democratic rule of law.

6 Final Considerations

The construction of any significant infrastructure project needs major democratic debates among all stakeholders. Listening to all those directly and indirectly affected by the project must be required of every democratic government.

It is not always possible to build consensus between local, regional, and national interests. Much of the executive decisions of the federal government are supported by scientific evidence and technical criteria. On the other hand, popular wisdom and, more specifically, local interests are legitimate but not always possible to be reached. Most of the time, some losses for local actors are intangible, but this does not justify being disregarded.

Public hearings with those affected are still an instrument that needs improvement, but it is the best in a democracy. The Jirau and Belo Monte projects' experience has shown that much needs to be improved concerning those affected, but it is clear that progress has been made. The debate on significant infrastructure projects needs to be democratic, but it also needs to be governed by guiding principles and values.

National sovereignty in large hydroelectric projects in the Amazon needs to be stressed. The supply of electricity to millions of Brazilians is not a simple marketing issue. Electric energy is a fundamental input for all industrial transformation and service provision processes, and consequently, it is strategic in defining the society you want to have.

National integration is a strategic value for any sovereign country. In Brazil, a land of continental dimensions, integration is vital. We have vast borders, a vast geographical and cultural diversity, and a population that needs to be socially integrated. The Brazilian electrical system has reached a high degree of national integration. But this integration needs to be protected and well known to Brazilians. The culture of integration is embedded in the principles of the Brazilian electricity sector.

At no time can we lose sight that an integrated electrical system with a high degree of quality in the services provided is an economic policy instrument. In Brazil's specific case, the system's hybrid nature, with a considerable weight of water as a primary source, poses advantages such as the possibility of exchanges between regions and enormous risks of seeing this wealth exploited and without direct social control.

Brazil needs to understand that there will not be magical solutions for the energy supply. The energy matrix is so diverse that it requires significant studies to find a way forward. Unwise proposals present ridiculous plans as if energy diversity was a passport to escape social conflicts. All possible paths showed their difficulties at the beginning. Engineers must always learn to build the tracks of democratic debate, particularly when designing and constructing large energy generation plants on environmental and social sensitive areas.

Chapters ("Introduction", "Introduction Complexity—Diversity—Coherence—Meaningfulness", "Key Concepts for Frameworks: Values, Aspects, Normativity and Enkaptic Structures", "Towards a Holistic Design for Engineering Infrastructures of the Future", "The Social Dimension—Engineering and the Social Welfare", "Industrial Innovation Practices Breakthrough by Process Intensification", etc.) presented before can also help engineers and administrators think through systems engineering, engineering systems, and other suggested lines of thought. These will help in the proper design of systems that consider all physical, environmental, and social aspects.

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Scalability and Normativity—System Requirement Definition Based on Social and Philosophical Consideration

Giordana Maria Rodrigues Silva and Paulo Fernando Ribeiro

1 Introduction

In this chapter, the terms scalability and normativity in the engineering environment are discussed concerning its natural relationships. Normativity and scalability are intimately related as the determined size of the project must be subjected to all the constraints required by the norms and rules, which can guarantee the social, economic, and environmental needs. The tools proposed by Chaps. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures" and "Toward a Holistic Normative Design" can help facilitate the design of a project or product holistically.

It focuses on a philosophical view of the positive social impacts caused when the common good is adopted as the essential requirement to the project and enterprise general. There is a discussion about the project requirements, including the socioeconomic benefits for the less favored spheres of a society, where it intends to insert large undertakings, which may harm or even be inaccessible.

It is discussed that the normativity mechanism to drive large enterprise projects and systems brings a benefit, which is evident for the region's progress and growth. Still, in the short term, they can be detrimental to people who depend on their small businesses, such as agribusiness. The term scalability will be conceptualized and questioned concerning the need to provide for the payment of benefits for all stakeholders and in particular, to those who, for social and economic reasons, are left on the edge of society.

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We will also discuss the pros and cons of an ever-increasing incentive in terms of innovation, which has been considered in the first place instead of planning and scheduling maintenance and growth of preexisting systems. This can lead to unbridled consumption of products, which often lose quality and even functionality for individuals who cannot keep up with such developments, being segregated from the technological segment.

Another major topic addressed in this chapter is the consequences of normativity, when not intended to benefit the neglected segments of the population. Some topics will be addressed in these aspects, such as ethics and morals against the escalation of technology. Finally, approaches are taken to discuss the social behavior of engineering, fulfill requirements in favor of companies, and parallel to the benefit of those unprotected by ineffective public policies, in the round against social and economic inequality.

Thus, the chapter's objective summed up the line that joins the concepts of scalability and normativity in awakening a vision and feeling of the engineering professionals, encompassing requirements that include technological growth and the favoring of all spheres, without distinctions or marginalization. Figure 1 summarizes the concepts addressed in this chapter.

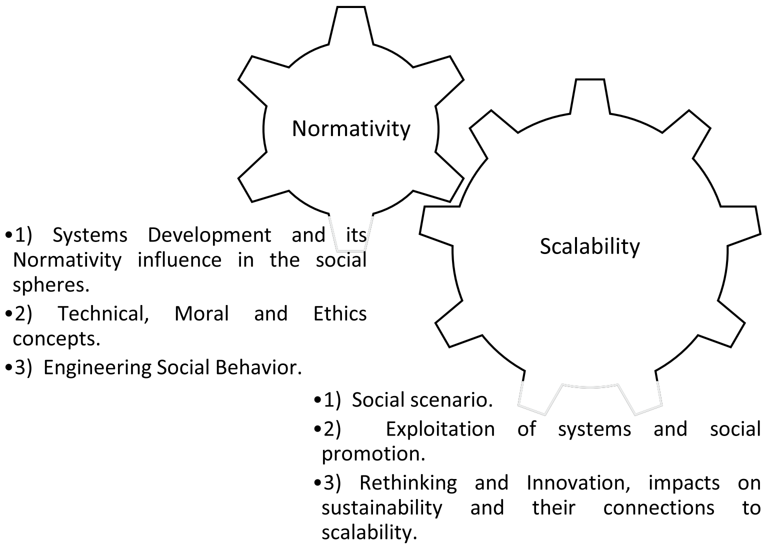

Fig. 1 Scalability and normativity mechanisms

2 Normativity

This chapter intends to take into account three spheres, the public sphere, representative of the interests of the communities, where the discussions start from the formation of public opinion, by the market sphere, which is composed of companies and investors, with the interests turned for the economic question and a mediating sphere. The last one can be represented by the normativity roles, responsible for performing the triangulation between spheres to prevent the construction of a polarized ethical and fair definition. The mediating sphere manages to balance values and expectations, adopting procedures to protect each party involved in a project.

2.1 Systems Development and Its Normativity Influence in the Social Spheres

At the first glance, there is no relationship between technologies and normativity (Christians, 1989), in the design phase of large systems, such as those discussed in the previous chapter. The rules and standards to be followed are generally built based on the lessons learned, either by the financial success obtained by the implementation or by the incidents and accidents resulting from an unsuccessful definition. The normative dimension of the law, or rule, finds different definitions in the literature, which supposedly expands the concepts considered to be the norm. The purpose of what is "good" does not always take into account the entire social sphere impacted.

During their training and performance in the job market, engineers have the feeling that technologies are related to physics and mathematical calculation. They master these disciplines and apply them in a (very) smart way, believing that they serve society using their technical ingenuity to develop "good" types of equipment and systems.

At a second glance, however, the issue becomes more elaborate when we adopt words such as "sustainable development," "innovation," and "scalability", making a series of values come into play. Such engineers start to act as suppliers to the market sphere, guided by the rules and rules imposed to say what should or should not be done, even reaching rules for thought and social justice [Roy Clouser]. Values, such as care for the environment and careful management of natural energy sources, are essential and come to reflect the idea that engineers have a responsibility to contribute to the development of a sustainable society. That said, we agree that the public sphere discussions bring philosophical considerations, often very general and abstract, to the view of engineers as support in their daily activities.

The rupture among faith and reason results in estrangement from social concepts, about morals and ethics, and a consequent distancing from the exact sciences to the human sciences. Thus, discussions of this rupture are necessary nowadays, where the institution of the university, which is the place of broad activities, lacks real planning for the training of its students through a so-called interdisciplinary vision.

2.2 Technical, Moral, and Ethics Concepts

The definition of a technical concept depends on several variables such as the field of application, the shape of the product, and its category. Thus, the definition of the technical concept has direct implications such as demand, cost, maintenance, and operation. The unfolding of these implications occasionally comes up against the interested parties: the public demanding a product or service. The construction of a technical requirement, according to current regulations, should translate the variables for achieving the product perceived as "good," so we are faced with new concepts, which take into account the thinking and action of the professionals involved in the activity. Differentiating what is "good" and what is "big" carries principles from the public and market spheres, and engineering should absorb all the expectations of these two customers in the technical requirements. The normative entities, in turn, translate the rules and procedures, based on laws and legal principles, in the definition of "good" and "great." According to private correspondence, changed with Andrew Basden, the escape from normativity is inevitable for those who seek seriousness in their actions.

> Normativity (that there is right and wrong, good and bad, function and dysfunction) is a central concept in a good framework. This is because normativity is something we cannot escape if we take everyday life seriously. It is also a natural outcome of there being a law side to temporal reality. (Andrew Basden).

If we risk a definition for the normative of a project, we could use three words to create it, thus "the *good* is that which at least achieves the *desirable* and is *permissible*." This would be correct and acceptable if the "good" for an investor was a beneficial consequence for the end user and the marginalized parts of our social sphere. But to reach such a level of excellence, if "good" means "profit," the good must be converted into rules to favor all the components of the sphere. We will face a dialectic of difficult solutions since we now speak of different spheres, with their truths, which contest divergent objectives.

In this line of reasoning, we can define good engineering and great engineering, as necessary concepts to differentiate the objectives of each interested party, at the same time that such adjectives, good, and great, become complementary, aiming to achieve the technical requirement and the common good. Great engineering herein mentioned can be pointed out in the creation of the new that impresses humanity. Within a total manufacturing cycle, from connecting a piece of equipment is just a small step or turning on a big system, we can affirm that when any kind of activity is done preserving humanity within the engineer, it justifies the emotion and the pounding heart, and the great engineering is faced with good engineering. On the other hand, good engineering can be guided, as the result of a creation that benefits the whole of society, but it depends on the angle observed and the use that the leadership of the companies establishes as the normative to be followed and either the moral concepts involved in its definition.

Every time engineers are faced with incidents and accidents caused by products or systems, it shall be improved to avoid new future events. Those who design the product or system engage in building an object of great precision during its use and application. During this path of continuous product improvement and search for accuracy, good engineering meets great engineering. The remaining question concerns how to introduce moral and ethical rules as initial requirements of a new project. For David Hanson, as mentioned in private correspondence, the solution will come from the distinction based on the principles and the natural and original sequence of things.

> It's the "ought-ness" of things, isn't it? Distinctions ought to be made correctly, Resources ought to be frugally harvested and saved or used. A painting ought to excite imagination. Children ought to be loved by parents. People ought to make themselves known to new neighbors and so on. (David Hanson).

The accepted standards must go beyond the ethos and guided by a culture built without imposed rules of behavior and conduct. This is the danger! Once it is knowing the existence of differences of cultures and behaviors, standards cannot be pointed out and forced to be respected, and each one will use his/her conceptual base to define what is good, desirable, or permissible. Philosophy, when applied to social behavior, is well understood and accepted. Still, we are now mixing technical concepts with normative ethics and moral philosophy, regulating what an individual should not do, how he should behave, and even how he should live. Some paths can be followed to offer answers to normative questions, one of which is the abstract discussion of systematization in ethics, or to follow the practical path with systematization actions, revising and expanding the moral view (Kagan, 2018).

Going further, when we talk about systems engineering, we rarely approach the term justice, a criterion that analyzes community members as part of a project, taking into account their needs. Equity in the distribution and use of a system's resources, for example, should address human development and understand their rights as a basis for the sustainability of the project. Thus, creating technical solutions that socially benefit humanity, leaving profit and recognition as a result of a job well done, requires revisiting the origins. There was no break between faith and reason, one being considered the basis of the other. From this view, we can start from justice to build morals, to reflect the necessary transparency in conducting a project linked to the commitment to the common good.

The mediating sphere role should be founded to balance the economics aspect through the promotion of goodness as an obligation to the normative regulation building. Abbas (2013) reflects in his article two distinct objectives between project companies, which either maximize profit, these being private companies and government organizations that adopt the requirement–value axiom. The author also makes normative reflections, related to incentives based on goals, that corporations offer to managers, which can bring consequences such as the construction of solutions that escape the expected result or application (Abbas, 2013). In his article, the author lists what is considered rational, according to each view, which may be the construction of values, or the demand estimate, which are the guidelines for defining a project.

Based on this aspect, defining the north of a project is where the gaps are identified to standardize attitudes to mitigate public sphere damage and create benefits for society, especially the least favored. Regarding the considerations pertinent to the public sphere, we can emphasize the gap in rules, standards, and recommendations, which minimize the negative social impact of large-scale system projects. We found, for example, more than 4000 recommendations (ITU, 2020) related to telecommunications systems, such as future networks and cloud computing e-health, but nothing is related to the mandatory free or reduced fees for the use of these resources by fragile socioeconomic individuals. From these observations, we began to enter the limits of ethics and morals, as primitive requirements of a large-scale project, which by its prospecting brings economic growth to the region to which it is inserted, but we cannot always say that the same proportions of benefits will be attributed to the common good.

If we can come to inference, establishing a technical or social concept is based on experiences and facts practiced over a period, be it in the evolution of humanity, or defined periods during the execution of a project or research. Based on the Dooyeweerdian philosophy, a design approach for engineers, known as Triple I, was created to guide and translate adjectives into concepts to direct the solution of problems in complex and current systems. This model translates what is *intrinsic* to the project, such as rules and norms that govern the user's practice, what is *inclusive* as the interests of the spheres involved, and what is *idealistic* as being values and dreams, that is, the translated subjective in design requirements (Verkerk, 2014). Engineering that has distanced itself from subjective issues such as morals and ethics, emphasizing only the physics of the thing, as if this distancing was the purification of rational ideas, is now orphaned by concepts for the definition of norms, which should govern the use and the practice of technological projects and innovations. The approach of faith and reason, previously dismembered, does not bring an obligation to become more human but seeks to enable social regulation, which is seriously defined by Shelly Kang (2018), who defends the impossibility of testing ethical concepts.

> Considering how different defending an ethical theory will have to be from supporting a scientific one. In choosing between scientific theories, we can appeal to empirical evidence. We can do experiments, testing predictions against observation. But none of this seems available in ethics (Kang, 2018).

The promotion of professional behavior focused on the humanitarian and social aspect is tough rhetoric that is not widespread in engineering environments. However, it is possible to open space for the beginning of the path until attaining the common good.

2.3 Engineering and Social Behavior

According to the public spheres and the market views, social behavior foundation can result from two motivators, with the former being the privilege of the common good and the latter the profit. To support this discussion, concerning the training of the engineer and the regulations that challenge his status quo, we must consider three pillars in the construction of thought and consequent social behavior, being the family, the school, and the engineering companies, the latter focusing on construction governance and its ethical ramifications. However, ethics define standards of behavior, which exclude behaviors considered "out of the curve." According to Charles Stromer, in private message exchange, standard behavior that results in the proper working function—both individually and simultaneously with other entities."

The privilege of the common good is a structured behavior based on the family and the first social groups, that is, the first sphere that delimits and shapes an individual's behavior. According to Shelly Kang (2018), commonsense morality is a concept known even to those who throw away it.

> People may differ about the details, but at least the broad features are familiar and widely accepted. Even those who reject commonsense morality – whether in whole or in part- are pretty typical familiar with it (it may influence their moral institutions, for example, even if they are institutions that, on reflection, they are prepared to disavow) (Kang, 2018).

The formation of citizens in their childhood considers the living environments, which are their home, school, and religious institution, to which the family belongs. We cannot fail to consider that when citizens enter the labor market, they carry cultural baggage influenced by their trainers, including their parents, teachers, and religious and political leaders. Thus, a transdisciplinary experience (home, school, religious institution) shapes their behavior. Here comes family formation, the foundation for morals and ethics, and the school to train citizens to know the history of weak initiatives taken by agencies and governments. The school must guide students to come together in an intrapreneurial vision, where the change starts internally and is fruitful for societies as a whole.

When the citizen enters the labor market, he is faced with the second motivator in forming social behavior, which is the vision of profit. At this moment, companies must act in the construction of sustainable knowledge, training professionals, basing on ethical concepts, to be an entrepreneur with a focus not on the company's or own profit, but prosperity for all. A sustainable project must consider economic and social aspects and work with non-renewable resources, creating innovations to become renewable and multiplied, and conserved.

With this example, we can now refer to the mediating sphere, which often has the role played by regulatory service agencies. These agencies must be moved to ensure equity among stakeholders, whether they are suppliers of equipment and services or the diverse range of consumers who regard innovation as a power to change our lives for the better. Innovation can make day-to-day activities more convenient and economical. Some of the devices that we have seen emerging as a result of innovation, such as the Internet and smartphones, seem to confirm this. It is possible to imagine that there is only an indication of the universal need for new beginnings in this demand for innovation, so the constant process for innovation also encourages the development of economic phenomena, which do not always work for everyone. For example, consider planned obsolescence, the idea that technology companies specifically design their products to expire or become less valuable with the emergence of a new version.

Normative solutions are required to validate and align expectations, as conflicts and financial consequences will affect those with less or greater economic opportunity. Normative solutions must be balanced to support and guarantee consumers free choice, the right to choose, with standards and conduct that ensure conformity with right and wrong, obedience and disobedience.

> Norms or principles are supposed to guide human conduct, and therefore they immediately call forth the idea of norm-conformity and antinormativity (obedience and disobedience).This distinction, in turn, presupposes the (human) capacity to identify and distinguish the possible avenues of action and to choose between the available options freely. There are not many choices at any specific moment – just one choice amongst multiple options. Therefore, freedom of choice presupposes an accountable agent to which the choice made and its consequences can be attributed." (Danie Strauss).

The engineering ethics goes beyond adopting a behavioral concept, but it must be monitored by all spheres so that deviations do not impair the final quality of a product, that do not bring economic impacts, and that do not harm the company's image. To this end, the rules and standards must be based on the client's interest and shaped by what society understands by appropriate behavior. Perhaps, errors will lie in the application of ethics as a concept, as humanity must walk and evolve toward collaborative thinking, instead of identifying and discussing behaviors as right and wrong. Transcultural, transdisciplinary, transnational, transreligious, and transpolitical thinking must be put into practice, eliminating the condition of "I" and starting to experience "we".

An example driven by social behavior can be observed from the sustainable electric energy generation, and distribution challenges are taken into account and its impacts that society faces nowadays. It is believed that in economies in which these life-sustaining infrastructure needs are not fulfilled and in which the inequality between rich and poor people is too large, an inherently unstable future should be expected. Fragments of a personal conversation by David Hanson reflect the system as a tool of humanity. As expected, the system must meet the requirements of society, "as a human tool, the grid which is not itself human, has to satisfy the normed demands of the Human Community." However, many times what is seen is the marginalized part of society unfolding to comply with regulations, which little favors them and makes them slaves to rules and choices that they cannot exercise, it simply shapes and fulfills what is determined. This portion ends up behaving like a system created and programmed to comply with rules, as David Hanson describes, in a private message, his understanding of power generation networks.

> It can function as a tool of liberation or oppression. […]. The grid can make no choices about its compliance with them. 'Smartness' necessitates that the grid demonstrates its unfailing subjection to physical laws as it varies its performance according to physical signaling. It hasn't the freedom to DECIDE whether to obey the rules or not, whether it OUGHT […]. (David Hanson).

The role of engineers in the face of these challenges, as human resources in the market sphere, is to go beyond technological challenges and design systems in a more holistic way, addressing the ethical and social implications of development, taking into account the social implications of technology, which they are not only requirements for members of the political and legislative spheres. In social and political discussions, the importance of values and norms for technological development is emphasized. Among other values, the following are mentioned: cultural adequacy, stewardship, pleasant harmony, justice, care, sustainability, trust, transparency, integrity, and humility.

The value of care differs from the others, which are simultaneously linked to the thinking of the public and marketing sphere, as care seems to be more applicable to human sentiment and, as previously said, engineering would be an area of purely technical knowledge. The normative entities, referred to here as representatives of the mediating sphere, should raise the concept of care, not only what is already determined by law, or based on the principle of legality, but revisiting the origins where faith and reason suffered a rupture, where one was the base of the other. With this, the technical solutions that are to come will benefit humanity, leaving profit and recognition as a result of a job well done. Regulatory agencies must concentrate on caring for human beings, for nature, standardizing procedures for creating sustainable projects and for the common good.

In a philosophical view, there may be three different perspectives to address moral issues: ethics of virtue, ethics of duty, and ethics of consequences. Virtue ethics focuses on the personality of the actor. This raises the question of which virtues are to be developed in which context. The ethics of duty focuses on the act itself. Is the act morally acceptable or not? Finally, consequentialism is focused on the consequences of the action in a specific context. It addresses the question of morality as the results of an action. These three theories do not compete with each other but complement each other.

When we refer to ethics in engineering, we should be referring to an international standard of procedures to be adopted and followed under penalty of losing the right to practice the profession. Suppose we permeate the codes of ethics instituted by companies. In that case, we will face respect for cultural differences and diversities, gender, race, and a position held in the company. This is the danger! Once the existence of differences is pointed out and forced to be respected, each one will use its conceptual base of ethics to define what is right and wrong. Therefore, regarding the nature of our task as developers of new technologies, we must be careful to avoid fatal pride, which usually accompanies the pursuit of profit and recognition within a business structure. However, what we really should be looking for is the global achievement of our projects and inventions, seeking equality and reaching the largest possible portion of the public sphere, in promoting the common good.

3 Considerations Regarding Scalability

The term scalability is widely used in projects which can be expanded in capacity. However, the literature attributes a certain degree of unawareness regarding its meaning and understanding (Duboc et al., 2007). Some analyses have been carried out concerning the failures, which are commonly found in the initial phase of operations, both due to neglected and bad dimensioning factors during its expansion or integration with other systems (Weinstock & Goodenough, 2006). The requirements involved in the definition phase outline if a system has the scalability capacity, when the physical resources maintain their roughly during its operation, meaning that an architectural change or growth faces the limitation imposed by its conception (Brataas & Hughes, 2004).

Schumacher (2011) depicts in his work current issues related to the "adequate scale" in different sectors, such as economics, politics, and social, and his observations can be extended to all possible applications (Schumacher, 2011). He highpoints the possibility of defining right and wrong at its extremes but highlighted the difficulty of establishing simple answers to such types of questions. Concepts can be introduced to rationalize the need to increase the capacity of a system and understand the difference between "great engineering" and "good engineering," and sometimes, a blend of both notions. It is supposed that great engineering is guided in the creation of the new that impresses humanity. On the other hand, good engineering is guided as the result of a creation that benefits the whole of society.

The question is "how to grow without an entity of control"? This chapter attempts to discuss a group of concepts involved during the design phase of a project, proposing a system's approach to be adequately scalable, bringing the desirable impacts to the socially and economically interested parties. The scalability must be such as to avoid putting a burden on a portion of the population, whether due to costs or inability to function harmoniously, and due to the consequences introduced by the system's growth.

A second question to be answered is "why this obsession with innovation?" In this chapter, some considerations will be made about the link between scalability and the constant search for innovation, to guide a thought when innovation within the growth aspect of a system is considered beneficial for all parts of society. In this way, if we want to create an intelligent and sustainable society—smart cities, etc.—perhaps it is time to come to terms with the reality of the obsession with "innovation" and stop neglecting the other components of this development. There is a prevailing idea, particularly among those working with new technologies, that innovation is inherently superior to maintenance or simply incremental improvement of life-sustaining tools and infrastructures. The word "Smart" has become a symbol of innovation for anything.

Some reflections can be made to highlight the points and mishaps, which cause engineering to misrepresent its function, being forced to create products with a predicted lifetime, which place profit above quality and forcing professionals to perform functions in favor of incomes while instead of pleasure and personal achievements. This reflection is about making the profession of engineer valuable. Criticism will come along with not understanding the ends. However, dear fellow engineers, exercise "make it count," perform daily tasks with righteousness, and place the common good as the end object of engineering. During this path of continuous product improvement and search for precision, good engineering can meet great engineering.

In this sense, it is valid to talk about social impacts, which are viewed in the context of some large systems linked in communities in all countries and which are part of the infrastructure of the local and world economy.

3.1 Social Scenario

Expanding the concepts, addressed by Schumacher (2011), for designing systems in general, we can evaluate the concept of scalability and make a parallel concerning its social impacts. The challenge is to find a model that is directly applicable to the complexity and modularity to enable both employment for the less favored portion of the population without stopping the fast and continuous development that is part of the most favored parts of the population, which have unrestricted access to the benefits of technological progress. To this end, the scalable systems have to be analyzed concerning the incoming impacts, which by their nature are designed to resolve issues of connectivity, infrastructure, and locomotion.

Given the unrestricted benefit generated by technological development, we can assume that projects started to increase their physical structure and carry out their design considering the reduction of social impacts. Such projects include systems that can hardly add new components, by definition of the word scalability, without causing damage to society, such as the depreciation of properties, as is the case with hydroelectric power plants and telecommunications networks, or noise and risk of accidents, such as aeronautical systems, during the lift and landing procedures in the airports.

According to studies carried out in the last two decades, to analyze the impacts of the deployment of large-scale hydroelectric, three main topics can be highlighted as relocation of the local population, harvest disruption based on aquatic resources, and encroachment by outsiders once the access shall be constructed as new roads and airports (Rosenberg et al., 1995). Hydroelectric plants and telecommunication network construction provoke the modification of the animals' habitat and plants, which directly impacts the socioeconomic condition of the population surrounding these areas. Consequences such as the devaluation of goods and a drop in production are usually seen after the construction of those systems. We can also mention the loss of jobs and sub-jobs, which are perhaps temporarily generated during the construction process since the permanent work positions are allocated to technically qualified professionals. Positive points can be related to humanity, which has access to the latest technological resources, but in contrast, negative points like the expropriated sectors, both to facilitate the placement of tower structures and mitigate the irradiation effects generated by transmission lines and microwave antennas.

The conception of a large-scale systems architecture adopts planning that foresees requirements such as security and reliability. However, it does not anticipate socioeconomic requirements to protect vulnerable populations, such as riverine people and indigenous people, young and old, to create policies for training and generating employment for these people. The advancement of technologies requires new professionals and that they are constantly trained to be prepared due to the obsolescence of equipment, which requires changing equipment and constant software updates. The moment of renewal of a system requires financial investments, so policies must be created to include mandatory services for the population neighboring the enterprise, as a form of social royalties for investment in education and research, to promote the segments of the population negatively affected by the accelerated and disorderly growth.

The adequacy of the physical size for installing a system could only be considered legally viable if the projects were designed to evolve and grow without causing social impacts on the population. In this way, when expanding the offer of products and services aimed at social inclusion and expanding access to new technologies for the most deprived parts of the population, the increase in demand for services can be considered as a positive aspect.

Therefore, when a plant is enlarged or altered, to include machinery to increase production, the social consequences, such as the transfer of costs to the consumer, and losses of socioeconomic infrastructure, must be measured, avoiding the burden of the less favored.

A scalable infrastructure must be planned so as not to compromise the unfeasibility of growth. It is possible to identify initiatives to promote projects with widespread participation, opening for investments with the social return. However, there are few initiatives to create economic quotas, for return to the population, according to consumption/economy and mandatory provision of free/low-cost services to needy populations.

The growth accelerated by the search for investment by entrepreneurs and shareholders to create systems capable of growing and generating more profits, directly implying companies' monopoly in the market, which are not concerned with establishing criteria for an escalation controlled. The direct negative consequences are reflections of dissatisfied consumers with system instability, high cost to keep up with technology developments, high prices for service provision, requiring the search for alternatives, such as renewable energy sources and the search for illegal telecommunications services, widely found in the parallel market, such as streaming videos, cloned equipment, and Internet service providers. We can point out as indirect consequences the incompatibility of equipment and low quality of services.

It is apparent that the stakeholders usually do not include all spheres of society in the planning but are restricted to investors and entrepreneur's interests. The profit will come from consumers willing for technological progress, but the economically vulnerable, increasingly illiterate in technology, is increasing. Thinking about the scalability of a product requires not only control over security but also a strategic vision to generate profit and minimize risks. Corporate creativity is a process discussed by Alan Robinson and Sam Stern that can direct the solution of problems through rethinking a product or service, at the same time, the organization assumes a risk. For the authors, it is possible to manage the rethinking or innovation of technologies used in a product and connect the promotion of the common good with the effective profit for an organization (Robinson & Stern, 1998).

3.2 *The Exploitation of Systems and Social Promotion*

Social promotion must be considered during the design phase of a large-scale and comprehensive system so that the growth phases are sustained by investors instead of transferring increased costs to the less favored population. Actions for the benefit of these layers must be reversed as positive credits to investors.

Services provided from large-scale systems, often performed by third-party providers, are usually low quality, as concessions are made for long periods. The evolution of technologies and market instabilities are points that gradually transfer financial costs and losses to end customers to maintain contracts based on the quality and maintenance of systems. Quality of service and commitment to safety are criteria that do not strictly have the necessary inspection periodically. Also, service providers do not care for maintenance, so the growth of systems on demand transfers costs to final prices, penalizing society with the payment of abusive maintenance fees without fair policies that only cover the use of systems.

Initiatives must be promoted and regulated so that the end user pays a reduced amount as a benefit acquired due to their weakened social condition, or through actions of their generation, or even by consuming services in periods of low use. Thus, public policies must be created, requiring that the least favored portion of the population be benefited, by donation of equipment for the generation of renewable energy, and the reduction of tariffs, in exchange for the concession of exploration of large systems by private companies. Projects must be created, which bring the populations neighboring the undertakings to work both in the construction and operation of the systems.

When the displacement of entire communities is necessary for a given construction, social policies must be applied to benefit families, generating a quality of life for the population, including the creation of school-building jobs. The favoring of the local people must be guaranteed, and the fauna and flora, which are parts of the production of sub-existence, and the output for the local market must be preserved.

When the displacement of entire communities is necessary for a given construction, social policies must be applied to benefit families, generating a quality of life for the population, including creating school-building jobs. The favoring of the local population must be guaranteed, and the fauna and flora, which are part of the production of sub-existence and the production for the local market must be preserved.

Here comes ethics, which in its definition does not show faith and reason, but draws limits on social behavior and community living. The exploitation or devastation of natural resources causes economic and social conflicts. Avoiding here to create a political discussion, the exploitation of resources should be ethically adopted. To be possible, everyone has access to employment, productivity, and everyone without exception would be prosperous. It is necessary to cite the need to promote sustainability, so we can now discuss the connection between ideas that seem to be directly related: sustainability and scalability. Thus, in the following topics, concepts are described to identify connections, and associates are directly linked to the promotion of the common good from the development of large enterprises.

3.3 Rethinking and Innovation, Impacts on Sustainability and Their Connections to Scalability

Instead of innovating, rethinking a requirement or system should be at the lead of a project since rethinking is directly linked to the improvement of something that already exists, be it an idea or even a product. One cannot speak of sustainability as uncontrolled disposal of products, since the capacity to recycle waste, whether organic or electronic, is still below what is necessary for nature preservation. Therefore, we are no longer talking only about human behavior that generates the common good in the economic aspect and the existence of the entire planet, so now engineering must add to the requirements and environmental requirements.

When the growth of a large-scale system comes up against technical issues that can cause the beheading or even its rupture, engineering starts to seek innovations instead of upgrading the existing product. Abandoning systems to obsolescence often means high costs involved in maintenance or even returning to the initial phases of the project to work on requirements that allow for an increase in production scale. Of course, there are many reasons why our infrastructure is so inadequate, but our prioritization of innovation, instead of improving and maintaining existing infrastructure, plays a significant role in this. And that seems to make sense, because as it is said in Ecclesiastes: “What was will be, what happened, will happen again, what has been done will be done again; there is nothing new under the sun.”

There are dangers in prioritizing innovation instead of rethinking one system. We educate generations of engineers believing that one of the best strategies for a career is to invent something new, create an idea, an applicative, or start a new business. However, this can be destructive, considering the high failure rate of start-ups. As if that were not enough, we also have generations of people who despise jobs that do not require creativity or innovation. We need trained scientists and engineers to rethink and consider sustainability as a requirement to preserve non-renewable resources, such as water, oil, and minerals, such as iron and gold. Through research, we can develop a formula to reproduce the resources that today are considered non-renewable.

Other professionals, who undertake to work with renewable resources, can also create processes to double the resources, but they need to add the ethical ingredient to the recipe. Given a simple example, trees are renewable resources because they generate seeds that fall to the ground and sprout new plants through their fruits. But, if there is indiscriminate wood exploitation or cutting trees to implement an extensive system as hydroelectric, airports, and telecommunication networks, there will be no seeds, fruits, or trees, because the lack breaks the renewable cycle of ethics. It directly affects the population who depends on this kind of resource. Therefore, the forecast of improvement opportunities, as a basis for the undertaking, must be based on the diagnosis to identify sources for change or innovation, such as external events and failures, or even changes in the direction of the market or the perception of the consumer (Drucker, 2014).

Another strong candidate to exemplify this thought of rethinking is renewable energy systems and smart grids that are in vogue today. Current work (Verkerk et al., 2014) shows the search for solutions that provide renewable energy has been growing, involving a task force between schools, companies, and governments, developing ideas that exceed the traditional advantages of the electric power network, such as the possibility of distribution over long distances. In this work, new technologies are needed to create renewable energy supply systems and rethink the architecture, which requires significant locations for infrastructure implementation. According to the authors, this can be achieved by rethinking local infrastructures, which now play an important role in the distribution of energy, which will no longer be centralized. Also, the authors foresee a change in thinking to manage the distribution of electricity due to its unpredictability, making the system more intelligent, and adapting supply and demand at the local, regional, national, and transnational levels.

The discussion on sustainability and innovation has its genesis from the moment the universe was created. Philosophical discussions about creationism and evolutionism would fit here. Avoiding debate, but only introducing thinking, seems logical that there will only be evolution if something was previously created. But it was always warned that if we indiscriminately use natural resources, it can run out if life is not respected. Suppose the link between faith and reason was a break in the past. In that case, those who make undue and unrestricted use of natural resources are more faithful, without worrying about whether they are renewable or not, as they are waiting for a miracle. Such attitude cannot be classified as rational. To be successful in an innovation project, changes must be taken as the main requirement. Thus, one must consciously seek opportunities for change to achieve both economic and social purposes (Drucker, 2014).

Perhaps one of the biggest attractions for innovation in a capitalist, commercial society is the possibility of its creators becoming rich. And since we tend to equate money with real value, we think of innovators as inherently more valuable to our society than other people.

Work the resource and do not explore. The problems, which over time have been created by exploitation for profit, cannot be ignored. But where will the solution come from? Creating carbon credits, encouraging the use of renewable energy? No, not. It comes from the formation of new intra-entrepreneurial citizens, who promote improvements in the social fields through an inner vision of a company, changes, and enhancements aimed at the common good. Entrepreneurship with its innovative business vision, however aiming at its gain, must be abandoned. Our obsession with innovation leads us to devalue maintenance and conservation, which are necessary to keep our world running. It is much more attractive to invest money in a new technology start-up than to invest in repairing roads or basic sanitation.

We can argue that this can happen anyway; after all, companies are expected to behave to maximize their interests and sell new products. However, our continuing demand for new products allows this vicious cycle to continue undiminished and feedback into the problem. We see countless “inventions” that are inferior copies of existing technologies or combinations of unnecessary technologies. Many are innovating just for the sake of innovation, instead of genuinely essential technologies. Sometimes the marketing department injects changes in the terminology—and new technology is born for an old concept.

No matter where you fall on the political spectrum, you are likely to recognize that there is a problematic issue of social inequality that is only getting worse. A boss of a large company often earns more in a single day than a worker earns in a year.

Here comes family formation, the foundation for morals and ethics, and the school to train citizens to know the history of weak initiatives, taken by agencies and governments. The school must guide students to come together in an intrapreneurial vision, where the change starts internally and is fruitful for societies as a whole.

Institutions must take actions to build sustainable knowledge, in the training of a professional, who must be based on ethical concepts brought from home and the basic school to be an entrepreneur, focusing not on the company’s or own profit, but prosperity for all. A sustainable project must consider economic and social aspects and work with non-renewable resources, creating innovations so that they become renewable and multiplied and conserved.

4 Conclusion

Traditional engineering has remained distant from the conception of products, systems, or services, which encompassed the requirements of the social sphere to the technical specifications. The promotion of the common good is not the target of engineering education and training, as it was considered a general and abstract subject. The practical influence that a system can have on society has been a subject of growing debate (Waelbers, 2011). Therefore, throughout this chapter, the object of discussion was the scalability and normativity concepts mapping, according to a vision to promote individuals and societies marginalized socioeconomically and environmentally by an engineering project. The promotion of the common good was taken into account by leveling the triad between profit, progress, and humanity.

Risking a comparison between the concepts discussed throughout this chapter, with the worldly know work Chronicles of Narnia (Ford, 2005), brings a scenario where the characters leave the known to live the unknown adventures. Even without knowing the concept of adventure, the characters live possibilities that maximize their lives. It can then be conjectured that engineering should maximize its action and responsibility in society, inserting itself in a new crusade to permeate seemingly different concepts, such as technology and its social promotion. Thus, the engineer would be putting himself in the character’s place, exploring the new, and promoting the design of products and systems with a social and philosophical vision in favor of the common good.

According to safety rules and procedures, the exercise of eliciting requirements to contemplate the proper scope of scalability and normativity is inherent to the engineer's activity in a project conception. That is why it must be far from adventure but close to experiencing technical and social situations previously unknown, which can be considered learning in the short and medium term. Finally, talking about lessons learned, the decision to include a social security requirement must be based on minimizing problems generated by a new project, the possibility of reversing a defect or failure, and the possibility of the planned growth of a system (Waelbers, 2011). In this sense, Waelbers (2011) defines the promotion of the common good impeccably, saying that it should be taken "as a starting point for the discussion on the desirability of the possible social role of a technology."

Several chapters, concepts, and examples in this book can be of great help to help the designer and constructor of large or small engineering products or systems to think more objectively about the possible social consequences of their decisions.

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The Interdisciplinary Nature of Engineering Education and Practice

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Keywords Engineering education · Ethical programs · Interdisciplinarity · Technological and industrial development

1 Introduction

1.1 Definitions of Multidisciplinarity and Interdisciplinarity

The definition of such terms is still something much discussed in the specific literature and debated by scholars, not having a concrete conclusion.

The concept of multidisciplinarity and interdisciplinarity is directly linked to the understanding of the complexity of human reality. As seen in Chap. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures", human reality is multi-aspectual, with each aspect having its own nature and consequently generating unique knowledge. In this context, multidisciplinarity and interdisciplinarity are bridges that connect such knowledge, enabling the integration and interaction of those involved. In addition, such concepts can be related to different systems, different levels of systems, subsystems, and each subdivision having its multidisciplinary particularities. An example of such peculiarities is seen in Chap. "Towards a Holistic Normative Design" applied to smart grids.

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1.2 The Multidisciplinary Nature of Engineering Knowledge

Engineering projects are excellent examples of the multidisciplinary nature of engineering education showing the collaboration of several areas for decision making. For example, if one works with a smartphone project, one must take into account the hardware and the software that the product will use, which niche of target consumers the marketing will act on, ergonomic parameters, device design, the materials on which its batteries will be produced so that when discarded they do not impact the environment and so on. A second example—if one is to undertake a power grid project, the project must consider its environmental impacts, technical restrictions on its transmission, generation and distribution characteristics, users' needs and investor's demands, etc.

Therefore, several variables must be taken into account in the development of complex multidisciplinary projects forcing developers to use a holistic approach to better satisfy all the requirements such as environmental, social, economic, technical, logistical, cultural, and ethical. This approach also implies taking into account all levels of the system, subsystems, and the relationship between humans and infrastructure.

Due to global warming and environmental concerns, the concept of multi and interdisciplinarity is rapidly being incorporated into the academic world. In countries like the USA, Germany, UK, and Canada, they already have specific multidisciplinary and interdisciplinary courses focused on developing those advantages (Danish Business Research Academy, 2008).

2 The Need for an Interdisciplinary Approach for Engineering Education

2.1 Definitions for Engineering System and Systems Engineering

The definition of these two recurring terms in engineering, "Engineering System" and "Systems Engineering", are: Rhodes (2008) on the term Engineering System, "A field of study taking an integrative holistic view of large-scale, complex, technologically enabled systems with significant enterprise-level interactions and socio-technical interfaces.", and the term Systems Engineering, "Systems engineering is a branch of engineering that concentrates on design and application of the whole as distinct from the parts… looking at the problem in its entirety, taking into account all the facets and variables and relating the social to the technical aspects". The first term encompasses the second, as it adopts a holistic view for the development of a design, while the second prioritizes the development of parts of the design. The engineering system concept is also directly linked to the idea of enkaptic relationships expressed

	Aspect			
	Scope	Perspective	Socio-technical policy	Stakeholders
Engineering Systems	Large-scale complex systems	Hollistic view to the technology and project design	Optimized and adaptable system solution to benefit society as a whole	Focus on all stakeholders impacted by the system
System Engineering	Subsystems, system of systems	Focused on technology or product system	Use of standards and requirements to benefit stakeholders	Focus on those directly impacted by the system

Fig. 1 Comparing engineering systems to systems engineering (Adapted from Ribeiro, 2020)—See Chapters "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures and Towards a Holistic Normative Design"

in Chap. "Key Concepts for Frameworks: Values, Aspects Normativity and Enkaptic Structures", where the interaction between different types of wholes implies mutual influence, constituting a network. Further details in Fig. 1:

According to the authors Forsberg and Mooz, the cycle begins in the exploratory research and assessment of the needs of whom the design will be elaborated for. In this stage, surveys are performed on social, cultural, ethical, and philosophical aspects of the design, so as to divide them into smaller segments up to the highest level of detail, this being the stage that "System Engineering" focuses on small-scale technical problems. This process dissects the design, enabling designers and engineers to better manage and to take a more holistic view of it, facilitating development and problem-solving in all distinct parts of the design.

2.2 *The Role of Interdisciplinarity in the System Engineering Process*

The ever-increasing demand for faster and more efficient solutions for complex challenges stimulates the rupture of interdisciplinary boundaries (Allmendinger, 2015). Morin and Kern (2003) state that knowledge specialization hampers the ability to see the big picture, restricting more complex interpretations related to the functioning of things and global problems. Therefore, understanding human complexity and diversity can only be attained by changing from reductionist thinking to complex thinking.

Based on these concepts, to understand the complexity of a system, a holistic analysis involves a composition of people, products, and processes to achieve a goal. Systems engineering uses interdisciplinary management of engineering processes that verify an integrated set of solutions in favor of the specific needs of the consumer (Defense Systems Management College, 2001) and is defined as a comprehensive, iterative, and recursive descending process applied to all development processes. Figure 2 demonstrates the steps in a system engineering process and integrating different aspects such as social, technical, economic, and ethical (Defense Systems Management College, 2001). The development of each stage involves several areas

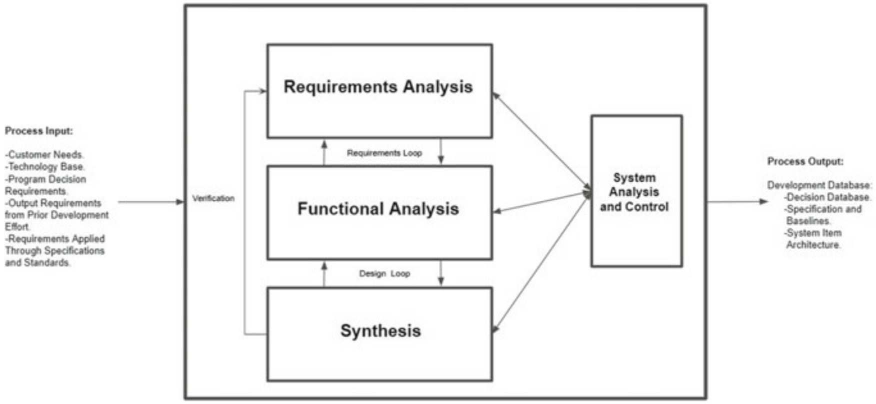


Fig. 2 Overview of system engineering process (Adapted from Defense Systems Management College, 2001)

of knowledge, from the definition of the technology used and economic limitations to ethical issues involving people management.

It is also essential to notice the subjectivity in the analysis of engineering processes. As stated by Baron (2019), any engineering system is subject to judgment and human values. Therefore, even the interpretation of data can be biased. Given the complexity and countless variables in the engineering process, the engineer must have the ability to think systematically, keeping the architecture of the whole system and all the interrelations of each subsystem in mind (Krus & Pereira, 2016). Such execution can only be achieved by overcoming disciplinary barriers, fostering interdisciplinary thinking.

2.3 The Link Between All the Processes

For Ribeiro (2020), classic architectures of a system usually do not contemplate a complete holistic framework that takes into account the most important components and interrelations between the subsystems. The proposed framework is called holistic normative engineering design and composed of several analytical tools that facilitate understanding the complexity of the system. For example, in a smart city, the problems faced are evidenced in the growing complexity of smart grids, in the physical structures integrated with renewable sources, regulatory aspects, and problems from an environmental and social perspective.

He also states that the best-suited tools for this analysis would be philosophy of technology, ranging from social perspectives up to engineering processes, design criteria, and modal aspects that represent the range of variables in the system moral aspects.

Ribeiro demonstrates this framework being used for smart grids. The engineering system tool would contemplate the technologies and policies, management, operation, and system analysis. System engineering would address generation, distribution and transmission processes, environmental, aesthetic, and economic requirements, and several other multidisciplinary aspects, including technology, type of network, sustainability, life cycle, etc. Each topic analyzed would link to modal aspects representing the complexity of existing connections and their integration.

2.4 Philosophical Tools to Assist Complex Designs

The concept of interdisciplinarity is increasingly accepted among academics, improving engineers' abilities to see a project holistically. For Verkerk et al. (2007), to solve projects of great complexity, the easiest way is to divide them into simpler parts, addressing them through three types of approaches, aspectual or dimensional, technological, and stakeholder needs.

The aspectual or dimensional complexity is related to several dimensions of the project, such as technological and socioeconomic aspects. The technological complexity refers to different technologies applied in the project. The economic challenges are related to the stakeholder needs and economic limitations of the project. Dealing with the three aspects is a challenging task for any designer. Nonetheless, there are specific engineering tools to deal with each of those challenges. Ribeiro et al. (2012) describe T-Dim, T-Tech, and T-Stake, where the first tool is used to specify the different aspects or dimensions, such as the systems and technological artifacts operated. The second identifies the different technologies and artifacts required by the project, and the third tool is used to identify the interests of the parties involved.

After using the three tools described above, the engineer will have all the information necessary for the project design; however, the data remains not interrelated. A fourth tool is required which allows the integration of all data, balancing the different priorities and needs, such as functions, aspects, technologies, and interests of all parties, presenting itself as a connection between the light of philosophy and its development through engineering.

3 Impact of Education in the Engineering Design

3.1 Quality of the Curriculum: An Interdisciplinary Challenge

The development of this sub-chapter uses University College London (UCL) as a model, which was cited in Gombrich (2018).

Before the existence of interdisciplinary and multidisciplinary concepts, European universities developed a curriculum known as Liberal Arts, determining the areas of knowledge which students from universities were supposed to practice, such as Grammar, Logic, and Arithmetic. Subjects were taught individually, having the goal of creating a more generalist mentality.

Technological and industrial development has influenced the academic area, making curricula more technical to meet the demands of a more qualified workforce. However, the studies covered in this section show that these "technical" criteria in the curriculum only partially satisfy the needs of undergraduates and the industrial sector, as, in purely technical academic development, the overall usefulness of the course is limited. To corroborate this statement, UCL put into practice little content in professions like in the United Kingdom.

Adding the above factor to the birth and expansion of the internet makes the world more dynamic. The fact that today's society is more complex creates a scenario that requires more holistic approaches. This influenced University College London to develop courses that attempt to reverse the current technical model, adding modernized topics from the old liberal arts curriculum. Students can create their technical skills and humanities disciplines, which should make graduates more critical and accustomed to situations present in the current job market, embracing business ethics, economics, and sociology.

This innovative program started in late 2008/early 2009 has about 500 students annually and requires an interdisciplinary/multidisciplinary term paper for the conclusion, boasting of memorable numbers in terms of quality and student satisfaction. Epistemology requires an empirical method to develop and integrate interdisciplinarity and multidisciplinarity in the current academic environment, and several other universities can adopt this case as an example of success.

Besides the example cited, most universities promote interdisciplinary research mainly by establishing organized research units (ORU) counting with professors from various departments. Several universities have implemented formal funding programs to support new research collaborations between departments and colleges. This availability of subsidies offered by the Government plus interdisciplinary awards is a tremendous external incentive for these programs. As these grant proposals require research effort to build a scientific basis for long-term collaborations, universities have felt the need to support professors searching for awards. For instance, Ohio State University uses its funding scheme called the Interdisciplinary Scholarship Development Program, and to apply for such funding, professors must agree to seek federal prizes up to a minimum pre-defined amount (Sá, 2008).

According to Weingart (2014), despite these incentives, the structure of disciplines still faces resistance from universities, inhibiting change since there is a link between fields and the organizational structure of departments (or faculties). With an interdisciplinary perspective in the scientific approach, new organizational challenges that conflict with this structural conservatism of the disciplinary university arise. Among these challenges, there are financial problems, such as competition when allocating funds for departments within the institutions, where more renowned courses prevail over interdisciplinary ones. There also are institutional challenges such as the recruitment of professors from different departments, which generate conflicts of interest, or such as a curricular system pre-fixed by departments, restricting interdisciplinary teaching. Such facts discourage students who are willing to work with interdisciplinary themes due to the lack of career opportunities.

3.2 Curriculum Evaluation from ABET Perspective

Courses require a standard that regulates their quality requirements. In this sense, Accreditation Board of Engineering and Technology (ABET) creates the accreditation of university programs worldwide, emphasizing the American ones. In this context, there are educational and institutional criteria that are the basis for engineering courses. Those criteria are founded on the premise that students must be evaluated to ensure the educational program's success, and this educational program must be aligned with the institutional mission. These premises are the basis for a structural understanding of American undergraduate and graduate courses and their quality standards (ABET, 2019).

From the educational perspective, the results expected are based on the capacity of students to identify and solve complex engineering problems. To accomplish that, one must be able to undertake engineering projects that consider several factors involved, such as public health, security, and economy. Also, they must communicate effectively among diverse audiences, recognizing ethical and professional threats. ABET also expects efficient teamwork, besides the usage of new knowledge acquired.

In addition to educational requirements, there also are institutional requirements. The curriculum must have at least 30 h per semester of higher education mathematics or basic science subjects. It must also contain 45 h of engineering-oriented disciplines. Specifically, in electrical engineering, a school curriculum must have probability and statistics, advanced mathematics through integration and differential equations, science (biology physics, chemistry), and engineering subjects for analyzing complex software and electrical systems. The program must also demonstrate that it has sufficient teaching staff to cover all areas of the course, and the institution must also provide good structure and equipment for use. Therefore, institutional support is necessary, including services, infrastructure, and financial support.

3.3 International Surveys

Research is being done to improve the understanding of difficulties and recommendations raised in the previous subtopics. Some institutions analyze the quality of these courses and the different characteristics surrounding the curricula of each course. Among these institutions, National Science Foundation (NSF) through the National Center for Science and Engineering Statistics (NCSES) organizes a questionnaire called Survey of Earned Doctorates (SED). In these surveys, they ask American students who have a doctorate about academic, social, racial, and economic aspects. In this context, engineering had the greatest increase in the percentage of graduates in the last two decades, going from 13% in 1999 to 18% in 2018. Within engineering, most (19.2%) of the doctorates completed in 2018 belong to the areas of electrical, electronic, and communications engineering (National Science Foundation, 2018).

Based on these questionnaires, the NCSES surveyed to identify the interdisciplinary impact on the dissertations of doctors who graduated between the years 2001 and 2008 in the United States. Analyses were made based on answers concerning the area of the dissertation or "dissertation research field or fields". As seen in Table 1, there are small fluctuations in the percentage of interdisciplinary dissertations in the period. It is essential to point out that as of 2004, the question on the multidisciplinary topic became more thorough, leading candidates to report areas of research less related than in previous years (Falkenheim, 2010).

For a macro-view of disciplinary boundaries, interdisciplinary dissertations by field of research also were analyzed, as shown in Table 2. Fields related to natural sciences, such as biological sciences and agricultural sciences, presented a slightly larger interdisciplinary percentage when compared to exact sciences, such as computer science and engineering. Biological sciences was the field most listed as the second area of research by respondents, except for engineering and social sciences. These data corroborate the idea that one creating academic engineering researches seeks solutions in closer areas instead of taking risks and venturing into further fields (Falkenheim, 2010).

Regarding the research field, respondents are divided into large research fields and subfields, correlating with the social and economic aspects, thus creating scope for interdisciplinary analysis in a broader context. Kniffin et al. (2017) reported the indicative model of interdisciplinary research that relates demographic variables,

Table 1 Doctorate recipients who reported one or more dissertation research fields: 2001–08 (Falkenheim, 2010)

				Interdisciplinary dissertations				
Year	All	Reported research field		Reported more than one field		Number of research fields reported		
	Recipients	Quantity	% Total recipients	Quantity	% Reporting field	Two	Three	Four
2001	40,738	37,327	91.6	8969	24.0	8969	*Na*	*Na*
2002	40,025	36,276	90.6	10,234	28.2	10,234	*Na*	*Na*
2003	40,758	37,101	91.0	10,274	27.7	10,274	*Na*	*Na*
2004	42,118	38,228	90.8	1065	27.9	9699	676	275
2005	43,381	39,192	90.3	11,758	30.0	10,642	842	274
2006	45,615	41,176	90.3	11,499	27.9	10,372	842	285
2007	48,112	43,331	90.1	12,275	28.3	11,128	856	291
2008	48,802	44,032	90.2	12,642	28.7	11,833	615	194

Na not applicable; question was not asked

Table 2 Doctorate recipients' secondary field of dissertation research, by primary research field: 2004–08 (Falkenheim, 2010)

Primary research field	All doctorate recipients	Reported research field	Reported more than one field		Secondary research field (%)										Non-S&E
			Quantity	Percent	Science									EN	
					BI	AG	EAO	MA	CO	PH	PS	SO	Total		
Biological sciences (BI)	33,929	31,909	11,304	35.4	81.1	3.8	1.3	0.9	1.1	3.2	1.8	0.8	94.0	1.8	4.2
Agricultural sciences (AG)	534	4738	1842	38.9	31.8	32.6	4.9	2.6	0.7	2.6	0.5	11.2	86.9	5.8	7.3
Earth, atmospheric, ocean sciences (EAO)	3822	3697	1296	35.1	17.0	7.2	50.9	3.2	1.0	6.8	0.0	3.3	89.4	8.8	1.9
Mathematics (MA)	6399	5941	1239	20.9	25.0	0.9	3.5	28.5	8.0	7.7	0.6	4.4	78.6	11.6	9.8
Computer sciences (CO)	6972	6377	1244	19.5	17.9	0.2	0.9	11.6	11.3	1.9	5.9	7.5	57.2	23.4	19.4
Physical sciences (PH)	19,103	17,498	4296	24.6	22.7	0.9	2.7	1.6	1.0	49.3	0.2	0.3	78.7	18.7	2.6
Psychology (PS)	1656	14,172	304	21.5	10.8	0.2	0.0	0.1	0.9	0.2	48.7	9.3	70.2	1.0	28.7
Social sciences (SO)	2157	19,851	5778	29.1	2.5	3.2	1.6	0.5	1.2	0.1	4.3	49.3	62.7	0.7	36.5
Total Science	113,755	104,183	30,039	28.8	39.8	4.6	3.9	2.6	1.8	9.1	6.8	12.1	80.7	5.8	13.6

(continued)

Table 2 (continued)

Primary research field	All doctorate recipients	Reported research field	Reported more than one field		Secondary research field (%)										Non-S&E
			Quantity	Percent	Science									EN	
					BI	AG	EAO	MA	CO	PH	PS	SO	Total		
Engineering (EN)	34,995	31,559	8758	27.8	9.6	1.6	3.0	3.5	6.5	11.3	0.5	1.7	37.7	58.5	3.7
Non-S&E (Science and Engineering)	79,278	70,217	20,027	28.5	3.2	0.6	0.1	0.6	1.4	0.5	6.3	17.4	30.1	1.0	68.8
All fields	228,028	205,959	58,824	28.6	22.8	2.8	2.5	2.1	2.3	6.5	5.7	12.4	57.1	12.0	30.9

such as gender, age, ethnicity, educational level of parents, and the impacts of this propensity on the tests of individuals. Regarding demographic variables, the conclusion was that children of parents with higher education are 1.3% more likely to work in interdisciplinary research and that non-American citizens use interdisciplinary research 4.6% more than those of American citizenship. Regarding economic gains, those who use interdisciplinarity earn 2% less than other doctors in the first year after getting the degree, stressing that, partially, this penalty is caused by the continuing of studies of a large part of those performing interdisciplinary research, as a post-doctoral process.

3.4 How to Overcome These Difficulties: A Philosophical Guide

By looking at interdisciplinary and multidisciplinary development within higher education institutions, institutions are assisted by structures and definitions drawn up by related bodies and entities. Initially, the needs of the productive sector guided these definitions instead of studies that prove interdisciplinary effectiveness. This is complex as it is necessary to develop a viable solution empirically. Epistemology can guide through these complexities and assist in developing practical, intelligible, and more efficient guidelines.

As mentioned earlier, research in the interdisciplinary area, according to Boon and Van Baalen (2019), can be developed in an expansion of the well-known hypothetical-deductive (empirical) method, adding three topics: decision making in relevant disciplines; incorporation of the establishment or choice of a comprehensive theoretical framework with the participants within; and integration of results and insights. The same author describes three metaphors that help connect the interpretations from the steps described earlier into scientific knowledge. Without these, one still does not have something concrete, like a building without walls. These metaphors are jigsaw-puzzle, conflict-resolution, and engineering-design; the first describing the integration of knowledge as pieces, which fit perfectly but do not alter the content of the others; the second describes the emergence of problems due to the understanding of topics which are issued through dialogues; the latter focuses on the designer's creativity to solve problems operating within the epistemological line.

Summarizing, this approach can guide future research in the area and achieve increasingly relevant results. Unfortunately, this epistemological approach is not yet applied on a significant scale, becoming a guide in structuring and developing interdisciplinarity within higher education institutions only. Still, it paves the way for future improvements, understandings, and approaches to overly complex topics such as interdisciplinarity and multidisciplinarity.

3.5 Two Ethical Programs in the Berkeley-Delft Universities

Delft University of Technology (TU Delft) has been implementing ethics as a curricular component in engineering courses for two decades for undergraduate students and master's degree students. Further, several other TU Delft initiatives have emerged to promote ethics in engineering, such as creating a computer program in partnership with other universities to teach ethics applied to engineering. University of California (UC) at Berkeley offered courses with this theme at the beginning of the current century, having a specific program since 2011 (Taebi & William, 2016).

Thus, together they created a collaborative project aimed at creating research combining ethics and technology, fostering interdisciplinary collaboration, mainly between philosophy and engineering among doctoral students. The first edition of this program took place in Berkeley in 2013, encouraging students to participate in discussions and workshops. However, two factors were rather challenging in this first edition: the lack of long-term collaborative research and the low participation rate.

The second edition of the program occurred at TU Delft in 2014 to stimulate research on teaching engineering ethics and prepare doctoral students to teach ethics courses at the university. The program reached the maximum number of participants due to incentives from the Dutch institution. However, the program was unsuccessful in terms of collaboration in teaching since the students' time commitment could hamper their theses. Also, the course could not implement activities related to engineering ethics, which may have occurred because most students were starting their Ph.D. Despite these setbacks, some theses were results from the collaboration between the engineering and philosophy departments at TU Delft.

From these experiences, the academic and institutional areas were presented with challenges that must be addressed. In the academic field, it is necessary to change the view that interdisciplinary research, especially engineering ethics, is less important when compared with technical areas. At the institutional level, support and recognition of ethics applied to engineering are sought. Thereby, methodologies from the lowest to the highest institutional level must be considered (Taebi & William, 2016).

3.6 Education Improving Engineering Design: A Competitive Advantage

Villeneuve et al. (2020) report the methodologies and difficulties faced in an interdisciplinary program. A study of collaborative autoethnography evaluated the practices of an interdisciplinary doctoral research group in urban mobility. This type of study is based on researchers' experience in assimilating the cultural context. The results from interdisciplinary use are categorized into three key aspects: interactive process, productive process, and negotiation process.

Individual perception and group perception are consequences of the interaction between the participants of an interdisciplinary program. The individual perception occurs in the mentality and experiences of each participant, taking the analysis of the project in different directions, creating new ideas and musings. However, participants noticed that people with similar approaches and similar disciplinary backgrounds presented more informal interactions, highlighting the need for information exchange between individuals with different research approaches. Group contribution occurs through a social notion, through a familiar or friendly feeling. Members feel safe to expose their views and discuss their ideas with others.

The production process and the negotiation process originate as consequences from the interactions in the group and are reported as a common interest for the project and different steps of the process and the incorporation of the research interactions. These interactions lead individuals to become more political and have better critical thinking, shaping their personal views and discussions in an attempt to be understood by all. The clash between personal development and disciplinary narratives evidentiates the negotiation process, where individuals find themselves somewhat limited in their disciplinary approach in favor of broader and more political thinking. Therefore, there may be conflicts to be dealt with.

Intersubjectivity is the key to solving all these interdisciplinary challenges. It can be defined as a continuous effort in which individuals develop themselves to understand each other better, breaking through barriers of individual perceptions and experiences. To achieve such intersubjectivity, trust must be created between the members, involving themselves in a feeling of friendship. To have interdisciplinarity taking place, it is necessary to combine several disciplines and a “perverse” problem to be solved, so the development of a healthy interdisciplinary environment occurs through intersubjectivity.

3.7 Academics Approach for the Design (MIT)

Massachusetts Institute of Technology (MIT) has been an example of interdisciplinary integration to improve engineering designs. The Doctoral Program in Social Engineering Systems (SES) focuses on identifying complex social problems through engineering tools and social sciences. The emphasis on problems occurs mainly in the areas of social networks, autonomous systems, energy systems, financial networks, and urban systems. Also, surveys can be used in the structuration of governmental policies. Students graduating from this program can pursue an academic career or serve the public sector by working in regulatory agencies, for example, or in the private sector in industries and consultancies (Massachusetts Institute of Technology, 2019a, 2019b).

Concerning the curriculum, SES is divided in four areas: Core, Systems and Decision Science, Social Science, and Problem Domain. The composition of core classes is formed by subjects of probability, microeconomics, and designing empirical research in social sciences. Information, systems, and decision science include five more rigorous disciplines of probabilistic modeling and systems control theory. Social Sciences, in turn, contains four subjects that should develop the background students will need for their research. Problem Domain consists of two subjects involving the student's research topic.

MIT also presents programs more focused on engineering design, such as the integrated design and management (IDM) and system design and management (SDM) programs. The purpose of these programs is to develop management techniques and systems development, besides fostering a spirit of leadership in the participants. Both are master's programs; however, SDM students have an average 10 years of experience, whether from the private or public sector, while IDM students have none. The SDM program presents disciplines divided into three areas: systems engineering, architecture, and optimization, while the IDM program has its core curriculum taught at the Integrated Design Lab, where interdisciplinary teams have dedicated space for the team to practice the human-centered design process.

4 Smart Cities: An Example of the Interdisciplinary Engineering

The topics aforementioned enable a more realistic approach, which will be performed citing smart cities. Having a wide scope of definitions, such as "Smart cities must be considered as systems of people interact and use flows of energy, materials, services, and financing to catalyze sustainable economic development, resilience and high quality of life, these flows and interactions are smart through the strategic use of information and communication infrastructure and services in the process of transparent urban planning and management that responds to the social and economic needs of Society" (Maschio, 2013). From a different perspective, Washburn et al. (2009) "The use of smart IO technologies makes the critical infrastructure components and services of a city—which include city administration, education, health care, public safety, real estate, transportation, and utilities—more intelligent, interconnected, and efficient.". Summarizing, smart cities is a new concept where cities seek to integrate all their systems to promote sustainable growth and a better quality of life for their inhabitants.

With these ideas in mind, PricewaterhouseCoopers (PwC) (2018) suggested a structure for implementation of the "smart city" in three different formats. The first refers to implementing smaller scale infrastructure projects, whereas the government, author of the infrastructure project, relies on private institutions to provide the service, technology, or solutions for the project. This format of projects is the initial basis for implementing smart cities. The second format refers to the development and implementation of digital services in the city's basic infrastructure using projects of the first format as a base. This implementation is performed in a public–private partnerships (PPP) arrangement, where the private sector provides the service, and the public sector benefits through part of the revenue from the concessions. The third format, which is still under development, is defined as building a digital ecosystem inside and outside the city's infrastructure. The result is that new products, services, companies, and government revenue opportunities are created in the smart city platform. This format is an incubator for new ideas.

At first, the earlier definitions fail to effectively demonstrate the complexity and size of the challenges that are imposed to achieve this ideal. Dividing the topic "smart cities" into subtopics, namely the energy system, the health system, the transport system, the population input system (water, sanitation, etc.), and the communication system, will facilitate the discussion. The energy system, which is in full-speed transformation in some countries, is shifting from traditional generation to new alternatives such as renewable energy and integrating them into the grid as described by Maitra et al. (2017), benefiting consumers and new producers that have their energy matrices based in renewable energy. However, with this advancement, problems arise regarding the stability of the system as a whole, its security, and reliability, even the privacy of information regarding its operation, which can and should be considered national security issues (Public Safety Canada, 2018).

The benefits and difficulties are found in all the ramifications of the implementation of "smart cities", and this is an example that places multidisciplinarity and interdisciplinarity under the spotlight, integrating IT, biological sciences, administration, public policies, human sciences, etc. Only by solving these challenges through a holistic perspective will these designs become feasible.

5 Philosophy of Innovation: The Fuel for Interdisciplinarity

In modern society, innovation derives from the interdisciplinary mentality and some aspects of engineering systems. Blok (2019) demonstrates a philosophical view of innovation by contesting the uncritical view of innovation as something intrinsically good, taken as a panacea for all socioeconomic problems. Blok warns of the concept of the term, often associated with technological exploitation and commercial exploitation. This association generates a socioeconomic paradigm, making its concept often implicit.

In Blok's view, the economist Joseph Schumpeter influenced this contemporary technological and economic notion of innovation. For Schumpeter, innovations imply in waves such as the economic wave generated with the creation of streaming services to the detriment of old CDs and LPs. Schumpeter associates innovation with a phenomenon called creative destruction, wiping out the old, and creating the new, revolutionizing the capitalist structure. This destruction is essential for capitalism, preventing its collapse. Based on this thinking, Blok argues that innovation does not belong to the capitalist system itself but indirectly imposes its limit.

This idea raised by Schumpeter contrasts with common sense that innovation is something intrinsically good since this creative destruction negatively affects other places, making clear that innovation may be a necessary condition, but not enough to solve current social challenges. Blok also discusses the differences between the terms technology and innovation, often used as synonyms. Technology has concrete objects as a starting point but can be a process, unlike innovation that begins from a process level. Blok also argues that all new technologies are innovation products, but not all innovations produce new technology, social innovation being a good case in point. Another difference occurs in the form of a disruption of the innovation since it changes the system's rules (as seen in creative destruction), as technology is based on destructive creativity. Another rationalization is that technology derives from something known, while innovation has the unknown as its starting point.

Besides these discussions regarding the concept of the term, he also reflects on the ontic and ontological vision of innovation. Starting from Schumpeter's thought, what is destroyed is not the artifact itself, but the associated political and economic order. For example, the innovation of streaming services concerns the ontogenesis of this service at the ontic level, but, secondly, the ontogenesis of the political–economic order of the world associated with digital networks at the ontological level. Innovation as creative destruction, therefore, does not concern only the things in the world, but mostly the order in which these things come up and the sequence that they can be interpreted.

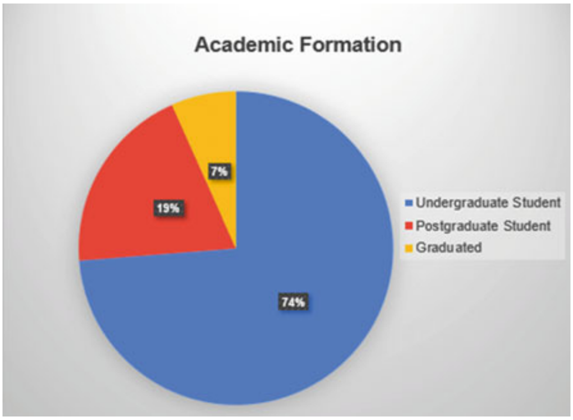
In addition to addressing this philosophical aspect of innovation, it is also important to know the practical aspect that several companies have instigated throughout the world. In Brazil, EMBRAPII (Brazilian Company of Industrial Research and Innovation) is a federal social organization that supports technological research institutions fostering innovation in the Brazilian industry. Until July 2020, the company supported 991 projects and 680 companies, with an investment of R$ 1.5 billion (approximately US$ 270 million) in research and development projects, being 32.2% from EMBRAPII, 49.5% from other companies in the private sector, and 18.3% corresponding to other EMBRAPII partners. The areas mostly encouraged by the company are applied technologies, mechanics and manufacturing, biotechnology, materials and chemistry, information technology, and communication technology (EMBRAPII, 2020).

6 Interdisciplinary Engineering Education: A Brazilian Case Study

To support the importance of interdisciplinary teaching in engineering education reported in this chapter, a questionnaire containing ten questions addressing the interdisciplinary incentives in Brazilian educational institutions was created for engineering students. Further questions were addressed to students with professional experience to understand better the efficiency of educational institutions in preparing students for their professional lives. The questionnaire was answered by a total of 480 engineering students from 26 different institutions in Brazil.

As shown in Fig. 3, almost 75% of the responses were from undergraduate students. This type of student is an important factor in analyzing the efficiency in

Fig. 3 Engineering student groups evaluated



preparing students and the interdisciplinary view of the institutions as postgraduate students and graduates often already have a base formed by universities or professional training, making these groups less impactful for this analysis.

In the professional context, the first two questions checked whether the student had any professional experience. Around 54% of the students responded positively. About 58% of the interviewees answered that their courses provided the basis required for the job market. Furthermore, the questionnaire contained a discursive question about the individual view of each student on their courses' preparations for the job market. They evaluated the efficiency of the course in this sense and suggested improvements to their curriculum. The conclusion is that on average students considered 54.7% of their course to be useful for their professional performance from the data collected. The comments reported some points to be improved in the curricular structures of their institutions, covering topics such as finances and improvement in the teaching of software. These comments will be better analyzed through this sub-chapter. Regarding academic aspects, some questions asked students about issues ranging from the infrastructure of the institutions and level of interdisciplinary incentives to actual teaching in the classroom.

Most students indicated a good interdisciplinary incentive by institutions. In total, 75% of the interviewees answered that the institutions promote projects among groups of different areas of knowledge, and 59% responded that their universities encourage exchange programs to carry out projects in other areas. Figure 4 shows the result for three questions indicating that despite teachers looking for different types of tools in class, teaching itself is static, without interaction with other areas, reinforcing the difficulty of engineering courses in breaking knowledge barriers. Despite that, the need for an interdisciplinary approach in research and academic production is clear.

Students were asked to mention professional improvement courses sought by them on the latter part of the questionnaire. This highlights the flaws in the curricular structure of undergraduate courses, resulting in the search for courses outside the institution. Figure 5 illustrates a word map for undergraduate students, and Fig. 6

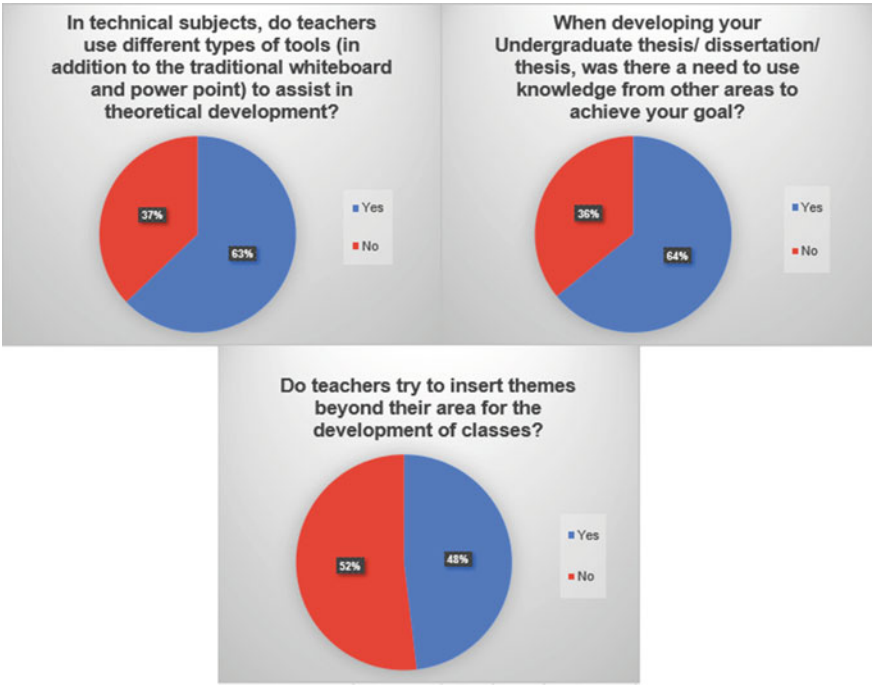


Fig. 4 Questions about interdisciplinary encouragement and teaching

Fig. 5 Relevant external courses for engineering undergraduate students

illustrates the map for postgraduate students and graduates. Such maps represent illustratively the majorly sought after areas for development and training. Totaling a number of 27 types of engineering areas present among the interviewees, generalizations have been made on the terms, leading to a key idea within the comments of each

Fig. 6 Relevant external courses for postgraduate and graduated students

individual. It is crystalline that undergraduate students are concerned with programming and usage of specific software, reinforcing once again the need for more technologically integrated teaching with practical applications and area-specific use of the software. Another truly relevant external course for these undergraduate students is management of people, projects, or even technical areas. Postgraduate students and graduates, in turn, showed greater interest in further specializations, yet again the concept of management came up in several areas.

7 Conclusions

The engineering practice depends on countless factors, ranging from economic and technological to environmental or social reasons. Therefore, holistic thinking that breaks through barriers is necessary, thinking that promotes understanding the whole process. This thinking is achieved by comprehending the processes involved and the relations among them, culminating in a global perspective of the facts. The applicability of these concepts is greatly important as they reflect the teaching of engineering in universities.

The importance of interdisciplinarity as a tool of social change has become clear when proceeding with topics related to education and the teaching of engineering. It is necessary to better integrate institutions, professors, and students to allow the multidisciplinary mentality to become a foundation in the teaching of engineering. Hence, an increase in the number of debates on this topic is expected, aspiring to make this process beneficial to all involved.

In order to build a solid foundation for the rationalizations hereby presented, students were asked to supply information through an online questionnaire, where students shared their opinions on what is discussed in this chapter, questions regarding the skills developed through the undergraduate course, their uses in the job market, whether there was a need to seek courses outside of undergraduate programs to complement skills required for their jobs, etc. The data collected demonstrates that courses still are afflicted by inefficiencies concerning the curricular structure, offering opportunities of developing more efficient scenarios, reducing the costs for students and better molding the development of students' skills, possibly through partnerships with companies or only with universities, and making them more qualified to perform their functions in their future job positions.

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A Multi-aspect Dynamic System Model to Assess Poverty Traps

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Keywords Nonlinear systems · Poverty traps · Social modeling · Sustainable development · System dynamics

1 Introduction

In a world with growing inequality, conflicts, and a critical state of the environment, it is crucial to understand the principles that govern societal issues such as population distribution, poverty, and violence in modern cities. For the sake of developing novel solutions, a holistic analysis of the dynamics of social systems is of paramount importance to ensure good and sustainable standards of living. This analysis takes into account the systemic interdependencies among individuals, households, institutions, and nations, and this integrated perspective may help to promote a more favorable trajectory out of poverty and a sound and sustainable social welfare (World Bank, 2018).

Nothing exists by itself or for itself. Everything exists in connection with other things, and when multiple aspects related to the complex issue of poverty and its perpetuation (e.g., economy, demography, environment, education, public health, and safety) are considered within a systemic perspective, the careful dynamic modeling of the inseparable social system constituents is required (Meadows, 2009). Further, not

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only these multiple aspects are interdependent, but there is also strong evidence that supports the theory that poverty is self-reinforcing due to behaviors that perpetuate low standards of living (Barret et al., 2016). These 'poverty traps' concentrate poverty spatially and impose obstacles for public policies and interventions.

In this chapter, we present a multi-aspect dynamic system model to assess poverty traps. This system model is evaluated through a case study involving the Brazilian state of Minas Gerais, the second-most populous state in the country. The model indicates that it is possible to alleviate poverty through government policies and long-term interventions. Overall, systemic analysis and tools, such as the one presented in this chapter, are essential to inform public policy, because, in the absence of careful policy assessment and changes, more people could be driven into deeper poverty traps.

1.1 A Discussion on Social Modeling

There are evidence-based studies about how poverty-reinforcement behaviors can be interpreted and modeled alongside their adverse effects in micro- or macroscale levels. These levels can vary from a single individual or a neighborhood to a region or a country. The process of building and analyzing poverty models from the perspectives of economists, demographers, ecologists, engineers, and others helps to represent the influence of poverty among the interdependent subsystems (Azariadis & Stachurski, 2005).

Several mathematical models using dynamic systems theory are available in the literature (Baguant et al., 1994; Meadows et al., 1972; Sanderson, 1992). Although excluding poverty traps theory, the Wonderland model (Sanderson, 1992) is prominent due to its simplicity. Such a model has been analyzed and discussed in proper detail in (Milik et. al., 1996; Wegenkittl et al., 1997). In further studies, the model was extended (Herbert & Leeves, 1998) to consider the effect of government taxes and stochastic external disturbances. Moreover, reference (Vasconcelos et al., 2021) discusses the effects of energy poverty and the effects of energy access on a demographic and economic levels.

It is essential, though, to realize that all models, even dynamic differential equation-based models, are simplifications of real-world phenomena. Models are usually strong and coherent, but as complexity increases, they may fall short of an accurate representation due to the unpredictable or unforeseen interactions with other systemic aspects (Kim, 2000).

This chapter takes on the challenge of extending the lifetime of the Wonderland model by, based on its time-varying equations and dynamics, introducing new aspects of social systems and poverty traps. Parameters of the proposed model equations are inspired by targets and indicators of the millennium sustainable development goals proposed by the United Nations (United Nations General Assembly, 2017) and world development indicators available in (World Bank, 2020). The main objective is to develop a mathematical framework that serves as a tool to analyze possible trends for public policymakers, thus helping to improve the quality of life and eradicate poverty and its reinforcing behaviors.

2 The Wonderland Model

The original model proposed by (Sanderson, 1992) has nine equations that can be classified into three groups, dealing with: (1) economy, (2) population, and (3) environment and environmental policies. The period in which the equations are evaluated is suggested by the subscript t. Therefore, $t + 1$ refers to the parameter value at subsequent interactions or years. Equations and descriptions include Greek letters that are the parameters of the model. Some of them cannot be precisely estimated or are potentially not important to the discussion. In these cases, only the sensitivity of the results about the referred parameter is discussed.

Dream and horror scenarios were originally discussed for the Wonderland model, but the model outcomes can change dramatically by varying parameter values and initial conditions. The former is the best possible scenario, where the economy grows exponentially, and the size of the population stabilizes after a while. Natural capital remains undiminished as pollution decays exponentially. The latter is where sustainable development gives way to a catastrophic collapse of the economy, population, and environment. Escape scenarios are the ones that take control measures into account to avoid the implications of the horror scenario. A solution investigated in (Herbert & Leeves, 1998) is the increase in pollution control expenditures and the creation of environmental taxes that encourage the reduction of the pollution output.

The small number of equations in the Wonderland model is an advantage (e.g., World3 (Meadows et al., 1972) and Mauritius (Baguant et al., 1994) have more than a hundred). The model can be relatively easy to implement, and its equations and parameters can be adjusted to represent different scenarios with distinct dynamics. However, this very advantage imposes a shortcoming. Natural capital appears to be a rather vague concept, and some specific parameter values and initial conditions may lead to unpractical results in real-life scenarios.

This means that the Wonderland model should not be shown as a forecasting or quantitative analysis tool. It requires the modeler to rely on critical analysis and thinking, as a plethora of solutions exists. Therefore, it provides a qualitative understanding of possible development paths and questions about sustainability and the meaningfulness of public policies in dynamic social systems.

3 Structure and Theory of Poverty Traps

Some studies address poverty as a transitory phenomenon, even acknowledging the long time required to resolve this issue—especially if bad luck strikes frequently. The term 'stochastic poverty' (Dutta and Kumar, 2016) refers to adverse income shocks that smooth out consumption and impose negative effects on household income and access to credit.

The question of whether communities and individuals can be structurally trapped in poverty is central to our understanding. Some household characteristics that seem to be results of poverty and poverty traps—low educational achievement and accumulation of assets, precarious living conditions, and poor access to education and health services, are reviewed in this section. Supported by the poverty trap theories described below, Fig. 1 shows the causal structure diagram that is assumed by this work. This diagram indicates there could be, in the worst case, causal links leading to a state of the perpetuation of poverty.

The dynamics of poverty traps become more complex and strengthened as more of these structural traps are mutually considered. Visual interpretation of these cyclical, nonlinear dynamic systems requires the design of causal structure diagrams that offer an effective way to show how a state influence another. Since these are mutual interactions, parts of the system cannot be easily separated.

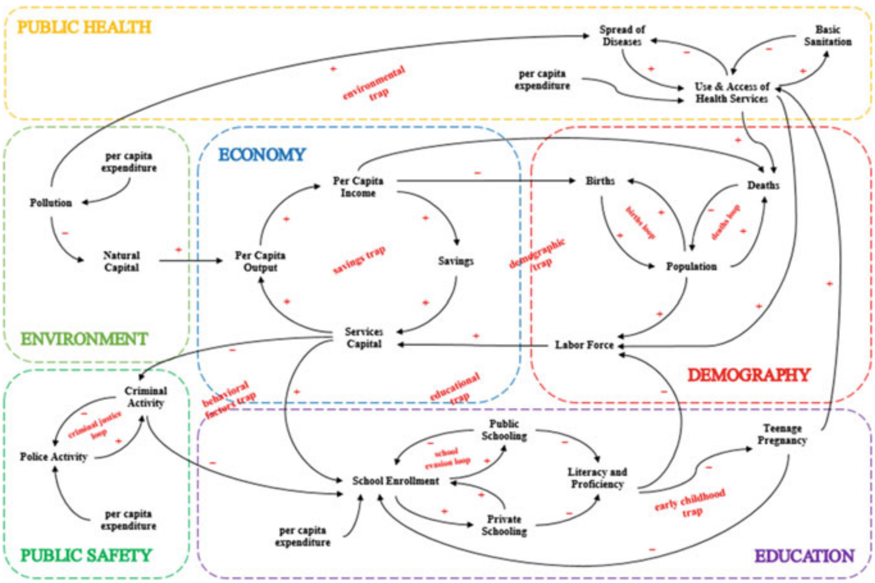

Fig. 1 The causal structure diagram of the Wonderland model including poverty traps

3.1 Demographic Trap

Based on the assumption that poverty is characterized by low household income, it is recognized that high fertility rates are observed among the less developed regions and the world's poorest people (Ansah, 2010; Sinding, 2009).

With low income per worker, it is expected that the fertility rate will increase, causing the birth rate to rise. Population growth creates new entrants to the labor market and increases the costs of infrastructures of education, health, and public safety services, which consequently reduce the net economic output, thus lowering the income per worker. This relationship tends to maintain low income in regions in which poverty is already established. The demographic trap is counteracted via the reduction of population growth when the death rate is higher than the birth rate, or through a reduction of the birth rate by supporting family planning and other public policies, as discussed later.

3.2 Savings Trap

Households may save or invest some of the surplus income once the basic needs and infrastructure (i.e., personal health, food and water intake, and sanitation) are met (Sachs, 2002).

In regions where income is very low, the savings rate can be nonexistent, because impoverished households use all their income in the struggle to survive. Consequently, output per worker is expected to decrease due to low capital accumulation and high population growth (Ansah, 2010). This observation shows how the savings trap harmonizes with the demographic one. It is diminished when overall economic output is higher than expenses on local education, health, safety, and other public services.

3.3 Intergenerational Traps

In addition to affecting the current generation, poverty and income inequality may have long-term consequences, impacting the distribution of health, human capital, and income to the next generations (Aizer & Currie, 2014). Some authors emphasize how a low-income family background can hinder intergenerational social mobility of the offspring's life, leading to similar educational achievements, social attitudes, early childhood cognitive and physical development failures, and hence to the transmission of a disadvantaged status to descendants (Barret et al., 2016; Nishimura & Raut, 2007).

3.3.1 School Choice and Demand for Education

Education is often viewed as the main route out of poverty; however, poverty itself constrains investments in education. Although family income should play no role in schooling choices (only the returns of education should matter), there is a concentration of literacy in some specific income levels, where low educated workers tend to choose low-level education for their descendants, perpetuating low wages for these family units (Glewwe & Jacoby, 2004; Maldonado et al., 2012; Nishimura & Raut, 2007).

It is considered that the choice between public or private schooling systems is based entirely on household income. While the family income per capita remains above a defined threshold, private schooling is a natural choice; if it is below, public education becomes the only option. Further, it is assumed that public and private school systems have different effects on the labor force of future working generations. Effects of economic growth and opportunity costs of schooling are observed as the demand for education changes. This is a serious drawback of public school in Brazil. Dealing with the way to improve the public school is certainly a matter of interest. We understand that changes in habits may create political demand for better schools.

3.3.2 Teenage Pregnancy and Early Childhood Development

Women living in poverty are more likely to smoke, have poorer dietary habits and lower educational achievements, and engage in higher risks for teenage pregnancy (Larson, 2007).

The difficulty of an unplanned pregnancy and disadvantaged maternal prenatal conditions are often related to lower weight at birth (Aizer & Currie, 2014; Larson, 2007). Studies in the USA (Aizer & Currie, 2014) and Sweden (Bharadwaj et al., 2018) show that children with low birth weight have substantially worse adult outcomes in terms of school attainment, employment, health, and wages, which constitute a long-term poverty trap.

3.3.3 Pollution and Basic Sanitation

Another way in which household economic status influences future generations is through exposure to harmful environmental factors, such as pollution and the absence of basic sanitation.

Because of lower housing costs, low-income families tend to reside in inadequate conditions, often near—and therefore exposed to—pollution sources (Aizer & Currie, 2014). Such coexistence of issues can lead to a poverty trap. The incidence of diseases due to the proximity to polluted areas and the lack of basic living infrastructure increases the number of deaths and reduces household labor working capacity (Akpandjar et al., 2018).

3.3.4 Behavioral Factors: Stress, Violence, and Crime

A different mechanism receiving growing attention in the literature deals with behavioral patterns that reinforce poverty. Such an idea posits that poverty and income inequality have particular psychological consequences that can cause stress, short-sightedness, and risk-averse decision-making (Haushofer & Fehr, 2014), resulting in a lower standard of living (Barret et al., 2016). This scenario is described in (Mani et al., 2013) as a temporary reduction of cognitive capacity that reduces working productivity.

Some theories complement this assumption, pointing efforts to the social tension, anxiety, and opportunity costs of crime, supported by income inequality. Exposure to violence and other traumas can lead people to become violent and prone to illegal activities (Barret et al., 2016). In the same line of work, some authors also claim (Enamorado et al., 2014) that poverty and inequality are significantly correlated with property crimes and violent crime occurrences.

The proposed model assumes that, as the number of criminal occurrences varies, police activity reacts proportionally, thus government expense on violent crime prevention changes. Government costs affect the share of the economic output that is transferred to the population as per capita income. Therefore, it is assumed that regions with high numbers of criminal occurrences and police activity tend to have lower shares of local economic output.

4 Overview of the Dynamic System Model

These poverty trap hypotheses provide a common understanding of the philosophical design of the model and a moral imperative for interventions that combat extreme and generalized poverty. In the next subsections, the relationships between social, demographic, economic, and environmental aspects are discussed mathematically. In this section, the dynamic system equations and the main assumptions of the model are presented. It is subdivided into four main parts, which are: (1) economy, (2) demography, (3) environment, and (4) social aspects.

The economy subsection aggregates concepts related to the local capacity of producing goods and services, capital accumulation, as well as government expenses on public services and infrastructure maintenance. The demography and environment subsections present equations similar to the original Wonderland model of (Sanderson, 1992). The social subsection is further subdivided into education, public health, and public safety. The first one, education, models parental choice between public and private schooling systems to provide education to their offspring, and the respective effects of literate and proficient workers on the development of the local labor force. Public health deals with the use and access to health services and basic sanitation. Public safety deals with the incidence of criminal occurrences and the police activity response.

Table 1 Model variables by subsection

Var	Description	Subsection
Y	The per capita output	Economy
C	The total government expenditure	Economy
I	The per capita income	Economy
S	The household savings	Economy
L	The labor force	Economy
Ks	The services capital	Economy
B	The crude birth rate	Demography
D	The crude death rate	Demography
N	The population	Demography
F	The flow of pollutants	Environment
Kn	The natural capital	Environment
Cp	The govt. expenditure on pollution control	Environment
P	The pollution per unit output	Environment
De	The demand for education	Education
E	The school enrollment	Education
$Npriv$	The population in private schools	Education
$Npub$	The population in public schools	Education
Ce	The govt. expenditure on education	Education
An	The adult illiteracy index	Education
Kw	The basic sanitation and safe water index	Public Health
Fw	The need for safe water and sewage treatment	Public Health
Cw	The govt. expenditure on basic sanitation	Public Health
Sd	The spread of diseases through water	Public Health
Ca	The criminal activity	Public Safety
Pa	The police response activity	Public Safety
V	The crude rate of violent crimes	Public Safety
Cv	The expenditure on crime detention	Public Safety

In total, the model comprises 27 equations. We shall deal with each one of these equations in turn. The model variables are described in Table 1.

4.1 Economy

The following equations represent the economic aspect of the model, including the economy's per capita output Y, household savings S, and capital (Kn and Ks).

$$
\begin{aligned}
Y_{t+1} = Y_t \Big\{ 1 + \gamma - (\gamma + \eta) \left[(1 - Kn_t)^{\lambda_n} + (1 - Ks_t)^{\lambda_s} \right] \\
- \frac{\gamma_n \tau_n}{1 - \tau_n} - \frac{\gamma_s \tau_s}{1 - \tau_s} - \frac{\gamma_c \tau_c}{1 - \tau_c} \Big\}
\end{aligned} \tag{1}
$$

$$C_t = Ce_t + Cp_t + Cv_t \tag{2}$$

$$I_t = Y_t - C_t \tag{3}$$

$$S_t = \begin{cases} \phi_s (It - Ith), & I_t > Ith \\ 0, & It \le Ith \end{cases} \tag{4}$$

$$L_t = \kappa_s \left(\frac{e^{\epsilon_s S_t \phi_w N_t}}{1 + e^{\epsilon_s S_t \phi_w N_t}} \right) - (1 - \phi_w) N_t I_t An_t \tag{5}$$

$$Ks_{t+1} = Kn_t \frac{e^{\ln \frac{Ks_t}{1 - Ks_t} + \delta_s Ks_t^{\rho_s} - \omega_s L_t}}{1 + e^{\ln \frac{Ks_t}{1 - Ks_t} + \delta_s Ks_t^{\rho_s} - \omega_s L_t}} \tag{6}$$

The economy's per capita output Y, in Eq. (2), depends on the previous levels of the stock of natural capital, Kn, and services capital, Ks. Services capital refers to the flow of productive services provided by the government and the local economy. Similar to natural capital, services capital varies between 0 and 1. If the public infrastructure is unable to provide its services and the labor market is deficient in literate and healthy workers, it assumes a value of 0. If the economy prospers and all resources are available, then it takes the value 1.

Again, it is assumed that environmental taxes, τ_p, have the effect of reducing pollution per unit output. Similarly, services taxes, τ_s, lead to education, public health, and safety services with greater quality. Both taxes would also be expected to have the effect of reducing economic output, proportional to γ_p and γ_s, respectively. Environmental and services taxes are control variables of the model and are not applied in the dream scenario. Equations (2) and (3) represent the sum of government expenditure in pollution control measures and in maintaining public services infrastructure, and the net per capita output, respectively.

Household savings are determined in (4) based on the assumption that there is a level of minimum real consumption, Ith, to meet basic needs of personal health, food intake, and shelter. As soon as per capita income I is above the income threshold, the household saves a constant fraction of the excess $(I - Ith)$. When the income is below Ith, household savings is zero.

Equation (5) describes the labor force of the population. It is assumed that, as household savings and the working share of the population, $\phi_w N$, increase, the labor force is augmented proportionally to a factor, κ_s. Non-working population, $(1 - \phi_w)N$, inequal per capita income, and illiterate workers, represented by An, negatively impact the local capacity of sustaining services capital, Ks.

Services capital, in (6), reflects the physical conditions of producing infrastructures and the existence of sufficient literate, proficient, and healthy workers. In a similar way to the Wonderland model's natural capital, a positive labor force L permits the services capital to regenerate itself, due to new entrants in the labor market. The constant parameters capital δ_s, ρ_s, and ω_s set the dynamic behavior of the services.

4.2 Demography

Population growth (N) is represented by Equations (7) to (9).

$$B_t = \beta_0 \left[\beta_1 - \left(\frac{e^{\beta_2 I_t}}{1 + e^{\beta_2 I_t}} \right) + \left(\frac{e^{\beta_3 (1 - An_t) I_t}}{1 + e^{\beta_3 (1 - An_t) I_t}} \right) \right] \tag{7}$$

$$D_t = \alpha_0 \left[\alpha_1 - \left(\frac{e^{\alpha_2 I_t}}{1 + e^{\alpha_2 I_t}} \right) \right] \left[1 + \alpha_3 (1 - Kn_t)_1^{\theta} \right] \left[1 + \alpha_4 (1 - Ks_t)_2^{\theta} \right] + \alpha_5 Sd_t \tag{8}$$

$$N_{t+1} = N_t \left[1 + \left(\frac{B_t - D_t}{1000} \right) \right] \tag{9}$$

In Eq. (7), both the environment and economy interact with the crude death rate, since the levels of the natural resources, Kn, and services capital, Ks, can act as a proxy for the health of the community. Decreases in Kn and Ks cause the death rate to rise. It is reasonable to assume that significant changes in the local environment affect household medical and nutritional conditions, as well as exposure to pollution.

When compared with the calculation of the crude birth rate on the original model, Eq. (7) presents a new term related to the crude teenage pregnancy rate. It is adapted to assume higher values when the population illiteracy index An is high, and the per capita income is low. However, it tends to zero or be eliminated, as per capita income increases, if the parameter β_3 is below zero.

The crude death rate of (8) is also incremented by a fraction of the number of diseases resulted from contamination through water and lack of basic sanitation, Sd. This is discussed later in the public health subsection of the chapter.

4.3 Environment

Environment equations remain unchanged from the original Wonderland model.

$$F_t = N_t Y_t P_t - \kappa_n \left(\frac{e^{\epsilon_n C_t N_t}}{1 + e^{\epsilon_n C_t N_t}} \right) \tag{10}$$

$$Kn_{t+1} = \frac{e^{\ln \frac{Kn_t}{1 - Kn_t}} + \delta_n Kn_t^{\rho_n} - \omega_n F_t}{1 + e^{\ln \frac{Kn_t}{1 - Kn_t}} + \delta_n Kn_t^{\rho_n} - \omega_n F_t} \tag{11}$$

$$Cp_t = \phi_p (1 - Kn_t)_p^{\mu} Y_t \tag{12}$$

$$P_{t+1} = (1 - \tau_p) \chi_p P_t \tag{13}$$

Equations (10) and (11) describe the annual flow of pollutants and natural capital stock, respectively, while (12) and (13) model the government expenditure on pollution control measures the pollution per unit output.

4.4 Education

Five equations model the overall educational level of the population.

$$De_t = N_t I_t An_t - \kappa_e \left(\frac{e^{\epsilon_e C_t \phi_e N_t}}{1 + e^{\epsilon_e C_t \phi_e N_t}} \right) \tag{14}$$

$$E_{t+1} = \frac{e^{\ln \frac{Ks_t}{1-Ks_t} + \delta_e Ks_t^{\rho e} - \omega_e FDe_t + \omega_s Ks_t - \omega_v Vt}}{1 + e^{\ln \frac{Ks_t}{1-Ks_t} + \delta_e Ks_t^{\rho e} - \omega_e FDe_t + \omega_s Ks_t - \omega_v Vt}} \tag{15}$$

$$Npriv_t = \phi_e N_t E_t \left(\frac{e^{\Delta_e (GI_t - Ith)}}{1 + e^{\Delta_e (GI_t - Ith)}} \right) \tag{16}$$

$$Npub_t = \phi_e N_t E_t - Npriv_t \tag{17}$$

$$Ce_t = \phi_e N_t (1 - Ks_t)^{\mu_e} Y_t \tag{18}$$

$$An_{t+1} = (1 - \tau_e) \chi_e An_t \tag{19}$$

The first equation, Eq. (14), represents the demand for education. It varies with household income, I, size of the population in studying age, $\phi_e N$, the government expenditure on education services, Ce, and the adult illiteracy index, An.

Increased demand for education leads to higher school enrollment, E, as stated in (15). Note that the equation structure is similar to the ones of natural and services capitals. School enrollment tends to regenerate itself, representing the positive effect of education toward maintaining students at schools, face the opportunity costs of the demand for workers on the labor market. Parameters ω_e, ω_s, and ω_v allow the influence of variables representing the demand for education, services capital, and public safety on school enrollment.

Although income should not be the sole factor that influences parental schooling decisions to their offspring, the choice between private and public schools is modeled as an economic decision. Equations (16) and (17) define the sizes of population studying on private and public schools, respectively. As soon as household income surpasses a threshold, Ic, it is considered that a private school is chosen, otherwise public school. This, though undesirable, reflects the low and medium-class behavior in many emerging countries.

Government expenditure on education, Ce, in (18) is related to three variables: first, the size of the population in studying age, $\phi_e N$; second, the deterioration level of the services capital; and, third, the economic per capita output. In (19), An represents the per unit portion of the population that persists illiterate, even with government efforts.

The parameter χ_e is an important factor in the model because as it approaches unity, the adult illiteracy falls slowly and the consecutive impacts on other variables, mainly during the first interactions after model deployment, set out the horror scenario. More on development scenarios of the model are presented in the next section.

4.5 Public Health

Six equations comprise the public health aspect of the model.

$$Fw_t = N_t Y_t P_t - \kappa_w \left(\frac{e^{\epsilon_e Cw_t N_t}}{1 + e^{\epsilon_e Cw_t N_t}} \right) \tag{20}$$

$$Kw_{t+1} = \eta Kn_t \frac{e^{\ln \frac{Kw_t}{1-Kw_t} - \delta_w Kw_t^{\rho w} - \omega_w Fw_t}}{1 + e^{\ln \frac{Kw_t}{1-Kw_t} - \delta_w Kw_t^{\rho w} - \omega_w Fw_t}} \tag{21}$$

$$Cw_t = \phi_w (1 - Kw_t)^{\mu_w} Y_t \tag{22}$$

$$Sd_t = \phi_d (1 - \tau_d)(1 - (Kn_t + Kw_t))^{\mu_d} N_t \tag{23}$$

First, the demand of the population for drinkable water and sewage treatment is estimated in (20). It is considered that it grows as a function of the economic output, the size of the population, and pollution per capita output. Parameter κ_w represents the effectiveness of the economy's water pollution and consumption control measures.

Equation (21) models the availability of basic sanitation and safe water to the population. Similar to the natural capital at the environmental subsection of the model, this variable is considered to be capable of sustaining itself until the request for sewage treatment and safe water is high enough. By multiplying the whole fraction by ηKn_t, the dynamics of variable Kw is slowed, if η is less than 1. Also, if the natural capital stock is completely depleted and assumes zero value, it is considered that there is no such thing as safe and drinkable water. These assumptions represent the inability of losing basic sanitation infrastructure, once it is established and the contamination of water, respectively.

The government expenditure on basic sanitation, as shown in (22), varies with the variables described earlier. As the availability of the basic sanitation infrastructure, Kw, deteriorates, government expenditure expands proportionally to a factor ϕ_w of the economic output, Y.

Lastly, (23) models the spread of diseases through contaminated water—a result of pollution and lack of basic sanitation. The crude rate of medical cases is the output of the equation, which depends on the actual state of the natural capital stock, the size of the population, availability of safe water, and government expenditure on these services, Cw. A government tax, τ_w, can also affect the number of cases, if introduced, as shown in (23). A fraction of the crude number of disease cases further increases the crude death rate.

4.6 Public Safety

Finally, the public safety subsection models the crude rate of violent crime occurrences V, given in (26).

$$Ca_t = \alpha_{v0}\left[\alpha_{v1} - \left(e^{\alpha_{v2}I_t}1 + e^{\alpha_{v2}I_t}\right)\right]\left[1\alpha_{v3}(1 + Ks_t)^{\theta_v}\right] \tag{24}$$

$$Pa_t = Ks_t V_{t-1}^{\gamma+\tau_v} \tag{25}$$

$$V_{+1} = V_t\left[1 + \left(\frac{Ca_t - Pa_t}{1000}\right)\right] \tag{26}$$

$$Cv_t = \phi_v(1 - Ks_t)^{\mu_v} Y_t \tag{27}$$

The criminal activity, Ca, in (24), models the opportunity cost in favor of illegal activities. As the per capita income, I, increases, it tends to stabilize after a while. However, the influence of the services capital is sensible. If it is at unity, no further increases on criminal activity are observed, representing, for example, the existence of sufficient employment for the population. Constants α and θ dictate the dynamics of this variable.

In (25), the response of police activity, Pa, is proportional to the violent occurrences on the previous accounted period. Government tax for criminal detention, τ_v, increases the efficiency of these services. It is also dependent on the state of the services capital.

The third equation in this subsection of the model describes the crude rate of violent crimes (the number of violent occurrences on year t per 1,000 inhabitants). It is considered the difference between criminal activity and police response.

Finally, the government expenditure on crime detention, (27), is considered to be a share of the economy per capita output, also dependent on the state of the services capital.

4.7 Economic and Environmental Disturbances

So far, the model has been considered deterministic. It would be more realistic to consider the implications of stochastic disturbances to the economy and natural capital stock. This is modeled by the introduction of independent white Gaussian noises to equations (6) and (13).

The insertion of external disturbances has the potential of representing unexpected influences of economic and environmental policies, or natural disasters that may compromise nature itself, thus the economy and the welfare of the population.

4.8 State-Space Representation

Dynamical systems theory embodies a representation of solutions to ordinary differential equations of the form $\dot{\mathbf{x}} = f(\mathbf{x}, \mathbf{u}),\ \mathbf{x} \in \mathbb{R}^n,\ \mathbf{u} \in \mathbb{R}^l$, where $\mathbb{R}^n$ refers to the phase space and $\mathbb{R}^l$, to the space created by the controllable inputs.

Since the Wonderland is a discrete time-invariant model, the entire set of equations is represented in state-space form as $\mathbf{x}_{t+1} = f(\mathbf{x}_t, \mathbf{u}_t) + H\boldsymbol{\epsilon}_t$, where $\mathbf{x}$ is defined as the vector of states ($[\mathbf{Y},\ \mathbf{Ks},\ \mathbf{N},\ \mathbf{Kn},\ \mathbf{P},\ \mathbf{E},\ \mathbf{An},\ \mathbf{V},\ \mathbf{Kw}]^T$), and $\mathbf{u}$ is the vector of controls (which, in this case, is constituted by the government taxes—parameters τ). Further, considering stochastic external disturbances on economy and environment, $\boldsymbol{\epsilon}$ is the vector of white Gaussian noise, and H is a 9x9 matrix with the value 1 in the first, fifth, and ninth elements of the leading diagonal and zeros elsewhere.

For now, all the relevant relationships and main assumptions of the model have been discussed. It is incumbent upon the next sections to present the different development scenarios that can be generated, as well as their visual interpretation.

5 Development Scenarios and Simulation Framework

The implementation of the model using the MATLAB software permits the simulation to be undertaken in a convenient and interactive environment. In this section, the different development paths that the model can endure and the overall simulation framework are presented, so the visual simulation of the model can be captured.

5.1 The Basic Model Scenarios

For all development scenarios, the economy, Y, the population, N, the pollution output, P, and adult illiteracy index, An, are initially at unity. The stock of natural capital, Kn, and services capital, Ks, are at 0.98 and 0.95, respectively, giving a near undiminished stock and labor market producing capacity. The introduced school enrollment starts at 0.7, and the initial crude rate of violent crimes is set to 40. This results in the following initial state variables vector $\mathbf{x}_0 = [1,\ 0.95,\ 1,\ 0.98,\ 1,\ 0.7,\ 1,\ 40,\ 1]^T$.

From this initial position, the state trajectories evolve. A long-time horizon is used to show the effects upon future generations. Depending on specific parameter values, states of the model evolve to diverse situations. The following development scenarios are generated by differing values of the parameters χ, κ, and ω, in all aspects of the model.

5.1.1 Dream

Under this scenario, all appears well in the model. Using the parameters of Tables 2, 3, 4, 5, 6 and 7, Fig. 2 shows how the economy grows exponentially, and pollution output rapidly falls. The recovery of natural and services capital is much faster than in other scenarios.

Table 2 Parameter values in economy (for the dream scenario)

Parameter	Value	Parameter	Value
γ	0.04	κ_s	2
η	0.04	ϵ_s	1
λ_n	2	ϕ_w	0.7
λ_s	2	δ_s	1
γ_n	0.05	ρ_s	0.2
γ_s	0.05	ω_s	0.1
ϕ_s	0.6	–	–

Table 3 Parameter values in demography (for the dream scenario)

Parameter	Value	Parameter	Value
β_0	40	α_2	0.09
β_1	1.375	α_3	1
β_2	0.08	α_4	2
β_3	-0.2	α_5	0.1
α_0	10	θ_1	10
α_1	2.5	θ_2	15

Table 4 Parameter values in environment (for the dream scenario)

Parameter	Value	Parameter	Value
κ_n	1	ϕ_n	0.5
ϵ	0.02	μ_p	2
δ_n	1	τ_p	0.00
ρ_n	0.2	χ_p	0.96
ω_n	0.1	–	–

Table 5 Parameter values in education (for the dream scenario)

Parameter	Value	Parameter	Value
κ_e	1	ω_v	0.005
ϵ_e	0.02	Δ_e	0.2
δ_e	1	G	0.7
ϕ_e	0.2	Ic	50
ρ_e	0.2	μ_e	4
ω_e	0.5	τ_s	0.00
ω_s	1	χ_e	0.95

Table 6 Parameter values in public health (for the dream scenario)

Parameter	Value	Parameter	Value
κ_w	1	ϕ_w	0.5
ϵ_w	0.02	μ_w	2
δ_w	1	ϕ_d	0.5
ρ_w	0.2	μ_d	2
ω_w	0.5	–	–

Table 7 values in public safety (for the dream scenario)

Parameter	Value	Parameter	Value
α_{v0}	30	θ_v	5
α_{v1}	1	γ	1
α_{v2}	0.001	ϕ_v	0.05
α_{v3}	2	μ_v	2

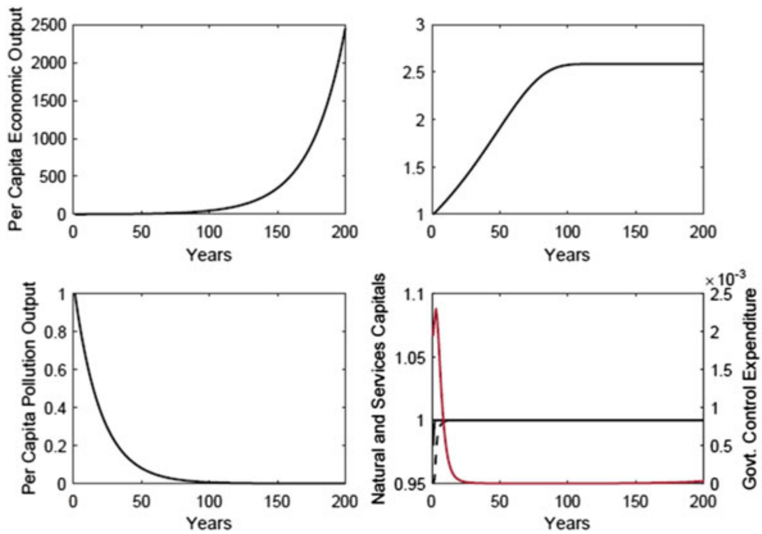

Fig. 2 Development of different aspects of the model on the dream scenario. In this graph, dashed and red lines correspond to services capital and government expenditure on control measures, respectively

5.1.2 Horror

At least two horror scenarios can be generated. Originally, the model could be brought to the point of collapse of the economy, population, and environment by adjusting the rate at which the per unit pollution output falls. This condition leads to the depletion of the natural capital and is hereon addressed as the environmental collapse scenario.

Additionally, the depletion of the services capital can also expose the model to a collapse of the economy, representing the exhaustion of the producing infrastructures and lack of sufficient healthy, safe, and educated workers. This scenario is hereon addressed as the labor force collapse. Both scenarios are described below.

Environmental collapse: This scenario is set by adjusting the parameter χ in (13) such that the rate of pollution per unit output falls naturally by 1% per year ($\chi_p = 0.99$). Continued economic and population growth, while nature itself is unable to assimilate the pollution flow, leads to the depletion of the natural capital. At this point, the economic output is hindered, and the costs of pollution control measures reduce the net per capita income, the crude birth, and death rates, thus cascading into the other aspects of the model.

Labor force collapse: The only difference between this and the dream scenario is that χ in (19) is set to 0.99; and ω_e, to unity. The first represents a reduction in the continuous decreasing rate of the number of illiterate adults. The latter, an increase in the influence of illiterate adults in the labor force output. The economy is hindered as the capital natural is depleted. This reflects the system's inability to produce goods and generate income.

5.1.3 Escape

This scenario differs from the horror scenarios through the variation of some parameters that may represent the deployment of government control actions. Changes on parameters χ, ω, and κ are the target of this subsection. Since two horror scenarios were discussed, at least one escape scenario can be proposed for each one.

Escape from environmental collapse: This is the same as the environmental collapse horror scenario except for that κ, the effectiveness of the economy's pollution control measures in (10) surpasses a 100-fold increase ($Kn = 100$). This represents a robust increase in pollution control measures effectiveness. However, it is not enough to halt the collapse in the stock of natural capital completely, and it does rebound back quickly, producing cycles in population growth and per capita output growth. The development path regarding this scenario is shown in Fig. 3.

The slower reduction of pollution output drives the natural capital to a collapsing state, no more capable of regenerating itself. As shown in Fig. 3, after almost 70 years of apparent sustainable development, the economy and population are dramatically affected. The services capital also breaks, resulting in the system's inability to provide goods and services.

The government expenditure on the last graph has an important dynamic. The sudden peak after the collapse is a result of an anticyclical investment policy, a

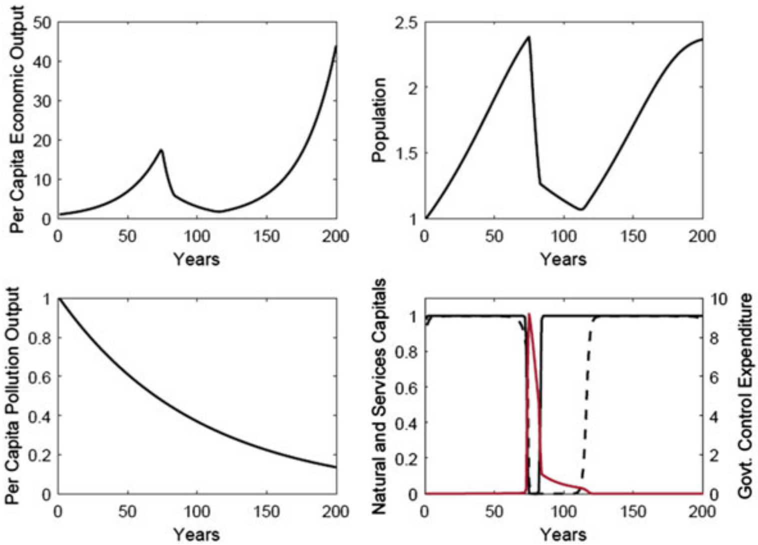

Fig. 3 Model development on the environmental escape scenario. In this graph, solid, dashed, and red lines correspond to natural capital, services capital, and government expenditure on control measures, respectively

common practice of a government on spending and taxation policies in developing countries (Ocampo, 2003). High expenses greatly reduce the household per capita income, as stated in (3). This causes the population to decrease. After a short period, the natural capital collapse resolves, and the recuperation of services capital does not occur instantaneously. Only when the latter is restored. The model turns back to apparent prosperity.

Escape from labor force collapse: This scenario is the same as the labor force collapse horror scenario, except that the parameter ω, the impact of analphabetism on services capital through labor force, in (6), has been doubled. Also, parameters δ and μ, positive integers that help the services capital variable to maintain its value toward unity—that indicate the ability of the services capital to maintain the infrastructure and capacity to provide goods and services, are reduced. This scenario shows the resilience of population growth even during longer periods of economic chaos. This scenario is depicted in Fig. 4.

Despite the collapse of services capital, the natural capital stock is not compromised. The anticyclical recovery policy of the model through government expenditure is present again, promoting oscillations in the model response. Similar cyclic behaviors can be observed on data from developing countries (Ocampo, 2003) but are here exaggerated to represent a chaotic situation for the population, that must be avoided at all costs.

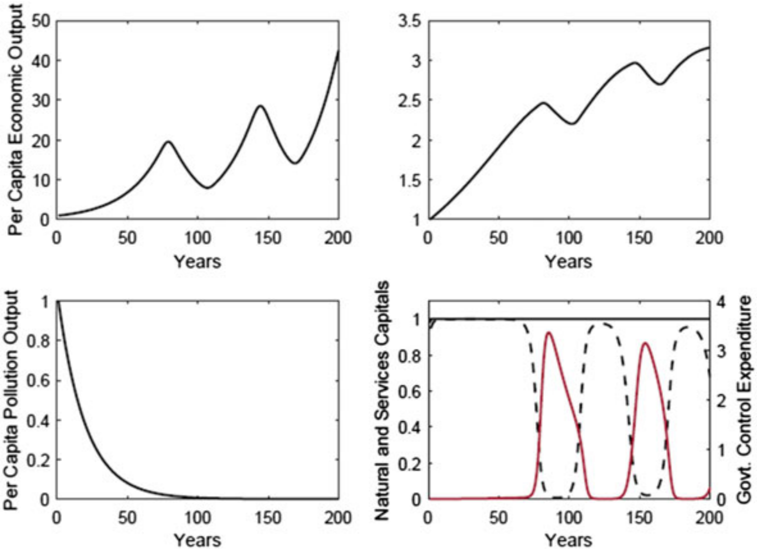

Fig. 4 Model development on the escape from labor force collapse. In this graph, solid, dashed, and red lines correspond to natural capital, services capital, and government expenditure on control measures, respectively

Model with taxation: Suppose several governmental taxes are introduced in the model to reduce pollution and hone public education, health, and safety systems efficiencies. Equations (10) through (27) present parameters τ that represent the rate of governmental taxes.

It has been assumed that the effect of these taxes on economic per capita output is a scale factor (proportional to parameters γ_0) of parameters τ, as shown in (1). Further, the model with taxation may also be considered an Escape model since with the sole introduction of governmental taxes the consequences of the horror scenarios are minimized or even extinguished.

5.2 *Expected Model Limitations*

The authors are aware that a myriad of factors could be incremented in the model (e.g., microeconomics, population density, longevity, migration, diversity of economic activities, the spread of diseases and vectors, trades of economics resources or products between regions or external entities and so on). However, only the most frequent ones described in the references were considered.

Similar to the observations made for the original Wonderland model, its extensions proposed here should only be considered as a qualitative analysis tool. Also, the correlation between system variables should be studied, modeled, and validated in further studies through real statistical data. In addition, the causal loop diagram in Fig. 1, although being a strong visual component that helps to clarify the complex structure of the model and poverty traps, hinders the interpretation of specific loops and associations. This could result in some ambiguities and misunderstandings for readers.

The reader should notice that the discussion on the philosophy of engineering of Chap. 3, confirmed by the normative design presented in Chap. 4, poses a complexity that may turn this model limited. In this sense, people may react in so many different ways according to their interaction with their environment. Thus, one cannot guarantee that an improvement in income will result in favoring private schools. The opposite may occur if this financial gain comes along with a policy that values public services in a general manner. Another aspect overlooked by the model regards the role of social organizations, especially the church. Religious organizations tend to propose some patterns of behavior that impact the way people organize their lives. This affects the use of contraception to deniability of a pandemic, for example. The effects of both examples may create positive or catastrophic consequences to society, and this is not modeled here.

6 Results and Discussion

In this section, we evaluate the proposed dynamic model described in the previous sections through a case study involving the Brazilian federal state of Minas Gerais.

6.1 Case Study

Minas Gerais is ranked as the fourth largest state by area in Brazil, the second-most populous, and the third by gross domestic product (GDP). The interest in the region is because this large landlocked state is subdivided into twelve mesoregions that present unequal regional development; and diverse social, economic, and environmental characteristics (Pereira and Hespanhol, 2015).

The Brazilian Institute of Geography and Statistics (IBGE) provides sufficient statistical data to set the initial conditions of the variables of the model, i.e., the actual size of the population; GDP; school enrollment rates; and others (Brazilian Institute of Geography and Statistics, 2012a, 2012b, 2012c). To adapt the data into the model, variable values were adjusted in the per unit (p.u.) system, so that the maximum value within each set of data is the base value. Table 8 provides the values for each mesoregion of Minas Gerais.

Region 4 concentrates most of the population and GDP per capita of the state. There are regions that, despite the rather small population, the GDP is above average, such as Regions 1, 2, 5, 7, 8, and 9. Regions 11 and 12 are at the average of both indexes, while Regions 3, 6, and 10 are below it.

Table 8 Set of initial conditions of the case study

Mesoregions	*Y*	*Ks*	*N*	*Kn*	*P*	*E*	*An*	*Kw*
1. Vertentes Region	0.48	0.95	0.09	0.98	1.00	0.98	0.93	0.87
2. Central Region	0.52	0.95	0.07	0.98	1.00	0.99	0.90	0.83
3. Jequitinhonha Valley	0.25	0.95	0.11	0.98	1.00	0.98	0.89	0.77
4. Metropolitan Region	0.95	0.95	1.00	0.98	1.00	0.98	0.96	0.96
5. Northwest Region	0.76	0.95	0.06	0.98	1.00	0.97	0.91	0.79
6. North Region	0.35	0.95	0.26	0.98	1.00	0.98	0.88	0.93
7. West Region	0.57	0.95	0.15	0.98	1.00	0.99	0.96	0.90
8. South and Southwest Regions	0.69	0.95	0.39	0.98	1.00	0.98	0.94	0.98
9. Triangle e Upper Parnaíba River	1.00	0.95	0.35	0.98	1.00	0.98	0.95	0.98
10. Mucuri Valley	0.31	0.95	0.06	0.98	1.00	0.97	0.81	0.77
11. Doce River Valley	0.47	0.95	0.26	0.98	1.00	0.97	0.89	0.93
12. Mata Region	0.47	0.95	0.35	0.98	1.00	0.98	0.95	0.94

Other indexes, such as the adult illiteracy, An; and the access to safe water, Kw, reflect the reality of these regions and, if no interventions are considered, it is expected to aggravate regional poverty, accentuating the differences between each mesoregion. As stated in (Pereira and Hespanhol, 2015), these differences are due to historical and environmental facts. Central and southwest areas concentrate most of the industrial and mechanized farming production, while the north and northeast suffer from long dry periods and low regional development.

To confront income inequality, the government and regional municipalities often institute incentives for the installation of industries and support of small agricultural producers. These policies may increase the number of available workplaces and are adjusted into the model as a step increase on per capita income and further effects on services capital, per capita economic output, and other variables.

It is considered that, through taxes, the government is capable of maintaining efficient public education, health, and safety infrastructures, which may result in the reduction of the income threshold for household savings, as discussed in (4). One of the effects of increased income and savings is observed in the model as more households invest in their offspring's education. Finally, temporary monetary aid is also considered a viable intervention. Again, this is modeled into the proposed equations as a step increase in household income.

6.2 Model Deployment

Information from Table 8 is implemented on the model. Figure 5 shows the per capita economic output for each region, on a color scale. At the initial time, no government taxes or interventions are employed.

Figure 5a represents the starting conditions of the model. Initially, most of the GDP per capita is concentrated on the central and southwest regions, and after 100 years, the regional differences between each area are aggravated, as shown in Fig. 5b. Some of the areas that started at high economic output continued to do so, while others have stagnated or even decreased.

Region 4 is expected to present such prosperous development since it started with the overall best economic, social, and demographic indexes. On the opposing direction—despite the above-average economic output of 5—Regions 2, 5, and 10 have decreased economic output. This occurred because they present small populations and starting indicators of school enrollment and access to safe water and sanitation below average, and relative high adult illiteracy index. As described in Sect. 3, poverty trap theories have considered these variables as evidence of regional poverty and also the proposed model.

Aiming to eradicate poverty and alleviate the internal differences of economic development within the state of Minas Gerais, the implementation of government taxes and control actions are considered next. Taxes in the context of the proposed model, as described in Sect. 5, represent government efforts to increase the effectiveness of control actions against pollution output, and in favor of school enrollment, the response against criminal activity and effectiveness of health services and basic sanitation.

The remaining regions, although not deviating from the dream scenario and presenting exponentially increasing economic output, are also targeted for these policies to accelerate economic development. Hereon government taxes with $\tau = 0.15$ on the environment, education, public safety, and health are considered. Figure 6 concludes the results of this case study. No stochastic external disturbances were considered.

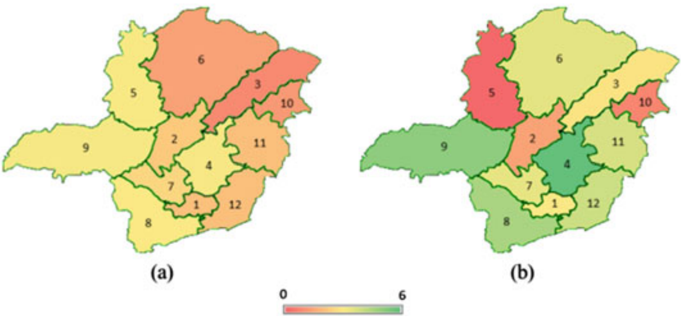

Fig. 5 Development of the case study: **a** initial per capita economic output and its distribution after **b** 100 years

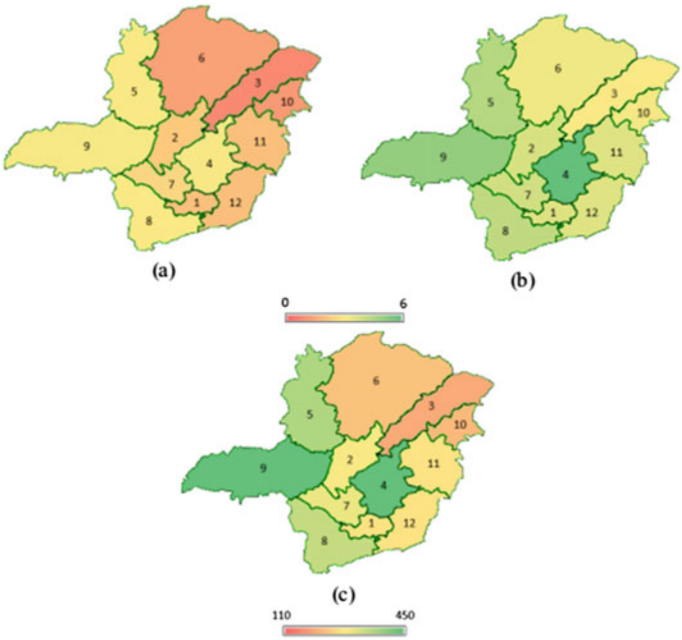

Fig. 6 Development of the case study: **a** initial per capita economic output and its distribution after **b** 100 and **c** 200 years

The inclusion of government taxes mitigates the economic performance of regions that previously were set to decrease or to a slow increase in the economic output. After 100 years, Fig. 6b shows the development of the model. Note the difference between this and 6b. Here, Regions 2, 5, and 10 were driven out of the collapsing scenario and prospers. In Fig. 6c, it is possible to infer that after 200 years all mesoregions prospered. The regional economic disparities were alleviated through the inclusion of government expenses that increase public services' effectiveness. However, despite the significant growth in per capita economic output, they still exist.

7 Conclusion

This chapter proposed a multi-aspect dynamic system model to assess poverty traps based on an extension of the Wonderland model. Equations and parameters that model poverty and its regional development were chosen based on several poverty trap theories and the goals and targets of the 2030 United Nations agenda for sustainable development. Further fieldwork is necessary to validate this model. However, there is sufficient evidence indicating the urgency of taking action against poverty and its self-reinforcing behaviors. The case study involving the Brazilian federal state of Minas Gerais showed that it is possible to alleviate poverty in such a culturally, economically, and environmentally diverse state through government policies and long-term interventions.

Future work includes the consideration of a broader set of variables and parameters, to improve the range and effectiveness of the proposed model and its validation with real data and historical trends. Models could additionally include specific models of the public school system itself, to assess whether good quality public schools are provided to low-income families.

Finally, according to existing literature, the dynamic systems theory constitutes a strong background for the modeling of social behaviors, violence, economy, and other aspects. Here, the proposed model aggregates several of these factors into a single set of differential and algebraic equations. After discussing many of these factors, a general insight gained from such complex modeling of sustainable development, poverty traps, and other aspects is that control actions and interventions should be targeted with careful consideration to people in poverty. For that, systemic analysis and tools, such as the ones presented in this chapter, are essential to inform public policy, because, in the absence of careful policy assessment and changes, more people could inadvertently be driven into deeper poverty traps.

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Microgrid Operation and the Social Impact of Its Deployment

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Keywords Microgrid · Rural areas · Social dimensions

1 Introduction

The growth of the application dispersed energy resources (DERs)—which is a diverse definition that includes both energy storage systems (ESSs) and distributed generators (DGs), with an emphasis on those based on renewable energy sources (RESs)—and the corresponding use of highly efficient control systems for DERs are fostering a growing presence of the microgrid topology in distribution systems. The concept of a microgrid emerges as an evolution of the conventional grids, closely tied to the idea of active distribution grids (ADNs) and allowing a more flexible operation of DERs due to an increased level of automation of the distribution grids.

Although there are several definitions present in the literature, one of the most accepted ones is given by the US Department of Energy (DOE) by the Microgrid Exchange Group: "A microgrid is a group of interconnected loads and distributed

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energy resources within clearly defined electrical boundaries that acts as a single controllable entity concerning the grid. A microgrid can connect and disconnect from the grid to enable it to operate in either grid-connected or islanded mode."

Based on this definition, some characteristics must be present in a microgrid (Parhizi et al., 2015):

1. The electrical boundaries must be clearly defined;
2. A master controller must control the operation of DERs and loads as a single controllable entity, and;
3. The local installed generation capacity must exceed the peak critical load to enable its operation disconnected from the utility grid.

The DG units can be separated into two main classes: dispatchable and non-dispatchable. The first one can have its power output controlled by the microgrid master controller according to its limits based on the following parameters: nominal capacity, ramping limits, minimum on/off required times, stored primary energy, and even emission constraints for the fossil-based sources. On the other hand, non-dispatchable units typically operate as uncontrolled active power sources. Solar and wind generators are examples of non-dispatchable units, due to their intermittent nature.

There are also two sorts of microgrid loads: fixed and flexible. Fixed loads must be fully supplied under normal operating conditions as they cannot be adjusted by the master controller. Usually, critical loads, like hospitals or factories with sensitive production lines, belong to this class. The flexible loads (also called adjustable or responsive loads), comprise the curtailable loads and shiftable loads that are responsive to control signals from the master control and can be adjusted to help the system to reach its balance between supply and demand.

Due to a high level of penetration of RESs with intermittent nature, the maintenance of stability in a microgrid can be a challenging task. Therefore, ESSs can be fundamental actors to increase the stability and reliability of these systems and to reduce power curtailments (Gao, 2015), which are unwanted since the main objective of an electrical system is to adequately supply its load demand. The most common types of ESSs are the battery energy storage systems (BESSs) and the flywheel energy storage systems (FESSs).

Currently, the main drawbacks of BESSs are the relatively low capacity of charging/discharging of batteries within their life cycles and their high implementation costs (the latter being valid also for FESSs), making the financial viability of these systems a severe constraint. Such barriers can greatly impact the pace of development of microgrids. Therefore, many researchers are working to overcome these limitations. Hybrid energy storage systems (HESSs), which combine two or more ways of storing electricity, are considered by many researchers as a solution to increase the life expectancy of batteries (Faisal et al., 2018). Furthermore, due to the steady growth in the production of these systems, its manufacturing processes are being optimized, and the cost of the raw materials has decreased. These facts are making the prices of ESSs go down over the years (Nykvist & Nilsson, 2015).

As previously seen, a microgrid must be capable of disconnecting from the main grid. The point where a microgrid is connected to the main grid is referred to as the point of common coupling (PCC). Two scenarios are possible for this disconnection (Vasquez et al., 2010):

1. **Preplanned islanded operation**: If the power quality delivered from the main grid is low, due to events such as long-time voltage dips or faults in general, among others, islanded operation must be started;
2. **Nonplanned islanded operation**: If there is a de-energization at the PCC, the microgrid should be able to detect it and change its operational mode to maintain its operation in an acceptable condition.

In a preplanned microgrid disconnection, previous modifications in the local generation profile of the microgrid can be made to minimize the imbalance between inner levels of supply and demand, resulting in a smooth disconnection transient. However, in an unplanned disconnection, the balance between the inner levels of load and generation at the moment of the disconnection and the islanding detection time define the severity of the transient (Lopes et al., 2006). When connected to the main grid, the DGs usually act as constant power sources and, after the disconnection, voltage and frequency regulation must be provided by them (which means their output power can no longer be constant).

Under islanded conditions, the low inertia due to the reduced presence of synchronous generators, and the inverter-based generators in the grid-connected mode injecting constant power at the grid can lead to a power imbalance. Such a power imbalance in the islanding process can be the root cause of the instability of the microgrid. Therefore, energy storage units and controllable loads are fundamental to improve the power balance, as they usually present a fast dynamic response.

During grid-connected operation, the microgrid can import/export power from/to main grid. Therefore, the microgrid must be capable of establishing a bidirectional power flow at the PCC. However, traditional overcurrent protection schemes and voltage control devices (for instance, on-load tap changing transformers) assume unidirectional power flow. In this context, these schemes are inefficient to protect microgrids considering diverse fault scenarios or control their voltage levels at different operating points (Ramamoorty & Venkata Naga Lakshmi Lalitha, 2019). Thus, the replacement of equipment originally designed for passive and traditional distribution grids (and its associated cost) constitutes another challenge to the growing implementation of microgrid topologies.

In some cases after the clearing of a fault event that results in an islanded operation condition, the microgrid must be reconnected to the main grid. The successful reconnection depends on the resynchronization capacity at the PCC. An out-of-phase reclosing can lead to oscillations in the power system and potential damage to equipment, depending on the differences in the values of frequency, voltage, and phase at the instant of reclosing.

As several components of a microgrid are often based on power electronic converters, the synchronization process is different when compared to the conventional power systems that use the quasi-synchronism control for such a task (Tang et al., 2015). One challenging point is that, for synchronization, voltage, frequency, and phase must be adjusted through the control of several DG units in a coordinated way, which can require a high-speed communication infrastructure (Lidula & Rajapakse, 2014). Therefore, one key point is to reduce the amount of data required in the resynchronization control in order to reduce communication dependency, enhancing the viability and safety during the synchronization process.

Sometimes, a failure in a smooth transition from grid-connected mode to islanded mode or a disturbance during islanded operation can result in the microgrid outage. Therefore, the microgrid must be capable of restoring the electric power without relying on an external electric power system, and this process is called black start. For the restoring process, the system must have enough startup power capacity and some communication infrastructure available.

In a microgrid, due to diverse technologies coupled in a dispersed way, the black start process has unique characteristics. A hierarchical sequence of actions including the distributed generators and storage devices must be elaborated and adequately coordinated. Once again, although a high-speed communication infrastructure is required, its topology must be carefully planned to minimize costs and ensure reliability (Cai et al., 2011).

The success of the transition process from conventional distribution systems to microgrids highly depends on technical solutions for the broad range of engineering challenges highlighted above. However, this process also entails human aspects as people are involved in many levels of the development, implementation, management, and maintenance. Furthermore, the end-user habits are also influenced in this transition, what can create support or resistance to the process. As a result, the individual characteristics of the community must be also considered, as the requirements for urban and rural areas are quite different. In this context, Sect. 2 addresses the de-social impacts and cultural aspects of microgrids.

2 Social Aspects and Impacts of Microgrids

The understanding that people do not consume commercial energy directly, but rather the energy services provided by energy availability, allows us to better link energy access and social welfare. Commercial energy is embedded in all goods and services of modern society and is consumed indirectly even for those that do not have access to an energy supply to afford their basic needs (Haas et al., 2008). Some examples of energy services consumed by people are lighting, food refrigeration, conditioned living spaces, ommunication devices, among others. It is imperative to establish a strong relationship between access to energy services and life quality. Indeed, even clean water consumption and basic sanitation are related to minimal access to energy services.

The level of access to energy services does not depend only on a reliable energy supply, but also on the energy cost, the efficiency of the conversion of the energy into services, and the cost of the devices that require energy to provide the service.

Although most existing indicators and composite indices of societal development focus on access to energy or the degree of development related to energy, some recent methodologies are focused on indicators based on the lack of access to modern energy services (Nussbaumer et al., 2012).

Energy systems can be defined as socio-technological systems that involve not only mechanical, electrical, and electronic devices, but also the humans who participate in the technological development process, work in the implementation, maintenance, and management of energy systems, and mainly use and consume energy. Also, energy systems include a wide range of complementary institutions as financial networks, workforces and the schools necessary to train them, institutions for trading in energy, roads, regulatory commissions, land-use rules, city neighborhoods, and companies as well as social norms and values that assure their proper functioning (Miller et al., 2013).

Therefore, when considering the energy systems expansion and technological transitions, it is important to consider the socio-technological aspects that are commonly neglected in the traditional analytical approaches. Such aspects include (Miller et al., 2013):

1. The social processes that can stimulate and manage energy transformation;
2. The social changes that derive from progress in energy technologies, and;
3. The social outcomes from the organization and operation of novel energy systems.

Among the multiple social aspects involved in the supply of energy through microgrids, the perception of the end-users at several stages, starting from the project publicizing, going through the implementation, and finishing with the use of the system. The implementation of microgrids can impact different aspects of the lives of the consumers, depending on the project. As an example, for some rural communities, these projects can be the only way to provide electricity access. For other types of communities, it can increase energy availability as well as power quality. In industrialized sites, microgrids can improve system efficiency, reduce the price of energy, and promote sustainability by giving preference to the dispatch of DGs units based on renewable energy sources.

To understand the social belief system that affects the responses to technological changes, including objections and resistance, support and adoption, apathy, disinterest, and disengagement, is not only important to understand the crucial role held by social actors (e.g., policymakers, journalists, community leaders) but also to consider political, economic, socio-cultural and geographical factors into account (Devine-Wright et al., 2017).

Considering that acceptance is a multidimensional problem, including the socio-political, communal, and financial dimensions, some key factors are decisive for investors and users to embrace new technologies (particularly, in this case, the ones related to renewable energy) (Sovacool & Lakshmi Ratan, 2012):

1. Strong institutional capacity;
2. Political commitment;

3. Favorable legal and regulatory frameworks;
4. Competitive installation and/or production costs;
5. Mechanisms for information and feedback;
6. Broad access to financing;
7. Prolific community and/or individual ownership and use;
8. Participatory project siting, and;
9. Recognition of externalities or positive public image.

Due to the lack of energy services, the social impacts of the microgrid implementation can be quite different in urban and rural areas. Considering rural areas, the microgrid is mostly related to the first access of the community to a reliable energy power supply and also to its access to basic energy services such as clean water pumping and food refrigeration, for example. On the other hand, in urban areas, the transition from conventional grids to microgrids can promote a reduction in energy costs, allowing low-income individuals and families to fulfill their basic energy needs. Furthermore, microgrids in urban areas can also convert the traditional consumers into prosumers (consumers that also produce energy), which gives rise to a new paradigm of energy production that brings the end-user closer to the operational utility context.

2.1 Microgrids in Rural Areas

Recent surveys estimate that around 900 million people have gained access to electricity in developing economies in Asia since 2000. In the same period, in sub-Saharan Africa, the electrification process reached around 200 million people. Despite this remarkable progress, around 1 billion people still do not have access to electricity worldwide. Remote areas of sub-Saharan Africa, Southeast Asia, and South America are the ones most affected by this problem (International Energy Agency, 2018). The remoteness of such communities surpasses the limits of the expansion capability of the centralized energy systems. In such cases, decentralized solutions such as hybrid microgrids are the most viable alternatives (Mandelli et al., 2016).

Electricity access has a positive impact on education, health, and employment, for example, along with other derived benefits from the access to energy (e.g., impacts on gender equality through education). Furthermore, there is no need for these benefits to be gained at the expense of augmenting the carbon footprint of the respective community if renewable and sustainable energy sources are employed to provide electricity access. However, it cannot be taken for granted that the benefits of maintaining a low-carbon footprint will be fully understood by the respective community. For this reason, social perception can directly influence the development and implementation of microgrid projects, delaying or even halting the transition from the conventional grid to this new paradigm (Alvial-Palavicino et al., 2011).

The lack of electricity is more common in rural areas and exacerbates the poverty of these regions. Although there is no unique definition for rural areas, in a general sense, they are characterized by non-urbanized regions with low population density. This term can be applied to most of the regions in the world and can vary depending on the country, being characterized by high portions of land devoted to agriculture or vast arid regions, for example. In these regions, access to electricity can improve the quality of life by increasing the level of health, education, and welfare. In order to stimulate the development of these regions, there are different implemented policies to improve access to electricity services in countries with lower access to electricity, especially in the rural areas, and part of them relies on the exploitation of renewable sources (Javadi et al., 2013; López-González et al., 2019; Veilleux et al., 2020).

The use of the social value of electrification is proposed in Miller et al. Jan. (2015). The authors suggest that the assessment of the social value of electrification projects would create a positive feedback loop, giving community engagement for these initiatives and, thus, resulting in measurable values for communities, companies, and governments to justify energy investments. For this purpose, the social value of energy is defined in terms of the total value derived by an individual or community from the use of energy, including economic and other forms of value, minus any risks or burdens due to energy production, transmission, and consumption. This definition enables the evaluation of whether projects are worth investing in by comparing the social value of energy projects to their costs. This is especially significant in contexts such as off-grid or renewable energy projects that may have higher energy costs. The social value of electrification projects also allows evaluating the socio-technical design of energy projects to determine whether the project will deliver the kinds of energy services, via appropriate strategies, that enhance social value.

Social factors may be a key cause of the failure of rural electrification projects based on renewable energy, as discussed in García and Bartolomé (2010). The authors pointed out that, typically, users experience improved living conditions after the installation and launch of new projects, which resulted in an initial positive perception related to the project. However, unexpected failures, which are intrinsic to any electrical system but are not predictable, may lead to user dissatisfaction in the longer term. In some cases, instead of resulting in engagement to solve the problems, the project may be abandoned due to this long-term negative perception. Thus, the failures are sometimes blamed on the poor use of technology. Nevertheless, the project ignored the complex relationships established between technology and its new users.

As discussed in García and Bartolomé (2010), some analysts argue that new technologies introduced in a social and cultural context that is quite different from the in which they were produced may generate an incompatibility in its use. Thus, according to the authors, the main aspects to be considered in a project are the assessment of the need for electric power, selection of technical options, performance evaluation after the project is installed, economic costs, and forms of participation. In these aspects, it is important to consider factors like the socio-cultural circumstances of the future consumers, the level of homogeneity and social cohesion of the community, and the expectations of the end-users. When these factors are taken into consideration, it is easier to understand why a system is not accepted. The authors present some examples of electrification projects for which particular social-technical solutions would increase the likelihood of successful results. As a conclusion, for rural electrification areas, they recommend that a social evaluation needs to be performed, exploring social habits, cultural attitudes, and the networks of social relationships and behaviors in the community.

Keeping the previously mentioned factors in mind, it is possible to analyze the social impact of microgrids as potential solutions to rural electrification. In Kirubi et al. (2009), the analysis of a case study of a microgrid is conducted to quantify the effect on social and business services in a community, leading to a consistent rural development process. In this survey, the following areas were pointed out as the most positively affected by electrification:

- Small and microenterprises;
- Agriculture;
- Banking and communication, and;
- Education services.

In Kirubi et al. (2009), it is also shown that when electricity consumption is closely linked to productive applications, increasing productivity and producing growth in revenues, higher social and economic benefits are achieved. Besides, in this case, the local electricity users have the ability to charge and enforce cost-reflective tariffs, making it feasible to recover the cost of investments in the microgrid establishment feasible in an acceptable time frame.

2.1.1 Main Social Dimensions of Electrification in Rural Areas

Considering human capability as what people are effectively able to do and be or the positive freedoms that people have enjoy valuable beings and doings and defining being and doings a group of things that makes a life valuable, technological advances address important inputs for the expansion of human capabilities. Electricity is a necessary resource for the most part of modern technologies, therefore, is closed linked to the expansion of such capabilities (Oosterlaken & van den Hoven, 2012). Although, the lack of electricity supply in rural areas is still today a limiting factor for the human development. The lack of electric lighting, food refrigeration, and communication and entertainment provided by electrical devices can sound a quite distant reality that belongs to ancient times, although in rural areas, mainly in poor countries, people still live the way life used to be one hundred year later.

The evaluation of the impact of electrification in rural areas is quite complex. Therefore, understanding the relationship between energy access and socio-economic development indicators involves the same complexity. On the other hand, understanding such impacts is fundamental to define electrification policies, projects to meet future demand expansions, and the required investments over time.

Health, education, habits, living, and social networking are the main social dimensions of local development influenced by the electrification process. Each of these social dimensions is analyzed in sequence.

Health

A larger offer of household, jobs, and healthcare can directly lead the community to an improved overall health condition. Some of these factors are addressed below (Riva et al., 2018; Spalding-Fecher, 2005):

- The substitution of kerosene and paraffin for electric lighting, and the use of electric stoves and heaters rather than coal and wood for cooking and heating, can reduce household air pollution (which are linked to lung diseases and sight problems) and also avoid poisoning and burning;
- Electric fans can increase the comfort in the houses, at schools and in the workplaces, increasing the general welfare and, consequently, reducing the exposure to mental stress;
- Electric refrigerators can sustain the quality of food longer, preserving food from external contamination;
- Electricity can provide access to clean water, avoiding several diseases associated with contaminated water;
- The substitution of diesel generators can provide a healthier work environment enhancing the air quality and providing noise reduction, and;
- Access to a reliable electricity source can considerably improve the medical services offered by health centers and hospitals.

Indoor air pollution, strongly related to households without access to electricity, was appointed as the second risk factor to the regional and global burden of diseases and injuries in 1990, and the fourth risk factor in 2010, only surpassed by high blood pressure, tobacco smoking, and alcohol drinking (Lim et al., 2012).

A survey made in El Salvador has shown that the fine particulate concentration (a complex mixture of small particles and liquid droplets composed of potentially hundreds of chemicals) was on average 66% lower among households that were randomly encouraged to connect to the electrical grid, through the distribution of discount vouchers in the connection fees, compared to those that were not. Therefore, in the encouraged group, the prevalence of acute respiratory infections among children under six years old shows an 8–14% less incidence (Barron & Torero, 2017).

A 2013 survey, considering 11 countries in sub-Saharan Africa (with 6 of the 10 most populous countries in the region among them), showed that 26% of the healthcare facilities did not have access to electricity. Despite the relatively high level of facilities with electricity access, only 28% of all facilities had access to a reliable electric energy supply (8 of the 11 considered countries reported this data). Besides, a mean of 7% of the healthcare facilities relied on only one generator for electricity supply, ranging from an average of only 1% of facilities in Uganda and Zambia to 33% in the Gambia (9 of the 11 considered countries reported this data). Although the impact of the lack of reliable electricity supply in healthcare facilities, in terms of health, disability, and loss of life was not estimated, it is possible to presume that it was (and maybe still is) significant (Adair-Rohani et al., 2013).

Education

Education is a factor that is found to have a bidirectional causal relationship with energy access. In other words, energy access can increase schooling, and, in turn, education leads to human capital development, which helps to maintain and expand electrification projects. Furthermore, one key challenge in rural electrification projects is to provide sufficient local expertise for the operation and maintenance of the electric system (Zhang et al., 2018).

Some improvements provided by electrification in the educational process are given below:

- Electric lighting can extend study hours at home and allow evening and early morning classes at school, which can enhance the access to education as, in many underdeveloped regions, students need to work on the family business or to do housework during the day;
- Electricity allows the use of devices that can help in the learning process as computers, audiotapes, TVs, and radio;
- Fans can provide a more comfortable environment, enhancing the learning process, and;
- School electricity enhances staff retention, as teachers are reluctant to work in areas that lack basic facilities such as electricity, good housing, and healthcare. Also, electricity allows the use of information and communications technologies, which facilitates better teacher training (Sovacool & Ryan, 2016).

A case study in Madagascar showed that electrification allowed children to do their homework in the evening, helping mainly the girls that spent most of the time doing housework. In addition, parents (mostly mothers) spend all day long in housework, and electric lighting allows them to help their children with homework at night (Daka & Ballet, 2011).

A survey made in Philippines found that adults living in non-electrified households achieve only an elementary level of education, while those in electrified households manage to achieve a secondary level of schooling. On average, people living in electrified households attend school for 8.54 years and those without access to electricity attend school on average for 6.38 years, a difference of 33% (World Bank, 2002).

For an overview of the lack of electricity in schools in developing countries, some data from surveys available in the literature are given below:

- According to the Poor People's Energy Outlook 2013, considering the limited available data, it is possible to state that sub-Saharan Africa had the lowest rate of primary school with access to electricity. In this region, 90 million students attended school without electricity, which corresponded to 65% of the total of students in the region. In South Asia, 52% of the students had no access to schools supplied by electricity, which represents 94 million students. In Latin America, this number is about 4 million students, which means that around 7% of the students attended school without electricity (Action, 2013);
- According to a survey made by the UNESCO Institute for Statistics (UIS) and published in 2008, over one-half of students in India were in schools lacking

electricity. In Peru and Sri Lanka, 20% of the students were in the same situation. Considering Argentina, Brazil, India, Paraguay, Peru, the Philippines, and Sri Lanka, more than 10% of students did not have even access to running water in schools (Zhang et al., 2008), and;
- According to the 2020 edition of Tracking SDG 7: The Energy Progress Report, in 2018, a survey was made compiling data in public institutions in Cambodia, Ethiopia, Kenya, Myanmar, Nepal, and Niger. In these countries, 60% of the educational facilities had no access to electricity, 31% are electrified through an on-grid source, and 9% through off-grid systems (World Bank Custodian Agencies of Sustainable Development Goal (SDG), 2020).

Habits, living, and social networks

In addition to healthcare and educational facilities, several public institutions directly affect the functioning of a community and the well-being of its people. Such institutions provide a broad range of social services: organization and administration of government services and operations, promotion of security and safety for individuals and property, promotion of social, cultural, and spiritual health, and social care, for example. These institutions can also have their services improved and expanded by electrification and by the consequent access to electric lighting, ambient conditioning, information and communications technologies, etc. The institutions that provide social services can include (Action, 2013), for instance:

- Government administrative offices;
- Police stations;
- Religious buildings;
- Prisons;
- Community centers;
- Public libraries;
- Orphanages, and;
- Sports facilities.

The improvement in the social services can impact directly the social dynamics of a community, increasing the access to information, extending the duration of social events and public meetings, speeding up bureaucratic procedures, and fostering the practice of sports, for example.

One of the main impacts of electrification in the habits of people is to increase the duration of the active period of the day. People have the option to wake up earlier and/or go to bed later, extending the period that they can work, make domestic labor, or do leisure activities (Riva et al., 2018). Furthermore:

- Lighting is associated with an enhanced perception of security, allows evening market operations, seems to increase outdoor and/or indoor evening meetings and chats, and connectivity among people;
- Communication and connectivity range is enhanced to outside the local communities through the diffusion of television, radio, and mobile phones;

- Electric water pumps can substantially reduce the time spent collecting water, and;
- The use of electric devices can facilitate domestic labor.

As can be seen, the electrification process is not limited to provide people with a reliable electricity supply. Complementary policies are pointed out as the main factor for the long-term success of such initiatives. These policies insert people into a new culture where electricity is the main pillar that increases access to social services, living and working conditions, access to communication, and social well-being. Some examples of factors included in these complementary policies are the improvement of the economic conditions, access to finance, access to education, investment in public services and infrastructure, and supporting the participation of the private sector (Zhang et al., 2018).

Rural electrification has been identified as fundamental for socio-economic development. It is also directly related to improvements in health care through upgraded facilities and to an enhanced offer of employment (mainly among women), by enabling income-generating activities and augmenting rural productivity.

Once again, taking into account all the factors mentioned in the previous paragraphs, it is possible to infer that islanded microgrids are a promising alternative to fostering rural electrification and harvesting its analyzed benefits. In such regions, the low energy consumption does not attract new investments, which turns into poor service quality and reduced reliability. As a result, their main supply sources typically rely on diesel generation, installed as a backup generation, which in many situations can be used for long periods due to problems with the connection to the main grid. In this context, the use of small-scale renewable energy technologies associated with microgrids ensures a higher power quality level, being a viable option for the electrification of rural communities (Javadi et al., 2013). In the next section, a special type of microgrid, named mini-grid, largely applied in the electrification process of poor regions in developing countries, is addressed.

Mini-grids

Mini-grids are one of the most commonly applied solutions for rural electrification and play a fundamental role in accomplishing one of the main goals established on the Sustainable Energy for All Initiative (Agenda, 2012), which seeks to ensure universal access to modern energy services by 2030. According to Hartvigsson et al. (2018), mini-grids can be defined as:

> a form of integrated energy infrastructure with distributed energy generation resources and loads. They provide the autonomous capability to satisfy electricity demand through local generation, mainly from renewable energy sources. Renewable energy mini-grid systems can also include power storage appliances; smart meters and smart devices for control, management, and measurement; and power conversion equipment. Mini-grids can be either isolated and fully autonomous or connected to the main grid. Renewable-based mini-grids include generation capacity that can range from kilowatts (kW) to over 100 megawatts (MW).

Note that this definition largely overlaps the one of a microgrid, so the content of this part of the text is fully applicable to assess the impacts of microgrids for electrification of remote areas.

According to the World Bank's Energy Sector Management Assistance Program (ESMAP), at least 19,000 mini-grids are already installed worldwide, covering 134 countries and territories and providing electricity to around 47 million people, most of them in Africa and Asia (Hartvigsson et al., 2018).

The significant reduction in the costs of key components, such as solar panels, inverters, batteries, and smart meters, enhances the economic viability of the mini-grids. According to an ESPMAP survey in Africa and Asia, in 2010, the average value of the capital costs of a mini-grid was around \$8,000 per kilowatt of firm power output. In 2018, this value had been reduced to around \$3,900 per kilowatt of firm power output (ESMAP, 2019), which is a promising indicator.

Despite their potential, mini-grids in rural electrification have resulted in various levels of success according to their economic performance. Some inner characteristics of rural mini-grids, associated with inadequate policies can difficult the cost-recovering process. The main conditions that lead mini-grids to poor economic performance are (Hartvigsson et al., 2018):

1. Low customer electricity consumption;
2. High capital costs;
3. Low utilization factor;
4. Inappropriate tariff schemes;
5. Lack of promotion of productive uses of electricity;
6. Unreliable electricity supply, and;
7. Dispersed populations.

Also, mini-grids are often managed by local operators, which may suffer from weak financial performance. Therefore, mini-grids planning studies must not only focus on the reduction of the initial costs but also consider the risks associated with the long-term financial performance of the operator, reducing the necessity of subsidies. Indeed, most rural electrification projects do not focus on the recovery of investment costs, as they are largely or entirely funded by governments or international donors. In addition, the operational costs are hardly covered by the end-users. Therefore, rural tariffs are often highly cross-subsidized by urban consumers (Peters et al., 2019).

Together with the economic aspects, the assessment of the viability of rural mini-grids in the long run, their implementation, and the respective technological solutions employed must all be treated as an open process which goes far beyond technical learning. The long-term success is related to the way that the technologies become socially embedded, considering how the end-users perceive a technology to be useful and how the technology is inserted into social practices, values, and institutional settings (Russell & Williams, 2002; Ulsrud et al., 2011).

2.2 *Microgrids in Industrialized Areas*

It is impossible to understand life in contemporary cities without understand how technology contributes to it. The technology has already profoundly changed the way that urban environments are perceived and experienced. The everyday lives of urban dwellers are based on the use of technological devices and on the dependency of a reliable electricity source. Therefore, new urban technology solutions, and how they are defined, applied and used, change the everyday experience of dwellers, what impacts directly in behavior, habits, expectations, and preferences. Urban environments cannot be considered homogenous or stable, their diversity and fast pace of change are main characteristics that defines the urban habits. Such dynamic nature makes it difficult to understand how particular technologies affects the urban lifestyle and in what type of timeframe it occurs (Nagenborg et al., 2021).

While in rural areas, the main social impacts of the microgrids are mostly addressed concerning the benefits provided by the access to a reliable power supply, in urban areas, where power systems are much more developed, the social impacts are mainly addressed in terms of the accessibility to the energy they provide due to potential cost reduction and the cultural change imposed by the new regulations and by the end-user participation in the energy systems as a prosumer.

As previously mentioned, the lack of access to a reliable distribution system or energy source is not the only issue related to the electricity supply. Although industrialized locations have a reliable power supply, a portion of the population cannot fulfill all their energy needs, as the energy consumption can correspond to a large proportion of the monthly income of an individual or a family.

The term "fuel poverty" relates to individuals or families who technically have access to energy but cannot afford adequate levels to meet their basic needs (ESMAP, 2019). Any household spending more than 10% of its annual income on energy is considered in fuel poverty. This type of poverty is strongly associated with mental stress and exposure to inadequate environmental conditions, with direct impacts on health and wellbeing. According to the Annual Fuel Poverty Statistics in England-2020, drafted by the UK Department for Business, Energy & Industrial Strategy, in 2018, 10.3 percent of households in England (2.4 million households) were classified as fuel poor (BEIS, 2020).

Fuel poverty seems to have different dynamics in rural and urban areas. A study in the UK showed that the average rural fuel poor appears to have a direct relationship with the energy price. In contrast, people living in urban areas present a higher probability of fuel poverty persistence, with this condition lasting longer (Roberts et al., 2015).

Microgrid market policies can establish an internal "over-the-grid" energy market within themselves. In these local energy markets, it may be possible for some microsource units to sell at higher prices compared to the wholesale one, while some end consumers may be able to buy at prices lower than the retail one (Operation et al., 2014). In addition, microgrids can provide diversified energy services with different costs that can fit the energy needs of each economic and social reality (Martínez-Cid &

Table 1 Benefits of microgids (Martínez-Cid & O'Neill-Carrillo, 2010)

Benefits for customers	Benefits for utilities
Increased reliability	Loss reduction
Increased power quality	Increased system capacity
Reduced outages	Provide reactive support
More efficient use of energy	Improved voltage profile
Lower energy cost	Reduce expansion investments
Incentive renewable energy	Fault reduction
Reduce emissions	Improves customer-utility relationship
Diversified energy services	

O'Neill-Carrillo, 2010). Such market policies, associated with financial support to provide end-user affordability of energy, can be effective and sustain social policies to address energy inclusion (Morris et al., 2007).

Since energy is a key aspect for community development, for the assessment of the impact in economy and life quality, the main benefits of a transition from the conventional grid to a multi-microgrid paradigm must be evaluated considering all agents involved, which in this case include the customers and utilities, considering benefits such as the ones shown in Table 1.

Microgrids have also proved to have remarkable resilience to natural disasters, being able to continuously supply power to essential loads under atypical conditions or to restore the supply quicker than bulk power systems (due to faster black-start processes that involve a smaller number of actions). During the 2011 great east Japan earthquake and tsunami, the Roppongi Hills (RHM) and Sendai (SM) microgrids presented exceptional performance under islanded and grid-connected conditions. Immediately after the earthquake, 4.66 million homes with electricity supplied by the Tohoku Electric Power Company (ToPo) and 4.05 million homes with electricity supplied by Tokyo Electric Power Company (TEPCo) experienced a power outage. ToPo achieved 90% restoration in six days and 95% restoration in ten days, whereas TEPCo achieved 90% restoration in four days and 95% restoration in seven days. Under the same scenario, RHM remained in islanded operation for several hours, being able to completely supply its loads, through its own local RES. After the reconnection, it was also capable of supplying electricity to TEPCo. After the earthquake, ToPo stopped supplying power to the SM area in an almost three-day outage. However, the Sendai Microgrid was able to continuously supply power to critical loads for two and a half days (Marnay et al., 2015).

2.2.1 Cultural Aspects of Microgrids

An important question that must be done is if the technologies must be developed to intentionally support desirable actions in the human being. The answer to this question is not trivial and two perspectives must be addressed in this discussion. First of all, according to Verbeek (2006), technologies mediate our actions regardless of whether we design them to do so or not; therefore, we had better try to give to this influence a desirable form. In contrast, from a Kantian perspective, design technologies to steer actions lead to a loss of human virtuousness, moral intentionality, and moral freedom, since the action is not the result of a good character and, therefore, is a moral (Waelbers, 2011). The answer to this question can enhance the freedom of people or, antagonistically, provide a more desirable society though the use of persuasive technologies.

Currently, there is a transition to a new culture and social behavior around energy use, encouraging a new energy system concept. The implementation of microgrids allows that loads are no longer passive elements and the traditional customers become a prosumer, creating a new relationship between the user and the utility.

Considering a prosumer connected to a microgrid, the regulation codes can be made in order to provide to the prosumer different levels of control over their loads, energy sources, and energy storage devices. Again, the antagonism between freedom of choice and imposition of actions, seeking a better global performance of the microgrid, is present. Therefore, two possible scenarios can be foreseen for regulating these grids (Wolsink, 2012):

1. The policies will focus on the autonomy of the end-users and on providing options for the prosumer to inject energy into the grid, to store it, and to define limits for their respective power consumptions, and;
2. The policies will focus on centralized control of the microgrid. The smart metering devices will be used to regulate the end-user consumption behavior and the power delivery and storage according to what fits best to the grid, in a framework where the network manager oversees the whole network, including its consumers.

The implemented policy can influence social acceptance according to the benefits perceived by the end-user. In this sense, centralized policies tend to create more dissatisfaction on the part of the user. Changes in the present energy use culture are not trivial tasks since they imply lifestyle changes. For example, new taxation rules that penalize the use of energy-intensive devices, changes that penalize habits deeply entrenched in daily routines, or even imposed limits in the user consumption during peak demand hours tend to have a resistance by the end-users. Therefore, an educational process must be carried out in parallel with the adoption of new regulations, comprising campaigns, training programs, and other educational methods.

The understanding of the social acceptance of new energy consumption and production paradigms must consider that this process involves multiple actors in different levels and not only the public. Institutional actors in policy-making, as well as among powerful market participants, are key players in the creation of proper conditions for the acceptance level needed by an urban microgrid project to be achieved. Considering social acceptance as a complex, multi-level, and polycentric processes, it can be understood as (Wolsink, 2018):

> a bundle of processes of decision-making on issues concerning the promotion of –or counteraction against– new phenomena and new elements in the transformation of current energy systems.

According to Wüstenhagen et al. (2007), the social acceptance of renewable energy has three dimensions:

1. Socio-political acceptance, which is social acceptance on the broadest, most general level. Both policies and technologies are subject to societal acceptance;
2. Community acceptance, which refers to the specific acceptance of siting decisions and renewable energy projects by local stakeholders, particularly residents and local authorities, and;
3. Market acceptance, which refers to the process of market adoption of new technology.

In addition, each one of these levels is by itself complex and multidimensional. Each one of them includes (Wolsink, 2019):

- Different processes;
- Different procedural frames (legal frames, strategic frames of the actors involved, etc.);
- Different objects of acceptance, and;
- Different sets of actors operating at each level.

The cultural change around the energy use required by microgrids with large shares of renewable energy sources goes beyond the change in the amount of energy consumed, the impact on the energy cost, and the comfort provided by the increased reliability of the supply. Energy, in this case, can be seen as a common good, where the end-user is not only a consumer but a co-producer that actively participates in the energy market. The cultural changes, and also the social acceptance of the microgrids, depend on the policies adopted and also on the decisions taken by the institutional actors.

3 Final Considerations

This chapter presented the main characteristics, technical solutions, and social aspects involved in the transition to a scenario where power is delivered by microgrids to the end-user. From the technical viewpoint, the high penetration of non-dispatchable microsources with intermittent nature has a significant impact on the ability to control voltage and frequency, making it more difficult to ensure grid stability and creating more strict performance requirements for the control devices. In this context, energy storage systems play an important role, mostly in terms of the dynamic response of the microgrid to perturbations in general (especially in issues related to grid frequency), due to the increased ability to match supply and demand that these systems enable in a microgrid during transient conditions.

Another concern is about the microgrid capacity to disconnect from the main grid when the desired power quality is not achieved. Under islanded operation, the distributed generators cannot operate as constant power sources, so frequency and voltage regulation must be provided by them. To achieve the power balance under such conditions, particularly right after the disconnection from the main grid, can be quite challenging. Concerns about the impact of the bidirectional power flow in the protection system, the resynchronization capacity for the reconnection to the main grid, and the black-start capability were also described.

The second part of this chapter analyzed the social aspects involved in the impact of the supply of energy using the paradigm of microgrids. Electricity is embedded in modern goods and services and, therefore, is closed linked to social welfare and human capabilities. The distribution system architecture strongly impacts the energy cost and the reliability of the energy supply, and together with the regulations that govern the relation between utility and consumers, settle the level of access of the dwellers to electricity. It was shown that social aspects of electricity can be quite different in rural and urban areas. In rural areas, the social impacts arise mainly from the first access to a reliable electricity source, which directly affects health, education, habits, living, and social networking of communities. Failures in rural electrification projects are quite common and closed linked to solutions that ignore social factors. On the other hand, in urban areas, social impacts can be derived from a reduction in the energy costs and a more diversified range of energy services available, giving people affordable access to electricity that is suitable to their needs. In addition, mainly in urban areas, microgrids can turn the traditional consumer into a prosumer (i.e., a consumer that also produces energy), potentially creating a new culture around energy use and production.

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Epilog—Final Considerations

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This book has grown out of cooperation among friends who have a common interest, expertise, and passion for engineering and social practice.

It has evolved from an initiative to create engineering courses at the Federal University of Itajubá, Brazil, and contacts with friends worldwide who have similar interests. Among the courses designed in the last five years are: Philosophy and ethics of technological developments, renewable energy integration for smart cities and grids, systems engineering for power and energy systems, etc.

The increasing complexity of critical-life-sustainable infrastructures requires integrating all disciplines to promote a harmonious and sustainable society. Engineers are not only crafters of physical infrastructures but also agents of environmental and social justice. This cooperation of engineers, philosophers, sociologists, and politicians is of paramount importance for a just society.

To access the fundamental role of engineering and technology in society, one must understand how these practices change society and the environment. To produce a more humane engineering practice, it is necessary to ask philosophical questions about technological artifacts and systems and their effects on different aspects of society, social development, and quality of life. With this understanding of the complexity in engineering practice, this book attempted to offer direction and guidance at all strategic, tactical, and operational levels.

Engineering and technology design is not something strict, rigid, and singular. There are different aspects and perspectives to be considered. Considering only one

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of these aspects can compound the effects in the face of interactions with different types of systems and sub-systems. When understanding the irreducibility and interconnectivity between the various aspects (physical, social, economic, aesthetic, etc.) that describe a system and its relations, it seeks to avoid a reductionist view of society's problems. Therefore, it is essential to develop a holistic normative design, so that complex systems such as smart grids and smart cities can consider all aspects combining human and technological development.

Following this thought, the engineer and his/her practices must have a primary role in society's positive transformation. However, the means of production must also seek improvements that corroborate with social factors and other aspects of society. The search for a more sustainable society, for example, has transformed several systems into practice for decades around the world. As stated in this book, agents, including ordinary people, must take responsibility for communities' problems and the environment. From this, engineers, when considering these aspects in their design, will be corroborating and magnetizing improvements at different levels.

Engineering practices have traditionally been based on a purely technical view without considering the social effects. However, the application and implementation of the engineer's work directly impact society, the economy, and the environment. Technologies can be used to improve efficiency, promote equality, resilience and reduce risks of adverse effects. Communication and Information Technologies (ICTs), for example, are being used on a large scale and have brought disruption to different sectors and also how people interact with others and with systems. The intensive use of ICTs must and is already trying to promote the quality of life in society, promoting a revolution from innovation. It also comes up against other technologies, such as renewable energy sources, artificial intelligence, computing, and automation.

In this book, the authors and editors have tried to integrate several topics related to engineering practice about technical, economic, environmental, and social aspects. Also, the book attempted to establish a philosophical and ethical basis for the development of holistic and normative designs which will help accomplish the desired goals defined in global projects that take into consideration technical aspects and social implications.

The book's objective was to show in different ways basic examples to cover in a comprehensive way the topics related to the social aspects of engineering and technology practices. For this sake, a coherent structure that enabled the reader to navigate the topics addressed was proposed. A framework to understand the development of the whole book was presented in Chap. 2. Such a chapter started from an essential point: acknowledging that the mass of humanly-created structures and products exceeded the total biomass on earth. It imposes a dramatic challenge for engineers that must respond to this call comprehensively and responsibly. It triggered the sequence of topics addressed by the book. Hence, engineering faced many times as the villain responsible for deteriorating the environment may help society fight global warming while preserving the fauna and extracting the most from renewable sources. Thus, the following chapters explored social and human aspects of engineering, bringing attention to holistic aspects of engineering and also a discussion about how the labor environment may help (or harm) the well-being of a human person as a worker.

Once the importance of social aspects of engineering was established, a set of topics, generally addressed under strict technical points, was presented. However, this time, human aspects have been incorporated, offering a different perspective about economics, optimization, and statistics. That was an important goal since the interdisciplinary of the emerging power system requires an engineer to have a good sociological background. Therefore, acknowledging an engineer as a leader and a worker poses an interesting problem that pushes him/her to create a healthy labor environment. Social interactions in the labor environment must also be extended to society as a whole, and social inclusion must also be observed in designing engineering projects. It, if considered by the syllabus of engineering courses, tends to make better engineers. They will be social actors that promote society's progress by respecting minorities, low-income people, and the environment. It was the drive of some other chapters that addressed pandemic and societal models, for example. The discussions provided by the authors may work as an awakening process in readers eager to study engineering.

The engineer as a social actor must be ready to face the transformations of society. In this sense, he/she must have the necessary background to work on the technological changes. For this sake, the reader should be aware that the cycle of knowledge–science–technology is currently under transformation since technology enables new ways of acquiring knowledge and creating a quick-transforming society. Therefore, engineers are invited to be protagonists in this process.

If the technical background is vital in this era, social care is about to make the dominant difference. This point is crucial to implement ideas that must be proposed with the meaning of "nobody left behind," including people and improving processes. However, sometimes changes are not planned, as the pandemic paralyzed the economy and killed millions of people. In this case, besides economic relief, people need to embrace activities that bring hope and comfort. Once again, as described in this book, engineers may help society overcome difficult times by proposing new artifacts while respecting the different cultural aspects of the people involved.

Society can no longer afford to continue utilizing engineering without fully integrating it into its social and environmental implications. The global village is a reality, and global warming is a sign which needs to be taken seriously if we care for the future of our children and grandchildren and humanity as a whole.

The authors hope that this book will be received and used and help engineers and non-engineers understand the implications of engineering and technology practices. We also hope that the material discussed here breaks down the unnecessary wall that splits human studies from engineering, rendering a creative environment where the artist–engineer–designer–poet may bring hope and harmony to society.