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Waste

► Reduction in Consumption for Sustainable Development

Waste Diversion and Sustainability

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Introduction

The waste concept can be found in the Cambridge Dictionary (2018) as an "unwanted matter or material of any type, especially what is left after useful substances or parts have been removed." But defining something that is not desired may fall back on a subjective concept, since it depends on how each one will relate to what he wants to discard and the many reasons that can lead him to this action, as Largerkvist and Dahle'n (2012) say, "it includes a decision by someone regarding the usefulness of some material matter, and that which is worthless for one may have a value for another. Thus, one cannot define any material properties which define waste, but rather a situation where waste appears."

Although it is subjective, the connotation of the word waste already sounds like one of the society frustrations, demonstrating the inefficiency of the processes, since it is a negative output, therefore a cost for the system (Mersky 2012).

The waste generation is inevitable for all human productive processes, from extraction of resources, its transformation to consumption, relating all these three steps to the economy growth and, consequently, a decrease of its generation with a decrease of the Gross Domestic Product of a nation, that is, the higher the income is, the greater the share of the goods consumption become, in turn, it generates discards (Largerkvist and Dahle'n 2012).

It is important to discuss that waste, as a result from human processes, it becomes a problem in relation to its disposition and the need to increase resource extraction to feed the vicious circle of extraction–consumption–disposal–resource extraction.

The change of attitude towards the constant generation of garbage that occurs on the productive system is urgent, when the society faces the transformation of natural resources in materials to be discarded and the constant increase of these discards on the landfills, which bring

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numerous problems, considering the lack of space, the pollution, and the waste of resources that could have another less impacting destination on the nature, once the generation is unavoidable.

The university is a profitable place to meet this challenge by producing leaders able to understand and manage environmental issues such as the increasing generation of waste and its impact on the environment, going beyond the graduation trend in providing only the specific knowledge of the academy areas (Mino and Hanaki 2013).

It will be discussed in this chapter, actions that create possibilities to deal with the waste in order to reduce the impact of this market process, together with the challenges faced by the innumerous qualifications shared by the university, so that society can have an increasingly approach to the way the environment does with its "disposal," getting closer to the sustainability.

The Waste Disposal

Nature and Its Waste

Any organized process that can be observed holds a beginning, a middle, and an end. Nature, as the basis for all processes, would not be out of this organizational parameter.

In fact, the natural balance is due to the diversity and ability of this diversity to deal with the nutrients recycling after the end of a cycle. As an example, it could be pointed leaf fall in autumn, which serves the entire chain of microorganisms present in the soil with a valuable element which brings fertility when transformed, strengthening the nutrient cycle (García-Oliva et al. 2003; McNabb et al. 2001).

A rainforest structure is a self-regulated ecosystem that maintains its own temperature and produces its own food. So, it is a chain of creation and transformation that takes from itself its survival and perfectly demonstrates the environment position in its rich experience of dealing with its waste (Capra and Luisi 2014). As Everett (2012) sums up, "Nature is a cycle of birth, growth, death and decay."

Society and Its Waste

According to the first law of thermodynamics, in a closed system, matter and energy are invariant, just as are ecosystems. The second law, which is the entropy law, points out a tendency to transform free and available energy into a dissipated energy and no longer available, that is, it is a unidirectional and irreversible and purely qualitative action, as pointed out by the first law (Georgescu-Roegen 1999; Martin et al. 2013).

From this point, the sustainability could be analyzed sustaining the ecosystems structure against pressure and the wear of entropy, the death. The Earth is characterized as an open system in terms of energy (since it sustains life by absorbing the low solar entropy), as well as a stable system, its material recycling capacity allows its sustainability, which is opposed to the material entropy (Georgescu-Roegen 1999; Martin et al. 2013.

Society, in its production processes, transforms energy and natural resources that comes from a sustainable system, therefore with low entropy, in wast and pollution which ultimately increase the systems entropy, transforming sustainable into unsustainable. Since landfills are the destiny of much of the produced garbage (Mersky 2012), this place turns out to be the representation of an energy that does not return to the system, which accumulates any type of residue, therefore without material sustainability, as previously discussed.

So, for the nature, the waste produced is welcome, but for the society, they are the remains of their activities, considered by their generators as useless, undesirable, or disposable, as not participating of a cycle, though, uncontrolled and unsustainable.

The waste generation is often related to the urban way of life (Largerkvist and Dahle'n 2012), where the concentration of population also has concentrated benefits and harms, reducing the per capita welfare. The growth and the populational concentration combined with industrialization are factors that contribute to a significant increase in the solid waste generation worldwide, which generates pollution, an overload of human waste that has not been recycled or reused but has been left in the environment, in water, air, or soil, which even though they are far away from the generator, it causes harm to them by the contamination of resources.

Thus, with this accumulation, the natural cycles of decomposition are threatened in an industrial society, because of the amount and the quality of waste produced, that are beyond the natural ability to assimilate these kind of tailings (Everett 2012). The quality of this waste has changed along the past half of the century, since many materials are not biodegradable, or if they are, they take many years to decompose (Rathje and Murphy 2001).

As in general, the garbage destination is the landfills, the environment impact is still high since the amount of waste is expected to grow and more land is necessary to accommodate the result of the consumption process. In the landfills, the materials are put all mixed, which is a problem, because even the biodegradable one, that is less complex as food, becomes almost impossible to be decomposed into a low aeration system, being able to be found after many years after discarded (Rathje and Murphy 2001).

The lack of aeration of landfills inhibits the fast decomposition and also produces methane, one of the potent greenhouse gases, that is why many European countries surcharges or banish the food routing our any organic residue for landfills (Babbitt 2017).

As exposed, alternatives should be sought to encourage a transformation in the way the society generates and allocates waste, since the forecast is to the growth of the generation rate, considering that population, urbanization, and energy consumption also tend towards to growth (Largerkvist and Dahle'n 2012). The quest for a greater awareness in generation and destination of society's waste is the outstanding importance to achieve sustainability and a less impact in an environment that has already been altered in its equilibrium.

The university campus turns out to be a microcosm, but an open system that is maintained by low entropy, but in its processes does not free itself from the generation of waste, increasing the entropy, like most places. The academic community awareness through information, debate and action, should come primarily from the internal view, extending it to the external view through its students or even its graduated professionals.

Waste Diversion

The discussion of sustainability in the context of waste management refers to reaching as close as possible to how nature deals with its waste, so that the cycle could be closed with as few discards as possible. Thus, some alternatives have been given to divert the waste from landfills, so the resources could be more utilized (Mueller 2013; Thompson et al. 2012; Bahor and Van Brunt 2013).

These alternatives are called Waste Diversion that can be defined as the ways to dispose of the waste, so as not to deposit them in landfills (Mueller 2013; Thompson et al. 2012; Bahor and Van Brunt 2013) and provide a direction to extend life cycle of the materials, avoiding more pressure over the environment and health risks for humans as well.

The diversion of garbage from landfills avoids costs such as the lack of spaces to be converted to landfills, since the amount of garbage tends to increase as mentioned above, avoids problems with the gas that accumulates, prevents leaching and contamination of groundwater, as well as the emission of toxins and toxic gases, while avoiding incineration (Thompson et al. 2012).

According to the discussion of Thompson et al. (2012), there is a scale of importance in ways to divert waste from landfills. And that will be treated next.

Consumption Reduction

The first action is waste generation reduction through consumption reduction, whose result certainly comes from education and social awareness. For this, it is necessary a search for a frugal life, aiding in the reduction of the goods consumed, then it also reduces the pressure on the resources extraction to replace raw material for a new production (Thompson et al. 2012).

This pervasive products flow based on extraction–production–consumption–disposal, which ultimately stimulates the economy, also puts pressure on natural resources, not only in raw material extraction, but also in water, soil, energy use, but also through pressure on planet when goods are discarded, becoming waste (Miller 2004).

If the intermediate chain of consumption is lower, there is consequently a decrease in the volume of waste generated, thus a lower accumulation of wastes to be destined to the landfills, facilitating the reuse or recycling cycle (Thompson et al. 2012).

The concept of sustainable development came by the Brundland Report (WCED – Our Common Future 1987), whose definition falls on meeting the needs of present generations without compromising access to resources for future generations, proposes not only a social and economic approach, but also searches for a synergy between living people's well-being in space and time, with preservation for natural resources (Boeve-De-Pauw et al. 2015).

The economic approach presupposes a questioning of the sociocultural pattern which was established in the unlimited human needs, but not only this, but also the generations capacity to change not only the consumption patterns, but the need to adapt the impacts and changes that have already been caused on the planet by this utilitarian stance (Assadourian 2017).

The expansion of university students' access to a more multidisciplinary formation parallel to the specific formation would allow a broader view of the causes and consequences of the production–distribution–consumption process, broadening the context of analysis and, therefore, confronting the challenges that converge to the amount of garbage generated by society.

Materials Reuse

A second step in this sphere in the quest to sustainability is objects and materials reuse that have been produced, making possible avoid more waste in the landfill, decreasing the pressure in resource extraction or even "prevent the creation of new materials or products to be used in their place" (Thompson et al. 2012).

Equipment and material repairing can be the key to extend the life cycle, counteracting the trend of premature obsolescence which products increasingly face in order to short their use and advance their destination for disposal, causing the consumption cycle to start.

The use of durable materials such as bags and returnable packaging helps on using less resources with only one use, promoting a more efficient materials handling that are used in productive processes (Thompson et al. 2012).

The formation in the areas that correspond to the engineering in the development of products, machines, or even in those more strategic areas that involve the consumer or the market knowledge, is launched as a challenge for the formation of differentiated professionals who can face a new context of environment that requires more durable products, thus extending their life cycle.

Annastas and Zimmerman (2003) exposing the 12 principles of green engineering report in principle thirteen that the complexity of the product should be maintained when choosing between recycle and reuse. They report that the complexity built in a product on a macro-, micro-, or molecular scale is due to the expenditure on materials, energy, and time; therefore, the more complex the material structure, with more substances with high entropy, it would be counterproductive to recycle and it would be highly recommendable to reuse, the opposite being valid for less complex materials.

Material Recycling

The third and most widespread of the three Rs is recycling, which is characterized by the transformation of used materials (plastic, paper, glass, aluminum, etc.) into new ones from a new production process. Although it demands an energy consumption again, some elements, such as aluminum, present an efficient energy consumption reduction (Thompson et al. 2012).

Although a large part of the products that are produced today are coined with the recyclable symbol, but there is still much that needs to be analyzed in terms of public policies in order to increase the waste recycling rates, that could be through taxation of generation and collection of waste, or environmental education or other forms that encourage the help families allocating materials back to the production process rather than to landfills (Mueller 2013).

Another fact to be noted is that the market took advantage of the increased people's awareness to environmental issues and, in a way, made most popular the term "sustainability." So, marketing sometimes uses the fact that the product is recyclable to stimulate consumption, which makes it returns to the cycle of consumption and disposal. For the consumer, he gets the slightest awareness when he purchases a product that is made of recyclable material, which does not determine its destiny, but it poses as a great opportunity of market consumer exploration.

By creating the conditions for any company to be able to produce recyclable products, it creates a wide playing field for any company big enough to compete in the market; small and uncompetitive companies, unable to be part of scale economies, will be placed outside this field. With the entry of companies in the reuse business, it would offer a distinct advantage to small and localized businesses, supposedly inefficient, which would be considered a form of protectionism (Fairlie 1992).

The role of junior companies with young professionals and students within universities is extremely important in pinpointing business risks and analyzes, as well as stimulating and supporting the recycling companies incubation, helping them to stay on the market and expand it.

Composting

Its function is to transform the organic material into compost, which can be used mainly as fertilizer in agriculture. It is made of food remains, pruning of plants, and paper, whose quantity is extremely significant in garbage composition that is destined to the embankments. It accounts for some 40% in high- or middle-income countries and about 30% in low-income countries (Gautam et al. 2010).

Among its advantages are: the significant decrease of the materials that would have as destiny the landfill; avoiding the organic matter of landfills, there is a decrease in the generation of greenhouse gases; it increases landfill's life by reducing management plans and with less maintenance and results in a fertilizer, therefore in a product that can be sold; it is a cheap method to deal with wet organic residue, and, finally, it helps municipalities achieve their goals in terms of solid waste management (Gautam et al. 2010).

Prerogatives of Waste Diversion

Waste diversion is the key to sustainability, as it seeks ways to move away the destination of solid waste from landfills, thus minimizing the impact of tailings accumulation (Thompson et al. 2012).

The search for alternatives that approximate the relation of society to its rejects with the relation of equilibrium that exist in not built environments, closer to the natural, will reach a relation of low entropy, therefore, of less wear of the resources, minimizing the extraction and the discard, therefore the impact of this human action on the environment.

These alternatives include the reuse of materials or products already used, either by use or repair; the reduction of consumption from a new awareness of need; recycling with the reuse of materials in a new production process; or by the composting of organic matter, avoiding its waste and not decomposition in the landfills, making use of it and transforming it into fertilizer (Thompson et al. 2012; Gautam et al. 2010).

The reduction of consumption together with reuse is the most desired solution in terms of waste management, followed by recycling process, which must have a whole technology implemented (Bahor and Van Brunt 2013) that enables the logistics of the process for efficiency in the collection, separation, and transformation of the material.

Therefore, for an effective change of posture in relation to the waste generated and its diversion from landfills, public policies are essential to stimulate, raise awareness, and change habits of the population. Whether it is by the economic taxation of the amount of garbage generated or putting a limit of bags collected, the population feels encouraged to allocate most of the garbage to the destination of recycling regardless of social class (Ferrara and Missios 2005).

The search for sustainability permeates the management of waste produced by society as well suggests chapter 21 of the Brundtland Report (WCED – Our Common Future 1987) which deals with the issue of solid waste and sewage, whose reduction is of paramount importance to minimize the effects of accumulation in the environment. It suggests a reduction that begins with the minimum and with a maximum increase in waste reuse and recycling, its healthy disposal and treatment, and the extension of the scope of services dealing with waste.

Changes are always shrouded in utopia so that it can only remain in today, but studies (Mueller 2013; Franchetti 2012) show that there is space for applying of projects and public policies to stimulate change, as well as a work in education and awareness are essential for a change of attitude towards the consumption and disposal of natural resources.

Education is the basis of this change. The discussion and multidisciplinary understanding, placed above the classic specific studies in universities, widens the scope of environmental issues management.

This expanded vision could open market perspectives in search of developing products that could be associated with this new vision of waste diversion, including changes in persuasion of consumer strategies by arousing their sensitivity to the problem developed here.

Thus, the multidisciplinary understanding promotes not only the basic needs that make up this discussion, but also adapts environmental issues promoting "ecoliteracy, moral education, system thinking, and critical thinking, to name a few" (Assadourian 2017).

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Waste Management

► Waste Management Strategies for Sustainable Development

Waste Management Evaluations and Sustainability

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Definition

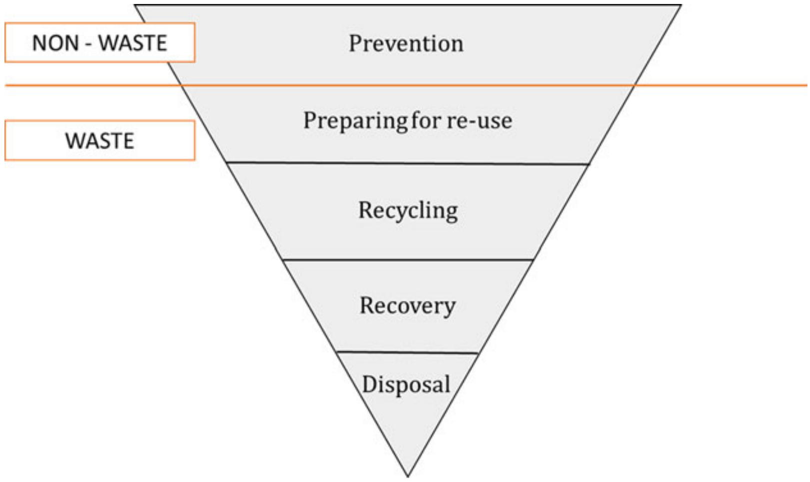
The term waste management is generally used to define the set of practices necessary to collect, transport, dispose of, recycle, and monitor municipal solid waste.

Introduction

The term waste management is generally used to define the set of practices necessary to collect, transport, dispose of, recycle, and monitor municipal solid waste. Wastes are managed for several reasons, for example, to avoid adverse effects on human health, to obtain resources, and to protect the environment. In other term, waste management is a fundamental component of each country strategy for achieving SDGs, as it contributes to improving living conditions and human health.

Waste management methods differ significantly across nations, both in terms of different collection practices and types of disposal choices adopted. As a consequence, it is very complex to assess the sustainability of different waste management systems. For this reason, a hierarchy of different disposal choices has always been a fundamental pillar of the European strategy for waste management and one of the main principles of the waste framework directive (2008/98/EC). As shown in Fig. 1, the hierarchy puts prevention at the highest priority level, emphasizing that reducing the amount of waste produced is the most efficient way to reduce the environmental impact of waste management and improve resource efficiency. In a similar vein, the second highest factor in the hierarchy is "Preparation for Re-Use." Among disposal choices, the ranking is very clear, showing recycling as the preferred choice, followed by energy recovery and landfill disposal (see http://ec.europa.eu/environment/waste/framework/ for more info on the European waste hierarchy).

Nevertheless, one obvious possible critique of this classification is its geographical specificity, which makes it suitable for European countries but not necessarily adaptable in all non-EU countries. In particular, the ranking of the three disposal choices can be affected by several factors. Land availability and its cost, for instance, significantly influence the social cost of landfilling, while urban characteristics may significantly influence the unitary cost of recycling, as collection activities are much cheaper in highly concentrated urban areas than they are in less densely populated cities or rural areas. As a consequence, the "one size fits all" approach is not always the best one, and it might become necessary to customize waste management evaluations according to different contexts. The aim of this chapter is to guide the reader through different approaches that can be used to define a customized "waste hierarchy" capable of helping the transition of different systems towards more sustainable waste management. In particular, section "How Sustainability Can Be Evaluated: Life Cycle Assessment (LCA), Cost-Benefit Analysis (CBA) and Multiple-Criteria Decision-Making (MCDM)"



Waste Management Evaluations and Sustainability, Fig. 1 European waste management hierarchy

summarizes a series of tools that can help assess the impact of different disposal practices; section "Policies for a Transition Towards a Sustainable Waste Management System" briefly describes the main steps in the profound reorganization of waste management systems experienced in the last 20 years in Europe; section "Insight from Academic Research on the Drivers of Waste Management Transformation" summarizes the main ideas stemming from the relevant academic literature; section "Waste Management Practices, SDGs and the Role of Academia" focusses on the relationship between waste management and SDGs, and, finally, section "Lesson for Waste Management Evaluation and Sustainability" concludes and gives some relevant policy implications.

How Sustainability Can Be Evaluated: Life Cycle Assessment (LCA), Cost-Benefit Analysis (CBA) and Multiple-Criteria Decision-Making (MCDM)

The aim of this section is not to explain in detail the most relevant techniques for environmental policy evaluation but to explain how they can be used to assess, both *ex-post* and *ex-ante,* the sustainability of different waste management systems. In particular, we focus on the following three tools: life cycle assessment (LCA), cost-benefit analysis (CBA), and multiple-criteria decision-making (MCDM).

LCA is a technique with the aim of assessing the overall environmental impact of different products or processes considering the emissions produced in all stages of their life cycle. The outcome of this analysis is, therefore, an index accounting for the environmental impact of the products from cradle to grave, including the impact of their material extraction and final disposal or recycling. In the specific case of the evaluation of waste management systems, LCA can be used to compare the environmental impact assignable to different disposal and management options, in a fashion similar to that in the abovementioned European waste hierarchy (see for example: Cherubini et al. (2009), Finnveden (1999) and Lundie and Peters (2005)). The main added value of this technique in the specific field of waste management is that it can help national policymakers have a proper understanding of the impact of different technologies in their own country. A large host of factors can influence the environmental damage related to different disposal choices, such as the available recycling technologies, land availability, and the country energy mix. As a consequence, this tool can help policymakers in designing the mix of treatment options that better suits each country.

CBA is an approach generally used to compare total expected costs against total expected benefits of different policy scenarios or different projects. By "total," we mean not just the present costs and benefits but also costs and benefits expected to occur in the future. More specifically, costs and benefits are expressed in monetary terms and are adjusted for the time value of money. This allows researchers to express the cost-benefits of different options in terms of their net present values. In our specific case, CBA tools can be used to compare different reform schemes of the waste management systems with the status quo. An example of the application of CBA to the waste sector is the so-called "impact assessment" promoted by a group of experts from the European commission, which is, as the commission website states, "Environmental assessment is a procedure that ensures that the environmental implications of decisions are considered before the decisions are made. In other words, in this specific case, CBA is used as an ex-ante evaluation tool of different policy options. Another example of application of CBA can be found in the work by Jamasb and Nepal (2010), which discuss the potential role of waste to energy in the UK. Their findings show that waste to energy can play an important role in meeting the EU targets, being socially more cost-effective than the current practices.

We acknowledge that CBA is only one approach used for environmental assessments and is the approach most commonly used to assess waste management (more on this point can be found in Hogg et al. 2011). In this vein, CBA can be a powerful ex-ante tool to assess the costs and benefits of a transition from one waste management system to another. CBA, for instance, can help quantify the net present impact of moving from 40% to 60% recycling in a given country.

Interestingly, there are several important overlaps between LCA and CBA, as LCA can provide base data for a sequent CBA analysis. Here, the intuition is that if we want to quantify the impact of moving from 40% to 60% recycling, we need, among other things, data on the overall emissions of recycling technologies and the monetary value of these emissions. LCA can provide these data.

MCDM is an alternative tool that can help in instances in which data availability might be an issue, or in which, due to time constraints, there is not enough time to conduct a proper CBA. MCDM can be considered an alternative ex-ante assessment tool, which, instead of focusing on the monetarization of the alternative costs and benefits of different projects, summarizes their impact according to different criteria. More specifically, MCDM can be used to evaluate multiple conflicting criteria in the decision-making process. Example criteria that can be of interest in the case of waste management are costs, environmental impacts, and employment impacts. The results of this analysis are generally helpful to understand which and to what extent trade-offs across different criteria exist. This is especially relevant in the waste case. Generally, for instance, the comparison of landfilling and recycling can produce a picture in which landfilling performs better based on the cost criteria, while recycling performs better based on the environmental criteria.

Overall, the abovementioned tools can help policymakers and stakeholders have both an *ex-ante* evaluation of the sustainability of different waste management configurations (with CBA and MCDM) and an *ex-post* assessment of specific technologies, thanks to LCA.

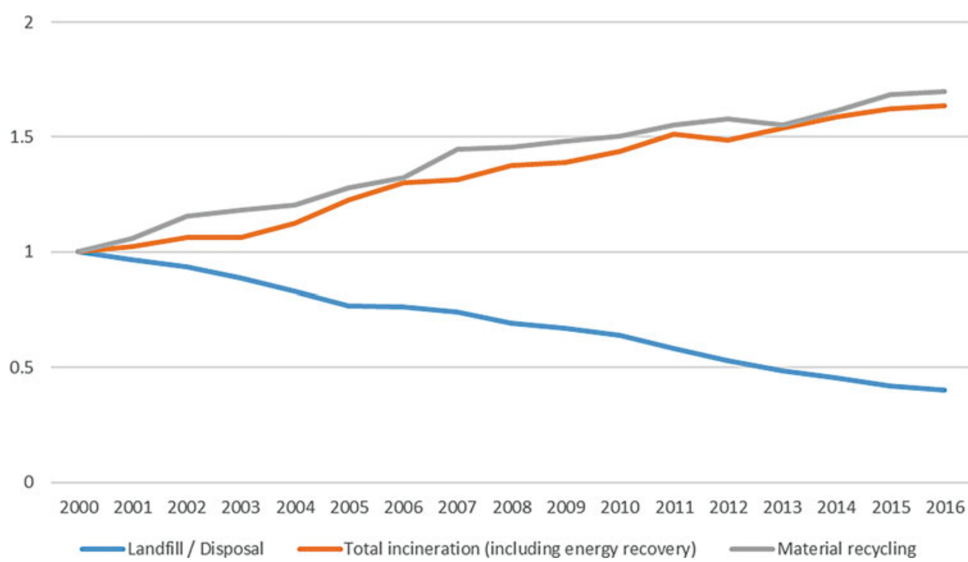
Policies for a Transition Towards a Sustainable Waste Management System

The transition towards a sustainable waste management has been a pillar of the European commission environmental agenda for the last 20 years. The first important step in this direction was the so-called landfill directive (1999/31/EC), which, according to the principles of the waste management hierarchy, tried to limit landfilling to the necessary minimum. Moreover, it also specified some technical requirements for existing landfill sites to limit their negative impacts on the environment. A second important step was the Waste Framework Directive (Directive 2008/98/EC), which described the policy and conceptual frameworks that should guide the European waste management evolution towards a "recycling society." A third and still on-going step in this long path is the promulgation of the circular economy package, which provides the basis for a new definition of the European Economic System. In a few words, by circular economy, the European parliament means a new concept of the economy in which production is a circular flow that is based on a combination of reusing, repairing, refurbishing, and recycling, with the final aim of turning waste into resources. More precisely, the most recent circular economy package includes the following targets:

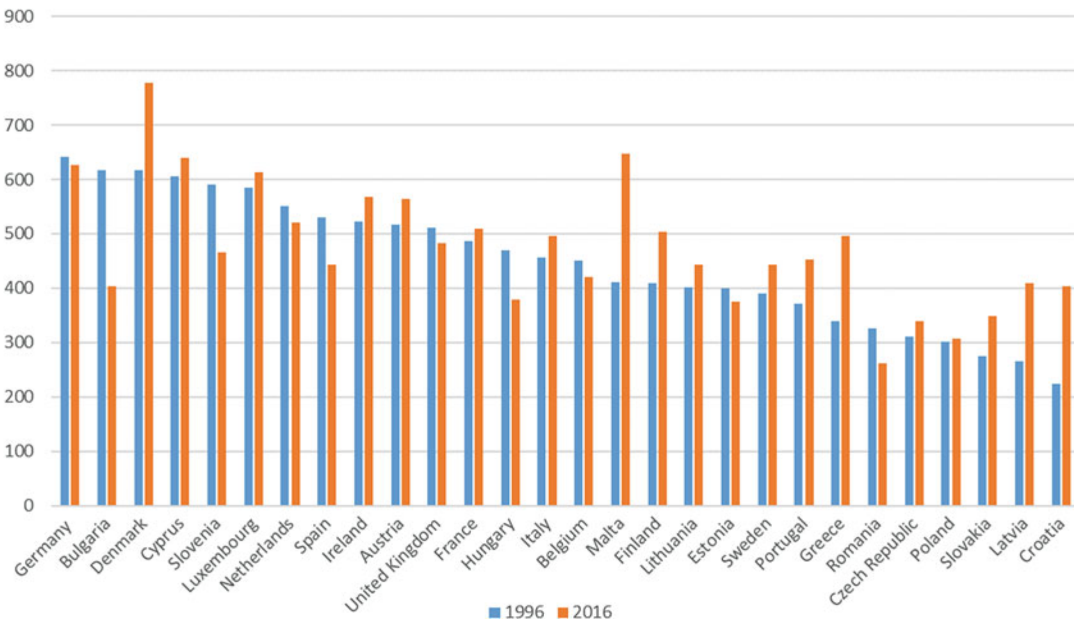
- A common EU target for recycling of 65% of municipal waste by 2030;
- A common EU target for recycling of 75% of packaging waste by 2030
- A binding landfill target to reduce landfills to a maximum of 10% of municipal waste by 2030
- A ban on the landfilling of separately collected waste
- The promotion of economic instruments to discourage landfilling
- Simplified and improved definitions and harmonized calculation methods for recycling rates throughout the EU
- Concrete measures to promote re-use and stimulate industrial symbiosis, turning one industry's by-products into another industry's raw material
- Economic incentives for producers to put greener products on the market and support recovery and recycling schemes (e.g., for packaging, batteries, electric and electronic equipment, and vehicles)

This long and still on-going legislative process has had an impact on the evolution of the European waste management system, as shown in Figs. 2 and 3. Figure 2, in particular, shows that the trends of different treatment options have changed significantly over time. Landfilling, in particular, has decreased almost 60% in the period from 2000 to 2016, moving from being the dominant waste disposal choice to being less prominent. As a consequence, total incineration and recycling levels have increased significantly, and their share is now 60% higher than that in the year 2000. Overall, this preliminary and simple descriptive evidence seems to suggest that European policies have been able to promote landfill diversion. More on this point will be discussed in the next section.

In contrast, a different result can be found in the case of waste generation. If, on the one hand, the set of legislative reforms enacted in the last few decades has been able to promote the more sustainable disposal and treatment of waste, the evidence for waste minimization and prevention is still mixed. Figure 3, below, shows several



Waste Management Evaluations and Sustainability, Fig. 2 Waste treatment in EU 28. Reference year 2000 = 1



Waste Management Evaluations and Sustainability, Fig. 3 Waste generation. Personal elaboration on Eurostat data

interesting trends. First, it shows that income per capita and consumption levels still explain a big share of waste generation. Several of the countries with the highest amount of waste generated per capita are also countries with a high consumption level. There are, however, some notable exceptions, such as Malta and Cyprus. Second, we note that 18 of the 28 countries generated more waste in 2016 than they did in 1996. This is one of the reasons why the new circular economy package significantly stresses the roles of reducing and reusing.

Overall, this short description of the European situation shows that while the first wave of European policies for waste management has been capable of reducing landfilling and promoting more sustainable waste disposal, they have not been capable of promoting prevention and minimization. Mazzanti and Zoboli (2009) stressed, as one reason underlying this only partially good result, the first wave of European waste policies targeted landfilling, while prevention needs specific legislative support to occur. The challenge of the circular economy is to provide this legislative support.

Insight from Academic Research on the Drivers of Waste Management Transformation

The waste management system transition experienced in the EU that was explained in the previous section has been the focus of several contributions in the literature. Mazzanti and Zoboli (2009) and Mazzanti et al. (2011) highlight the important role of several driving forces in this transition.

First, income per capita is a precondition of his phenomenon. Empirical analysis shows that richer countries have diverted more waste from landfills and had the resources to incentivize the use of more advanced waste management options, such as recycling or incineration with energy recovery.

Second, social factors, such as population density and urbanization, played an important role, influencing the economic value of land and, consequently, the marginal costs of different disposal choices, especially landfilling. This is one of the main reasons why, in the second section of this chapter, we stressed the role of country- and technology-specific LCA analyses of different disposal choices. To provide a simple example, the opportunity cost of using land for a landfill site in a vast and low rural region is very different from that of a highly populated and densely urbanized urban area. Thus, the operational costs of a landfill site can be very different across the two areas.

Third, environmental innovation, favoring the adoption of recycling technologies, has been favored by this transition.

Fourth, a relevant role has been played by environmental policies, which alter the natural marginal cost of different disposal choices and have been able to promote landfill diversion, incentivizing the development and diffusion of alternative and more advanced treatment options that have become more viable and less expensive in several countries.

Moreover, the literature highlights that the success of modern collection schemes, which focus on separate collection, reusing, and recycling, heavily depends on the contributions of citizens and households. This means, in other words, that studying and understanding recycling behavior has become increasingly relevant. Prior contributions have identified several relevant factors that determine individual recycling performances. The most relevant ones are demographic and socioeconomic characteristics of households, individual recycling costs (in terms of time, effort, and money), specific knowledge (owned by households), social pressure, and environmental awareness. In addition to the socioeconomic aspects, some of these factors are more strictly connected to waste management public policy; others, instead, concern individual motivations towards the environment and waste behaviors. Individual recycling costs and specific knowledge, for example, are easily influenced by waste policies.

Regarding costs, since recycling by individuals is characterized by high time opportunity costs, any recycling policy that contributes to facilitating separate collection, thereby reducing the time spent on recycling by households, has a direct effect on household recycling costs. In other words, this means policies capable of making separate collection easier (e.g., increasing the number of drop-off sites and introducing door-to-door collection) are expected to influence both the quantity and quality of separate collection and the final recycling rates.

Specific knowledge, also known as concrete knowledge (Barr 2007), which essentially consists of all the information regarding what to separately collect and the collection locations, is strictly influenced by information policies on the specific actions to be undertaken by households. Additionally, in this case, the academic literature predicts that government efforts to increase the specific knowledge of citizens are expected to have a positive effect on recycling.

Social norms and environmental awareness are mainly connected to individual motivations, both extrinsic and intrinsic, and the role of these motivations as the drivers underlying individual decisions on waste management has been recently analyzed in the economic literature (Berglund 2006). In this case, the link between policy intervention and motivation is less straightforward and beyond the scope of this chapter. The only exception is given by all these awareness policies and campaigns, which, by increasing citizens' environmental consciousness, are expected to have a positive impact on recycling.

In summary, the literature highlights that there are at least three types of factors that may influence the sustainability of waste management systems. The first one, population density and urbanization, is beyond the control of policymakers but significantly influences the disposal costs of different options. In contrast, the second one, environmental policies, is a powerful tool controlled by policymakers at different levels. Finally, consumer behaviors, influencing the efficacy of environmental policies and collection systems, also significantly influence the sustainability of the waste sector. Again, this is a channel through which some intervention is possible.

Waste Management Practices, SDGs, and the Role of Academia

The implications of a proper strategy for waste management on SDGs are massive. The Global Waste Management Outlook (Wilson et al. 2017) summarizes several examples of public health issues that arose from uncollected waste around the world both in the developed and the developing world. In the city of Naples, Italy, a 20-year-long waste crisis, due to the structural absence of permanent solution for waste treatment and disposal, has generated piles of uncollected waste along the street with obvious health and economic consequences. In Accra, Ghana, every year many floods are caused by drains blocked by plastics and other wastes, with important security health and economic implications.

More specifically, Rodic and Wilson (2017) show that at least 12 SDGs and their relative targets have a direct link to solid waste management. As shown by the two examples above, the link between a proper waste management system and SDG 3 "Good health and well-being" is fairly straightforward, as uncollected waste can cause pollution and contamination. Moreover, waste can clog drains, generating floods and keeping stagnant water. This last aspect may also influence targets "3.3 – end malaria and combat water-borne diseases" and "3.9 – reduce illness from hazardous chemicals and air, water and soil." Similarly, adequate waste management practices can prevent emission of greenhouse gasses thus helping to reach the target of SDGs 13: "Take urgent action to combat climate change and its impact.".

As a consequence, it becomes obvious that the challenge for achieving the SDGs involve the development of a national waste management system. In order to reach this target, there are several different challenges, and the Academia can play a decisive role in tackling some of those.

The definition of a regional or country-specific mix of treatment options, for instance, is a key issue in OECD countries. Even though the "waste hierarchy" acts as a useful benchmark in choosing between different treatment technologies, there is not a one-size-fit-all combination that is applicable to all countries. The waste management system depends significantly on country and regional characteristics, as described in the previous section, and academia can play a significant role in supporting local and national authorities in finding the better combination for their area. The above mentioned article by Jamasb and Nepal (2010), for instance, concludes that waste to energy has a very interesting potential to increase the sustainability of the sector in the UK, but its development is conditional on the development of heat delivery networks. In this context, LCA and CBA are two very useful tools to evaluate the impact and value of different treatment options and capacity to adapt to different context.

Environmental policy assessment is a second area of research which can play an important role in this field. As shown in Mazzanti and Zoboli (2009), waste policies can promote the transition toward a sustainable waste system, but the optimal design of a waste-policy mix is still an open question.

This aspect is even more relevant for marine litter research, an understudy topic which has a massive environmental impact worldwide (Panti et al. 2019). In this specific field, the academia can play several roles. Firstly, public awareness about the risks of marine litter is still rather scarce; moreover, also the monitoring activities need to be improved and, even more important, there is a huge need of environmental policies capable of reducing this growing source of pollution. The aim of the recent directive of the European parliament (COM (2018) 340) goes exactly in this direction. (Among other things, the proposal introduced new measures on single use plastics as well as derelict fishing gear.)

Finally, as mentioned in the previous section, more research on the behavioral aspect of the circular economy are needed, in order to understand the role played by non-market factors in promoting a transition to a sustainable waste management system.

Lesson for Waste Management Evaluation and Sustainability

The sustainability of waste management systems means at least two different things. First and foremost, the final aim of all waste management strategies should be waste minimization and re-use, as they are the only possible ways to achieve sustainability in terms of both environmental impacts and resource use.

Second, it implies the use of treatment technologies associated with a low environmental impact capable of transforming wastes into resources. This means, in several economies, the initiation (or finalization) of a transition from a landfill-based society to a system in which wastes are treated by a combination of recycling, incineration (with energy recovery), and landfilling. We note here that the optimal combination of these treatment technologies is not something that can be found in textbooks, as it depends on a host of geographically specific aspects.

As mentioned in the second section of this paper, there are several tools that can help to assess, both *ex-ante* and *ex-post*, the best combination of different treatment choices. They represent a set of tools that policymakers can use to make informed choices regarding the planning of future waste treatment choices.

Finally, the academic literature suggests how a system can move towards a sustainable path through the use of environmental policies. In particular, a policy mix including market-based instruments, better collection practices, and good information campaigns seem, to us, to be a good tool to achieve sustainability.

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Waste Management Strategies for Sustainable Development

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Synonyms

Higher education; Strategy; Sustainable development; Waste management

Definition

Waste management refers to the activities and actions that handle waste materials. It includes collection, transportation, processing, and disposal of waste. Waste prevention, recycling, reuse, and recovery are important waste management strategies that eases the burden on landfills, conserves natural resources, and saves energy. This helps utilize resources more effectively and sustainably.

Introduction

The world is besieged with growing pressure of waste management. The amount of waste has been increasing along with expanding population and rising human activities (The Washington Post 2017; The World Bank 2018). The World Bank estimated that there were approximately 1.3 billion tons of municipal solid waste generated globally in 2012 and the volume is expected to reach 2.2 billion tons by 2025 (Hoornweg and Bhada-Tata 2012). Waste levies a heavy tax on the environment and human health; it is also a barrier to socioeconomic advancement. Waste is an unavoidable by-product of human development, but protecting the environment and safeguarding public health are equally important. To achieve viable economic, environmental, and social objectives, sustainable waste management strategies become highly desirable. Higher education institutions (HEIs) in this regard are crucial in achieving the objective of waste management for sustainable development, because the tertiary education sector is often considered as a key initiator of societal transition. Over the last two decades, an increasing number of HEIs have incorporated sustainable development (SD) into waste management practices. Since sustainable development is a relative new and abstract concept, the paradigm shift toward sustainability in waste management still presents a tremendous challenge to HEIs and contributes to the low rate of change of organizations (Lozano et al. 2013). To better promote implementation of sustainable development in HEIs, this entry intends to provide information on the paradigm shift toward sustainability in waste management and the role of HEIs in facilitating the movement. The discussion would focus on waste management strategies for sustainable development in HEIs context. The entry also highlights current challenges behind the movement. It is expected that this entry would enlighten stakeholders of HEIs across the world about the development of waste strategies for sustainable development.

Shifting the Paradigm Toward Sustainability

The sustainable development concept has become increasingly prominent since its appearance in the United Nations Conference on the Human Environment in 1972 in Stockholm. Defined in the Brundtland Report, the concept refers to "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (World Commission on Environment and Development 1987). It is a holistic approach for human development which foregrounds a state of equilibrium between environmental protection and economic and social progression for improving the quality of life; economic, social, and environmental needs for both the present and future generations could be balanced by incorporating the concept into concrete practices (cf. Leal Filho 2011; Lozano 2006).

Among the human activities, waste management is one of the areas that needs close attention in pursuit of sustainable development. Waste causes enormous negative impacts on economic development and human health. Every year in high-income countries, hundreds of million tons of municipal solid wastes are buried in landfills or incinerated (The Guardian 2018; The New York Times 2018); and most low-income countries dispose of waste in open dumps (Hoornweg and Bhada-Tata 2012; The Economist 2018; The Times of India 2018). Landfilling and incineration are the popular and common strategies for waste management; but none of them are sustainable practices because of the considerable environmental and financial costs (Nabavi-Pelesaraei et al. 2017; Zhang et al. 2010). For instance, both waste management facilities are often opposed by potential neighboring residents. Collecting and transporting waste for landfilling and incineration also produce greenhouse gas and cause great energy consumption. Landfill sites produce landfill gas and are expensive for maintenance; the problems associated with landfills would become a burden to future generations. Incineration causes air pollution if not well executed; it is also a massive inefficient use of materials if recyclable materials are not being separated before combustion. To meet the present needs and reserve the rights of development for future generations, a set of waste management strategies integrating the concept of sustainable development should be developed to achieve the goal of protecting the environment while yielding economic and social benefits. In this connection, HEIs have an important role in helping societies become more sustainable in waste management.

The Role of HEIs

Historically, HEIs are major contributors of human development. The sector is expected "to play a pivotal role in sustainable development, economic growth, decent work, gender equality and responsible global citizenship in all regions" (UNESCO 2015). It is an agent of social changes, which has a critical role in setting out principles of development, demonstrating relevant practices, and making improvements upon delivery. Specifically, universities may create sustainable future by increasing the awareness, knowledge, skills, and values needed (Cortese 2003). The institutions also serve as a role model of making the transition to sustainable lifestyles for now and for future generations (Cole 2003, p. 30). Universities have a moral obligation to act and behave according to socio-environmental concerns (Armijo de Vega et al. 2008; Zhang et al. 2011). Universities' substantial potential to catalyze and accelerate societal transitions toward sustainability (Stephens et al. 2008) contributes to a growing demand from societies on HEIs regarding the actions of sustainability. HEIs are expected to drive the efforts toward sustainable development. Acting as a microcosm of society, daily activities and operations in colleges and universities generate considerable number of materials consumption. HEIs should address, involve, and promote the minimization of negative effects of resources to help society make the transition to sustainable lifestyles (Velazquez et al. 2006, p. 812). Higher education can model waste management practices which shift toward sustainability for societies. Practical concerns and challenges for implementing sustainability in waste management would also set as reference to societies (Stephens et al. 2008).

Waste Management Strategies (WMS) in HEIs Context

Intervention Techniques Governing the Development of WMS

Production of waste is closely associated with human behaviors such as consumption patterns and lifestyles; it is a mixed result of cultural, economic, and social environment where human behaviors are taken place (Hansen et al. 2002). Steg and Vlek (2009) proposed two intervention techniques which aim at changing human behaviors and improving surrounding environments, namely, informational interventions and structural interventions (see Abrahamse and Matthies 2012 and Bolderdijk et al. 2012 for a detailed review). The ultimate goal of WMS is minimization of waste. To meet the objective, the development of waste management strategies should be built on the challenges of changing individuals' attitudes and in turn their behaviors as well as individuals' surrounding environments where behaviors are taken place.

Informational interventions aim at changing individuals' attitudes, awareness, knowledge, perceptions, and norms which influence individuals' motivations for taking a behavior (Steg and Vlek 2009). There are different types of informational interventions. Providing information is the most commonly used intervention. Disseminating information about waste problems increases individuals' awareness and knowledge of the problem; it offers possible solutions of the problem for individuals to follow (Abrahamse and Matthies 2012). This can be done by launching education and promotional campaigns. Another strategy accompanying with information dissemination is prompting. It is usually a spoken or written message which reminds individuals to behave in an appropriate way, for example, a recycling slogan which draws individuals' attention to participate in recycling practices. Prompting information can also be presented in the form of picture, photos, or cartoon to increase its attractiveness. Our behaviors are partly influenced by people around us. It has always been the pressure of individuals to act upon according to perceptions and behaviors of their important others. The strategy of setting role model would strengthen social norms and inform individuals the perceptions and behaviors of others. Setting a goal and spelling out when, where, and how to reach the goal is goal-setting strategy. Usually, an attractive and easy-reached goal would increase individuals' incentive to engage in behaviors. Goal-setting strategy is closely related to two other informational interventions, namely, commitment and feedback. The former one is asking individuals to make a pledge to perform certain behaviors, while the latter one refers to disclosure of information about how well participated individuals perform the behaviors, for example, the volume of waste that an individual has been reduced over a given period of time.

Improvement of surrounding environments would facilitate behavioral changes. There are different external barriers to behavioral changes, for instance, lack of facilities to complement behavior taking. Structural strategies aim at removing these external barriers by reducing costs while increasing the attractiveness of participating in behaviors. Therefore, availability and quality of infrastructure and facilities, advancement of technology, and establishment of organizations and services which facilitate behavior engagement would be needed. Regulatory measures such as rules and policies would also change the circumstance and thus affect the decision of behavior taking. Moreover, every behavior is associated with consequences, and people tend to obtain positive consequences and avoid negative consequences (Bolderdijk et al. 2012). Thus, rewards and penalties which based on the above assumption would be useful for creating incentives to individuals for behavioral changes.

WMS for Sustainable Development

As mentioned above, daily activities of universities can contribute to pollution and environmental degradation; and common waste management strategies such as landfills and incineration are not sustainable practices. To shift the waste management paradigm to sustainability, developed strategies need to address socioeconomic development without endangering public health and the environment. In this regard, waste management strategies should follow the priority order set out in the waste hierarchy in pursuit of sustainable development. Waste hierarchy was set by the European Commission for establishing preferred program priorities based on sustainability (Hansen et al. 2002, p. 3). It provides a framework for developing waste strategies for sustainable development. According to the hierarchy, a priority order for waste management strategies is prevention, reuse, recycling, and recovery; disposal would be the last resort for waste management. The following will present the strategies with reference to university context in more detail.

Waste prevention is highlighted as a top prioritized strategy for sustainable development. It is the first step that avoids a substance become waste. The strategy reduces the total amount of waste generated as well as the adverse impact associated with waste and optimizes efficiency use of resources. The success of the strategy requires a change of both consumption and production patterns. Amutenya, Shackleton, and Whittington-Jones (Amutenya et al. 2009) suggested that developing policies and regulations would transform waste prevention to a norm and campus-wide practice. Take paper products as an example. Double-spaced and single-sided hard copies of assignments and enormous printed documents for administration make paper products as the single largest component of waste stream in campus (Smyth et al. 2010). Setting up guidelines would facilitate reduction of generating paper waste, for example, providing guidelines to academic departments that students are no longer required to submit assignments printed in double-spaced and single-sided paper or developing policies which require duplex printing for every administrative document; use electronic form to replace printed version of memo for circulation, or centralize all procurements to reduce printing paper (Zhang et al. 2011). Formulating policies also provide clear instructions for preventing the generation of waste. Particularly, green procurement policies with the objective of purchasing products and services that generate minimal waste and reduce adverse environmental impacts become more popular in universities around the world. Financial incentives can be applied to a variety of university activities. Canteen caterers may offer price reduction to participants who order less volume of meals. Students and staff who choose duplex and economic printing may receive cash rebate. To encourage more waste prevention behaviors, there must be provision of facilities to complement waste prevention practices, for instance, more hand driers should be provided to prevent the generation of paper towel waste. Waste prevention requires cooperation from different campus units. Therefore, in addition to various informational interventions for encouraging waste prevention, campaigns and promotional work that aim at raising awareness of and cooperation from different parties within the campus would be necessary.

Reuse is a key component of waste prevention; it is also the second prioritized strategy for achieving sustainable development according to the waste hierarchy. Reuse of products can extend products' life span and reduce the amount of waste directed to landfills or incineration. Procurement policy which includes the requirement of selecting long life span products would be structurally important (Zhang et al. 2011). Besides, establishing exchange center in campus that offers support for reuse practices to students and staff (e.g., allocating products to new users) is suggested. It is expected that reuse of materials or products may not be accepted by every individual. In light of this, changing individuals' perceptions of reuse may be more important than improving the surrounding environments for facilitating behavior change. Other than popular promotional programs, setting up quality-assurance scheme which provides information about the quality of reused materials and products would be more effective for promoting reuse behavior.

Recycling is one of the most popular strategies adopted by universities for making campuses more sustainable. Recyclables provide economic value and further enhance the efficiency use of materials. The practice also reduces the volume of waste being dumped into landfill sites or incinerated and thus causes less harmful effects on the environment. It involves processes that separate collected waste and convert recyclables into useable materials or new products. A large proportion of waste in HEIs is recoverable (Armijo de Vega et al. 2008). For example, there were 33% and over 37% recyclable materials in Brown University in the USA and the Prince George campus of the University of Northern British Columbia in Canada, respectively (Brown University 2017; Smyth et al. 2010); in some developing countries such as the Philippines, about 90% solid waste are potential recoverable in faculty rooms in three universities in Baguio City (Anacio 2017). Common examples of recyclables in university context are paper and paper products for administrative and academic purpose, disposable beverage containers, and food packaging materials.

Investment into recycling infrastructure and hardware contributes to a sound recycling strategy. Facilities such as recycling bins for various types of recyclables should be strategically positioned across campus. Location of distribution needs to be convenient enough that would reduce the cost of participating in recycling behavior (Kelly et al. 2006). Novel and innovative structural interventions are highly encouraged for increasing the attractiveness of participating in recycling. For example, the Chinese University of Hong Kong has introduced PET recycling bins exclusively for bottles made from PET with a No. 1 code around the campus due to the costly source segregation for plastics (seven types of plastic wastes). The practice can sort out PET plastic bottles from other types of plastic bottles, reducing the cost and increasing efficiency of handling recycled plastic bottles (Chinese University of Hong Kong 2015). Offering rewarding incentives such as redemption of gift or coupon to participants once they had recycled a certain amount of waste would also help boost recycling rate. Besides, developing regulations and policies advancing recycling practices in campus environment is utmost important for an effective recycling strategy. A potential structural intervention would be to institute policies requiring all university departments recycle common recoverable substances such as paper products, plastic bottles, glass bottles, and the arising waste electrical and electronic equipment (Zhang et al. 2011). All these structural recycling strategies would not be succeeded without adequate information provided. Interventions such as education campaigns (e.g., Kaplan 2008), posters, eye-catching slogans, exhibitions, and game booths, prompts (e.g., Austin et al. 1993), goal setting (e.g., McCaul and Kopp 1982), and feedback (e.g., Kim et al. 2005) have been adopted by universities' recycling programs of previous studies (Kaplowitz et al. 2009). The information spreads messages such as the importance of recycling may change individuals' attitudes, beliefs, and level of responsibility for recycling (Schultz 2002) and in turn encourage recycling behaviors. Quality of collected recyclables could also be improved by educating participants about the proper practices of recycling.

It is impossible that generated waste could be prevented, reused, or recycled. Recovering waste is an option after all previous strategies have been considered. **Recovery** refers to the processes of extracting energy or materials from the waste. For example, waste can turn into energy through thermal treatment; recovery of organic waste can be converted into energy and compost; materials recovered through recycling are of economic value. Although recovery is prioritized in a relatively low position in the waste hierarchy, the strategy contributes to sustainable development by reducing the demand of using resources as well as the amount of waste being buried in landfill sites. Food waste from campus canteens is a common substance used for recovery. For example, Ithaca College, USA, uses 5 tons of food waste per week to produce compost (Armijo de Vega et al. 2008). Since materials used for recovery (e.g., food waste) usually occupy a large space for storage and need effective odor control measures, facilities and space for storage and advance technologies for recovery (e.g., reducing energy consumption during recovery processes) are required. Besides, increasing awareness of students and staff by using various informational techniques would in turn gain support from them for waste recovery projects.

Disposal is perceived to be contradictory to sustainable development because it is inefficient in making use of potential resources, making energy consumption during waste collection and transportation, causing harmful effects to the environment and public health. However, not all waste can be prevented, reused, recycled, or recovered. With appropriate informational and structural inventions, disposal can also be a strategy that complies with the principle of sustainable development. Universities are suggested to make environmental-friendly disposal management compulsory; specifically, processes of collecting and transporting disposed waste should consume least energy and have minimal adverse environmental impact as possible. Setting goal such as to achieve zero waste to landfill by the targeted year would guide the implementation of other waste strategies (e.g., Arizona State University 2012). Conducting disposal waste audit would give the university itself the performance of reducing waste for disposal (Appalachian State University 2012).

Looking Forward: Challenges of Advancing Sustainability in Waste Management

In recent years, proliferated studies have been found that attachment to a place may cause behavioral responses on behalf of that place (Stedman 2002).

The attachment raises from different sources that related to a place, including place identity, emotional bond between individuals and a place, and connectedness to natural environment of a place (Giuliani 2003; Scannell and Gifford 2010; Stedman 2002). Empirical studies have proved that place attachment is a key driver of taking specific forms of behavior such as private-sphere pro-environmental behaviors (Devine-Wright and Clayton 2010). In other words, actions taken to protect the environment of a specific geographical location, such as recycling and waste reduction, can be considered as place-based behaviors. Such kind of attachment varies across cultures, geographical locations, and societies due the heterogeneity of society, culture, and individuals' backgrounds, which could in turn affect the place-based behaviors. The increased evidence of place-based behaviors (e.g., Scannell and Gifford 2010; Stedman 2002; Uzzell et al. 2002) signifies that waste strategies which are developed based on traditional intervention techniques may not be sufficient to drive the momentum of changing individuals' behaviors. Therefore, alongside informational and structural intervention techniques, human-place relations such as individuals' emotional bonds with a place have the potential to form an independent set of techniques to influence individuals' behaviors.

Another challenge of taking responsible waste management would be the effectiveness of strategies. Informational strategies such as education campaigns may receive a quick response from individuals, but the effectiveness may last for only a short period of time. It is less possibly to maintain the behavior shift and participation rate is likely to diminish once education campaigns were removed or prompts/commitments become insensitive to targeted individuals over a long period of time. By contrast, Iyer and Kashyap (2007) pointed out that effectiveness of structural strategies such as policy measures and regulations are relatively long lasting and return for a more satisfied result. It is because most structural strategies have already been institutionalized, which the behaviors had become normal and routinized. Majority of waste management strategies adopted by HEIs were developed based on the informational and structural techniques. Their effectiveness of changing behavior remains uncertain. It may be a challenging work when deciding the proportion of resources allocated to each type of strategy. Therefore, more empirical studies on effectiveness of WMS should be conducted in HEIs. It is expected that the empirical evidence would provide insights on which strategy would be the best working practice for a specific institution or what combination of strategies would optimize the effectiveness of behavior shift.

Many higher education institutions were found to be heavily relying on recycling programs as their waste management strategies for sustainable development (Fournier 2008; Smyth et al. 2010). It is true that recycling diverts waste from landfills or incineration. However, processing recyclables requires the use of energy and resources (Smyth et al. 2010) which implies that recycling alone is not sufficient for achieving the goal of sustainable development (Armijo de Vega et al. 2003). A genuine implementation of sustainable development in campus operations should include multiple waste management strategies which greater emphasis is placed on waste prevention. More strategies targeting at reducing waste at source should be developed to articulate the commitment of sustainability goals. For example, starting from July 2017 the University of Hong Kong bans the sale and distribution of water in disposable plastic bottles in one liter or less in volume across its campus (University of Hong Kong 2017). The institutionalized strategy provides clear instructions in moving campus operations beyond recycling. Overall, the shift toward sustainability in waste management requires complementation of diversified management strategies which follow the priority order set by the waste hierarchy (Tammemagi 1999).

Conclusions

Rapid economic development results in more waste and thus poses greater threats to ecosystems and human health. Sustainable waste management is important that enables a steady socioeconomic development and protects the environment and our health. It paves the way of development that fulfills the present needs without endangering future generations' development. HEIs would be increasingly important for leading the role of societal transition in this regard. This entry summarized the role of HEIs in facilitating the paradigm shift toward sustainability and provided a set of waste management strategies for sustainable development with reference to HEIs context. Specifically, informational and structural intervention techniques should be incorporated into the development of waste management strategies. Next, different types of strategies for sustainable development according to the overarching principles set by the waste hierarchy were discussed. Prevention should be prioritized above reuse, recycling, recovery, and disposal. There are potential challenges of the sustainable WM movement. This entry would assist universities to set out waste management strategies for sustainable development, which in turn serve the role model of building a better and resilient society.

Cross-References

► Sustainability on Campus
► Sustainability Perceptions

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Waste Reduction and Sustainable Development

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Definition

The meaning of waste has evolved in close connection with socioecological transformations and capitalist ideas of value and nature (Cooper 2010).

Waste often refers to any material or object that is discarded after the end of a process either because it is no longer useful or desirable. The characterization of waste is mainly from the perspective of the user, and what constitutes waste to one person may still constitute a useful input to another person for a different process. Nonetheless, waste reduction simply entails minimizing the amount of useful resources (like food, water, or energy) that is disposed or applied for alternative uses which do not maximize their value. It could also refer to minimizing the amount of waste generated from anthropogenic activities, through efficient product design, production process management, and changes in consumption patterns.

Despite its defining role in the evolution of international environmental law and policy, there is no consensus on the meaning of sustainable development. Significantly, in 1987, the United Nations World Commission on Environment and Development (WCED) published what has become one of the most widely mentioned definitions of sustainable development in its report, Our Common Future. Our Common Future, also popularly called the Brundtland Report because of Gro Harlem Brundtland who served as the head of the Commission that authored the report, states that:

> Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It contains within it two key concepts: the concepts of 'needs,' in particular the essential needs of the world's poor, to which overriding priority should be given; and the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs. (WCED 1987: Chap. 2, para 1)

The Brundtland report further presents sustainable development as "a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional changes are all in harmony and enhance both current and future potential to meet human needs and aspirations" (WCED 1987: Chap. 2, para 15). Other definitions of sustainable development by scholars and technocrats attach varying degrees of importance on each of the three pillars of sustainable development (economic growth, social development, and environmental sustainability) and the role of technology in meeting the needs of the present and future generations.

Introduction

Waste reduction simply entails minimizing the amount of useful resources (such as food, water, or energy) that are disposed of or applied for alternative uses which do not maximize their value. It also means minimizing the amount of waste from anthropogenic activities through efficient product design, production process management, and changes in consumption patterns. Waste reduction and the economic, environmental, and environmental pillars of sustainable development are intricately linked. To start with, waste production is driven by a variety of cultural, personal, political, economic, and geographic factors which vary from place to place (Amritha and Anilkumar 2016; Thyberg and Tonjes 2016). Conversely, waste reduction strategies may impact on culture, personal development, politics, the economy, and geographic landscape, and this affects the prospects of achieving sustainable development. As a result, in addition to technological instruments for waste management (such as recycling and the use of renewable energy in the production process), research focus is also shifting towards understanding what motivates individuals and businesses to produce less waste (for instance, see Ebreo and Vining 2001). Although sustainable development requires waste reduction, an increase in production and consumption patterns aimed at improving human well-being may also inadvertently increase waste production without necessarily addressing the human security challenges faced by the poorest and most vulnerable people (King et al. 2006; Obani and Gupta 2016). For instance, the pressure of population growth has increased both food demand, the food processing industry, and amount of food waste while billions of people still suffer from hunger globally (Ravindran and Jaiswal 2016). On the other hand, reducing food waste requires further efficient production, use, and disposal strategies to ensure sustainability

(Ermgassen, Balmford and Salemdeeb 2016). This makes it imperative both to delink human development from waste production and advance waste reduction strategies which do not compromise human well-being, equity, or environmental protection, in order to advance sustainable development. This entry specifically analyses waste reduction in the context of the increasing global focus on sustainable development and begins with analyzing the evolution and legal status of sustainable development.

Sustainable Development

Evolution

Sustainable development is a widely accepted global objective that is enshrined in over 300 treaties and in the decisions of international courts like the International Court of Justice in the Pulp Mills case and Gabcikovo Nagymaros case (Schrijver 2008). Sustainable development is also enshrined in legal instruments, like statutes, constitutions, and case law, at the national and subnational levels of governance. The concept of sustainable development is aimed at pursuing economic growth and human development, within the carrying capacity of natural systems. Its origin is closely linked to sustainable forest management in Europe during the seventeenth and eighteenth centuries, and the related environmental protection advocacy which highlighted the negative impacts of the overexploitation of renewable and nonrenewable resources (in the pursuit of economic growth and human development) on the environment. Sustainable development had gained global momentum by the nineteenth century, particularly in 1980, when it was recognized as a global priority in the world conservation strategy published by the International Union for the Conservation of Nature.

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In its current form, the broad conceptualization of sustainable development makes it amenable to different development paradigms that would otherwise have been considered to be irreconcilable. As noted by Dryzek (1997: 125), "it is not unusual for important concepts to be contested politically." Although critics question the relevance of an amorphous concept like sustainable development for providing any meaningful change or addressing development concerns (see for instance, Coyle and Morrow 2004), the Brundtland Report significantly highlights the need to delink economic growth/human development and environmental degradation. The definition of sustainable development in the report also emphasizes the need to meet the "needs" of the present and future generations, and "limitations imposed by the state of technology and social organisation on the carrying capacity of the environment" (WCED 1987). Hence, at its core, sustainable development requires intergenerational and intergenerational equity, as well as integration.

The concept, and the principles required to achieve it, is constantly evolving and continues to influence the course of the global development agenda. At the start of the twentieth century, world leaders and international organizations committed to eight Millennium Development Goals, during the United Nations Millennium Summit held in 2000, to address the inequities in human development and promote environmental sustainability through goals and targets that ranged from eradicating extreme poverty and hunger to combating HIV/AIDS, malaria, and other diseases, and developing a global partnership for development. Goal 7 of the MDGs was focused on ensuring environmental sustainability, thereby integrating sustainable development principles into the global development agenda. The MDGs significantly highlighted the inequities in development and sought to redistribute resources in favor of the poorest and most vulnerable people. However, some of the targets (including Target 7c on sanitation) were not met, and some that were met did not fully integrate the three pillars of sustainable development (including Target 7b); the progress achieved with the MDGs was therefore generally uneven.

Again in 2002, the world leaders reiterated their commitment to sustainable development in the Johannesburg Declaration on Sustainable Development and World Summit on Sustainable Development (WSSD) Plan of Implementation. Similarly, the global commitment to sustainable development was reiterated by world leaders at the Rio + 20 Conference held in Rio de Janeiro, as reflected in the outcome document, The Future We Want. More recently, in 2015, the United Nations General Assembly (UNGA) adopted Resolution A/RES/70/1, "Transforming our world: The 2030 agenda for sustainable development" which includes 17 Sustainable Development Goals (SDGs) and 169 targets. The SDGs build on the MDGs (which mainly focused on poverty eradication) and are even more extensive in integrating social, economic, and environmental goals. The SDGs also mirror human rights principles to some extent (for instance, Goal 6 on water and sanitation which incorporates universal and equitable access, safety, and affordability).

Legal Status

Sustainable development is recognized as an objective for the international community, both directly (as reflected in the ICJ decision in the Pulp Mills case and in treaties like the Barcelona Convention for the Protection of the Mediterranean, Energy Charter Treaty, and the UNFCCC), and indirectly (in treaties like the Convention on Biological Diversity and the Kyoto Protocol, that imposes a duty on the contracting parties to promote sustainable development, *inter alia*); this gives sustainable development its legal character. However, the legal status of sustainable development is debatable because of the intricacies of the evolution of international law rules. For instance, there are different opinions on whether or not soft law obligations can establish international law rules (Thirlway 2017). From a positivist perspective, sustainable development can only become a legally binding rule of law if it is contained in one of the sources of international law mentioned in the Statue of the International Court of Justice, like customary law, treaties, judicial decisions, and the writings of publicists.

To establish a custom requires evidence of *opinio juris* and state practice and critics point out the difficulty in establishing *opinio juris* and state practice in relation to a binding obligation on States to develop sustainably (Lowe 1999). Hence, sustainable development cannot be said to have attained the status of custom; rather, it qualifies as "a meta-principle, acting upon other legal rules and principles – a legal concept exercising a kind of interstitial normativity, pushing and pulling the boundaries of true primary norms when they threaten to overlap or conflict with each other" (Lowe 1999: 31). This implies that sustainable development does not directly regulate conduct, but it defines the interactions between primary norms that are regulatory in nature.

Sustainable development is also reflected in more than 300 treaties, including 112 multilateral treaties, and many of the provisions recognize sustainable development as an objective for State Parties to pursue. The treaty provisions are sometimes contained in the preamble (which is generally nonbinding) or stated in general or conditional terms within the operative parts of the treaty. While for some scholars, such soft provisions cannot establish rules of international law (see for instance, Lowe 1999), for others, "the softness of the obligation set out in a treaty provision should not be an obstacle to its validity and binding legal nature" (Barral 2012: 384) and even provisions that are too general to impose a binding obligation to develop sustainably may still constitute interstitial norm by imposing obligations to promote sustainable development which Barral refers to as "obligations of means or best efforts" (Barral 2012).

Further, sustainable development plays a significant interpretative role in judicial decisions which is best served by the flexibility of the content and the wide margin of appreciation that it affords the judiciary in interpreting legal instruments (Barral 2012). Even where sustainable development is not expressly contained in a contractual or legal instrument, it can still influence the interpretation or treaties, by virtue of the provision of the Vienna Convention on the Law of Treaties, Article 31(3)(c), that "any relevant rules of international law applicable in the relations between the parties." Nonetheless, sustainable development can be invoked to resolve tensions between competing development priorities (as in the Gabcikovo Nagymaros case) or where treaties are subject to evolutive interpretation (for instance, in the *Shrimp–Turtle* case).

A Tale of Prospects and Economics

The waste reduction literature mainly focuses on two themes. One theme highlights the positive impacts of waste reduction on various aspects of human development. The second theme expounds on the economic case for waste reduction with reference to both development processes and the environment (like cleaner production and eco-efficiency research). Both themes similarly emphasize on the importance of the human factor in achieving waste reduction but hardly assess the correlation between waste reduction and human well-being.

The positive impacts of waste reduction on sustainable development cut across significant human security threats, like poverty, hunger, diseases, water insecurity and poor sanitation services, and climate change, which the SDGs seek to address. Hence, prospects of sustainable development through waste reduction can be readily illustrated by analyzing the relevance of waste reduction to realizing the SDGs. Based on simple macroeconomic principles of demand and supply, waste reduction could increase the amount of resources that are available for development activities and thereby reduce the cost of development and alleviate poverty and inequality (Goals 1, 8, and 10); contribute to ending hunger, achieving food security and improving nutrition (Goals 2 and 12); improve health outcomes (Goal 3) and gender equality especially as women often bear the brunt of waste (Goal 5); and promote education among children especially (Goal 4). Specific examples can be drawn from food waste, water management, and solid waste management through the use of landfills.

Food waste (which includes discarding food or using food that is safe for human consumption for alternative nonfood purposes) contributes to food loss, waste of nonfood resources that are employed in the food production process, and significant climate impact (see for instance, Betz et al. 2015; Katajajuuri et al. 2014). In the USA alone, nearly 40 percent of the food produced is wasted; about 52.4 million tons of food ends up in landfills, while around 10.1 million tons are unharvested; this leads to losses of up to $218 billion per annum yet around 50 million Americans face food insecurity (Hunt 2016) which entails lack of safe and nutritious food; lack of economic, physical and social access; an inability to use food to meet dietary needs for wellbeing; and lack of stability along the food value chain. Globally, approximately 815 million people are undernourished with the highest prevalence in sub-Saharan Africa (United Nations 2018).

Nonetheless, food waste can be harnessed for anaerobic digestion and renewable energy production (see for instance, El-Mashad and Zhang 2010; Hobbs et al. 2017; Zhang et al. 2007). Hence, food waste reduction may also improve environmental sustainability by reducing the amount of food that ends up in landfills and water bodies (Goals 6, 14 and 15). Nonetheless, some strategies for addressing overproduction and waste at the end of the value chain (including serving waste and plate waste), which are some of the main sources of food waste (Betz et al. 2015; Eriksson et al. 2017; Silvennoinen et al. 2015), may inadvertently lead to loss of livelihoods for manual laborers working in food production or exacerbate hunger where much higher costs are imposed for larger food portions.

Similarly, the use of water that is safe for drinking for alternative personal or productive purposes which do not require water of drinking water quality (including personal sanitation, agriculture, and laundry) amounts to waste and also contributes to economic scarcity and water insecurity for the poorest (Goal 6), while increasing the amount of wastewater produced from anthropogenic activities (Obani and Gupta 2016). Waste reduction in production and manufacturing, for instance, through Total Quality Management strategies, reduces the amount of renewable and nonrenewable resources expended on human development and economic growth and thereby promotes sustainable production patterns (Goal 12). The conversion of waste to energy can also promote universal access to affordable, reliable, and sustainable energy (Goal 7), which would enhance the sustainability of communities (Goal 11) and reduce greenhouse gas emissions (Goal 13).

Waste reduction further benefits the environmental pillar of sustainable development (Goals 13, 14 and 15) by reducing the amount of plastic debris and other harmful waste that are already contaminating the environment at an alarming rate (Jambeck et al. 2015), minimizing the need for new landfills, preventing the associated conflicts (Goal 16) over scarce land resources and related environmental justice issues over the siting of landfills, and eliminating groundwater pollution, leachate contamination, greenhouse gas emissions, and negative impacts on soil stability (Amritha and Anilkumar 2016). However, waste reduction may further affect the livelihoods of small scale waste managers, like scavengers and waste pickers. For instance, a recent study of waste picker livelihoods and solid waste management in the La Chureca garbage dump site in Managua, Nicaragua, shows evidence of displacement and impoverishment of poor informal waste pickers despite attempts to modernize and enclose the municipal waste management system (Hartmann 2017).

Implications for Sustainability Science

Sustainable development is a global concern which underlies the SDGs, and waste reduction is one of the imperatives for realizing the 17 SDGs by 2030. Waste reduction may minimize environmental degradation and enhance the efficient use of natural resources to address human security threats like hunger and poverty. With waste reduction strategies primarily designed to minimize environmental degradation and conserve resources, the impacts on the social pillar of sustainable development become underemphasized. This entry has highlighted the intricate links between waste reduction and SDGs. Nonetheless, waste reduction strategies may inadvertently exacerbate inequities and the human security challenges which the SDGs ought to address. This buttresses the need for waste reduction to serve as an instrument for improving the social pillar of sustainable development, rather than being considered as an end in itself or as an instrument for advancing the economic and environmental pillars predominantly. Hence, waste reduction needs to be structured to balance economic, environmental, and social objectives both in the short term and long term in order to truly advance sustainability. To achieve this, waste reduction strategies should be designed through participatory approaches that involve the poorest, most vulnerable and marginalized communities, with consent rules that ensure their perspectives are integrated in the decision-making process.

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Water Conservation Strategies for Sustainable Development

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Definition

Water is one of the most essential elements to survival. Globally, the amount of available water is rapidly decreasing, affecting availability and access for potability, sanitation, and agriculture. Water scarcity is an urgent and growing problem.

Introduction

Water scarcity is defined as the lack of available, safe water and water supplies to meet the needs of the community. Statistics show that, globally, 2.1 billion people lack the access to water that is safe to consume and 4.5 billion people lack access to services of sanitation. Estimates are that 40% of the global population is affected by water scarcity, and this number is predicted to increase (United Nations n.d.-a). The significance of access to potable water is clearly articulated in Sustainable Development Goal (SDG) 6, "Ensure availability and sustainable management of water and sanitation for all." The targets of SDG 6 cover all aspects of both the water cycle and sanitation systems, and the connection of SDG 6 to the attainment of the SDGs overall can be found in the relationship between water and health, education, economics, and the environment (United Nations n.d.-b). Sustainable Development Goal 6 has six subsections of targets to be reached by 2030. These include universal access to safe, affordable potable water, access to adequate sanitation, reducing water pollution by reducing chemical dumping, increasing sustainable withdrawals, creating integrated water resources management, and improving protection for natural ecosystems that provide water. SDG 6 also includes goals of cooperation and participation at both a local and international level (United Nations 2018). Water is crucial for energy production, food production, and every ecosystem including human. Globally, 70% of water withdrawals are used in agriculture, around 75% of industrial water withdrawals are used in energy production, and 80% of untreated wastewater flows into natural ecosystems (United Nations n.d.-a).

A water footprint is the quantified value of water consumption and is the water used in production processes for goods and services. There are three types of water that contribute to this water footprint, and they are categorized as blue, green, and gray water. Blue water is defined as freshwater evaporated from surface water and includes groundwater. Green water is water that has evaporated from rainwater that becomes stored in the soil, and gray water includes polluted water resulting from human use and production activities (Hoekstra and Mekonnen 2012). The use and creation of these water types affect the limited supply of naturally occurring water.

Water, Pricing, and Scarcity

A main contributor to the overconsumption of water is its pricing. Water is considered a normal good, and because of its low price, it is consumed on a want basis instead of a need basis. This results in the overuse of water. The system of setting prices leaves out externalities, so the price of water is skewed by perceived abundance on the supply-side and market power on the demand-side. Different countries have different access to different amounts of water resources and have different resources for recycling and treatment of water leading to variation in value and cost (Skene and Murray 2017, 97).

Another varying measure of water is the groundwater footprint. This varies from the general water footprint because it measures the land area required to supply sufficient rainwater to underground systems. The more land required, the less sustainable the use of groundwater. While all countries vary in their footprints, globally 131 billion square kilometers of land are required based on the footprint measurement (Skene and Murray 2017, 99); the magnitude reveals the unsustainability of the present use of groundwater.

Presently, there is a global water crisis emerging. There are solutions that have been proposed: a soft water path and a hard water path. The soft water path focuses on demand to reduce the use and waste of water and on decentralizing supply to disperse the water as wide as possible (Skene and Murray 2017, 100). The hard water path focuses on supply and on the centralization of water by using dams and boreholes to contain large amounts of water (Skene and Murray 2017, 100). The hard water path focuses on the future and is based on forecasts of future water needs based on the current trends. The soft water path focuses on back-casting, what is needed to achieve the current goal.

Water Vulnerability

Water vulnerability measures water's potability and the amount of potable water. Developing countries have the highest need for access to safe water. Lack of safe water and sanitation cause 80% of illnesses in developing countries. The lack of sanitation creates an increased vulnerability and lack of safety for women (Global Affairs Canada 2017). Developing countries also lack access to safe drinking water. Their water is highly contaminated and causes many diseases and health impacts due to contamination by bacteria and viruses. *Escherichia coli*, *Vibrio cholerae*, and acute bacillary dysentery are a few bacterial pathogens. In addition, the most common viruses are often found in water sources and lead to infant diarrhea, which can become dangerous and fatal. These viruses cause over a million deaths annually (Sudha et al. 2012). In the past decade, 1.3 billion people gained access to safe drinking water in developing countries. Globally 2.1 billion still lack the access (United Nations n.d.-b). The relationship between potable water access, sanitation, and morbidity and mortality is the principal reason for the United Nations adoption of SDG 6. These conditions are consistent with poverty and poverty elimination is central to the SDGs. Furthermore, lack of safe drinking water and sanitation are also consistent with a lack of sustainability related to population, health, and political and economic stability (United Nations n.d.-c).

Agriculture requires water and accounts for 70% of water utilization in developing countries (Lawson and Lyman 2007). The water intensity places harder burdens on developing countries; in developed countries the water utilization is lower. For example, in the United States, only 37% of water withdrawals are used for agriculture (Weil 2013). Developing countries have inefficient methods of irrigation and agricultural practices, leading to excessive withdrawals and slow replenishment. Their practices also lead to deeper water tables, highlighting the depletion risk within these countries (Lawson and Lyman 2007). A water table measures how deep the ground is filled with water. Water tables have gone through ups and downs in their depths, and the speed of climate change is leading to deeper water tables and drier surfaces. As a result, even deep water tables are showing evidence of depletion (Nijp et al. 2014). Developing countries do not have the necessary finances to expand their water supplies, and their low tariffs on water lead to further wasteful use (Lawson and Lyman 2007). In developed countries, water consumption is at high levels due to large systems of irrigation and consumer overconsumption (Haddeland et al. 2014). In just the United States, an average family consumes 552 gallons of water on a daily basis (Weil 2013). These human impacts are increasing the global scarcity of water.

Further exacerbating water access and availability is the speed of man-made climate change. Climate change is leading to rapid increases in the rate of snowmelt and runoff. The pace disrupts water storage because of the early, unexpected runoff. Reservoirs and dams presumably built to collect this water are not capable of holding the rapid accumulation, resulting in flooding, which has been observed on a global level. The inability to capture water is a contributing condition to limiting the supply of usable water (Zellmer 2012). To counter natural shortages and emerging risks, human intervention through technology has been focused on desalinization of sea or salt water sources and also cloud seeding. Further, given the use of water in agriculture, there has been a technology focus related to irrigation and bioengineering drought-resistant crops.

Animals and Plants

Producing animal products accounts for around a third of global water consumption. The production of a single egg requires 53 gallons of water, and one hamburger requires 660 gallons of water. Up to 33% of freshwater consumption is from animal agriculture (Mercy For Animals 2018). Livestock's blood is composed of 80% water, requiring high levels to maintain proper hydration (Ward 2019). This is greater than the levels of water in human blood. A human requires 2.7 l for women and 3.7 l for men of daily water consumption to survive (Mayo Clinic 2017). Animals are composed of more water, so they require much more water to survive. For example, a milking cow can require over 150 l of water daily depending on its level of production (Ward 2019). These large water needs to animals only make up a third of global water consumption. Seventy percent of blue water collection is used for agriculture and will increase by another 19% in the next 30 years from just irrigation consumption (Weltagrarbericht n.d.). For irrigation alone, almost 70% of freshwater withdrawals are used (United Nations n.d.-a). These withdrawals used for plant growth are extremely variable due to climate effects. For example, a plant in a hotter, drier climate requires more daily water than one in a cool, humid climate. Standard grass water consumption can vary from 1 mm to 10 mm of daily water based on the temperature and climate zone (Brouwer and Heibloem n.d.).

Irrigation

Agriculture requires immense amounts of water. Water used for agriculture is withdrawn from surface water areas likes rivers, reservoirs, and lakes, from groundwater, and from rainwater. The water withdrawn for agriculture used for irrigation totals to almost 90% of consumption use (Houser et al. 2015). Increased dependence on surface water has caused an increase in the depletion of surface water areas. An additional problem is soil and ground water pollution. Fertilizers and other chemicals used for agricultural purposes increase the levels of pollution in the soil and cause moisture deficiency in the soil (Houser et al. 2015). Nitrogen, an important chemical in fertilizers can become a harmful pollutant to groundwater. Excessive amounts used leads nitrates to enter and invade water. Nitrates in groundwater, a major drinking water source, causes fatal diseases to infants and nitrosamines which can be cancerous (Huang and Lantin 1993).

Several methods and strategies exist focused on conserving water via new irrigation systems. This modernization of irrigation infrastructure saves water without sacrificing agricultural production. Trickle irrigation should replace sprinkler irrigation (Atkinson 1979). Trickle irrigation applies water directly onto the surface by the root of the plant. This uses less water because it focuses on areas that need watering instead of spraying the water everywhere in a space that has plants (Atkinson 1979). This system eliminates weeds because there is less water between the plants where sprinkler irrigation would've created moisture.

Another method of water-saving irrigation is irrigation using reclaimed wastewater (Asano 1987). Wastewater is water that has changed in quality due to use and is no longer usable for drinking or agriculture. Wastewater can be broken down into domestic wastewater, industrial, and infiltration-inflow. Domestic water is the water supply of the community that is used, inflow is the flow of storm water into the sewage systems, and infiltration is groundwater that has improperly entered the sewage systems (Asano 1987). The process of wastewater purification starts with a sewage system that drains and screens water. Then the water enters a chamber that removes grit from the water, known as preliminary treatment. Next, primary treatment sends water to primary settling tanks which purify the water by separating particles out of the water. Next, secondary treatment uses bacteria to consume the remaining contaminants in the water. These contaminants removed turn to sludge, and the treated water is inspected with extremely high standards to ensure highest level of safety of water (Yoneda 1980). The result of the purification process is reusable water available for irrigation. The sludge of contaminants from the secondary treatment is mixed together and heated to produce biogas. Activation of sludge is used for both electrical and thermal energy. The facility that is treating wastewater uses the sludge for energy production. By producing their own electricity and heating, they become self-reliant for energy consumption (Yoneda 1980).

Organic farming is another sustainable method of agriculture that reduces reliance on fertilizers and harmful chemicals. Developing countries have the most pesticide poisonings because of their misuse of the pesticides, due to their lack of access to information and efficient uses (Ravnborg et al. 2013). Organic farming focuses on sustainable soil and ecosystem health. Instead of changing ecosystem functions to produce a desired outcome, organic farming relies on the natural ecosystem functions to produce wanted results (Diekmann and Polacek 2013). Organic fertilizers are made from organic materials like manure or compost. Using these natural fertilizers and promoting sustainable soils have led to increases in organic carbon levels (Gattinger et al. 2012). Working with organic farming to restore and sustain soil health is the reduction of tillage systems. Tillage causes erosion of soil and shrinking of its pore space for water. The removal of these tillage systems promotes soil moisture increasing its sustainability and organic makeup (Mäder and Berner 2012).

Water and Desalinization

Salinity of soil measures the concentration of salt in the soil. High salinity is dangerous to agriculture because it prevents crop growth. 20% of agricultural land and 50% of cropland globally is over-concentrated with salt (Xu et al. 2014). Desalinization is the process of removing the excess salt minerals from the soil, so it can be used for agriculture. Methods include heat distillation, ion extraction, ion exchange, electrodialysis, freezing desalinization, solar humidification, and iceberg towing (Schutt n.d.). Heat distillation is heating water to the point of evaporation and condensing the vapor to create freshwater (Schutt n.d.). Ion extraction is the use of chemicals or electricity to remove ionized salts from the water (Schutt n.d.). Ion exchange is replacing the ions from the sea water with ions from a resin (Schutt n.d.). Electrodialysis uses electric currents to attract the ions. The specific current only allows the positive ions to escape the water's membrane to ensure only necessary elements are removed (Schutt n.d.). Freezing desalinization involves freezing water because salts are not included in the components of ice, automatically removing the components (Schutt n.d.). Solar humidification uses solar energy to increase water vapor creation. The vapor is condensed, as in the heat distillation method (Schutt n.d.). Iceberg towing is using icebergs as a freshwater source and transporting parts of the iceberg to land (Schutt n.d.).

Cloud Seeding

Rainwater is a major source of water. Too much water is held in clouds and not released. This water could be used effectively to reduce water scarcity. Cloud seeding is the concept of getting the clouds and the atmosphere to release this stored water. The water needs to be at a temperature low enough to increase the weight of the water, so it is released and falls from the air. Cloud seeding is purposefully modifying the weather to increase this water precipitation. Silver iodide is used to seed the clouds to promote the precipitation. Silver iodide imitates ice crystals. The seeding causes the water in the air to attach to the silver iodide, giving them the weight necessary to drop (Baum 2014). This increases rainfall, increasing supply of water that can be collected and used.

Drought-Resistant Agriculture

Attempts have been made to create drought-resistant crops in order to improve agricultural systems. Genetically modifying crops to become drought-tolerant or drought-resistant is an expensive, failing process. Droughts have a variety of types and causes, so engineers cannot prevent all of these from affecting agriculture (Gurian-Sherman 2012). These attempts are small in number and success, so the goal of water conservation has not occurred (Gurian-Sherman 2012). Major problems include the limits of genetic engineering, drought variation, and soil interference (Gurian-Sherman 2012). A few genes can be modified at a time, and these few cannot be made completely drought-tolerant. There are several forms of droughts based on severity and timing in season. Soil quality, which is not modified, reacts to droughts and impacts the crop's ability, even with genetic modification (Gurian-Sherman 2012). The genes changed to tolerate the drought can also lead to other problems like slower growth rates (Gurian-Sherman 2012). There are also so many unknowns to the effects of attempting to create drought-resistant crops. Genetically modifying agriculture to resist droughts is an expensive, counterproductive method of water conservation. Modifying farming and breeding approaches are more cost-effective and successful in conserving water (Gurian-Sherman 2012).

Water and Sanitation

In developing countries, a lack of access to sanitized water is the leading cause of death for children under 5 years old; accounting for approximately 1,000 deaths of these children daily is poor sanitation of water ("Water, Sanitation and Hygiene," n.d.). Sanitized water means water purified to a point where drinking it is completely safe and does not come with risk of infection or disease. The large amounts of contaminated water around the globe makes sanitization difficult. This leading cause of child mortality is the lack of drinking water and sanitation, causing diarrhea so extreme that the children die. 780 million people around the globe have no access to sources of safe water ("Global WASH Fast Facts," n.d.). Poverty and disease stem from a lack of access to sanitization. Contaminated water leads to infections like the Guinea worm disease. GWD is a parasitic infection that consists of worms coming out from one's body via blisters (Hopkins and Foege 1981). This is spread through the drinking of unsafe water. Trachoma, which leads to blindness, comes from poor sanitation (Treharne 1985). Without facilities to safely remove waste from human contact, people turn to open defecation ("Water, Sanitation and Hygiene," n.d.). This creates two major problems. One is for women who have to wait until it is dark out to avoid assault, interfering with their natural bowel movements. The other is fecal matter becomes exposed in the environment seeps into consumed resources, increasing disease prevalence ("Water, Sanitation and Hygiene," n.d.). Poor water sanitation is a danger to education. Children, usually girls, are sent to find and collect water for their families, preventing them from getting an education because of the time spent looking for water sources ("Water, Sanitation, and Hygiene," n.d.). By improving sanitation and increasing quantities of safe water, "there is the potential to save the lives of 840,000 people who currently die every year" due to the lack of safe water and sanitation ("Water, Sanitation and Hygiene," n.d.).

Modifying and creating infrastructure to prevent runoff of contaminated water into freshwater sources will increase sanitation. This will increase the volume of safe drinking water, as well as take away the risk of how safe it really is to drink. One method to collect water and increase sanitation is through rain catchment systems (Stevenson 2008). These function to give the individual control in collecting their water and using it to their needs. The system connects a tank that collects water through a gutter, so rain water runoff is collected and used instead of lost and wasted (Stevenson 2008). Especially in poor, developing countries, every drop of water is necessary, so this system makes extreme differences in their hygiene. Another solution for the distribution of freshwater especially in poorer countries is through solar-powered water pumps ("Solar-Powered Water Pumps," n.d.). These pumps function to distribute 30,000 l of clean, safe water every day. A hole is drilled far down to reach a water source, usually around 100 m. Then solar panels are used to power a motor that pumps the water from underground into a tank. This tank is connected to pumps throughout the community via a system of pipes increasing water availability and safety ("Solar-Powered Water Pumps," n.d.). This saves the children's energies and times increasing their opportunity for education.

Water and Infrastructure

Many water infrastructure systems built are composed of unsustainable materials causing problems with current infrastructure function. The costs of these problems have grown because of the lack of action to fix the problems. The aging pipes allow hundreds of billions of gallons of wastewater to flow into waterways, deeply threatening human health. In the United States alone, around seven billion gallons of water are lost every day (Terrero et al. 2013). Infrastructure is inefficient and leads to a lack of water because of the quantities wasted and lost. The large numbers of overflows from sewage systems has led to 10 billion gallons of untreated wastewater ending up in the United States' surface water areas.

The costs of replacing and fixing all of the infrastructure in a country can be extremely expensive, trillions of dollars from the buildup of lack of action. There are cheaper alternatives to creating sustainable infrastructure to decrease the non-safe water being distributed into our safe water sources. Using Public-Private Partnership programs, or P3 programs, allows public agencies to create agreements with any private association. This private company will take care of the constructions, operations, and rehabilitation of the water infrastructure systems. This allows the private company to manage the finances of the project, to decrease prices for the public to pay (Woodside 1986). Filters exist to fix the problem of old pipes carrying pollution. The Berkey Water Filter removes any metal ions from the water, including fluoride and arsenic ("Alternative Technologies and Assessment for Water and Wastewater Utilities," 2017). Eliminating this pollution creates a method of purifying the water, increasing the sustainability of water by removing pollution and creating new, safe water. These filters last many years, therefore increasing sustainable practice.

These irrigations systems of water purification use reclaimed wastewater; this purification level is not up to a standard of safe-to-drink (Lowrie et al. 2014). In order to be deemed safe-to-drink, water must be analyzed for numerous contaminants. Regulations include treatment for 81 MCLs, for inorganics and organics, 6 MCLs for microbial organisms, 4 radionuclide MCLS, filtration and disinfection, and treatment for lead, copper, acrylamide, and epichlorohydrin. These treatment requirements are protecting human health by ensuring the safest drinking water (Cotruvo 2012). Risk still exists for contamination requiring constant technological development to minimize exposure. To wisely use funding, regulations dealing with low-risk contaminants should be eliminated, priority needs to be made with the most risk situations, local action should be taken, and infrastructure needs to be cleared of contaminants (Cotruvo 2012).

Infrastructure that is old and contaminated can lead to the distribution of unsafe drinking water. Focusing on small systems should be prioritized instead of the large-scale systems that are costly and not effective. A small system is the green infrastructure (Henrie 2008). This is a technique of replicating the natural water cycle to clean storm water and reduce its runoff. Because the actions taken are replicating nature, they are both cost-effective and sustainable (Henrie 2008). Examples of green infrastructure are green roofs, which involve extending a roof to include waterproofing, root repellents, filters, draining, and areas of growth for plants. This green roof idea is almost creating a space of nature, as it should come about naturally without interference from pollution. Another method of green infrastructure is planting trees. Something so simple yet effective as trees collect water and reduce runoff. Lastly creating porous pavements to allow water to go through and into the ground below that requires water to strive (Spicer 2010). These simple, sustainable methods of infrastructure create a world of difference in conservation and smarter use of water. Aside from green infrastructure, a focus needs to be put on protection the sources of freshwater. If we focus on methods to protect and increase these sources, we can save money on operating systems of treatment and on large infrastructure. The last small-scale method that makes large-scale difference is decentralizing wastewater. This involves small septic systems to treat and disperse wastewater. It takes small amounts of the wastewater to different places away from domestic homes and commercial buildings. This decentralization prevents wastewater overflow, reducing risk of health damage (Santora and Wilson 2008). These small-scale solutions are cost-effective, and their impacts reduce many of the larger scale problems. These all contribute to sustainability of the infrastructure, creating sustainability of the water involved. If steps are not made, developed countries will continue to waste money attempting to delay system decay, and developing countries will never be able to attain infrastructure that could improve potability and sanitation.

Conclusion

Water scarcity is a significant issue globally; however, its impact is disproportionately felt between developed and developing countries. Developing countries battle with the problems of inefficient overuse of water in agriculture, limited supply of potable water, and insufficient resources to enable proper sanitation. The latter leads to millions of deaths annually from preventable bacterial and viral infections, primarily in infants.

The pricing of water has promoted its overuse. In many areas around the world, water is provided free of charge; in the majority of the remaining, the price is negligible. Arguably, the perceived cheapness of water has led to both its overuse both in direct human consumption and in the production sectors. Externalities related to agriculture are placing pressure on water resources. Crop yield is protected by herbicide ad pesticide use, both of which impact groundwater, contaminating its potability and potentially contaminating the waster for other uses as well. Animal agriculture impacts water through the production of feed, which is water intensive, as well as direct animal consumption.

There are present technologies in use and being developed to address the water shortage, and these include drip irrigation to desalinization to experimental cloud seeding. SDG 6 is dedicated to water and sanitation and is also connected to poverty eradication, the central theme of the SDGs. By addressing water in the context of a fundamental human right, the SDGs elevate the responsibility of providing access to water to the global forum. This latter attribution is a next step in the history of water.

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Water Demand Reduction and Sustainability

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Definition

Mulch: A mulch is a layer of material applied to the surface of soil. Reasons for applying mulch include conservation of soil moisture, improving fertility and health of the soil, reducing weed growth, and enhancing the visual appeal of the area.

A mulch is usually, but not exclusively, organic in nature. It may be permanent (e.g., plastic sheeting) or temporary (e.g., bark chips). It may be applied to bare soil or around existing plants. Mulches of manure or compost will be incorporated naturally into the soil by the activity of worms and other organisms. The process is used both in commercial crop production and in gardening and, when applied correctly, can dramatically improve soil productivity.

Introduction

As the population in tertiary education is continuing to grow, this has increased the demand for food, thus adding pressure to the food supply system. At the same time, food producers are experiencing great competition for land, water, and energy (Godfray et al. 2010). Overarching all of these issues is the threat of climate change and concerns about how mitigation and adaptation measures may affect the food system.

Agriculture as their main food source in higher education institutions relies on water for the survival of crops. However, it is severely affected by frequent droughts which leads to crop failure, hunger, poverty, and pests and disease outbreaks. Identifying ways to mitigate drought and stabilize yields by encouraging smallholder farmers to adopt best management practices is fundamental to realizing food security and improved livelihoods (Shen et al. 2012; Bhardwaj 2013). This entry highlights how mulching conserves soil moisture in crop lands, hence reducing the amount of water supplied to crops. This can increase food production for institutions of high learning.

Mulching

Mulches are important in higher education farms especially in arid and semiarid regions to modify soil temperature. The practice of mulching is as old as agriculture itself. Mulching is an essential agricultural technique in which the use of organic or inorganic material is used to cover the soil surface around plants. The usual purposes of surface treatment by some type of mulch are to prevent water loss by evaporation, to influence soil temperature, or to minimize weed growth (Qin et al. 2015). This technique is useful for water conservation, erosion control, helping to produce healthier plants, potentially increasing crop yields, soil conservation, moderating soil temperatures, and protecting the roots of the plants from heat and cold, thus reducing water supplied to the plant stations, reducing salinity and weed control. It reduces the amount of work by higher education workers or students and exerts decisive effects on earliness, yield, and quality of the crop. Mulching is applicable to field crops, fruit orchard, flower and vegetable production, nurseries, and forest where frequent cultivation is not required for raising the crops.

After decomposition, organic mulch adds plant nutrients, improves soil structure, and increase crop quality and yield. Thus, they facilitate more retention of soil moisture and help in the control of temperature fluctuations; improve physical, chemical, and biological properties of soil, as it adds nutrients to the soil; and ultimately enhance the growth and yield of crops. In addition, mulch can effectively minimize water vapor loss, soil erosion, weed problems, and nutrient loss (Shen et al. 2012).

Types of Mulching Materials

Organic Mulches

Organic mulches in tertiary farms are derived from plant and animal matter such as straw, hay, peanut hulls, leaf mold, compost, sawdust, wood chips, shavings, and animal manures. The mulches return organic matter and plant nutrients to the soil and improve the physical, chemical, and biological properties after decomposition, which in turn increases crop yield. Soil under mulch remains loose and friable, making it suitable for root penetration. The organic mulches not only conserve the soil moisture, but they also increase the soil nutrients through organic matter addition to achieve optimum advantage from the organic mulch; the mulch is applied immediately after germination of crop or transplanting of seedlings at quantities depending on specified needs. Organic mulches are efficient in the reduction of nitrates leaching, improve soil physical properties, prevent erosion, supply organic matter, regulate temperature and water retention, improve nitrogen balance, take part in nutrient cycle, as well as increase the biological activity (Bhardwaj 2013). However, natural materials cannot be easily spread on growing crops and require considerable human effort. Expense and logistical problems have generally restricted the use of organic mulch in horticultural crop production with only limited use on a large commercial scale. Nevertheless, most farms in tertiary institutions keep animals and grow crops (mixed farming) for consumption; thus organic mulches can be used.

Crop residues affect soil water content by having a direct effect on the evaporation from the soil surface and on the amount of water that infiltrates into the soil. The residues significantly influence evaporation by affecting (Teame et al. 2017) (1) net radiation due to changes in surface albedo, (2) aerodynamic vapor conductance due to changes in wind speed, and (3) resistance to vapor diffusion, which is dependent on mulch thickness, tortuosity, and volumetric air fraction. Decreases in infiltration due to sealing of the pores caused by raindrop impact are reduced by crop residue cover. The surface residue affects the absorption of solar radiation and decreases the thermal admittance of the surface relative to that of bare soil, so that more of the absorbed radiant heat goes to the atmosphere, thus decreasing the energy available to heat the soil (Yunusa et al. 1994). Soil warming is also affected by the evaporation under a mulch relative to a bare soil and the decrease in sensible heat transfer between overlying air and the soil.

Inorganic Mulches

The most common types of inorganic mulch are rocks or gravel, plastic sheeting, landscape fabric, and rubber mulch. Inorganic mulches are made from nonliving materials. Inorganic mulches do not decompose. Some slowly break down only after a long period of time. The benefits of inorganic mulch are that they may initially cost more, but they are more cost-efficient because they do not need to be reapplied or topped off as frequently as organic mulches. The disadvantages of inorganic mulches that do not decompose is that they do not add any nutrients to the soil, and, in fact, some can prevent nutrients from reaching the soil altogether. Using inorganic mulches adds aesthetic value, and they work well to suppress weeds. However, they do not help much in retaining soil moisture, protecting plants through winter, or adding nutrients to the soil from decomposition as organic mulches do (Kwambe et al. 2015).

Inorganic mulch includes plastic mulch and accounts for the greatest volume of mulch used in higher education crop production. The plastic materials used as mulch are polyvinyl chloride or polyethylene films (Hossen et al. 2017). Black plastic mulch is most commonly used in agriculture in schools, colleges, and universities. Clear plastic mulch is also used due to its increased soil warming characteristics. Owing to its greater permeability to longwave radiation, it can increase temperature around the plants during night in winter. Hence, polyethylene film mulch is preferred as mulching material for production of horticultural crops (Bhardwaj 2013). Research has shown that white or aluminum reflective mulch also repels aphids which spread some virus diseases in vine crops such as squash. Thus, mulching can be effective change in increasing crop production in water scarcity regions.

Data Collection

Researchers from higher education institutions conducted some experiments investigating the effects of different types of mulch on soil moisture. Literature on their publications on the effects of mulching on water conservation were searched using Google Scholar. Search terms included “mulch” and/or “mulching,” “soil moisture” and/or “conservation,” and “water” in the article title, abstract, and keywords. Conference proceedings and non-English language publications were excluded. This search produced publications, which were screened on the basis of the following criteria: (1) studies must contain both no-mulching and mulching treatments (either organic or inorganic mulching); (2) soil moisture and water demand were all reported so that the interactions between mulching and water can be quantified; and (3) location and year information of the experiment were stated.

Results

Effect of Organic Mulching on Soil Moisture

Depar et al. (2016) conducted a field to evaluate the effect of different mulches on soil moisture and yield of wheat. Five types of organic materials such as wheat straw, mung bean straw, rice husk, farmyard manure, and poultry litter were used for mulching. A control without any mulch material was kept for comparison. Findings show that different mulches conserved the soil moisture content to 16–27% over control (Table 1). Wheat straw retained maximum soil moisture, while the control field retained the least.

Application of different mulches had significant effect on soil moisture. These findings suggest that wheat straw and sugarcane trash mulch could be used effectively for mulching to conserve soil moisture and increase crop productivity.

Effect of Inorganic and Organic Mulching on Soil Moisture

A field investigation on the effects of mulching using clear polythene, black polythene, grass, and rice leftovers on soil moisture revealed significant differences (Kwambe et al. 2015). The highest soil moisture content was recorded from soil mulched with rice leftovers and lowest soil moisture content of 45.77% from control soil which was not mulched (Table 2).

Higher soil moisture content below the mulches in various mulching treatments is due to reduction of water erosion, reduction in soil surface evaporation, and suppression in extreme fluctuation of soil temperature. This has resulted more stored soil moisture and the minimum soil moisture in control plot due to higher evaporation from the bare soil surface of the basin.

Water Demand Reduction and Sustainability, Table 1 Percentage increase in soil moisture over the control (no mulch) as a result of organic mulching at 0–20 cm depth

Type of mulch	Soil moisture retained (%) over the control
Wheat straw	27
Farmyard manure	24
Rice husk	20
Mungbean straw	19
Poultry litter	16
Soybean straw	13
Sugarcane trash mulch	28
Intercultural operation	8

Source: Depar et al. (2016), Chavan et al. (2010)

Conclusion

This paper makes a review of literature from higher education research work on the role of mulching in preserving soil moisture. Mulch is a protective ground covering that saves water, reduces evaporation, prevents erosion, and controls weeds. Mulches can be classified as organic or inorganic. Organic mulches enrich the soil. Mulching reduces soil moisture loss through evaporation. It also reduces the soil's exposure to wind which also reduces water loss through evaporation. The insulating quality of mulch helps to keep the soil cooler in the summer and warmer in the winter. By maintaining more even soil moisture and temperature, mulch promotes better root growth and plant health. Mulch also helps to reduce rain splash and runoff, which can help to prevent erosion is steep areas.

Water Demand Reduction and Sustainability, Table 2 Effects of organic and inorganic mulches on soil moisture content at 0–30 cm depth

Type of mulch	Soil moisture conserved (%)
Black polythene	60
Clear polythene	57
Grass	50
Rice straw	63
Maize straw	60
Control (not mulched)	46

Kwambe et al. (2015)

Mulching influences the soil hydrothermal regime by influencing the radiation balance, the rate of heat and water vapor transfer, and heat capacity of the soil. Mulching improves the physical condition of the soil by enhancing soil aggregation and helps in conservation of water by checking evaporation, increasing infiltration, and retarding runoff loss. Conservation of soil moisture is one of the major benefits of mulch farming system. Organic mulches add nutrients to the soil when decomposed by microbes and help in addition to soil organic carbon and nitrogen. Favorable soil edaphic environment under mulch improves crop productivity, enhances input-use efficiency, and checks environmental pollution.

Conservation of soil moisture through mulching is due to modification of favorable microclimatic conditions in soil. When soil surface is covered with organic mulch, it helps to prevent weed growth, reduce evaporation, and increase infiltration of rainwater during growing season. In addition, plastic mulch helps in shedding excessive water away from the crop root zone during periods of excessive rainfall. This can reduce irrigation frequency and amount of water used; it may help to reduce the incidence of soil moisture-related physiological disorders such as blossom-end rot in tomato and fruit cracking in lime and pomegranate (Mohapatra et al. 1999).

The review shows beyond doubt the importance of surface residues on soil water conservation, reduction in wind and water erosion, and enhanced water infiltration and evaporation. Thus, the practice can be implemented in higher education farms where and when water is in short supply.

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Water Security and Sustainability

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Introduction

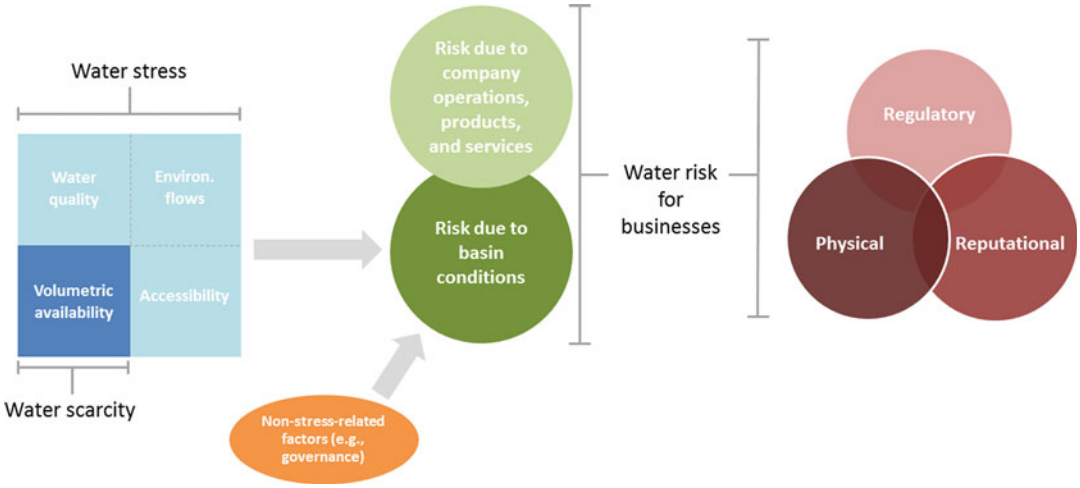
Water availability, including the security of water supply and sanitation, is essential to achieving the United Nations Sustainable Development Goals

(SDGs; United Nations 2015a). The term water availability, which the UN refers to as available freshwater resources (UN-Water 2006a), indicates the amount of fresh water that is available to one person per year. Depending on the available water volume, the subordinate terms are water scarcity, water stress, and water risk, down to water crisis. The interaction between water availability, abstraction, subsequent stocking, and distribution is denominated as water management. Worldwide, around four billion people, or two-thirds of the world's population, do not have enough water for at least 1 month a year, so they suffer severe water shortages. About 1.8 to 2.9 billion people suffer from severe water shortages for 4–6 months a year and about 0.5 billion people do so year-round (Mekonnen and Hoekstra 2016). Climate change will have a further negative impacts on the vulnerable, aggravating the consequences of poverty, poor governance, and political instability (Nightingale 2017; FAO 2011; Smith and Vivekananda 2008). The challenges of effective protection and efficient use of water resources are becoming more and more important on the agenda of international politics, and with increasing water consumption coupled with increasingly unsafe supply and increasing pollution, water safety is now becoming as important as energy security (FAO 2011; Smith and Vivekananda 2008). Water scarcity can significantly exacerbate existing political rivalries or, on the contrary, promote international cooperation for the management of transboundary waters or water resources. In this article the authors will (1) briefly portray the current situation of water scarcity and how conflicts result from this situation, (2) provide insight into sustainable water management strategies, (3) outline a change in viewpoint from conflict to benefit, and (4) provide an example of conflict resolution in a water-scarce area.

Based on the definition proposed by Winpenny (1997), the World Water Development Report (UN-Water 2006a) defined water scarcity as: "The point at which the aggregate impact of all users impinges on the supply or quality of water under prevailing institutional arrangements to the extent that the demand by all sectors, including the environment, cannot be satisfied fully [...], a relative concept [that] can occur at any level of supply or demand. Scarcity may be a social construct (a product of affluence, expectations and customary behaviour) or the consequence of altered supply patterns stemming from climate change. Scarcity has various causes, most of which are capable of being remedied or alleviated."

According to FAO (2012), water scarcity is "both a relative and dynamic concept, and can occur at any level of supply or demand, but it is also a social construct: its causes are all related to human interference with the water cycle." The dimensions that characterize water scarcity are a physical lack of water availability to satisfy demand; the level of infrastructure development that controls storage, distribution, and access; and the institutional capacity to provide the necessary water services (FAO 2012). In May 2013, the CEO of the Water Mandate Secretariat initiated a dialogue among the Alliance for Water Stewardship, the Carbon Disclosure Project (CDP), Ceres, The Nature Conservancy, the Water Footprint Network (WFN), the World Resources Institute, as well as the World Wildlife Fund (WWF) to reach a shared understanding and to apply corporate water stewardship. Under consideration of the UN-Water definition (2006a), the following evolving descriptions were developed (World Resources Institute 2013; Schulte 2014). How these terms relate to one another is illustrated in Fig. 1.

> "Water scarcity" refers to the volumetric abundance, or lack thereof, of water supply. This is typically calculated as a ratio of human water consumption to available water supply in a given area. Water scarcity is a physical, objective reality that can be measured consistently across regions and over time.
>
> "Water stress" refers to the ability, or lack thereof, to meet human and ecological demand for water. Compared to scarcity, "water stress" is a more inclusive and broader concept. It considers several physical aspects related to water resources, including water scarcity, but also water quality, environmental flows, and the accessibility of water.
>
> "Water risk" refers to the probability of an entity experiencing a deleterious water-related event. Water risk is felt differently by every sector of society and the organizations within them and thus



Water Security and Sustainability, Fig. 1 Relation between "water scarcity," "water stress," and "water risk". (Schulte 2014)

is defined and interpreted differently (even when they experience the same degree of water scarcity or water stress). That notwithstanding, many water-related conditions, such as water scarcity, pollution, poor governance, inadequate infrastructure, climate change, and others, create risk for many different sectors and organizations simultaneously.

Water availability, water quality, and water accessibility are components of water stress. Water stress can happen due to availability, quality, and accessibility limitations, while water scarcity only refers to limited water availability. Water scarcity is an indicator for limited water availability characterized by a high ratio of water consumption to water resources in a given area. Water scarcity and additional indicators (e.g., access to drinking water, limited financial resources) can be used to assess water stress. Scarcity and stress both form the characteristics for basin water risks (Young et al. 2015). To get insight into basin water risk, an understanding of the various components of water stress is necessary (i.e., availability, quality, accessibility), as well as of governance and other non-water-related stress factors, which is fundamental also for water businesses. The CEO Water Mandate "Understanding Key Water Stewardship Terms" (2016) defined "water risk for businesses" as the ways in which water-related challenges potentially undermine business viability. It is categorized into three interrelated types:

- *Physical* – Having too little water, too much water, water that is unfit for use, or inaccessible water
- *Regulatory* – Changing, ineffective, or poorly implemented public water policy and/or regulations
- *Reputational* – Stakeholder perceptions that a company does not conduct business in a sustainable or responsible fashion with respect to water

Water scarcity is a local problem that can trigger international disputes in the case of cross-border use (UN-Water 2006b). Worldwide 405 river basins are known, out of which 263 are cross-border catchments (Wolf 1998). In the respective countries, 40% of the world's population is living (Wolf 1998) and is being exposed to an increasing pressure on international water resources and adjacent ecosystems. Competing usage claims of agriculture, energy, and water supply form a core cause of water conflicts. Water scarcity is, in principle, a local problem, which becomes international in the case of cross-border conflicts of use or competing usage claims, and therefore plays a major role in ensuring food security (FAO 2011, 2012). The conflict of use resulting from increasing water consumption calls for differentiated approaches. The international legal framework for cross-border water management of international importance so far is formed by the UN-Ramsar Convention for Wetlands (ratified in 1979), the United Nations Economic Commission for Europe (UNECE) Convention on the Protection and Use of Transboundary Watercourses and International Lakes (ratified in 1996), and the UN Convention on the Law of the Non-Navigational Uses of International Watercourses (ECE Water Convention) (1997, ratified in 2014 by just 36 states).

The opposite of water scarcity is water security, which was defined as "the reliable availability of an acceptable quantity and quality of water for health, livelihoods and production, coupled with an acceptable level of water-related risks" (Grey and Sadoff 2007). The further development of the characterization by the UN-Water Task Force on Water Security (2013) leads to the following definition: "The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability." The definition already indicates that ensuring water security can lead to disputes about fair distribution and equitable use, a situation that requires a sustainable water management in accordance with SDG6. In the field of water management, the concept of integrated water resources management (IWRM) has prevailed in recent years, which combines the impacts at the catchment scale with an interdisciplinary approach to ensure the best management option for man and nature regardless of political boundaries. However, through its focus on water, IWRM often neglects the needs of users from agriculture and/or energy services. Striving for a more holistic approach, the water-energy-food security (WEF) nexus has been proposed linking the decision-making processes of the different sectors and examining the "trade-offs" between them in order to solve the sector's supply risks and the resulting political challenges (Hoff 2011).

The World's Water Resources

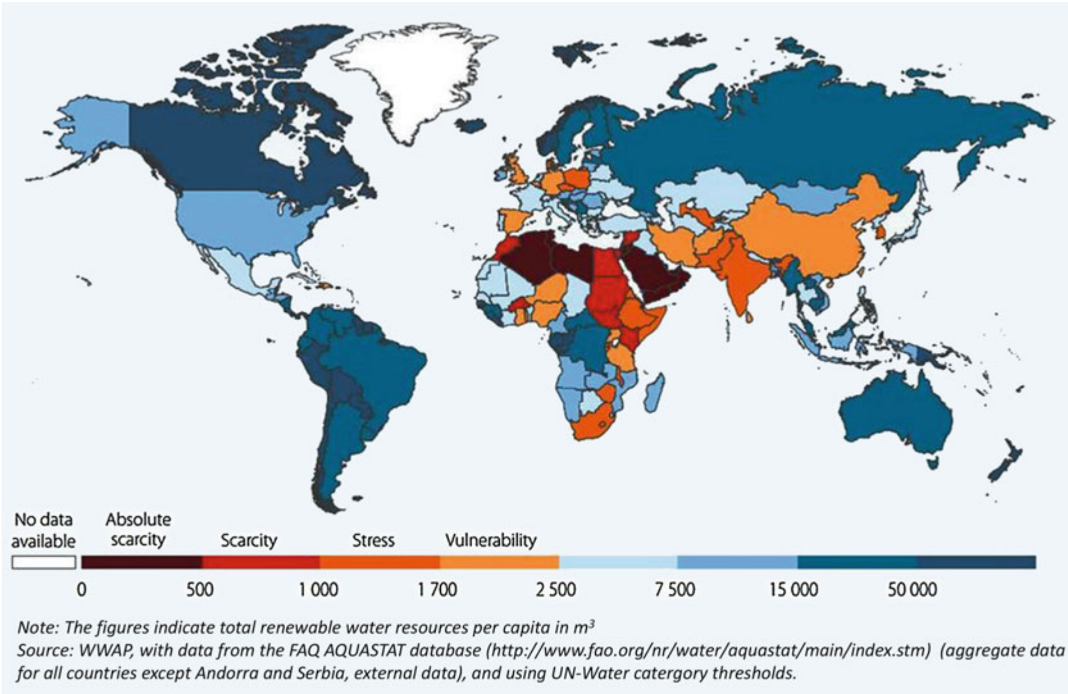
Water Scarcity

Water scarcity is caused on the one hand by natural factors, such as drought (Bates et al. 2008). On the other hand, it is due to the reduced access to drinking water and "water stress" that arise when water demand is rivaling. Water scarcity is on the rise with population growth, urbanization, and economic growth. However, the availability of fresh water in relation to the population is spatially unevenly distributed. According to the World health Organization (WHO 2013), a human being needs a minimum of 7.5–15 L per day water for survival (drinking and food 2.5–3 L per day), basic hygiene practices (2–6 L per day), and basic cooking needs (3–6 L per day).

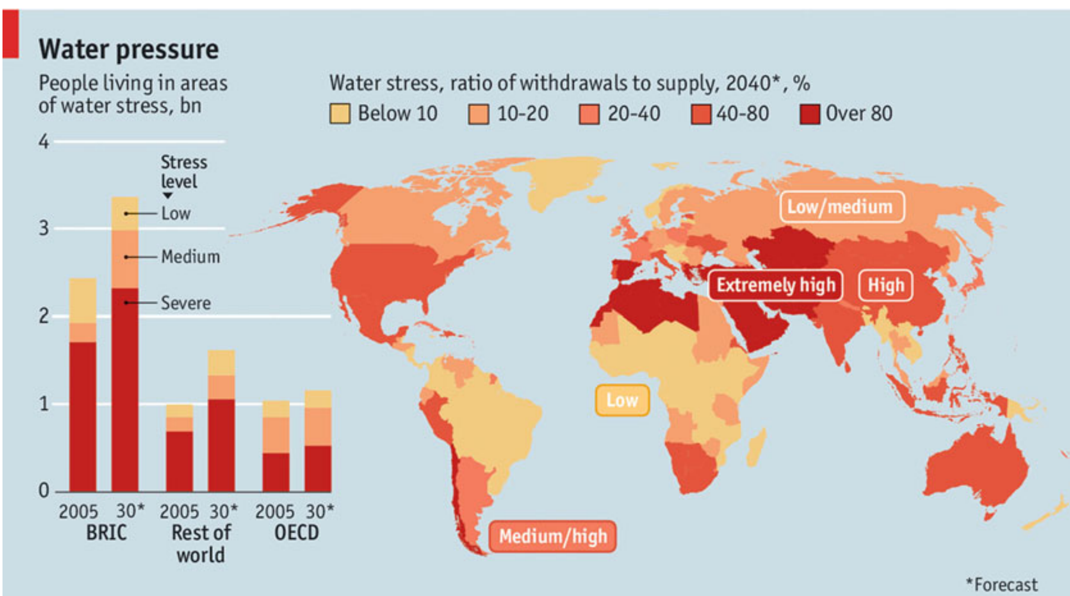
Globally, about 300,000 km^3 are accessible to humans without difficulty, for example, in lakes or rivers (Shiklomanov 1993). However, this water is spatially and temporally unevenly distributed, leading to regional water scarcity. One reason for the unequal distribution of water lies in the uneven distribution of rainfall. Geographically, the Middle East, North Africa, and much of Asia are the most exposed to water scarcity (FAO AQUASTAT 2013, Fig. 2). Currently 60% of the world's population live in Asia, but only 36% of the world's water resources are in that continent. Worldwide, 40% of people live in regions where water is scarce, a number which will further grow in the future (UN Water 2016; Fig. 3).

Paradoxically, in water-scarce regions, water efficiency in the municipal, industrial, and agricultural sectors can generally be greatly improved. This is accompanied by population's perception that water as a vital commodity should be for free. According to the World Resources Institute (WRI) currently, Antigua and Barbuda, Bahrein, and Barbados are listed as most water-scarce countries in the world. WRI further found that 33 countries will face extremely high water stress in 2040, among them being Chile, Estonia, Namibia, and Botswana. Fourteen of those 33 water-stressed countries in 2040 are in the Middle East.

The provision of water is perceived as personal ownership and the access and servicing as an



Water Security and Sustainability, Fig. 2 Total renewable water resources per capita 2013. (FAO AQUASTAT 2013)



Water Security and Sustainability, Fig. 3 People living in areas with water stress, forecast 2040. (Source: OECD, World Resources Institute) obligation of the government. It does not take into account that the costs incurred in drinking water supply and disposal by the associated water services (Vetter 2014). The result is that water operators do not have sufficient access to capital to effectively and sustainably provide their water-related services for the extraction, treatment, storage, distribution, and collection and treatment of effluents. This can lead to the perverted situation that high-quality water is only available in bottles and thus disproportionately expensive in poor areas of developing and emerging countries. Conversely, many of the driest countries in the world have the highest per capita water consumption because the water sectors are heavily subsidized by the state. Often there is also a lack of awareness of environmental and water sustainability or a lack of knowledge about the interrelationships in water issues, especially with regard to quality and hygiene. In the industrial and agricultural sectors, it is the lack of legal regulations and their enforcement that promote excessive water consumption and heavy pollution (FAO 2011, 2012). These common patterns have led to the conclusion that water crises are governance crises (UN-Water 2016). This is particularly pronounced for the drinking water sector (Vetter 2014).

Water Disagreements: Disputes and Conflicts

Disputes and conflicts, as the two types of disagreement, can occur independently or may also be connected. According to Burton (1990), a dispute is a short-term disagreement that can be negotiated for a resolution, while a conflict, in contrast, is long-term with deeply rooted "non-negotiable" issues. Water conflict is a term describing a conflict between countries, states, or groups over an access to water resources (Dombrowsky 2007). Global water security challenges indicate profound difficulties and potential hotspots (Kreamer 2012). The UN recognizes that water insecurity results from opposing interests of water users. We recognize the following reasons for water insecurity:

- Scarcity of naturally available water resources, reinforced by climate change impacts
- Rapid increasing demand on these resources due to the rapid population growth and ambitious urbanization development programs, including the irrigation sector
- Lack of proper management of these water resources and/or inefficient usage, including using old irrigation methods as well as industrial and agricultural pollution
- Old water networks with high losses and unaccounted externalities
- Cultivation of crops with a high water demand
- Using freshwater quantities in wrong places like swimming pools and noneffective water uses like for products with a poor water footprint, etc.
- Not using alternative water resources in an efficient way (like treated wastewater, salt water desalination, and cisterns)
- Lack of proper cooperation between the countries of the region

Conflicts often occur when opposing interests concern the fair distribution of transboundary water resources and especially, when they are superimposed by externalities. An externality is an economic expression for a situation that influences the welfare of individuals or a community through a nonmarket process (Young 2000). In the context of water conflict resolution, externalities are considered as "spillover" impacts on others that are not taken into account by a private economic agent when a decision is made (Kosturjak and Halim 2014). Besides the fact that water-related externalities can be of positive or negative nature, they can be unidirectional and reciprocal (Dombrovki 2010; Chandrakanth 2015; Dasgupta 2008). Unidirectional externalities are externalities in which the external costs or benefits of the resource use are "one way," while in the case of reciprocal externalities, each party inflicts an externality on all others (Chandrakanth 2015). Typically these unidirectional externalities are directed downstream (Dombrovki 2010) and may lead to inefficient water uses. An example of a unidirectional externality is the disposal of (partially treated) sewage into an estuary or ocean (Chandrakanth 2015). Upstream and downstream individuals are paired in upstream-downstream transactions (Kelsey 2009), and from an economic point of view, each of them will want to achieve the maximum benefit.

Approaches to Ensure Water Security for Sustainable Development

Many countries rely on food imports due to limited water resources. This is equivalent to importing virtual water, but it may be useful for water-shortage countries. For instance, a significant import of cereals is observed in Egypt, Algeria, Libya, Israel, Morocco, and Tunisia (Yang and Zehnder 2002). The import of physical water, if feasible at all, is associated with high costs for the water infrastructure and the energy expenditure for transport (WHO and UNICEF 2010). Nowadays, with a world population of around 6.9 billion, water is scarce and in some cases heavily polluted in many parts of the world. Around 1.1 billion people have no access to clean water, 2.6 billion have no adequate sanitation, and 1.8 million die every year from water-related diseases (WHO and UNICEF 2010). According to our opinion, sustainable development applied to the water means:

- To find ways and means to ensure clean drinking water and safe sanitation for all people
- To ensure water supply for agriculture and industry
- To promote effective water management, in particular measures to save water and protect against water
- To improve international cooperation and provide sufficient financial resources for a global water strategy

Integrated approaches to ensure water security for sustainable development are described below.

Integrated Water Resources Management (IWRM)

According to Gerlak and Mukhtarov (2015), water security has emerged as a new discourse in water governance challenging the discourse of integrated water resources management (IWRM). The definition of IWRM that is most widely accepted and of relevance today was given by the Technical Committee (TEC, former Technical Advisory Committee, TAC), of the Global Water Partnership (GWP). It states that IWRM is "A process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." (GWP 2000).

Integrated water resources management (IWRM) is based on a management approach for balancing water demand and availability under a spatial planning approach, practically combining water management and water protection at catchment level (Grigg 2008). The aim is to coordinate the influences on the water body in an interdisciplinary approach in such a way as to ensure the best possible status for humans and nature, independent of political boundaries. IWRM principles include planning for all water sources; addressing water quantity, quality, and ecosystem needs; incorporating principles of efficiency, equity, and public participation; and having a multidisciplinary approach and sharing of information (Grigg 2008; Bielsa and Cazcarro 2014). The implementation process was described as an iterative spiral of four phases: (1) recognizing and identifying, (2) conceptualizing, (3) coordinating and detailed planning, and (4) implementing, monitoring, and evaluating (IWRM Guidelines at River Basin Level). A systemically important factor to balance water demand and availability has to consider increasing the water resource efficiency, including wastewater reuse and water recycling.

The formalized framework of IWRM was developed from the Dublin Principles that were ratified during the 1992 International Conference on Water and the Environment. The United Nations (1992) recognized in the Dublin Statement on Water and Sustainable Development the increasing scarcity of water as a result of the different conflicting uses and overuses of water and sets out recommendations for action at local, national, and international levels to reduce the scarcity, through the following four guiding principles:

- Principle 1: Fresh water is a finite and vulnerable resource, essential to sustain life, development, and the environment.
- Principle 2: Water development and management should be based on a participatory approach, involving users, planners, and policy-makers at all levels.
- Principle 3: Women play a central part in the provision, management, and safeguarding of water.
- Principle 4: Water has an economic value in all its competing uses and should be recognized as an economic good.

The Human Right to Water and Sanitation (HRWS) was recognized by the UN General Assembly on 28 July 2010 (United Nations 2010). A revised UN resolution in 2015 highlighted that the two rights were separate but equal (United Nations 2015b).

Water-Energy-Food Nexus

An intensification of cooperation and the participation of different actors does not necessarily lead to coherence in water resource management. The Water-Energy-Food security nexus (WEF) (Hoff 2011) provides a link between the decision-making processes of the various sectors and examines the synergies and "trade-offs" between them in order to resolve sector-wide supply risks and policy challenges. In doing so, the advantages of cooperation mechanisms are clearly illustrated. The nexus approach to environmental resources' management examines the interrelatedness and interdependencies of environmental resources and their transitions and fluxes across spatial scales and between compartments (Huelsmann and Ardakanian 2014). Instead of just looking at individual components, the functioning, productivity, and management of a complex system are taken into account.

Networked and coherent governance approaches are needed within and across the three sectors in order to understand, assess, and manage risks of supply. UNECE has recently developed a methodology for the nexus term Water-Food-Energy-Ecosystems (WEFE), which examines how greater cohesion can be achieved between the sectors involved through Transboundary River Basin Nexus Approach (TRBNA, de Strasser et al. 2016). Taking a closer look at the WEF approach indicates the missing link to a sustainable approach: natural capital and its services. Finally, the further integration of biodiversity led to the extended WEFE nexus term (UNECE 2014; de Strasser et al. 2016).

From a Problem Shed Towards a Benefit Shed

Wicked Water Problems: The Problem Shed

A watershed is a common unit of analysis for assessing inputs and outflow for a water resource and water management (Agarwal et al. 2000). This multifaceted complexity of water security is why water allocation problems today are so wicked to resolve. A wicked problem is a problem that is difficult to solve because of incomplete, contradictory, and changing requirements that are often difficult to recognize (Australian Public Service Commission 2007). Wicked problems suggest participatory models to address these problems in practice (Kirschke and Newig 2017).

Already Kneese (1968) defined the "problem shed" as a unit for environmental control and refers to certain technological characteristics which prevent a system from an optimal mode, defined as "market failure." The relevant causes for market failures are "externalities" and "decreasing cost" production processes which can prevent the efficient use of resources. A typical example are environmental problems, which often cause externalities, e.g., consequences respectively impacts of an economic activity experienced by unrelated third parties, and they can be either positive (benefits) or negative (cost, for instance, from pollution). Having in view a watershed, an externality resulting from a given water problem can be caused when a "problem shed" and "policy shed" are not aligned and prevent effective and efficient water management (Islam and Susskind 2012). Cohen and Davidson (2011) proposed that there are at least five recognized challenges associated with the watershed approach to water resource management:

- The difficulties of boundary choice (like upstream-downstream transactions Moellenkamp 2007; Kelsey 2009)
- Accountability
- Public participation
- Asymmetries with “problem sheds” and “policy sheds”

Wicked water problems cross multiple domains (natural, societal, political) at different scales (space, time, jurisdictional, institutional), and aspects of these problems occur at different levels within each scale (Islam and Repella 2015). According to Islam and Repella (2015), water diplomacy is the way to solve wicked problems of water management like water disputes and conflicts. Water diplomacy is a negotiated and participatory approach to manage complex water problems as the basis for transboundary water management (TWM).

Benefit-Sharing Strategies for the Resolution of Water Conflicts

A conceptual basis for the implementation of benefit-sharing concepts is the access and benefit-sharing (ABS) mechanism. ABS was introduced by the 1992 Convention on Biodiversity (UN 1992) and has been an integral part of a binding international treaty since 1994. In addition to access to genetic resources, ABS is concerned with the equitable balancing of the benefits resulting from the use of a resource. The Nagoya Protocol on Access to Genetic Resources and the Fair and Equitable Sharing of Benefits Arising from their Utilization to the Convention on Biological Diversity (UN 2015) is an international agreement which aims at sharing the benefits arising from the utilization of genetic resources in a fair and equitable way. There have been several cases to use the benefit-sharing approach also for water conflict resolution (Soliev et al. 2015; Jalilov et al. 2015; Belinskij 2015; Hensengerth 2015). To resolve transboundary water conflicts, positive and negative externalities as well as regulations on access to resources must be taken into account (Dombrowsky 2009). In this regard, the scope of the approach is also the internalization of potential damage cost of the shared resources. Due to its holistic approach, the WEFE nexus provides the frame for the transboundary conflict resolution and in this way stipulates the principle of equitable and reasonable utilization; the obligation not to cause significant harm; principles of cooperation, information exchange, notification, and consultation; and peaceful resolving of disputes.

Using benefit-sharing approaches to make cooperation more attractive is based mainly on the following questions (Soliev et al. 2015):

1. What benefits are there?
2. How can they be shared?
3. What are the costs of achieving shared benefits?

Conflict Resolution: The Benefit Shed?

Conflict resolution for negative externalities can be based on an economic approach, creating a win-win situation for all pivotal states. In economic terms by focusing on the benefits from the water rather than on the allocation of water rights, a zero-sum game of water-sharing can be replaced by a positive sum game of benefit-sharing (Dombrowsky 2010; Biswas 1999). This approach must be accompanied by a communication process for conflict resolution. In 1974, the Thomas-Kilmann Conflict Mode Instrument (TKI) was introduced, which is based on a five-category scheme for classifying interpersonal conflict-handling modes: competing, collaborating, compromising, avoiding, and accommodating (Thomas and Kilmann 1974). Even the TKI was originally developed for interpersonal conflict-handling on small scale, the concept also applies to communities on a larger scale. In water conflict resolution, the collaborating approach was step by step implemented to share water and its benefits (UNESCO 2010). In the last years, the approach of benefit-sharing has been advanced as a strategy to promote cooperation on transboundary rivers (Dombrowsky 2010). The general approach of the benefit-sharing concept is to move from the sharing of water quantities to the sharing of the benefits the users receive from its use.

The further development of the benefit-sharing concept on watershed scale lead to the term "benefit shed," in conscious linguistic proximity to the problem shed (Avellan et al. 2017), through the assessment of resource flows within a nexus context. Avellan et al. (2017) investigated the boundaries of resource flows and the respective interlinkages between compartments or resources and proposed a practical application of the benefit-sharing approach to the water-soil-waste nexus. A benefit shed is apparent, when at least two physical resource systems interact and thus form a nexus system and when the involved stakeholders aim to reveal mutual benefits through increased efficiency.

Of particular interest are the points in a resource flow or chain, where the interaction of components of the nexus system is visible. The nexus system will take resource flows external to its system as drivers and inputs to the analysis of the interlinkages of the overlap, e.g., the benefit shed (Avellan et al. 2017). The existence of a benefit shed creates an added value in the nexus system. Analyzing the interlinkages between the resource systems through a nexus perspective at the scale of the benefit shed allows assessing the benefits to this particular system without having to understand in their entirety the overarching systems (Avellan et al. 2017). The authors consider that changes to those systems (e.g., amount of wastewater delivered to the benefit shed due to changes in wastewater management) can be included as singular external factors thus allowing for particular scenario analyses, flux analyses, and impact assessments within the benefit shed. The overall intention is to reduce the level of complexity of the nexus problem without ignoring that the complexity is inherent to each of the overarching systems. According to the authors' opinion, through this perspective, countries participating in the respective catchments may identify increased efficiency potentials which in turn might provide benefits and in this way may contribute to the mitigation of conflicts based on wicked problems of water insecurity. Benefit-sharing approaches as well as the benefit shed analysis process particularly support ensuring water security.

Dimensions of Water Security: The Case of Amu Darja and Syr Darja Catchment

What Is the Conflict?

In semiarid to arid Central Asia, life and the economy depend heavily on the water resources from the upper reaches of the Tien Shan and Pamir rivers. The states of Central Asia (Kyrgyzstan, Uzbekistan, Turkmenistan, Tajikistan, Kazakhstan) have more than 63 million people, mainly concentrated in the fertile oases and capitals of the states. By 2100, a doubling of the population is expected. The area is one of the world's most important regions likely to face water scarcity, social conflict, and political violence as a result of climate change due to snow and glacier melt (Unger-Shayesteh et al. 2013). Eighty percent of the water resources are located in Kyrgyzstan and Tajikistan (Unger-Shayesteh et al. 2013).

The water use of the region varies. The upstream countries rich in energy (Kyrgyzstan, Tajikistan) use water to generate electricity, while the downstream countries (Uzbekistan, Turkmenistan, and Kazakhstan) need irrigation water in summer (Luxner and Drake 2015). At 85–97%, water resources in Central Asia are mainly used by agriculture (Unger-Shayesteh et al. 2013). More than 8 million hectares of land were irrigated. Around 22 million people depend on irrigated agriculture, which (with the exception of oil-rich Kazakhstan) also has a central economic position. Since the 1950s, the irrigation industry has also intensified greatly, with partially serious environmental consequences such as the extensive dehydration of the Aral Sea. The water use of the region is complicated by the fact that the main rivers Syr Darya and Amu Darya with their catchment areas extend across several countries since the end of the Soviet Union (Luxner and Drake 2015).

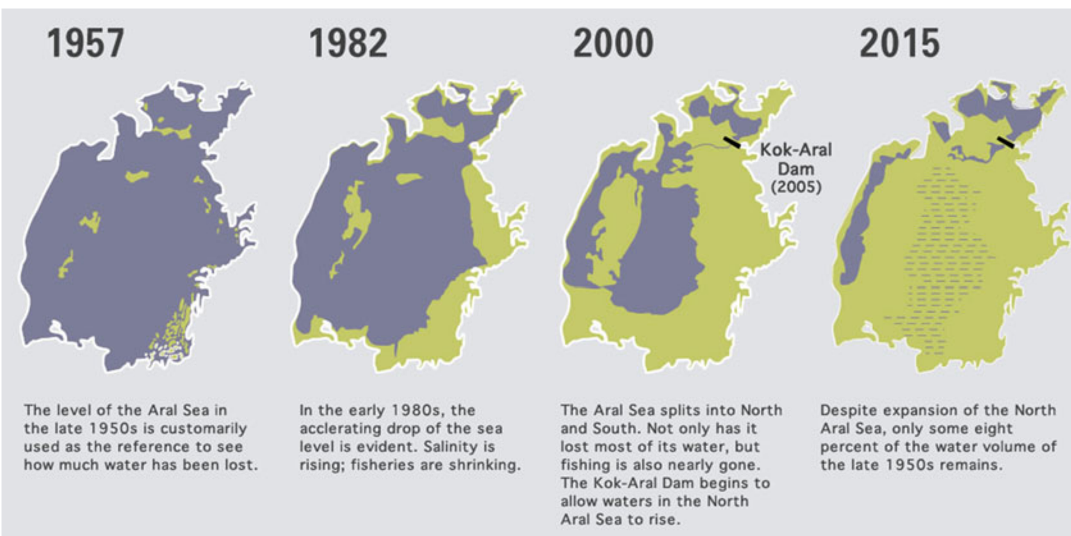
Consequently, water is a precious commodity for the states of Central Asia. Although there is not a shortage of water in the region yet, the unequal distribution leads to competition in its use (Luxner and Drake 2015). The water of the rivers, especially the two large rivers Amu Darja and Syr Darja, is the basis for the drinking water supply, for irrigation agriculture, and for the production of energy from hydropower (Luxner and Drake 2015). In the 1950s, large-scale irrigation land was expanded for cotton cultivation – the Central Asian republics supplied cotton to the entire Soviet Union. Since cotton is one of the most water-intensive crops in the world, water consumption has increased sharply, the main reason for the desiccation of the Aral Sea, which has catastrophic consequences for the region, Fig. 4 (Luxner and Drake 2015).

Being formerly one of the four largest lakes in the world with an area of 68,000 km, the Ara Sea is continuously shrinking (see Fig. 4). Also, the North Aral Sea in Kazakhstan had decreased by 2007 to 10% of its original size. By 2009, the southeastern lake had disappeared, and the southwestern lake had retreated to a thin strip in the far west of the former southern sea. NASA satellite imagery from August 2014 showed that for the first time in modern history, the eastern basin of the Aral Sea was completely dehydrated (Luxner and Drake 2015). Therefore, the eastern basin is now called Aralkum Desert. The Kok-Aral Dam was built in 2005 in a constant effort to store and re-flood water in the North Aral Sea in Kazakhstan. In 2008, the water level in the North Aral Sea had risen by 12 m compared to 2003, and the salinity had decreased to such an extent that there were enough fish left to give the fishermen a livelihood. With this activity, the North Aral Sea was hydraulically decoupled from the South Aral Sea. The maximum depth of the North Aral Sea is 42 m.

The shrinking of the Aral Sea has been described as "one of the worst environmental disasters on Earth" (Luxner and Drake 2015). The once prosperous fishing industry in the region is essentially destroyed, so that unemployment has risen sharply and economic hardship prevails. The Aral Sea region is now heavily polluted by pesticides, with serious consequences for the health of local residents. The desaturation of the Aral Lake has also been significantly impacted by local climate change, with ever hotter and drier summers and ever-colder and longer winters (Luxner and Drake 2015).

What Resources and Potential Benefits Are There?

With the independence of Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan in the early 1990s, many rivers became transboundary water courses, and the young states were faced with the task of developing cooperation mechanisms for balanced and equitable water distribution and use, particularly for



Water Security and Sustainability, Fig. 4 Desiccation of the Aral Sea. (Luxner & Drake 2015) agriculture and energy production (Luxner and Drake 2015). The water of the major rivers of the region, above all the Amu Darja and the Syr Darja, is the basis of the drinking water supply, for the irrigation of the agriculture, and in the mountain regions also for the hydropower production; see Fig. 5.

How Can They Be Shared?

Although the states of Central Asia have already signed a first water distribution agreement in 1992 (Almaty Agreement), there is still no binding cooperation framework for joint water management. Each country has certain quotas for the use of water. In order to define it, the International Fund for Saving the Aral Lake (IFAS) was founded in the 1990s with a structure called the Intergovernmental Commission for Water Cooperation. The participants, so all five countries of the region, meet every 3 months and determine exact quotas.

In 1992, the Interstate Commission for Water Coordination (ICWC) was established, which includes all five Aral Sea basin countries and covers the two main rivers, Amu Darya and Syr Darya (McKinney 2013). The Almaty Agreement determines the regional water management policy and regulates the use and the protection of transboundary water. The agreement administers basin management organizations and has clauses on (1) approval prior water allocations (% of flow), (2) no harm, (3) provision for "extremely dry years," (4) requirement for information sharing, and (5) promotion of joint research and efforts to resolve Aral Sea "problem" (McKinney 2013).

The Almaty Agreement was followed 1998 by the Syr Darya Agreement, which established the management of Syr Darya cascade of reservoirs, having as main clauses (1) annual negotiation, (2) reservoir releases for irrigation, (3) surplus electricity delivered to Kazakhstan and Uzbekistan, and (4) fuel compensation to the Kyrgyz

Water Security and Sustainability, Fig. 5 Water resources of the Aral Sea basin, including water diversion. (Source: CAWater-Info)

Republic (McKinney 2013). The 1998 Agreement proposed revisions regarding the sharing of water resources (releases and storage) and the compensation compromise (energy transfers) between summer irrigation and winter hydropower water uses (McKinney 2013).

What Are the Costs of Achieving Shared Benefits?

The revised 1998 Agreement was implemented under a benefit-sharing approach, considering the following benefit-sharing strategies (McKinney 2013):

- Kyrgyzstan (KG): receives fuel to cover energy deficit
- Uzbekistan (UZ): receives water for agricultural production and electricity from KG and provides gas to mitigate the energy deficit in Kyrgyzstan
- Kazakhstan (KZ): receives water for agricultural production and electricity from KG and provides coal to mitigate the energy deficit in Kyrgyzstan

This solution leads to benefits of cooperation for all pivotal states.

In the last years, the opinion manifested that the water security problems in the Amu Darja and Syr Darja catchment must be solved under a water-energy-food security nexus approach (The East West Institute/The International Water Association/IUCN 2014; Guillaume et al. 2015; Wegerich et al. 2015; Jalilov et al. 2015). The upstream countries are water rich, but they face energy and food insecurities, while the downstream countries are major producers of fossil fuel energy and agricultural crops but depend on water to sustain their agricultural activities (The East West Institute/The International Water Association/IUCN 2014).

Since 2013, the "Nexus Dialogue on Water Infrastructure Solutions" in the frame of the Central Asia nexus was conducted as a series of regional meetings with IWA and IUCN to reconcile competing water demands in river basins (The East West Institute/The International Water Association/IUCN 2014). Concrete outcomes of this joint initiative were five action plans, which addressed the following tasks:

- A system of payment in exchange for ecosystem service provision, ensuring that wealthier downstream users cooperate financially in protecting upstream water resources
- Building an integrated basin-wide information system on natural resource use
- Strengthening regional economic integration as a catalyst to simultaneously minimize border disputes
- A network of training centers for improved irrigation capacity building and service provision
- A network of nexus knowledge and innovation centers to tackle food insecurity

In 2008, the Federal Foreign Office of Germany as an independent mediator launched the Water Initiative Central Asia ("Berlin Process") in order to strengthen regional cooperation on water issues and thus sustainable water management (Ministry of Foreign Affairs Germany 2017). In Phase I (2008–2011), the focus was on policy advice and strengthening institutions for the management of transboundary rivers. Phase II (2012–2014) supported as a priority the development of solutions to address the growing impact of climate change on water resources in Central Asia (Ministry of Foreign Affairs Germany 2017). The "Water and Good Neighborly Relations in Central Asia" conference in September 2015 marks the start of Phase III (2015–2017), which brings together regional institutions and processes, notably the International Fund for Saving the Aral Sea (IFAS), an organization for regional water management, to be sustainably strengthened. The goal is to institutionalize independently managed water cooperation between the Central Asian states (Ministry of Foreign Affairs Germany, 2017).

Conclusions

Globally, water is not managed sustainably enough. The United Nations Educational, Scientific and Cultural Organization (UNESCO) therefore calls for a better coordinated water policy to tackle challenges such as poverty, nutrition, and energy supply (UN-Water 2017). The UNESCO demanded from politics, science, and industry effective strategies for global water management. Only then, the connections between development problems such as water supply and health, agriculture, and nutrition can be taken into account (UN-Water 2017). Without integrative approaches, sustainable development is not possible. Over the years, the importance of an in-depth study of the complex interdependencies between food, water, and energy resources has been noted essential for the development of nations and for the functioning of ecosystems, highly pressured by population growth, climate change, and new habits and lifestyles that increasingly demand scarce resources as water. The "disputes" and "conflicts" between food, water, and energy resources can be addressed in the Water-Energy-Food security nexus and underscore the complexity and interdisciplinarity of water security.

In many cases, the availability of clean drinking water determines life and death, and the availability of economic water causes prosperity or misery. Therefore, water can also be used as an occasion for social conflicts and armed conflicts. Sustainability of water use and water supply has therefore become an issue worldwide. Scarcity can be expected to intensify with most forms of economic development, but, if correctly identified, many of its causes can be predicted, avoided, or mitigated.

According to Brian Davidson, professor of water resource management at the University of Melbourne, "wicked problems do not have a single, optimal, one-off solution. They have a temporary solution. And it is a solution that has to change over time in response to changing circumstances."

As James and Shafiee-Jood (2017) pointed out, interdisciplinary information is necessary for achieving water security that means data covering the hydrologic (water quantity and quality), engineering, economic, financial, environmental, social, political, and legal dimensions.

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Water-Energy-Food Nexus and Sustainability

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Definition

A generally agreed-upon definition of a nexus approach has not yet emerged (Avellan et al. 2017). Conceptually, a nexus describes the linking of multiple resource-use practices and serves to understand interrelations among such practices. In the view of Hoff (2011), the water-energy-food nexus focuses on achieving water, energy, and food security in an emerging green economy. Within that context, the WEF nexus aims to support the respective transition through achieving greater policy coherence and higher resource use efficiency. Through reducing tradeoffs and building synergies, the intentions of the WEF nexus are to increase the security of water, energy, and food, which would result in secure access for all the people (Hoff 2011).

Introduction

In September 2015, the United Nations adopted the Sustainable Development Goals (SDGs), the Agenda 2030 which range from ending poverty in the world to gender issues. The 17 goals set as measurable variables comprise 169 concrete targets, built on the previous eight Millennium Development Goals, and are intended to guide the development of the world over the next 15 years. The objectives are universally applicable and implementable at national level taking into account the different circumstances, capacities and development stages of individual countries.

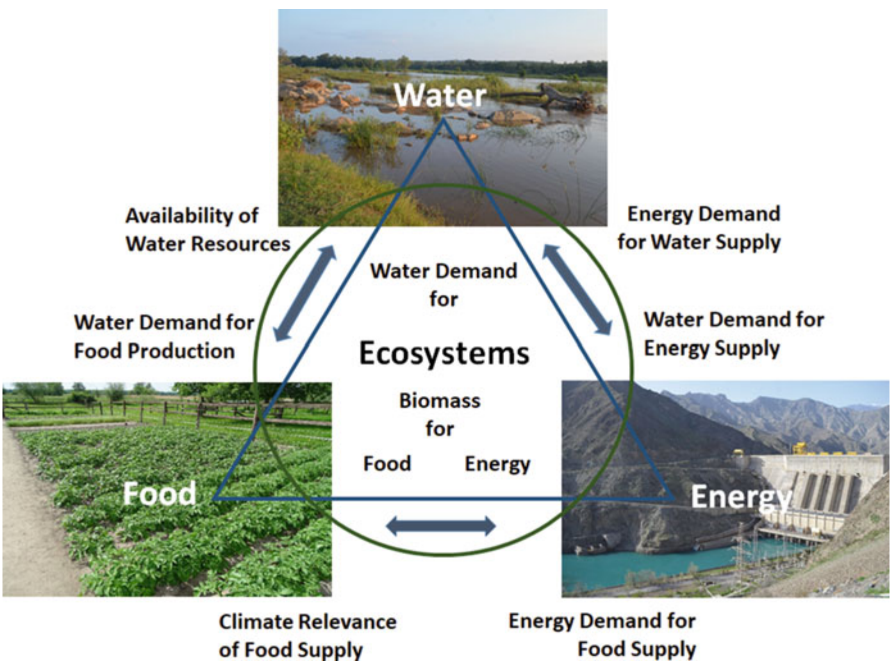
The nexus approach, which was discussed for the first time on a broad international level between experts and decision-makers at the "Bonn2011 Conference: The Water Energy and Food Security Nexus - Solutions for the Green Economy" (Hoff 2011), presents a number of interesting potential solutions. The basic concepts are founded on the principle of sustainability, which the participating states declared as a global maxim 20 years ago at the first UN Conference on Sustainable Development in Rio. The Water-Energy-Food (WEF) nexus constitutes a framework for analyzing the dynamic interrelations between water, energy, and food systems to achieve equitable water, energy, and food security and developing strategies for sustainable development (Hoff 2011). The WEF nexus postulates that water security, energy security, and food security are inextricably linked causing impacts in one or both of the others. Networked and coherent governance approaches are needed across the three sectors to understand, assess, and manage supply risks.

Particular emphasis is placed on the interconnections between the individual sustainable development goals as a basis for sustainable development and its integrative character. Nexus refers here to the interaction of the system components of individual goals in the form of mutual influence, dependency, and impact.

Consciousness and the knowledge of mutual influence are not new as also for instance the integrated natural resources management (INRM) has traditionally an interdisciplinary holistic approach (Avellan et al. 2017). This is necessary for a nexus approach (Howarth and Monasterolo 2016). Nevertheless, the establishment of the nexus idea at the international strategic level represents a decisive step. Isolated, linear approaches are not suitable to solve the complex problems facing the world under resource-limited conditions. Central challenges such as water, energy, and food security are therefore treated under the term "water-energy-food nexus." Between these three singular terms, numerous dependencies can be identified, as exemplified in Fig. 1.

For the Global Risks 2012 report of the World Economic Forum, 469 experts assessed various risks according to their probability and potential impact (Beisheim 2013). According to the World Economic Forum (2012), water supply and food crises rank right after the financial crisis as a risk, along with high volatility in energy and food prices. In the most recent emission, the Global Risks 2018 report of the World Economic Forum underlined that environmental risks have grown in prominence in recent years. According to the World Economic Forum (2018), biodiversity is being lost at mass extinction rates, agricultural systems are under strain, and pollution of the air and sea has become an increasingly pressing threat to human health. Still, more than a billion people have no access to clean drinking water and safe sanitation, suffer from malnutrition, and cannot use modern energy sources. At the same time, climate change, a growing world population, changing consumer habits and, under- and mis-investments in infrastructure in many places are leading to an increasing shortage of resources such as water, energy sources, and land.

The interdependencies in the use of resources to secure the provision of water and energy and the production of food are becoming increasingly apparent. For example, the cultivation of agrofuels can supplant the cultivation of food and contribute to the depletion of water resources. Intensive agricultural use upstream of the watershed can increase downstream erosion and affect hydropower production. Energy subsidies for farmers make



Water-Energy-Food Nexus and Sustainability, Fig. 1 Illustration of the water-energy-food nexus

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irrigation pumps affordable, but with their use, the groundwater level can be lowered. Not only climate change but also climate change measures can increase the pressure on water and land resources (World Economic Forum 2011). The nexus approach explicitly addresses these dependencies.

In this entry we wish to further illustrate (1) the concepts of water, food, and energy securities, (2) the connection of the concept of securities with sustainable development and (3) show examples of nexus methodologies that support achieving water, energy, and food security.

The Concepts of Water, Energy, and Food Security

Water Security and Integrated Water Resources Management

UN-Water proposes the following definition of water security: "The capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (United Nations University UNU-INWEH 2013).

According to the World Economic Forum (2011), water security is understood as "the grossamer that links together the web of food, energy, climate, economic growth and human security challenger that the world economy faces over the next two decade." Water security has emerged as a new discourse in water governance challenging the more traditional dominant discourse of integrated water resources management (IWRM) in the past decade (Gerlak and Mukhtarov 2015). The definition of IWRM that is most widely accepted and of relevance today was given by the Technical Committee (TEC, former Technical Advisory Committee, TAC), of the Global Water Partnership (GWP).

It states that IWRM is:

> *A process which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.* (GWP 2000).

IWRM explicitly challenges conventional, partial water development and management systems and underlines the importance of an integrated approach with greater coordinated decision-making across sectors and scales. It recognizes that a pure top-down, supply-side, technology-based, and sector-based approach to water management puts mankind at a non-sustainable high economic, social, and environmental cost. IWRM and its relation to sub-sectors are illustrated in Fig. 2.

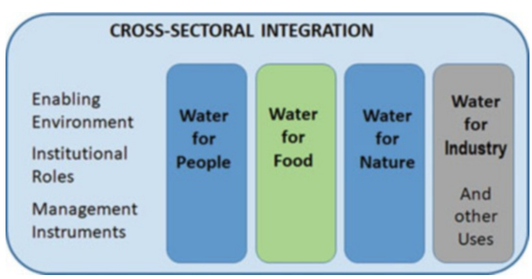
IWRM has a strong sustainability dimension, expressed through:

Social responsibility: ensuring equal access for all users (in particular marginalized and poorer user groups) to an adequate quantity and quality of water necessary for the maintenance of individual well-being

Economic efficiency: delivering the most value to existing financial and water resources for the largest possible number of users

Ecological sustainability: requires the recognition of aquatic ecosystems as social and economic actors and the adequate distribution of their natural functions

The pressure on water resources is growing with the increasing world's population and the resulting need for food security as well as the increasing urbanization causing an increasing energy demand. Since the 1950s, the water demand from the agriculture sector and the industry has more than



Water-Energy-Food Nexus and Sustainability, Fig. 2 IWRM and its relation to sub-sectors (GWP 2000) tripled, while the demand from households has doubled; see Fig. 3 (Gleick 1998, 2000).

Since the 1970s, there is also an increasing water demand from the energy sector through the construction of reservoirs for water power generation and water storage.

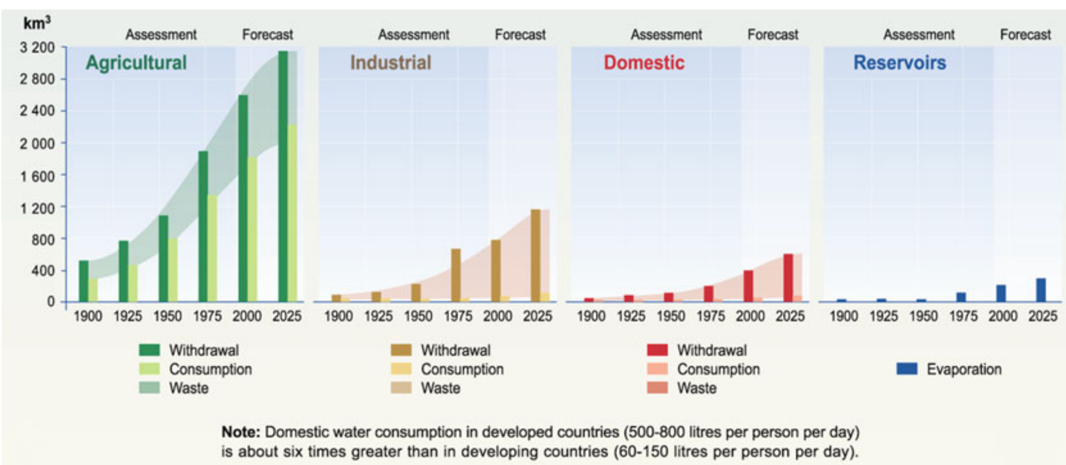
Energy Security and Use of Renewable Energies

The International Energy Agency (IEA) defines energy security as *the uninterrupted availability of energy sources at an affordable price*. Long-term energy security which mainly deals with timely investments to supply energy in line with economic developments and environmental needs. Short-term energy security focuses on the ability of the energy system to react promptly to sudden changes in the supply-demand balance (source: IEA).

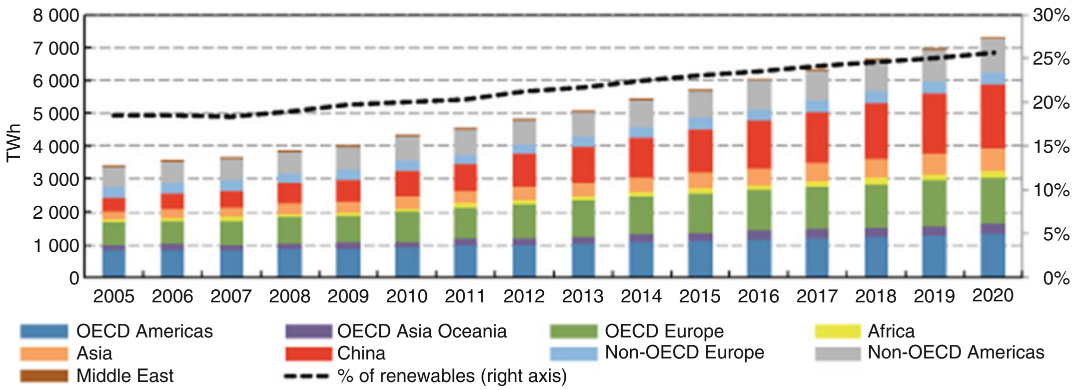
According to the IEA's 2017 Medium-Term Renewable Energy Market Report (International Energy Agency (IEA) 2017), there has been substantial growth in renewables in some sectors and regions. Paolo Frankl, Head of Renewable Energy Division of the IEA, stated that renewables (including hydropower) have made "tremendous progress." They now account for 22% of global power generation. IEA (2016) forecasts that by 2020, hydropower (4669 TWh) will provide the lion's share of the total renewable energy production, which is projected to be 7313 TWh, or 26% of global power production (International Energy Agency (IEA) 2017). Bioenergy production (615 TWh by 2020) also needs water. In 2016, global renewable electricity generation grew 5% by 240 TWh to reach 5070 TWh (International Energy Agency (IEA) 2016). The global renewable electricity production by region, historical and projected, can be seen from Fig. 4. The figure indicates an increasing trend for the global energy demand.

Food Security

Concepts of food security have a long history and arrived in the last 30 years in the official policy thinking (Clay 2002; Heidhues et al. 2004). The term has its origin in the mid-1970s, when the World Food Conference (1974) defined food security in terms of food supply as assuring the availability and price stability of basic foodstuffs at the international and national level. Later definitions addressed demand and access issues. In 1983, the definition of the FAO focused on food access, leading to a definition based on the balance between the demand and supply side of food security. The understanding of food security moved from a more economic view to a more social ones, that includes the negative effect on



Water-Energy-Food Nexus and Sustainability, Fig. 3 Evolution of the global water use – withdrawal and consumption by sector. (Source: Igor A. Shiklomanov, State Hydrological Institute (SHI St. Petersburg) and United Nations Educational Scientific and Cultural Organization (UNESCO, Paris), 1999)



Notes: unless otherwise indicated, all material in figures and tables in this chapter derive from international Energy Agency (IEA) data and analysis. Hydropower includes pumped storage; the onshore and offshore wind split is estimated; total generation is gross power generation.

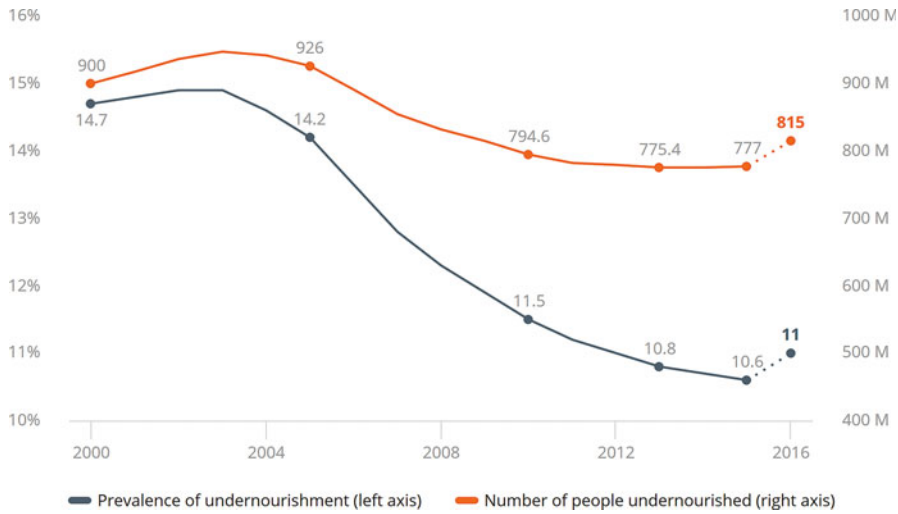
Water-Energy-Food Nexus and Sustainability, Fig. 4 Global renewable electricity production by region, historical and projected. (Source: http://energypost.eu/global-renewable-energy-cross-roads/). Note: the figures are from the IEA. Hydropower includes pumped storage

the physical, social, emotional, and cognitive development of human (Pérez-Escamilla 2017). The 1996 World Summit on Food Security declared that "food should not be used as an instrument for political and economic pressure" (FAO 1996).

The current definition was developed at the FAO World Food Summit (WFS), which took place from 13 to 17 November 1996 in Rome and aimed at renewing the global commitment to fight world hunger: "Food security exists when all people, at all times, have physical and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO 1996). The background to this World Summit was, in particular, the malnutrition prevalent among large parts of the world population and the limited capacity of agriculture to meet the food needs of the future. World grain stocks were at their lowest levels since the early 1970s, prices had risen enormously, and food aid had almost halved in the years 1993–1996.

Notable progress has been made in some countries and malnutrition is slowly declining in many developing countries. Theoretically, world food production is enough to feed all people, but the poorest of the poor often have no access to it, and 815 million people suffer from hunger (FAO 2017), see Fig. 5. At the end of the summit, a declaration on global food security and an action plan on world nutrition were adopted. The FAO estimates that over the next 30 years, food production will need to increase by over 75% to ensure adequate food supplies to the world's population of approximately 7.6 billion people in 2017.

The links within the WEF nexus in terms of global food security are obvious as food production is by far the largest consumer of global freshwater supplies, representing an average of 70% of the freshwater consumption on the global scale. Further, there are also quite high energy needs in food production as for irrigation, machinery, transport, and storage of food. As reflected in SDG 2, one of the main global challenges is ensuring food security for a growing global population (UN-DESA 2011), which is projected to rise to around ten billion by 2050 (FAO 2017). The resulting need of increasing the food production by 75% globally by 2050 requires a holistic approach to all forms of malnutrition, productivity and incomes of small-scale food producers, resilience of food production systems, and the sustainable use of biodiversity and genetic resources (FAO 2017). It requires a sustainable and innovative use of water resources which are needed to grow that food, including the use of wastewater in agriculture.



Water-Energy-Food Nexus and Sustainability, Fig. 5 Prevalence and number of undernourished people in the world, 2000–2016. Figures for 2016 are projected estimates (United Nations Food and Agricultural Organization (FAO) 2017)

The Nexus Approach to Foster Sustainable Development

The WEF nexus provides the framework for the sustainable linkage of the water, energy, and food sectors (Kurian 2017; UNU-FLORES 2015; Walker et al. 2014). Water is a key factor for food production along the entire value chain. Energy is also of vital importance for food production, water supply, and sanitation. Thirty percent of global energy consumption is needed for food production. There are a large number of synergies and conflicting goals between the three sectors (Leck et al. 2015). For example, extracting water for the agricultural sector can increase food production but leads to a reduction in runoff and hydroelectric potential.

The future supply of water, food, and energy largely depend on global developments that will change the supply and demand for these resources. Among the most important drivers are population development, climate change, and changes in living standards (von Braun and Mirzabaev 2016). All components of the global population development (birth rate, life expectancy, and migration) are characterized by economic and social conditions as well as by individual behavior.

The development of living standards and consumption patterns toward higher resource consumption per capita is driven by two forces: economic development (prosperity) and international market integration (globalization), which also increases the availability of goods. Demographic aspects, such as changes in age structures, influence this factor. At the same time, climate policy has consequences for the nexus of water, energy, and food security (WEF nexus). All three trends can cause supply risks to increase. Both the growing demand for water, energy, and food by more people or ever higher demands and the decreasing supply of these resources as a result of climatic changes are global processes, which, however, are predominantly local and regional (Obersteiner et al. 2016). Therefore, politics is required at all levels. Although complex relationships and risks in the supply of water, energy, and food can easily be seen, a corresponding "nexus" on the part of the policy is missing. In order to deal adequately with the problems, cross-sectoral and cross-border cooperation and coherence must be strengthened (Stiftung Wissenschaft und Politik).

Yillia (2016) described the water-energy-food nexus in the context of the SDGs, which considers in more detail the framework of the nexus approach. Specifically, the following SDG goals are considered:

SDG 2. Stop hunger, achieve food security and nutrition, and promote sustainable agriculture.
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.

The interface with other SDGs presents concrete content-related contributions and solution approaches derived, for instance, from wastewater treatment or responsible consumption in the nexus (UN-Water 2013, 2016).

The nexus perspective investigates the interdependencies across the water, energy, and food sectors and influences policies in related areas, climate and biodiversity. Taking these relationships into account can result in greater resource efficiency while minimizing environmental hazards and impacts.

Allouche et al. 2014 discussed the assumption that discourses over nontraditional forms of securities are affecting ways of policy framing of long-term sustainability in the area of water, energy, and food, which was originally based on an equilibrium thinking between these aspects as summarized by the idea of balancing. Allouche et al. (2014) agreed the approach of Leach et al. (2010) that recent understanding of ecological systems has shifted from seeing nature as "in balance" to recognizing ecological systems as being in a dynamic non-equilibrium with potentially nonlinear responses and multiple stable states. Leach et al. (2010) prioritized different aspects of systems dynamics (see Fig. 6) as dynamic properties of sustainability and proposed different strategies to deal with them.

Stability: if a system is assumed to move along an unchanging path, the strategy may be designed to exercise control.
Resilience: if limits to control are acknowledged, the strategy might be to resist shocks in a more responsive way.
Durability: if a system may be subject to stresses and shifts over time, interventions may attempt to control the potential changes.
Robustness: strategies that embrace both the limits to control and openness to enduring shifts.

Thus, these criteria are also relevant for the implementation of the WEF nexus to foster sustainable development. The nexus approach, from an economical point of view, aims to integrate sectors through making them visible and thereby to address externalities that link sectors together (Allouche et al. 2014) with the scope to openly discussing trade-offs between them.

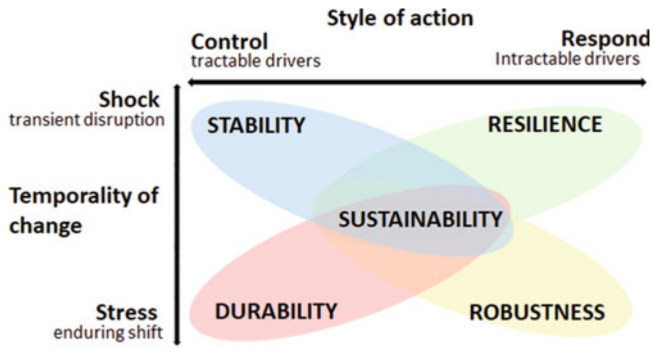
Practical Application of the Nexus Approach

By now, there are pilot applications of the WEF nexus, among others driven by UN organizations. The developments in the WEF nexus involve cross-border and networked or even systemic risks. These are "highly interconnected problem contexts with unpredictable effects in terms of scope, depth and time horizon, the management of which due to the complexity of the effects, uncertainty and ambiguity is associated with considerable knowledge and assessment problems" (Renn et al. 2007). Foresighted governance of risks opens up opportunities for positive (side) effects if it strengthens coping capacities. The WEF nexus can theoretically even achieve "triple win" effects if improvements are achieved not just in one but in all three sectors (European Commission 2012).

Below, we show examples of different methodologies that have been drawn up to implement and test the nexus approach on the ground.

UNECE: The Role of the Water-Energy-Food Nexus in the Context of Transboundary Water Management

The WEF nexus was selected as one of the thematic areas of work under the UNECE Water Convention for the 2013–2015 program of work,



Water-Energy-Food Nexus and Sustainability, Fig. 6 Dynamic properties of sustainability (Leach et al. 2010)

particularly for the investigation of the Transboundary River Basin Nexus Approach (TRBNA) in the catchment of the Sava River (de Strasser et al. 2016). The TRBNA methodology consists of six steps as illustrated in Fig. 7.

Steps 1–3 include the preparation of a desk study of the basin, which will be used for the more in-depth analysis of nexus interlinkages in steps 4–6, where stakeholders are actively involved (de Strasser et al. 2016).

The Sava River Basin has a total area of 97,713 km^2 and about 8.1 million inhabitants. It is partially situated in Bosnia and Herzegovina, Croatia, Montenegro, Serbia, and Slovenia, as well as a very small part of Albania. The countries achieve a significant share of water, hydropower, land area, and economic activity from the basin, for example, electricity generation capacity amounts to 53% or 76% of thermal power plants (United Nations Economic Commission for Europe UNECE 2016). The scope of the TRBNA in the Sava River Basin approach was to advance transboundary cooperation through nexus-based management of the Sava Basin's resources in a way that Sava countries can exploit many potential benefits (United Nations Economic Commission for Europe UNECE 2016). The benefits worked out under the nexus approach are displayed in Fig. 8, comprising economic benefits, social and environmental benefits, regional economic cooperation benefits, as well as geopolitical benefits.

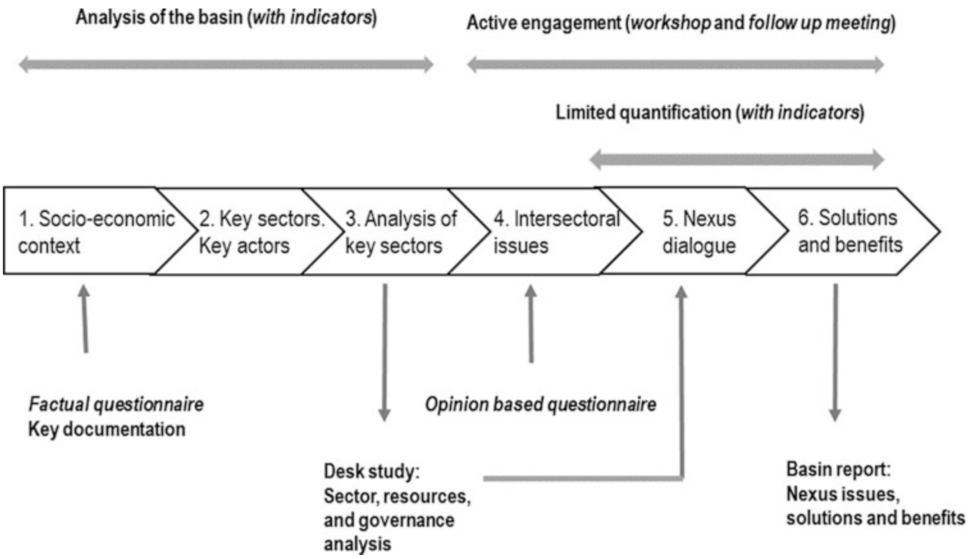
This method has been applied in several watersheds in Europe and Central Asia and is being refined further with every case. Overall the iterative process of desk studies with stakeholder interaction makes this methodology very hands-on and ensures that international expert knowledge is contrasted with national expert perception. One challenge is the selection of national expert which come from all countries of the rivershed and from various ministries within each country. In many cases this is the first time that this group of people comes together requiring the establishment of a baseline vocabulary to allow for a fluid transdisciplinary communication, a step that is, unfortunately, often ignored.

In terms of addressing the concepts of water, energy, or food security, the methodology is rather vague and not explicit. The benefits assessment could however provide a tool for looking into the aspect of security more in depth.

UNU-FLORES: Interlinkages Between the Water-Energy-Food Nexus and the Water-Soil-Waste Nexus

As an immediate response from the scientific community to the major outcomes of Rio+20, the United Nations University Institute for Integrated Management of Material Fluxes and of Resources (UNU-FLORES) was established in December 2012 in Dresden, Germany. Its main mandate is to further the approach of the water-soil-waste (WSW) nexus.

At the "International Kick-off Workshop: Advancing a Nexus Approach to the Sustainable Management of Water, Soil and Waste" in 2013, the WSW nexus was hence described: "The Nexus Approach to environmental resources' management examines the inter-relatedness and interdependencies of environmental resources and their transitions and fluxes across spatial



Water-Energy-Food Nexus and Sustainability, Fig. 7 Schematic of the six steps with inputs and outputs (de Strasser et al. 2016)

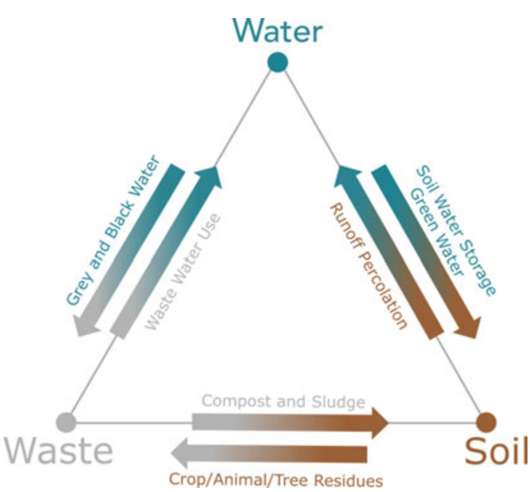
	On economic activities	Beyond economic activities
From improved management of basin resources	**Economic benefits** • Increased viability of economic activities relying on basin resources • Development of agricultural sector and its value added • Development of sustainable river tourism • Reduced economic costs of water-related hazards (floods and droughts) • Reduction of transport costs or increased volume of traffic (thanks to increased capacity and use of better maintained waterways) • Reduction of energy costs (thanks to optimisation of potential energy sources) • Reduction of water infrastructure costs (thanks to avoidance of duplication and sub-optimal location)	**Social and environmental benefits** • Employment creation (e.g. in agriculture and tourism sectors) • Reduced human costs of water-related hazards (e.g. floods) • Health benefits from improved water quality • Improved water services for users • Improved recreational opportunities from improved water quality and healthier ecosystems
From increased trust among Sava countries	**Regional economic cooperation benefits** • Increased trade through waterways • Development of regional markets for goods, services and labour • Increased cross-border investments	**Geo-political benefits** • Improved likelihood of complying with EU requirements and regional targets (e.g. regarding status of waters, renewable energy targets and agricultural policy)

Water-Energy-Food Nexus and Sustainability, Fig. 8 The benefits of transboundary cooperation on the nexus issues in the management of the Sava Basin's resources (United Nations Economic Commission for Europe UNECE 2016)

scales and between compartments. Instead of just looking at individual components, the functioning, productivity, and management of a complex system is taken into consideration" (UNU-FLORES 2015; Avellan et al. 2017).

As the WEF nexus considers the wide field of securities, the WSW nexus tries to focus on a systems perspective of the interactions between selected resources that support water, energy, and/or food security. The sustainable management of these resources, namely, water, soil, and waste, is considered key in achieving security. Such economic growth and increase in gross domestic product leads to the generation of waste or by-products, along with contamination and eutrophication of water resources. According to estimates by the United Nations Food and Agricultural Organization (FAO), 222 million tons of food are thrown away every year globally. Resource efficiency, the integration of environmental parameters, and social balance in economic decisions “pay off,” suggesting that more can be achieved with less. The use of treated wastewater (waste compartment) as irrigation supply (water compartment) for food production (soil compartment) is considered a prime example for the assessment of WSW nexus interlinkages at the environmental resource level but also for its effects on the governance level (see also Fig. 9).

As water is included in the WEF and the WSW nexus, the basin scale is of importance in the discussion and different nexus-related research, some also including ecosystems or climate (Lawford et al. 2013; de Strasser et al. 2016; Karabulut et al. 2016). The WEF nexus has not yet come to a common understanding regarding the scale of assessing water, energy, and food interlinkages. What we know is that the different interlinkages of the WEF nexus are not fully understood on all scales (Hoff 2011), that it is not clear how to implement a nexus across scales (de Strasser et al. 2016), and that we need to find methods to connect these various scales (Endo et al. 2015). In order to provide a clearer picture for the system of the WSW nexus, Avellan et al. (2017) proposed the benefit-shed, which refers to



Water-Energy-Food Nexus and Sustainability, Fig. 9 Exemplary interlinkages between the resources water, soil, and waste. (Design adapted from UNU-FLORES, content based on R. Lal (2013))

a geographic area where at least two resource systems overlap and thus form the WSW system. The analysis of physical interlinkages within this system must aim to reveal benefits through increased resource use efficiency.

A distinct methodology for assessing securities has not been developed so far, but common risk assessments, environmental impact assessments, or sustainability impact assessment can be readily applied to each of the resources and the WSW nexus system as defined by the benefit-shed. This could also be linked to the benefits assessment of UNECE as described above providing a direct link between the WSW nexus and the WEF nexus.

Interlinkages Between the Water-Energy-Food Nexus and the Minerals-Energy Nexus

There are also strong interlinkages between the water-energy-food nexus and minerals-energy nexus according to McLellan (2017). This shall be illustrated using the example of the sand extraction in South East Asia, particularly Vietnam.

So far, sand in Vietnam has been extracted only by dredging from rivers as the country does not have other natural sand resources. This has led to enormous environmental impacts in the last few years, including a significant increase of the flood risk due to the altered hydromorphological structure of the rivers, which (a) resulted in a higher flow velocity and thus provoked increased risk of erosion in the rivers and (b) massive geotechnical problems with regard to the slope stability of the rivers and the related infrastructure. For this reason, there are river sections in which sand extraction has already been completely banned. The situation has led to a four or five told increase in the construction sand prices.

A government report from the Department of Construction Materials in the Vietnamese Ministry of Construction, issued in August 2017 and based on statistics from 49 provinces and cities, indicated that by end of 2016, there have been issued permits for the mining of 691 million m^3 of sand and gravel. According to information from the Ministry of Construction in Vietnam, the domestic demand for construction sand between 2016 and 2020 is estimated at around 2.1–2.3

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billion m^3, while the country's total sand reserves are just about 2 billion m^3. With this rate of sand consumption in Vietnam, the country will run out of sand as building material by the year 2020. But this is just one side of the problem. Scientists from the Institute for Climate Change at the Cần Tho University recently pointed out that unbridled dredging for the sand extraction has already created deep holes in the Mekong River and it is causing massive land subsidence in the Mekong Delta. Due to land subsidence, the Mekong Delta loses around 500 hectares of land every year, and hundreds of families lose their homes and agricultural fields. It has also been noted that in the near future, once all 11 dams for water and energy supply on the upper Mekong are completed, there will be no alluvial sediment transport into the delta anymore. If the dredging continues at the operational sites and further pits become accessible, one-third of the Mekong Delta will disappear by 2050, resulting in irreversible environmental impacts in terms of flood risk, land subsidence, and biodiversity.

Meanwhile, the Mekong transports about 20 million t/year of sediment in the direction of the Mekong Delta, where it has been intensively used for decades for sand extraction. Nowadays, the volume of sand dredged from the Mekong River is twice as high as the sediment material delivered by sediment transport in the river. This has serious consequences not only for the ecosystem but also for living conditions along the river. Massive erosion has started, combined with land subsidence and slope instabilities. The river morphology has changed due to the dredging; the spawning grounds of the fish have shifted farther away, so that also the food provision by fishing is affected. For example, both tributaries of the Mekong, Tiền and Hậu, were deepened 5–7 m since 2008. The river level depletion accompanying the extraction of sand has an impact on agriculture: sludge and fine material are no longer reaching the agricultural land, resulting in a reduction in soil productivity. The overexploitation also has negative consequences for the environment and people in the sand extraction areas: in the Mekong Delta and other coastal areas of Southeast Asia, the sand extraction is already causing groundwater depletion and land subsidence. As a result, seawater penetrates further and further into the hinterland and spoils drinking water, agricultural fields, and soils (Fig. 10).

Sand extraction is also a common cause of shore and coastal erosion, making them more vulnerable to natural disasters such as floods, storm surges, or tsunamis. For instance, intense sand extraction in Sri Lanka worsened the effects of the tsunami in 2004. The focus of the An Giang Province in Vietnam recorded an increase in landslides and slope breakdown, which in 2017 caused provincial authorities to issue landslide warnings for the first time. In An Giang, the provincial authority identified 51 endangered river sections, with a total length of 161,550 m (DONRE An Giang 2017). Finally, this affects the food and energy provision in the catchment area. The Mekong River cannot provide its ecosystem services anymore in terms of food and energy to its full extent due to overexploitation of the natural capital.

Water-Energy-Food Nexus and Sustainability, Fig. 10 Impressions of the Mekong Delta including effects of sand dredging

Conclusions

The nexus approach provides a tool for the implementation of the SDGs as the main scope is defragmentation and consideration of the demands of all sectors and stakeholders, as well as the recognition of the demands of the ecosystems as part of the natural capital.

The WEF nexus intends to equitably achieve water, energy, and food security. This is considered key to achieve the agenda 2030 and thus sustainable development. For now, a handful of approaches to implement the nexus approach on the ground exist (more than what we have illustrated in this entry). In all cases the intention of addressing securities is present although not explicitly and probably forcefully enough. In general, the challenge still exists of assessing and interpreting the interlinkages of resources and acting upon these findings to achieve security in all fields at all scales, local, national, regional, and global.

In the near future, teaching the WEF nexus will be part of the curricula in higher education as one framework for the implementation of sustainability using a defragmentation tool, e.g. the teaching-research-practice nexus (Schneider et al. 2018).

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Well-Being

► Social Welfare and Sustainability

Wellbeing and Sustainability

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Definition

Well-being and sustainability can be defined as two essential goals that sustainable development seeks to achieve.

Introduction

Wellbeing and sustainability are two distinct ideas, each with its own distinct history, that have converged to become interconnected concepts when considered in relation to the solutions required for the environmental crises of global warming, climate change, and pollution. Both wellbeing and sustainability are ideas that emerged in ancient cultures; however, the current concept of sustainability arose out of the ecological thinking and practices of the latter half of the twentieth century. Wellbeing and sustainability emerged from ancient cultures, one in the theoretical sense and another in the practical sense. The search for wellbeing in the ancient world is known today because of the preserved writings of ancient philosophers. Sustainable practices from ancient cultures are revealed through the archaeological record and extant historical documents. It can be said with great certainty that some ancient cultures and civilizations were indeed engaged in sustainable practices, for there was an awareness that was manifested through actions that understood that a balance must be preserved in nature. Sustainability in ancient cultures was practiced through various activities by seeking a balance between the extraction of resources and the long-term vitality of the environment. Such practices provided safeguards for the continuous integrity of a particular civilization. Preindustrial civilizations existed mostly in a state of balance with nature due to the technological limits in relation to the depth of the extraction of resources in the earth and the limited knowledge of methods of control of the fossil fuels buried deep underground. The loss of this balance was foreseen in the productive yet quite destructive mining techniques of medieval Europe. The environmentally destructive medieval mining practices in Europe were precursors to the Industrial Revolution and to the current state of resource extraction and processing that is reliant on dirty fossil fueled machines (See *De Re Metallica* by Georgius Agricola for an extensive study on medieval mining techniques and metallurgy.). The pursuit of wellbeing, sustainability, and the 17 Sustainable Development Goals are being carried out in order to regain this lost balance. In order to better understand how individuals, communities, universities, local and central governments, and private and public organizations may actively participate in the creation and implementation of sustainable and green systems, it is essential to understand the various ways in which an awareness of wellbeing contributes to such systems, and why wellbeing is such a central issue within the theoretical and practical thinking involved in the creation of such systems. Although sustainability in its current form is a modern, twentieth-century idea, many ancient and preindustrial civilizations and societies did indeed live sustainably, and it is therefore of great value to investigate the various methods of production and ways of living that existed throughout history. Such investigations are necessary because groups and individuals living in technological, industrial, and postindustrial societies in the twenty-first century and beyond may benefit by recognizing and understanding that certain ancient sustainable practices and technologies have a place in the contemporary world. Furthermore, it is crucial to investigate the philosophical and scientific foundations of a society in order to better understand its intentions and pursuits. In order to not only address but also to solve the environmental crises the world faces, humanity must deeply consider the nature of work, the mechanisms of industrialization, the questionable decisions and flawed thinking that allows for environmental pollution, and the hidden, underlying causes that determine daily actions. Archaeological remnants, philosophical texts, and other historical documents reveal secrets hidden by the passage of time that assist researchers and scholars in determining the ways of living that may be described as sustainable, educated, prosperous, and enduring.

Ethics and the Good Life

One direct pathway toward reaching an understanding concerning the nature of human action and the attainment of wellbeing is found in an investigation into the extant writings of ancient philosophers. These writings, which survived throughout history, are in a way archaeological remnants, and they were transcribed over centuries on parchment in many languages, and these writings reveal the science, ethics, and cosmology of particular advanced and lasting societies and states that were engaged in sustainable practices. This pathway toward understanding wellbeing leads to an investigation into the writings of the ancient Greek philosophers, especially into the ethical and political writings of Aristotle and in particular the *Nicomachean Ethics* and the *Politics*. Aristotle's investigations into human nature in the *Nicomachean Ethics* are centered on the pursuit and permanent possession of the good life. Aristotle states at the beginning of the *Nicomachean Ethics* that all human actions and choices aim at some good; the goal of economics is wealth, the goal of medicine is health, and the goal of strategy is victory. Beyond the particular goals of each activity, there exists the good, which is the reason behind all human actions. All actions and activities are teleological in the sense that they are partaken in because of the search for the acquisition of the good. The good is the object of study in the science of politics, because states in a way are responsible for sanctioning approved activities and determining what is just. This sanctioning is carried out in order for states as a whole and their citizens to attain the good ("For even if the end is the same for a single man and for a state, that of the state seems at all events something greater and more complete both to attain and to preserve; for though it is worth while to attain the end merely for one man, it is finer and more godlike to attain it for a nation or for city-states." *Nicomachean Ethics*, Book I, Ch. 2, $1094^{a}7$–11.). All sciences and activities strive toward their respective goods; however, beyond those particular goods, there exists the highest good, and that is what all actions are carried out for. Aristotle identifies this highest good as happiness or *eudaimonia*. Etymologically, this word in ancient Greek is composed of the words *eu* (good) and *daimon* (spirit), and it is often translated as happiness, or human flourishing. Happiness and wellbeing are achieved through living well, or *eu zen*, and living well is characterized by partaking in virtuous activities. Happiness is the goal of all human actions, and it is sought after for its own sake, and because of this fact, it is the most complete and self-sufficient of goals. Aristotle illustrates this point in the following passage:

> Now such a thing happiness, above all else, is held to be; for this we choose always for itself and never for the sake of something else, but honor, pleasure, reason, and every virtue we choose indeed for themselves (for if nothing resulted from them we should still choose each of them), but we choose them also for the sake of happiness, judging that through them we shall be happy. Happiness, on the other hand, no one chooses for the sake of these, nor, in general for anything other than itself. (*Nicomachean Ethics*, Book I, Ch. 7, $1097^{a}36$-$1097^{b}7$.)

For Aristotle happiness is not a state nor is it an emotion; it is an activity that if achieved becomes a permanent possession of the soul. Aristotle states that in order to understand happiness and wellbeing, we must discern what is the function, or *ergon*, of human life. A virtue, or *arête*, is a state of character that assists humans in grasping their function. Rationality is particular to humans, and its possession and active use in conjunction with virtuous activities may lead to a life well lived. The function of human life, then, is to achieve happiness and wellbeing by partaking in virtuous actions. Practical wisdom, or *phronēsis*, is developed by practicing virtuous activities, and this in turn assists us in understanding the proper comportment in any situation. Human life is composed of internal and external goods. Internal goods are goods of the soul and the body, such as wisdom, health, and strength. The external goods are the goods that exist independent of the soul and body. The external goods are things such as a few good friends, prosperity, and honor. Both the internal and external goods are requisites for the attainment of the good life, and it is through practical wisdom that humans achieve an understanding to what those goods are. Aristotle identifies two kinds of virtues: moral virtues and intellectual virtues. Moral virtues are developed through habit and constant practice in conjunction with rationality that strive for attaining what is moderate in any situation. Practical wisdom, or *phronēsis*, assists a person in recognizing what is moderate, and that choosing moderation is what assists in the permanent possession of happiness. The intellectual virtues are developed through instruction and are essential for understanding the first principles of the sciences and the metaphysical nature of reality. Aristotle identifies five intellectual virtues, and they are *epistēmē*, i.e., scientific knowledge; *noûs*, i.e., intuitive understanding; *sophia*, i.e., wisdom; *phronesis*, i.e., practical wisdom; and *technē*, i.e., crafting knowledge. The possession of the intellectual virtues assists in the comprehension of the three categories of infallible knowledge: theoria, i.e., theoretical knowledge; poiesis, i.e., productive knowledge; and praxis, i.e., practical knowledge. The acquisition of the moral and intellectual virtues are necessary for Aristotle because in order to live a life well lived, one must comprehend both morally correct actions and scientific knowledge that is grasped by rationality. Aristotle's investigations in the *Nicomachean Ethics* are directed at uncovering the ways in which *eudaimonia* is achieved. It must also be stated that the challenging environmental conditions of ancient Greece shaped local and regional attitudes and practices concerning natural resources. Summers were hot and dry, and fresh water was extremely limited, and the collection of fresh water was a difficult and time-consuming chore. It was the job of mostly women and slaves to partake in long daily journeys to collect water from springs. Aristotle and all of the ancient Greeks understood the necessity of the virtue of moderation and implicitly its importance as a central tenet of sustainability and the long-term vitality of the Greek civilization. Concerning the positive impact the Mediterranean climate had upon the wellbeing and the political characteristics of Greek civilization, Aristotle states the following:

> Those who live in a cold climate and in Europe are full of spirit, but wanting in intelligence and skill; and therefore they retain comparative freedom, but have no political organization, and are incapable of ruling over others. Whereas the natives of Asia are intelligent and inventive, but they are wanting in spirit, and therefore they are always in a state of subjection and slavery. But the Hellenic race, which is situated between them, is likewise intermediate in character, being high-spirited and also intelligent. Hence it continues free, and is the best-governed of any nation, and, if it could be formed into one state, would be able to rule the world. (*Politics*, Book VI, Ch. 7, 1327^{b}24-32.)

Moderation and sustainable ways of living were part and parcel of the daily life of the Greeks and all flourishing ancient civilizations. The insights concerning the nature of human action that Aristotle uncovered in the *Nicomachean Ethics* and the *Politics* are a crucial part of the solutions required for the transition to renewable energy and a sustainable world and those discoveries on the foundations of human nature are extremely relevant in our quest to create a sustainable world in all of its forms because those discoveries reveal the reasons behind human actions which may in turn lead to better solutions that take into account the teleological aspect of human nature.

Ethics and the Sustainable Development Goals

The 17 Sustainable Development Goals (SDGs) and their accompanying 169 specific targets were accepted and adopted on September 25, 2015, at the United Nations Headquarters in New York City ('A/69/L.85 – Draft outcome document of the United Nations summit for the adoption of the post-2015 development agenda,' *United Nations Sustainable Development Platform*, accessed June 17th, 2018, http://www.sustainabledevelopment.

un.org.post2015/summit). The attainment of the SDGs will have a transformative effect on wellbeing on a global scale and will help to alleviate some of the unnecessary suffering of hundreds of millions if not billions of people. In order to better grasp the fundamental ethical ways of being and actions that may contribute to attaining the SDGs, it is helpful to present them here.

The 17 Sustainable Development Goals ("Sustainable Development Goals," *United Nations Sustainable Development Knowledge Platform,* accessed June 17, 2018, http://www.sustainabledevelopment.un.org).

1. No Poverty
2. Zero Hunger
3. Good Health and Wellbeing
4. Quality Education
5. Gender Equality
6. Clean Water and Sanitation
7. Affordable and Clean Energy
8. Decent Work and Economic Growth
9. Industry, Innovation, and Infrastructure
10. Reduced Inequalities
11. Sustainable Cities and Communities
12. Responsible Consumption and Production
13. Climate Action
14. Life Below Water
15. Life on Land
16. Peace, Justice, and Strong Institutions
17. Partnerships for the Goals

When considered in relation to Aristotelian ethical theory, it becomes clear that the 17 SDGs are attainable because it is a part of human nature to pursue virtuous goals. Activities that pursue the achievement of the possession of the 17 SDGs are virtuous because the solutions require examinations of human practices that are done in excess and are therefore vices, and those vices or immoral activities must then be redirected toward that which is moderate. If the purpose of human nature is to strive to achieve *eudaimonia*, and therefore wellbeing, then the collective global allegiance of states and communities are in a way responsible for the creation of programs and infrastructure projects that promote the actualization of the 17 SDGs. Human actions, when conducted in full cognizance of the moral and intellectual virtues, and in conjunction with the 17 SDGs, and with the perfect functioning of the human nervous system which allows for the faculty of rationality, and the positive consequences that arise from their completion, by nature seek that which is moderate. Our purpose-driven lives are made better by pursuing prosperity, and all the external and internal goods, through a state of moderation, by which the vices of excess and deficiency are avoided and by which wellbeing is cultivated and maintained. It makes only common sense that if almost all existing things related to economics and industrialization are subject to some form of taxation, then pollution itself in all of its forms must be priced and taxed too. To develop wellbeing and a sustainable world where happiness applies to all and not to just the few, then the excesses and deficiencies in modern industrialization and capitalism must be addressed, confronted, and changed. To embrace excess and deficiency is to deny the virtue of moderation, and this in turn is a denial of ecological thinking and a possible sustainable world. To act locally and to think globally, with renewable energies, and shared resources and shared knowledge, while embracing moderation and striving for the actualization of the 17 SDGs, is to live a life fully aware of the teleological element of human nature and to use that purpose-driven life to create the best possible chances for the attainment of *eudaimonia*. Wellbeing and *eudaimonia* are achieved through moderation and virtuous actions, and ethical theory has been traditionally focused on the actions and intentions of the individual. Our modern environmental crises require us to synthesize and present the results from ethical theories and moral reasoning so that not only individuals but also communities and cities and states initiate the cultivation of the good life through policies and practices on a massive scale. This will insure that all citizens benefit from these actions. The practice of moderation in action and thought will assist in the attainment of *eudaimonia* and wellbeing because of the continuous engagement in virtuous activities. Individuals, local and central governments, connected inhabitants, universities, and businesses should practice moderation in all of its permutations because by doing so is good in itself; safeguards established habitats, dwellings, and the local environment; and fosters wellbeing by embracing the benefits of clean and healthy places. The elimination of noise, light, air, and water pollution would have a remarkably transformative effect on the inhabitants of any modern city. The actualization of the SDGs is the responsibility of everyone, from individuals to the largest, most powerful organizations and governments. By embracing technological advancements humanity has a great chance of reducing and/or eliminating carbon emissions and creating opportunities that foster wellbeing. Machine learning will allow humanity to reconnect with nature and with themselves; for universal incomes and having all basic services provided for will create possibilities where learning and advancement will be available to all citizens, of any nation. Transitioning to renewable energies will create opportunities for universities and other institutions to power themselves and their neighborhoods. Providing free and supplemental electricity to local area residents will increase wellbeing in developing countries and communities in the sense that local inhabitants will feel connected to the institutions and in the sense that residents will reap the benefits of living in dwellings that are enhanced by electricity and the devices and appliances, i.e., the external goods that contribute to wellbeing. Perhaps when considered in relation to Aristotelian ethics, the current dilemma of global warming is partially rooted in some humans making the mistake in thinking that an excess of external goods directly leads to *eudaimonia*. Excesses in almost any way are unsustainable for the individual, the community, and the environment and are considered to be vices and obviously are not virtues. A moderate and sufficient amount of external goods is enough for the fostering and preservation of happiness and wellbeing. The reintegration of nature with urban communities through sustainable practices based on conservation and preservation will exponentially increase the wellbeing and happiness of citizens because of the resulting reduced pollution, reduced stress, and reduced crime. Renewable energy projects, combined with universal education, universal healthcare, universal housing, and urban organic farming, will transform societies into groups of connected communities where all basic needs are met, and this is a transformation rooted in the cultivation of wellbeing that creates peace and quiet and promotes ecology and ecological thinking. States and cities that embrace and truly implement practices aimed at the achievement of the 17 SDGs will be known and remembered as pioneers in clean energy, human equality, and postindustrial ecology. The individuals who will be remembered in the coming centuries as heroes will be people that eliminate the inherent flaws of capitalism and industrialization by virtuous actions based on philosophical and ecological thinking. To live sustainably is to practice constantly the virtue of moderation in all daily activities, and doing so in conjunction with the realization of the teleological nature of humanity greatly increases the chances of attaining *eudaimonia* and the possession of a life well lived. Concerning the development of a city that could be considered enduring and sustainable Aristotle states the following:

> We had already said that the city should be open to the land and to the sea, and to the whole country as far as possible. In respect of the place itself our wish would be that its situation should be fortunate in four things. The first, health–this is a necessity: cities which lie towards the east, and are blown upon by winds coming from the east, are the healthiest; next in healthiness are those which are sheltered from the north wind, for they have a milder winter. The site of the city should likewise be convenient both for political administration and for war. With a view to the latter it should afford easy egress to the citizens, and at the same time be inaccessible and difficult of capture to enemies. There should be a natural abundance of springs and fountains in the town, or, if there is a deficiency of them, great reservoirs may be established for the collection of rain-water, such as will not fail when the inhabitants are cut off from the country by war. Special care should be taken of the health of the inhabitants, which will depend chiefly on the healthiness of the locality and of the quarter to which they are exposed, and secondly, on the use of pure water; this latter point is by no means a secondary consideration. For the elements which we use most and oftenest for the support of the body contribute most to health, and among these are water and air. For this reason, in all wise states, if there is a want of pure water, and the supply is not

> equally good, the drinking water ought to be separated from that which is used for other purposes. (*Politics*, Book VI, Ch. 11, 1330^{a}34-1330^{b}17.)

Life is the purpose-driven pursuit of the good. If we are able to discover through scientific research and philosophical investigations that the possibility of a sustainable world hinges on good, virtuous actions that are based on moderation, then it may be said that the highest good, i.e., happiness or wellbeing, is that which humans must strive most to cultivate. All of our actions are ultimately striving toward the acquisition of wellbeing, and therefore philosophical thinking and an awareness of the inherent teleological nature of human life will assist in the realization that the negative aspects of industrialization must be corrected with haste and with permanence. If *eudaimonia* is indeed the highest good, is achieved by living the good life, and is the end of all pursuits, then actions, ideas, and policies that foster its development and protection are the best things to strive toward. Like *eudaimonia* and wellbeing, sustainability is a type of action, or many actions, that must be fostered and cultivated through virtuous and correct thoughts and activities. Sustainability and its positive consequences cultivate *eudaimonia* and wellbeing by rethinking and retooling ways of living and industrialization that are detrimental to our environment. The cultivation of *eudaimonia* and wellbeing are in many ways dependent upon the state of the environment. As the world becomes more sustainable, it also will become much cleaner, which will benefit the health of all humans and all living beings on Earth, and those health benefits and sustainable practices will in turn positively affect the wellbeing of all people, everywhere. The retooling of our transportation infrastructure and all other industries from being based on fossil fuels to sustainable, clean energy will require much effort and investment. This great, necessary retooling will be initiated by visionaries and risk-takers that understand that sustainability and wellbeing are greater motives for action when compared to all things, yet especially when compared to dirty and ethically questionable profiteering. What humanity must embrace in the twenty-first century is a redefined concept of prosperity that is aware of and cares for the Whole. Previous to the coming halt to humanity's immersion in unethical economic models and methods of industrialization that allow extreme pollution and resource depletion, it will be required that all systems, all consequences of industrialization, and all purpose-driven activities contain elements of ecological and sustainable first principles that are defined, defended, and engaged in for the wellbeing of current and future generations. The 17 SDGs are an excellent starting points for action. The virtuous actions required for their ultimate implementation and normalization overlap into different SDGs and seek to regain the ecological balance that we have lost.

Conclusion

Even in consideration of the Second Law of Thermodynamics and the inherent universal tendency toward disorder and entropy (See The Encyclopedia of Philosophy, volume 1, s.v. 'Entropy.'), it must be said that our actions and our thoughts are fully ordered by the cognition and activity of the faculty of rationality which allows us to create logical systems and ordered lives that are based on happiness, wellbeing, and organic and sustainable ways of living. To live simply, quietly, without too much competition, and locally, organically, socially connected to neighbors and respective communities through shared resources and extensive public transportation services, with universal healthcare within a safe region, is to experience community living how it should be, that is, based on a prosperity that is grounded in the Whole. The first four SDGs can be achieved on a global scale with great effort and dedication and by redirections of wealth and resources. These redirections must occur locally, nationally, and internationally. Great advancements toward the attainment of the SDGs could be initiated by the redirection of worldwide military budgets into renewable energy infrastructure projects and local organic farming initiatives. A world in which all inhabitants have access to clean food and water, universal healthcare and education, and sustainable housing is a world in which equality and peace flourish, and militaries exist yet in diminished capacities such as for self-defense and disaster rescue situations. The remaining SDGs can be achieved simultaneously through virtuous activities and policies that originate from the first four. Technology and machine learning will initiate solutions on an exponential scale and will create the machines that will assist us in reclaiming a pollution-free Earth. The ethical algorithms that dictate the boundaries of the actions of the thinking machines will be based on the ecological principles of conservation, preservation, peace, and sustainability. Clearly defined first principles of a science must be established and agreed upon before any rational inquiry can commence within that science. If local communities and state governments adopt the 17 SDGs as the first principles or starting points upon which their economic policies were based, then the world would prosper and initiate a recovery from centuries of blatant pollution and industrialization. Sustainable policies and practices based on wellbeing will insure the long-term stability and recovery period necessary for the Earth and all of its inhabitants. The redirection of funds for activities and profits related to fossil fuels and toward projects that foster wellbeing and green prosperity will create sustainable communities around the world. To have individuals, community members, and global citizens to embrace all of the 17 SDGs is to accept certain foundational beliefs and scientific truths about the world. One of those truths is that capitalism and industrialization contain fundamental flaws that are detrimental to humanity and the Earth. And it must also be said that the secondary and tertiary actions and activities that create pollution are also flawed, because if the greatest good is happiness, and it is what we are all seeking, then doing things that are destructive and harmful are diametrically opposed to that which is virtuous and good. While humanity embraces technology in order to assist with the cultivation of wellbeing, it is equally crucial to look deep into the past, to rediscover forgotten sustainable practices and ethical theories that offer explanatory clues concerning how to live correctly, which in turn may assist in the resolution of the many economic, philosophical, and scientific puzzles that exist within this exceptionally complex world. It seems as if the solutions to global warming are as complex as the problems themselves. When all world governments and corporations and individuals embrace wellbeing and sustainability as the foundational motives for actions and activities, then the environment will start to heal; peace, health, and happiness will blossom; virtuous, green prosperity will replace the flawed, selfish models of capitalism and globalization; and humanity as a whole will become smarter, more ethical, and more aware of the virtuous activities that lead to a life well lived. The recognition and elimination of the mistakes and flaws in current accepted industrial practices will permit the commencement of a unified quest toward perfection, and this quest is something good, ethical, and worthy of pursuit.

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Whole-Systems Approach to Sustainability

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Three entries in this encyclopedia serve as a trilogy that interconnects co-design, sustainable development, complex systems, and a whole-systems approach to sustainability. This entry helps build a whole-systems understanding of sustainability. Another entry of the trilogy – Complex Systems and Sustainable Development – addresses complex systems (using a complexity theory approach) and the relationship of

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complexity and sustainable development. The other entry of the trilogy – Co-Design Methods and Sustainable Development – focuses on the ongoing transformations in design methods and sustainable development.

Definition of Whole-Systems Approach

This entry introduces and defines a whole-systems approach to sustainability as viewed through the perspective of complex adaptive systems. Looking through this lens, a whole-systems approach appreciates the co-adapted relationships existing among the entities that constitute these systems, including both physical and behavioral co-adaptation. It appreciates the need to sustain the deep interconnectivity of these systems and their ability to co-adapt with broader system change. The whole-systems approach seeks to appreciate and collaborate in complex adaptive system functionality, sustainability, and regeneration.

Introduction

This presentation focuses on sustainability at three system levels. At the object-level, it focuses on entities and their co-adapted behaviors. At the systems-level, focus shifts to optimizing complex adaptive system performance through enhanced network conversation, life-cycle flows, and whole-systems functionality, regeneration, and resilience. At the meta-level, emphasis shifts again to sustaining the ability of complex systems to co-adapt at the intensity and rate of contextual change, to realign system with context, to build transformative resilience, and to provide the transformative innovations needed as feedstock for transformative change, complexification, and emergence to higher levels of biocapacity.

Whole-Systems Approach to Engaging Complex Adaptive Systems

From the complex adaptive systems perspective, a whole-systems approach calls for humanity to operate as an appreciative system (Jantsch 1975) that positively engages in the complex system it helps create. It calls for humanity to appreciatively engage systems in ways that help sustain continuous and non-interrupted functionality of the entirety of the complex adaptive system. This whole-systems approach appreciates how complex adaptive systems build greater complexity and regenerate higher levels of productivity through immense cycles of innovation and co-adaptation. It sees current challenges through a big history lens, with an emphasis on three transformations of complexity including the physically complex transformation of the universe, the profoundly greater transformation of a biologically complex planet earth, and the immense potential of the cognitively complex transformation of planet earth that is still in its immature stage (Swimme and Tucker 2011).

The whole-system approach appreciates how the recent history of human engagement in complex adaptive systems, empowered by advances in science and technology produced, from 1950 to 2000, what has been called the Great Acceleration of human knowledge, productivity, and well-being (Stokols 2018). The whole-systems view is also aware that the unsustainable behaviors during the period of the Great Acceleration also contributed to the subsequent Great Recession, with its compromised ability to sustain co-adapted complexity. There is a growing concern, also from the whole-systems perspective, that the rapid and massive growth in digital computing has expanded humanity's ability to think logically, mathematically, and analytically without an equal expansion in the ability to think analogically (Callaos 2017). Looking through the whole-systems lens also reveals the crucial need at this pivotal time in human history to re-empower whole-systems network conversation to enable the massive amounts of co-adaptation needed to reactivate biological complexity and foster maturation of a cognitively complex planet earth.

Whole-Systems Approach to Sustainability

From a whole-systems perspective, and using systems language, a whole-systems approach to sustainability operates on three system levels: object, systems, and meta. At the object-level, a whole-systems approach focuses on entities including buildings, sites, built-sites, other objects of development, and their behaviors in relation to each other and the complex system of which they are a part. At the systems-level, a whole-systems approach promotes physically, biologically, and cognitively complex systems and network behaviors that are co-adapted and synergistic. At the meta-level, a whole-systems approach promotes the emergence of new systems with transformative resilience provided by objects, systems, and behaviors that promote co-adaptation with each other and changing conditions and collaborate with the complex adaptive system in transforming systems in ways that enable them to co-adapt at the rate and intensity of contextual systems change (see ► "Co-design Methods and Sustainable Development" entry of this Encyclopedia).

At this unique time in history, where humanity has developed the intelligence required to operate unsustainably outside metabolic processes at increasing rates and scales, but has not yet developed the intelligence needed to operate sustainably in ways that avoid the profound unintended consequences of unsustainable development, whole-systems are increasingly at risk of collapse. In addition, growing dis-alignment between whole-systems needs and human decisions has resulted in rapidly accelerating negative impacts. These impacts are currently motivating a shift to meta-level thinking with the robustness needed for humanity to realign whole-systems needs and human behavior, embrace the deep network conversations needed for co-adaptation, and implement the transformative innovations needed as feedstock for the emergence of transformative resilience and for complex system regeneration at higher levels of whole-systems complexity, productivity, and capacity to sustain life.

Implementing a Whole-Systems Approach to Sustainability

A whole-systems approach appreciates that complex adaptive systems operate, sustain functionality of the system and its interdependent parts, regenerate system capacity, and emerge to higher levels of complexity, productivity, and stability through deeply interconnected metabolic processes. This approach contends that to be sustainable, development must integrate into these metabolic processes (Lyle 1994; Fisk 1989). Recent and growing awareness of profound and irreversible complex system change due to the history of unsustainable development is now pushing humanity toward a whole-system, complexity-appreciative awareness that to be sustainable, development must sustain the immense regenerative cycles of innovation and co-adaptation that characterize complex systems (Swimme and Tucker 2011; Johnson 2001).

Complex adaptive systems operate through network flows of massive amounts of information that inform physical and behavioral coordination and co-adaptation among immense numbers of diverse participants to empower whole-systems functionality and complexification. To sustain these systems and their interdependent parts, intervention strategies must collaborate in renewing and enhancing this massive network conversation. In the current period of massive system change resulting from unsustainable development, a whole-systems approach is needed to help humanity quickly learn how to thrive, operate in today's unsustainably provisioned system, and simultaneously learn how to reprovision planet earth to catalyze a future where humanity thrives by living appreciatively within complex adaptive systems (CMPBS 2009).

Mark Lawrence (2015) sees Anthropocene consciousness at a turning point, and challenges humanity to replace its immature Anthropocene 1.0 consciousness and resulting impacts with a more mature Anthropocene 2.0 consciousness, where humanity participates appreciatively in renewing and re-empowering complex adaptive systems. Several streams of knowledge are being developed within higher education and society that can increase humanity's ability to make this shift. As an overview of ongoing activities to meet this challenge, this section looks at entities and activities that use whole-systems approaches to re-empower planet earth as a biologically complex system. It discusses how these entities and activities are reprovisioning the planet for the emergence of a mature cognitively complex system. It closes with a discussion of professional urban design project proposals, motivated by Anthropocene 2.0 consciousness, which are building an understanding of how cognitively complex development and learning-by-doing can reprovision urban neighborhoods and promote the identification of transformative innovations that can help transform planet earth into a cognitively complex adaptive system while empowering design professionals to bring the knowledge gained to their courses in higher education.

Whole-Systems Approach to Re-empowering Biologically Complex Systems

As a catalyst for re-empowering living systems and a biologically complex world, a whole-systems approach can reactivate the immense amount of genetically and epigenetically coordinated network information flow and co-adapted behaviors needed for ecological systems to regenerate their performance and whole-systems functionality. At the most basic life-sustaining level, this includes empowering complex adaptive systems to regenerate the deeply coordinated action needed to harvest energy from immense numbers of photons of sunlight, concentrate the low-level energy from these photons into higher-energy chemical bonds, and use this concentrated energy to transform what was originally a gray planet earth into the ecological complex, productive, and regenerative network of interconnected ecosystems that constitute the biologically complex planet earth that sustains the web of life including all of humanity.

Challenge Presented by Unsustainable Anthropocene 1.0 Provisioning

By the end of the twentieth century, the immature mind had developed the intelligence needed to operate outside complex system limits, but not the wisdom to appreciatively collaborate in the full regeneration of biologically complex systems. Anthropocene 1.0 awareness, grounded in the false belief that humanity could sustain itself without co-adapting in ways that regenerate positive eco-balance in the complex system, had become empowered by science and technology to unsustainably operate at scales and intensities that profoundly degrade the highly productive and interconnected networks of biologically complex adaptive systems. Unsustainable development had also loaded ecosystems with residuals that compromise the ability of these biologically complex adaptive systems to renew their full functionality and productivity and to co-adapt and complexify at levels needed to complete planet earth's transformation into a cognitively complex adaptive system.

Two-Phase Strategy for Reactivating Biologically Complex Systems

In 2007, the Buckminster Fuller Institute created the Buckminster Fuller Challenge as an annual international design competition to provide awards for comprehensive solutions to crucial global problems (BFI 2018). By its focus on comprehensive solutions, this Challenge helps build appreciation of whole-systems approaches to understanding and intervening to today's complex adaptive systems.

In its 2009 submission to the BFI challenge, the Center for Maximum Potential Building Systems (CMPBS) provided a two-pronged response. The first sought to optimize human engagement within today's unsustainable Anthropocene 1.0 human support systems and the second to build knowledge needed to reprovision the complex adaptive system for a sustainable future. CMPBS used the term Proto-1 to refer to a systems-level focus on optimizing engagement in current unsustainably provisioned development; and Proto-2 to refer to the meta-level focus on reprovisioning for a sustainable future. At the Proto-1 level, CMPBS sought to optimize performance and enhance functionality of the whole-systems within current unsustainable provisioning and to build the knowledge system needed for Proto-2 level reprovisioning as meta-level change. In the BFI competition, CMPBS sought to re-empower coastal regions as biologically complex systems and as a global region case study to re-enable planet earth to fully function and regenerate as a biologically complex system (CMPBS 2009).

Reprovisioning for Emergence of a Mature Cognitively Complex System

At the meta-level, Motloch (2016) called for a big science project and research agenda for unlocking biologically complex adaptive systems so they can regenerate the higher levels of complexity and biocapacity needed for maturation of cognitive complexity. He lamented how residuals of Anthropocene 1.0 engagement have locked up biologically complex systems and compromised their ability to sustain whole-systems functionality, regeneration, complexification, and emergence of conditions conducive to transforming to cognitively complex systems. He called for unlocking complexity through massive innovation and co-adaptation cycles as feedforward-feedback loops that help build the wisdom needed to enable local networks to co-adapt the immense, deeply coordinated behaviors needed to re-empower biologically complex adaptive systems, metabolize interconnectivity, reactivate positive eco-balance, and unlock the arrested maturation of planet earth as a cognitively complex adaptive system (2016). Unlocking complexity requires massive growth of key knowledge system dimensions that are currently being empowered by diverse initiatives, including but not limited to the following.

Empowering Information, Collaboration, and Co-reliance

A whole-systems approach to re-empowering biologically complex systems and accelerating maturation of cognitively complex systems begins with undistorted information flow, deep collaboration, and transparency. As discussed by Rushkoff, this requires a meta-system reversal of the 800+ year trajectory of increasing waves of hierarchical messaging – including chartered monopolies, global corporations, platform monopolies, and digital corporations – that disempowered local capacity building networks (2016). It requires that humanity implement a meta-level shift to healthy local and community networks, economies, and metabolic flows and that economic systems be changed to unlock network conversation by addressing the needs of the full diversity of agents needed to empower whole-systems network conversation.

Building Healthy Networks

Various entities are engaged in activities that together can have potential to reprovision complex adaptive systems in a way that can re-empower biological complexity and promote cognitively complex systems. Together these initiatives are helping shift systems from ones provisioned to maximize human need satisfaction to ones that optimize satisfaction of the needs of all human and nonhuman entities. They are also helping build the cognitive-complexity knowledge system. This knowledge system includes the generation, application, management, and diffusion of knowledge about complex system concepts, dynamics, and complexity-centric co-design strategies (Motloch 2017) needed to effectively manage whole-systems metabolic processes (Fisk 1989), positively balance life-cycle resource flows (Fisk 2008), and implement built-sites and community regions as complexity-centric systems (Motloch 2017). As a mosaic, they are collectively building the knowledge needed for complexity-centric co-design and the deep, robust collaboration needed to reverse social fragmentation, address individual and collective needs, promote living in safe and just space (Raworth 2012), and deepen the interconnectivity among development and the physicality and behavior of complex adaptive systems (Motloch 2017).

One of the most comprehensive initiatives is UNESCO's program since 1992 to build the Encyclopedia of Life Support Systems (EOLSS) as a global repository of regional e-books and other key components of the knowledge system that can sustain earth as a life-supporting system. Other entities are developing and applying qualitative models to use these and other data to conceptualize complex adaptive systems and subsystems with the analogical richness needed to provide insights into whole-systems complexity and using user-friendly software like the Kumu System, to visualize complex systems, model the relationships between people or organizations, and map large networks (Kumu 2018). Still others are developing and applying quantitative modeling software such as iThink systems dynamic modeling software to predict, quantify, implement, and evaluate aspects of system performance

(ISEE 2018). Together, the EOLSS, qualitative modeling, and quantitative modeling are building components of the new knowledge system that can facilitate meta-level change of Anthropocene consciousness to its 2.0 ability to catalyze cognitively complex systems.

These initiatives are helping build the knowledge needed to reprovision development (Armistead 2011) as nested human support systems (Motloch 2016) and to envision transformative innovations needed to build transformative resilience (Wahl 2017). They are also building knowledge needed for this nested support system at all three system levels: the object-level of designing buildings, sites, and built-sites as appreciative systems; the systems-level of co-designing and co-managing development as sustainable systems; and the meta-level of transformative resilience and emergence of ability to change as rapidly and intensely as the complex adaptive system is changing.

Reprovisioning Local Metabolics

Emergence of Anthropocene 2.0 consciousness and maturation of cognitive complexity are enabled by interventions that promote metabolically complex, interdependent, and co-adapting local networks (CMPBS 2010; Motloch 2016). Complex systems can function better if human interventions support these systems as metabolic networks by realigning the location and scale of decisions with whole-systems feedback that encourages co-adaptation of decisions and the complex systems with which they are interdependent. Since coordinated flow and behavior happen most easily at the local level, sustainability is a global concept which is best achieved through human engagement integrated into locally coordinated networks. These local metabolic networks, in turn, are enhanced and empowered by decisions that appreciate the full spectrum of capitals (Armistead 2011) and internalize all costs so local socio-ecological systems can sustain their full functionality, build virtuous cycles, fully regenerate their biocapacity, and develop transformative resilience (Wahl 2017). An excellent example of ongoing maturation of planning and design methodologies informed by cognitive complexity that are helping build an Anthropocene 2.0 consciousness is the Center for Maximum Potential Building System's proposal – Beyond the Petroleum Era: A Proto-Cooperative Means for Re-mineralizing Coastal Regions – to the Bucky Fuller Challenge (CMPBS 2009).

Co-building Whole-Systems Functionality

Complex adaptive systems build whole-systems functionality through interconnected behaviors of immense numbers of diverse entities co-adapted in ways that produce deeply coordinated flows of information and coordinated action. Anthropocene 2.0 consciousness seeks to deeply embed human actions in the immense numbers of cycles of innovation and co-adaptation through which complex adaptive systems operate as deeply interconnected networks. It shifts focus from linear to circular economies, from waste-producing production of things to networked production and net-zero production streams, from wealth-extraction hierarchies to wealth-building networks, and from decisions informed by bounded knowledge to decisions robustly and analogically informed by diverse knowledge systems: indigenous, vernacular, scientific, informal, community-based, and other. Anthropocene 2.0 consciousness also shifts the goal of engagement from humanity creating new systems to humanity and complex adaptive systems collaborating in co-designing deeply interconnected and co-adapted systems. Initiatives seeking to co-build whole-systems functionality will appreciate the catalytic role of the local scale and will therefore shift decision loci *from* external entities and global economies that mine local wealth *to* local entities and economies that regenerate local performance and build local wealth (Neighborhood Economies 2018).

Optimizing Intelligent Assets, Analogical Thinking, and Life-Cycle Flow

Diverse streams of knowledge are being developed to enhance the ability of people, as intelligent agents, to leverage the analogical power of the mind to think in ways that optimize whole-systems life-cycle flows. The streams are growing from initiatives such as Raworth's call for humanity to live within safe and just space (2012), Sustainable Communities Institute strategies for Living in Systems™ (2015), Callaos' focus on accelerating the analogical power of the mind to understand complexity (2017), and initiatives using digital platforms to organize complex system data, visualize system complexity, and make appreciative decisions about complex systems (Kumu 2018). These diverse initiatives are collectively building capacity to produce transformative innovations as feedstock for building transformative resilience during periods of rapid system change (Wahl 2017) and to implement complexity-centric co-design processes to catalyze complex system co-adaptation that builds transformative resilience (Motloch 2017).

The Ellen MacArthur Foundation (2018) is contributing to the shift from Anthropocene 1.0's linear economy focus to an Anthropocene 2.0 consciousness of people as intellectual assets of circular economies. Glendenning and Armistead are similarly focused on helping humanity move *from* its Anthropocene 1.0 story of maximizing financial capital by mining all other capitals *to* co-management of the full spectrum of capitals and network flows including natural capital, energy capital, time capital, material capital, labor capital, human skill capital, financial capital, social network capital, knowledge capital, community capital, empathy capital, and wisdom capital (2018). Equally important are Wahl's focus on the big questions humanity must address (2016), Motloch's call for unlocking complexity as big science project and research agenda (2016), and Armistead's focus on empowering wisdom leaders as wise men and visionaries (2011).

Re-empowering Living Systems

The emergence of an Anthropocene 2.0 consciousness and maturation of conscious complexity needed to re-empower living systems can be catalyzed by activities that help heal and re-empower the complex adaptive systems that have been compromised by consumption-driven Anthropocene 1.0 consciousness and lifestyles and the chemically enriched, fossil-fueled powered unsustainable systems implemented by Anthropocene 1.0 consciousness. This healing can be triggered by removing – from soil, air, and water systems – the fossil fuel residuals, accumulated chemicals contaminants, and other agents that have them currently locked up, thereby re-empowering living systems.

Optimizing the EWF Nexus

At the heart of maturation to an Anthropocene 2.0, consciousness is the shift in intention from maximizing human benefits to optimizing whole-systems functionality. As indication that this shift is in-progress is the growing recognition of the need to sustain, regenerate, and co-manage the energy-water-food nexus as interdependent set of essential life-supporting systems. Various entities are building the knowledge system needed to optimize this EWF Nexus. These include urban planning and design approaches like the Center for Maximum Potential Building System's processes of Metabolic Planning and Design™ and Eco-balance Design™ (CMPBS 2010) and the Sustainable Community Institute's four-stage learning-by-doing strategy for Living in Systems™ – training > seeding > building > living – that seeks to transform communities into complex systems where people thrive by optimizing and collaborating in the local energy-water-food nexus so the community and nexus thrive together as a cognitively complex system (SCI 2015). Grounded in complexity science, these and other transformative urban planning and design initiatives can help communities as whole-systems build the deep interconnections among diverse systems needed to sustain and regenerate complex systems, including the complex system needs to regenerate the EWF Nexus and its ability to help communities thrive now and into the future.

Implementing Cognitive-Complexity Knowledge-Building Projects

As stated in the ► "Complex Systems and Sustainable Development" entry (this Encyclopedia), humanity is shifting to its third development tradition. In the first, people lived within local systems, struggled with limited resources, and survived by co-adapting within these systems. In the second, technology and science empowered humanity to mine resources, externalize costs, and degrade systems at increasing rates, intensities, and scales. In the emerging third tradition, system breakdown is motivating humanity to become an appreciative system (Jantsch 1975) that co-adapts in ways that help build complexity, transformative resilience, and sustainability. Diverse streams of knowledge are analogically developing understanding to enhance human ability, as intelligent agents, to build the Anthropocene 2.0 consciousness needed to optimize whole-systems life-cycle metabolic flows. In one of these streams, the Sustainable Community Institute has been envisioning analogically robust urban planning and design project proposals, including one for a neighborhood in Baltimore and another in Indianapolis. These proposals seek to help people and their local communities thrive by integrating analogically robust knowledge systems designed to inform local system reprovisioning for sustainability and transformative resilience (2015). The projects each integrate complexity science knowledge and community-based knowledge about local complex systems to help people live appreciatively by managing their local EWF Nexus; by harvesting from, using and regenerating the EWF Nexus; by integrating ecological, infrastructural, and built-environment supports; by interconnecting previously disconnected decisions; by building life and job skills; and by appreciatively managing the local EWF Nexus.

The first project is a prototype urban farmstead proposed for the Sandtown-Winchester neighborhood in West Baltimore – where the profound need for transformational change resurfaced following the death of Freddie Gray (Reid 2015). The project is part of the ministry of Martha's Place, a center for peace and justice, with a recovery program for women overcoming substance abuse and homelessness. At Martha's Place, people help women who are overcoming drug addiction and homelessness maintain sobriety, develop vital life skills, enhance nutritional intake, develop healthy diets, and learn food production, preparation, and value-adding skills. The prototype urban farmstead project built on previous urban agricultural activities by Martha's Place, to develop an urban homestead on property managed by the center. The project also sought to address local water and food problems and catalyze transitional housing and life skills. It included an urban agriculture initiative to provide organic food and help Martha's Place become more self-sufficient. It also proposed launching micro-businesses as value-adding activities (food service, processing, and products) and food distribution activities (food carts and food trucks). The urban farmstead project, proposed as a catalyst for self-sufficiency and community thriving, included skill development and training for the women in recovery, with skill-building and knowledge in the areas needed to build the local neighborhood economy. The proposed project received a first place award in the 52nd International Making Cities Livable conference and the People's Choice Award in the Baltimore Growing Green Initiative design competition sponsored by the City of Baltimore, US Environmental Protection agency, and Chesapeake Bay Trust (Truex 2015).

The second project included community visioning to provide analogically informed insight around a food hub proposal for a challenged Indianapolis urban neighborhood with an aging population, employment challenges, and health issues. A Quality of Life Plan had recommended development of a food hub as a community and economic redevelopment catalyst. In this project, the Sustainable Communities Institute partnered with the engineering firm designing the site redevelopment project and the existing steering committee to develop the vision for the food hub. In community visioning sessions, participants from diverse community and societal sectors self-identified their biases by declaring the relative value they placed on job creation, healthy food, and a stronger community. Each team of similar biases, with members from diverse community sectors, then engaged in an interactive board game designed to stimulate network conversation among different sector-framed views. Each team placed game pieces over tabletop community maps while engaging in deep conversations to dialectically decide how best to allocate land. Each team allocated land to diverse components of a food hub, local food system, and community development. Components of the food system included land for growing food, distribution, job training, education, value-adding, and food consumption, as well as employment centers, new housing, start-up businesses, community space, and education and wellness services. After making its land allocations, each team received a scorecard and scored its solution. Then the collection of solutions, each generated by visioning through a unique set of lenses, were used to stimulate network conversation among all teams, each of which had make its own land allocations looking through its unique set of lenses. This analogically rich network conversation provided insight for robust design proposals for the project.

The game created for this community-based visioning was later evolved by Sustainable Communities Institute into a learning tool where teams in academic and nonacademic contexts can engage in four cycles of play. In each cycle, teams allocate lands based on a specific economic paradigm and then are given a score sheet which they use to score their solutions. In the first cycle, teams allocate land based on market value and perceived first cost/benefit of solutions. In the second cycle of play, they allocate lands based on market considerations adjusted to optimize the energy-water-food nexus. In the third cycle, teams allocate land based on market considerations, optimization of EWF nexus, and provision of green infrastructure as secondary supports that collaborate with ecological systems as primary supports. In the fourth cycle, teams allocate land based on market considerations, optimizing the EWF nexus, green infrastructure as secondary supports and built environments as tertiary supports that collaborate with ecological systems as primary supports. This evolved game has been used by the designers as a sustainable development learning tool in a range of academic contexts (master's degree programs, undergraduate programs, high school, etc.) and global contexts (US and international).

Sustainability Through a Whole-Systems Approach

In summary, a whole-systems approach to sustainability focuses on complex adaptive systems, how they build complexity and transformative resilience, how the history of unsustainable economic and community development has arrested co-adapted complexity, and how development can unlock complexity, reactivate biologically complex system, and reprovision for emergence of conscious complexity. This whole-systems approach operates at all three systems-levels: the *object-level* of entities and their co-adapted behaviors; the *systems-level* of optimizing complex adaptive system performance through network conversation, life-cycle flows, and systems functionality, regeneration, and resilience; and the *meta-level* of transformative innovations as feedstock for co-adapting with rapidly changing complex systems, building transformative resilience, and facilitating transformative system change, complexification, and higher levels of biocapacity.

The whole-systems approach appreciates that sustainable development must operate within current conditions while simultaneously reprovisioning for a sustainable future. It must also have the transformative resilience to survive the inevitable changes that are the deepest metabolic dynamic of complex adaptive systems.

The whole-systems approach appreciates the profound and rapid ongoing change in complex systems due to the history of Anthropocene 1.0 unsustainable development. It also appreciates that when complex systems are changing rapidly, as they are now and in the next few decades, development and support systems must be provisioned to enhance transformative resilience. Since complex adaptive systems build resilience through innovation/co-adaptation cycles, in these times of profound change, a whole-systems approach sees transformative innovations essential for providing feedstocks to build transformative resilience. It sees this feedstock fueling the boundary-expanding robustness needed to reprovision development in ways that help people and the complex systems of which they are part sustain, enhance metabolic capability, regenerate their health and productivity, build new potential, and thrive into the future. It also sees complexity-centric co-design processes as catalysts for transformative change to a sustainable future.

Cross-References

► Complex Systems and Sustainable Development
► Co-design Methods and Sustainable Development

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Wicked Problems and Sustainable Development

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Synonyms

Complex; Intractable; Messy

Definition

Wicked problems are intractable social issues that defy traditional problem-solving approaches because they are characterized by high levels of complexity and ambiguity and involve multiple stakeholder groups with strongly divergent values and perspectives. While initially applied in a social planning context, sustainability researchers have increasingly utilized this lens to explain the multidimensions of many sustainable development issues and explore new ways for addressing these complex issues.

Introduction

In this entry, the origin of wicked problems as a concept and its ten distinguishing properties is discussed. These characteristics are then used to discuss vexing dimensions of sustainable development that are highlighted in the research literature. There is increased attention by sustainability researchers to how traditional decision-making approaches, management strategies, public policy responses, and education are insufficient for effectively addressing sustainable development problems, as well as growing interest in identifying productive pathways for addressing these deficiencies. An overview is provided of three general themes identified in the research literature for addressing the complexities associated with the wicked nature of sustainable development. As researchers and practitioners have struggled with the wicked nature of sustainability issues, recognition has emerged that problems like climate change have additionally troublesome features that make them especially challenging to address; the entry ends with an overview of discussions of super wicked sustainability issues found in the research literature.

Wicked Problems

The concept of wicked problems emerged in the United States in the late 1960s anchored by two defining events: urban revolt that ravaged African American urban neighborhoods and the landing on the moon. American philosopher and systems scientist West Churchman received a grant from NASA to explore the application of space program technology to urban problems and with this organized a weekly seminar in 1967 (Skaburskis 2008). Horst Rittel, a design theorist and professor with interests in planning, engineering, and policymaking, attended one of these sessions and introduced a list of differences between technical/scientific and intractable social problems (Crowley and Head 2017). He argued that applying a rational, scientific, system-based approach to wicked issues often results in proposed solutions that are worse than the symptoms of the problem (Churchman 1967). Persistent encouragement over the next 5 years, by Rittel's colleague Melvin Webber, for him to publish this list resulted in the now famous paper, "Dilemmas in a General Theory of Planning" (Rittel and Webber 1973; Skaburskis 2008).

The list details ten properties of "wicked problems." The word "wicked" denotes vicious, tricky, malignant, or aggressive planning problems that are highly resistant to defining and resolving. Wicked problems contrast with tame or benign ones – problems that may still be complicated but that can be solved using rational or technical solutions or routine management approaches (Rittel and Webber 1973). Wicked problems defy such straightforward analytical techniques because they are characterized by the following features:

1. Wicked problems have no definitive formulation.
2. Wicked problems have no stopping rule.
3. The solutions to wicked problems can only be good or bad, not true or false.
4. There is no immediate or ultimate test of a solution to a wicked problem.
5. Attempts to solve wicked problems are a "one shot" deal.
6. Wicked problems are highly resistant to clear and agreed upon solutions.
7. Every wicked problem is unique.
8. Every wicked problem is a symptom of other societal problems.

9. Discrepancies between explanations of a wicked problem can be explained in multiple ways; each explanation frames the slate of possible solutions.
10. There is no public tolerance for failure in solving wicked problems (Rittel and Webber 1973).

Over the past four decades, interest and support have grown for the idea that there are intractable social problems that defy resolution using traditional methods and instead must be addressed through political argumentation and networked and communicative approaches. Other scholars have developed similar ideas to those of Rittel and Webber about socially complex, politically fraught, and imperfectly understood social issues in their analyses of radioactive waste management, cybernetic research, and urban redevelopment, describing them using different adjectives such as "messy," (Metlay and Sarewitz 2012), "clumsy," (Frame 2008; Hartmann 2011) or "fragmented" (Conklin 2005). While there are critics of Rittel and Webber's wicked problem concept (e.g., Bahm 1975; Catron 1981), "Dilemmas in a General Theory of Planning" has become the most cited article in *Policy Sciences* (Crowley and Head 2017). The trajectory of references of Rittel and Webber's paper has steadily increased with citations reaching double digits in the 1990s and increasing beyond 100 annually by the late 2000s. Interest in wicked problems extends far beyond scholars and practitioners of planning theory, design, and practice, with application of the model found in disciplines such as public policy, political science, public administration, public management, philosophy, health, and, most prominently, environmental/ecological management and theory (Crowley and Head 2017; Head and Alford 2008).

Sustainable Development as a Wicked Problem

Rittel and Webber's model of wicked problems has been employed as a conceptual framework for framing sustainable development issues and for providing additional insights concerning why many natural resource and environmental "policies and programs generate controversy, fail to achieve their stated goals, cause unforeseen effects, or are impossibly difficult to coordinate and monitor" (Head 2010, 3). Within the research literature, scholars highlight how these wicked properties become conditions of the complexity that must be understood and adequately responded to in undertaking sustainable development efforts. Wicked properties of sustainable development include:

1. Sustainable development is difficult to define.

Despite the ubiquity of the concept in a contemporary context, and widespread consensus that it is a worthwhile goal, there is little agreement about what sustainable development is, how it differs from sustainability, and how to attain it (Du Plessis 2009; Morelli 2011; Redclift 1989; Vos 2007). There is always more than one explanation of wicked problems and their scope. How sustainable development issues are defined (e.g., as economic, as ecological, as social, etc.) suggests some solutions "(e.g., carbon trading, regulation, international aid, etc.) and excludes others from being considered (Powys Whyte and Thompson 2012). Scholars and professionals alike provide case studies that demonstrate how sustainable development remains an elusive goal. To illustrate, Allen and Gould (1986) talk about national forest management in the US as typically plagued by a lack of consensus about the problem and solution: "long-range forest plans involve power struggles, imprecise goals, fuzzy equity questions, and nebulous information and thus become wicked" (23).

2. There is no end point to sustainable development.

Scholars whose work draws on complexity theory speak of sustainable systems as dynamic, complex, and adaptive (see Biggs et al. 2010; Olsson et al. 2004; Remington-Doucette 2013; Westley et al. 2011). They explain that the social and ecological elements self-organize to optimize the function of the system, or take advantage of certain functions, thereby creating new niches as necessary and changing their composition (i.e., the elements and relationships of which they are composed) to fit the changing patterns they encounter (Du Plessis 2009). As the conditions within the socio-ecological system continually change over time, solutions must perpetually adapt to meet the new conditions (Remington-Doucette 2013). Consequently, the target of the decision constantly morphs and moves, and there is no obvious point at which one can cease working on the problem because sustainable development has been achieved. Rather, one stops working on a sustainable development problems because they have run out time, money, or patience, not because they have found the ultimate solution.

3. Strategies to achieve sustainable development are always better or worse, not right or wrong.

Wicked problems associated with sustainable development are linked to social pluralism that is articulated through multiple stakeholder interests and perspectives (Head and Alford 2008). Given such divergence, there can be no absolute view of whether the formulation and proposed solutions for sustainability problems are true or false (Norton 2005). Because proposed strategies for achieving sustainable development are so closely tied to problem formulations, even if there is agreement about the problem, disagreements arise as the stakeholders foresee themselves as being impacted differently by the solutions. Underlying discussions and debates are questions about what is it that will be sustained and for whose benefit (Vos 2007)? Hence, rather than being right or wrong, solutions to sustainable development problems are better or worse, or good enough or not good enough relative to a specific situation, who is judging the outcome, and the resources available to work on it. As Remington-Doucette (2013) explains, “A solution that is good enough for one place and time might not be good enough for another” (48).

4. Sustainable development problems have no objective measure of success.

Sustainable development problems exist in complex systems that exhibit unpredictable, emergent behaviors and thereby result in unforeseen consequences. Adaptive responses and interactions within socio-ecological systems allow for emergence within the system, as the socio-ecological system undergoes spontaneous self-organization into collective structures with properties that cannot be predicted from the characteristics of the parts and which the agents or elements may not have possessed individually (Du Plessis 2009). Given the ongoing dynamic nature of socio-ecological systems and the ripple effects created by interventions for achieving sustainable development, it is difficult to develop a test or criteria to judge if and when success is realized (Norton 2005).

5. Responses to sustainable development problems have irreversible consequences.

Implementing solutions to achieve sustainable development creates changes in the world that cannot be undone, and because the consequences of any proposed solution for a wicked problem leave permanent marks, there is no learning by trial and error. Geoengineering proposals to counteract anthropogenic climate change are a clear reminder of this wicked factor. Actions such as fertilizing the ocean with iron or other nutrients, though based on sound science of marine plant photosynthesis, have resulted in algae blooms that have not been as effective as expected, and resulted in depleted oxygen levels, which potentially could create oceanic dead zones and have other potential side effects including suppressing Asian monsoons or modifying the ocean’s acidity (UNEP 2011).

6. Sustainable development problems have innumerable possible solutions.

There is no way to determine if all the possible solutions to a sustainable development problem have been identified and considered (Powys Whyte and Thompson 2012). As understandings of the problem constantly evolve, and constraints and resources for the solution change over time, there is no established set of potential solutions or permissible activities. Hence, there is need for continuous learning and developing knowledge to cope with the changes and uncertainty associated with socio-ecological systems (Olsson et al. 2004).

7. Every sustainable development problem is unique and requires context-specific solutions.

While sustainable development problems may have commonalities with other social and technical problems, because they are socially complex, politically fraught, imperfectly understood, and morph over time and space, the transfer of external solutions to them is often highly problematic. One cannot rely on precedent to determine how to act to achieve sustainable development. As Remington-Doucette (2013) explains, "Every specific situation is distinct because the cultural, political, social, environmental, technological, economic, and other important aspects will be different in particular contexts" (49).

8. Sustainable development issues are nested and interdependent.

Sustainability problems result from the multiple interactions between human activities and ecosystems across multiple policy domains and authority structures within and between organizations. According to Head (2010), "This feature raises great difficulties both for clear analysis and for devising practical interventions to tackle the problems" (7). As Balint et al. (2011) explain, this is often because multiple objectives and decision-making processes characterize sustainable development initiatives, which when combined make "the goal of developing and implementing politically acceptable, technically feasible, and ecologically and economically effective policies seems unattainable" (34).

9. The causes of and solutions for sustainable development problems can be explained in numerous ways.

Experts and stakeholders often disagree about how to achieve sustainable development in part because they see the issue from different worldviews (Salwasser 2004). The loss of biodiversity can be argued to be an effect of globalization, but it can also be explained as being caused by climate change, industrialization, individual greed, and social oppression (Powys Whyte and Thompson 2012). Further, natural resource and environmental problems are complex because multiple factors are at work that influence each problem area or objective. For example, "the condition and trend of a wildlife population are a result of interactions among the prior population, habitat, weather, predators, disease, off-site factors, and chance events. Resource managers can influence only some of these factors, and scientists only vaguely understand how they all operate together to affect a population outcome for many, if not most, species. Most of what affects wild plant and animal populations falls into the arena of uncertainty and unknowns" (Salwasser 2004, 9).

10. There is no room for error in trying to achieve sustainable development.

Because the impact of sustainability issues and the proposed solutions for them have profound and lasting consequences, there is no forgiveness or understanding for grievous mistakes in trying to solve these issues. There is no lack of social and technological innovation in the world, but sadly much of it does not respect interacting planetary boundaries and is creating tipping points in the earth's systems (Westley et al. 2011).

Paths Forward

In addition to descriptive/analytical discussions of the concept, much of the environmental and natural resource research literature that discusses wicked problems focuses on innovative approaches and new ways of thinking for effectively addressing sustainable development challenges. Suggested guidelines for helping build capacity to effectively address the complexities associated with the wicked nature of sustainable development include:

1. Expanded conceptualizations of the problem

Innovation, creativity, and imagination are central to addressing wicked problems (Brown et al. 2010). Higher-order thinking that transcends disciplinary boundaries and is grounded in ethical or moral perspectives is found necessary for moving beyond the linear thinking and fragmentation common to more traditional problem-solving approaches (Palmer et al. 2009). Holistic or systems thinking is critical to ensure a more integrated understanding of the complexity and interconnected components of the socio-ecological system (Burch et al. 2014; Head and Alford 2008; Olsson et al. 2004; Remington-Doucette 2013). Additionally, reflexivity (the ability to consider and evaluate multiple frames at once) allows one to appreciate the multiple perspectives at play and reconsider dominant frames as a means for avoiding tunnel vision (Termeer et al. 2012).

Several tools are discussed in the research literature for enabling more creative and expanded perspectives, including visioning (Remington-Doucette 2013); transformational sustainability research (Wiek and Lang 2016); backcasting, creating future scenarios and tracing back the steps required to get from the present to the future vision (Head and Alford 2008); identification of transition or leverage points, those places or times in a socio-ecological system that create barriers for change (Remington-Doucette 2013); scenario analysis (Head 2014); solution-focused sustainability assessment (Zijp et al. 2016); and the use of simulation games (Learmonth et al. 2011).

2. Deeper and broader collaboration

There is widespread consensus that collaboration between scientific experts and stakeholders is critical to achieving progress on sustainable development issues (Termeer et al. 2013; Webber and Khademian 2008). Because decisions about natural resources and the environment are not merely scientific and technical in nature, but also political and social, more inclusive stakeholder engagement is necessary for managing environmental problems. Many argue that this observation is particularly true in the context of wicked problems that are ill-defined, rely on political judgments rather than scientific certitudes, and require innovative methods beyond legislation, fines, and taxes to motivate organizations and individuals to actively cooperate in the transformation (Balint et al. 2011; Head and Alford 2008; Remington-Doucette 2013).

Scholars use various terms to describe formal collaborations between scientists and citizens. Adaptive management is described as requiring a range of innovations in approach that creates “a learning and decision making framework linking science, stakeholder knowledge, and integrative processes for new thinking” (Head 2014, 675). Others, such as FitzGibbon and Mensah (2012), call this adaptive co-management. Adaptive management involves scientists working “side-by-side with managers in designing, implementing, and monitoring project work” and with the “management projects. . .treated as experiments with sufficient scientific design so that they clearly lie in the interface between research and routine management” (Salwasser 2004, 19). Tools such as coping strategies and structured decision analysis are utilized to allow for continuous learning and improvement. Frame (2008) and Head (2014) label this “postnormal science” and describe it as a qualitative change in how science and policymaking are approached, “with its emphasis on including stakeholders in the consideration of information and policy options and its insistence that solutions to such problems are highly provisional and need continual renegotiation” (Head 2014, 665).

Head and Alford (2008, 17–18) explain that these forms of expert/citizen collaborations help in addressing wicked problems in three ways: it “increases the likelihood that the nature of the problem and its underlying causes can be better understood; “it increases the likelihood that provisional solutions to the problem can be found and agreed upon”; and “it facilitates the implementation of solutions.” According to Salwasser (2004), collaboration done well should increase credibility and trust in the solution to the sustainability problem. Yet, scholars often find that conventional public engagement processes often not only fall short in achieving these results but worse fuel distrust, controversy, adversarial politics, and inaction (Balint et al. 2011; Carcasson 2013; Head 2014). Most public engagements on sustainability issues are too limited in scale and duration to understand the full dimensions of the wickedness of sustainable development issues and for diverse knowledges and perspectives to surface (Balint et al. 2011). Given that wicked problems are not solved but rather managed translates into long-term engagement and collaboration between experts and stakeholders in identifying the problem to evaluating the implementation strategies. As Salwasser describes, this is a fundamental challenge for contemporary bureaucracies, because it requires that the "collaborators must agree to share power" (15). Methods discussed for overcoming these barriers, bringing to surface the multiple perspectives, building shared understandings, and effectively integrating multiple values and perspectives into policy and action strategies include dialogue- and participatory-based approaches such as deliberative engagement (Carcasson 2013); systems thinking and case-based inquiry (Brown et al. 2010); multi-stakeholder forums and participatory action research (Verweij and Ney 2015), mess, and resolution mapping (Horn and Weber 2007); and participatory modeling (Davies et al. 2015).

Mitigating the negative consequences of sustainability issues and forging more desirable trajectories toward sustainable development also require long-term and coordinated responses across and within government departments. As Berkes (2009) explains, different levels of organizational scale, from local to international, have distinctive strengths and comparative advantages in the generation and mobilization of knowledge for socio-ecological problems. Developing networks is therefore seen as key in harnessing this expertise and overcoming the limitations of hierarchical and fragmented administrative systems because they provide "flexible, efficient and innovative organizing hybrids that enable participants to accomplish something collectively that could not be accomplished individually" (Webber and Khademian 2008, 334). Enabling these collaborations often requires organizational adjustments to allow for greater coordination and tolerance for uncertainty, flexibility and agility, trust, long-term funding, extended time lines, and support for collaborative champions (Frame 2008; Head and Alford 2008; Termeer et al. 2013; Waddock et al. 2015).

3. Education

Many sustainability scholars contend that realizing the innovation, creativity, imagination, and success of new approaches for solving wicked problems requires new paradigms in education. In the words of Miller et al. (2011), "building sustainability knowledge requires a fundamentally different approach to the ways academic institutions organize research and education and relate to society" (178). Allen et al. (2014) argue that students not only require "strong content knowledge in relevant fields as well as skills in systems thinking, active and creative problem solving, collaboration, and communication" (52). To overcome some of these issues, Brundiers and Wiek (2011) propose sustainability research education that provides problem and solution-oriented educational opportunities for students to work on real-world sustainability problems with entities outside of academic institutions. Others such as Dale and Newman (2005) speak of the need for sustainable development education that emphasizes problem-based interdisciplinary learning.

Beyond Wicked Sustainability Problems

When Rittel and Webber conceived the model of analysis for wicked problems, they had little appreciation of global developments like climate change. But in the decades following, scholars such as Levin et al. (2012) have found that the interdependency, circularity, and uncertainty associated with wicked problems are further confounded by a set of additionally troublesome features that make an issue like climate change a "super wicked problem":

1. Time is running out.
2. Those in the best position to solve it are largely responsible for it and have the least incentive to do something about it.
3. The central authority tasked with solving the problem is weak or nonexistent.
4. The proposed policy solutions discount the future irrationally (Lazarus 2009; Levin et al. 2012).

Levin et al. (2012) explain that super wicked problems create a tragic dilemma: "even when we collectively recognize the need to act now to avoid the catastrophic impacts, the immediate implications of required behavioral changes overwhelm our collective interest in policy change and the ability of the political and policy systems at multiple levels to respond" (148). Scholars such as Levin et al. (2012) and Westley et al. (2011) are examining "path dependence" associated with super wicked and wicked sustainability problems and looking for solutions or mechanisms that can "unlock" humanity from the unsustainable trajectories that constrain innovation and limit the options available for societal transformation.

Conclusions

The concept of wicked issues helps explain why complex social issues like climate change cannot be solved using expert-driven, centralized, and rational-technical approaches. Value-centered sustainability problems that are highly resistant to resolution using existing problem-solving approaches require transformation in the way we conceptualize and approach them.

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Work-Based Learning

► Reflective Practice for Sustainable Development
► Service-Learning and Sustainability Education
► Work-Integrated Learning for Sustainability Education

Work-Integrated Learning for Sustainability Education

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Synonyms

Action inquiry; Action learning; Action research; Co-inquiry; Collaborative action research; Cooperative inquiry; Experiential learning; Internship; Living case study; Negotiated work-based learning; Problem-based learning; Reflective practice; Service learning; Systemic inquiry; Work-based learning

Definition

Work-integrated learning is a form of pedagogy which is situated, experiential, and collaborative with industry or community partners. Specifically, it has been characterized as intentionally integrating theory with authentic activities which then form part of an authentic assessment. Work-integrated learning for sustainability education specifically applies such pedagogical approaches to sustainable development challenges such as climate change, community recovery and resilience, or local poverty reduction.

Introduction

Work-integrated learning is a form of education which broadly connects practice settings as a location or vehicle of learning (Billett 2014) and has expanded rapidly in response to increasing pressures for global employability agendas (Smith and Worsfold 2015; Wall 2017). It is variously known as work-based learning, workplace learning, work-related learning, placement learning, internship learning, practicum, simulation learning, fieldwork, cooperative education, and experiential learning (ibid). Although it can be argued that work-integrated learning is distinctive from workplace or work-based learning, in that it *integrates* disciplinary knowledge (Smith 2012), in practice, this is variable (Wall 2013). In their review of the literature and practice in higher education settings, Edwards et al. (2015: 38) found that work-integrated learning had a number of common features but that these are variously prioritized across institutions:

- Integrating theory with the practice of work
- Engagement with industry and community partners
- Planned, authentic activities
- Purposeful links to curriculum and specifically designed assessment

In this way, the application of work-integrated learning utility, in the context of education for sustainable development in higher education, relates to (1) learning which is across multiple, contextualized sites in real (or real-simulated) settings and (2) which is aligned to competency or the "how" (as well as "what," "why," and so on) (Barth et al. 2007). For example, work-integrated learning has been found to develop disciplinary and professional knowledge, graduate capabilities such as critical thinking, problem-solving skills, communication and interpersonal skills, work-readiness, self-esteem, and confidence (Smith and Worsfold 2015). Similarly, work-integrated learning can inculcate systems thinking, interpersonal, anticipatory, strategic, and normative competences relevant to sustainability in higher education (Wiek et al. 2011).

Forms of Work-Integrated Learning

Work-integrated learning as a form of sustainable education manifests in a variety of ways. As Coll et al. (2003) conceptualized, there are three broad possibilities: (1) utilizing work and workplace learning as a *means* of delivering sustainability education (outside of the higher education

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classroom), (2) developing sustainable development knowledge first (in the classroom) and then taking this out to the workplace to influence practice, and (3) *integrating* the development of sustainability and workplace-based knowledge. Whereas Coll et al. articulated these as "proposals," Edwards et al. (2015) more recently found empirical evidence of these models in practice, but with a more nuanced set of four models: "trust transfer will happen," linear "theory to practice," gradual immersion, and "industry" (or stakeholder community) oriented models. The Edwards et al. (2015) framework helps to articulate how work-integrated learning manifests in relation to sustainability education.

Trust transfer will happen model. In this model, the design of the course prioritizes the disciplinary knowledge and skills deemed important to the discipline. This means there is no *explicit* focus or developmental approach to sustainability, and it is assumed that the student *in* higher education will be able to apply their learning in relation to sustainability *outside* of their studies. For example, Hindley and Wall (2017) found evidence of this in relation to climate change through an extensive mapping of university curricula, where climate change was evidenced in a very small number of educational units. In addition, evidence suggests that some forms of negotiated, work-integrated learning may prioritize the immediate perceived development needs of the individual or organization (Wall 2013), which may in turn mean the development of sustainability knowledge and skills may not feature explicitly in the curriculum.

Linear theory to practice model. This model represents the most common modality of work-integrated learning (Edwards et al. 2015), where disciplinary knowledge and skills form the basis of the curriculum but are supplemented by sustainability-related inputs and interventions. This "bolt-on" model can include sustainability case studies, guest lectures, field trips, and a variety of work- or industry-oriented projects. This model reflects the work of Wall et al. (2017a) to develop a major resource bank of climate change learning materials (such as cases and website links) which were specific to multiple disciplinary contexts (such as psychology, engineering, tourism) in a university setting and could therefore be utilized at the disciplinary level.

Gradual immersion model. This model is similar to the previous model but with an increasing exposure and immersion in the particular area of sustainability. This might include, for example, guest lectures and case examples at the start of the higher education course, leading to extended periods on sustainability projects. An example of this is the use of capstone experiences at the end of the higher education course, focusing on a large independent work-integrated project (or projects) (Hauhart and Grahe 2015). Such projects may be designed to have multiple outcomes through volunteering or community or place development.

"Industry" (or stakeholder community) oriented model. This model of work-integrated learning for sustainability education is less typical but is where work-integrated learning and sustainability are present from the first day of the higher education course and where work-integrated learning then continues throughout the program. For example, Franses and Wride (2015) discuss a variety of pedagogical philosophies and structures which engage the higher education learner in a phenomenological and holistic science from the outset and which are conducted in nature throughout the course. Here, there is a strong emphasis on immersion to develop a deep and intimate appreciation of the natural world and human connectedness to (or wholeness with) it. Also see chapters on *art-based teaching for sustainable development*, *art-based approaches for sustainability*, and *reflective practice for sustainable development*.

Embedding Sustainability Education Through Work-Integrated Learning

In terms of how sustainable development is embedded (or not) into higher education curricula, Rusinko (2010) and Painter-Morland et al. (2016) developed and expanded matrix models to articulate and categories different strategies. Wall et al. (2017a) explored and expanded the application of this model in the specific context of work-integrated and work-based learning forms and included piggybacking, digging deep, mainstreaming, focusing, and delivering outside of the formal higher education curricula (Rusinko 2010; Painter-Morland et al. 2016).

Piggybacking: integrating sustainability education into existing curricula using work-integrated learning. Within the piggybacking model, the integration of sustainability involves a *narrow focus* developed through *existing* work-integrated learning pedagogical structures. For example, Wall et al. (2017a) examined the establishment and implementation of a climate change project (which might be understood as a relatively narrow focus of sustainability), conceptualized as a workplace project within a core work-integrated learning course for all undergraduate students within a university. Although the piggybacking model may be seen as a "bolt-on" strategy with limited scope for institutional change, Wall et al. (2017a) found that this strategy may initiate cultural change in a higher education setting if it engages, for example, interdisciplinary teams and generates cross-disciplinary learning resources.

Digging deep: creating new disciplinary-specific sustainability education curricula using work-integrated learning. As a strategy for embedding sustainability education through work-integrated learning, digging deep is about taking a *narrow* focus of sustainability through *new* work-integrated learning pedagogical structures. For example, in response to cyclone Yasi's destructive effects on Mission Beach in Queensland in 2011, Philips and Boland (2013) developed a new pedagogical model which established new university-community partnerships and social entrepreneurship. This involved higher education students working with a community organization, through work-integrated learning, to deliver local and ecologically driven projects (such as a sustainable marketing plan). Similarly, San Carlos et al. (2016) explored a week-long educational experience in Japan, exposing students to the community resilience and reconstruction processes after the Tohoku Earthquake Tsunami of March 2011. San Carlos et al. (2016) found multilayered educational effects including the development of knowledge and skills relevant to researching sustainability and science, with a specific (relatively "narrow") focus on resilient communities.

Mainstreaming: integrating sustainability education into common core curricula using work-integrated learning. Mainstreaming sustainability education through work-integrated learning is a pedagogical strategy which involves a *broad* focus of sustainability developed through *existing* work-integrated pedagogical structures. One example of this is where, in the context of events management program, Robertson et al. (2012) conceptualized sustainable development knowledge and skills as a core competency at the program level and then embedded and integrated throughout the program utilizing authentic, work-integrated learning experiences (in a model such as the gradual immersion and "industry" collaboration models above). Similarly, Isacsson and Ritalahti (2015) embedded sustainability education through a core "responsible self" strand of the curriculum and delivered it through work-integrated experiences attracting academic credit. Other examples focus on embedding similar embedded competences and work-integrated combinations at the university level (Purvis et al. 2013).

Focusing: Creating new cross-disciplinary sustainability education curricula using work-integrated learning. In this model, there is a *broad* focus of sustainability, which is developed through *new* structures (e.g., Kurland et al. 2010). For example, a new, interdisciplinary course and teaching strategies were established drawing on various disciplines including urban planning, communications, and marketing, to offer "in situ" learning through higher education sites (Marchioro et al. 2014). Likened to a simulated provider-supplier relationship in an interdisciplinary-problem-based-learning approach (Diamond et al. 2011), Marchioro et al. (2014) set up a pedagogical process to tackle local sustainability issues as experienced by the students, to encourage the exploration of issues and options, as well as making recommendations to enhance life on campus. The results of this activity then fed in to final year capstone experiences in relation to the detailed planning of the community development and enhancement activity.

Delivering sustainability education outside of the formal curricular through work-integrated learning: cocurricular activity. Sustainability education which is delivered outside of the formal curriculum has been a common strategy in higher education and is a viable option when the responsibility of sustainability is outside of the academic departments of universities. For example, Tansey and Gonzalez-Perez (2007, p. 6) developed the ALIVE (A Learning Initiative and the Volunteering Experience) volunteering program, which sought to "foster civic engagement, enhance student learning and serve community needs" (also see *service learning*) (O'Flaherty et al. 2011). In addition, Wall et al. (2019) discuss a European professional development course for training teachers, utilizing drama processes to embody sustainability awareness and action planning. Such cocurricular approaches provide a flexible strategy to target a wide range of sustainability issues.

Aspects of Effective Work-Integrated Learning for Sustainability Education

Work-integrated learning in the context of education for sustainable development seems to offer the following attributes (Smith 2012; Wilson and Pretorius 2017: 253–254):

1. *Authenticity*, both physical and cognitive, is achieved through learning environments that are similar to the real-world environment. Realistic problems and projects, which are meaningfully consequential and collectively solved by students, motivate engagement and relevant learning. In addition, Edwards et al. (2015) suggested that "a clear value proposition" is required in work-integrated learning, so that there is a stronger buy-in and understanding of the nature of the experience. In the context of work-integrated learning for sustainability education, this means establishing work contexts and situations where the authenticity of a sustainability project to localized community is explicated and explained, for example, where a project recognizes the social impacts of litter in a locality and attempts to tackle it (Hindley and Wall 2017).
2. *Alignment of learning with integrative learning objectives* aims to develop the ability of students to integrate theory and practical subject knowledge. This moves students beyond mere application and aims to develop abilities to discern what, when, and how integrated knowledge should be applied. Edwards et al. (2015) also highlight the importance of designing experiences to enable "ah ha" moments where the practical and theoretical aspects of the educational program appear to merge in some way. For example, alignment can be generated through explicitly deriving the workplace experience from the reflective learning goals of a work-integrated learning course (Hindley and Wall 2017).
3. *Alignment of assessment with integrative learning objectives* requires assessment of integrative learning knowledge applied to work and reflection on their experience. In the case of a work-integrated learning for sustainability education project, the artefacts produced can form part of the assessment load of the course, such as climate change resources or a recycling mobile application (Hindley and Wall 2017).
4. *Integrated learning support* at the university or workplace is needed to alleviate stress and/or improve learning processes and can include tutors, mentors, and workplace supervisors working together. Curriculum designers and deliverers should make explicit reference to these services.
5. *Supervisor access* is the mentoring role between the institution contact and the student on placement, which provides feedback and support through the learning experience. In the context of sustainability projects, this is particularly important in relation to ensuring appropriate health and safety practices are adhered to, including (a) the use of special scientific and protective clothing when dealing with waste or toxins and (b) dealing with vulnerable adults or children.
6. *Induction and preparation process.* This includes clear processes at the start of the

work-integrated learning experience, in order to frame the experience and clarify expectations of those involved in the experience. Edwards et al. (2015) also highlight the importance of facilitated opportunities for reflection on the work-integrated learning experiences as the end of the experience.

According to Smith (2012), the extent to which authenticity is achieved is the most impactful. Specifically, he found that students' sense of whether or not they had had an "authentic" work placement was found to have the strongest relationship with each of three outcomes: their sense of work-readiness (i.e., their ability to work independently, solve problems, reflect on their level of knowledge, and so on), self-efficacy (i.e., their confidence in themselves as both a practitioner and/or student), and team skills (i.e., their ability to work effectively in a team).

Conclusions and Future Directions

The development and enhancement of work-integrated learning, as part of vocational education and training, has been a focus of significant educational reform over the last decade (Wall 2017; Wall et al. 2017a,b). As such, the practical implementation of work-integrated learning generally, and specifically in relation to sustainability education, will continue to be a focus of research and practice development. This reflects Leal's call for more research into applied sustainable development activity. Practical issues for work-integrated learning include access to relevant placements and access to placements which offer suitable *scope* for higher-level learning, development and impact appear to be a perennial and significant issue (Patrick et al. 2008). Some areas, such as science and agriculture, are particularly difficult to find appropriate work-integrated learning opportunities, which makes expansion in these areas near impossible (Edwards et al. 2015).

However, and with particular pertinence to the sustainable development goals of quality education for all, equality, and inclusive work, there continues to be difficult challenges with work-integrated learning. Some of the most significant challenges relate to (1) the accessibility of work-integrated opportunities for higher education students with diverse profiles, including international students and students with disabilities (physical or mental health), and (2) their treatment during the workplace experience (Gribble et al. 2015; Wall 2017). Evidence suggests that the latter of these reflect wider trends in how migrant workers are treated in workplaces, and so further partnership working needs to be done to facilitate a greater inclusivity to work-integrated learning experiences (Wall et al. 2017b).

Cross-References

▶ Service-Learning and Sustainability Education

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