The Value of Science and Technology Studies (STS) to Sustainability Research: A Critical Approach Toward Synthetic Biology Promises

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1 Introduction: Sustainability: A New "Venture" for Science and Technology Studies?

Sustainability has emerged as the newly ascendant policy issue of the twenty-first century. While we continue to argue about the true definition of "sustainability" – particularly since it has become a fashionable buzzword for the policy community and related funding agencies – the challenge of converting our present socio-technical system to a "sustainable" system has developed as a new master narrative, inspiring policy discourses both in Europe and the United States.

Sustainability science and policy are situated at the intersection of two transformations with in-depth ramifications as to how we conceive the world: one regarding the production and assessment of knowledge; the other about the very foundations of politics.

Issues of social and policy concern, like sustainable development, are conventionally assumed to be knowable through science, awaiting only "technical fixes." Yet, I would like to argue that the meaning and implications of sustainability as a policy issue are not intrinsic, but, for the most part, a human construction (Wynne 2007b). In the case of environmental governance, for example, measures for dealing with uncertainty and precaution, methods for storing and assessing data and, more generally, approaches to understanding the dynamics of the human-nature relationship, are not only structured and constrained by natural realities, but also socially and normatively shaped.

On the political front, the increasing focus on sustainability has largely changed the way we frame, conceive and discuss politics. According to Beck, "we require new, exploratory ideas and schemata, for example, 'reflexive governance', in order

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to describe, understand, observe and explain the shifts now occurring in the very foundations of political action" (Beck 2006:31). Indeed, we are witnessing a progressive weakening of the authority of nation-states, coupled with disruptive global economic dynamics, which both require rethinking and re-organizing the space and contours of collective political action. This shift has diminished the connections between states and citizens, reducing the capacity of national governments to handle their citizens' expectations (Jasanoff 2005). While supranational concerns, such as the demand for sustainable development, are gaining political salience, policy leaders and officials fear that the necessary civic confidence may fail to transpire.

These are complex challenges emerging from powerful and pervasive socio-political forces. As such, I suggest that new avenues should be found to develop collective and critical approaches to understand the multiple meanings and normative dimensions of the notion of sustainability. There needs to be deliberate transdisciplinary and collective exploration of the socially and normatively constructed dimensions of sustainability, and in particular, to define the trajectories for research and innovation.

One of the ways to achieve this is with the development of inter and transdisciplinary research to understand the dynamics of human action, production of knowledge and environmental change. Encouraging collaboration across disciplines may lead to the creation of spaces, such as institutional forums and related mechanisms – where discussions about sustainability commitments can take place under the light of questions, uncertainties and ambiguities that are motivated by multiple disciplines.

This contribution explores the extent to which Science and Technology Studies (STS), rather than existing as a mere playing field between natural and social sciences, offers solid and productive theoretical models to approach sustainability challenges. For emerging technologies like synthetic biology that have been branded as "sustainable," Science and Technology Studies provides useful critical lenses to approach (1) technoscientific promises and their actual relevance to sustainable development; (2) socio-technical and socio-ecological alternatives in the development of these new technologies; and (3) the dynamics and interests at stake in the co-evolution of these technologies and society.

The purpose of this paper is to build a preliminary research agenda for sustainability grounded in the intuitions, lessons and theoretical insights derived from STS. To this end, the first section will discuss the value of STS to sustainability and initiate some reflections designed to help STS scholars better integrate sustainability into their research on synthetic biology. The second section will outline decisive research pathways which address the inherent ontological, epistemological and normative dimensions of sustainability and identify core perspectives brought by STS to the study of sustainable development. Inspired by the discussions of a group of experts in STS, sustainability science and synthetic biology,[1] I also consider a set of research practices and their related infrastructures

[1]On May 10 and 11, 2010, the Science and Technology Innovation Program at the Woodrow Wilson International Center for Scholars organized with the support of the University of Virginia and the U.S. National Science Foundation, a 2-day workshop to promote discussions between experts from STS, sustainability science and synthetic biology. This chapter is inspired by the discussions that took place on May 10 and 11, 2010.

that need to be built into the *Science and Society* agenda, as it addresses the challenges raised by sustainable development and emerging technologies.

2 Taking Constructivism Seriously

My primary question considers the value of Science and Technology Studies to sustainability. With this broad question in mind, the next section will begin on a wide canvas, with a review of the impact of recent work in Science and Technology Studies on the sustainability discourse – along the traditional notions of "technological progress."

2.1 A Critical Approach Toward the Notions of Sustainability and Progress

In the wake of the Enlightenment culture, notions of progress have unquestioningly been viewed in "western" governance discourse as the harbinger of better times. If society's view of scientific enquiry has become more sophisticated and nuanced, scientific and technological progress continues today to be considered worthy goals in and of themselves. Western nations have tied their visions of scientific research to that of economic competitiveness through continual technological innovation (Aho Report 2006; NAS 2009) (BLF, NRC Report 2009). A corollary is the production of normative discourses, in which parables of scientific or technological innovations are used to legitimate their inherent social value.

Against this background, leading STS academics suggest that dominant assumptions about science, sustainability and progress – which implicitly define existing institutional approaches to these issues – need to be fundamentally rethought (Wynne 2007b; Voß et al. 2006). They argue that "'scientific' object – sustainable development, 'safe limits' to human interference with climate, or 'risk', for example – is itself ambiguous, and in need of continual collective work to negotiate and at least temporarily stabilize its collective meaning" (Wynne 2007b:17).

Additionally, the concept of "sustainable science" conveys an array of complex, ambiguous, and discrepant positions over knowledge, values, meanings and interests that would lose from being reduced to questions of "technological fix." The related societal, ethical, and political controversies are only occasionally considered pertinent to "sustainability goals," raising the concern that other social dimensions are also being ignored. This reflects the fact that "sustainability" is not a "revealed" concept, but a contested one. Its substantial content cannot be analyzed exclusively through objective and factual scientific discourses. Instead, it will always include normative meanings that develop in the process of social interaction (Stirling 2006). Sustainability as a pathway to improve our social tolerance and the resilience of our systems of governance is an ambiguous and moving target. This is particularly true when it comes to questions of social need and prioritisation in defining the trajectories for scientific research and technological innovation.

Is Synthetic Biology the New Technological Fix?

Synthetic biology combines the principles of biology with the practices of computer engineering to build living machines from off-the-shelf chemical parts. Although synthetic biology is often confused with traditional genetics, since both seek to manipulate the building blocks of life, it nevertheless possesses a crucial difference: it seeks to *produce* genetic material from scratch, rather than modifying or copying material of existing organisms.

Narratives of technoscientific progress – such as those which combine general societal "progress" with technological "advance" – have existed for decades and, in this context, synthetic biology is not an exception. Synthetic biology, with its aim to engineer biological pathways, lies at the heart of what the U.S. National Research Council (NRC) has called *A New Biology for the 21st Century* (2009). This report recommends that a "New Biology" approach – one that depends on greater integration within biology, and closer collaboration with physical, computational, and earth scientists, mathematicians and engineers – be used to find solutions to four key societal needs: sustainable food production, ecosystem restoration, optimized biofuel production, and improvement in human health.

Synthetic biology is also presented in the U.S. press coverage as a key solution – a "technological fix" – to address the challenges of sustainable development by "greening" chemical and engineering sciences. As mentioned in the *San Jose Mercury News*, "Just as the first wave of biotechnology revolutionized agriculture and medicine, scientists today herald synthetic biology as a second wave of innovation capable of solving society's most pressing challenges. In the laboratory, researchers are developing customized organisms with powerful new capabilities. These modified cells can be programmed to fight diseases, create new wonder materials for manufacturing or produce an abundant source of clean, renewable energy."[2]

Synthetic biology in the scientific community discourse is thus often staged as the solution to a range of social ills, including the problematic sustainable development. However, opposite perspectives emerging from the civil society sector are voiced in the press to contest this: "Fearing that 'frankencells' will threaten the ecosystem, environmental groups such as Greenpeace and Friends of the Earth have labeled synthetic biology 'genetic engineering on steroids' and condemned it as 'a grave biosafety threat to people

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[2]D. Ballon, Opinion – "Synthetic Biology is a key to energy independence," *San Jose Mercury News*, 12/15/2008.

and the planet.'"[3] Some activists have already called for a complete research moratorium. Up to date, there is no solid reason to deny or question that synthetic biology may offer an unprecedented opportunity to transform modern medicine, generate clean biofuels and promote more sustainable infrastructures. However, several voices from the academic sector have warned that the technology may develop in an unsustainable way – in regard to environmental and societal concerns. In a report published in 2009, Michael Rodemeyer identified specific cases where research processes and infrastructures used to develop synthetic biology products of first, second and third generations will need more sophisticated risk assessment procedures than those on which the U.S. federal agencies currently rely (Rodemeyer 2009). In her testimony to the U.S. Presidential Bioethics Commission (July 8, 2010), Alison Snow systematically described how ecosystems might be impacted by the environmental release – intentional or unintentional – of synthetic organisms.[4] Current disagreements about the management of synthetic biology make it a particularly apposite lens through which to analyze the wider uncertainties about the relationship between science, society and sustainability.

2.2 Productive Theoretical Models: Portability and Co-production of Knowledge

As mentioned, decades of studying the social construction of science and technology have urged us to reconsider categorical assertions of objectivity and progress. Substantial time has passed since Mertonian norms were considered the "Holy Grail," defining "Science" as the institution capable of liberating the truth of nature from social and cultural horizons. More recent work in the social studies of science has, on the contrary, emphasized the portability of scientific knowledge. Among others, Bruno Latour, sociologist and philosopher of science, has relied on this concept to demonstrate the capacity of science to produce independent objects which exist "out there" in nature and are knowable exclusively through scientific methods (Latour 1987). The production of "scientific object" theory is based on an *in-principle* indisputable distinction between nature and culture that relegates the non-humans – supposed to exist independently of human agency – to the natural world. Central to the Science and Technology Studies enterprise has been the revival of these "hybrids" that traditional scientific views aimed to distinguish between the different spheres of nature and culture. Yet, the world around us is

[3] Idem.

[4] Pr. Alison Snow gave her testimony to the U.S. Presidential Commission for the Study of Bioethical Issues in the session entitled "Benefits and Risks" on July 8, 2010, at the Ritz-Carlton in Washington D.C. The testimony is available at: http://www.tvworldwide.com/events/bioethics/100708.

full of “hybrids” or “boundary objects,” such as synthetic engineered microbes, genetically modified crops, acid rain, and climate change itself. Interestingly, the reason that these hybrid entities are bound to provoke endless disputes between scientists, environmentalists and other stakeholders, is because they inevitably depend on *co-produced* knowledge to be legitimated.

The theme of co-production – the simultaneous production of natural and social orders – has been salient in Science and Technology Studies for over a decade. “Through such investigations, it has been possible to demonstrate that the products of the sciences, both cognitive and material, embody beliefs not only about how the world is, but also how it *ought* to be. [. . .] Accordingly, to understand how social entities such as the “state” or natural entities such as the “gene” function in the world, one has to ask how diverse actors use and understand the concept, how it is articulated through formal and informal practices, where and by whom it is contested, and how it reasserts itself in the face of challenges to its integrity or meaning” (Jasanoff 2005: 19). The construction and stability of knowledge ultimately depends on the valuation of existing institutions, discourses, representations and common social practices. For example, the practices of environmental science are supported, even justified to some extent, by other social practices – including normative discourses.

The theoretical model of co-production that is developing out of Science and Technology Studies provides a window for analyzing the daunting array of questions, tensions, ambitions and concerns raised by sustainable development. Recognizing some of the connections between science and society in the making of knowledge may lead us to critically evaluate and question the construction of ethically and politically sustainable images of human-nature relationships.

Engineering Life or Engineering for “Better” Life?

By “engineering life,” synthetic biology may have an unprecedented impact on the contemporary dynamics of human-nature relationships, with special attention on the beliefs and ideas that shape how people understand and value nature and assign it meaning in their lives. Synthetic biology may also have an effect on tightly coupled social and technological arrangements – what STS experts term *socio-technical systems* – that order human-nature relationships. In the long term, synthetic biology and its applications may bring about ontological changes and reclassifications in the world, producing new entities and new ways of understanding old ones. Such changes may entail a fundamental rethinking of the identity of the human self and its place in larger natural, social and political orders.

The following vision described by Rob Carlson is a good example of the potential changes we may be facing in the coming decades (Carlson 2001:1): “In 50 years, you may be reading *The Economist* on a leaf. The page will not look like a leaf, but it will be grown like a leaf. It will be designed for its function, and it will be alive. The leaf will be the product of intentional biological design and manufacturing. Rather than being constantly green, the

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cells on its surface will contain pigments controlled by the action of something akin to a nervous system. Like the skin of a cuttlefish, the cells will turn color to form words and images as directed by a connection to the internet of the day. Given the speed with which the cuttlefish changes its pigment these pages may not be fast enough to display moving images, but they will be fine for the written word. Each page will be slightly thicker than the paper *The Economist* is now printed on, providing room for control elements (the nervous system) and circulation of nutrients. When a page ages, or is damaged, it will be easily recycled. It will be fueled by sugar and light. Many of the artifacts produced in 50 years and used in daily living will have a similar appearance, and have similar origin. The consequences of mature biological design and manufacturing are widespread, and will affect all aspects of the economy including energy and resource usage, transportation, and labor."

2.3 Transdisciplinarity and Collective Experimentation

As introduced in the previous section, recent research in Science and Technology Studies has been conducted with the goal to re-define how scientific knowledge is produced and, subsequently, how this generation of knowledge will fit into the functions of society. Several STS academics have suggested that the traditional "Republic of Science" is being replaced by a new "Mode 2" of knowledge production (Gibbons et al. 1994). Two properties linked to this new "Mode" – transdisciplinarity and an orientation toward problem-solving – are particularly relevant for our discussion.

Analysis of long-term transformations in socio-ecological systems such as energy production and consumption, transportation, agriculture, resource extraction and manufacturing, requires understanding the systemic interconnections to which these problems refer. Yet, they deal with an array of heterogeneous elements, ranging from chemical pollution, to ecosystems, scientific studies, economic parameters, policy-making processes and cultural values and concerns. The traditional model of disciplinary science does not fully consider the interdependence of social, technological and ecological systems. Instead, it focuses on a very specific range of elements and interconnections. Outside of the laboratory, however, researchers have to face the constant interaction of scientific processes with the systemic embedding of cause and effect in which these processes operate. Regarding sustainability problems in particular, spill-over effects extend well beyond the scope of how they are defined by conventional disciplines.

Confirming the theoretical added-value of the model of co-production, I submit that the inherent limitations of one-dimensional perspectives also apply to scientific methods of knowledge generation. As such, the transdisciplinary model of knowledge production – which draws upon and integrates empirical and theoretical elements from a variety of fields – may help in analyzing the interactions between multiple sets of actors as they interact in real world entanglements. As argued by Voß and Kemp, "Considering the heterogeneity of the elements that play a part in sustainable development, effective problem treatment calls for the use of methods of integrated knowledge production that transcend the boundaries between disciplines and between science and society" (Voß et al. 2006: 10–11). They also insist on the benefit of integrating "the tacit knowledge of societal actors" – which is "generated in interactive settings in which knowledge is co-produced by scientists and actors from respective fields of social practice". Concretely, citizen and "concerned groups" get actively involved in the process of knowledge production, with the consequent result that some interactions between scientists and lay persons become permanent and build trust and mutual learning by working together in hybrid collectives.

A subsequent challenge lies in finding practical ways to integrate complex forms of "transdisciplinary" knowledge-making and assessment with more inclusive forms of stakeholder engagement and citizen deliberation. A corollary is to work with the potential of stakeholders and citizens to be independently knowledgeable agents. Each stakeholder is capable of their own reflective thinking about collective rationalities, knowledges and responsibilities. According to the 2007 Wynne report (p. 18), "this may lead to develop the cultural and political conditions under which widespread civic ownership of societal problems, like sustainability, and climate change (among others), and real engagement with the salient science, might be achieved".

In this respect, the European Commission is moving a step further. The recent internet public consultation on the "Nano Code of Conduct"[5] constitutes an effort not only to communicate science but also to set up a framework in the form of guidelines for carrying out responsible nanotechnology research. By doing so, the Commission wishes to internalize public consideration of potential implications of nanotechnology research in the research process itself and to participate in the ongoing global dialogue on the socio-economic impacts of nanotechnologies.

Besides the governance of nanotechnologies, the European Commission is also funding cooperative research processes between researchers and civil society organizations, which include both research and dialogue on relevant societal issues. There are other rich examples of newly emerging groups of actors in the field of science and innovation such as, the involvement of patient organisations and the elderly in the development of new technologies for health and social care. These citizen groups who engage with research constitute another layer of the system of knowledge production – often called the third sector of knowledge production – and bring a different logic into the knowledge-making process with the subsequent added-value of being capable of experimental practices and, ipso facto, of exploring alternatives to our socio-technical systems.

[5]Available at : http://europa.eu/sinapse/directaccess/science-and-society/public-debates/nano-recommendation/.

"Syn-Bio": A Complex and Transdisciplinary Science

Synthetic Biology is at the front edge of a wave that the US National Science Foundation (NSF) has termed "converging technologies" and involves bio, info, nano, and cognitive sciences. A lot of innovation will occur in the interstitial spaces between these disciplines, but the emerging multi-disciplinary smorgasbord will create challenges in terms of the ability of new fields to regulate their own actions, anticipate unintended consequences, communicate effectively with each other and the public and solve what some political scientists call "collective actions."

There will likely be new challenges in managing ethical, social and legal issues at the boundaries between disciplines. For instance, the emergence of biohacking reveals a growing culture of people interested in playing with genetic software and hardware in much the same way conventional hackers play with computer software and hardware. The key question then becomes: How do you establish a framework for socially and ethically responsible development of synthetic biology when the person you need to reach is an adolescent teenager constructing new biological code in his basement? Another potential concern may be that engineers entering the domain of biology have different ethical norms, standard practices and professional expectations vis-à-vis regulators and the public. Many engineers have little training in biology, toxicology, environmental sciences, and ecology – all of which are crucial for impact assessments of new biological organisms.

Synthetic biology thus crosses important technological frontiers, like the boundary between science and engineering, and is part of what has been called by the NRC the "Coming Biology Revolution." Such a revolution in the life sciences, its nature and goals, would ideally call for parallel transformations under the chapter of societal governance, but despite the efforts of visionary researchers to overcome the divisions between the two cultures of humanities and natural sciences (Jasanoff 2003), the new biology gets imagined mainly under the auspices of biologists, other natural scientists, mathematicians and engineers. A comprehensive understanding of the epistemic, ontological and normative changes induced by this new biology paradigm would require the involvement of researchers from humanities, social and environmental sciences, including STS and sustainability science.

2.4 Political Conditions for Dissenting Imaginations

Alongside the growing enthusiasm for the early participatory style of knowledge production, assessment and deliberation, several STS researchers have voiced their concerns that these emerging technologies of public elicitation might create a new form of technocracy by stripping away the political dimension of both science and participation (Wynne 2005, 2007a; Lezaun and Soneryd 2007). These concerns reflect recent STS interpretations of participatory approaches which lower democratic expectations but focus on understanding the conditions and perspectives under which these kinds of approaches might promote more plural and overtly political understandings of sustainability (Stirling 2008). Recent STS research has increasingly argued in favour of plural forms of engagement with civil society organisations and other groups of concerned citizens, which combine "governance from outside system" – such as upstream public engagement – and engagement "driving on inside of system"[6] – such as the above mentioned cooperative research processes (Stirling 2008, 2009; Fisher et al. 2006).

As we have argued under the co-production paradigm, knowledge is not simply transmitted from science to people, but is actively translated, construed and renewed in the context of emerging uncertainties, ambiguities, and collective experiences. On this basis, an array of STS scholarships has shown the decisive role played by civil society actors toward encouraging institutional reflections: to get decision-makers to question their own assumptions and consider a wider range of alternatives in face of these uncertainties and ambiguities (Wynne 2005, 2007a, b; Wilsdon 2007; Dryzek et al. 2009; Jasanoff 2003). According to the 2007 Wynne report (p. 78), "autonomous agents of civil society act and interact epistemically and socially in their own independent worlds and cultures. Against the dominant narrative of a singular hierarchy of knowledge, with publics imagined as epistemically-incompetent, thus untrustworthy, European institutions have the evidence-base to attribute a more active and creative role to their publics – and, as a result, to further encourage such a social capacity."

The evidence-base that has been taken into account by European policy-makers is the capacity exemplified by different layers of civil society actors in the GMs crops and food controversy to be attentive to what Wynne calls an "epistemic other" (2009: 13): "it is difference manifesting itself as an unknown set of realities, acting themselves as unknowns and beyond our control (but not beyond our responsibility), into a world we thought we controlled." On the surface of this epistemic variety, a democratically-committed knowledge-society is supposed to have the scientific and political imaginations to work out how a plurality of social actors could share knowledges, practices, and experiences with diverse scientific, policy and economic actors (Jasanoff 2009). Central to comparative studies within STS is the emphasis on "civic epistemologies" shaping the democratic practice of science and technology. Beyond the distributed nature of expertise, what matters most is the consideration of the divergent socio-cultural contexts in which technoscientific politics take place, *inter alia* the modes of knowledge-making in the public sphere and the levels of accountability and trust in the knowledges produced (Jasanoff 2005).

[6]Both expressions "governance from outside systems" and engagement "driving on inside system" have been eloquently described by Andy Stirling in the Session "Sustainability and Emerging Technologies" at the 2009 Conference of the Society for Social Studies of Science (4 S), October 29, 2009.

The above propositions progressively move us from "Mode 2" of knowledge production to the "Agora" – "where science and innovation interact with societies"[7] – and provide a role for public engagement of a more complex kind. In this case, scientists, engineers and policy-makers, sensitised through engagement to wider social imaginations, might decide for themselves to approach science and innovation differently. Interestingly, what lay expertise help picture, are hidden (1) *questions*, (2) *connections* and (3) *suggestions* (Wilsdon 2007): (a) interrogations might be about *what we don't know* and *how to learn what we should not do*; (b) connections might show the risky entanglements between public-private, global–local interests involved in techno-scientific promises; (c) suggestions might range from anecdotal evidence to alternative practice or alternative technology scenario. As explained by Stirling about current discourses on sustainability (Stirling 2009: 5):

> Often, the position is expressed as if there were 'no alternatives.' The questions asked are thus typically restricted to 'yes or no?'; 'how much?'; 'how fast?' and 'who leads?' If we move instead to more plural understandings of progress, then the quality of debate – and of the ensuing choices – thereby stands to be enriched. Instead of fixating on some contingently-privileged path, we might ask deeper, more balanced and searching questions about 'which way?'; 'what alternatives?'; 'who says?' and 'why?' This is the essence of a normative, analytic, epistemic, ontological – and consequently intrinsically political – project of 'pluralising progress'.

In a nutshell, the above-mentioned STS scholars eloquently demonstrated the importance of creating political conditions for dissenting imaginations (Wynne 2009; Jasanoff (2009). Beyond designing ideal participatory-governance processes, the prelude is intended to more reflexively understand the political background within which actors from different fields of social practices will be invited to interrogate particular framings of socio-technological regimes and their potential transition pathways, and to re-open them for debate (Stirling 2008; Smith and Stirling 2008). In this journey toward change-oriented research and policy, there is a necessary need for "daring to imagine" (Wynne 2009), for reflexivity and for empowerment as suggested by Jamison (2010: 13) "change-oriented research is about empowerment, by which the researcher applies knowledge gained from experience to processes of social learning, carried out together with those being 'studied'."

Jamison's reflection left us with a daunting yet challenging array of questions of how to promote empowerment, how to dare to imagine change and its uncertainties and how to open controversies to discussion. In this perspective, the work of Arie Rip brings remarkable insights into the value of (1) enabling future-oriented actions between actors who share an environment and (2) supporting them to create narratives about the potential resulting uncertainties and ambiguities (Rip 2006). More importantly, Rip stresses the need for *diversity* as a source of renewal by creating grey zones and interstitial spaces in existing orders and institutions where

[7]This concept of the "Agora" was introduced by Andy Stirling in the Session "Sustainability and Emerging Technologies" at the 2009 Conference of the Society for Social Studies of Science (4 S), October 29, 2009.

dissenting imaginations might be voiced. This reminds us that the ultimate challenge is about reviving atmospheres of our democracies which allow for the expression of dissenting imaginations. The ultimate challenge is avoiding "high-pace technoscientific politics" to withdraw from the democratic scene (*learning is forgetting*) and to cultivate the ability of "making things public," of turning "matters of facts" into "matters of concern" (Latour 2005). In a vibrant call, Latour invites us to give a chance to what he names *Dingpolitik* (2005: 23).

> The point of reviving this old etymology is that we don't assemble because we agree, look alike, feel good, are socially compatible or wish to fuse together but because we are brought by divisive matters of concern into some neutral, isolated place in order to come to some sort of provisional makeshift (dis)agreement. If the Ding designates both those who assemble because they are concerned as well as what causes their concerns and divisions, it should become the center of our attention: Back to Things!

Finally, at the core of this vibrant call for returning to *Dingpolitik* lies the diagnosis that the *modus vivendi* between modern democracies and technoscience has become increasingly compromised. The transformative power of technoscience reshapes societies in destabilizing ways, by imposing certain normativities and replacing controversies with "safe and serious" forms of knowledge which have significant ramifications as to how we conceive the world. STS research takes precedence over this diagnosis to investigate the conditions of emergence, both political and cultural, of collective practices for democratizing innovation – specifically when innovation aims at promoting sustainability. It encourages us to avoid substituting Enlightenment with "Sustainability normativity blinkers," but rather to focus on uninvited parties (*inter alia*, civil society actors, concerned group of citizens, and researchers favoring qualitative explorations of sustainability's meanings) as a "cauldron of concocting normativities" for emergent sustainability institutions.[8]

Throughout this theoretical section, I have tried to highlight the value of Science and Technology Studies for the research agenda on sustainability. In short, STS academics bring home the extent to which sustainability is raising long-term and collective issues that hinge on the political as well as the intellectual question of how much confidence we place in our knowledge (and in what forms of knowledge) which we use to legitimate new interventions in nature. The salient properties of our knowledge-making process are the following:

- In key aspects, such as the way their boundaries are framed, their dimensions selected and their meanings defined, issues of social and policy concerns – like sustainability – are partially human constructed.
- Changes in the modes of knowledge production have made science more embedded in society and more closely tied to its applications.

[8]Both expressions "Sustainability normativity blinkers" and "cauldron of concocting normativities" have been eloquently used by Andy Stirling in the Session "Sustainability and Emerging Technologies" at the 2009 Conference of the Society for Social Studies of Science (4 S), October 29, 2009.

– The renewed attention being directed towards transdisciplinarity and collective experimentation represents a promising development in defining trajectories for research and innovation.
– The transition from "Mode 2" of knowledge production to the *Agora* – where science and innovation interact with society – elaborates on the diagnosis of failure in developing open, inclusive, and diverse mechanisms of accountability in technology innovation. On this basis, this transition requires political conditions that promote plural and reflexive social normativities of progress.

Food for Thought: Make Synthetic Biology a "Matter of Concern," but How?

Below are a few questions about synthetic biology research developments that might help to produce the greater "reflexivity" of "science-in-the-making". At the very least, these questions might highlight some of the issues involved in synthetic biology research trajectories.

Emergence of Synthetic Biology Research Trajectories

To what extent do the synthetic biology research trajectories integrate the paradigm of sustainability? How are the meanings of "sustainability" negotiated in the rhetoric and economics of synthetic biology promises? To what extent do the synthetic biology practitioners themselves reflect about these trajectories – especially in terms of "sustainability transitions"? What ideas (concepts, beliefs, knowledge, ethics and values) underpin synthetic biology practitioners' understanding of nature, environment, science, technology and society as they relate to sustainability? What practices (behaviours, relationships, arrangements, and institutions) underpin the construction and maintenance of these ideas?

Actors, Dynamics and Configurations

Who are the leading actors (synthetic biology practitioners, the related stakeholders and celebratory institutions) and the marginalized actors ("non-invited parties") surrounding the development of synthetic biology? How do they present themselves through their research goals and practices? How do they define what would be a success in their research practices? To what extent is this definition of success effectively integrating sustainability research (and which exploration and meanings of sustainability)? What spaces are left for epistemic openings in an attempt to explore diverse meanings of "sustainability"?

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Related Social Science Researches and Their Practices of Engagement
To what extent do the lab-scale studies – which have flourished around the emergence of synthetic biology research[9] – lead to a better capacity to critically analyze synthetic biology promises and to collectively experiment with possible alternatives within synthetic biology? To what extent will they succeed in developing co-production among multiple disciplines and perspectives from the outset as opposed to downstream reflection upon the ethical, legal, and social implications of synthetic biology?

Entanglements Around the Notions of Ownership
What are the different models of ownership that are tacitly emerging inside and outside the laboratory, and within the public-private partnerships surrounding the development of synthetic biology? What reflections and analyses can be brought up by STS and Sustainability Science on this debate over different models of ownership? What are the implications of these different ownership models for our socio-technical systems, our socio-ecological systems, and our socio-economic systems?

3 Building a Science and Technology Studies Research Agenda for Sustainability

This section will outline possible research trajectories grounded in the work of STS scholars who focus on the social, philosophical and policy studies of science, technology and the environment.[10]

In this perspective, it is important to highlight some of the remarkable and exciting changes within recent STS research. STS research has become more relevant to understanding the co-production of science and technology with policy, democracy, law, and the management of environmental change, among other major institutional matters. Because of this, STS researchers have become increasingly involved with practices of technology development, policymaking, legal decision-making and governance in different fields, such as science & technology policy and environmental regulation.

[9]Two collaborative lab-scale projects might serve as field work: the *Human Practices* Laboratory directed by Paul Rabinow within the NSF-sponsored SynBERC project (http://www.synberc.org/content/articles/human-practices); and the Center for Synthetic Biology and Innovation as a collaboration between the BIOS Center (LSE) and the synthetic biology team of Imperial College (http://www.lse.ac.uk/collections/BIOS/synbio/synbio.htm).

[10]Sections II and III are based on exchanges and discussions in which I took part during the Workshop "Science, Technology and Sustainability," held at the National Science Foundation, September 8–9, 2008.

The balance between observation and participation seems to have shifted in these consequential practices of engagement. Such engagement is likely to have consequences for research methodologies, for researchers' obligations toward different publics, and for the kind of products STS-researchers deliver. In addition, like other aspects of science and technology, interventions by STS researchers are subject to contingencies and negotiations that can lead to unanticipated consequences.

3.1 Ontological, Epistemological and Normative Dilemma

At the end of the nineties, visionary minds from STS and environment studies started to take precedence over the diagnosis that science is not responding adequately to the challenges of our times, and particularly, those posed by the quest for sustainable development. Recognizing the need for a new "Social Contract for Science," they essentially identified three types of challenges that future societies would have to cope with (Gallopin et al. 2001).

As a first diagnosis, society is facing ***ontological*** changes which encompass changes induced and driven by human behaviors impacting nature. These changes are proceeding at unprecedented rates and scales, and subsequently result in growing interconnections at many levels. These ontological changes are made visible and understood through the analysis of what STS research, among other fields, calls socio-technical systems, which consist of our large-scale technological infrastructures (such as transportation systems and energy distribution grids) embedded in a dense web of human and social values, behaviors, relationships, and institutions (Smith and Stirling 2008). Socio-technical developments, and the powerful applications created in their wake, intertwine science, technology and society dimensions – making understandings of both the human and social aspects of science and technology critical to analyzing and responding to sustainability challenges (Miller et al. 2008).

These ontological changes have progressively rippled our systems of knowledge production and assessment, changing the ways we view the world and inviting us to think in terms of connectedness, relationships, context and socio-ecological patterns (Gallopin et al. 2001). They have bound us to new ***epistemological*** challenges which would benefit from being addressed through STS lenses. Indeed, central to the STS endeavor has been to explore the human and social practices, as well as philosophical and ethical frameworks, that have determined how we have come to learn about and value aspects of sustainability research, such as society and the environment (Jamison 2001; Jasanoff 2005; Miller 2005; Norton 2005). STS scholarship has similarly developed a comprehensive expertise into future-oriented analyses facing the uncertainties, ambiguities and unpredictability that are built in the fabric of reality (Stirling 2006; Guston et al. 2002; Sarewitz 2005).

Building on this increasing expertise in anticipatory thinking, researchers have also developed experimental modes of participative foresight for science and technology governance as well as environmental and sustainability studies (Kasemir et al. 2003). This is only the tip of the iceberg as STS researchers have produced, among their core conceptual areas, critical analyses of the strategies used by political and policy institutions for governing science and technology in society. An array of STS researchers have been increasingly concerned with the politics of environmental sciences, articulating positions with respect to questions about the role of expertise in democracy (Miller and Edwards 2001; Jasanoff and Martello 2004; Irwin 1995; Fischer 2000), or engaging in studies that directly refer to questions of reform and activism (Smith 2005). This indicates why STS scholars are particularly entrenched in addressing the third kind of challenges – the ***normative*** dilemma that emerges in science and technology policy, management, and regulation.

The next sub-sections synthesize some key research questions which address the above-described ontological, epistemological and normative dimensions and might be identified as core perspectives brought by STS to the study of sustainability.[11]

3.2 Participatory and Anticipatory Thinking for Sustainable Socio-Technical Systems

Significant attention in STS has been paid to co-production within the functioning of socio-technological systems and socio-ecological systems (*inter alia*, Jasanoff 2004, 2005). This body of knowledge might be decisive to understand why and how these systems' structure and dynamics contribute to sustainable and unsustainable outcomes as well as why these systems have been designed that way and how they have become incumbent parts of our socio-technological landscapes. Building on these findings, STS research could help better understand the social dynamics that prelude to replacing incumbent socio-technical systems with alternative, more sustainable, ones.

In a nutshell, STS scholarship brings home critical insights into how human societies make choices impacting the design of current socio-technical systems and how these choices and their spill-over effects influence how societies envision the systems of tomorrow (Miller et al. 2008). As the discipline has developed a useful set of tools to analyze technology within society, it might be able to identify the social conditions that inhibit modern societies from choosing sustainable technologies and practices. For instance, STS researchers have started to focus on sustainability technologies as practices, including the understandings, learning and stabilization processes that underlie these practices. Sustainability practices might be explored through ethnographic studies as a complement to participatory settings

[11] Researchers in sustainability science have identified other challenges which pertain to public perceptions, such as cultural practices and social learning (Pahl-Wostl et al. 2008).

designed to understand conceptions of "current" practices, of their amenability to change, and of the ways in which they can be shaped into sustainable ones.[12]

As a parallel area of inquiry, STS research could significantly address the question of how sustainability is apprehended within the functioning of socio-technical systems with a subsequent focus on how these systems cope with their inherent ambiguities, vulnerabilities and collective responsibility. When it comes to sustainability, only limited research effort has been devoted to understanding the socio-economic impacts resulting from the introduction of new technologies within society. In contrast, considerable more attention has been paid to their impacts on the environment. But, here, hybridization in the process of assessing ecological and socio-economic implications would benefit from being explored. What choice of indicators will make it possible to track important social values within a particular socio-technical system? What are the social dimensions to be sustained? What tradeoffs have been made in the past between social and ecological sustainability and why? How can we better understand the dynamics within the social formations driving and hindering sustainability transitions?

Given that we live in social systems which are organized, for the most part, around a plurality of values, research aimed at exploring social meanings of sustainability should involve anticipatory and participatory thinking (Stirling 2006, 2009). They should also rely on empirical methodologies that are capable of guiding public deliberations toward visualizations and framings that endorse multiple and varied values (Shaw et al. 2009). STS researchers could reflect on models for engaging civil society actors and wider publics in processes of envisioning and assessing technological futures (Fischer 2000; Irwin 1995). Cooperative research processes between STS scholars, experts in engineering and sustainability science, and civil society actors could lead to create deliberative spaces where communities interact in practice and, *ipso facto*, contribute to the reflection on more sustainable socio-technical systems for the future.

3.3 Critical Assessment of Sustainability Knowledge Production and Valuation

As shown in our theoretical analysis, STS scholars have begun to demonstrate the importance of introducing exogenous normativity into discourses of progress and the role of marginalized and unconventional actors to play in the directions of innovation. Similarly, STS research can investigate the conceptual and epistemological premises of sustainability, and the social practices on which they are built.

[12]This is the approach applied within the EPSRC-supported project "CHARM" which includes research on electricity consumption. CHARM is coordinated by R. Rettie and K. Burchell, both at Kingston University. See: http://business.kingston.ac.uk/charm.

This investigation might help to deconstruct the values, reasoning and framings at stake in controversies over sustainability.

A related area in need of investigation includes empirical studies of the knowledge production and assessment practices not only within scientific disciplines but also within government agencies, corporations, and other social formations concerned with the environment. Indeed, when it comes to sustainability research and decision-making, there is a need for empirically-based analyses of how knowledge systems work and how they might become better integrated with decision-making. Such empirical studies might reveal the social and political arrangements that prevail in knowledge and production assessment, the opportunities for opening these processes up to alternatives, and the pathologies of closing up (Stirling 2006). For instance, a growing body of STS research has begun to explore the various ways that "green knowledge" is being constituted and mobilized (Jamison 2001). How is sustainability expertise produced, distributed, and, subsequently, transformed through decision-makers' interpretative frameworks and political agendas? How are local knowledges, skills and technologies evaluated and mobilized towards sustainability? What is the role of social formations (social movements, business and government actors) in producing knowledges and arbitrating environmental controversies?

Such controversies have often been used by STS scholars as a basis for investigation. Further research might examine why there is a perceptible lack of controversy lying beneath areas that could become a "sustainability matter of concern." In this perspective, STS research is challenging the assumption in sustainability research – and potentially, in sustainability science – that there is already an agreement on the meanings of sustainability and on its social translations, measurement and realizations (Stirling 2006, 2009; Voβ and Kemp 2006; Norton 2005). A robust STS-centered engagement would significantly broaden current thinking in sustainability research by offering critical insights into how sustainability knowledge systems function in societies – for example, what has been exposed through "lab studies" – what their implications for community decision-making are, and how to confront them with processes of transition (Cash et al. 2003). The specific emphasis of the field on material practices, including human and non-human entanglements within knowledge production systems, constitutes a distinctive added value to other approaches to sustainability research (Jasanoff 2005; Latour 2004). More recently, research at the crossroad between STS and political ecology has explored case-studies that connect dynamics of local expertise with political and policy practices of expertise at national and international scales (Jasanoff and Martello 2004; Miller 2005; Miller and Edwards 2001). These studies might help reflect on improved models for transcending and connecting data generated in local and context specific sites to trends and challenges at the global scales.

Finally, when it comes to a "sustainability matter of concern," the question of our collective ignorance might be as interesting as the question of our systems of production of knowledge (Proctor and Schiebinger 2008). What are the epistemic, social and political rationales behind our socio-ecological and socio-technical ignorance? There might be some room here for STS scholars to problematize the sociological and historical roots of the dynamics that lead to non production of knowledge about what and who we are supposed to "sustain".[13]

3.4 Democratizing Sustainability Innovation: Deliberating about Socio-Technological Futures

The above argument reminds us that at the core of the deliberations regarding our socio-technological futures lie collective questions about the nature and scope of what we want to sustain. These questions involve normative positions about human-nature relationships with a particular focus on the values that influence how societies understand nature and assign it meaning in their lives (Norton 2005). Deliberation about these collective preferences imply being able to track democratic tradeoffs and contradictions within sustainability issues and, subsequently, better integrating normative aspects into decision-making (Cash et al. 2003). This is particularly crucial when sustainability challenges give rise to necessary and large-scale changes. How can change be promoted in our current socio-technical systems and whose agencies and responsibilities are at stake? How can social practices of human decision-making be conducted to improve the aptitude to design more sustainable socio-technical systems in the future?

Because it gives special attention to the interactions between epistemic and political processes, STS can genuinely study knowledge and technology as integral parts of policy-making. Therefore, it has been able to reflect on and design more reflexive and inclusive approaches to governance of science and technology (Stirling 2009; Smith and Stirling 2008). This expertise might be extremely valuable when starting to think about comparable models of policy and decision-making oriented toward the transformation of incumbent socio-technical systems. Further in-depth expertise will be needed in the social practices of policy and decision-making related to scientific and technological change as well as collective experimentation to test inclusive practices of engagement with technical, business, policy and civic communities (Wynne 2007b).

On the theoretical front, it requires *inter alia* developing conceptual and methodological frameworks to tackle the inherent complexity and diversity of knowledges blended into sustainability decision-making processes (Grin 2006). This implies finding experimental ways to integrate complex forms of transdisciplinary assessment with more inclusive forms of stakeholders' engagement and citizen deliberation. Among these challenges, one is about improving the visualization of the socio-technological choices we are faced with (Shaw et al. 2009); the other is to foster networks that bring practitioners together with scholars to promote the co-evolution of diverse forms of knowledges (Rip 2006; Stirling 2005).

[13] The question "What is it we want to sustain?" was eloquently posed by S. Jasanoff at the Workshop "Science, Technology and Sustainability," held at the National Science Foundation, September 8–9, 2008.

This co-evolution could take the form of collaborative research networks that can collectively pursue the knowledges' synthesis, and cooperate with colleagues in technical, civic, entrepreneurial, and policy communities to translate research into new approaches to meet the sustainability challenges.

Finally, democratizing sustainability innovation entails rethinking the distribution of responsibilities within our complex socio-technological systems. Such rethinking must be an interdisciplinary and an inter-cultural process, in order to conform to important notions of democracy and justice. This reflection takes us back to our starting point. It finds its inspiration in a critic of the conventional linear Enlightenment understanding of scientific and technological progress viewed as endogenously determined, teleological and likely to impose self-referential normativity (Stirling 2009). It finds its inspiration in an array of scholarly work which has attempted to show why scientific, social and political actors have mutually failed to distinguish, as a "matter of concern," several roles and responsibilities of science in our globalized knowledge-societies (Wynne 2009; Jasanoff 2009).

4 Empirical Reflections at the Crossroad Between Science, Technology and Sustainability

I conclude this kaleidoscope of possible research trajectories, with empirical reflections which arise from the discussions of a group of experts in STS, sustainability science and synthetic biology that gathered on May 10–11, 2010, at the Woodrow Wilson International Center for Scholars, with the support of the U.S. National Science Foundation. The workshop led to intense cross-field reflections, debates and controversies on production of knowledge, impact on policy-making, and cross-national differences in the way research cultures reproduce and emerging technologies – like synthetic biology – interact with societies. It finally shed light on potential collaborations as well as research, education and policy initiatives at the crossroad between science, technology and sustainability.

I do not assume that these reflections are final and comprehensive, but hope that they can play a valuable role in stimulating further thinking and proposals for additional and consequent cross-field collaborations. They focus on the kinds of research practices and infrastructures necessary to make possible not only the pursuit of the research agenda outlined in Sect. 2, but also the capacity to translate its findings into concrete action to enhance sustainability in human societies. Key aspects of and questions concerning these research practices and infrastructure include:

– The development of collaborative research groups that can collectively pursue this research (cf. Sect. 2), combine its findings, and cooperate with colleagues in technical, civic, entrepreneurial, and policy communities to translate research into new approaches to meeting the sustainability challenge; The concept of "collaboration" itself provoked interrogations among the participants: How do you create the infrastructures so that complex ways of thinking from different fields can seat somewhere and learn from each other? How can we think about forms of "cohabitation" where researchers from different fields would reflect together on design, options, research questions and trajectories? Is there a possibility for different socio-technical imaginations to cohabit? What are the necessary conditions (institutional, epistemic, political and cultural) to develop different forms and places for *reflexivity*, at different levels, in different contexts and networks such as the educational systems, the policy systems or the laboratories?

– The creation of novel training programs that are able to prepare the next generation of researchers in the new methods and theories that emerge from the research agenda outlined in Sect. 2; transdisciplinarity appeared as one of the key features on which novel training programs should be built. Additionally, the concept generated new questions: What are the barriers to developing a transdisciplinary research program within universities or research centers that foster the type of partnerships needed in the assessment and governance of emerging technologies like synthetic biology (What are the impacts of cost structure, pressure from departments and power structure within universities)? How should we re-think the roles, goals and practices of knowledge-producers like universities, academies, and research centers when it comes to cross-field collaborations, especially with the aim of transitioning towards more sustainable socio-technical and socio-ecological systems?
– The fostering of networks that bring practitioners, policy-makers and scholars together to promote the co-evolution of diverse forms of knowledge; The notions of "impact," "intervention" and "channels of action from academia to policy-making" were explored in terms of opportunities for (1) theorizing transdisciplinary and systemic ways of critically assessing problems and producing knowledge about them, and (2) institutionalizing cross-field experiments: How can channels of influence on policy-making be maximized through cross-field collaboration? What are the obstacles? How can we build on funding schemes, publications, and public infrastructures to promote cross-field collaborations?

The following diagram builds on the above reflections to propose potential parallel, yet distinct, discussions for sustainability and synthetic biology (Fig. 1).

5 Conclusion: From Technoscientific Hubris to Socio-Technical Hybrids[14]

In the first section of this contribution, I highlighted the theoretical value of Science and Technology Studies to sustainability research. In this respect, an important conclusion of this contribution is that steps should be taken away from narrow and

[14]See the book by M. Hard and A. Jamison, *Hubris and Hybrids: A cultural History of Technology and Science*, New York and London: Routledge, 2005.

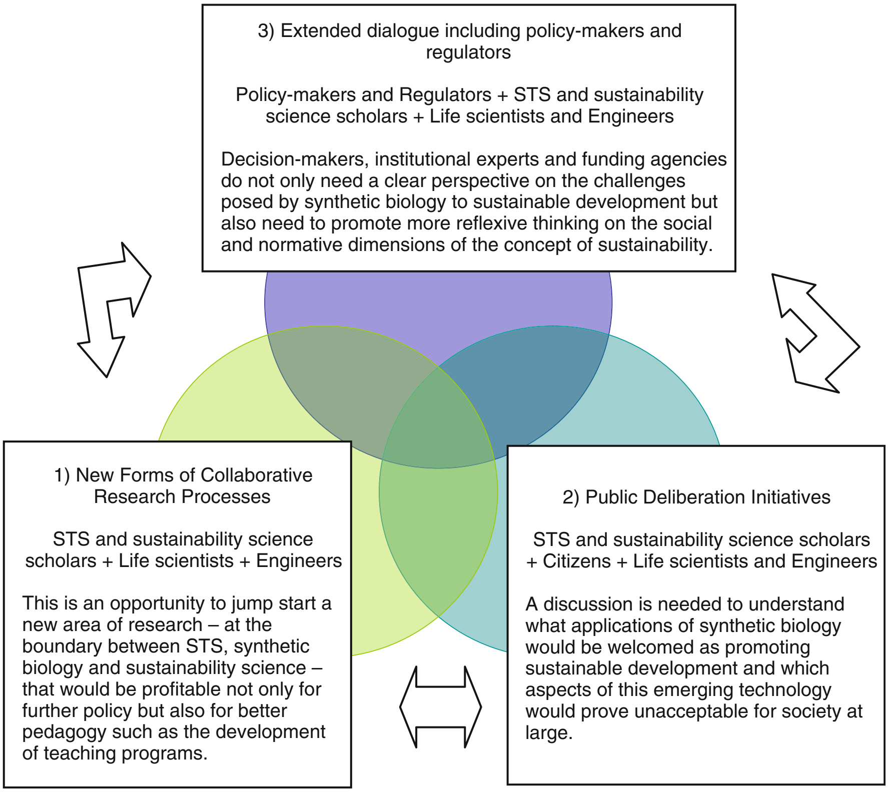

Fig. 1 Interactive representation of potential parallel but distinct discussions on synthetic biology and sustainability policy

exclusive understandings of knowledge production and assessment toward recognising more socially distributed autonomous and diverse collective forms of producing knowledge.

Recent discussions of Mode-2 science have pointed out that ways of producing techno-scientific knowledge already extend well beyond the classical mode of basic science. A stronger role of application contexts in the very production of knowledge, transdisciplinarity and preliminary attempts to develop collective experimentation and spaces for dissenting imaginations are but a few elements which indicate much broader social involvement in how knowledge is produced, contested and validated.

However, the public and policy debates surrounding synthetic biology have been narrowly focused around a utilitarian calculation of its technological benefits versus its potential regulatory risks. Although the technical aspects of synthetic biology policy are immensely important, spanning from controversies on ownership, socio-technical implications to biosecurity and biosafety concerns (nobody would like to the re-engineered flu virus mysteriously escaping from the lab), they ignore fundamental questions about *what* applications of synthetic biology should be considered sustainable, and thus limit the discussion to the opinions of a few technocratic elites.

Indeed, there are serious social, ethical and safety questions surrounding synthetic biology. The purpose of these questions is not to cause undue alarm, or advocate a knee-jerk form of neo-luddism. Rather, it is to expand awareness on what effects synthetic biology could have on both our political systems and our conception of humanity as a whole.

Ultimately, the research priorities and infrastructures identified in Sects. 2 and 3 acknowledge and focus on the inextricable human dimension of our socio-technical system; they also build on the social and collective practices and dimensions that characterize our forms of knowledge production and assessment, and related forms of decision-making.

If, in the real world, scientific and technological hubris encounter the wider societal context of values and aspirations, giving birth to novel constructions of technological artefacts and socio-organisational innovations, the case of sustainability might be a good example of such long "hybridisation" processes.

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