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SPECIAL FEATURE: ORIGINAL ARTICLE

People, Technology and Governance for Sustainability

Strengthening the science–policy–industry interface for progressing toward sustainability: a systems thinking view

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Abstract

The purpose of this paper was to discuss the need of "general reference frameworks that can support the understanding of complex phenomena related to sustainability and sustainable development that cannot be effectively faced by adopting existing disciplines in isolation". Recognizing the complexity of sustainability, we discuss two main problems: (1) the yet unfulfilled need to overcome the fragmentation of knowledge necessary to address sustainability, and (2) the crucial need to strengthen the science–policy–industry interface in order to effectively co-create knowledge and solutions for sustainability. Advancing a 'triple helix' model for sustainability that has been recently developed in the field of managerial studies, the conditions for knowledge co-creation and effective *science–policy–industry* collaboration are discussed. Findings highlight: (1) the contribution of systems thinking to bridge the ways each discipline interprets sustainability and the ways actors look at its challenging requirements; (2) the relevance of 'interface' roles among actors involved in the theoretical and practical progress toward sustainability. Following the 'helix' stream, a novel representation of the sustainability triple helix shows how systems thinking, as a boundary-crossing and knowledge-bridging perspective, can trigger a virtuous interaction among key actors involved in the challenge for sustainability.

Keywords Sustainability · Sustainability science · Systems thinking · Triple helix of sustainability

Introduction: a joint effort of science, policy, industry and society for progressing toward sustainability

Envisioning "the way forward" of sustainability research, Takeuchi et al. (2017: 853) highlight a fundamental requirement for the next research agenda: "Through strengthening the science–policy–society interface, and co-production of knowledge as well as future scenarios with innovative policy options, new relationships between the sciences and society should be explored to lead effective actions for operationalizing and implementing SDGs [Sustainable Development Goals] from local, national, regional to global scales". Embracing a mission that is not only academic, sustainability science, in fact, "not only emphasizes the importance of integrating the fragmented disciplines, but also seeks to collaborate with society" (Takeuchi 2017).[1]

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[1] Special Feature CfP http://static.springer.com/sgw/documents/1609767/application/pdf/Special+Feature+of+Sustainability+Science+Journal_WOSC2017.pdf.

As it has been argued by Kerkoff (2013: 82), "sustainable development is a knowledge intensive process, but plagued by persistent concerns over our apparent inability to connect what we know with more sustainable practices and outcomes". Science, policy, society, as well as industry, are expected to more effectively collaborate for realizing sustainable development especially co-creating knowledge and effectively linking it to action. However, despite the recognized progress since the initial discussion in late 1980s—when the sustainable development paradigm emerged to provide a framework through which economic growth, social welfare and environmental protection should be harmonized; more than 30 years later, such harmonization has proved elusive (Asara et al. 2015).

A call for a functioning *science–policy* interface for SD was launched by the UN member States since the Rio + 20 summit (Prototype Global Sustainable Development Report, UN-DESA 2014). On the other hand, there is a wide consensus on the fundamental role of *science–industry* collaboration to address effective innovation, hence, development (Ranga and Etzkowitz 2013; Barile and Saviano 2014).

Integrated research and decision-making are necessary for progress on the Sustainable Development Goals (SDGs). A gap emerges, however, in current research and policy analysis regarding "how to think systematically about interactions across the SDGs" (Nilsson et al. 2018).

In our opinion, the unsatisfactory outcomes of integration and systematic thinking show the still unfulfilled need to overcome the fragmentation of knowledge, on the one hand, and the persistent distance between science, policy and industry as key actors of sustainable development, on the other hand. Hence, we believe that more effective integration is still required first *within* science (Problem 1), and second *between* science, policy, society and industry (Problem 2).

In the present work, we assess the two aforementioned problems. Particularly, we aim to respond to the "call of systems thinkers" to address the need of "general reference frameworks that can support the understanding of complex phenomena related to sustainability and sustainable development that cannot be effectively faced by adopting existing disciplines in isolation".[2]

Embracing the mission of Sustainability Science and wearing the lens of systems thinking, our aim is to provide a general framework to analyse the conditions for effective *science–policy–industry* collaboration to co-create knowledge for sustainability, while also clarifying the role that society plays. To this end, after an analysis of the two problems under discussion, we build upon a 'helix' model that has been recently developed in the field of managerial studies of sustainability (Barile et al. 2017; Barile and Saviano 2018; Farioli et al. 2018) following the Triple Helix model of Etzkowitz (1998). The model highlights roles and relationships of science, policy, industry and society in an integrated framework for sustainability. The integrated model shows also the fundamental role of science as a key "interface" among involved actors and its importance in the progress toward sustainability.

The rest of this article is organized as follows: First, we discuss Problem 1 by highlighting the complexity of sustainability and exemplifying *how* Sustainability Science is overcoming the dominant vertical pathway of disciplinary knowledge for sustainability addressing its complexity ("The yet unfulfilled need to overcome the fragmentation of knowledge (Problem 1)" in section). Then we introduce an analysis of Problem 2, by using a 'triple helix' model of sustainability to highlight *how* science can contribute to strengthening the science–policy and science–industry interfaces and the way society is involved ("The yet unfulfilled need to strengthen the science-policy and science-industry interfaces (Problem 2)" in section). Then we focus on *how* integrating the science–policy and science–industry interfaces into a unitary framework for co-creating knowledge for sustainability ("Strengthening the consonance in the science-policy-industry interface to co-create knowledge: the contribution of revised systems thinking" in section). Finally, we propose one synthesis and conceptual representation of applying revised systems thinking and its role in developing the sustainability science utility of the helix model ("Concluding remarks" in section).

The yet unfulfilled need to overcome the fragmentation of knowledge (Problem 1)

Complexity of sustainability

In an impactful perspective article published in Science in 2009, Nobel Prize winner Elinor Ostrom, with reference to the necessity of a general framework for analysing the sustainability of social-ecological systems, argued that the "Understanding of the processes that lead to improvements in or deterioration of natural resources is limited, because scientific disciplines use different concepts and languages to describe and explain complex social-ecological systems (SESs). […] Scientific knowledge is needed to enhance efforts to sustain SESs, but the ecological and social sciences have developed independently and do not combine easily" (Ostrom 2009: 419).

[2] Takeuchi (2017). http://www.springer.com/environment/environmental+management/journal/11625—Downloaded in September 2017.

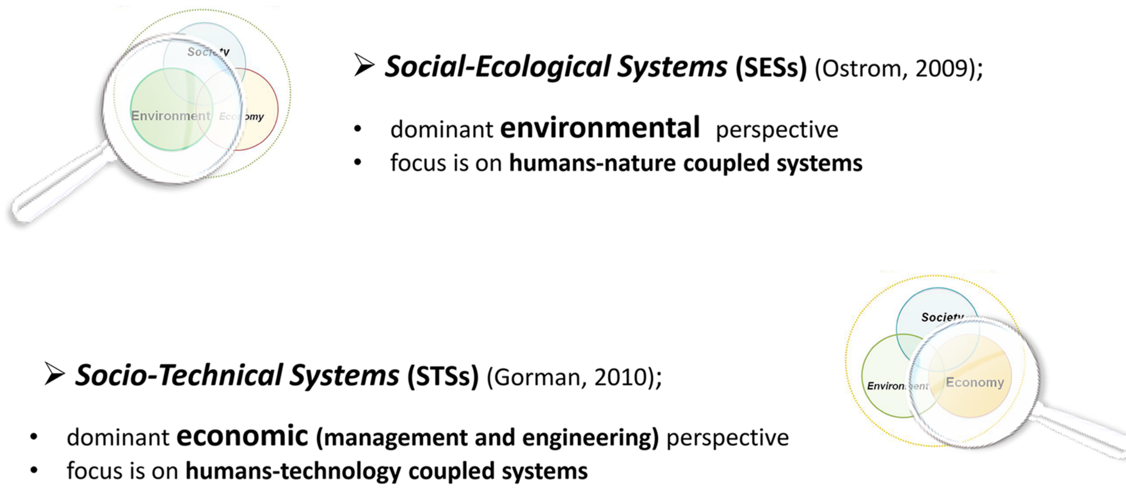

Fig. 1 Social-ecological and socio-technical systems. *Source* Elaboration from Barile and Saviano 2018. www.asvsa.org

Problems at the interface between environment and society characterize the study of Social-Ecological Systems (SESs) (Berkes and Folke 1998; Berkes et al. 2003; Ostrom 2009). The focus of the study is on human–nature coupled systems and, although other areas of inquiry from the social and economic sciences views have emerged over time, the environmental perspective has traditionally dominated. Problems at the interface between society and economy, on the other hand, characterize the study of Socio-Technical Systems (STSs) (Trist 1981; Gorman 2010). In this case, the focus is on human–technology coupled systems, and the social, business and engineering perspectives typically dominate (Fig. 1).

To understand the complexity of sustainability, it is useful to recognize that both social-ecological systems and socio-technical systems behave as *Complex Adaptive Systems* (CAS) (Folke et al. 2002; Rammel et al. 2007), i.e. "systems that involve many components that adapt or learn as they interact" at the heart of important contemporary problems (Holland 2006: 1). Understanding CAS is challenging and requires the adoption of interdisciplinary approaches (Mabry et al. 2008; Barile et al. 2012a). The most critical aspect to deal with is that interactions in such coupled systems are characterized mainly by 'non-linear' relationships whose outcomes are generally unpredictable. Linear deterministic relationships, i.e., relationships that can be designed and controlled, are less relevant in CAS.

Complex phenomena that involve social-ecological and socio-technical systems are not only characterized by similar behaviours and dynamics but also reciprocally interconnected and, through interaction, produce the changes we observe in reality and in the three 'spheres' of sustainability. There is then an apparent convergence between the interests, the problems to face, the requirements and approaches of the two complex systems. Accordingly, their fields of inquiry may be expected to be in part similar, and potentially complementary in what they differ.

Moreover, debates about sustainability "likely require transdisciplinarity to transcend a singular disciplinary viewpoint and to allow for the consideration of different perspectives and types of knowledge" (Wals and Rodela 2014: 1). Nevertheless, and despite the evident complexity of sustainability, the progress of science has continued to follow a vertical pathway through the development of increasingly specialized knowledge, thus generating fragmentation and divides that make dialog among disciplines difficult. Essentially, this 'silos' development of disciplines has delayed the building of the multi-, inter- and trans-disciplinary knowledge necessary to address the complexity of sustainability (Kline 1995). Integrating the various disciplines into a unitary body of knowledge and linking it to action are key challenges for progressing toward sustainability. Sustainability Science plays a key role in this direction.

The contribution of Sustainability Science to address the complexity of sustainability

Describing *Sustainability Science*, Kazuhiko Takeuchi affirms that a progress has been made from an original discussion held in individual disciplines towards the definition of an open field of shared knowledge in which "fragmented academic disciplines have become merged to create a new,

Table 1 Sustainability science between descriptive and transformational modes. *Source* Authors' elaboration

Mode	Focus	References
Descriptive-analytical	Focus is on the enhancement of understanding of problems derived from complex human-nature dynamics	Kates et al. (2001), Clark and Dickson (2003), Turner et al. (2003), Komiyama and Takeuchi (2006), Farioli et al. (2009), Komiyama et al. (2011) and Wiek et al. (2012)
Transformational	Scientists engage with a broad range of stakeholders from other domains of society, to improve the collective understanding of coupled systems and to develop joint and coordinated strategies for solving sustainability problems	Wiek et al. (2012)

holistic dimension, with the aim of creating the core of sustainability science" (Takeuchi 2017).[3]

Sustainability Science emerged about a decade ago as an interdisciplinary and innovative field of inquiry attempting to conduct solution-oriented research that links knowledge to action in order to address the challenges posed by global change and its associated socio-economic impacts (Kates et al. 2001; Clark and Dickson 2003; Orecchini et al. 2011; Turner et al. 2003; Komiyama and Takeuchi 2006; Komiyama et al. 2011; Wiek et al. 2012; Cornell et al. 2013; Manifesto of IASS retrievable at www.scienzasostenibilita.org).

Global change challenges, also described in the literature as'wicked problems', referring to problems that are life-threatening and urgent, have long-term impacts, are highly complex (systemic), and are difficult or impossible to resolve because of incomplete, contradictory and changing requirements that are often difficult to recognize (Funtowicz and Ravetz 1993; Dovers 1996; Frame 2008; Brown et al. 2010).

Addressing them, therefore, requires new research paradigms able to reflect complexity, to encompass different magnitude of scales, multiple balance (dynamics) and interests (actors).

These new paradigms can be found in "post-normal" and "Mode 2" genres, both embraced by Sustainability Science with the aim being of providing a response to the crisis of "normal sciences" in addressing contemporary challenges.

In "Mode 2" Science—academic and social, trans- and inter-disciplinary, participative, uncertain and exploratory—(Gibbons 1994; Martens 2006), scientists are part of a heterogeneous network. Their scientific tasks are components of an extensive process of knowledge production and they are also responsible for more than merely scientific production.

In "post-normal science" (Funtowicz and Ravetz 1993) elements such as uncertainty, value loading and a plurality of legitimate perspectives are considered as integral to science, and a new task for Science is required, that of quality assurance of the knowledge production and decision-making process. This entails organizing effective and adequately managed participatory processes in which different types of knowledge (not only scientific) come into play (horizontal knowledge production), involving the whole set of perspectives in the problem framing as well as in the decision making and implementation process. In fact, as claimed by Funtowicz and Ravets (1993) most of complex science-related policy problems have more than one plausible answer, and many have no well-defined scientific answer at all.

Sustainability Science is being developed in a constructive tension between a descriptive–analytical and a transformational mode (Table 1).

In Wiek et al. (2012), on the basis of a comparative appraisal of empirical sustainability science projects, Authors highlight that in order to fulfil its transformational function, the process, i.e., credibility, saliency, legitimacy (Cash et al. 2003) and impact, i.e., transferability, scalability, outreach, of the solution options have to be improved through the "implementation of strong collaborative research processes in which scientists and stakeholders interact starting from problem framing to strategy implementation and problem transformation" (Wiek et al. 2012: 8). This implies the adoption of trans-disciplinarity as a "reflexive, integrative, method-driven scientific principle aiming at the solution or transition of societal problems and concurrently of related scientific problems by differentiating and integrating knowledge from various scientific and societal bodies of knowledge" (Lang et al. 2012).

Transdisciplinary research requires a strong link with the specific social/local/place context and institutional setting from where sustainability problems originate. This is expressed in the inclusion of public and civic values and common goods perceptions along an iterative circular co-production process, linking scientific and experiential knowledge, enabling mutual learning amongst researchers

[3] Takeuchi (2017). http://www.springer.com/environment/environmental+management/journal/11625—Downloaded in September 2017.

Table 2 Academic work on sustainability Source: Authors' elaboration

Academic networking experiences	*European Sustainability Science Group*, *Future Earth Partnership*, the *Integrated Research System for Sustainability Science* hosted by University of Tokyo, the *International Society for Sustainability Science* (ISSS), which every year organizes the International Conference on Sustainability Science, and the *Italian Association for Sustainability Science,* its Italian counterpart
Peer-reviewed, interdisciplinary Journals	*Sustainability Science* (the journal of the ISSS); *Sustainability*; *Sustainability: Science, Practice and Policy*; *Current Opinion in environmental Sustainability*; *Challenges in Sustainability;* *Proceedings of the National Academy of Science (section devoted to sustainability science)*

from different disciplines as well as from actors outside academia, promoting societal learning, transformation and reflexivity (Lang et al. 2012; Sala et al. 2013; Marsden and Farioli 2015).

The parallel growth of collaborative networks across different geographical locations and contributing disciplines and that of interdisciplinary journals (Table 2) show an important step towards the consolidation of sustainability science as a unifying field of investigation and research community (Bettencourt and Kaur 2011; Sala et al. 2013; Scalia et al. 2016, 2018).

A further step in the consolidation of the field requires addressing the theory using an empirical bottom-up approach, so as to improve the practice and outcome of Sustainability Science. Design principles for transdisciplinary sustainability research that draw from various strands of literature on collaborative research approaches as well as on practical experience have been proposed (Lang et al. 2012). However, coproducing and engaging sustainability knowledge to wider publics and stakeholders still remain the main challenge.

How barriers between not just disciplines but also knowledge domains outside could be reduced? This is critical to progressing and reinventing sustainability practice.

For that purpose, networks of long-term integrated demonstration projects need to be collected, evaluated, monitored and disseminated in order to demonstrate achievements and challenges in co-creating and implementing knowledge, in order to encourage experimentation with different approaches for analysing and building the capacity to deal with global change and achieve sustainability (Wiek et al. 2012; United Nations Department of Economic and Social Affairs 2014). The long experience of Sustainability Science has proven to be successful in promoting integration of knowledge for sustainability providing a platform for co-creation that can be a reference for other scientific and professional community. To concretely exploit and benefit from this opportunity, however, action is necessary from both the Sustainability Science and other scientific and professional communities to reciprocally recognize their contribution in working for a common shared knowledge platform. There are, indeed, many signals from various domains of science that show a growing interest and commitment to cross their borders and contribute to address the global challenge of sustainability (Kajikawa et al. 2014; Saviano et al. 2017a; Tàbara and Chabay 2013). There still remains, however, much work to be done to engage all actors in a shared and global commitment for sustainability.

The yet unfulfilled need to strengthen the science-policy and science–industry interfaces (Problem 2)

Having acknowledged the need to recover unity in science by effectively linking together disciplines to address the complexity of sustainability (Problem 1), and having exemplified the successful pathway of Sustainability Science in building a body of unitary knowledge for sustainability, we move on to discuss the need to strengthen the *science–policy* and *science–industry* interfaces in order to create the conditions for a harmonious and successful action for sustainability (Problem 2).

The 'Triple Helix' stream

In the discussion of Problem 2, our focus is on traditional roles of three actors: science, policy and industry, which recall the well-known model of the *Triple Helix* by Etzkowitz and Leydesdorff (1997). This model has been further developed and analysed (Leydesdorff 2012) and recently applied in the field of sustainability research by including the perspective of sustainability in the original model. The original concept of the Triple Helix was developed by Etzkowitz (2001), and Leydesdorff and Etzkowitz (1998), to analyse the structural links between universities, industry and government as institutional agents whose roles in innovation processes are crucial. The basic rationale of the model is that effective innovation can be pursued and realized only through the functional integration of the three actors (Dzisah and Etzkowitz 2008).

Table 3 Expanding the Triple Helix to include sustainability Source: Authors' elaboration

Ideas	Proposals	References
A quadruple helix?	Fourth Triple Helix Conference in 2002: debate on whether the Triple Helix model should have been expanded to include a fourth helix	Leydesdorff and Etzkowitz (2003)
A twin helix?	Etzkowitz and Zhou (2006)—who recognize the need of taking into account the role of civil society in the change for sustainability but do not agree with the idea of a quadruple helix—argued that a Sustainability Triple Helix of university-public-government could be introduced as a complement to the Innovation Triple Helix of university-industry-government: a 'twin model', developed to obtain that "innovation and growth take place in ways that will not be harmful to the environment and health" (Hetzkowitz and Zhou 2006: 80)	Hetzkowitz and Zhou (2006)
A quintuple helix?	Carayannis et al. (2012) contextualize the Quadruple Helix to sustainability by adding the perspective of the 'natural environments of society'. According to Carayannis et al. (2012: 1), "The Quintuple Helix stresses the necessary *socio-ecological transition* of society and economy in the twenty-first century; therefore, the Quintuple Helix is ecologically sensitive. Within the framework of the Quintuple Helix innovation model, the natural environments of society and the economy also should be seen as drivers for knowledge production and innovation, therefore defining opportunities for the knowledge economy"	Carayannis et al. (2012)
A co-creation framework?	Trencher et al. (2014) joined the debate on the third mission of universities and triple-helix partnerships, by incorporating sustainable development and place-based co-creation with government, industry and civil society, hence, proposing a more comprehensive 'co-creation' framework	Trencher et al. (2014)

The key assumptions of the model are that: interaction among the three actors is a fundamental process that is expected to trigger a virtuous cycle; university (science) plays a central role in innovation processes; virtuous collaborative relationships between the three institutional spheres are to be established; temporary 'replacement' of roles between the three actors through the so-called hybridization processes can be necessary to ensure that each role is played.

Several efforts have been made to apply the model in the field of governance for sustainability by enriching the original scheme. Table 3 summarizes the main proposals.

More recently, the shift from the triple to the quadruple models has been proposed again especially to acknowledge the diffusion of the new "Mode 3" Knowledge Production System defined by Carayannis and Campbell (2009, 2012) (Miron and Gherasim 2018). The "Mode 3" Knowledge Production System is characterized by a multi-layered, multi-modal, multi-nodal and multi-lateral architecture made of Innovation Networks and Knowledge Clusters for knowledge creation, diffusion and use (Carayannis and Campbell 2012).

The sustainability helix model

While agreeing with the opportunity of better focusing on complementarity, co-creation and the necessity of a coherent and more comprehensive framework to understand the keys for effective knowledge co-creation in the field of sustainability, we think that it is not necessary to add new models or further dimensions to the helix model. Hence, our intention is to better explore the contribution of existing models.

Along this line, the Sustainability Helix model (Barile et al. 2017; Barile and Saviano 2018; Farioli et al. 2018; Scalia et al. 2018), which we advance here, has been developed in the field of management studies within the research stream of the Viable Systems Approach (*v*S*A*) (Barile 2009, 2013; Golinelli 2010; Barile and Saviano 2011). Essentially, recognizing the inner systemic nature of any phenomenon of reality, the *v*S*A* mission is to re-explore the common *systems* roots of disciplinary knowledge, including management, by developing an interpretative and governance methodology for organizations that is based on systems thinking (Barile et al. 2012b).

With reference to the debate about sustainability (Barile et al. 2013, 2014a), the *v*S*A* has proposed an integration of the Triple Helix model into the Triple Bottom Line framework (Elkington 1997). According to the Authors, the integration allows the inclusion of the perspectives and roles of society and natural environment into the triple helix model without adding new blades.

The novelty in the *v*S*A* interpretation of sustainability is that the helix is viewed as the institutional mechanism that explains interaction between the environmental, social and economic dimensions of sustainability, to which the roles of policy, science and industry are connected.

As illustrated in an elaborated version of the model we developed in Fig. 2, the helix movement represents the dynamic of interaction among three actors identified as key players of sustainable development: policy, science and

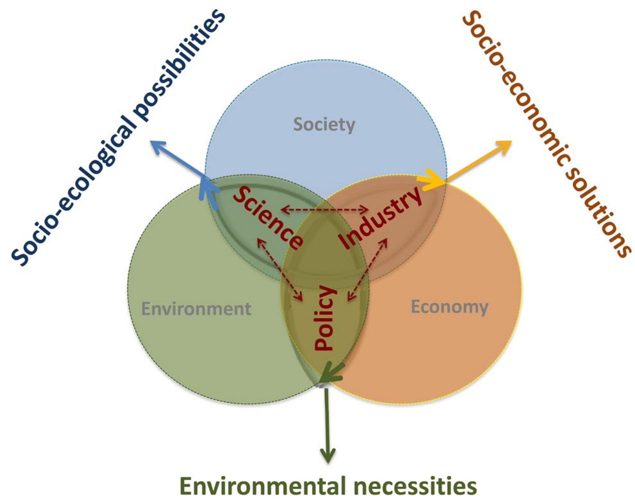

Fig. 2 The Triple Helix of Sustainability. *Source* Elaboration from Barile and Saviano 2018. www.asvsa.org

industry. The roles of these actors are essentially defined as follows: governments (policy) interpret the *environmental necessities,* i.e., the constraints with which the socio-economic activities must comply when 'using' environment as a complex of resources; science (university/academia), in turn, defines the *socio-ecological possibilities*, i.e., what can be done, given the necessities, thanks to the progress of knowledge; finally, industry develops the *socio-economic solutions*, i.e. the selected feasible possibilities. Beside these functional roles, however, the logic of the model, and what we take to be its major strength, is that each actor can play any role that is necessary to the overall functioning to the achievement of the desired goals. This interchange of roles is accomplished through the so-called 'hybridization' processes like those, for example, that, in the original representation of the Triple Helix model, affirmed the entrepreneurial mission of university.

In our integrated framework, we fundamentally confirm the validity of the basic rationale of the Triple Helix model against the various critiques that it has received over time, which essentially refer to its theoretical abstraction and practical distance from the real world (Elzinga 2004; Tuunainen 2002; Cooke 2005; Viale and Pozzali 2010; Amir and Nugroho 2013). Amir and Nugroho (2013: 7) well summarize these main criticalities in the following words: "The Triple Helix model appears to be more of a "political directive" suggesting an imperative that success is likely achieved through linking universities, business organizations, and government bodies rather than a conceptual framework of *how* to effectively create the links, let alone *why* these all matter. The *process* of how the helix works remains a black box as the model is uncritically adopted."

Our integrated framework provides a possible answer: to open the 'black box', it is necessary to go back to the general scheme behind the model and search for the principles and the 'simple' rule that explains its 'complex' functioning, as suggested by the *vSA* (Barile and Saviano 2018).

We detect the general scheme behind the Triple Helix model by wearing the lens of the *vSA* and, specifically, using the 'structure-system' paradigm (Barile and Saviano 2011) which suggests approaching the understanding of complex phenomena by shifting focus from the analysis of their structural components to their functioning dynamics: such shift implies to move focus from components and relations to *interaction*. Accordingly, we shift focus from the blades of the helix (and their number) to the inner dynamic that characterizes the model, that is, *interaction* among the three actors. This constitutes at once the core and the most challenging aspect of the model, namely, *how performing effective interaction among the actors*.

As the rationale of the model suggests, effective interaction between the three actors is necessary for proper and wise decision making about sustainability. For example, in order to define the direction of the appropriate policy and of governance mechanisms for sustainability:

1. policy-makers should determine the constraints on the basis of the scientific evidence provided by science;
2. science should envision possible scenarios by taking into account both the perspectives of policy and industry;
3. industry should develop feasible solutions by valorising and safeguarding resources, on the one hand, and promoting attention to sustainability on markets, in the other hand.

Regarding the 'how the helix works', it remains to be clarified at what conditions effective interaction occurs. According to the *vSA*, effective interaction among different-minded actors—like in the case of science, policy and industry—requires the creation of conditions of 'consonance' among them, that is an alignment based on shared values systems, non conflicting goals, effective communication and reciprocal understanding (Barile et al. 2014b). Regarding how to reach consonance, it should be first considered that these conditions cannot be evaluated by analysing each actor in isolation or the way they are connected in an organizational structure (that is, statically), e.g., in a collaborative project. Rather, it is required to shift focus from the actors to the *context* in which they behave by interpreting their behaviour as expression of the influence their 'supra-systems' are capable of exerting on them. Thus, to assess the conditions of consonance among the three actors, it is necessary to read their supra-systemic environments. For example, policy makers are much influenced by the political-institutional system that appointed them. According to the consonance view, collaboration is not simply a matter of participation at a common project: it requires effective sharing of information and communication and, what is mostly important, reciprocal understanding, i.e., engagement and commitment to the achievement of shared goals. Such engagement and commitment strongly depend on the interpretation of the problem based on rooted cognitive models that are generally different and direct toward the achievement of different goals. Hence, what can harmonize the different views in similar situations are the *values* deeply rooted in any person's life.

Essentially, what differs in our model from the previous helix representations of interaction among university/academia, policy/government and industry, is that these actors' behaviour, hence interaction among them, are interpreted as expressions of the *contexts* in which they act, which involve the different supra-systems that dominate for each of the key institutional actors in the environmental, social and economic 'spheres' of sustainability. These dominant systems, perspectives and goals define the value systems and principles of reference of the community, i.e. the dominant *culture*. In this way, environment, society and economy are included in the model not in the form of added actors (hence, added blades of the helix) but as the *contexts* in which dominant values, perspectives, rules and expectations, hence, culture, are defined and influence the views and behaviours of institutional actors and key actors.

In this sense, the three dimensions of sustainability are to be viewed as *supra-systemic* contexts, i.e., *eco-systemic* contexts made of actors whose actions and impact are played bottom-up in various forms and through various settings and entities influencing the three institutional actors.

The interface roles of actors in the Sustainability Helix Model and state of the facts

The complex system of interactions that emerge from the overall relational context represented through the Sustainability Helix Model may result in a more or less balanced equilibrium in which dominant values and priorities in play are reflected through the roles played by the three actors.

To be really effective in promoting sustainability and sustainable development, environmental *necessities*, socio-ecological *possibilities* and socio-economic *solutions* should be defined and developed as dynamically emerging at the intersection among all actors' views and perspectives, whereby each of them can play significant 'interface' roles, not only accomplishing their institutional functions, but also favouring hybridization processes.

The interface role of science

As the highest expression of a society's dominant culture and value systems, science is expected to play a fundamental role in a knowledge-based society, especially when embracing the sustainability challenges. One key interface role is indeed played by science in the interaction between society and environment by providing the knowledge necessary to support effective policy decision-making complying with the environmental constraints of development processes. These constraints are to be taken into account when science, interpreting the needs of a society expressed through the dominant culture, envisions the socio-ecological *possibilities* that can be sustainably explored to develop innovations. A second interface role is played by science in the interaction with industry (Orecchini et al. 2012). At this stage, all the envisioned possibilities are subject to a feasibility evaluation; they are selected, developed, and put on market—subsequently impacting not only on economy, but also, circularly, on society and environment. Science should actively contribute to make developed solutions sustainable and inclusive by strengthening interaction with policy and industry (Saviano and Caputo 2013; Saviano et al. 2017b).

The interface role of policy

In our revised view of the triple helix, policy plays a relevant interface role in the interaction space between environment and economy, where, through government mechanisms and tools (e.g. incentive mechanisms), action in the socio-economic contexts is regulated. Policy plays also important roles in society–environment and society–economy interaction, producing a 'regulatory' knowledge that aims to correctly inform behaviors. As stated, the main responsibility of governments in this respect is to correctly interpret the environmental necessities and derive the set of constraints and rules that should regulate the social and economic life of populations to ensure long-term viability for all.

The interface role of industry

The role of industry is relevant as well, especially in determining the condition of equilibrium of the overall system. Industry has long dominated the environmental and social context putting the economic interests at the centre of a power system that is mainly responsible for the current disequilibrium among the three spheres of sustainability. Instead of being an inclusive development for all population, it has been long and often characterized by speculative and opportunistic behaviours at the damage of both the environment and the society, although providing short-term satisfaction of populations' needs. With the necessary exceptions, this behaviour of organizations, however, will soon and definitely affect their own long-term viability. Viability is increasingly becoming dependent on the capability of decision makers to establish conditions of consonance with a wider than economic context recognizing as relevant (and satisfying the needs of) also 'supra-systems' that do not currently and directly show a power of influence on their economic performances, e.g., future generations. A paradigmatic shift from pure logics of competitiveness to logics of consonance that goes beyond the Corporate Social Responsibility framework (Carroll 1991) is required, embracing a true view of sustainability as necessary condition for viability. In a nutshell, companies must soon recognize that their own survival (and viability) depends on the viability of the environmental and social context (the *eco*-system) in which they themselves live. In this view, given that industry increasingly defines the consumption behaviours of citizens, a possible interface role of industry could be between environment and society, to be interpreted as an ideal (but really potential) educational role of industry towards society promoting more sustainable consumption.

The interface role of society

Society, although not 'institutionally' included in the helix structure, results fundamental in creating the appropriate context conditions for sustainable development, activating drivers that are determinant for political, social and economic decision and actions.

Society can play a fundamental interface role among the variety of actors, by unifying views, and challenges of sustainability, so creating the 'field force' necessary to general engagement and commitment toward sustainability. This important aspect, which also characterizes our framework, will be highlighted in the next section, when completing the overall framework.

The state of the facts

How successful these actors are in synergistically promoting sustainability is still questionable. The current state of the facts is that we are far from the desired condition of harmonization. Almost all actors tend to express their own interests as deriving from the influence of supra-systems they perceive as much as relevant. We have support from everyday-evidence: most of the collaborative projects that involve policy, science and industry, also mentioned "The contribution of Sustainability Science to address the complexity of sustainability" in section, have laudable aims; however, more than often they end up being only opportunities to exploit or to gain access to other actors' resources far from a true scheme of resources integration and value co-creation (Barile and Saviano 2014).

This is the problem with sustainability: a true commitment to the cause recognized as a value in itself and shared among all relevant actors. Such a condition would create the required consonance, so generating effective *science–policy–industry* interaction and harmonically connecting the three dimensions of sustainability.

Hence, playing appropriate *science–policy* and *science–industry* as well as *policy–industry* interface roles, a harmonic movement of the helix would be obtained, triggering a virtuous interaction between the three economic, social and environmental dimensions of sustainability, indispensable to create the necessary conditions for sustainable development.

On the basis of the above, believing, as scholars, that science should play a key role, we wonder, *how successfully is science contributing to progress toward sustainability through promoting effective science–policy–industry interaction?*

Given the apparent unbalanced relationships that still characterize development, there seem to be relevant criticalities in a harmonious 'helix' functioning of the three spheres of sustainability and relative actors.

In order to deepen such interaction criticalities, in the next section we analyse perspectives and views that traditionally characterize action in the interface spaces between the three dimensions of sustainability and related key actors, as represented in Fig. 2.

Strengthening the consonance in the science–policy–industry interface to co-create knowledge: the contribution of revised systems thinking

In the proposed integrated model, science, policy and industry, in their institutional roles, can be viewed as 'representative' actors of the three dimensions of sustainability (environment, society and economy). Coherently, they reflect views and schemes dominant in the respective contexts and adopt different perspectives. Agreeing that: (1) according to the *vSA*, consonance is a necessary (although not sufficient) condition for effective interaction among actors, which is in turn important to co-create knowledge and that (2) knowledge is always inherently and unavoidably co-produced alongside the social orders in which it is shaped and driven (Ely et al. 2018), we deepen here the basis for generating consonance in a knowledge co-creation context that is typically multi-actor and multi-perspective.

As highlighted in the first sections, the complexity of sustainability requires general frameworks of reference that can support the building of a unitary perspective through which interpreting the wide variety in play. As discussed, the main problem is to integrate the social-ecological and the socio-technical perspectives to ensure that the development and innovation pathways, defined and implemented in the political and economic context, are in harmony with the environmental and social necessities. In this respect, Tàbara and Chabay argued that to develop sustainability learning feedbacks between knowledge and action, it is necessary the

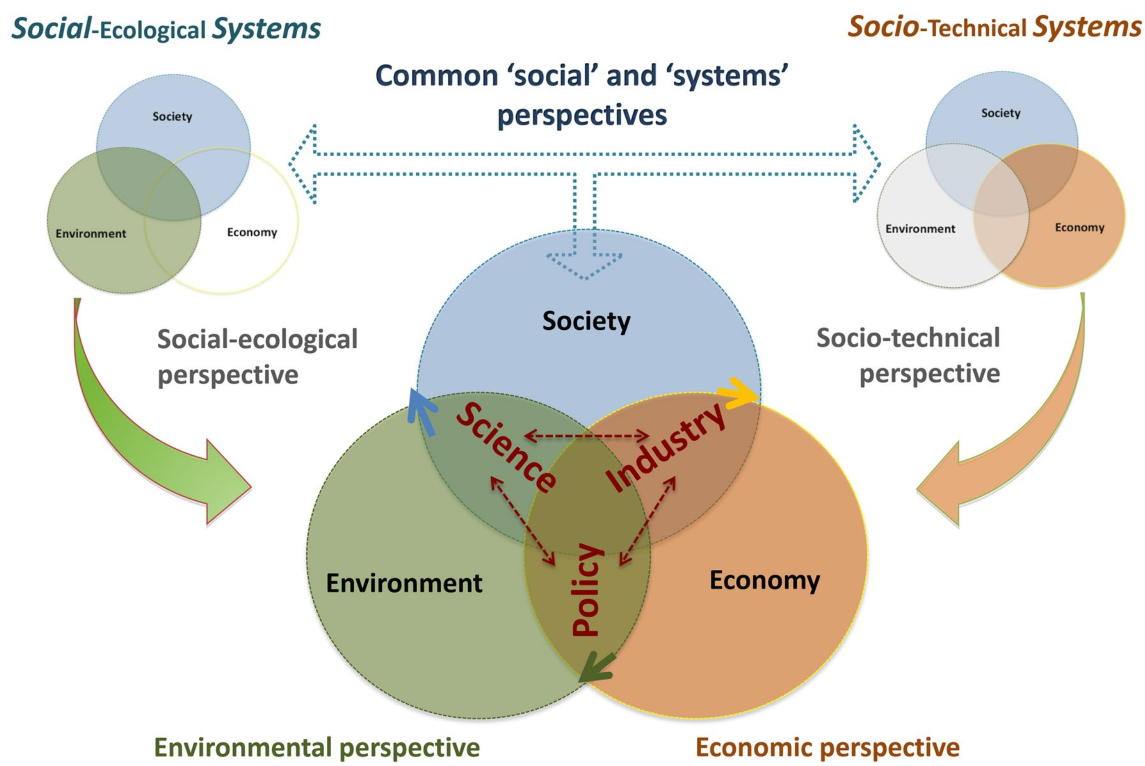

Fig. 3 Integrating the social-ecological and socio-technical systems perspectives. *Source* Elaboration from Barile and Saviano 2018. www.asvsa.org

coupling of Human Information and Knowledge Systems with social–ecological systems dynamics.

The representation proposed in Fig. 3 suggests a way forward: to leverage the 'social' and 'systems' dimensions that are common to both the perspectives of *social*-ecological *systems* and *socio*-technical *systems*.

Indeed, the social dimension (Dillard et al. 2009; Dempsey et al. 2011), common to both the CAS, seems to have received less attention than the environmental and the technical–economic ones in the study of such complex systems (Folke 2006). Moreover, following Ostrom's thought, it seems that social sciences have developed independently from ecological sciences, and subsequently do not combine easily with them. Instead, as branches of social sciences, the set of disciplines involved in the study of socio-technical systems seem to have more commonly embraced the social view. However, effective integration among them all is still the problem.

It should be said that the socio-economic dimensions of socio-technical systems are becoming increasingly relevant in the study of sustainability issues and now represent key areas of enquiry in sustainability research (Takeuchi et al. 2017). While, however, sustainability research is more engaged in finding the ways to make the planet *more sustainable*, research in the socio-economic context appears more engaged in making it *smarter*. A potential complementarity hence emerges, though, between the 'smartness' of socio-technical systems and the 'sustainability' of social-ecological systems as long as the formers embrace the challenge of sustainable development and both contribute to strengthen the whole science–policy–industry collaboration for sustainability. This potential complementarity, from a *vSA* perspective, can be the way for creating the required consonance between the two domains.

A robust way to exploit the observed potential complementarity is to leverage the second common element, that is, the 'systems' dimension, as illustrated in Fig. 4.

The systems dimension is intrinsic to any phenomenon of reality that has an irreducible unitary interconnected 'functioning'. Hence, to understand the fundamental principles underlying any complex phenomenon, essential features of its *systemic* nature should be recognized and understood, and their implications adequately considered.

Hence, what is required is to detect and focus on the common (complex) *systems* nature of social-ecological and socio-technical systems relying upon the fundamental contribution of *systems thinking*. The main advantage of systems thinking, as an interpretative lens to link the variety of sustainability, is the ability to capture the very general (if not universal) dynamics that characterize it. This approach makes abstraction a strength instead of a weakness when

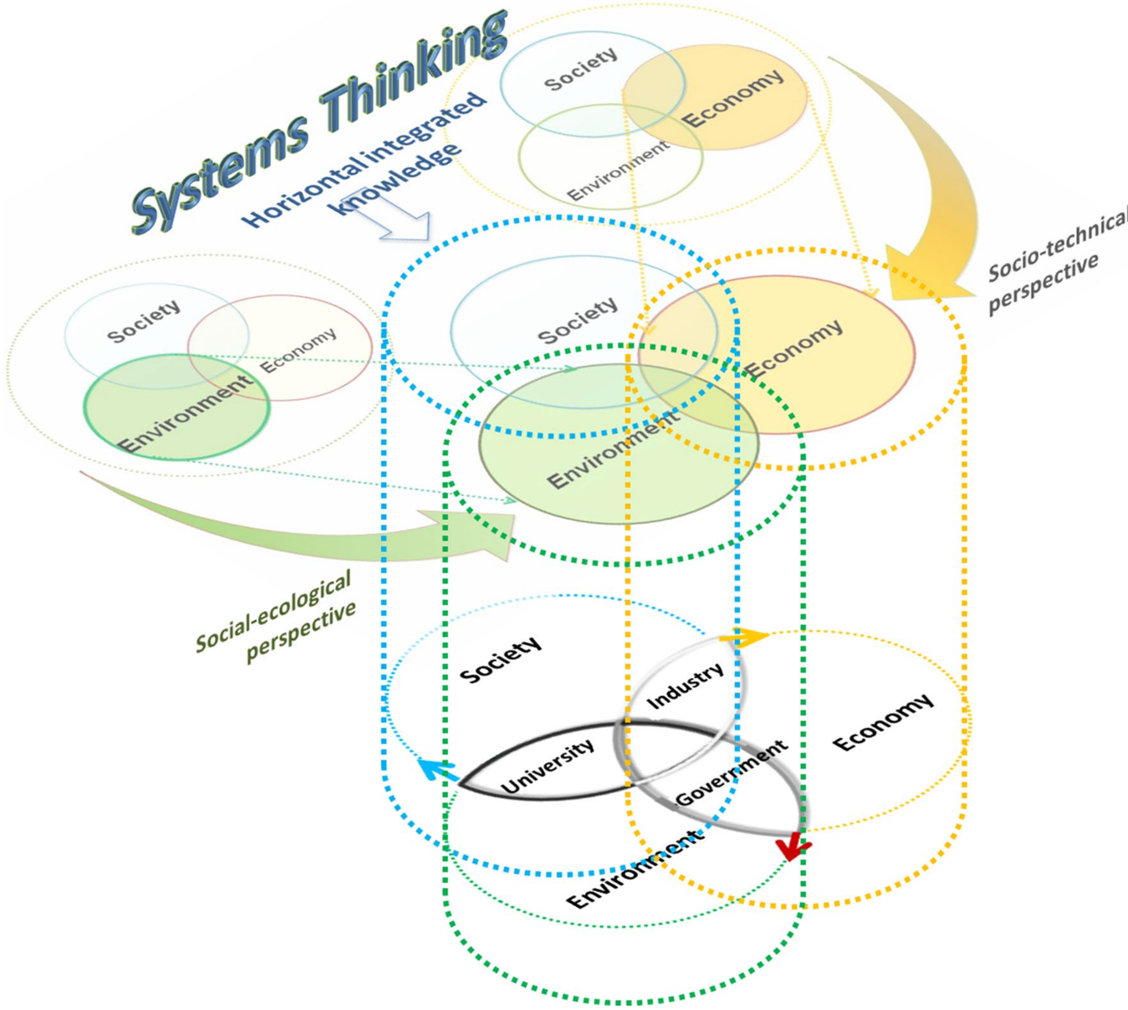

Fig. 4 From silos to integrated knowledge for sustainability. *Source* Elaboration from Barile and Saviano (2018) and Saviano et al. (2017a). www.asvsa.org

complex dynamics are to be interpreted and, what is even more challenging, governed. The criticism of high abstraction that was attributed to systems thinking in the past Seventies (Kast and Rosenzweig 1975) would not appear appropriate now: systems thinking is a powerful interpretative framework which, avoiding reductionism, can support the unitary reading and understanding of complex phenomena by searching for their invariant proprieties.

Interestingly, the first areas of enquiry of systems thinking were the structure and operations of living systems and their relationship with environment. Subsequently, these areas of enquiry have been enriched with the contribution of biologists (Maturana and Varela 1975), ecologists (Hannan and Freeman, 1977), sociologists and psychologists (Clark, 1993). The fundamental work of von Bertalanffy (1968) has then provided a General Systems Theory as new epistemological and methodological approach of science. After, the studies of Stafford Beer (1972) enriched the body of knowledge of systems with the contribution of cybernetics. The *viable system model* of Beer is still a reference in management studies and a basis for adopting a systems approach (Espejo and Harnden 1989; Yolles 1999; Barile 2009; Barile and Saviano 2011; Golinelli 2010). There is also a long tradition of systems thinking contributions to social sciences and business management (Barnard 1938; Buckley 1967, 2008; Emery 1969; Jackson 2000).

Systems thinking is fundamental to recover the unity in the view of reality. It should be at the basis of any science (Boulding 1956), providing the kind of knowledge that can help overcome the divide between disciplines. As re-affirmed by *vSA*, systems thinking offers a set of general principles and schemes that capture and explain the inner systemic nature of any entity and phenomenon of the world (Barile and Saviano 2011; Barile et al. 2016; Saviano et al. 2017c). Adopting a systems view implies a focus shifts from the parts to the whole and from an objective and static to a subjective and dynamic view (Barile 2009, 2013; Golinelli, 2010; Barile and Saviano 2011; Capra and Luisi 2014). In particular, systems thinking shifts attention from the connections and relationships among the components of the observed phenomena to the dynamics of interaction that link them into a unitary interconnected whole. Hence, a key for deciphering the complexity of social-ecological and socio-technical systems under an overall sustainability view, is in grasping their systemic functioning (Barile et al. 2018): the simple rules that govern complex phenomena are to be identified.

Systems thinkers are firmly convinced that it is not possible to understand sustainability without a systems approach (Clayton and Radcliff 1996). Moreover, they believe that systems (and cybernetics) (Wiener 1948; Ashby 1961) may provide the foundations for the process of integrating sciences into a common general framework for addressing the challenge of organizing sustainability (Schwaninger 2015).

Strongly agreeing with this line of thought, we believe that systems thinking can provide the general principles and meta-models necessary to effectively support understanding of the complexity of sustainability by helping to integrate what appears fragmented when an analytical reductionist approach is used (Barile and Saviano 2018).

In the integrated (knowledge) framework for sustainability (see again Fig. 4), the distance between social-ecological and socio-technical perspectives is overcome by adopting the bridging concepts and principles on which interface communication and interaction can be based.

The three key actors of sustainability—science/university, policy/government and industry—could rely on a common body of knowledge in which the three dimensions and perspectives of sustainability are bridged and integrated through the general schemes of systems thinking. Hence, systems thinking could facilitate communication and reciprocal understanding thanks to common language and cognitive models (Barile et al. 2012a). Certainly, however, as suggested by *vSA*, effective communication and reciprocal understanding are only necessary conditions for collaboration because effective action for sustainability requires the sharing of values and priorities (Barile et al. 2012a). A social culture based on shared principles and priorities can facilitate the co-creation approach (Mauser et al. 2013; Saviano et al. 2018a, b) and makes successful the whole challenge of a shared effort for realizing sustainability (Arnold 2017). The bridging role of society based on shared culture can effectively stimulate bottom up actions from within and from outside the 'silos' in which disciplines are compartmentalized.

Thus, concepts like *interface communication*, *boundary crossing interaction* (Barile and Saviano 2013; Saviano 2015) and *knowledge brokering* (Hering 2016) help to break down barriers to interaction rendering the transfer of information and knowledge to the various actors and fields more fluid. Leveraging a common systems thinking framework, actors involved to play the discussed 'interface' roles can also more easily accomplish important 'hybridization' processes, both *within* and *between* the main domains involved in *economic growth*, *social progress* and *sustainable development*, all recognizing sustainability as a common *scientific paradigm* (Kuhn 1996).

The central role of science in the progress toward sustainability is then unquestionable: it is science (also through education) that can more effectively contribute to progress toward sustainability directing a general understanding of the rules and the mechanisms that allow balanced interaction between economy, society and environment and, subsequently, among the actors involved in these processes for scientific, political, social or economic reasons. Engaging 'dissonant' actors, however, is unlikely to produce the desired outcome.

Concluding remarks

This paper attempts to provide a contribution to the global of the 2030 Agenda for Sustainable Development. It joins the call for enhancing policy coherence within social sectors "through integrating social policy/perspectives into broader and more complex policy-making processes, and vice versa; incorporating economic and environmental perspectives into social policy-making."[4] To this aim, this work builds upon the Triple Helix of Sustainability as a reference model, putting science, as the main cultural expression of a society, at the centre of effective interfaces necessary for triggering a virtuous interaction among:

1. the three dimensions of sustainability (environmental, social and economic);
2. the three representative actors (science/university, policy/government and industry);
3. the three disciplinary domains (environmental, social and economic sciences).

Therefore, in a context of scientists and practitioners engaged in the study of environmental, social and economic processes from multiple viewpoints to address sustainability issues, this work provides insights not only from a scientific research perspective but also for rethinking government and management approaches by putting sustainability at the centre of the policy and business decision makers' agenda (Shiroyama et al. 2012).

[4] https://www.un.org/development/desa/socialperspectiveondevelopment/issues/sustainable-development.html—Downloaded in September 2017.

Our work promotes a more collaborative approach at the various tiers of individual and organizational involvement in not only economic but also political and social decision making. Sustainability science still "needs to be widely discussed in the scientific community, reconnected to the political agenda for sustainable development, and become a major focus for research." (Kates et al. 2001). Academia may effectively lead this process because it plays a crucial role when looking at the government and economy fields in which, respectively, constraints and solutions must be linked to effectively work (Trencher et al. 2014).

Of course, to be useful, our proposal requires a huge work of rethinking the approach to sustainability at each of the three above listed levels. Certainly, this requirement would open up many further research paths, involving many different disciplines, as well as professional developments, also beyond the scope of the traditional environmental, social and economic domains. For example, the role of ITC (Information & Communication Technologies) should be explored developing and using new ICT solutions to provide the appropriate infrastructure for effective interaction, helping to break down the still existing barriers by leveraging the common social and systems views.

However, a problem remains regarding the way systems thinking can *practically* support effective *science–policy–industry* collaboration. General principles and rules of systems thinking should be the basis of any kind of knowledge development; hence, not a further discipline but horizontal knowledge crossing the boundaries of traditional knowledge domains (Barile et al. 2014c). Following the 'T-shaped' stream (Demirkan and Spohrer 2015), which suggests that future managers and decision makers must be capable of combining horizontal capabilities to mode across various fields and vertical expertise, systems thinking should be developed as a fundamental horizontal capability of crossing the various problematic contexts that characterize the multi-dimensional and multi-disciplinary nature of sustainability (Saviano et al. 2017a, b, Saviano et al. 2017c).

In this view, our study lacks discussion of practical examples of such crossing boundaries processes through which the difficulties of putting systems thinking, as well as sustainability, in practice should be highlighted and analysed (Barile et al. 2012a). Our aim, however, was primarily contributing to highlight still unfulfilled problems with the approaches to sustainability only outlining possible pathways to follow. Accordingly, we hope that our work would succeed in opening up new knowledge development trajectories by proposing a co-creation approach to overcome the traditional divide *within* knowledge domains and *between* knowledge and society (Golinelli et al. 2015) thus contributing to fostering shared efforts for a smarter planet and, therefore, addressing the challenges of a more sustainable world.

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