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System dynamics modeling as a circular process: The smart commons approach to impact management

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ABSTRACT

This study argues that the mainstream approaches to system dynamics (SD) modeling processes lack effective impact-based performance management tools and, paradoxically, build upon a nonsystemic view of some social dynamics that are key to sustainability transformations. A causal loop diagram of the mainstream approaches to participatory SD modeling is developed to discuss the fragilities of the learning and decision-making systems that result from such approaches. The analysis suggests that when common resources are at stake, ad hoc organizational solutions are needed at the field level, in addition to the traditional facilitating action at the project/group level, for SD modeling to succeed. Then, to address the fragilities of the existing approaches to participatory SD modeling, this study integrates concepts and solutions from institutional theories, adaptive co-management, and the body of knowledge on the (new) commons. A second causal loop diagram is provided to show how this new proposed approach could restructure the processes that link SD modeling inputs, activities, outputs, outcomes, and impacts due to a higher-level permanent organizational unit with specific roles and data management capabilities labeled “smart commons organization”. This study suggests that the proposed smart commons approach could enhance the contribution of SD modeling to sustainability transformations.

1. Introduction

Systems thinking is often considered essential for addressing the complexity of sustainability challenges (Nabavi et al., 2017). In fact, systems thinking is particularly suited to understand the big picture around a problem and forecast its long-term evolution rather than concentrating on specific, short-term cause-effect relationships (Meadows, 2009). Through system dynamics (SD), systems thinking provides methods and techniques for viewing problems and human action as interconnected wholes and for understanding the (often lagged) feedback loops that may make complexity very difficult to address through the traditional, linear modeling processes. SD enables us to rigorously define sustainability challenges in terms of measurable levels and flows of common resources (such as air quality or youth employability) and to build mental models of the complex net of cause-effect relationships that revolve around such common resources (Dietz et al., 2003).

From a performance management perspective (Heinric, 2002), a systemic approach to sustainability challenges should translate into processes that link SD modeling inputs and activities to SD outputs (that is, the quality of SD models), outcomes (that is, the consequences of outputs, such as model-based decisions) and real-world impacts (that is, the levels of the relevant common resources, such as air quality). These processes should be *circular*, that is, feedback loops should be present across SD modeling inputs, activities, outputs, outcomes, and impacts, to enable cycles of adaptive decision-making and learning for sustainability. Unless such circular processes are effectively organized and managed, the potential of SD modeling may remain largely unexploited.

Despite the relevance of this issue, it has thus far been only partially addressed in the literature on SD modeling management.

The studies on stakeholder engagement in SD modeling (Hernantes et al., 2013) provide valuable insights into the possible circular relations between stakeholder involvement (as a key input), facilitating action (as a key activity) and SD model accuracy and consensus on the SD model (as key outputs). However, these studies tend to consider the much-needed links between SD modeling outputs, outcomes, and impacts as out of their scope.

The complementary streams on group model building (GMB), participatory SD modeling for policymaking, and community-based SD (Király and Miskolczi, 2019) enable significant advancements in the understanding of the links between SD modeling outputs and outcomes. However, the activities-outputs-outcomes links described by these mainstream approaches are linear rather than circular. In addition,

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these mainstream approaches do not address the outcomes-impacts links and feedback loops.

Considering this gap in the body of knowledge on SD modeling process management, it is perhaps not surprising that, even if many sophisticated system dynamic models have been published in important scientific journals (e.g., Bassi et al., 2012; Kwon, 2012; Musango et al., 2014; Stern et al., 2015; Zhao et al., 2016), very few of them have actually been used to durably support real-world processes of sustainability transformations to date (Taylor et al., 2009). The link between system dynamics modeling and real-world sustainability transformations is still weak.

It is more surprising, instead, that some SD experts and researchers tend to place the blame of this weakness on phenomena that they perceive as external to the SD modeling system, such as paradigm conflicts, people's difficulties in understanding SD diagrams, or power games between decision-makers (Lane, 2017). Many experts of SD modeling management seem to think that their job is to complete outputs (high-quality models) and, at best, achieve specific outcomes (such as participants' empowerment): the actual impact of SD outcomes on common resources is often perceived as someone else's business, which is paradoxical because blaming a system's failure on factors that are external to the system is the one main mental mistake that system thinkers are expeted to most strenuously combat (Meadows, 2009).

In other words, despite significant progress in the management of the links between SD modeling inputs, activities and outputs, the links between SD modeling outputs, outcomes and impacts still tend to be thought of in a nonsystemic way.

Considering these problems, this article aims to

1 Propose an impact-based performance management framework that is usable for all SD modeling processes;
2 Analyze the fragilities of the mainstream approaches to the management of SD modeling processes by building a causal loop diagram representing the learning and decision-making system enabled by these approaches;
3 Integrate the existing mainstream approaches with a new, complementary approach that addresses the hitherto neglected links between SD modeling outputs, outcomes, and impacts, and demonstrate the potential of this approach through a second causal loop diagram;
4 Discuss the organizational implications of the novel proposed approach to SD modeling process management by critically comparing the two diagrams (points 2 and 3 above).

Consistently, the contribution of this article is fourfold.

First, this study reviews the performance measures that are mentioned in the literature on participatory SD modeling and recognizes that while there is convergence on SD modeling output and outcome measures, a standard method for measuring SD modeling impact is still missing. Therefore, this study proposes the (changes in the) levels of relevant common resources as key indicators of SD modeling sustainability impact.

Second, to the best of the authors' knowledge, this is the first time that SD tools, such as causal loop diagrams, are used to critically represent the fragilities of the learning and decision-making systems that are based on SD modeling itself. The results of such a meta-modeling effort allow for a clear and synthetic explanation of the main problems hindering SD modeling from fully developing its potential contribution to sustainability transformations. As shown in analysis of the diagram in Fig. 1, these problems can be conceptualized as system problems rather than mere consequences of external factors, and they can then be addressed through system (re)design.

The third main contribution of this study builds upon previous ones. To perform system (re)design and propose a new integrated approach to SD modeling management, this study leverages the joint explanatory and normative power of three literature streams that, although scientifically sound, viable and highly complementary, have not yet been leveraged to improve the management of SD modeling processes. These three streams are the literature on institutional logics (Thornton et al., 2012), adaptive co-management (Berkes et al., 2003), and the body of knowledge on the (new) commons (Dietz et al., 2003).

Cross-fertilization between the existing mainstream approaches to participatory SD modeling and these three streams allows for the development of a novel view of SD modeling as the engine of a wider learning and decision-making system that is capable of (re)generating and protecting the stocks of relevant common resources, as shown in the analysis of the causal loop diagram in Fig. 2. According to the results of this cross-fertilization, (i) solutions borrowed from the institutional logics approach can be usefully leveraged to control the tensions that could exacerbate the accuracy-consensus trade-off in collaborative SD modeling processes; (ii) solutions borrowed from the literature on the commons and on adaptive co-management can be usefully leveraged to structure effective outcome-impact links, through the development of system resilience; and (iii) the management of data as common resources is key to enable effective feedback loops that circularize the processes, from SD impacts back to SD modeling inputs, thus allowing for adaptive learning and institutional work.

The fourth key contribution of this article stems from the critical comparison between the two proposed causal loop models (Figs. 1 and 2). The authors argue that the organizational solutions proposed by mainstream SD modeling management, based on SD group facilitators, can only manage the group-level circular processes linking SD inputs, activities, outputs, and, at best, outcomes. Instead, to manage the higher-level processes linking SD outputs, outcomes, and impact, a further, higher-level, permanent organizational unit is needed. Based on the cross-fertilization synthesized above, this study proposes that this higher-level organizational unit should embody the key characteristics of the hybrid organization envisaged by the institutional logics literature and the bridging organization envisaged by the adaptive co-management literature, along with advanced capabilities to manage data as common resources. As shown in the second causal loop diagram in Fig. 2, this "smart commons organization" plays an irreplaceable role in enabling system resilience, learning process circularity, and long-term contribution to the common good in the restructured system proposed in this study. The smart commons organization proposed by this study fills a critical gap, since no organizational unit is envisaged, in existing mainstream approaches to SD modeling, which has a specific mandate to protect and (re)generate a certain common resource and the relevant data around it, and which integrates the contributions of different SD modeling groups throughout time, the choices of decision-makers, and the relevant data management activities for improved system resilience (Armenia et al., 2017). This study concludes by arguing that universities may play a perhaps irreplaceable role as generators of smart commons organizations in the emerging age of data.

The following four sections are dedicated, respectively, to the four aims listed above.

2. Sustainability-related impact, outcome, and output measures of SD modeling processes

2.1. SD modeling is a process based on systems thinking that lacks a proper performance management system

Systems thinking emerged as a new, powerful means for sense- and decision-making in the second half of the twentieth century (Forrester, 1989). A system is broadly defined as a set of interconnected elements that are coherently organized in a way that achieves something (Meadows, 2009). A system, then, is characterized by its constituting elements (e.g., people, stones, cells, molecules, beliefs), the interconnections and rules organizing the relationships between its elements (e.g., physical laws, chemical reactions, traditions, feelings,

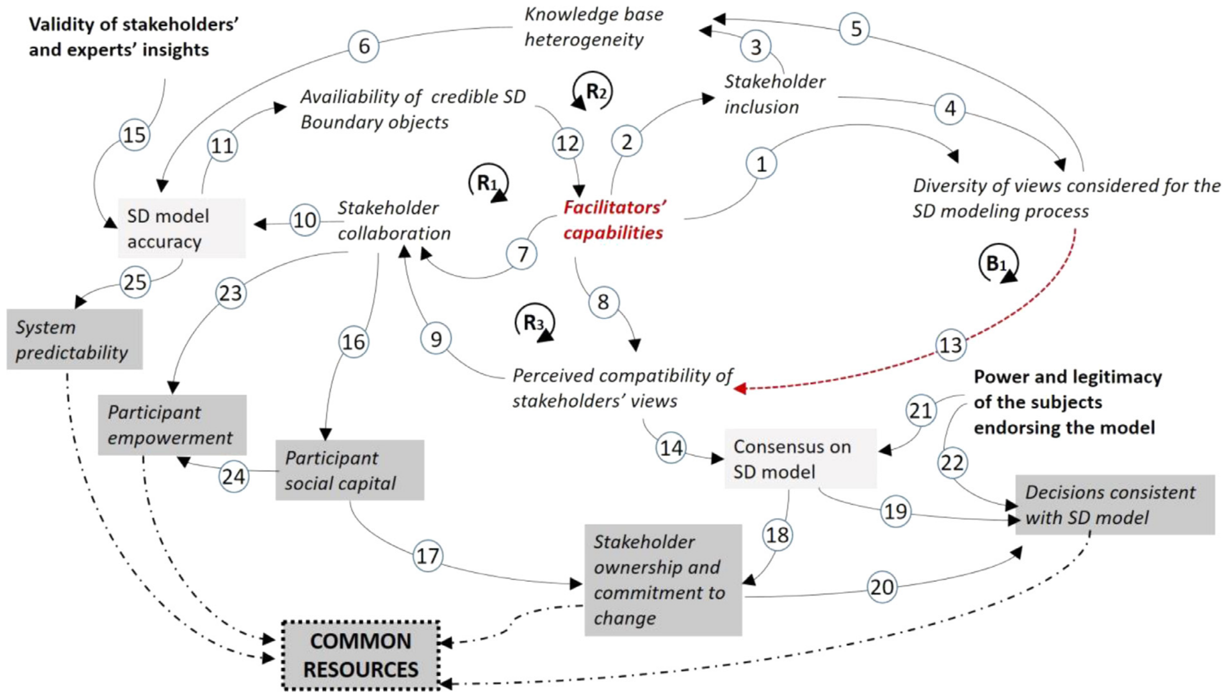

Fig. 1. A causal loop model of the participatory SD modeling process, according to the main approaches available in the literature. Source: Authors' elaboration. LEGEND Black lines: positive causal relations. Red dotted lines: negative causal relations. Black dashdotted lines: ambiguous causal relations. See Table 1 for the types of performance indicators (gray boxes) and Section 3.2 for the description of the numbered relations.

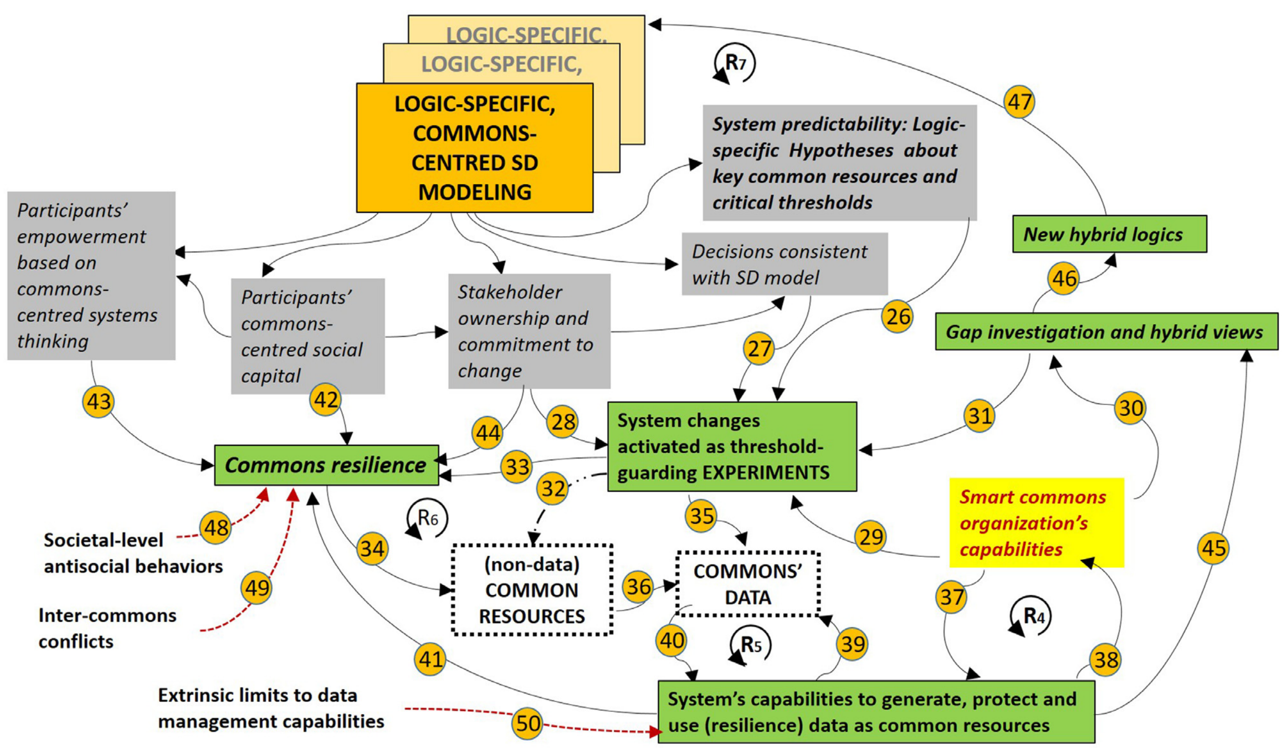

Fig. 2. A causal loop model of the proposed Smart Commons Approach to SD modeling impact management. Source: Authors' elaboration. LEGEND Black lines: positive causal relations. Red dotted lines: negative causal relations. Black dashdotted lines: ambiguous causal relations. See Table 1 for the outcome indicators of SD modeling (gray boxes) and Sections 4.3, 4.4. and 4.5 for the description of the numbered relations. Green framed boxes include the expected outcomes of the smart commons organization.

business strategies, social norms) and the system's purpose(s) or function(s) (e.g., survival, digestion, profit, victory, equilibrium). The system displays behaviors and functions that are clearly distinguishable from the behaviors of its individual elements: for example, the behavior and function of a firm is not the mere sum of the behaviors and functions of its constituting elements, such as employees and technological infrastructures (Pretorius et al., 2015). For this reason, systems thinking posits that the system's behavior is an emergent property of the system itself.

According to systems thinking, a system's behavior largely depends on the system's structure, that is, the very nature of its elements and interconnections (Wolstenholme, 2004). “The system may be buffeted, constricted, triggered, or driven by outside forces. But the system's response to these forces is characteristic of itself […] The system, to a large extent, causes its own behavior! An outside event may unleash that behavior, but the same outside event applied to a different system is likely to produce a different result” (Meadows, 2009, p. 11).

There is a large consensus that the so-called grand challenges (such as hunger, poverty, climate change, energy shortage, pollution) are system problems, that is, undesired behaviors of the larger social-ecological system, rather than linear consequences of specific, isolated causes (Nabavi et al., 2017). To quantitatively describe and analyze the main aspects of a system's behavior, scholars and practitioners often use the SD approach, which has been developed some decades ago (Forrester et al., 1976) with the ambition to map, simulate and predict the evolution of systems, when these systems become too complex for the ordinary cognitive capabilities of human beings (Qudrat-Ullah, 2012; Sverdrup et al., 2017). SD leverages some systems thinking tools, particularly causal loop diagrams and stock and flow diagrams, to operationalize the relations and feedback loops between variables, such as balancing loops and reinforcing loops (including both vicious and virtuous cycles) (Sterman, 2000). Many scholars claim that system dynamics may significantly improve policy-making, on the one hand, and performance management, on the other hand, by injecting feedback-based learning and adaptive change into these processes (Armenia et al., 2014; Mureddu et al., 2014; Santos et al., 2018).

The process of system dynamics modeling is usually conducted by experts (researchers and/or consultants) based on their modeling expertise and understanding of a certain system's dynamics. However, the participation of system stakeholders is increasingly considered essential for an effective SD modeling process. Stakeholders are considered carriers of valuable insights that the expert modeler could not access by working in isolation. Therefore, SD modeling is increasingly considered a participatory process (Király and Miskolczi, 2019). Participatory SD modeling poses specific organization and management challenges because people with diverse backgrounds, assumptions, perceived interests, preoccupations, social pressures are required to converge on a shared mental model. As illustrated in Section 3, approaches and techniques to manage participatory SD modeling groups and processes have significantly progressed in recent years. However, many SD models, although sometimes very refined from a mathematical perspective, and even despite stakeholder participation, remain on paper only (Qudrat-Ullah, 2012; Taylor et al., 2009). Policy- and decision-making rarely follow the results of SD modeling, and behavioral changes are usually triggered by other social mechanisms than SD model cocreation and dissemination. Thus, even if participatory SD modeling is carefully designed and managed as a process, it usually struggles to achieve an impact. This study argues that, to build a sound basis for investigating the fragilities of the SD modeling process, a consistent and generalizable performance management framework (including impacts, outcomes, and outputs) is needed.

2.2. Measuring the sustainability-related impacts of SD modeling processes

The limited adoption of SD models in real-world choices has triggered a debate concerning the expected impact of SD modeling as a method for addressing problems. This debate has not yet resulted in a convergent view. Some SD scholars and experts tend to measure the SD impact in terms of decisions that have been taken or behavioral/cognitive changes that have been implemented based on the SD model (e.g., Größler, 2007). However, from the sustainability standpoint, decisions and behavioral/cognitive changes are outcomes rather than impact measures. Other scholars concentrate on case-specific impact measures, such as a certain marine area's biodiversity or a certain firm's prosperity. However, these measures cannot be generalized to a performance management framework that is usable for all SD modeling processes.

Therefore, this study leverages the body of knowledge on the commons (Ostrom et al., 1999, 1990, 2010) and proposes that the sustainability-related impact of SD modeling, viewed as a process, should be measured in terms of (changes in the) levels of relevant common resources.

A common resource is a resource that is available for the collective benefit of a certain community but is vulnerable to misbehaviors (e.g., overexploitation, sabotage, or neglect) by that very community. For example, the fish stock of a certain marine area is available for the benefit of the fishermen, but its desired levels are vulnerable to the fishermen's overexploitation. The social inclusion of a certain neighborhood benefits the whole local community, but its desired levels are vulnerable to that community's neglect and disengagement. A balanced composition of the atmosphere could protect us all from global warming, but the desired levels of carbon dioxide and methane are vulnerable to our inertia and climate change deniers’ sabotage.

The actual and predicted levels of common resources (and changes in such levels) are considered excellent measures of the system's sustainability (Dietz et al., 2003). Therefore, the sustainability-related impact of SD processes can be usefully measured through the (changes in the) levels of the relevant common resources (see Table 1). For example, the expected impact of a process of SD modeling relating to climate change mitigation can be measured in terms of (changes in the) levels of climate security in a certain area.

In this light, a clear identification of the common resource(s) whose levels can be influenced by the modeling process is a key step in the process's performance management.

2.3. Measuring the outcomes of SD modeling processes

The outcome indicators of SD modeling processes should measure the consequences of the SD modeling processes and/or products that are potentially key in terms of impact, that is, the protection and (re) generation of common resources.

The different streams of literature on SD modeling management have identified different sets of key outcomes. The most classical, model-centered approaches to SD modeling often mention *system predictability* as a key outcome of the SD modeling process. If the model is accurate, the consequence of its creation is the possibility of improved

Table 1
A general framework of sustainability-related impact, outcome and output measures of SD modeling processes. Source: Authors’ elaboration.

	OUTPUT measures	OUTCOME measures	IMPACT measures
SD MODELING PROCESSES	Model accuracy (Qudrat-Ullah, 2012) Consensus on the model by decision- (policy-) makers participating in the modeling process (Király and Miskolczi, 2019) Consensus on the model by the community(-ies) participating in the modeling process (Király and Miskolczi, 2019)	System predictability (Stave, 2002) Number, relevance, and consistency of the decisions made based on the SD model (Andersen et al., 2007; Stave, 2002) Participants’ social capital (Andersen et al., 2007; Hovmand, 2014; Stave, 2002)Participants’ empowerment (Hovmand, 2014) Stakeholder ownership and commitment to change (Andersen et al., 2007)	(Change in the) Levels of relevant common resources

forecasting.

A second measurement outcome that is considered very important by almost all the streams on SD modeling management is the number, importance, and consistency of the *decisions that are made based on the SD model* (including also policies).

The most recent research streams, which stress the importance of participatory modeling, also mention *stakeholder ownership and commitment to change* as a key expected outcome of SD modeling processes. If the process of model development is inclusive, and the model is properly shared and discussed, the knowledge conveyed by the model and its normative implications are more likely to be accepted and translated into practice.

The literature on community-based SD particularly insists on the importance of participants' *empowerment* as a key expected outcome of participatory SD modeling. This approach insists that systems thinking and SD modeling capabilities are especially important for marginalized people and for communities that are usually excluded from decision-making processes. Thanks to systems thinking, these subjects can be empowered to achieve a better understanding of the dynamics influencing their condition and to take action accordingly.

Finally, almost all the more recent research on participatory SD modeling agree on participants' *social capital* as a key expected outcome of the modeling process. Table 1 synthesizes the key outcome measures that emerge from the literature.

2.4. Measuring the outputs of SD modeling processes

The main deliverable of the SD modeling process is, of course, the SD model itself. The literature on SD modeling converges in identifying three key quality measures for such an output: model accuracy, consensus by decision-makers who have participated in modeling, and consensus by the relevant communities who have participated in modeling.

Model accuracy measures the degree to which the behavior of the system, as predicted by the model, mirrors the real-world system behavior. For descriptive SD models, model accuracy can be assessed by leveraging real-world data, if available. For normative models, model accuracy can instead only be assessed if the changes envisaged by the model are actually implemented. In addition, many SD models represent chaotic systems (Rosser Jr, 2001), in which even very small failures in the measurement of the initial condition disrupt the researcher's capability to mathematically predict the final condition. In other words, model validation is often an issue in SD, and this problem must be taken into account when designing the performance management system of an SD modeling process.

Participants' *consensus* on the SD model can be considered an important process output if the SD modeling processes are participatory. When (some categories of) stakeholders participate in modeling, the quality of the model as a final deliverable can be measured by the degree to which participants' understandings and beliefs have converged on the model's contents (Rouwette and Smeets, 2016). Of course, consensus may be completely independent of accuracy (since it depends on cognitive, social and cultural factors), but it is certainly important to enabling process outcomes such as decisions that are consistent with the SD model, stakeholders' sense of ownership of the model's contents, and stakeholders' commitment to change (von Wirth et al., 2014).

The two most popular approaches to participatory SD modeling are group model building and participatory SD modeling for policymaking. Group model building (Vennix et al., 1999) focuses on participatory modeling to address the problems of a specific client organization (for example, supply chain optimization problems) (Andersen et al., 2007; Rouwette, Korzilius, Vennix, and Jacobs, 2011). Participatory SD modeling for policymaking, by contrast, focuses on participatory modeling to support policy-makers (Stave, 2002). Although these two approaches differ significantly in terms of the goals and techniques of group work management, they both share the idea that the *consensus on the SD model by participant decision- (or policy-) makers* is a key output measure.

Another emergent approach to participatory SD modeling, instead, focuses on the *consensus on the SD model by participant community (-ies)*: it is the stream on community-based SD (Hovmand, 2014). According to this approach, participatory SD modeling should prioritize the involvement of marginalized communities to help them develop new capabilities of understanding and changing their conditions.

Table 1 synthesizes the performance measures described in this section.

3. A causal loop model of mainstream participatory SD modeling

3.1. Group facilitation as the key organizing principle in mainstream SD modeling approaches

There is great consensus regarding the importance of involving stakeholders in the modeling process when sustainability issues are at stake (Nabavi et al., 2017). If an SD model is simply handed down from above on the part of experts, the model's intended users are more likely to be dissatisfied with it (because it does not include aspects that they deem important, for example), and even understanding the model is more difficult to them (Stave et al., 2019). Therefore, a participatory approach to system dynamic modeling is increasingly viewed as essential to include these models in real-world sense- and decision-making cycles (von Wirth et al., 2014). In addition, a participatory approach can boost insights into the system to be modeled and is an invaluable mechanism to control possible misjudgments by modelers (Nabavi et al., 2017).

In light of the stakeholder theory (Crilly et al., 2012; Friedman and Miles, 2002; Jones et al., 2017), if decision-makers, interested communities and/or cross-disciplinary experts are engaged in the system modeling process, the model will synthesize a usefully wider range of viewpoints; the stakeholders, whose interests are represented in the modeling process, will cooperate in the data collection and model validation; and people will perceive the model as a reasonable compromise they have contributed to achieving, rather than a controversial or dangerous interpretation that someone from above is trying to impose.

Therefore, to achieve the expected levels of accuracy and consensus, sustainability-related SD modeling is usually conducted by heterogeneous teams including modelers, multidisciplinary experts, and diverse stakeholders. These teams must be organized and managed to maximize the modeling process performance (see Table 1) (Hernantes et al., 2013). Consistently, the modeling process is increasingly also considered an organization and management challenge.

Following the recent review by Király and Miskolczi (2019), this study identifies three main approaches to participatory SD modeling: group model building, participatory SD modeling for policymaking, and community-based SD. These three approaches significantly differ in terms of the category of stakeholders to be involved, the facilitating techniques, and the key expected outcomes.

The *group model building* approach (Andersen et al., 2007) involves executives, entrepreneurs and/or professionals in a corporate context; recommends facilitation techniques that do not overload the clients and keep the model simple and understandable; and prioritizes model-consistent decisions, participant ownership and commitment to change, and social capital as key expected outcomes.

Participatory SD modeling for policymaking (Stave, 2002) involves people from NGOs and/or government agencies; recommends facilitation techniques that maximize participation in the initial phase of problem setting and in the final phase of simulation testing, while the simulation building process is left to expert modelers; and prioritizes system predictability, model-consistent decisions, and social capital as key expected outcomes.

Community-based SD (Hovmand, 2014) involves whole communities, especially marginalized ones; recommends facilitation techniques that are based on social therapy; and prioritizes participants' social capital and empowerment as key expected outcomes.

Despite the differences synthesized above, these three approaches agree on the centrality of facilitation as the key organizing principle in participatory SD modeling, as well as on model accuracy and participants' consensus as key output measures. Therefore, it is possible to build an integrated causal loop diagram of the mainstream approaches to participatory SD modeling. The results of this modeling effort, represented in Fig. 1, will be synthesized in the next section.

3.2. Modeling the modeling process: the trade-off between accuracy and consensus and the nonsystemic nature of SD modeling's performance management in mainstream approaches

Based on the literature on stakeholder engagement in SD modeling (particularly the streams on group model building, participatory SD modeling for policymaking, and community-based SD), it is possible to draw a causal loop diagram representing how the two key expected outputs of the modeling process (that is, SD model accuracy and participants' consensus on the SD model) emerge from the interaction between expert modelers and stakeholders (Fig. 1).

Despite the differences between the approaches to participatory modeling that have been considered in this study, all of these approaches consider facilitation as the organizational principle at the core of the modeling process. Therefore, even if the required facilitators' capabilities differ depending on the facilitation techniques, they can be considered the engine of the process.

Facilitators' capabilities enhance the diversity of the views considered for modeling both directly, by encouraging the expression of different standpoints and insights (causal link 1 in Fig. 1), and indirectly, by including a higher number of stakeholders (causal links 2 and 4). Stakeholder inclusion and diversity of views both increase the knowledge base heterogeneity (3 and 5). Knowledge base heterogeneity, in turn, is an essential factor to increase a key output measure of the SD modeling process, that is, model accuracy (6). By contrast, facilitators' capabilities increase stakeholder collaboration, both directly (7) and by striving to enhance the perceived compatibility of stakeholders' views (8, 9). In fact, unless the different views of participants are sufficiently reconciled, polarization may become intractable: some participants may lose interest in participation because they think their ideas are not going to be adequately represented, while other participants may conceive participation as a power game to get their views to prevail, rather than a collaborative sense-making activity (Weick and Sutcliffe, 2005).

Stakeholder collaboration is an important leverage to enhance model accuracy (10) since collective learning and constructive discussion are the most powerful means to gain insights and correct misjudgments. SD models are created and tested through recursive cycles of discussion and revision; in these cycles, progressively increasing SD model accuracy provides participants with credible boundary objects (Andersen et al., 2007; Nabavi et al., 2017), which in turn help facilitation (11, 12). Therefore, a reinforcing loop exists, according to mainstream approaches, between modeling and facilitating work (R1 in Fig. 1).

Despite having a positive effect on knowledge base heterogeneity, the diversity of views considered for the modeling process has a negative effect on the perceived compatibility of stakeholders' views (13), thus negatively affecting the second output measure of the process, that is, the participants' consensus on the SD model (14). Conversely, the first output measure, that is, model accuracy, is, of course, vulnerable to a lack of validity in stakeholders' and experts' insights (15).

All the mainstream approaches to participatory SD modeling agree that the participants' social capital is a key expected outcome of SD modeling and, in particular, of the collaboration process (16). Social capital, in turn, enhances another key expected outcome, that is, stakeholder ownership and commitment to change (17). The latter is also influenced by the participants' consensus on the SD model (18), which, in turn, is the key leverage through which SD modeling can enhance the likelihood that decisions will be made consistently with the model (19, 20). The literature remarks that factors that are external to the modeling process, that is, the power and legitimacy of the subjects endorsing the model, are key to both consensus (as an output) and decisions (as an outcome) (21, 22). For the remaining key expected outcomes (see Table 1), the literature suggests that participant empowerment mainly depends on stakeholder collaboration, both directly (23) and through social capital (24). System predictability depends on model accuracy (25).

The causal loop diagram in Fig. 1 shows that the mainstream approaches to participatory SD modeling result in a trade-off between model accuracy and participants' consensus. This trade-off is due to the balancing loop B1, which counteracts the effects of the reinforcing loops R1, R2, and R3. In fact, the diversity of views is important to increase accuracy through the knowledge base heterogeneity (5, 6), but it decreases consensus through the perceived compatibility of views (8, 14). Therefore, facilitators have to manage a structural tension in their job and must face that it is impossible to achieve, contemporaneously, the highest levels of both accuracy and consensus.

Therefore, the causal loop diagram of Fig. 1 provides a sound, systemic explanation of a paradox that many SD experts experience and complain about: the more accurate the model (that is, the more capable of predicting the system's behavior), the less likely is such a model to be adopted for concrete decision-making and real-world change.

This paradox has serious consequences for SD modeling performance because only models that enable both high system predictability and concrete decisions and changes can positively impact the common resources. In fact, if inaccurate models are adopted for decision and change, an unexpected negative impact on common resources may occur; conversely, if accurate models remain on paper only because they do not translate into decision and change, their impact is zero. In this light, it is not surprising that the causal links between outcomes and impact are ambiguous, if not completely overlooked, in mainstream approaches to SD modeling (see Fig. 1).

A systemic view of outcome and impact management would be needed to address this problem. Thus far, the mainstream approaches to participatory SD modeling have considered the management of the outcome-impact links as beyond their scope. In fact, Fig. 1 shows that no organizational solution has been envisaged to manage the tensions between output and outcome, to manage the external factors that influence outcomes (see especially links 21 and 22) and to structure functional loops between and across SD modeling inputs, outputs, outcomes, and impacts. Thus, the mainstream approaches to participatory SD modeling display a surprisingly nonsystemic view of what occurs after the key outputs (or, at best, outcomes) have been achieved.

An organizational solution for managing the outcome-impact links, and the feedback loops between outcome-impact and SD modeling inputs, are missing. The next section will demonstrate how some recent, complementary developments in the organization and management literature could provide valuable hints for restructuring the dysfunctional system depicted in Fig. 1.

4. Restructuring the system that (re)generates the SD modeling impact: the role of the smart commons organization

4.1. Parallel logic-specific submodeling

Even if institutional theories, per se, are neutral concerning the system-level consequences of institutional dynamics, institutional logics are emerging as key forces for sustainability transformations (Etzion et al., 2017). An institutional logic (Thornton et al., 2012) is a socially recognized system of rules, values, expectations, and beliefs that are catalyzed by and around societal institutions, such markets, universities or social movements (Sauermann and Stephan, 2013;

Wooten and Hoffman, 2008). Institutional logics shape behaviors and make cooperation and reciprocal understanding possible. For instance, the family institutional logic is a societal-level system of laws, roles, expectations, beliefs, and assumptions that prioritize the nurturing and generative capabilities of the family, along with its safety and wellbeing (Fairclough and Micelotta 2013).

According to the most recent developments of institutional studies, organizations are immersed in organizational fields (Greenwood et al., 2010), that is, relational spaces governed by rules, values and cognitive assumptions rather than mere market forces and abstract rational choices. Therefore, in light of this literature stream, institutional logics are the key forces shaping organizational fields.

The concept of institutional logic is wider than those of the paradigm or world view (Bakken, 2019), which have already been used by SD scholars to explain the tension and difficulties of participatory modeling. In fact, the paradigm concept describes a worldview, a way of understanding things, a set of beliefs. These aspects are also present in the concept of organizational logic; however, in addition to these aspects, an organizational logic also includes the corresponding system of laws, rules, roles, social expectations, and social pressures that directly influence behaviors, and not only through the subject's beliefs and knowledge. Thus, subjects will show strong resistance to an SD model that contradicts their logics, not only due to cognitive dissonance but also, and perhaps even more importantly, because they do not want to make choices and to adopt behaviors that they perceive as socially punishable in their respective contexts. The sociocognitive concept of institutional logic, then, explains why efforts to convince people (then changing merely their beliefs about the system) are often insufficient in participatory settings: people's social embeddedness is often a stronger driver than their cognitive situation alone.

Institutional logics coevolve dynamically through technological and scientific innovations, activism, political action, institutional entrepreneurship and bottom-up practice-driven changes (Ansari et al., 2013; Beckert, 2010; Dalpiaz et al., 2016; Greenwood et al., 2014; Markard et al., 2012; Tracey et al., 2011; Zietsma and Lawrence, 2010). Thus, not only governance bodies and social movements but also entrepreneurs and managers can influence the evolution of a certain organizational field's relationships and logics, and these intertwining influences are key to making this evolution sustainability-oriented (or not) (Cantino et al., 2017). For example, family logics may contribute to shaping the organizational field of a wine district (along with business logics, sustainability logics, etc.) through the influence of family firms (Reay et al., 2015).

In terms of SD modeling, we can acquire at least as many different views of the system under study as the number of different institutional logics shaping the relevant organizational field. The different logics populating a field may be reciprocally reinforcing but also conflicting. In this situation, not only are actors sometimes influenced by interests that can be rationally identified as conflicting, but in most cases they also face conflicting social pressures and display different knowledge bases, which may hinder successful collaboration at least as much as the so-called rational conflicts of interest (Negoita, 2018). Consequently, the views and expectations of the actors participating in collaborative modeling may diverge dramatically.

Even a single stakeholder group may include people with very different views, due to the presence of several institutional logics. For example, professors, as stakeholders of the university system, do not share a one and only view of the system. Each professor may be influenced to different degrees by a dissemination logic of research, an entrepreneurial logic of research, an inclusive logic of teaching, among others. Not only does each of these logics have its own paradigms, but also its own systems of social incentives and punishments. Even the experts who perform SD modeling are not just "neutral" technicians, but introduce different logics in the modeling process. For example, some modelers may prioritize environmental logics, while others may prioritize regional development logics. In light of the institutional logics theory, modeling does not stem from a dialogue between "rational" experts and homogeneous groups of stakeholders, but from a hybrid, chaotic relational space populated by intertwining and ever-evolving social expectations that cut across groups of stakeholders and experts.

Discussion around SD modeling forces people with different logics to disclose their terminal values. For example, experts prioritizing an environmental logic will consider the natural ecosystem equilibrium as a key common resource, while experts prioritizing a regional development logic will consider the population's employability as a key common resource. Studies show that disclosure about terminal values results in polarization and tightening (Rossignoli et al., 2018), which often hinders constructive dialogue. In fact, since it is often impossible to represent all logics equally in the model because the coexistence of conflicting logics may make the model contradictory, actors whose logics are being excluded from the model are likely to engage in the development of rival or alternative models and decisions.

Then, the approach proposed by this study borrows the method for hybrid field management from the literature on institutional logics (Mair and Reischauer, 2017; Sauermann and Stephan, 2013; Wooten and Hoffman, 2008). Specific techniques can be developed to manage the different conflicting logics in hybrid organizational fields, and decoupling is the main one (Furnari, 2016).

Consistently, an effective way of preventing polarization and intractable conflicts in SD modeling could consist of organizing separate submodeling groups as relational spaces where each institutional logic can express itself through independent discussion. In this way, each institutional logic can develop its own ideas about the system's (expected) impact, structure, and behavior, as depicted in Fig. 2 (top). Only subsequently, and at a higher organizational level, can these proposals be compared for possible synergies and orchestration. Thus, the novel proposed approach addresses the accuracy-consensus tradeoff highlighted in Fig. 1 by clearly prioritizing the local consensus at the submodeling level and by shifting the responsibility to develop stronger forecasting capabilities at a higher organizational level, serving as a hybrid organization bridging different logics, as explained in the following sections.

4.2. Priority focus on commons-related critical thresholds

The second principle of the new proposed approach to SD modeling (after logic-specific submodeling, which has been described in the previous section) is the priority focus on commons-related critical thresholds.

A commons (Dietz et al., 2003; Hess, 2008; Elinor Ostrom, 1990) is defined here as a system that can (re)generate a common resource (that is, as defined above, a resource that is available for collective benefit but is vulnerable to beneficiaries' behaviors). For example, a marine area is a commons that can regenerate fish as a common resource. Wikipedia is a commons that can regenerate the contents of the online encyclopedia as a common resource.

A commons is usually a complex eco-socio-technical system. For example, the system that can regenerate fish often includes not only the marine ecosystem but also the fishermen with their practices and technologies, the tourists with their boats and habits, the activists with their social networks and digital tools, as well as others.

For SD modeling to make an impact, that is, to positively influence the levels of the relevant common resources, it must target not only the flows and resources that are the specific objective of the modeling project (for example, profits) but also the relevant common resources that can be influenced by model-based choices and decisions (for example, the marine area's biodiversity).

In fact, the commons' capacity to (re)generate common resources is, in most cases, fragile. The commons' regenerating capacity can be damaged, even irreversibly, if the system undergoes some critical thresholds that may be invisible to common sense.

In addition, most commons are eco-socio-technical systems in which the social component is important; therefore, they are level-two chaotic systems (Love, 2018) that react to predictions (including the predictions provided by systems dynamics modeling) in many and often unintended ways (De Gooyert et al., 2016). In this light, proper system predictability is simply unattainable because of the mere fact that making a prediction likely changes the behavior of the system (for example, by generating political struggle around that prediction).

Thus, to contribute to sustainability transformations, the links between SD modeling outputs, outcomes and impacts cannot be merely linear: they must be circular to allow for the continuous self-correction of forecasting.

Inside each logic-specific modeling group (like in Fig. 2), the participatory processes can be carried on as in Fig. 1 to achieve the expected outcomes. However, all participants should be invited to think in terms of commons from the beginning: What are the key common resources that (may) influence and/or be influenced by the processes that we want to model? What are the key elements of the eco-socio-technical system that can (re)generate such common resources? What are the critical thresholds of the commons, to the best of our understanding?

In this way, each logic-specific modeling group will develop their own ideas about the key common resources and relevant critical thresholds. For example, let us consider a marine area as a commons: according to traditional extractive logic, what matters is the commons' capacity to regenerate fish, while according to a tourism development logic, what matters is the commons' capacity to regenerate the attractiveness of the seaside. By unleashing each institutional logic's modeling potential through parallel submodeling processes, multifaceted hypotheses about the commons' critical thresholds emerge. The outcomes of logic-specific group modeling, as represented in Fig. 2 (in gray), can then be leveraged as inputs of a higher-level, integrated learning process, as explained in the next section.

4.3. Threshold-guarding experiments, commons resilience, and data as common resources

In this section, three further guiding principles of the new proposed approach to SD modeling impacting management are proposed: threshold-guarding experiments, commons resilience, and data as common resources.

In the presence of multiple, logic-specific modeling outputs, as represented in Fig. 2, multiple possible decisions and changes may take place that are directly or indirectly influenced by the logic-specific models emerging from the different groups. This situation mirrors the distributed experimentation environment envisaged by the robust action approach (Ferraro et al., 2015). According to the robust action approach, the best strategy to unleash sustainability-oriented innovation throughout a network of actors is to place these actors under the condition to obtain local experimental solutions to their problems and to exchange knowledge in a participatory organizational architecture.

However, when fragile common resources are at stake, the strategy of distributed experimentation, unless coupled to effective network steering strategies, makes the system vulnerable to (possibly unaware) actors passing critical thresholds (Etzion et al., 2017). For this reason, this study argues that the multiple logic-specific modeling processes envisaged in Fig. 2 should result in mental models that enable threshold-guarding distributed experimentation (see link 26 in Fig. 2). In other words, the different “threshold warnings” arising from the different logic-specific modeling processes should be taken into consideration when using SD models to trigger distributed experimentation.

In the proposed model, the system changes activated as threshold-guarding experiments also stem from two other key expected outcomes of SD modeling, that is, SD-based decisions and commitment to change (27, 28).

The ability to guard the commons' critical thresholds and to leverage changes as natural experiments depends, both directly and indirectly (29, 30, 31), on a higher-level organizational unit, labeled smart commons organization, the role of which will be further discussed in Section 5.

If system changes are leveraged as natural experiments (Sengers et al., 2019), their direct impact on sustainability in terms of common resources can be both positive and negative, because, of course, some experiments do not result in the expected consequences (32). However, over the middle and long-term, distributed experimentation (provided that the critical thresholds are guarded and lessons from experiments are learned) enhances the resilience of the commons (33) and then, indirectly, the levels of common resources (34).

The concept of commons resilience included in the proposed model is borrowed from the literature on social-ecological systems resilience and adaptive co-management (Folke, 2006; Plummer and Armitage, 2007). Commons resilience includes not only the system's ability to leverage difficulties and crises to innovate and become stronger (as in the concept of robust action described above) but also its ability to guard the points of no return, i.e., to prevent choices and behaviors that could result in an irreversible loss of resource (re)generation options (Berkes et al., 2003).

All system changes, if observed as experiments, produce data on the commons (35) that summarize the data derived directly from common-resource stocks and flows (36). Creating and managing system-level data can be unsustainable for an individual subject, but it can become sustainable if all subjects are placed under conditions to contribute, in exchange for the possibility to access the whole stock of the commons' data and data management capabilities. Therefore, if the smart commons organization nurtures (and is nurtured by) the system's capability to generate, protect and use the data as common resources (37, 38), this virtuous cycle (R4) enables further reinforcing loops: R5, and R6 (39, 40).

The system's data management capabilities, in turn, contribute to commons resilience (41) together with the “social outcomes” of SD modeling: commons-centered social capital (42) and empowerment (43) of the participants of modeling teams, and stakeholder ownership and commitment to change (44).

Last but not least, the ability to manage data as common resources is key to the model's full circularity (R7), since it reinforces the smart commons organization's capabilities to develop or facilitate the investigation of gaps in the many existing logic-specific models (45) and to contribute to institutional work through the creation of new, hybrid institutional logics (46) that, in turn, trigger further cycles of group-level, logic specific modeling (47).

This systemic restructuration of the system enabling SD modeling performance management, shaped by four reinforcing cycles, could be able to cope with the main external forces threatening SD modeling impact: antisocial behaviors at the societal level, such as opportunism, hate speech or antisocial punishment (48), intercommons conflicts, that is, situations in which a commons' resilience can only be increased at the expense of another commons' resilience (49), and extrinsic limits to data management capabilities (50), due to, for example, privacy laws.

5. The SD modeling process as a two-level organizational challenge

In the previous section, five principles were presented that characterize the new proposed approach to SD modeling performance management: (1) logic-specific group modeling; (2) when modeling, a prioritized focus on commons-related critical thresholds; (3) threshold-guarding-distributed experimentation; (4) commons resilience; and (5) commons-related data to be managed as common resources.

This study argues that these five principles can only be translated into practice if a further, overarching principle is implemented: the SD modeling process must be addressed as a two-level organizational challenge. In the proposed approach, the SD model production process is performed by participatory group work coordinated by facilitators, as in mainstream approaches; in contrast, the integrated, commons-oriented learning enabled by the outcomes of multiple modeling processes is coordinated by a higher-level organizational unit (the smart commons organization in Fig. 2) that has the responsibility to enable the overall circularity of the process, from SD modeling inputs to activities, outputs, outcomes and impacts, and vice versa.

The new organizational unit envisaged by this study embodies the responsibility to govern the tensions across organizational logics and contribute to building new, hybrid logics, in a similar way to the hybrid organizations described in the literature on institutional logics; the responsibility to unleash and facilitate distributed experimentation, in a similar way to the focal organization described in the literature on robust action; the responsibility to guard the commons' critical thresholds and translate the results of distributed experimentation into sound, evidence-based knowledge that is available for the entire network, in a similar way to the bridging organization described in the literature on adaptive co-management; and finally, the responsibility of enabling the system to manage commons-related data as common resources.

Therefore, we labeled this new type of organizational unit "the smart commons organization". A smart commons organization is a permanent organizational unit that integrates the performance of different modeling groups working around a certain (group of) commons throughout time.

The proposed smart commons approach is fully compatible and complementary with the mainstream approach to participatory SD modeling.

According to the smart commons approach, the outcomes of group-level SD modeling (gray boxes in Fig. 2) become the inputs for the action of the smart commons organization. The smart commons organization has its own expected outcomes (the green boxes in Fig. 2), which are clearly distinguished from the outcomes of group modeling.

In such a system structure, the key function of the smart commons organization would be the data-driven integrated learning on the state of the commons and evidence-based orchestration of commons-oriented actions (Lavertu, 2016; Mergel et al., 2016).

Notably, the data generated by system behavior are also considered common resources in this mental representation and enable the key activities of the commons organization. For this reason, we argue that this approach to SD modeling is consistent with the emerging big data age (Lavertu, 2016).

6. Conclusions

This study has leveraged some complementary bodies of knowledge from social and management science to address a need that is clearly perceived in the SD literature: develop a more effective approach for improving the contribution of SD modeling to sustainability transformations (De Cian et al., 2018). Our proposal paves the way to empirical studies on the effectiveness of the organizational principles that characterize the smart commons approach to impact management. Furthermore, the smart commons approach poses an important question: what subjects, in today's scenario, could play the pivotal role of the smart commons organization, as it has been depicted in this article?

We argue that universities are well-positioned to serve as generators of smart commons organizations for integrating learning and action on specific commons in the emerging age of data. The smart commons approach, in fact, requires a permanent organizational unit as a focal actor that enables highly distributed systems thinking with scarce possibilities of being rewarded by traditional market mechanisms. This idea has interesting implications for research and practice that, we hope, could contribute to fully exploit the potential contribution of systems thinking and system dynamics to sustainability transformations.

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Supplementary materials

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