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Integrating system dynamics and scenarios: A framework based on personal experience

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Abstract

System dynamics (SD) is a methodology to generate qualitative and quantitative models. SD has two main concepts that are highly suitable to use with scenarios: feedback processes that define the structure of sociotechnical systems and accumulation processes that are responsible for the dynamic behavior of systems over time. This article discusses a framework that integrates methodologically scenarios and SD. The integration can take multiple forms depending on the use of SD for creating or supporting scenarios. The framework is illustrated with multiple examples. Since SDs' practice uses processes similar to scenario practice, mutual enrichment between the communities can be highly successful.

KEYWORDS
intuitive logics, scenario, simulation, system dynamics

1 | INTRODUCTION

Scenario planning has grown in importance in the process of strategic planning since 1970s because long-term forecasting has become unreliable in contexts of accelerated change, complexity, and uncertainty (Ramirez & Wilkinson, 2014). While there are diverse schools or streams, the intuitive logics school, which is the most employed school, considers scenarios based on plausibility (over probability) that are revealed through logical stories based on cause-and-effect relations (Ramirez & Wilkinson, 2014). Extensive research has discussed the intuitive logics schools in terms of methods (Bradfield et al., 2005) and strengths/weaknesses (Derbyshire & Wright, 2017). Intuitive logics school mostly focuses on qualitative scenarios obtained through workshops. Jashari et al. (2022) suggest there is a gap in the field of scenarios in terms of the use of more strictly quantitative approaches. Quantitative approaches can open new horizons for scenarios as companies increase the use of analytics in strategic planning practices and focus on evidence-based decision-making. This article responds to this gap by identifying synergies between scenarios practice and a simulation methodology called system dynamics (SD).

SD started with Jay Forrester at the Massachusetts Institute of Technology in 1957 (Forrester, 1961). SD has been described as a “rigorous method for qualitative description, exploration and analysis of complex systems in terms of their processes, information, organizational boundaries, and strategies, which facilitates quantitative simulation modeling and analysis for the design of system structure and control” (Wolstenholme, 1990). Different from other simulation methods, SD can employ two approaches to modeling and simulation, qualitative and quantitative, depending on the purpose of the modeling project (Kunc, 2018). There are two basic uses (or modes) for SD models depending on the purpose of the project: a descriptive mode, where the aim is to elicit stakeholders' perspectives in order to achieve consensus on what the system is; and a predictive/prescriptive mode, whose aims is to solve dynamically complex problems through simulation on the premise that systems can be described and engineered using insights generated by quantitative models (Kunc, 2018). SD modeling can occur either in expert mode, where modelers work alone or in participative mode, where the model is built together with stakeholders in facilitated workshops (Kunc, 2018). SD modeling involves extensive cause-and-effect analysis of factors to identify feedback loops underpinning the structure of sociotechnical systems. In other words, SD is a flexible methodology, which overlaps with the intuitive logic school, and given its multiple modes of engagement can contribute to scenarios practice in different ways.

This paper proposes a framework that maps the synergies between SD to scenarios depending on the use of SD with respect to scenarios. The framework is based on the use of multiple methodologies in management science/operational research where the integration depends on the role, dominance, and order of use of each method (Bennett, 1985; Pollack, 2009). This is not the first attempt to integrate SD with scenarios. Previous work has been performed by Featherston and Doolan (2013), Schmitt Olabisi et al. (2010), and Morandi et al. (2014) among other scholars and practitioners. Zolfagharian et al. (2018) suggest the use of SD with another methodology can help to increase confidence and rigor in obtaining and quantifying variables, include multiple attributes and perspectives of agents, and develop structures and processes that support intervention and implementation. Bradfield et al. (2005) suggest SD as one of the tools to develop scenarios. There is evidence of the importance of joining SD with scenarios. However, there is a gap in terms of how, why, and to what effect SD and scenario can be combined. The main contribution of this paper is to present a taxonomy for SD modelers and scenario practitioners for the integration of scenarios with SD. The framework is illustrated with a set of examples that can provide an initial template for future use by academics and practitioners.

The article is structured in different sections. First, I discuss the literature related to scenarios mostly focused on the augmented intuitive logics (AIL) method together with the practice of SD in scenarios. At the end of this section, I present a framework for the use of SD in terms of scenarios. Second, I present examples of the different uses of SD with scenarios from personal experience and literature. Third, a discussion of the contribution of SD to scenarios is presented. The article closes with conclusions and future research.

2 | LITERATURE REVIEW

The literature review covers the developments of the scenario field and the use of SD in scenario-related areas.

2.1 | Scenario

Scenarios are not predictions, extrapolations, or positive or negative futures but purposeful stories about how the contextual environment may unfold over time (Derbyshire & Wright, 2017). Scenarios, under an intuitive logic approach, usually consist of a description of a future end state in a defined time horizon and an internally consistent account of how a future will unfold based on causal logic representing the dynamic interplay of predetermined elements and unresolved uncertainties (Derbyshire & Wright, 2017). The process of generating scenarios is a social-reasoning process, based on dialog and conversation where participants share their perceptions of the environment, and through interactions and storytelling, they engage in sense-making about a series of cause-and-effect relationships (Derbyshire & Wright, 2017). These relationships are assumed to lead to a set of specific future outcomes in a chronological sequence, which is called "efficient cause" (Derbyshire & Wright, 2017).

The AIL approach expands the traditional intuitive logic approach to scenarios by considering a broader set of causes, for example, material, formal, and final, as well as considering countervailing factors and contingent conditions that may either enhance or oppose the effects of efficient causes (Derbyshire & Wright, 2017). Material causes consider the step change that leads to state transformation from one qualitative state into another state. These changes can be associated with the behavior of complex systems, where a change is represented as a tipping point driven by nonlinear interactions (Derbyshire & Wright, 2017). Formal causes may involve natural tendencies or behaviors as well as formal blueprints or structures (Derbyshire & Wright, 2017). They aim to capture the constraints and supportive social and economic structures defining human actions. Final causes are associated with the purpose of behaviors driven by stakeholder's viewpoints and their power (Derbyshire & Wright, 2017). Contingent causation involves the analysis of how causal forces can prevent an expected outcome originating from a formal cause (Derbyshire & Wright, 2017). The approach also offers an enhanced reasoning-appreciation-and-evaluation procedure for experts' opinions. Table 1 presents the AIL process, which follows eight stages.

2.2 | SD

I present a basic introduction to the SD modeling process because the stages of the modeling process can help in understanding how SD and scenarios can be combined. The SD modeling process consists of five steps (Sterman, 2000).

- The first step defines the boundary of the system, articulates the purpose of the model, and involves selecting key variables with a defined time horizon, which includes the past and future. In this step, the modeling team discusses the scope of the model in a similar way to scenario-setting activities (Sterman, 2000).
- The second step comprises the identification of the current theories held by stakeholders associated with the causal structure driving the performance of the system. The aim of this step is to explain the dynamics of the system as an endogenous consequence of the feedback processes (Sterman, 2000). Feedback processes, which are processes of circular causality, in social systems have one important characteristic: they are mostly tacit because they are separated in time and

TABLE 1 Scenario development: Augmented intuitive logics (adapted from tab. 1—Derbyshire & Wright, 2017).

Stage	AIL approach
Stage 1: Setting the scenario agenda	Defining the issue of concern and process, and setting the scenario timescale. Developing a detailed analysis of the present that incorporates the identification of the material, formal, and final causes, as well as the efficient cause.
Stage 2: Determining the driving forces	Eliciting a multiplicity of wide-ranging forces by prompting the identification of the material, formal, and final causes, as well as the efficient cause.
Stage 3: Clustering the driving forces	Clustering causally-related driving forces, testing and naming the clusters by focusing on the transformation from the material, formal, and final causes, as well as the efficient cause.
Stage 4: Defining the cluster outcomes	Defining two extreme, but plausible and hence possible, outcomes for each of the clusters over the scenario timescale.
Stage 5: Impact/uncertainty matrix	Ranking each of the clusters to determine the critical uncertainties, that is, the clusters that have both the most impact on the issue of concern and the highest degree of uncertainty as to their resolution as outcomes.
Stage 6: Framing the scenarios	Selecting two initial critical uncertainties to create a scenario matrix, framing the scenarios by defining the extreme outcomes of the uncertainties.
Stage 7: Scoping the scenarios	Building a broad set of descriptors for each of the four scenarios prompted by the identification of causal loops.
Stage 8: Developing the scenarios	Developing scenario storylines, including key events, their chronological structures, and the "who and why" of what happens. The scenarios are likely to emphasize radical transformational change because of the augmented Stages 3 and 7.

Abbreviation: AIL, augmented intuitive logics.

space, as well as across multiple stakeholders. Longitudinal observations from stakeholders, who have experienced and observed the system over time, and causal-based theories are the sources of information for designing SD models (Kunc, 2018). However, observations from stakeholders may not be precise due to cognitive limitations and the use of heuristics so the importance of using multiple data sources (Kunc, 2016). The outcome of this step is a feedback loop diagram that is shared with all stakeholders. Qualitative SD projects usually stop at this step or jump directly to step 5.

- The third step involves formulating a computer simulation model based on the outputs of the previous step. This stage encompasses defining the type of variables: stocks, flows and causal networks, parameters, and initial conditions (Sterman, 2000). While numerical data is necessary to run the simulation, SD models are not only dependent on existing numerical data. The most important aspect of the formulation is the logic behind the equations because SD models test cause-and-effect relationships underpinning the structure of the system (Kunc, 2018). While SD models use existing data for parameter estimation, SD models can also include variables even if there is no specific numerical data by using experts' or stakeholders' estimations (Sterman, 2000). Models are grounded with all possible data: numerical, archival, interviews, observation, expert judgments, users' guesses, and so forth (Sterman, 2000).
- The fourth step involves validating the model with respect to the purpose, for example, correspondence with the system, and its verification, for example, how the model behaves with data uncertainty (Sterman, 2000).
- The fifth step is the experimentation with the model to support different activities: system interventions, what-if questions, sensitivity analysis, scenario testing, and so forth. If the model is qualitative, for example, a feedback loop diagram, this stage may involve a conceptual simulation of the transformations happening due to changes in certain variables. The results of qualitative models are narratives describing the transformation processes occurring due to feedback processes rather than numeric results, as in quantitative models. However, both types of models have narratives that explain the dynamics observed in the system.

2.3 | Framework to pair SD and scenarios

The framework starts with identifying the purpose of SD in terms of its integration with scenarios. Multimethodology is widely practised in the operational research field to address projects that involve dynamically complex problems with unstructured data (Bennett, 1985; Pollack, 2009). There are two approaches to integrate multiple methods: grafting and embedding (Pollack, 2009). Grafting implies attaching scenarios to SD. The objective is transforming a situation defined by social complexity, for example, multiple perspectives about the forces driving the future, into a problem suitable for quantitative approaches, for example, a set of variables and their relationships useful for an SD model. The dominant method is SD. Embedding involves using scenarios methodology to explore and learn about the uncertainties related to the future, while SD is used to facilitate the implementation of the scenario's recommendations. The dominant method is scenario. The integration of the methodologies can occur at any of the five stages of SD modeling or eight stages of the AIL. When SD is employed to help understand the future, the model uses input data to obtain estimates of future system states. In this case, the future is described by not only the results of the simulation but also the model structure, parameters, and inputs (Maier et al., 2016). In other words, the model is the evidence underpinning the scenarios. When scenarios are the dominant method, the use of SD can provide a quantitative approach to develop, test, and use scenarios for planning. To summarize, the framework has two branches: develop scenarios using SD modeling or support scenarios, which are built using intuitive logics, with SD modeling (see Figure 1).

Table 2 shows the correspondence between the components of the framework and the multimethodologies described previously. Each concept is explained in more detail in the following subsections.

2.3.1 | SD develops scenarios

Maier et al. (2016) suggest modelers estimate future system states based on different, but complementary, paradigms. First, they anticipate the future based on the best available knowledge and the result is one future state. Since models are not limited to current knowledge, it is expected the model can improve by further research, data collection, and fine-tuning over time, especially if results are unexpected. The initial result of the simulation may be known as a "business as usual" (BAU) scenario within the modeling community when the model continues the trends observed in historical data. Second, modelers can quantify future uncertainty, so the parameters will have a range of values that accounts for variability, and the estimation of the uncertainty is a distribution of results. The SD model assumes the structure is stationary so the fluctuations in results correspond to the impact of nonlinearities across feedback loops within the range of variability in the system. This is usually explored through Montecarlo simulations in key variables (Kunc & Kazakov, 2013). Third, they explore plausible futures using knowledge that indicates more than one future state as represented by specific new parameters or assumptions. Each future is considered sufficiently distinct and discrete. From the SD modeling perspective, this is usually considered as "what-ifs" and using diverse specific values for exogenous variables describing the impact of external events (Kazakov & Kunc, 2016). Another possibility is a future state that involves assumptions about changes in the system, for example, new feedback structures. In this case, a new version of the model is required and comparisons between structure and results need to be performed. Fourth, it is the combination of the previous three paradigms.

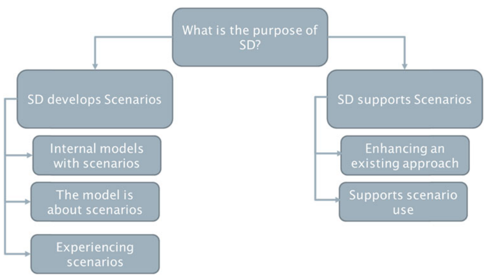

FIGURE 1 Methodological framework for system dynamic (SD) and scenarios.

Internal models with scenarios

SD models represent entities as endogenous systems underpinned by feedback loops. The model is developed to understand the structure of the system and provide solutions to the issues identified by stakeholders. Some examples of models in this category are organizations, supply chains, ecological systems, sociotechnical systems, populations, and so forth. The model represents the BAU

TABLE 2 Correspondence between framework and multimethodology.

Components of the framework	Relevant multimethodology approach
Internal models with scenarios	*Grafting*: Scenarios provide external inputs to an SD model describing the internal dynamics of a system. Both methods are developed in series (first SD and then scenarios) or in parallel. However, the dominant method is SD.
The model is about scenarios	*Embedding*: Scenarios is the dominant method as it provides all inputs (assumptions, values, etc.) to create and run an SD model. The methods are in sequence with scenarios being used first.
Experiencing scenarios	*Grafting*: The dominant method is SD as it is used to create an interactive environment for decision-makers to "experience" making decisions in different scenarios. Scenarios provide external inputs for different situations presented in the interactive environment.
Enhancing an existing scenario approach	*Embedding*: This component is similar to "the model is about scenarios." Scenarios is the dominant method as it provides all inputs (assumptions, values, etc.) and the SD model supports the scenarios methodology. The methods can be in parallel or in sequence with scenarios being used first.
Support scenario use	*Grafting*: The dominant method is scenarios, and scenarios are developed first. Then, SD can be employed to support the subsequence use of scenarios in strategic planning by rehearsing strategies or testing the impact of scenarios on the performance of the system. This component has similar characteristics to "internal models with scenarios" but the emphasis is different.

Abbreviation: SD, system dynamic.

scenario initially. However, exogenous forces can affect the performance of the system, which are captured as constant variables in the model because they are not part of feedback loops. Using scenarios methodology, modelers can identify a set of future states for those variables, and identify new external variables that describe the scenarios or new structures. Then, modelers run the SD model with different values for the exogenous variables, incorporate the scenario variables in the model, or change the model to describe the changes from the scenarios to represent the performance of the system under different scenarios. Both methodologies run in parallel or sequence, but they run independently.

The main objective of the integration is to test the system under different futures so the solutions being offered are robust under uncertainty. The contribution of scenarios is to integrate the perspectives of stakeholders about the uncertain futures, but they don't define the future state of the system, which is generated by the SD model. In this case, the model represents a combination of the first and third paradigms mentioned previously.

The model is about scenarios

The SD model represents the scenarios' concepts as part of endogenous feedback loops. In this case, the model describes the causal structure underpinning scenarios, which is constructed using intuitive logics or AIL. In this case, scenarios methodology runs first, and SD modeling uses its inputs and assumptions for the model. The scope of the model may comprise multiple systems depending on the scenarios. One example of models in this category is an industry with its companies, regulators, technology providers, and consumers. There are no exogenous variables since all variables are endogenous in the model. Modelers run the SD model with different values for the scenarios' variables in the model. Another option, which involves not having defined future states, is to consider deep uncertainty because of a lack of agreement on the interactions among the variables, the values of inputs, or the desirability of alternative outcomes (Maier et al., 2016).

The main objective of this combination is to use the model to describe the future state of the environment. The contribution of scenarios is to define the inputs and assumptions to be employed by the SD model to simulate the future state of the system. The contribution of SD is to test the consistency of the scenario and identify issues in its plausibility due to subjectivity in the definition of scenarios. This is an example of the third paradigm.

Experiencing scenarios

Berkhout et al. (2002) suggest that scenarios are learning machines because they provide heuristics that help to identify possible future vulnerabilities and assess the capacity to adapt to their impacts. However, decision-making-related heuristics are not tested unless decision-makers make decisions in those scenarios and learn from their successes and failures. Bradfield et al. (2005) propose four purposes for scenario work: making sense, developing strategy, anticipation, and adaptive organizational learning. The first two purposes are associated with specific one–off content needs and the last two to ongoing general organizational processes for long-term survival (Bradfield et al., 2005). The last two purposes can be supported by simulation models transformed into interactive scenario simulators.

SD models with interactive interfaces can work like wargaming for decision-makers because they can rehearse their decisions under different scenarios, experiencing the scenarios and improving their skills (Schwarz et al., 2019). In this case, the main methodology is SD and scenarios provide information for generating different environments. SD models can be used in an interactive mode, where users can enter decisions, observe the results, improve their understanding, and make additional decisions over a certain time horizon using sliders or other input methods. SD models employed in this way are called "management flight simulator or microworlds" because they are small-scale worlds representing the company and its environment (Warren & Langley, 1999). An SD model is created like in the previous approaches, but the difference is the development of an interactive interface for users. Users will make their decisions under different scenarios and compare their results, for example, how a certain strategy can work well under scenario A but perform poorly under scenario B? This process can help them to anticipate situations, learn about approaches to tackle different scenarios and improve their mental representation of the causal relationships defining the microworlds (Warren & Langley, 1999). In other words, microworlds are dynamic learning laboratories where a gaming interface reports to users the results of the interactive simulation using state-of-the-art graphics.

The main objective is to "facilitate the experience" of operating under different scenarios. While simulation can help decision-makers to reduce the lack of information about future performance under different scenarios, as discussed previously, it cannot help them to experience the pressures of making decisions unless they interact with the simulation by making decisions and observing the results (Langley & Morecroft, 2004).

2.3.2 | SD supports scenarios

Enhancing an existing scenario approach

In this case, the main methodology is scenario. The role of SD modeling is to provide support to any of the stages in the scenario process. For example, AIL considers adding "causal loops" to traditional influence diagrams (IDs) since it reduces the determinism implicit in intuitive logics where linear cause-and-effect is responsible for the changes expected in a scenario. Then, qualitative SD modeling can support mapping the driving forces and their causal relationships (direction and polarities) in clear causal loop diagrams. Later, the causal loop diagrams can support the development of storylines for scenarios as a result of feedback processes interconnecting the driving forces. Unless there is a specific objective that requires quantification of the scenarios, the main role of SD is to provide causal maps to formalize the result of some scenario stages.

The main objective of this integration is to enhance specific stages on an established scenario approach by using SD tools, for example, causal maps, and steps in the modeling process, for example, problem definition or dynamic hypotheses.

Supports scenario use

In this case, the main methodology is scenario. SD is only used after the scenarios are finished. SD models can be developed about the scenario in itself (like "the model is about scenarios"), or be a model of the system (as "Internal models with scenarios"). In the first instance, SD models may be used to provide quantitative evidence of the future states indicated by the scenarios (Willis et al., 2018). With respect to the second option, SD models can represent the system, for example, an organization, that will be subject to the scenarios to observe its behavior under different futures (Torres et al., 2017).

The main objective is to complement scenarios with quantitative evidence in the first use. The second use of SD may aim to support scenario planning by demonstrating the impact of future on the system and testing strategies to address them.

2.4 | Illustrating the framework

The framework is being illustrated through a set of examples from personal experience and a literature search. The paper does not aim to represent the current situation of the field but to provide a set of examples for further reference.

2.4.1 | SD develops scenarios

Internal models with scenarios

One example is Machado et al. (2019). In their work, they developed an SD model of the footwear industry in the south of Brazil. The model depicted the dynamics of the industry as an endogenous regional system with two main external factors: exchange rate and stability of the local economy. The authors had a key question to explore: "what business investments can contribute to increase resilience in the region?" through a set of scenarios. They employed two definitions of scenarios. Their initial definition reflected simulation practice because they were "internal" scenarios or representations of decisions to be made. The "internal" scenarios were: (i) the AS IS, (ii) the uniform distribution of investment, (iii) the labor training investment, (iv) the value-added marketing investment, and (v) the solid waste treatment investment. Then, they also explored four "exogenous" scenarios, which were closer to the traditional scenario practice: (i) the large exchange variation and low-level crisis of the local economy, (ii) the large exchange variation and high-level crisis of the local economy, (iii) small exchange variation and high-level crisis of the local economy, and (iv) the small exchange variation and low-level crisis of the local economy. This is an example of mixing the concept of scenarios between simulation and scenario practices.

Suryani et al. (2010) present a model to understand runway and passenger terminal capacity expansion under different air passenger demand scenarios. They found endogenous factors, for example, level of service, number of flights per day, and dwell time, and exogenous factors, such as airfare, gross value added, and population can impact the need for extra capacity. In their project, they developed a causal loop diagram showing the interactions between air passenger demand and passenger terminal capacity expansion before developing a quantitative SD model. They simulated a base run for 12 years. Then, they performed two types of scenarios: one changing the structure of the feedback loops, which they called "structure scenario," and another changing the parameters in the model, called "parameter scenario." This is an example of the first and third paradigms.

Torres et al. (2017) worked with five small- and medium-sized enterprises' CEOs to develop five individual SD models representing their companies and used them to test strategic initiatives with a set of scenarios. The process involved running a base case scenario (business as usual) as an extrapolation of past behavior. Then, the CEOs identified future possible developments in the external environment that could affect their internationalization strategies. Finally, the CEOs tested their strategic ideas to overcome challenges emerging from scenarios using the SD model. The authors found the use of causal loop and stock-and-flow diagrams facilitated CEOs' understanding of the business performance under different scenarios and mitigated their subjectivity in their decisions under uncertainty.

All examples show the dominance of SD modeling where scenarios are labeled to describe multiple runs for endogenous and exogenous variables. However, there isn't a specific process describing the development of the scenarios. In all cases, scenarios indicate changes in future states both internal and external.

2.4.2 | The model is about scenarios

Schmitt Olabisi et al. (2010) used SD modeling to examine selected scenarios for their consistency with respect to data trends, as well as comparing scenarios using quantitative measures. Scenarios allowed stakeholders to explore surprising events that can arise exogenously but could not have been modeled. The model structure was taken directly from the information of the scenarios, as well as causal inferences reflecting secondary effects from the scenarios. Data was obtained from secondary sources. The scenario variables considered the range of quantitative values. The methodology was sequential: Focal question ➔ Scenarios ➔ SD model ➔ Policies/Testing ➔ Research priorities/policy recommendations. The authors found there was tension between imaginative thinking, driven by scenarios, with quantitative analysis, performed with SD.

Another example of using SD for constructing scenarios has been performed by Carlisle et al. (2016). The objective of the SD model was to present quantitative evidence of plausible futures for a city's 2026 strategic plan. The process involved stakeholders identifying the uncertain and important driving factors affecting tourism, defining their casual relationships, and clustering them (stages 1, 2, 3, to 4 in AIL). Then, modelers transform these factors into stocks and flows, as well as causal links between them. Key factors were measured in terms of their importance and uncertainty (stage 5) to define the scenario matrix to perform stages 6–8 (see Table 2). In this project, modelers transform the concepts into values for each variable capturing the nuances between the scenarios.

Table 3 presents the four scenarios as organized in a 2 × 2 matrix, their narratives, and the values of the key uncertainties in each scenario and results in terms of total tourism spend by the year 2026. The results of the project were not dissimilar to an intuitive logics scenario process with a 2 × 2 matrix and narratives. The value added of the SD model was the quantitative evidence of the number of tourists and financial results expected under each scenario. Stakeholders were only interested in these values rather than understanding feedback processes.

These examples show good synergies between SD and scenarios as the inputs from scenario methods are easily transformed into SD models. It is interesting that stakeholders participating in the project have two different thinking approaches, creative and quantitative, so SD practitioners have to consider them as part of their projects.

TABLE 3 2 × 2 scenario matrix integrated with a summary of scenario narratives and values of variables used in SD model (adapted from tab. 7–9—Carlisle et al., 2016).

Attractiveness for staying visitors				
Level of investment	Low		High	
Low	*Urban decay*		*Little maritime village*	
	There is a high level of PR budget to promote the city as an English language learning destination so there is a growing number of educational visitors, who stay longer time as the exchange rate is favorable with more hosting houses. However, the streets are crowded, and the town is perceived as not being safe, mainly caused by the extended nightlife offer. This has reduced attractiveness for investors and staying visitors.		Bournemouth continues to develop in line with historic patterns. The town is attractive for overnight visitors due to the tidy public areas and the eliminated issues with nigh-time overcrowding. However, the limited investment in new hotels and cultural activities is limiting its growth.	
	Variable	Value	Variable	Value
	PR budget (1–10)	8	PR budget (1–10)	6
	Available commercial land (0–4)	0.5	Available commercial land (0–4)	2
	Day visitor growth (%)	0.9	Day visitor growth (%)	1
	Length of stay educational visitors (days)	50	Length of stay educational visitors (days)	45
	Value sterling to foreign currency (GBP to Euro)	1.05	Value sterling to foreign currency (GBP to Euro)	1.2
	Host accommodation (% of housing available students)	15	Host accommodation (% of housing available students)	9
	Total tourism spend (2026) (£ million)	550.9	Total tourism spend (2026) (£ million)	485.8
High	*English Ibiza*		*English Dubai*	
	Both public and private investment in nightlife creates a great base for the town's entertainment development. However, issues with night-time overcrowding and littering are, however, alienating the higher-spending visitor segments.		Nighttime overcrowding and antisocial behavior is an issue from the past. New investments have resulted in new higher quality, internationally branded hotels and extended cultural offers.	
	Variable	Value	Variable	Value
	PR budget (1–10)	5	PR budget (1–10)	2
	Available commercial land (0–4)	1	Available commercial land (0–4)	3
	Day visitor growth (%)	0.8	Day visitor growth (%)	0.7
	Length of stay educational visitors (days)	50	Length of stay educational visitors (days)	45
	Value sterling to foreign currency (GBP to Euro)	1.1	Value sterling to foreign currency (GBP to Euro)	1.3
	Host accommodation (% of housing available students)	10.5	Host accommodation (% of housing available students)	8
	Total tourism spend (2026) (£ million)	543.1	Total tourism spend (2026) (£ million)	598.5

2.4.3 | Experiencing scenarios

One example of a microworld is the Oil Producers' Microworld (Morecroft & van der Heijden, 1992). This SD model of the global oil industry was created with a management team from a major oil company during the late 1980s (Morecroft & Marsh, 1997). The model is moderately complex with 100 active and interrelated variables (Langley & Morecroft, 2004). The microworld has been adapted and used throughout the 1990s for scenario generation with the oil company managers and management education at a variety of business schools and oil companies (Langley & Morecroft, 2004). Players take the role of senior management in a commercial oil company, investing in upstream capacity and competing against OPEC with changes in industry demand, price, or overproduction. Simulations reveal the implications of investment policy under a variety of plausible industry scenarios including a “Green World,” “Asian Boom and Bust,” and a “Russian Oil Bubble” (Morecroft, 1999). Morecroft (2017) discusses a further update to the microworld including a scenario with shale oil. He argues there is an enduring feedback structure in the oil industry related to the competition and interrelationships between different producer groups. The microworld seems to be robust to generate and be used under different scenarios.

Franco et al. (2000) present an account of the development and use of an SD microworld to train traders in the Colombian energy market through scenarios. The scenarios were based on the impact of El Niño on the availability of hydroelectric power. In their project, they developed the SD model with the company, then trained the traders on the causal structure of the industry and the SD model before traders used the microworld to make decisions under different El Niño scenarios.

2.4.4 | SD supports scenarios

Enhancing an existing approach

Table 4 presents an enhancement of AIL using SD in each stage. The process follows the eight stages indicated in Derbyshire and Wright (2017). The second column includes the tasks in this approach. The final column indicates the contribution from SD modeling in each stage. While the intention is to map as closely as possible the stages with the SD modeling steps, there are steps that can cover more than one stage and stages that don't map directly to one SD stage. For example, stages 5–8 are a result of the analysis of the experimentation with the model and the development of narratives to explain the behavior over time observed in the model, which is not specifically indicated in any step in SD modeling but is widely done in practice.

However, a key difference is important to consider here: the definition of causality in AIL is more extended and detailed than in SD model. On the other hand, AIL does not provide the identification of feedback processes.

Figure 2 shows an AIL ID developed by Derbyshire and Wright (2017). In the figure, they add “causal loops” to traditional IDs used by intuitive logics approach. They indicate that causal loops ‘dilute’ the determinism indicated in traditional ID responsible for the changes expected in a scenario. In this way, ‘transformational change’ emerges through self-reinforcing positive feedback, as represented by causal loops. The existence of self-reinforcing positive feedback can lead to tipping points and bifurcations, which “are the very essence of a step-change in the nature of the future” (page 264).

From an SD perspective, there is some important information missing, for example, a sense of the direction of the impact from one variable into another. This information is added through positive (+) or negative (−) signs to the linkages between two factors. A positive sign indicates cause-and-effect linked variables change in the same direction. The negative sign indicates linked variables change in the oppositive direction. Figure 2 has been modified to add the missing information, see Figure 3. It seems most relationships are positive. However, the figure does not contain any indication of causal loops, as in Figure 2, because there are much more than four causal loops. Therefore, a table is created with this information, see Table 5.

Table 5 shows the structural analysis of the map indicating the importance of each variable in terms of causal loops. Given that all relationships are positive, the system is strongly driven by a self-reinforcing feedback process. The structural analysis indicates three variables, which are linked between them, are critical for the transformational change of the system due to its participation in 13 different causal loops. At the same time, there are variables that don't participate in any causal loop, so they seem to be exogenous to the system, for example, “inflation target level” and “housing-building standard levels,” and adequate as factors for scenario generation. However, only one of these variables can be appropriate for generating a 2 × 2 scenario matrix since they are linked directly.

To summarize, SD modeling can enhance AIL in terms of analysis of the causal relationships and scenario construction, as shown in Table 4 and Figure 3/Table 5. Some benefits from SD to AIL are the identification of the type of impact (+ or −) between driving forces, casual loops, type of feedback (reinforcing or balancing), and the possibility of simulating the scenarios to provide an appreciation of the potential transformation change in each scenario. This approach has been employed in other industries, for example, energy (Quiceno et al., 2019). A possible alternative different than embedding the model into the process is to have a dialog between scenarios and the model, for example, testing elements of the scenario narratives with the model (McDowall, 2014).

2.4.5 | Supports scenario use

Among different uses of scenarios, scenarios can support the development of strategies (Rigby & Bilodeau, 2007) or assess existing strategies against uncertain futures (Ringland, 2006). However, assessing strategies against scenarios can be difficult because of the complexity of the future environment and its impact on the organization but, more importantly, it is the limited information processing capacity to understand all the implications

TABLE 4 Scenario development enhancing AIL and SD.

Stage	AIL approach	SD contribution
Stage 1: Setting the scenario agenda	Defining the issue of concern and process, and setting the scenario timescale. Developing a detailed analysis of the present that incorporates the identification of the material, formal, and final causes, as well as the efficient cause.	Use step 1 in SD modeling.
Stage 2: Determining the driving forces	Eliciting a multiplicity of wide-ranging forces by prompting the identification of the material, formal, and final causes, as well as the efficient cause.	Use step 2 in SD modeling to support the detailed analysis of the system. Identify polarities for the causal links between causes.
Stage 3: Clustering the driving forces	Clustering causally-related driving forces, testing and naming the clusters by focusing on the transformation from the material, formal, and final causes, as well as the efficient cause.	Perform structural analysis using feedback loop tools to identify leverage points.
Stage 4: Defining the cluster outcomes	Defining two extreme, but plausible and hence possible, outcomes for each of the clusters over the scenario timescale.	Use step 5 in SD modeling to infer the transformations from the driving forces to identify similar effects and cluster them. If the evaluation is quantitative, steps 3 and 4 in SD modeling will be performed before step 5. Use the results of step 5 to select two extreme results for a cluster of variables over the scenario timescale.
Stage 5: Impact/ uncertainty matrix	Ranking each of the clusters to determine the critical uncertainties; i.e., the clusters that have both the most impact on the issue of concern and the highest degree of uncertainty as to their resolution as outcomes.	Evaluate the results of the previous stage in terms of the variables with the highest level of impact and uncertainty using structural analysis.
Stage 6: Framing the scenarios	Selecting two initial critical uncertainties to create a scenario matrix, framing the scenarios by defining the extreme outcomes of the uncertainties.	Selecting two uncertainties creates a matrix with the results from the extreme outcomes.
Stage 7: Scoping the scenarios	Building a broad set of descriptors for each of the four scenarios prompted by the identification of causal loops.	Identify feedback loops responsible for the results observed using SD analytical tools (Martinez-Moyano, 2012)
Stage 8: Developing the scenarios	Developing scenario storylines, including key events, their chronological structures, and the “who and why” of what happens. The scenarios are likely to emphasize radical transformational change because of the augmented stages 3 and 7.	Create narratives, supported by time series, for each scenario based on the feedback loops selected from the previous stage and time series.

Abbreviations: AIL, augmented intuitive logics; SD, system dynamics.

(Wright et al., 2009). While there are templates, primers, and step-by-step approaches, which are identified by Kunc and O'Brien (2017), the focus of this section is the use of SD in two forms: qualitative and quantitative.

One qualitative SD approach is called resource mapping (Kunc & Morecroft, 2009). Resource mapping follows the resource-based approach to formally assess the organization's strengths and weaknesses, but it is enhanced by a dynamic aspect to rehearse the performance path of the organization defined by the different scenarios. Resource mapping helps managers visualize the system of strategic resources based on the SD concepts of stocks, flows, and feedback processes (Kunc & Morecroft, 2009). Additionally, different analyses can be performed on the resource map to identify levels of dynamic complexity (Giorgino et al., 2020).

Basically, the insights from scenarios in terms of uncertain factors are incorporated into the resource map through connecting them to the dynamics of resources and capabilities. These factors have been employed to develop the scenario themes and represent changing social, economic, political, regulatory, technological, or competitive issues (Kunc & O'Brien, 2017). They are included in the map as exogenous factors directly affecting the resources/capabilities (Kunc & O'Brien, 2017). Therefore, there is a clear trail between the scenarios and their impact on the resources and capabilities of the business. The impacts can be presented through narratives about the future performance of the business under different scenarios and strategies (Kunc & O'Brien, 2017). Given the similarity between resource maps and SD, resource maps can be transformed into quantitative SD models to rehearse the performance of the organization showing trends over time of the key resources and financial profitability under each scenario.

Figure 4 shows an example presented by Kunc and O'Brien (2017) related to this integration. The example describes scenarios for a bookseller company with multiple stores on the high street. First, the map reflects all resources using rectangles and capabilities using circles together with their causal relationships, which are presented as arrows with positive/negative signs depending on the

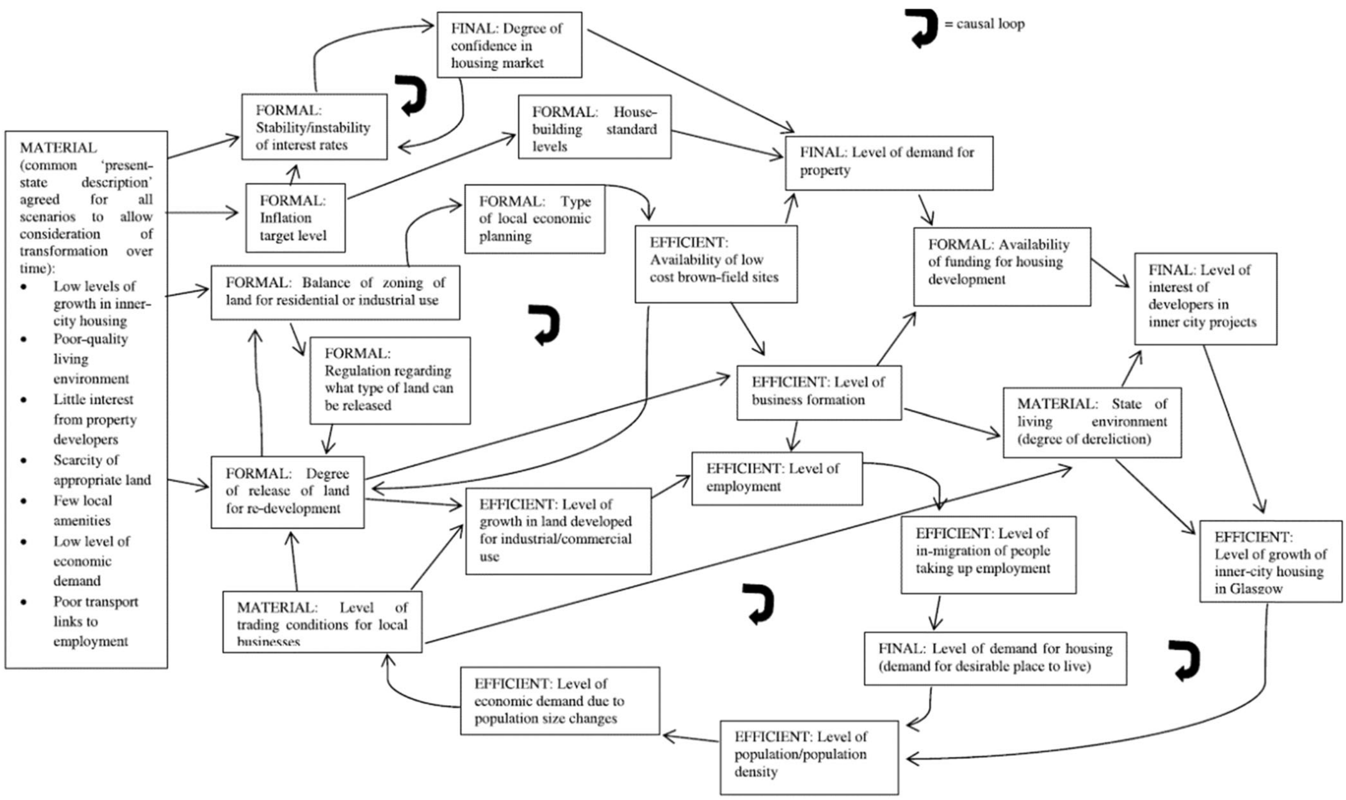

FIGURE 2 Original influence diagram from Derbyshire and Wright (2017; fig. 2, p. 263).

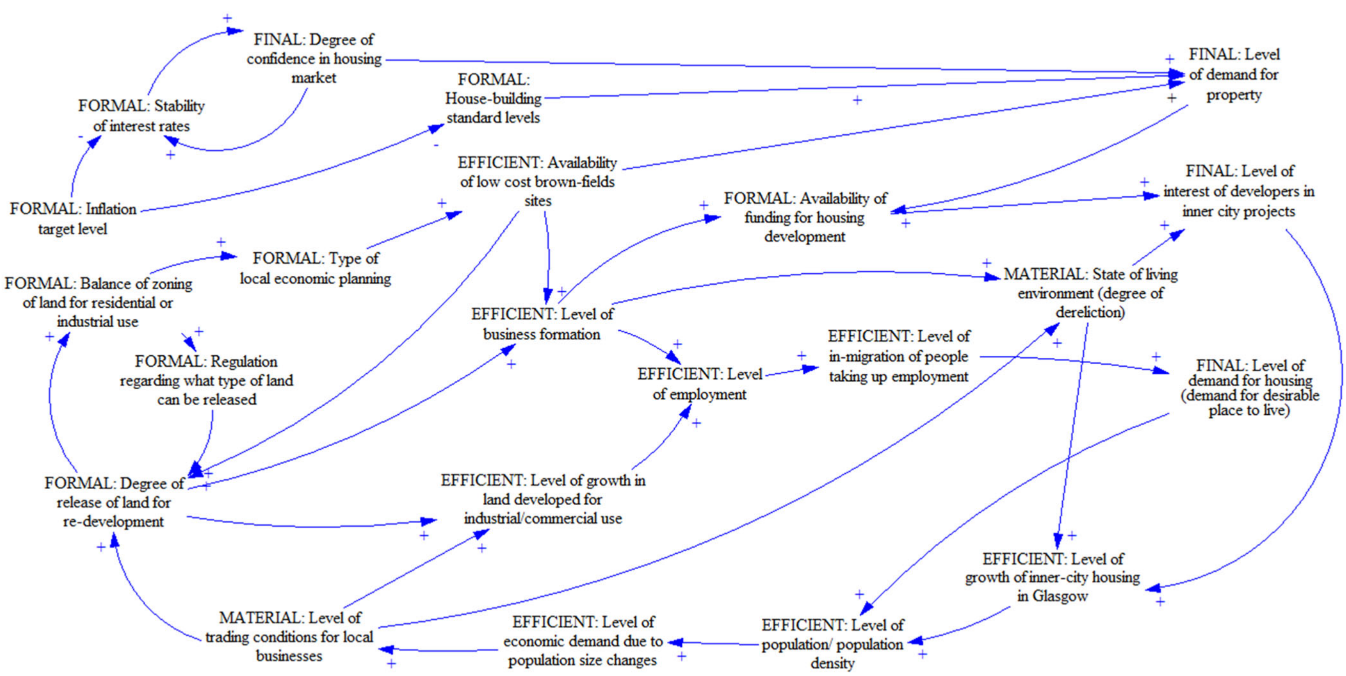

FIGURE 3 Redevelopment of influence diagram from Derbyshire and Wright (2017) (Figure 2) into a causal loop diagram.

impact on the performance. Each resource has included the drivers of its change using double lines entering (arrowheads are toward the resource), if it increases the resource, or leaving (arrowheads are outward), if it decreases the resource. The map also presents three key uncertainties, which are shown as hexagons, used to develop the scenario themes.

In this case of integration, scenarios are generated separately from the SD model following traditional methods, for example,

TABLE 5 Structural analysis of the influence diagram.

Variable	Number of causal loops	Types of feedback
Degree of confidence in the housing market	1	Reinforcing
Stability of interest rates	1	Reinforcing
Inflation target level	0	Not applicable
House-building standard levels	0	Not applicable
Balance of zoning of land for residential or industrial use	7	Reinforcing
Regulation regarding what type of land can be released	1	Reinforcing
Degree of release of land for redevelopment	12	Reinforcing
Level of trading conditions for local businesses	13	Reinforcing
Level of growth in land developed for industrial/ commercial use	2	Reinforcing
Level of business formation	8	Reinforcing
Availability of low-cost brown-fields sites	6	Reinforcing
Type of local economic planning	6	Reinforcing
Level of economic demand due to population size changes	13	Reinforcing
Level of population/population density	13	Reinforcing
Level of employment	4	Reinforcing
Level of demand for property	1	Reinforcing
Availability of funding for housing development	3	Reinforcing
Level of interest of developers in inner-city projects	6	Reinforcing
State of living environment (degree of dereliction)	6	Reinforcing
Level of in-migration of people taking up employment	4	Reinforcing
Level of demand for housing (demand for a desirable place to live)	4	Reinforcing
Level of growth of inner-city housing in Glasgow.	9	Reinforcing

intuitive logics, and their implications or impacts are used to identify future performance paths in a representation of the system using SD. The insights from this sequential process, scenarios-simulation, can help managers to understand the impacts of the model and prepare specific strategies that can be rehearsed using the simulation (O'Brien & Dyson, 2007). Another interesting example is the case discussed by Strohhecker (2005) supporting a bank to face a potentially chaotic short-term scenario where scenarios were presented by managers to the SD modeling team so they could test them.

3 | DISCUSSION

First, I discuss synergies between SD and scenarios, which have been exploited through a multimethodology framework, as well as the limitations and challenges of using both methods together.

3.1 | Synergies

First, if a critical aspect of building scenarios is to engage with the users (Rowland & Spaniol, 2021), then SD does not differ from scenarios. However, scenario literature has discussed extensively factors affecting the engagement with users and the issue of subjectivity during the process. For example, Franco et al. (2013) evaluated the impact of cognitive styles within participants on the efficiency of engagement, for example, reducing and selecting key uncertainty factors and creating storylines, during scenarios. Bryson et al. (2016) suggest that a deliberate and high degree of turbulence has to be promoted to influence the process of surfacing codified and tacit knowledge and enrich the group's framing of plausible futures. They indicate the need for an experienced facilitator given the complexity of scenario workshops, the multiple process steps, and the creation of turbulence. These lessons can be applied to facilitated SD modeling.

On the other hand, Rouwette (2016) provided a comprehensive review of studies on facilitated SD modeling, with a particular emphasis on behavior using two perspectives. On the one hand, SD modeling aims to change a problematic situation for the better, so it necessitates the users to implement the results from the modeling project. Implementation assumes that at least some stakeholders participating in the project change their behavior. To explain issues on implementation, researchers focused on the interaction between participants, the problem, and the model, which is observable during modeling sessions. This is an area that can potentially be useful to complement scenarios, whose focus is not implementation. On the other hand, a facilitated approach also encourages certain behaviors of participants in sessions. For instance, information sharing and equal participation instead of high levels of cognitive conflict and politicking. In this case, there may be room to embed lessons from scenario literature into SD practice.

Second, Jashari et al. (2022) suggest planners move toward a more quantitative approach when developing scenarios. Beyond the need for evidence-based decision-making, as a reason, the use of scenarios can be for exploration or in normative mode. When scenarios are normative, they may require additional evidence in terms of data and causal relationships because there is a need to document the solutions and/or the steps to achieve a desired future (Maier et al., 2016). Therefore, the use of quantitative approaches

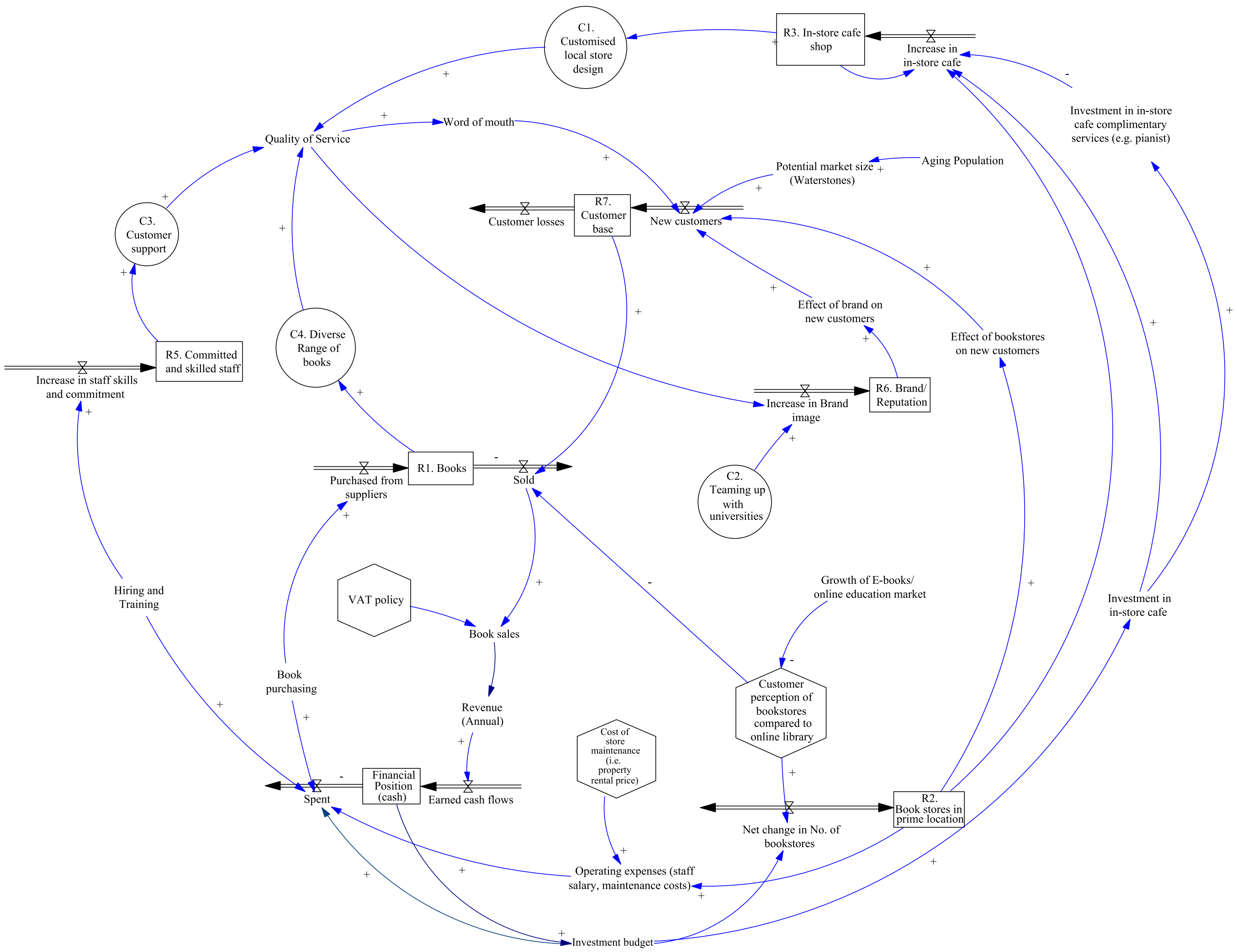

FIGURE 4 Resource map integrated with scenario factors (fig. 1, p. 157 from Kunc and O'Brien).

like SD can provide not only the evidence (inputs, assumptions, outputs) but also a systematic process to verify, validate, and document (Monks et al., 2018) the disciplined intuition employed to create the scenarios. Using a simulation model to develop scenarios can offer internal consistency and rigorous structural analysis and logics, which are evaluation criteria for scenarios (Bradfield et al., 2005). In exploration mode, SD can be considered as a potential robust decision-making method (Lempert et al., 2006) to address the challenge of decision-making under conditions of deep uncertainty, where uncertainty exists about the model of the system or its inputs.

Third, another key synergy is the use of scenarios for strategic planning. One of the strengths of simulations is to support the development of strategies or plans that are robust under uncertainty (Maier et al., 2016). There are two approaches to the development of strategies after scenarios: static or adaptive (Maier et al., 2016). The static approach involves running one strategy across all plausible futures using the simulation. The outcome is a matrix strategy scenario with the performances obtained, so the decision makers know the robustness of the strategy to different future conditions. The adaptive approach considers multiple strategies tailored to each plausible future. In this case, the outcome is a description of each strategy, as implemented in the simulation, within its corresponding scenario, so the evaluation is a collective robustness of the different strategies.

3.2 | Limitations and challenges

One of the limitations is the need for experienced modelers to design and build the SD model. The experienced modeler may or may not be an experienced scenario practitioner. If the experienced modeler is not a scenario practitioner, one challenge will be coordinating the process in terms of the data required for the model and the development of the scenarios. The lack of understanding may generate a disconnected process where each method is employed to address different issues, as we observed in some examples.

One challenge is in terms of communicating the outputs of the combination of the methods. While the common output of the intuitive logics approach is a discursive narrative of the scenarios, the output of an SD model is a time series of relevant variables. One of the key challenges is to integrate the narratives with the time series generated by the simulation, especially if scenario practitioners have limited quantitative skills or SD modelers can't generate adequate narratives.

One important limitation is the potential restriction to creative thinking when using SD. When the start of scenarios is based on an existing SD model, the scenarios may be framed, or constrained, on the existing driving forces or outcomes indicated by the model. In this situation, scenarios are limited in terms of the breadth of the plausible futures. On the other hand, if participants don't know the value of variables due to deep uncertainty using SD in exploratory mode can trigger creative thinking from the results obtained.

Another challenge is the longevity of the system structure within the time horizon of scenarios. Some scenarios may consider that new driving forces emerge over time, so the structure of the future state does not resemble the original state of the system. SD models cannot capture new emergent structures, for example, new stocks and flows or feedback loops. This is an important limitation of SD models. Modelers should check with scenarios' participants whether the emergent structure is completely novel, for example, new stocks or feedback loops, or it has already existed but hasn't been active, for example, stocks have zero value or feedback loops aren't dominant due to nonlinear effects. If a new structure is needed, then more than one SD model is necessary to capture the two future states.

4 | CONCLUSION

The paper proposes a framework that exploits the synergies between SD and the scenarios briefly described.

First, if a critical aspect of building scenarios is to engage with the users (Rowland & Spaniol, 2021), then SD does not differ from the traditional scenario development process. All the examples shown in the article indicate a high level of engagement with the users in the development of the models.

Second, when we use SD models to generate scenarios, we should assess the process against the definition of the scenario (Spaniol & Rowland, 2019). In general, SD models are future-oriented since modelers aim to understand the future performance of the system given the current conditions, which may be external depending on the model. At the beginning of the modeling process, there is a step to identify boundaries for the model classifying factors as internal and external to the system being represented similar to the scenario setting. Therefore, SD modelers should use the correct concepts: changes in internal variables should be called "experiments" and changes in external variables called "scenarios."

Third, SD models represent the future in a plausible and possible manner by understanding the causal linkages existing in the system, for example, efficient causes but they can be expanded to include additional causes as indicated by AIL. Many modelers represent their results in multiple ways including narratives or stories supported by time series. Scenarios created using SD models can come from a systematized set of variables selected as part of a normal scenario development process. The final aspect of comparatively different scenarios will depend on the strengths of feedback processes and the existence of tipping points that switch dominant behaviors over time. While scenarios usually depict extreme situations, systems tend to be more stable than assumed. This is a strong difference compared with traditional scenario development.

Definitively, there is room for mutual enrichment in this area. For example, an SD model can test if the scenarios described can be meaningful alternatives given the values of certain factors in each scenario looking for tipping points. Or a SD model can provide the value of the factors to obtain comparatively different scenarios and the team decides if they are plausible.

Fourth, Berkhout et al. (2002) suggest that scenarios are machines for learning as they enable to make explicit stakeholders' and experts' mental models through the development of the process. Similarly, SD modeling has been described as "modeling for learning" (Sterman & Morecroft, 1994) as model building and use is done together with clients.

One important limitation is the paper does not represent the current situation of the field since it only provides a set of examples about the approaches. While there is some adoption of scenarios across SD literature in areas such as security, tourism and sustainability, strategic decision-making, and health epidemics (Kunc et al., 2018), future research can perform a systematic literature review of SD and scenarios using the framework proposed. Another limitation is the lack of specific evidence of the use of the framework. Computer simulations and scenarios seem to be limited to one–off activity affecting their possibility of learning over time. Scenarios, as well as computer simulations, can improve over time as lessons are learned, especially if a framework is used. Future research should look at long-term usage by companies and governments to evaluate the suitability of the framework over time.

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CONFLICT OF INTEREST STATEMENT

The author declares no conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

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