ASSESSING SYSTEMIC DRIVERS AND BARRIERS TO SUSTAINABLE DESIGN TRANSITIONS: RELATIONSHIP STRENGTHS AND RESEARCH GAPS

Basereh Taramsari, Hossein (1);
McFarren, John (1);
Watz, Matilda (2);
Hallstedt, Sophie I. (2,3);
Hoffenson, Steven (1)

1: Stevens Institute of Technology, U.S.A.;
2: Blekinge Institute of Technology, Sweden;
3: Chalmers University of Technology, Sweden

ABSTRACT

The sustainable design transition has proven to be a challenging process, in part due to the diverse set of stakeholders, which includes the general public, policymakers, scientific researchers, and businesses. In prior work, the interconnected relationships among systematic drivers and barriers for sustainable design were identified and mapped using a causal loop diagram at a relatively abstract level. To further understand and characterize this complex system, this research aims to identify the relationship strength levels among the variables in the system, as indicated by previous research identified in the literature. In addition, the knowledge maturity levels of these identified relationships are specified to illustrate strengths and gaps in the literature. The findings are used to create a refined system representation that illustrates the power dynamics between systemic driving forces to sustainable design transitions. The results of this work reveal valuable insights about the linkages among the driving forces of sustainable design transitions that can be used as a foundation for further investigation, such as experiments and data analytics that can better quantify these relationships.

Keywords: Systems thinking, Sustainability, Ecodesign, Complexity, Sustainable design transitions

Contact:
Basereh Taramsari, Hossein
Stevens Institute of Technology
United States of America
hbasereh@stevens.edu

Cite this article: Basereh Taramsari, H., McFarren, J.,Watz, M., Hallstedt, S. I, Hoffenson, S. (2023) 'Assessing Systemic Drivers and Barriers to Sustainable Design Transitions: Relationship Strengths and Research Gaps', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.68

1 INTRODUCTION

Sustainability has become an essential topic for businesses that seek to improve their corporate image, gain customers who are conscientious about their consumption, and position themselves for long-term success amid environmental and regulatory uncertainty. In a time where humans are the main force for change on the planet, the so called Anthropocene, many proactive companies consider sustainability not only as strategically important but also business critical (Volvo Group, 2022; Airbus, 2022). Contributing to sustainable development, i.e., development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (UN, 1987), is now an essential topic for many businesses. Our society, economy, and environment are widely considered the three key dimensions that serve as primary stakeholders in sustainability efforts (Broman and Robèrt, 2017; Raworth, 2017; Rockström et al., 2021). The adjustments required to establish sustainable practices, like any other relatively new policies or standards, can cause friction with management in the form of reluctance or a bias against making foundational changes to systems that may already produce satisfactory results. Even if more companies recognize the importance of building capabilities for sustainable product development to remain competitive, the relationships among social, environmental, and economic performance are still oftentimes viewed as trade-offs where some profit must be sacrificed to be "sustainable." For example, revising a legacy system to include sustainability measures would carry an upfront cost for a business, a significant barrier to many small- to medium-sized companies. Given this dilemma, the successful promotion of sustainable product development and its benefits depends on the concept being made clear, concise, and systematic (Baumgartner and Rauter, 2017).

Prior research sheds light on the forces that influence sustainability within and around the context of product development activities (Watz et al., 2021). However, the significant influences on sustainable development remain somewhat abstract, as they are difficult to quantify. This difficulty stems from the fact that this web of influences includes societal trends and concerns as well as product domain specific factors, among other non-numerical factors that are challenging to measure. This research proposes an approach to estimate and visualize the power dynamics that surround sustainable product development. A more detailed understanding of the relationships regarding how systemic forces influence one another can lead to a systems model capable of revealing insights about that system's most significant leverage points. This model is intended to be applicable across various business sectors as a valuable tool for assessing the application of sustainable practices while also clarifying the roles of stakeholders and the flows of influences created by them. The research questions (RQs) addressed in this paper are: (RQ1) what does the literature indicate about the strengths of relationships that systemically influence sustainable design transitions? and (RQ2) What are the research gaps concerning systemic driving forces to sustainable design transitions?

2 BACKGROUND

2.1 Sustainable development and design

Global societies' practices of production and consumption, and within that, the manufacturing industry, are key contributors to the sustainability problems that we face today. To achieve the global sustainability goals, the manufacturing sector needs to transition into new modes of designing, developing, and manufacturing products and services (Bengtsson et al., 2018). In recent years, the rise of sustainability activism and the market shift favoring sustainable goods and services have enabled small steps towards loosening companies' resistance to sustainable design (Sneddon et al., 2006). With the advancement of ecodesign and tools such as life cycle assessment (LCA), the perceived feasibility and understanding of sustainable design and product development have improved, and companies are becoming increasingly interested in implementing sustainable development. However, few out of the plethora of presented tools and methods aiming to support companies in transitioning into sustainable design are in fact implemented and are often criticized for being either too reductionistic or too complicated to apply (Peace et al., 2018). For instance, traditional product LCA can give a detailed view of the environmental impacts across a product life cycle, but it is heavily dependent on data quality and the need to quantify all factors, even those with natively qualitative attributes (Chang et al., 2014) and is not applicable in the earliest phases of radical innovation projects. Having many different sustainability indicators can hinder effective decision making as they can generate an overwhelming amount of

https://doi.org/10.1017/pds.2023.68 Published online by Cambridge University Press

data which makes it a complex task to understand which factors are most important. Simplified tools, such as those that consolidate all environmental indicators and social impacts into a single score, might on the other hand not allow thorough understanding about potential trade-offs, sub-optimizations, and key-influencing factors (Peace et al., 2018).

Although policy-making towards sustainable development does help to further incentivize a transition to sustainable design through the enforcement of, e.g., new regulations (Hojnik, 2018), there is today a risk that enforced regulations might cause unintended sustainability sub-optimizations. An example of a recently enforced sustainability policy is the EU taxonomy framework, which requires all financial activities, including product design and development, to demonstrate to which extent they contribute to European sustainability goals. However, its implementation is imperfect. For example, a criterion in the EU taxonomy about increased circularity of resource flows does not state how to ensure that disposed materials are in fact recycled according to EU environmental and health regulation (Chakraborty and Chatterjee, 2017). To avoid such risks, policies targeting a transition to sustainable design need to be designed with a systems vision in mind rather than optimization of specific product or service characteristics (Milios, 2018).

To realize a sustainable design transition, actors within different societal system domains must take into consideration the interplays among key stakeholders in society, and how these affect and are affected by the practices of resource and energy use across product and service life cycles, which in turn induce different types of impacts on the environment and society. Sustainability transitions can therefore be viewed as an issue of complex system dynamics (Loorbach et al., 2017), which requires that effective leverage points in the various system domains and subsystems are identified and addressed using a systems perspective, rather than optimizing the efficiency of each individual system domain (Ceschin and Gaziulusoy, 2016), with a risk for unintended consequences (Hjorth and Bagheri, 2006).

2.2 Relationships strength assessment

Prior research mapped out and proposed some critical systemic elements that connect sustainable design practices to sustainability outcomes using a group model building (GMB) technique (Watz et al., 2021). The result of this work was a causal loop diagram (CLD) that identifies systemic variables that influence sustainable design and depicts how those variables qualitatively influence one another as part of an extensive system, with its variables and relationships summarized in Table 1. In the system dynamics field, the next step in advancing a model from a CLD is creating a dynamic system model using stock and flow functions (Andersen et al., 2007). The dynamic system model can then be evaluated in search of leverage points, representing opportunities for improvement in systemic sustainability, or exploring the impacts of different policies or interventions on system-level outcomes.

The CLD is made up of some variables that have apparent measurable aspects (such as monetary investment) and many that do not (such as societal awareness or fundamental knowledge). Most of the system's variables could be generally referred to as "invisible assets" (IAs), which identifies them as informational resources (Itami and Roehl, 1987). Examples of informational resources include consumer trust, cultural trends, or other elements which cast influence and enable corporate adaptation via a somewhat obscure mechanism (Itami and Roehl, 1987). This paper aims to advance the CLD from

Table 1. Variables of CLD and their input & outputs

Symbol	Variable description	Inputs	Outputs
V1	Sustainability performance of the socio-ecological system	V12, V13	V3
V2	Cultural value of sustainability	V3	V3
V3	Societal awareness and concern about sustainability	V1, V2, V4, V6, V13	V2, V4, V5, V13
V4	Established environmental and social sustainability policies	V3, V7	V3, V7,V8
V5	Investments in sustainability research and education	V3, V8, V13	V6, V9, V10, V13
V6	Fundamental knowledge about systems and sustainability	V5	V3, V8
V7	Availability/affordability of sustainable materials and processes	V4	V4, V8
V8	Sustainable design drivers for companies	V4, V6, V7, V9, V13	V5, V11
V9	Availability of value-added sustainable design approaches	V5	V8, V10
V10	Capabilities of sustainable design and product development	V5, V9, V11	V11
V11	Implementation of sustainable product development in practice	V8, V10	V10, V12
V12	Sustainability of available product and service offerings	V11	V1, V13
V13	Sustainable product purchasing and use behaviour	V3, V5, V12	V3, V5, V8

https://doi.org/10.1017/pds.2023.68 Published online by Cambridge University Press

the previous paper, toward a dynamic model, by investigating what is known in the literature about the influences among model elements, and identifying gaps that can motivate future work.

In the field of quantifying relationships, and in particular IAs, many approaches are proposed and analyzed in the literature, but a practical universal approach has not yet been established (Levy and Duffey, 2007). Most approaches are contained in specialized studies aimed at incorporating IAs in specific company valuations or analyzing IA contribution to a company's success and competitive advantage (Boj et al., 2014). Multi-Criteria Decision Analysis (MCDA) methods are powerful tools utilized frequently in practice for solving decision problems involving several agents, capable of quantifying the influence of multiple tangible and intangible factors on organizational performance and the accomplishment of objectives (Boj et al., 2014). Several methods fall under the classification of MCDA, and they generally fit into one of three different methodology groups: multi-attribute value theory, prioritization and classification methods, and interactive methods (Visentin et al., 2020). The method used in the most relevant literature is referred to as the Analytic Network Process (ANP) method (Saaty, 1996). The ANP method effectively quantifies the relationships between IAs and system objectives in the form of a network with dependencies, which helps to reduce the abstraction that exists in those relationships (Boj et al., 2014). However, using the ANP method in the present study would require extensive data on variable influences for developing complex network supermatrices, which has not yet been produced for this topic. The ANP method, like any MCDA method, also has some limitations for this research, given that it implies the presence of a decision-making problem. Despite this, the study of the ANP method's applications points towards the idea that making informed judgments about network influences and assigning a scale to their relative importance without relying on numerical data can still lead to realistic and meaningful outputs (Saaty, 2004). A large and growing number of other MCDA methods have been developed and studied. Commonly implemented examples include multiple attribute utility theory (MAUT), analytic hierarchy process (AHP), and evaluation matrix (Evamix) (De Montis et al., 2004). Each MCDA method's objectives, data requirements, and stakeholder involvement differ.

There are several challenges in quantifying the strength of the relationships between the elements of the CLD. These elements are diverse, cover different fields of study, and have various measurement units. Because of these reasons, the previously described methods cannot provide reliable and accurate values associated with the web of forces in CLD. Instead, the literature addressing these relationships' strengths can be used as a foundation to describe how strong they are. Knowledge maturity (KM) is a concept that can also address the knowledge and provide support to show the level of confidence in the information for decision makers (Watz et al., 2022). Different researchers have applied this method to assess and support decision-making and understand the reliability of their rationals (Johansson et al., 2011; Svensson et al., 2018). However, in this research, the knowledge maturity level is a metric that measures the level of the literature available to support the quantification or classification of relationship strength.

3 RELATIONSHIP STRENGTH LEVELS WITHIN STAKEHOLDER CLUSTERS

The previously-developed CLD's variables (see Table 1) can be classified into four stakeholder groups: the general public (V1, V2, V3, V13), policymakers (V4, V5), scientific researchers (V6, V7, V9, V10), and businesses (V8, V11, V12).

Due to the limited quantitative knowledge available in most linkages and the absence of a generally accepted method for evaluating specific values for each linkage, a relationship strength level (RSL) for each linkage is classified as one of three levels: strong, moderate, or weak. Another essential parameter to be characterized is the knowledge maturity level (KML) associated with each variable linkage. The KML has been scaled as acceptable and inferior, where acceptable means sufficient literature supports the RSL assignment, and inferior indicates gaps within the current literature addressing those linkages that require more attention. This analysis applies these visual representations to create a new model of the CLD that has essential and comprehensive data about the relationship strength and the knowledge behind that strength classification. In the updated CLD drawing, the arrow's color indicates the RSL, and the arrow's thickness indicates the KML supporting that RSL assignment.

https://doi.org/10.1017/pds.2023.68 Published online by Cambridge University Press

Figure 1 shows the four identified clusters (node color) with each relationship's respective RSL (arrow color) and KML (arrow thickness). Following the convention of CLDs, a positive (+) arrow indicates that the variables change together in the same direction, whereas a negative (-) arrow indicates that they change in opposite directions.

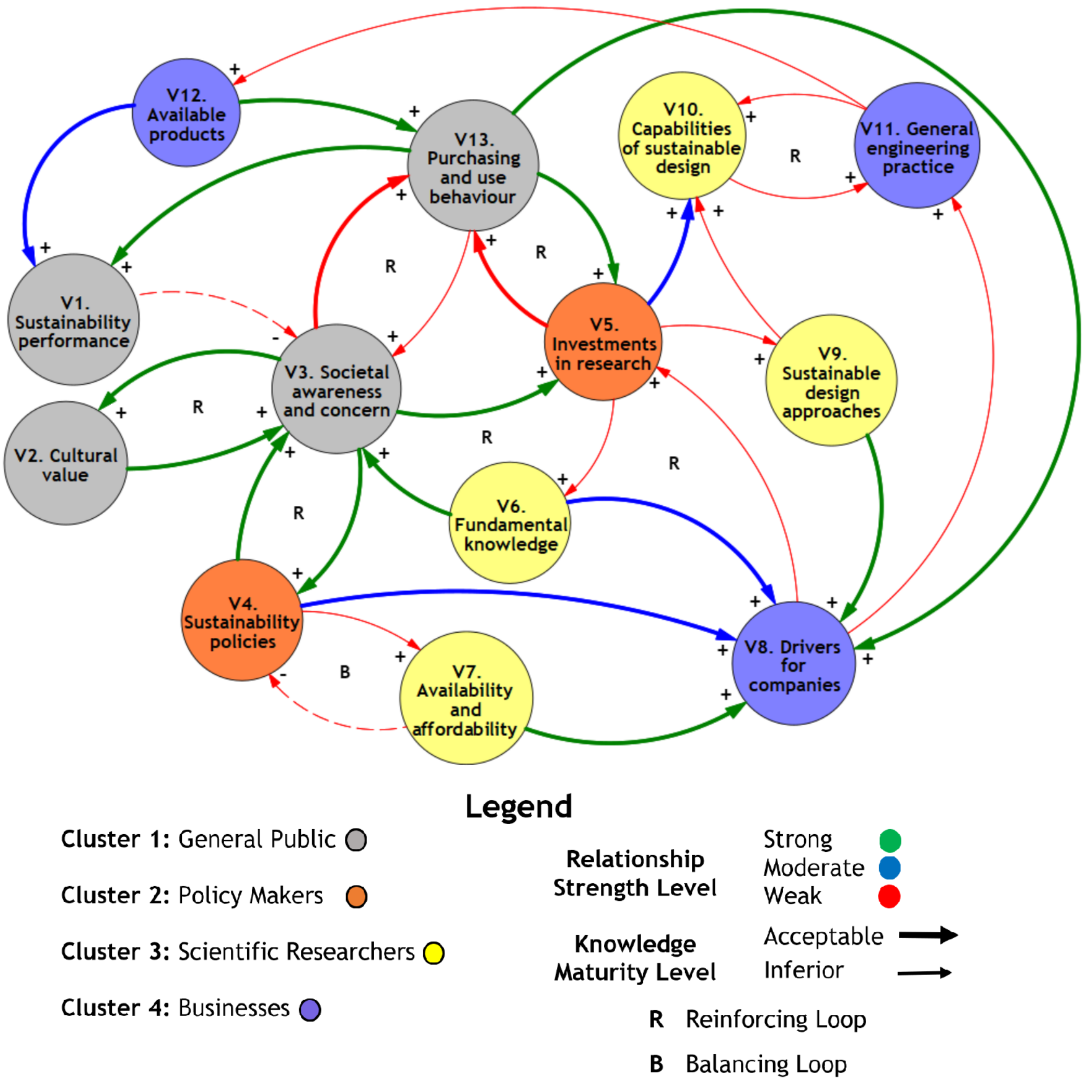

Figure 1. Causal loop diagram (CLD) of driving forces of sustainability

3.1 Cluster 1: General public

A series of case study analyses conclude that penetration of eco-innovations into the market is essential for environmental sustainability performance, but that heavily depends on market reception and customer assessment (Carrillo-Hermosilla et al., 2010). Findings suggests that the sustainability of available product offerings and product service solutions (V12) may have an intermediate impact on the sustainability performance of the socio-ecological system (V1). Sustainable product purchasing and use/behavior (V13) appears to be more influential to V1 since green products cannot make their intended impact without positive consumer reception, indicating strong relationship of V13 on V1.

The link between the cultural value of sustainability (V2) and societal awareness and concern about sustainability (V3) was found to involve a two-way relationship, despite the original CLD's one-way representation. Since cultural values can evolve due to widespread concerns, V3 influences V2, albeit with a delay. Research shows that attention to content from entertainment and news media, tasked with representing societal concerns, is a significant predictor of changes in ethics (Cho and Krasser, 2011). In other research that analyzes the link between a person's values and the direction of their

https://doi.org/10.1017/pds.2023.68 Published online by Cambridge University Press

support and concern for sustainability challenges, there is a substantial and statistically significant connection (Marcus et al., 2015), which points to a strong two-way influence between V2 and V3.

Research also finds a strong link between personal values and the direction of concern and support, suggesting a substantial impact for V2 (Marcus et al., 2015). One study shows that policy instruments are effective at stimulating societal concern, suggesting a strong relationship between V4 and V3 (Kinzig et al., 2013). Intense public reactions to scientific evidence of environmental hazards suggest a high impact of V6 on V3 (Lee et al., 2006).

The relationship between investments in sustainability research and education (V5) and sustainable product purchasing and use/behavior (V13) involves a positive reinforcing loop. Research points to the idea that the link from V5 to V13 is weak, as most Education for Sustainable Development (ESD) programs are not currently calling for personal behavior management, focusing instead on establishing sustainability values (Arbuthnott, 2009). This is explained further by investigating another relationship: the weak direct relationship between social concern (V3) and behavior (V13). This weakness has been concluded from psychological studies, which find that the relationship between attitude and behavior contains several intermediate factors, including contextual elements such as inconvenience or personal habits (Arbuthnott, 2009). One study that combines psychological, demographic, and situational variables to investigate consumer purchasing behavior sheds light on the relationship between the sustainability of available product offerings and product service solutions (V12) and sustainable product purchasing and use/behavior (V13) (Bhate and Lawler, 1997). The study reveals that the key factor behind purchasing sustainable products is their availability in supermarkets and elsewhere, which points to V12's strong influence on V13.

3.2 Cluster 2: Policy makers

In a study that analyzes the interaction between established environmental and social sustainability policies (V4) and societal awareness and concern about sustainability (V3), their two-way influence, as seen in the CLD, is validated. Research suggests that when education and social persuasion alone are insufficient to incite enough public concern about global sustainability problems, policy instruments such as penalties or incentives are a practical solution (Kinzig et al., 2013). Policy instruments are powerful for stimulating societal awareness and concern, leading communities to work towards a common goal. Simultaneously, societal awareness of problems such as global sustainability is a significant contributor to policy implementation. Social concerns have functional limits and eventually turn to policy-making for assistance. Policy, in turn, bolsters those social efforts and incentives others to join the cause, which points to a robust reinforcing relationship between V3 and V4.

The relationship between societal awareness and concern about sustainability (V3) and investments in sustainability research and education (V5) can be characterized by socially responsible investment (SRI) activity. The size of the SRI market is determined by the sum of assets under management that applies environmental, social, and governance (ESG) in their portfolio selections (US SIF, 2022). Primarily within the past two decades, SRI has exploded in popularity among investors, which reflects increases in investor responses to societal concerns. In 1995, the SRI market sat at $162 billion US, whereas it is was $2.3 trillion US by 2005 (Renneboog et al., 2008), and $17.1 trillion US in 2020, representing approximately 33% of all US assets under professional management (US SIF, 2022). This massive upward trend of SRI indicates a strong relationship between V3 and V5. Findings indicate that firms are most sensitive to market demands, suggesting a substantial impact for V13 (Lee et al., 2006).

In a study concerning sustainability information and knowledge flows, conclusions shed light on the relationship between fundamental knowledge about socio-ecological systems, sustainability, and sustainable development (V6) and societal awareness and concern about sustainability (V3) (Lee et al., 2006). The research indicates that the spread of scientific evidence of environmental hazards causes social concern and demand for improvement. The strength of the causation is characterized by examples of court cases from citizens over environmental impact statements made public by the government. This indicates that V6 has a substantial impact on V3. The same study revealed that firms are most likely to participate in a sustainable activity because of market demands above other reasons. Research investment is required for a firm to begin participation in sustainable development, indicating a solid link from sustainable product purchasing and use/behavior (V13) to investments in sustainability research and education (V5).

3.3 Cluster 3: Scientific researchers

Investments in sustainability research and education (V5) has been identified as the only input to the development and availability of value-added sustainable design approaches (V9), as it is shown in Figure 1. Further analysis of the literature concerning ESD has led to critical discoveries about this relationship. From a study that investigates how universities can meaningfully contribute to sustainability, it is determined that universities are not currently approaching ESD in a way that equips students to successfully challenge the paradigms and structures that oppose sustainability in real-world industry practice (Tilbury, 2011). The study argues that universities must unify in extending the scope of ESD beyond school walls, as many currently limit student exposure to sustainable action projects to those occurring on their physical premises. These findings point to a generally weak relationship between V5 and V9. Previous research sheds light on the relationship that investment in sustainability research and education (V5) has with capabilities for sustainable design and product development (V10). The research argues that technological capabilities and the generation of technological change are the direct results of highly specialized labor, which is not automatically nor directly derived from capital goods (Bell et al., 1995). These findings indicate that V5 likely has an intermediate influence on V10.

3.4 Cluster 4: Businesses

The relationship between several variables and sustainable design drivers for companies (V8) is described in a study that analyzes the stimuli that contributed to the realization of several ecodesign solutions across 77 companies (Van Hemel and Cramer, 2002). The study concludes that internal stimuli are the strongest drivers of ecodesign, the most compelling examples being innovation opportunities, product quality increases, and market opportunities.

The focus on market opportunities points to sustainable product purchasing and use/behavior (V13) having a substantial impact on the increase of V8. Additionally, the availability and affordability of sustainability-improving materials and flows and processes (V7) and the development and availability of value-added sustainable design approaches (V9) could very reasonably fall under the umbrella of innovation opportunities. This points to both V7 and V9 having strong impacts on V8. In the same study, although internal stimuli ranked highest in their influence on ecodesign, some external stimuli also hold considerable power. Two of the most significant external stimuli driving ecodesign are government legislation and customer demands. Not only does this point to an intermediate connection between the number of established environmental and social sustainability policies (V4) and V8, but it also reinforces the strength of the relationship between V13 and V8.

In a study that explores the link between the integration of organizational learning and corporate sustainability transitions, conclusions support the idea that innovative learning models are significant drivers of corporate sustainability (Jamali, 2006). Findings emphasize using intentional learning to help point organizations in more sustainable directions while increasing stakeholder satisfaction. This helps to describe the relationship between fundamental knowledge about socio-ecological systems, sustainability, sustainable development (V6), and sustainable design drivers for companies (V8). Due to the extensively formal learning measures that are found to be needed in order for them to catalyze corporate sustainability, the research points to V6 having an intermediate impact on V8. If a more straightforward, less formal integration of organizational learning were to be proven to have an equally significant impact on corporate sustainability transitions, the link between the variables might be considered more robust.

Although external stimuli do not rank highly in influencing ecodesign, government policy is dominant among them, suggesting intermediate impact of V4 on V8 (Van Hemel and Cramer, 2002). Integration of formal organizational learning models catalyzes corporate sustainability transitions, suggesting intermediate relationship between V6 and V8 (Jamali, 2006). Innovation opportunity is one of the most influential factors driving ecodesign, suggesting a strong impact for V7 and V9 (Van Hemel and Cramer, 2002). The market potential is deemed the most vital driver of ecodesign for companies, suggesting a very high impact for V13 (Van Hemel and Cramer, 2002).

4 CONCLUDING DISCUSSION

This research investigated the strengths of the relationships among key influencers of sustainable design implementation, along with the knowledge maturity level included in each of those links. Each element

https://doi.org/10.1017/pds.2023.68 Published online by Cambridge University Press

of a previously-developed CLD was investigated using the literature, organized by clusters of stakeholders, and the results demonstrated strong, moderate, and weak relationships between the variable pairs. The results obtained from this study revealed valuable insights about the linkages among the driving forces of sustainability. According to the clustered CLD shown in Figure 1, research, information, and policy influences cultural values and societal awareness for a behavior change. In addition, it is clear that behavior change impacts sustainable performance and, thereby, a transformation toward a more sustainable society. The implementation of sustainable product development in general engineering practice (V11) is influenced by the sustainable driving forces for companies (V8) and the capabilities of sustainable design (V10). Societal awareness is highly influenced by cultural values, fundamental knowledge, and the number of sustainability policies. However, there are still substantial gaps in the literature addressing these links, revealed by the KML classifications in Figure 1.

This paper contributes to sustainable design in several ways. First, key research gaps have been uncovered, showing where certain areas of the literature need further study. These research gaps and the requirements of these elements can be used to design survey or interview studies, or other empirical data collection activities, targeted at understanding the particular stakeholder groups identified in the CLD. Through the investigation of each link in the CLD, leverage points have also been uncovered. In a scenario where an organization is looking to improve on one of the nodes shown in the CLD, these findings differentiate the strong forces from the weak, clarifying their significance, which may help an organization determine the best course of action for reaching its sustainability goals. Although the relationships between some variables remain somewhat abstract, these findings significantly reduce the abstraction of many of the CLD variable relationships. Differentiating strong influences from moderate and weak ones in the web of sustainable design influences sheds light on leverage points and helps promote sustainable design practices through clarity and concision.

Some limitations and challenges arose in the process of determining intervariable relationship strengths. Unfortunately, one recurring theme throughout this study is contradiction. In the literature, for each CLD variable link, sources using different data and interpretations frequently offer mismatched and even entirely contradictory conclusions. The lack of objective conclusions is a source of uncertainty within the findings, limiting the trustworthiness and precision of the results. Although not perfectly objective, the results reported here reflect the general conclusions of some relevant pieces of available literature. Several CLD relationships have yet to be verified by existing literature. CLD links are considered inferior in terms of the knowledge maturity level if they are not supported by research or case studies from which a conclusion can be drawn.

The future work in this research includes conducting research and designing surveys that can address the research gaps revealed using the CLD. Utilizing the foundation created in this research, comprehensive interview or survey studies should elicit valuable information and help remedy some of the current shortcomings in the literature. Such a survey could collect input from experts from the identified stakeholder clusters to validate, further detail, and improve the understanding of relationships in the CLD, or to identify leverage points to inform, e.g., business strategy and policy-making. These surveys can be utilized to quantify the strengths between the elements of the CLD and seek more detailed information on the relationships variables, as well as data on influence delays to support a meaningful quantitative model that can be validated.

Narrowing the CLD model's scope from the general domain of sustainable design to focus instead on a particular product or subdomain may help reduce the abstraction of the model. Regardless of the resulting application of CLD, this research may serve as a valuable foundation for further research and development of similar models.

ACKNOWLEDGMENTS

Financial support from Sweden's Innovation Agency – Vinnova are gratefully acknowledged.

REFERENCES

Airbus (2022), "Sustainability commitments", Online, https://www.airbus.com/en/sustainability/sustainability-commitments. Accessed 20 November 2022.

Andersen, D.F., Vennix, J.A., Richardson, G.P. and Rouwette, E.A. (2007), "Group model building: problem structuring, policy simulation and decision support", *Journal of the Operational Research Society*, Vol. 58 No. 5, pp. 691–694.

Arbuthnott, K.D. (2009), “Education for sustainable development beyond attitude change”, *International Journal of Sustainability in Higher Education*.

Baumgartner, R.J. and Rauter, R. (2017), “Strategic perspectives of corporate sustainability management to develop a sustainable organization”, *Journal of Cleaner Production*, Vol. 140, pp. 81–92.

Bell, M., Pavitt, K. et al. (1995), “The development of technological capabilities”, *Trade, technology and international competitiveness*, Vol. 22 No. 4831, pp. 69–101.

Bengtsson, M., Alfredsson, E., Cohen, M., Lorek, S. and Schroeder, P. (2018), “Transforming systems of consumption and production for achieving the sustainable development goals: moving beyond efficiency”, *Sustainability science*, Vol. 13, pp. 1533–1547.

Bhate, S. and Lawler, K. (1997), “Environmentally friendly products: factors that influence their adoption”, *Technovation*, Vol. 17 No. 8, pp. 457–465.

Boj, J.J., Rodriguez-Rodriguez, R. and Alfaro-Saiz, J.J. (2014), “An anp-multi-criteria-based methodology to link intangible assets and organizational performance in a balanced scorecard context”, *Decision Support Systems*, Vol. 68, pp. 98–110.

Broman, G.I. and Robèrt, K.H. (2017), “A framework for strategic sustainable development”, *Journal of cleaner production*, Vol. 140, pp. 17–31.

Carrillo-Hermosilla, J., Del Río, P. and Könnölä, T. (2010), “Diversity of eco-innovations: Reflections from selected case studies”, *Journal of cleaner production*, Vol. 18 No. 10-11, pp. 1073–1083.

Ceschin, F. and Gaziulusoy, I. (2016), “Evolution of design for sustainability: From product design to design for system innovations and transitions”, *Design studies*, Vol. 47, pp. 118–163.

Chakraborty, P. and Chatterjee, C. (2017), “Does environmental regulation indirectly induce upstream innovation? new evidence from india”, *Research Policy*, Vol. 46 No. 5, pp. 939–955.

Chang, D., Lee, C. and Chen, C.H. (2014), “Review of life cycle assessment towards sustainable product development”, *Journal of cleaner production*, Vol. 83, pp. 48–60.

Cho, S. and Krasser, A.H. (2011), “What makes us care? the impact of cultural values, individual factors, and attention to media content on motivation for ethical consumerism”, *International Social Science Review*, Vol. 86 No. 1/2, pp. 3–23.

De Montis, A., De Toro, P., Droste-Franke, B., Omann, I. and Stagl, S. (2004), “Assessing the quality of different mcda methods”, in: *Alternatives for environmental valuation*, Routledge, pp. 115–149.

Hjorth, P. and Bagheri, A. (2006), “Navigating towards sustainable development: A system dynamics approach”, *Futures*, Vol. 38 No. 1, pp. 74–92.

Hojnik, J. (2018), “Ecological modernization through servitization: Eu regulatory support for sustainable product–service systems”, *Review of European, Comparative & International Environmental Law*, Vol. 27 No. 2, pp. 162–175.

Itami, H. and Roehl, T. (1987), “Mobilizing invisible assets, harvard university press”, *Cambridge, MA*.

Jamali, D. (2006), “Insights into triple bottom line integration from a learning organization perspective”, *Business Process Management Journal*.

Johansson, C., Hicks, B., Larsson, A.C. and Bertoni, M. (2011), “Knowledge maturity as a means to support decision making during product-service systems development projects in the aerospace sector”, *Project Management Journal*, Vol. 42 No. 2, pp. 32–50.

Kinzig, A.P., Ehrlich, P.R., Alston, L.J., Arrow, K., Barrett, S., Buchman, T.G., Daily, G.C., Levin, B., Levin, S., Oppenheimer, M. et al. (2013), “Social norms and global environmental challenges: the complex interaction of behaviors, values, and policy”, *BioScience*, Vol. 63 No. 3, pp. 164–175.

Lee, J.J., Gemba, K. and Kodama, F. (2006), “Analyzing the innovation process for environmental performance improvement”, *Technological forecasting and social change*, Vol. 73 No. 3, pp. 290–301.

Levy, F. and Duffey, M.R. (2007), “A review of existing methods to quantify intangible assets”, *International Journal of Accounting, Auditing and Performance Evaluation*, Vol. 4 No. 4-5, pp. 382–399.

Loorbach, D., Frantzeskaki, N. and Avelino, F. (2017), “Sustainability transitions research: transforming science and practice for societal change”, *Annual review of environment and resources*, Vol. 42, pp. 599–626.

Marcus, J., MacDonald, H.A. and Sulsky, L.M. (2015), “Do personal values influence the propensity for sustainability actions? a policy-capturing study”, *Journal of Business Ethics*, Vol. 127, pp. 459–478.

Milios, L. (2018), “Advancing to a circular economy: three essential ingredients for a comprehensive policy mix”, *Sustainability Science*, Vol. 13 No. 3, pp. 861–878.

Peace, A., Ramirez, A., Broeren, M.L., Coleman, N., Chaput, I., Rydberg, T. and Sauvion, G.N. (2018), “Everyday industry—pragmatic approaches for integrating sustainability into industry decision making”, *Sustainable Production and Consumption*, Vol. 13, pp. 93–101.

Raworth, K. (2017), “Why it’s time for doughnut economics”, *IPPR Progressive Review*, Vol. 24 No. 3, pp. 216–222.

Renneboog, L., Ter Horst, J. and Zhang, C. (2008), "Socially responsible investments: Institutional aspects, performance, and investor behavior", *Journal of banking & finance*, Vol. 32 No. 9, pp. 1723–1742.

Rockström, J., Gupta, J., Lenton, T.M., Qin, D., Lade, S.J., Abrams, J.F., Jacobson, L., Rocha, J.C., Zimm, C., Bai, X. et al. (2021), "Identifying a safe and just corridor for people and the planet", *Earth's Future*, Vol. 9 No. 4, p. e2020EF001866.

Saaty, T.L. (1996), *Decision making with dependence and feedback: The analytic network process*, Vol. 4922, RWS publications Pittsburgh.

Saaty, T.L. (2004), "Fundamentals of the analytic network process—dependence and feedback in decision-making with a single network", *Journal of Systems science and Systems engineering*, Vol. 13, pp. 129–157.

Sneddon, C., Howarth, R.B. and Norgaard, R.B. (2006), "Sustainable development in a post-brundtland world", *Ecological economics*, Vol. 57 No. 2, pp. 253–268.

Svensson, M., Bertoni, A. and Maximilian, L. (2018), "On knowledge maturity and biased nature of staged decision making in a high consequence industry", in: *15th International Design Conference, Dubrovnik*, Vol. 1, The Design Society, pp. 465–476.

Tilbury, D. (2011), "Higher education for sustainability: a global overview of commitment and progress", *Higher education in the world*, Vol. 4 No. 1, pp. 18–28.

UN (1987), "Report of the world commission on environment and development: Our common future", *Accessed Feb*, Vol. 10, pp. 1–300.

US SIF (2022), "The forum for sustainable and responsible investment, report on us sustainable and impact investing trends. us sif: The forum for sustainable and responsible investment.", Online, https://www.ussif.org/files/US%20SIF%20Trends%20Report%202020%20Executive%20Summary.pdf. Accessed 20 November 2022.

Van Hemel, C. and Cramer, J. (2002), "Barriers and stimuli for ecodesign in smes", *Journal of cleaner production*, Vol. 10 No. 5, pp. 439–453.

Visentin, C., da Silva Trentin, A.W., Braun, A.B. and Thomé, A. (2020), "Life cycle sustainability assessment: A systematic literature review through the application perspective, indicators, and methodologies", *Journal of Cleaner Production*, Vol. 270, p. 122509.

Volvo Group (2022), "Sustainability future.", Online, https://www.volvogroup.com/en/sustainability/sustainability-future.html. Accessed 20 November 2022.

Watz, M., Hoffenson, S. and Hallstedt, S.I. (2021), "Exploring systemic forces that influence sustainable design transitions", *Proceedings of the Design Society*, Vol. 1, pp. 1501–1510.

Watz, M., Johansson, C., Bertoni, A. and Hallstedt, S.I. (2022), "Investigating effects of group model building on sustainable design decision-making", *Sustainable Production and Consumption*, Vol. 33, pp. 846–862.

https://doi.org/10.1017/pds.2023.68 Published online by Cambridge University Press