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Characterizing the capability frontier: Key attributes determining the development of capabilities

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Abstract

System Dynamics research on capability traps, where organizations remain in low capability and performance equilibrium because of poor resource allocation, spans over two decades and various industries, including agriculture, industry, and humanitarian aid. However, there is a gap in understanding how specific capability attributes affect resource allocation decisions. This study advances the capability trap literature by developing a theoretical model analyzing how key capability attributes—development time, erosion time, and productivity—impact organizational performance and managers' decisions. We introduce the concept of a "capability region", an attractive area for capability investments, delineated by a "capability frontier" determined by threshold values of these three attributes. This model helps managers understand the factors driving capability development and supports better decision-making, especially in sustainable practices. By identifying where sustainability-related capability investments are likely to succeed, this research offers practical guidance for organizations to escape or avoid capability traps, promoting sustainable growth and adaptation.

KEYWORDS

capability attributes, capability frontier, capability region, capability traps, system dynamics

1 | INTRODUCTION

The capability trap, a concept defined by Repenning and Sterman (2001, 2002), manifests when organizations become stuck in an equilibrium of low organizational performance because of underinvestment in high-yield activities that demand prolonged periods to achieve desired outcomes. Such low organizational performance can imperil an organization's survival, as exemplified by the struggles of industry giants like Kodak, Blockbuster, and Nokia amidst the digital revolution (Bradley, 2017; Satell, 2014; Surowiecki, 2013). Kodak, a dominant player in the photography industry, invented the digital camera but did not fully embrace the technology, resulting in a significant decline in revenues and bankruptcy in 2013 (Bradley, 2017). Similarly, Blockbuster, a leading video rental company, failed to recognize the shift to digital streaming and mail order services, like Netflix did (Satell, 2014). As Blockbuster's business model became outdated, it filed for bankruptcy in 2010. Nokia, once a dominant force in mobile phones, struggled to adapt to smartphones and operating systems like iOS and Android (Surowiecki, 2013). Nokia eventually sold its phone business to Microsoft, because of its lack of agility and innovation. While failure to develop specific capabilities may not inevitably lead to organizational demise, it can severely impede competitiveness (Repenning & Sterman, 2001, 2002). This challenge intensifies within the sustainability context, where the failure to cultivate capabilities in areas such as diffusion of renewable energy technologies (RETs) (Tabrizian, 2019), financial strategies for long-term sustainable investments with evident impact (Cunha et al., 2021), or institutional frameworks for environmental regulation (Ostrom, 1990) can not only confer competitive disadvantages but also exacerbate global environmental and social crises.

In the realm of sustainability, capability traps highlight the dangers of organizations prioritizing short-term gains over long-term sustainability. Stern (2007) finds that "strong, deliberate policy action" is needed, implementation delays can be dangerous and costly, and international response should focus on long-term goals. Trade-offs between short-term development and long-term climate objectives are often exacerbated by the management of scarce resources (Dovers & Hezri, 2010). This short-term focus often leads to practices such as resource exploitation without considering regeneration rates, ultimately undermining sustainable development efforts (Daly, 1990; Sterman, 2000). For instance, unsustainable practices can deplete natural resources, mirroring how capability traps erode an organization's "resource pool" of skills, morale, and operational capacity. Notable instances of capability traps in sustainability permeate various industries and sectors, exemplified by Volkswagen Group's entanglement in the "Dieselgate" scandal (Becker & Traufetter, 2016), deep investment in fossil fuel extraction by major oil companies (e.g., BP, Shell, Total) (Christophers, 2022), and Indonesia's economic dependency on natural resource extraction, such as palm oil production, leading to significant deforestation and environmental degradation (Purnomo et al., 2020).

Repenning and Sterman (2001) advocate for a combination of capability-building and "day-to-day operations" to achieve optimal organizational performance. This echoes March's concept of exploitation, where organizations become entrenched in exploitative activities driven by short-term gains, neglecting investments in new activities or process improvements requiring more time to yield results (March, 1991; Repenning & Sterman, 2001, 2002). Underinvestment in developing capabilities, primarily focusing on exploiting activities, leads to "better-before-worse" scenarios, with performance declining in the long run (Repenning & Sterman, 2002). Conversely, investing in exploration, i.e., new activities and capabilities, can lead to a "worse-before-better" scenario, where performance initially falls but increases in the long run (March, 1991; Repenning & Sterman, 2001, 2002). This dichotomy underscores the significance of investing in sustainable practices and technologies, despite high upfront costs and long-term perspectives, given the substantial environmental, social, and economic returns they promise over time.

This research contributes to the capability trap literature examining the influence of three capability attributes (e.g., development time, erosion time, and productivity) on performance, a proxy for managers' propensity to develop them. It also contributes to the literature on sustainability, as such attributes influence the development of capabilities essential for environmental, social, and economic sustainability. Because managers are risk-averse and ambiguity-averse, the longer the time required to develop a capability, the less likely they are to develop the capability (Repenning & Sterman, 2002). Additionally, the time for a capability to become irrelevant, i.e., the erosion time, also affects managers' willingness to develop it. Capabilities that have a short lifespan are less appealing compared with those that endure for a longer time (ibid.). Finally, a capability affects performance through a productivity factor. These three critical attributes specific to a capability determine the impact of a capability on performance, but they also inform managers' decisions to allocate resources to develop it. Currently, there is little research guiding such resource allocation decisions.

The article is structured as follows: the next section focuses on capability traps in sustainability, then, we review the SD literature and the applications of the capability trap to different settings. Section 4 focuses on the capability attributes that influence resource allocation decisions for capability development. Section 5 provides the details of the formal system dynamics model and analyses the impact of different attributes on the model. Section 6 describes the requirements to develop capabilities to address sustainability challenges. Finally, we summarize the main capability insights, wereview contributions to theory and practice, we discuss research limitations, and provide directions for future research.

2 | CAPABILITY TRAPS IN SUSTAINABILITY

Sustainability represents an urgent global imperative, and addressing it effectively requires the development and enhancement of various capabilities. Challenges such as limited resources, inadequate technology, insufficient knowledge, and competing priorities often hinder the pursuit of sustainability (Sterman, 2008). Such challenges are exacerbated by global population growth, which put more pressure on natural ecosystems

(Wilmoth et al., 2022). By building different capabilities (e.g., technological, financial, institutional, etc.) nations, regions, municipalities, communities, and organizations can overcome these challenges and advance toward their environmental, social, and economic goals. For instance, consider the "dilemma facing pumpers from a groundwater basin where legal rights to withdraw water are not limited." (Ostrom, 1990, p. 137). A possible capability trap for this region, municipalities, and communities with access to this groundwater basin would be to pump as much water as "privately profitable … threatening the long-run survival of the basin." Instead, Ostrom (1990) develops design principles for governing the commons (i.e., evading capability traps) where the actors (e.g., nations, regions, municipalities, and communities) involved typically invested in the development of new capabilities. That is, they created "new private associations", developed mechanisms to "allocate water rights", "drafted legislation", introduced it to "the state legislature", galvanized support to ensure "the legislation passed", and "created special districts to tax all the water they withdrew" (Ostrom, 1990, p. 137).

Capability traps can present significant barriers to advancing sustainability, as they lock entities into inefficient practices because of gaps in different critical areas, such as technology, finances, institutional frameworks, knowledge, behavior, resources, and scalability. Technological capability traps occur when organizations lack the necessary expertise or resources to adopt sustainable technologies. For instance, small and mid-sized enterprises often struggle to implement energy-efficient processes because of high initial costs and a lack of technical knowledge (Purwandani & Michaud, 2021). Financial capability traps are exemplified by municipalities like those in developing countries where funding shortages impede the implementation of green infrastructure projects (Merk et al., 2012). Institutionally, the absence of robust policies or enforcement mechanisms can allow harmful practices to persist, as seen in some regions where weak governance fails to regulate the use of a common good (e.g., fishery, aquifer, etc.) effectively (Ostrom, 1990). Knowledge gaps also pose major obstacles, as in rural communities where a lack of awareness about sustainable agricultural techniques leads to continued reliance on harmful pesticides and fertilizers (Pretty, 2008). Behavioral capability traps are evident where traditional habits and cultural norms prevent the adoption of sustainable alternatives, such as in cities where car dependency overshadows public transport solutions despite clear environmental benefits (Mattioli et al., 2020). Resource-based traps often involve regions dependent on extractive industries, where transitioning to sustainable practices is hindered by economic reliance on non-renewable resources (Tcvetkov, 2022). Finally, scalability traps challenge the expansion of local sustainability successes to wider applications, often due to logistical and regulatory inconsistencies across different jurisdictions (Söderholm, 2020).

As communities often face challenges with a combination of these capability traps, it becomes critical to develop each area comprehensively. While integrating efforts across multiple capabilities can create synergies and overcome barriers, capability traps are typically difficult to escape. Therefore, to ensure more effective and widespread implementation of sustainable practices, a specific, detailed plan is essential. This plan should not only foster a broader shift toward sustainable practices but should also focus on strategically investing in the capabilities that are more likely to lead to the desired results. By studying the attributes that influence the effective development of capabilities, communities can be better prepared to confront the challenges imposed by capability traps that plague sustainability efforts.

3 | SYSTEM DYNAMICS APPLICATIONS OF THE CAPABILITY TRAP

Repenning and Sterman (2001, 2002) were the first to describe the dynamics associated with capability traps to capture the failure of organizations to develop improvement capabilities. In the twenty years that followed several researchers applied the capability trap to diverse settings, such as humanitarian organizations (Gonçalves, 2011), forest fire management (Collins et al., 2013), strategic management (Rahmandad & Repenning, 2016), critical infrastructure (Lyneis & Sterman, 2016), human systems (Landry & Sterman, 2017), highway systems (Guevara et al., 2017), homeless services (Fowler et al., 2019), agricultural systems (Herrera & Kopainsky, 2020), sustainability improvement (Faghihi, Kim & Ford, 2022), and non-profit organizations (Keith et al., 2024). Table 1 provides a structured analysis (reviewing context, causal loops, contribution, and implications) of selected capability trap articles.[1]

Below, we provide a summary of Repenning and Sterman (2001) describing the main aspects (e.g., causal loops, and dynamics) of capability traps. Repenning and Sterman (2001) introduce the concept of capability traps, where organizations become stuck in patterns of behavior that prioritize short-term operational gains over

[1]A more detailed review of each of the articles mentioned above including the complete table summarizing them is provided in an online appendix.

TABLE 1 Structured analysis of selected capability trap articles.

Title and authors	Context and objective	Main causal loops	Key contributions	Implications and practical applications
Nobody Ever Gets Credit for Fixing Problems that Never Happened — Repenning & Sterman, 2001	Introduces capability traps in organizations prioritizing short-term gains over long-term improvements.	Work harder, work smarter, reinvestment, shortcuts	Establishes foundational model for capability traps, emphasizing long-term thinking and continuous improvement.	Highlights the need for a culture that rewards long-term improvements and recognizes delayed benefits of investments.
Capability Traps and Self-Confirming Attribution Errors in the Dynamics of Process Improvement — Repenning & Sterman, 2002	Focuses on organizational process improvement dynamics, particularly managerial perceptions and workplace setup delays in recognizing improvement rewards.	Work harder, work smarter, reinvestment, rework	Detailed interaction of beliefs and workplace dynamics; adds "rework" loop to original model.	Provides insights into improving managerial understanding and structuring workplaces to foster genuine improvement efforts.
Balancing Provision of Relief and Recovery with Capacity Building in Humanitarian Operations — Gonçalves, 2011	Investigates challenges in humanitarian organizations, balancing immediate aid with capacity building for long-term effectiveness.	Relief/recovery focus, capacity focus, reinvestment	Adapts the original model to humanitarian contexts, introducing "worker experience" and "turnover" loops.	Suggests retaining lessons from field experiences to enhance quick aid effectiveness while building long-term capacities.
Forest Fire Management to Avoid Unintended Consequences — Collins et al., 2013	Analyses forest fire management in Portugal.	Fire control loop, prevention scarcity loop, native fire regime loop	Identifies the firefighting trap; proposes balanced fire suppression and prevention strategies.	Advocates for balanced fire management policies to manage long-term fire risks effectively.
How to Save a Leaky Ship — Lyneis & Sterman, 2016	Explores balancing maintenance and investments in critical infrastructure at a university, focusing on sustainability and profitability through energy efficiency investments.	Reactive and proactive maintenance, collateral damage, reinvestment in renewal and efficiency	Introduces "collateral damage" and specific reinvestment loops adapted to infrastructure maintenance.	Encourages significant and sustained investments to escape capability traps, enhancing social responsibility alongside profitability.
Capability Erosion Dynamics — Rahmandad & Repenning, 2016	Examines how organizational capabilities erode over time, exploring the dynamic interactions that undermine an organization's ability to maintain operational excellence.	Focuses on erosion mechanisms such as neglect of critical processes, attrition of skilled staff, and decay of physical assets.	Develops a model that quantifies how capability erosion can silently undermine organizations and offers strategies for identifying early signs of erosion.	Emphasizes the importance of proactive management strategies to prevent capability erosion and sustain organizational health.
The Capability Trap: Prevalence in Human Systems — Landry & Sterman, 2017	Explores the prevalence of capability traps across various human systems like foster care, healthcare, and education, focusing on how short-term pressures erode long-term capabilities.	Various, including pressures on short-term performance leading to neglect of maintenance, learning, and process improvement.	Applies the capability trap framework to social systems and identifies nested traps and caseload dynamics specific to human systems.	Calls for deeper research into capability trap dynamics in social systems and suggests focusing on long-term sustainable improvements over short-term gains.

TABLE 1 (Continued)

Title and authors	Context and objective	Main causal loops	Key contributions	Implications and practical applications
A dynamic perspective to farming system resilience and its trade-offs — Herrera & Kopainsky, 2020	Analyses the resilience of farming systems in Europe from a dynamic systems perspective, focusing on how these systems can adapt to and recover from adverse changes.	Examines trade-offs in resilience related to climate change and market fluctuations, highlighting how different resilience strategies may conflict.	Uses a system dynamics model to simulate impacts and explore strategic responses to environmental and market changes.	Suggests that understanding and managing trade-offs is crucial for developing resilient farming systems.
Designing Sustainability Programs to Avoid and Escape Capability Traps — Faghihi, Kim, & Ford, 2022	Explores how sustainability programs can be designed to avoid or escape capability traps, focusing on environmental and resource management.	Work harder, work smarter, reinvestment or ruin	Proposes design guidelines for avoiding/escaping capability traps; identifies high-leverage design features.	Offers policy and practical guidelines for sustainable program design, applicable to various contexts facing similar sustainability challenges

long-term improvements, leading to stagnation or decline in capabilities. Their foundational system dynamics model of capability traps (Figure 1a) captures four main loops — *Work Harder* (*B1*) ensures immediate problem-solving, *Work Smarter* (*B2*) enhances capabilities over time, *Reinvestment* (*R1*) captures the reinvestment of resources saved, and *Shortcuts* (*B3*) provide quick fixes that degrade long-term capability. The capability trap model generates two types of dynamics (Figure 1b). A "better-before-worse" behavior takes place when organizations rely on the *Work Harder* loop to handle variations in workload and solve immediate problems. In contrast, a "worse-before-better" behavior takes place when organizations rely on the *Work Smarter* loop.

A key insight of Repenning and Sterman (2001) is the need for organizations to develop a culture that values long-term gains over short-term fixes. This dynamic is particularly relevant in the context of sustainability management, where the need for immediate results often conflicts with the long-term investments required to achieve sustainability. Faghihi et al. (2022) extend these insights by examining how sustainability programs can be designed to avoid or escape capability traps. Their research provides a framework for integrating sustainability into organizational policies and practices.

4 | RESOURCE ALLOCATION DECISIONS FOR CAPABILITY DEVELOPMENT

To develop their stock of operational and dynamic capabilities, decision-makers at organizations make different resource-allocation decisions (Dierickx & Cool, 1989; Makadok, 2001; Maritan & Lee, 2017). To arrive at such decisions, decision-makers need to evaluate the returns to the capability investment, which is a combination of purchased tradable resources and firm-specific non-tradable resources (knowledge, skills, organizational processes) (Robins, 1992). Since it is this combination that makes the acquired assets more valuable to the organization than to its competitors, decision-makers would assess which specific combination of resources and current competences would be most beneficial to organizational performance (Greve, 2003; Repenning & Sterman, 2002) and evaluate make-or-buy decisions (Argyres, 1996).

Capability investments are crucial to organizational resilience, as they contribute to both current and future survival by meeting immediate organizational needs and providing an 'option value' for future contingencies (Bowman & Hurry, 1993; Kogut & Kulatilaka, 2001). In addition, there is a positive-feedback path dependence that leads to increasing returns on capability — the more capability an organization develops, the more it tends to develop in the future (Arthur, 1989, 1990, 1994; Nelson & Winter, 1982; Teece et al., 1997).

According to Dierickx and Cool (1989), capability stocks adjust over time, which they call "time compression diseconomies". This corresponds to the ***time it takes to develop the capability*** in the capability trap literature — the delay in developing the capability (Repenning & Sterman, 2002). The capability trap literature further operationalizes the capability lifecycle (Helfat & Peteraf, 2003) by specifying ***the time it takes for a capability to erode***, which is the time that the organization will be able to make use of that capability (Repenning & Sterman, 2001, 2002; Lyneis & Sterman,

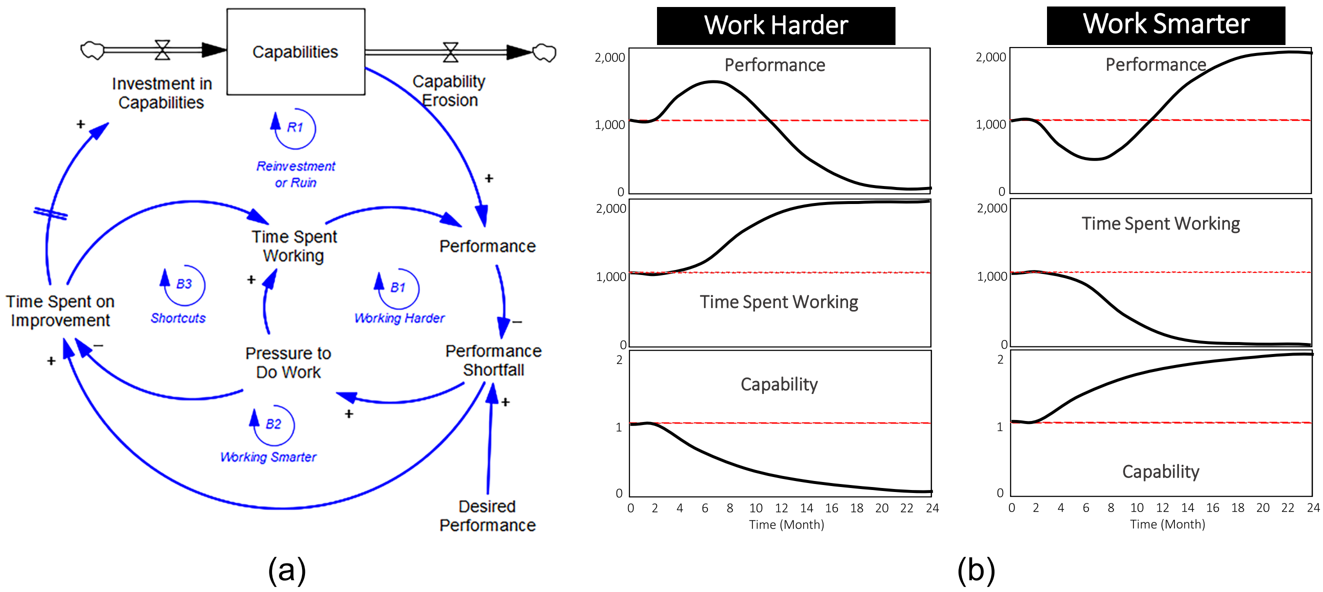

FIGURE 1 Stock and flow structure (a) and key dynamics (e.g., "better-before-worse" & "worse-before-better") of capability traps (based on Repenning and Sterman (2001)). [Colour figure can be viewed at wileyonlinelibrary.com]

2016; Landry & Sterman, 2017). Additionally, the returns to investment are operationalized as the ***productivity*** of effort, that is, a factor that multiplies the impact of applied effort on performance (ibid.). The three capability attributes influencing decision makers' capability investment decisions – capability development time, capability erosion time, and capability productivity (see Figure 2) – have been discussed in the capability trap literature (Repenning & Sterman, 2001, 2002; Gonçalves, 2011; Lyneis & Sterman, 2016; Landry & Sterman, 2017). The capability model (Figure 2) captures the stock of capabilities increased by the investment in capabilities and decreased by capability erosion. The time to develop capabilities has a direct effect on how fast the stock can increase and the capability erosion time affects how fast the stock of capabilities can deplete. Capabilities have a multiplicative impact on performance through their productivity. Finally, managers' resource allocation decisions are influenced by the pressure caused by performance shortfalls. With limited resources, allocation in work effort takes away from allocation in improvement effort.

While the three critical attributes of a capability determine its impact on performance, there is little research exploring how they influence resource allocation decisions. Different combinations of the three attributes may influence the appeal of a specific capability. Certain threshold values may render some capabilities unappealing and explain why some capabilities, while important, may not receive sufficient investment. Because the extant literature has little to say about these issues, we develop our formal model to enhance our understanding of the impact of capability attributes on resource allocations and capability investment decisions.

5 | MODEL STRUCTURE

Here, we develop a formal mathematical model to explore how the three capability attributes (e.g., development time, erosion time, and productivity) impact organizational performance and how they may influence the appeal of investments in the development of a capability. To determine the impact of the capability attributes on performance we start by defining organizational *Performance* (P_t) as the product of *Work Effort* (E_W), measured in work-hours, and the *Productivity of Capability* (*Pdy*), measured in people/work-hours:

$$P_t = E_{W_t} \cdot Pdy_t \tag{1}$$

where the *Productivity of Capability* (*Pdy*) is given by *Normal Productivity* (*NPdy*) multiplied by a capacity factor, with the ratio between the actual *Organizational Capability* (*C*) and its indicated level (C^*). The indicated level of organizational capacity (C^*) is determined by the ratio of reference investment in capability development (E^*_D) and total resources (E_T) allocated (e.g., total effort):

$$Pdy_t = NPdy \cdot (C_t/C^*) = NPdy \cdot \left(C_t/\left(E^*_D/E_T\right)\right) \tag{2}$$

The stock of *Organizational Capability* (*C*) accumulates the difference between the inflow of *Investment in*

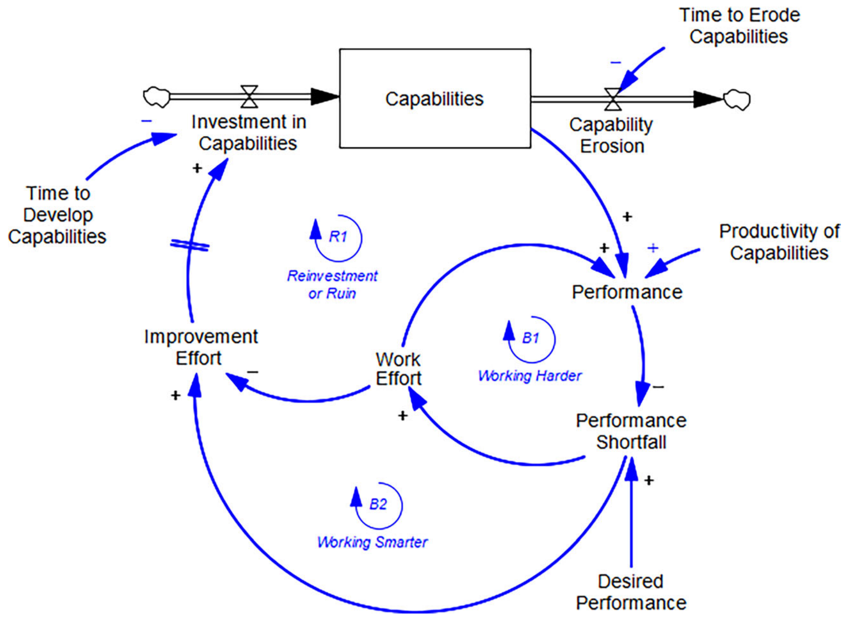

FIGURE 2 Stock and flow structure for capability traps (adapted from Repenning & Sterman, 2001). [Colour figure can be viewed at wileyonlinelibrary.com]

Capability (C_I) and the outflow of *Capability Erosion* (C_E). The *Investment in Capability* (C_I) is determined by a fractional adjustment of the gap between *Organizational Capability* (C) and the indicated one (C^*), and the fractional adjustment is given by 1/*Capability Development Time* (τ_D), capturing the rate that managers can build organizational capacity. And, *Capability Erosion* (C_E) is given by the ratio of *Organizational Capability* (C) and the average capability erosion time (τ_E).

$$\dot{C}_t = C_{I_t} - C_{E_t} \tag{3}$$

$$C_{I_t} = (C^* - C_t)/\tau_D \tag{4}$$

$$C_{E_t} = C_t/\tau_E \tag{5}$$

Organizations can assess whether a gap in performance exists by comparing actual performance with a desired performance level. Hence, the *Performance Shortfall* (P_S) is given by the difference between *Desired Performance* (P^*) and *Actual Performance* (P).

$$P_{S_t} = P^* - P_t \tag{6}$$

When managers prepare to make resource allocation decisions, they can assess the effort required from the *Performance Shortfall (P_S)*. They can estimate an *Effort Shortfall* (E_S) by dividing the *Performance Shortfall (P_S)* by the *Productivity of Capability (Pdy)*.

$$E_{S_t} = P_{S_t}/Pdy_t \tag{7}$$

Anchoring on the current level of *Work Effort* (E_W), managers can estimate the required increase in work effort by adding *Work Effort* (E_W) and *Effort Shortfall* (E_S). Furthermore, Managers can only allocate the resources available in the organization, facing a constraint in the *Indicated Work Effort* (E^*_W) at the *Total Effort* (E_T) available.

$$E^*_{W_t} = MIN(E_T, E_{S_t} + E_{W_t}) \tag{8}$$

The *Work Effort* (E_W) adapts smoothly to the *Indicated Work Effort* (E^*_W) with time. The amount of change in work effort is given by fractioning the difference between the *Indicated work Effort* (E^*_W) and the actual *Work Effort (E_W)*. The fraction of 1/*Time to Change Allocation* (τ_A) captures the speed with which managers seek to correct the effort allocation.

$$\dot{E}_{W_t} = \left(E^*_{W_t} - E_{W_t}\right)/\tau_A \tag{9}$$

Because of limited total resources, more resources allocated to *Work Effort* (E_W) results in fewer resources available to be allocated to the development of capabilities. The *Effort to Develop Capabilities* (E_D) is given by the difference between the *Total Effort* (E_T) and the *Work Effort* (E_W).

$$E_{D_t} = E_T - E_{W_t} \tag{10}$$

Managers establish the *Indicated Organizational Capability* (C^*) by adjusting the actual level of *Organizational Capability* (C) by the ratio of the *Effort to Develop Capabilities* (E_D) and its reference value. The *Reference Effort to Develop Capabilities* (E^*_D) is the amount required to maintain the current organizational capability at its current level. Because organizational capability aggregates across diverse dimensions (e.g., operational and dynamic capabilities), we conceptualize it as a variable ranging from zero to one. When organizational capability is zero, it cannot operate; when it is one, it has maximum capability allowing it to operate at maximum productivity.

$$C^*_t = C_t \cdot \left(E_{D_t}/E^*_D\right) \tag{11}$$

The 11 equations above completely describe the mathematical model capturing the impact of the three attributes – development time *(τ_D)*, erosion time *(τ_E)*, and normal productivity *(NPdy)* – on organizational performance. Substituting Equations (4) and (5) on Equation (3), we obtain:

$$\dot{C}_t = (C^* - C_t)/\tau_D - C_t/\tau_E \tag{12}$$

And, including the definition of *Indicated Organizational Capability* (C^*) in Equation (11), we can rewrite Equation (12) as:

$$\dot{C}_t = \left(C_t \cdot \left(E_{D_t}/E^*_D\right) - C_t\right)/\tau_D - C_t/\tau_E \tag{13}$$

Substituting Equation (10) into Equation (13), we obtain:

$$\dot{C}_t = \left(C_t \cdot \left((E_T - E_{W_t})/E^*_D\right) - C_t\right)/\tau_D - C_t/\tau_E \tag{14}$$

Reorganizing and collecting terms, we can rewrite Equation (14) as:

$$\dot{C}_t = \left\{\frac{E_T - E_{W_t}}{E^*_D \tau_D} - \frac{\tau_E + \tau_D}{\tau_E \tau_D}\right\} \cdot C_t \tag{15}$$

The solution of Equation (15) takes the form of an exponential function and can be written as:

$$C_t = K \cdot e^{\left(\frac{E_T}{E^*_D \tau_D} - \frac{\tau_E + \tau_D}{\tau_E \tau_D}\right)t} e^{-\frac{1}{E^*_D \tau_D}\int_0^t E_{wt}dt} \tag{16}$$

Remembering that organizational *Performance* (P_t), described in Equation (1), and *Productivity of Capability* (*Pdy*) given by Equation (2), we can rewrite:

$$P_t = E_{W_t} \cdot NPdy \cdot \left(C_t/\left(E^*_D/E_T\right)\right) = \left[\frac{NPdy \cdot E_T}{E^*_D}\right] \cdot E_{W_t} \cdot C_t \tag{17}$$

Finally, integrating the exponential solution captured in Equation (16), we can find an equation that expresses organizational *Performance (P_t)* in terms of the resources allocated by managers *Work Effort* (E_W), in terms of the product of *Work Effort* (E_W) and an exponential function of *Work Effort* (E_W):

$$P_t = \left[K\frac{NPdy \cdot E_T}{E^*_D}\right] e^{\left(\frac{E_T}{E^*_D \tau_D} - \frac{\tau_E + \tau_D}{\tau_E \tau_D}\right)t} E_{wt} e^{-\frac{1}{E^*_D \tau_D}\int_0^t E_{wt}dt} \tag{18}$$

Equation (18) has three components. The first one is a constant that depends on organizational parameters, such as fixed *Total Effort* (E_T) available, *Normal Productivity* (*NPdy*), and the *Reference Effort to Develop Capabilities* (E^*_D). The second parameter is an exponential function that evolves over time with constant parameters (e.g., development time *(τ_D)*, erosion time *(τ_E)*, *Total Effort* (E_T), and *Reference Effort to Develop Capabilities* (E^*_D). Finally, the third parameter describes a transcendental equation that depends on managers' allocation of resources, that is, *Work Effort* (E_W). By characterizing the impact of three key attributes on organizational performance, it is possible now to generate propositions to test how they moderate the impact of managers' allocation of resources (e.g., *Work Effort*) on organizational performance.

5.1 | Exponent analysis

If we assume that the effort allocated to "work" is constant, then we can easily integrate work effort over time obtaining the simple result ($E_{wt} \cdot t$). Performance over time can be written as:

$$P_t = \left[K\frac{NPdy \cdot E_T}{E^*_D}\right] e^{\left(\frac{E_T}{E^*_D \tau_D} - \frac{\tau_E + \tau_D}{\tau_E \tau_D}\right)t} E_{wt} e^{-\left(\frac{E_{wt}}{E^*_D \tau_D}\right)t} \tag{19}$$

Next, we introduce a new variable p to represent the percentage of total effort (E_T) allocated to work, such that:

$$E_{wt} = pE_T \tag{20}$$

And since E_{wt} is constant, K becomes the initial value of capability, C_0. Equation (19) becomes:

$$P(t) = \frac{p\,NPdy\,C_0\,E_T{}^2}{E_D^*} e^{\left(\frac{E_T}{E_D^*\tau_D} - \frac{1}{\tau_D} - \frac{1}{\tau_E} - \frac{p\,E_T}{E_D^*\tau_D}\right)t} \tag{21}$$

Focusing on the exponent of the exponential, we can assess whether it (and consequently performance), increases or decreases. The condition for performance to increase is:

$$\frac{E_T}{E_D^*\tau_D} - \frac{1}{\tau_D} - \frac{1}{\tau_E} - \frac{p\,E_T}{E_D^*\tau_D} > 0 \tag{22}$$

Working the algebra and isolating p, we obtain:

$$p < 1 - \frac{E_D^*}{E_T}\left(\frac{\tau_E + \tau_D}{\tau_E}\right) \tag{23}$$

That is, when p, the percentage of total effort allocated to work, is less than the quantity in the right-hand side (RHS), performance increases exponentially. The right-hand side depends on the required development effort with the times to develop and erode a capability. If τ_D is small, or τ_E is large the ratio of $\tau_E + \tau_D$ over τ_E approaches 1. Therefore, the right-hand side of the equation approaches:

$$p < 1 - \frac{E_D^*}{E_T} \tag{24}$$

This inequality shows that, if we want performance to increase, it we must allocate effort to capability development above the reference level of effort required to build a capability (E_D^*). If on the other hand, If τ_E is small, or τ_D grows larger than τ_E, the right-hand side factor gets multiplied by a factor (τ_D/τ_E) that is larger than 1.

$$p < 1 - \frac{E_D^*\tau_D}{E_T\tau_E} \tag{25}$$

The condition for the right-hand side to be positive leads to:

$$\tau_D < \tau_E\left(\frac{E_T - E_D}{E_D^*}\right) \tag{26}$$

which suggests that there is a maximum that τ_D can grow, beyond which it does not make sense to invest in the capability. Similarly, there is a minimum value of τ_E beyond which it does not make sense to invest in developing the capability.

$$\tau_E > \tau_D\left(\frac{E_D^*}{E_T - E_D}\right) \tag{27}$$

That is, for capabilities with small development times (τ_D) or long erosion times (τ_E) it is possible to develop the capabilities by simply investing effort beyond the reference level required to build a capability (E_D^*). In contrast, for capabilities with long development times (τ_D) or short erosion times (τ_E) there is a maximum length of development time and a minimum length of erosion time beyond which it does not make to try to develop the capability.

5.2 | Univariate analysis

First, we consider how performance in the model is influenced by each of the three parameters (e.g., $NPdy$, τ_D, τ_E). Then, we perform a partial derivative analysis of performance with respect to each parameter to inform the expected behavior of performance for changes in those parameters.

5.2.1 | Influence of NPdy

When the productivity of a capability ($NPdy$) is high, its impact on performance is also high, rendering the capability more attractive. In contrast, when productivity is low, it has a low impact on performance, rendering it less attractive.

Proposition 1. The higher the productivity of a capability (NPdy), the more attractive it is.

A partial derivative analysis of performance with respect to the productivity of a capability ($NPdy$) allows us to test Proposition 1. The equation below shows the result:

$$\frac{\partial P(t)}{\partial NPdy} = \frac{pC_0\,E_T{}^2}{E_D^*} e^{\left(\frac{E_T}{E_D^*\tau_D} - \frac{1}{\tau_D} - \frac{1}{\tau_E} - \frac{p\,E_T}{E_D^*\tau_D}\right)t} \tag{28}$$

Because the derivative $\frac{\partial P(t)}{\partial NPdy}$ is always positive – since the constants and exponentials are all positive – it implies that $NPdy$ has a positive impact on performance. Proposition 1 is confirmed.

5.2.2 | Influence of τ_E

When the time for a capability to erode (τ_E) is long, investment in the capability is more attractive, as the organization will be able to make use of the new capability for a longer period. The faster a capability erodes (i.e., the shorter a capability lasts), the lower its attractiveness.

> **Proposition 2.** The longer the time to erode a capability (τ_E) the more attractive it is.

A partial derivative analysis of performance with respect to the time for a capability to erode (τ_E) allows us to test the proposition. The next equation shows the result of that partial derivative.

$$\frac{\partial P(t)}{\partial T_E} = \left(\frac{t}{\tau_E^2}\right)\frac{p\,NPdy\,C_0\,E_T{}^2}{E_D^*}e^{\left(\frac{E_T}{E_D^*\tau_D}-\frac{1}{\tau_D}-\frac{1}{\tau_E}-\frac{p\,E_T}{E_D^*\tau_D}\right)t} \tag{29}$$

This derivative $\frac{\partial P(t)}{\partial T_E}$ is always positive meaning that, as τ_E increases performance does too. The longer it takes for a capability to erode, that is, the higher τ_E , the smaller the change in performance. Hence, Proposition 2 is confirmed.

5.2.3 | Influence of τ_D

When the time to develop a capability (τ_D) is short – what Landry & Sterman (2017, p. 36) describe as "quick wins" – the decision to invest in building the capability becomes more attractive. In contrast, the longer the time to develop a capability, the lower the attractiveness (Repenning & Sterman, 2001, 2002). The last proposition states:

> **Proposition 3.** The shorter the time to develop a capability (τ_D), the more attractive it is.

A partial derivative analysis of performance with respect to the time to develop the capability (τ_D) allows us to test Proposition 3. The equation below shows the result of that partial derivative.

$$\frac{\partial P(t)}{\partial T_D} = \left(\frac{E_D^* + E_T\,(p-1)}{\tau_D^2 E_D^*}\right)t\frac{p\,NPdy\,C_0\,E_T{}^2}{E_D^*}e^{\left(\frac{E_T}{E_D^*\tau_D}-\frac{1}{\tau_D}-\frac{1}{\tau_E}-\frac{p\,E_T}{E_D^*\tau_D}\right)t} \tag{30}$$

To investigate the sign of the $\frac{\partial P(t)}{\partial T_D}$ derivative, we must analyze the sign of the first coefficient in the right-hand side of the derivative, given below:

$$E_D^* + E_T(p-1) \tag{31}$$

When this derivative is negative, a reduction in the time to develop a capability (τ_D) will lead to an increase in performance. Hence, we check the condition for Equation (27) to be less than zero.

$$E_D^* + E_T(p-1) < 0 \tag{32}$$

This results in the familiar Equation (23). When the derivative is negative, a decrease in the time to develop a capability (τ_D) will lead to an increase in performance. Hence, the condition for Equation (27) to be less than zero.

$$p < 1 - \frac{E_D^*}{E_T} \tag{33}$$

Hence, for the proposition to hold, the condition above suggests that the fraction of total effort (p) allocated to work (p) should be lower than that of the reference effort to build a capability. A result that is sensible. If managers are trying to build up a capability, the investment in capability should be high (i.e., above the reference effort). When such condition is met, Proposition 3 can also be confirmed — that is, a shorter capability development time (τ_D), the more attractive it is.

5.3 | Multivariate analysis

When all three parameters take favorable values – e.g., short capability development time (τ_D), long erosion time (τ_E), and high productivity (*NPdy*) – developing the capability is very attractive for an organization. When all three parameters take unfavorable values – e.g., long capability development time (τ_D), short erosion time (τ_E), and low productivity (*NPdy*) – developing the capability is very unattractive. For favorable values, the attractive area we label the "capability region", it is highly likely that most managers would be interested in investing to develop the capability. For unfavorable values, the unattractive area, it is unlikely that managers would be interested in developing the capability.

Between the two regions (e.g., the attractive and unattractive) areas, an interesting situation arises where managers encounter a mix of favorable and unfavorable values for these parameters, making the decision to invest in a capability more challenging. We conjecture that there must be a frontier separating the two regions, a threshold surface separating managerial decisions to develop from managerial decisions to not develop a capability. We label this threshold surface "the capability frontier" (see Figure 3a).

Since the appeal of capabilities increases when it takes less time to develop it (τ_D) than the time to erode it (τ_E), we consider the ratio between the two (τ_D/τ_E) and productivity (*NPdy*) to create plots of their impact on performance. Intuitively, when the ratio between the time to develop and erode a capability is less than one ($\tau_D/\tau_{E\,<\,1}$), we would expect a positive impact on performance. Similarly, increasing productivity (*NPdy*) would favorably impact performance (Figure 3b). Below, we create three-dimensional surface plots to examine the sensitivity of performance to the three parameters. For *NPdy*, we assume values between 0 and 5 whereas the ratio of t_D/t_E ranges from 0.5 to 2. In addition, we use the simple closed form solution for performance, under constant work effort. Furthermore, we assume total work effort (E_T) to be 100; K, the integrating constant from the calculation of capability to be 0.1; and E_D^*, required effort to develop capacity to be 25 or 50 (Figure 4).

The color bar shows the percentage of effort (p) allocated for capability building. When the bar is black $p\ = 75\%$, when it is dark grey $p\ = 50\%$, and when $p = 25\%$ the bar is light grey. The surface plots show that, if managers invest enough to build capability (percentage effort allocated to capability building greater than 25% ($E_D^* = 25$, $E_T = 100$), then high performance occurs at the top right side of the scatter plot — characterized by high *NPdy* and $\tau_D/\tau_E < 1$. In addition, for increasing values of the τ_D/τ_E ratio, when the time to erode capability is faster than the time to build it, performance is low. That is, it is better to not build capability, which is characterized by

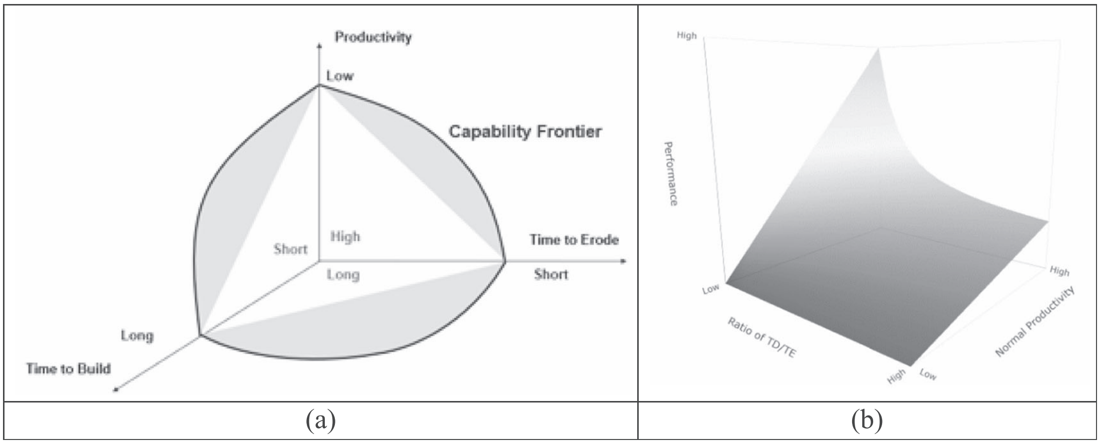

FIGURE 3 (a) The capability frontier and (b) performance as a function of τ_D/τ_E and NPdy.

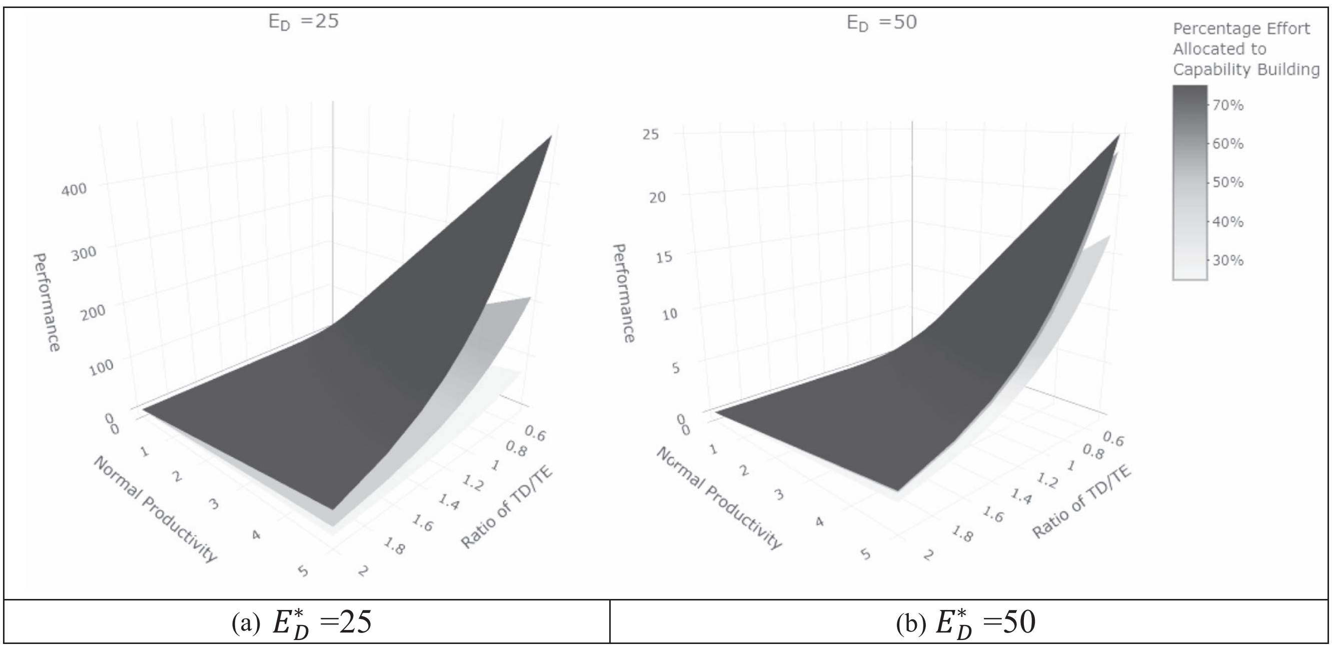

FIGURE 4 Scatter plots examining the impact of parameters on performance

the dark grey and light grey surfaces. When $E_D^* = 50$, we observe a similar pattern as before. To build capacity, the percentage effort allocated to capability building should be more than 50%. Consequently, high performance occurs again at high productivity and low τ_D/τ_E ratio.

6 | CAPABILITY DEVELOPMENT TO ADDRESS SUSTAINABILITY CHALLENGES: AN INITIAL EXPLORATION

The development of capabilities to address sustainability challenges is complex and context-dependent. The following analysis is tentative and exploratory, aiming to provide initial insights rather than definitive conclusions. Here, we revisit the capabilities required to advance sustainability (e.g., technology, finances, institutional frameworks, knowledge, behavior, resources, and scalability), considering the three key attributes identified for capability development. Table 2 below includes range estimates for capability development time (τ_D), erosion time (τ_E), and productivity (*NPdy*), supported by selected research, and educated guesses for the overall likelihood of their successful development. The estimates could help stakeholders prioritize interventions to tackle complex sustainability challenges. By understanding the dynamics of different capabilities, stakeholders could craft targeted strategies to address both the development and erosion of the capabilities, ensuring that efforts are not only effective in the short-term but sustainable in the long run.

To address sustainability challenges, we would require a structured approach capable of harnessing and amplifying the potential of various capabilities. This could be achieved through the organization of a capability development roadmap, establishing capability clusters focusing on pivotal areas of sustainability. These clusters would not only compartmentalize the broad spectrum of actions required but would also enable targeted interventions that could leverage interdependencies and synergies among different capabilities (Sachs et al., 2019). The capability clusters would include (a) foundational capabilities (e.g., knowledge and institutional capabilities), (b) enabling capabilities (e.g., technological, financial, and resource capabilities), (c) implementation capabilities (e.g., behavioral and scale capabilities), and (d) cross-cutting capabilities (e.g., integrating efforts across all areas).

The foundational capabilities cluster would form the foundation for effective climate action. Increasing public awareness and understanding of climate change (knowledge capability) would support the development of strong institutional frameworks and governance mechanisms (institutional capability) to coordinate and enforce climate policies worldwide. A foundational capabilities cluster would require comprehensive education and outreach programs, strengthened global governance structures, promotion of international cooperation, and knowledge sharing to cultivate a global commitment to climate action (United Nations Framework Convention on Climate Change, 2015).

The enabling capabilities cluster would equip countries and communities with the necessary tools, resources, and financial support to implement climate solutions effectively. Developing clean energy technologies (technological capability), mobilizing climate finance (financial capability), and diversifying economic resources (resource capability) enable countries and communities to transition to low-carbon, climate-resilient economies. This cluster would require investing in research and development of clean energy technologies, establishing climate finance mechanisms, and redirecting subsidies from fossil fuels to renewable energy and sustainable development projects (World Bank, 2020).

The implementation capabilities cluster would focus on actualizing the potential unlocked by the Foundational and Enabling clusters. The cluster would drive behavioral change and scale up successful climate initiatives. Encouraging sustainable behaviors (behavioral capability) and replicating and expanding proven climate solutions (scale capability) would be essential for achieving widespread emission reductions and building resilience to climate impacts. It would require promoting sustainable lifestyles through education and incentives, and facilitating collaboration and knowledge-sharing by engaging diverse stakeholders to ensure that sustainability measures are inclusive and comprehensive (OECD, 2018).

The cross-cutting capabilities cluster would integrate all efforts to maximize their impact. This cluster would promote a holistic strategy transcending and integrating individual capabilities, focusing on long-term vision and resilience. This cluster would recognize that sustainable development is a dynamically complex problem that requires interconnected solutions, ensuring that advances in one area are supported and amplified by progress in others (Intergovernmental Panel on Climate Change, 2014).

By focusing on these clusters of capabilities and implementing coordinated actions at local, national, and global levels, we would hope to accelerate progress towards achieving the goals of the Paris Agreement, while limiting global temperature rise below 2 °C. While each cluster would serve a specific functional role, they would also contribute to a comprehensive strategy that addresses the interconnected nature of sustainability challenges (United Nations, 2015). Still, the estimates provided in Table 2 and the proposed capability clusters

TABLE 2 Tentative and sample estimates for capability attributes in different domains.

Capability	Example	Development time (τ_D) (years)	Erosion time (τ_E) (years)	Productivity (*NPdy*)	Development likelihood
Technological	Small industries implementing renewable energy	2–5 In Australia, building a solar farm now takes on average 41 months (3.5 years), and building a wind farm — 53 months (4.5 years) (Longden, 2024)	5–30 Solar panels last 25–30 years, solar inverters — 10–15 years (Glover, 2023) Wind turbines last approximately 30 years (US Department of Energy, 2022)	High The "levelized cost of energy (LCOE)," measuring the average net present cost of electricity generation over its lifetime, "… for renewable energy sources … have declined [below non-renewable sources]" (Lazard, 2023)	Medium
Financial	Creating green investment banks (GIB) to fund ecological projects	5–10 "Building a totally new GIB would take five to 10 years" (Allen, 2022)	30–50	Medium "A GIB would be an ideal solution to a current shortfall in sustainable funding … [but] the limiting factor is the overly-complex and lengthy procedures for obtaining planning permission." (Allen, 2022)	Medium
Institutional	Establishing environmental regulations	2–15 The Environmental Protection Act (EPA) in India, 1986, was enacted partly as a commitment under the Stockholm Declaration and also as a policy response in wake of the Bhopal gas tragedy of 1984 (Ballal et al., 2021). "In December 2019, the Commission launched the European Green Deal … In 2021, the EU Climate Law was adopted …" (European Parliament, 2023).	5–7	Medium"In 2021, the EU Climate Law was adopted, binding the EU to achieve climate neutrality by 2050 and setting a target of reducing net greenhouse gas emissions by at least 55% by 2030, compared with 1990 levels." (European Parliament, 2023).	Medium
Knowledge	Community education on recycling and conservation practices	0.08–2 "Implementing a recycling program … can take anywhere from 1 to 3 months of collaboration to get started" (Gosnell, 2023)	>5	Medium "The findings underscore the transformative potential of community-driven waste management education programs. Participants not only improved waste management practices but also experienced a mindset shift, perceiving waste as an economic opportunity" (Nurhayati & Nurhayati, 2023).	High
Behavioral	Adoption of public transport over personal	5–10 "Montpellier's experiment with free public transport has been a success … the number	< 1 Can revert to old habits if	Low-medium "Surprisingly, where free public transport has been introduced, only a small	Low

(Continues)

TABLE 2 (Continued)

Capability	Example	Development time (τ_D) (years)	Erosion time (τ_E) (years)	Productivity (*NPdy*)	Development likelihood
	vehicles in urban areas	of people using public transport jumped by 23.7% in the first three months of 2024 compared with the same period in 2019." (Frost, 2024)	public transport is no longer free	number of car users make the switch." (Rees, 2022)	
Resource	Transition from coal to renewable energy	5–11 "In 2003, the government of Ontario committed to retiring all coal-fired electricity generation by 2007, something they did accomplish, albeit a few years behind schedule." (Sovacool, 2016)	5–7	Medium "Coal generation declined from 25% of provincial supply in 2003 to 15% in 2008, 3% in 2011, and 0% in 2014" (Sovacool, 2016)	Medium
Scale	National expansion of local recycling programs. Global expansion of renewable energy.	10–50"Renewable energy has grown exponentially over the past two decades … but … the crucial question is whether the world can ensure it occurs fast enough to limit global warming and meet goals set in the international Paris Agreement on climate change." "As of 2022, [global renewable energy] made up a total of 12% [up from 7% in 2017]." (Jaeger, 2023)	3–6	Medium-high "Only 1% of Sweden's trash is sent to landfills. By burning trash, another 52% is converted into energy and the remaining 47% gets recycled. The amount of energy generated from waste alone provides heating to one million homes and electricity to 250,000." "By converting its waste into energy, Sweden has reduced its carbon dioxide emissions by 2.2 million tonnes a year. Between 1990 and 2006, carbon dioxide emissions went down by 34%, and greenhouse gas emissions are projected to fall by 76% by 2020, compared with levels in 1990." (Kim & Mauborgne, 2021)	Medium

Note: The quotes and references included inTable 2 provide examples of the capability attributes that may apply only to a specific context, region, industry, etc. Hence, there are intrinsic limitations associated with the estimates above that prevent them from being readily generalized. Applications to different or broader settings will require significant additional empirical research.

are tentative and exploratory. Before a definitive assessment of their possible impact on sustainability, they require further investigation, empirical research, and validation.

7 | DISCUSSION

7.1 | Abstract

This research addresses a critical gap in understanding how specific attributes of capabilities influence organizational resource allocation decisions. By examining the development time, erosion time, and productivity of capabilities, we reveal how these factors shape managerial propensity to invest in capability development. The study introduces the innovative concepts of "capability region" and "capability frontier," which provide a novel framework for predicting the areas where investments in capabilities are most likely to occur based on their attributes. This insight advances our comprehension of how organizations can become entrenched in capability traps, leading to stagnant performance despite potential opportunities for growth and adaptation.

While existing research in system dynamics has extensively applied the concept of capability traps across diverse settings, it has overlooked the specific characteristics that make certain capabilities more attractive for investment. The introduction of a "capability region" characterized by favorable attributes—a short development time, long erosion time, and high productivity—sheds light on why some essential capabilities fail to attract necessary investments, possibly because they fall outside this region. These findings are crucial for understanding the tipping points that define the attractiveness of investing in particular capabilities.

The implications of this research extend into the realm of sustainability, where the development and maintenance of certain capabilities are crucial for addressing environmental challenges. For example, capabilities related to technological innovation, financial strategies for sustainable investments, and institutional frameworks for environmental regulation play pivotal roles. Understanding the attributes that influence investment in these capabilities can help organizations avoid capability traps that hinder their transition toward sustainable practices.

Organizations striving for sustainability must navigate complex interdependencies between different capabilities. By applying the model's findings, they can prioritize investments in capabilities that not only offer immediate benefits but are also sustainable in the long run. For instance, investing in renewable energy technologies requires understanding the time to develop these capabilities and their productivity benefits, which are critical for ensuring that such investments yield the desired environmental and economic returns.

Here, we emphasize the pivotal role of recognizing and accounting for feedback loops in the development and erosion of capabilities. Schaffernicht (2019) explores the overlooked interdependencies in mental models, specifically the "dark loops"—feedback loops unrecognized by decision-makers—which significantly amplify the risk of misjudging strategic and operational contexts. These unacknowledged interdependencies can greatly increase the likelihood of falling into capability traps. Our model aims to illuminate these "dark loops", enhancing the accuracy and effectiveness of capability investment decisions. By providing a detailed analysis of capability attributes, such as development time, erosion time, and productivity, our study builds on Schaffernicht's findings. It offers a comprehensive understanding of how these attributes interact within the system dynamics of organizational behavior, particularly in the context of long-term sustainability and capability development.

7.2 | Theoretical contributions

Our emphasis on the three capability attributes influencing the attractiveness of a capability advances the existing system dynamics literature by *shifting* the focus of study from applications and *redirecting* it toward the determinants of capability attractiveness. The research allows managers to gain a deeper understanding of the capability attributes that influence resource allocation decisions. It provides a better characterization of capability traps and the dynamics establishing tipping points, and sheds light on the role of key parameters determining the attractiveness of a capability. The integration of system dynamics modeling offers a nuanced perspective on how these attributes interact, enhancing theoretical understanding in several critical areas.

We introduce the novel concept of a "capability region" that predicts where investments in a capability are most likely to occur based on the value of its attributes. This concept aids in understanding the tipping points that define the attractiveness of investments in specific capabilities, thereby providing a clearer characterization of capability traps. By examining the interactions among different capability attributes, the research sheds light on why organizations might fail to develop crucial capabilities, deepening theoretical insights into the parameters responsible for the attractiveness of a capability, especially in terms of how short-term decisions may impact long-term organizational survival.

The study also discusses the concept of increasing returns to capability (Makadok, 2001), suggesting that the more capability an organization develops, the better its performance will be. This development enhances an organization's knowledge about how to develop future capabilities, thereby ensuring longer-term survival. This understanding is crucial in recognizing why some organizations fail to develop necessary yet unattractive capabilities, resulting in their failure to adapt to environmental changes. Finally, our research has direct theoretical implications for the development of capabilities required for sustainability. By applying the concept of a "capability region" to sustainability, organizations can identify and invest in capabilities that fall within the attractive region, thereby avoiding traps associated with unsustainable practices. This theoretical insight is pivotal for developing strategies that effectively balance short-term operational needs with long-term sustainability goals.

7.3 | Practical implications

Our study also provides insights for practitioners and managers by highlighting the importance of developing sustainable capabilities. The "capability frontier" concept offers a framework to direct resources towards capabilities that are impactful, durable, and sustainable. This approach is particularly important for sustainability initiatives, as it ensures that efforts are aligned with long-term environmental goals. The practical implications of our findings for sustainability are multifaceted. First, the research equips managers with advanced decision-making tools that improve their ability to assess the potential returns on investments in sustainability-related capabilities. By gaining a thorough understanding of the attributes that define the "capability region", managers can make informed decisions that balance immediate operational needs with long-term environmental goals.

Furthermore, the capability frontier concept enhances strategic planning by helping organizations identify when sustainability capabilities (e.g., renewable energy technologies, waste management systems) might fall outside the attractive investment region. Recognizing these boundaries enables managers to take preemptive actions to realign resources or modify strategies, thereby avoiding sustainability capability traps.

Additionally, these insights can be applied to the strategic allocation of resources, thereby promoting the development of robust capabilities essential for effective environmental management. For instance, by prioritizing investments in capabilities characterized by long erosion times and high productivity, organizations can ensure that sustainability practices are not merely initiated but are also sustained over time. This approach helps solidify the foundation for long-term environmental strategies that contribute significantly to an organization's sustainability goals.

7.4 | Limitations and directions for future research

For simplicity, our model focuses on a single organizational capability to develop our main insights. This approach inherently overlooks the interactions between multiple capabilities that typically exist within any organization. These interactions can significantly influence strategic decision-making and organizational performance, suggesting that an exploration of how different capabilities influence each other and the whole system is also necessary.

Future research can bring the model closer to reality by considering more than one capability (with their distinct development and erosion time, and productivity) as well as their possible interconnections. Our research only conjectures the existence of a capability frontier but does not actually compute it. Future research could theoretically characterize the capability frontier using phase plots to characterize the threshold values of combinations of parameters that lead to tipping points in performance. Future research could also empirically characterize the capability frontier, through laboratory experiments research using real subjects. By changing the values of key parameters (i.e., changing the characteristics of a capability) in different treatments, we could evaluate their impact in the willingness of subjects to develop such capabilities.

We were able to prove the three basic propositions mathematically. We could analyze the model further to derive more specific insights on the impact of combinations of the three attributes on performance. Future research on the propositions and the boundary conditions could be tested both cross-sectionally and longitudinally.

As organizations increasingly prioritize sustainability, understanding the interplay between capabilities related to environmental management, social responsibility, and economic sustainability becomes crucial. Future studies could explore how these sustainability-related capabilities interact within the capability frontier framework, helping organizations to navigate complex sustainability challenges and avoid capability traps.

By addressing these limitations and exploring these nuanced areas of research, future studies can offer more comprehensive tools and frameworks. These advancements will assist organizations in navigating complex environments more effectively, enhancing their ability to implement strategic changes and adapt to new challenges.

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REFERENCES

Allen, M. (2022). *Switzerland moots state-funded Green Investment Bank*. Swissinfo.ch. Available at: https://www.swissinfo.ch/eng/business/switzerland-moots-state-funded-green-investment-bank/47705816

Argyres, N. (1996). Evidence on the role of firm capabilities in vertical integration decisions. *Strategic Management Journal*, *17*(2), 129–150. https://doi.org/10.1002/(SICI)1097-0266(199602)17:2<129::AID-SMJ798>3.0.CO;2-H

Arthur, W. B. (1989). Competing technologies, increasing returns, and lock-in by historical events. *Economic Journal*, *99*(394), 116–131. https://doi.org/10.2307/2234208

Arthur, W. B. (1990). Positive feedbacks in the economy. *Scientific American*, *262*, 92–99. https://doi.org/10.1038/scientificamerican0290-92

Arthur, W. B. (1994). *Increasing returns and path dependence in the economy*. University of Michigan Press. https://doi.org/10.3998/mpub.10029

Ballal, A., Tambe, S., & Joe, E. T. (2021). The evolution of India's environmental policy. *Indian Forester*, *147*(8), 743–753. Available at: https://www.researchgate.net/publication/353901958_The_Evolution_of_India's_Environmental_Policy. https://doi.org/10.36808/if/2021/v147i8/165166

Becker, M., & Traufetter, G. (2016). *Dieselgate in Europe. How officials ignored years of emissions evidence*. Spiegel International. Available at: https://www.spiegel.de/international/business/volkswagen-how-officials-ignoredyears-of-emissions-evidence-a-1108325.html

Bowman, E. H., & Hurry, D. (1993). Strategy through the options lens: An integrated view of resource investments and the incremental-choice process. *Academy of Management Review*, *18*, 760–782. https://doi.org/10.2307/258597

Bradley, C. (2017). *What happened to the world's greatest companies?* McKinsey & Company - Strategy & Corporate Finance. Retrieved June 15, 2023, from https://www.mckinsey.com/capabilities/strategy-and-corporate-finance/our-insights/the-strategy-and-corporate-finance-blog/what-happened-to-the-worlds-greatest-companies

Christophers, B. (2022). Fossilised capital: Price and profit in the energy transition. *New Political Economy*, *27*(1), 146–159. https://doi.org/10.1080/13563467.2021.1926957

Collins, R. D., de Neufville, R., Claro, J., Oliveira, T., & Pacheco, A. P. (2013). Forest fire management to avoid unintended consequences: A case study of Portugal using system dynamics. *Journal of Environmental Management*, *130*, 1–9. https://doi.org/10.1016/j.jenvman.2013.08.033

Cunha, F. A. F. d. S., Meira, E., & Orsato, R. J. (2021). Sustainable finance and investment: Review and research agenda. *Business Strategy and the Environment*, *30*(8), 3821–3838. https://doi.org/10.1002/bse.2842

Daly, H. (1990). Toward some operational principles of sustainable development. *Ecological Economics*, *2*, 1–6. https://doi.org/10.1016/0921-8009(90)90010-R

Dierickx, I., & Cool, K. (1989). Asset stock accumulation and sustainability of competitive advantage. *Management Science*, *35*(12), 1504–1511. https://doi.org/10.1287/mnsc.35.12.1504

Dovers, S., & Hezri, A. A. (2010). Institutions and policy processes: The means to the ends of adaptation. *Wiley Interdisciplinary Reviews: Climate Change*, *1*(2), 212–231. https://doi.org/10.1002/wcc.29

Faghihi, V., Kim, A., & Ford, D. (2022). Designing sustainability programs to avoid and escape the capability trap. *Journal of Simulation*, *17*(6), 729–745. https://doi.org/10.1080/17477778.2022.2075804

Fowler, P. J., Wright, K., Marcal, K. E., Ballard, E., & Hovmand, P. S. (2019). Capability traps impeding homeless services: A community-based system dynamics evaluation. *Journal of Social Service Research*, *45*(3), 348–359. https://doi.org/10.1080/01488376.2018.1480560

Frost, R. (2024). *Free public transport in Montpellier has led to 20 per cent more journeys*. Euronews Green. https://www.euronews.com/green/2024/05/15/free-public-transport-in-montpellier-has-led-to-20-per-cent-more-journeys#:~:text=Montpellier's%20experiment%20with%20free%20public,few%20months%2C%20new%20figures%20show.&text=Officials%20say%20the%20number%20of,the%20same%20period%20in%202019

Glover, E. (2023). How long do solar panels last? *Forbes*. https://www.forbes.com/home-improvement/solar/how-long-do-solar-panels-last/

Gonçalves, P. (2011). Balancing provision of relief and recovery with capacity building in humanitarian operations. *Operations Management Research*, *4*, 39–50. https://doi.org/10.1007/s12063-011-0045-7

Gosnell, J. (2023). *How long does a recycling program take to replace?* CleanRiver. https://cleanriver.com/resource/blog-how-long-does-a-recycling-program-take-to-replace/

Greve, H. R. (2003). *Organizational learning from performance feedback*. Cambridge University Press. https://doi.org/10.1017/CBO9780511615139

Guevara, J., Garvin, M. J., & Ghaffarzadegan, N. (2017). Capability trap of the U.S. highway system: Policy and management implications. *Journal of Management in Engineering*, *33*(4), 04017004. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000512

Helfat, C. E., & Peteraf, M. A. (2003). The dynamic resource-based view: Capability lifecycles. *Strategic Management Journal*, *24*(10), 997–1010. https://doi.org/10.1002/smj.332

Herrera, H., & Kopainsky, B. (2020). *A dynamic perspective to farming system resilience and its trade-offs* (Vol. No. 302646). European Association of Agricultural Economists. https://doi.org/10.22004/ag.econ.302646

Intergovernmental Panel on Climate Change. (2014). Climate change 2014: Synthesis report. In *Contribution of working groups I, II and III to the fifth assessment report of the intergovernmental panel on climate change*. IPCC.

Jaeger, J. (2023). *These 8 countries are scaling up renewable energy the fastest*. World Resources Institute. retrieved May 23, 2024, from https://www.wri.org/insights/countries-scaling-renewable-energy-fastest

Keith, D., Taylor, L., Paine, J., Weisbach, R., & Dowidowicz, A. (2024). When funders aren't customers: Reputation management and capability underinvestment in multiaudience organizations. *Organization Science*, *35*(2), 387–404. https://doi.org/10.1287/orsc.2022.1579

Kim, C., & Mauborgne, R. (2021). *Turning waste to energy: Sweden's recycling revolution*. Blue Ocean Strategy. https://www.blueoceanstrategy.com/blog/turning-waste-energy-sweden-recycling-revolution/

Kogut, B., & Kulatilaka, N. (2001). Capabilities as real options. *Organization Science*, *12*, 744–758. https://doi.org/10.1287/orsc.12.6.744.10082

Landry, E., & Sterman, J. (2017). The capability trap: Prevalence in human systems. In *35th international conference of the system dynamics society* (pp. 963–1010). System Dynamics Society. https://proceedings.systemdynamics.org/2017/proceed/papers/P1325.pdf

Lazard. (2023). *2023 levelized cost of Energyplus*. Lazard. retrieved May 23, 2024, from https://www.lazard.com/research-insights/2023-levelized-cost-of-energyplus/

Longden, T. (2024). *Renewable projects are getting built faster — But there's even more need for speed*. The Conversation. https://theconversation.com/renewable-projects-are-getting-built-faster-but-theres-even-more-need-for-speed-221874

Lyneis, J., & Sterman, J. (2016). How to save a leaky ship: Capability traps and the failure of win-win investments in sustainability and social responsibility. *Academy of Management Discoveries*, *2*(1), 7–32. https://doi.org/10.5465/amd.2015.0006

Makadok, R. (2001). Toward a synthesis of the resource-based and dynamic-capability views of rent creation. *Strategic Management Journal*, *22*(5), 387–401. https://doi.org/10.1002/smj.158

March, J. G. (1991). Exploration and exploitation in organizational learning. *Organization Science*, *2*(1), 71–87. https://doi.org/10.1287/orsc.2.1.71

Maritan, C. A., & Lee, G. K. (2017). Resource allocation and strategy. *Journal of Management*, *43*(8), 2411–2420. https://doi.org/10.1177/0149206317729738

Mattioli, G., Roberts, C., Steinberger, J. K., & Brown, A. (2020). The political economy of car dependence: A systems of provision approach. *Energy Research & Social Science*, *66*, 101486. https://doi.org/10.1016/j.erss.2020.101486

Merk, O., Saussier, S., Staropoli, C., Slack, E., & Kim, J.-H. (2012). Financing green urban infrastructure. In *OECD regional development working papers 2012/10*. OECD Publishing. https://doi.org/10.1787/5k92p0c6j6r0-en

Nelson, R. R., & Winter, S. G. (1982). The Schumpeterian tradeoff revisited. *The American Economic Review*, *72*(1), 114–132.

Nurhayati, E., & Nurhayati, S. (2023). Community waste management education: Strategies and impacts. *JURNAL DIMENSI*, *12*(3), 677–686. https://doi.org/10.33373/dms.v12i3.5582

OECD. (2018). *OECD environmental performance reviews: Enhancing the contributions of SMEs to environmental sustainability*. OECD Publishing.

Ostrom, E. (1990). *Governing the commons: The evolution of institutions for collective action*. Cambridge University Press. https://doi.org/10.1017/CBO9780511807763

Parliament, E. (2023). *Environment policy: General principles and basic framework*. European Parliament Fact Sheets on the European Union. Available at: https://www.europarl.europa.eu/factsheets/en/sheet/71/environment-policy-general-principles-and-basic-framework

Pretty, J. (2008). Agricultural sustainability: Concepts, principles and evidence. *Philosophical Transactions of the Royal Society B*, *363*(1491), 447–465. https://doi.org/10.1098/rstb.2007.2163

Purnomo, H., Okarda, B., Dermawan, A., Ilham, Q. P., Pacheco, P., Nurfatriani, F., & Suhendang, E. (2020). Reconciling oil palm economic development and environmental conservation in Indonesia: A value chain dynamic approach. *Forest Policy and Economics*, *111*, 102089. https://doi.org/10.1016/j.forpol.2020.102089

Purwandani, J. A., & Michaud, G. (2021). What are the drivers and barriers for green business practice adoption for SMEs? *Environment Systems and Decisions*, *41*(4), 577–593. https://doi.org/10.1007/s10669-021-09821-3

Rahmandad, H., & Repenning, N. (2016). Capability erosion dynamics. *Strategic Management Journal*, *37*(4), 649–672. https://doi.org/10.1002/smj.2354

Rees, N. (2022). *Enabling behaviour change*. The Institution of Environmental Sciences. https://www.the-ies.org/analysis/enabling-behaviour-change

Repenning, N. P., & Sterman, J. D. (2001). Nobody ever gets credit for fixing problems that never happened: Creating and sustaining process improvement. *California Management Review*, *43*(4), 64–88. https://doi.org/10.2307/41166101

Repenning, N. P., & Sterman, J. D. (2002). Capability traps and self-confirming attribution errors in the dynamics of process improvement. *Administrative Science Quarterly*, *47*(2), 265–295. https://doi.org/10.2307/3094806

Robins, J. A. (1992). Organizational considerations in the evaluation of capital assets: Toward a resource-based view of strategic investment by firms. *Organization Science*, *3*, 522–536. https://doi.org/10.1287/orsc.3.4.522

Sachs, J. D., Schmidt-Traub, G., Mazzucato, M., Messner, D., Nakicenovic, N., & Rockström, J. (2019). Six transformations to achieve the sustainable development goals. *Nature Sustainability*, *2*, 805–814. https://doi.org/10.1038/s41893-019-0352-9

Satell, G. (2014). A look back at why blockbuster really failed and why it didn't have to. *Forbes*. Retrieved June 15, 2023, from https://www.forbes.com/sites/gregsatell/2014/09/05/a-look-back-at-why-blockbuster-really-failed-and-why-it-didnt-have-to/

Schaffernicht, M. (2019). Unrecognized interdependencies in mental models—The case for taking feedback loops into account. *Systems Research and Behavioral Science*, *36*, 580–603. https://doi.org/10.1002/sres.2572

Söderholm, P. (2020). The green economy transition: The challenges of technological change for sustainability. *Sustainable Earth*, *3*(1), 6. https://doi.org/10.1186/s42055-020-00029-y

Sovacool, B. K. (2016). How long will it take? Conceptualizing the temporal dynamics of energy transitions. *Energy Research & Social Science*, *13*, 202–215. https://doi.org/10.1016/j.erss.2015.12.020

Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Irwin/McGraw-Hill.

Sterman, J. D. (2008). Risk communication on climate: Mental models and mass balance. *Science*, *322*(5901), 532–533. https://doi.org/10.1126/science.1162574

Stern, N. (2007). *The economics of climate change: The stern review*. Cambridge University Press. https://doi.org/10.1017/CBO9780511817434

Surowiecki, J. (2013). *Where Nokia went wrong*. The New ppYorker. Retrieved June 15, 2023, from https://www.newyorker.com/business/currency/where-nokia-went-wrong

Tabrizian, S. (2019). Technological innovation to achieve sustainable development—Renewable energy technologies diffusion in developing countries. *Sustainable Development*, *27*, 537–544. https://doi.org/10.1002/sd.1918

Tcvetkov, P. (2022). Engagement of resource-based economies in the fight against rising carbon emissions. *Energy Reports*, *8*, 874–883. https://doi.org/10.1016/j.egyr.2022.05.259

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic capabilities and strategic management. *Strategic Management Journal*, *18*(7), 509–533. https://doi.org/10.1002/(SICI)1097-0266(199708)18:7<509::AID-SMJ882>3.0.CO;2-Z

United Nations. (2015). *Transforming our world: The 2030 agenda for sustainable development* (Vol. 1) (p. 41). United Nations, Department of Economic and Social Affairs.

United Nations Framework Convention on Climate Change. (2015). Adoption of the Paris Agreement. In *Conference of the parties (COP)*. (p. 1-32). United Nations Framework Convention on Climate Change.

U.S. Department of Energy. (2022). *The life of a wind turbine: Duration*. WINDExchange. https://windexchange.energy.gov/end-of-service-guide#:~:text=The%20Life%20of%20a%20Wind%20Turbine,-Duration&text=How%20long%20do%20wind%20turbines,to%20last%20for%2030%20ye

World Bank. (2020). *World development report 2020: Trading for development in the age of global value chains*. World Bank Publications. https://doi.org/10.1596/978-1-4648-1457-0

Wilmoth, M. J., Menozzi, M. C., & Bassarsky, M. L. (2022). Why population growth matters for sustainable development. (p.1-4) *United Nations Department of economic and social affairs*. Retrieved from: https://www.un.org/development/desa/pd/sites/www.un.org.development.desa.pd/files/undesa_pd_2022_policy_brief_population_growth.pdf

SUPPORTING INFORMATION

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