UNCERTAINTY MANAGEMENT IN PRODUCT DEVELOPMENT PORTFOLIOS: THE IMPACT OF GLOBAL SUSTAINABILITY AGENDAS

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ABSTRACT

Increased focus on sustainability significantly impacts product development portfolio management in organizations. This paper focuses on the significant unaccommodated uncertainty caused by the green transition for current mid- and long-term portfolio management processes. These uncertainties arise in areas such as the regulatory environment, market demands, and technical capabilities. This paper makes four contributions: First, current product portfolio management literature is mostly employing deterministic practices. Uncertainties are incompletely addressed, and current methods fail to address the deep uncertainties of the green transition. Second, building a literature-based conceptual framework of the sources of uncertainty in 6 areas: Business Models, Technology, Regulation and Legislation, Finance and Insurance, Market and Consumer, and Organizational Context. Third, preliminary empirical evidence supports the usefulness of our model for product development portfolio management. Fourth, concluding with a suggested empirical research agenda to develop a deeper understanding of challenges towards method and theory development to support the green transition on the portfolio management level.

Keywords: Portfolio management, Uncertainty, Sustainability, Green transition

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Cite this article: Filipovic, A. M., Welo, T., Willumsen, P. L., Oehmen, J. (2023) 'Uncertainty Management in Product Development Portfolios: The Impact of Global Sustainability Agendas', in *Proceedings of the International Conference on Engineering Design (ICED23),* Bordeaux, France, 24-28 July 2023. DOI:10.1017/pds.2023.369

1 INTRODUCTION: PRODUCT PORTFOLIO RISK MANAGEMENT AND THE GREEN TRANSITION AGENDA

The sustainability agenda is increasingly influencing society, politics, and company processes through policies, regulation, and public pressure (European Commission, 2019; Petro, 2022). These changing conditions significantly impact product development (PD) and manufacturing companies and the way they manage their PD portfolios. While dynamic conditions in markets and technology are far from new to organizations, the additional significant, and sometimes sudden, influence of international, national, or corporate green transition agendas are particularly changing legal and regulatory requirements and can have significant, non-negotiable impacts on companies (European Commission, 2019).

Portfolio management (PM) in PD is key to a company's performance, including planning and governance of new development activities and supporting and upgrading existing products and services (Cooper et al., 2001). As product planning is essential to companies' success and survival in a rapidly changing market (Kahn, 2015), PM plays a vital role in managing and cultivating the product portfolio and its related activities (Cooper, 2017; INCOSE, 2015; PMI, 2017). However, PM practices are often deterministic and fail to properly address uncertainty in its processes, including portfolio risk management (Martinsuo et al., 2014).

The green transition adds complexity and increases dynamics to an already complex and dynamic task (Villamil et al., 2021) and there is a gap in how to address uncertainty in green transition projects(Messerly et al., 2019; Taebi et al., 2020; Villamil et al., 2021). We argue that to fully support a green transition agenda with the increased uncertainties it introduces, and we must also expand the capabilities of PM to accommodate green transition projects. For example, we observe a trend towards developing flexible, robust, or adaptable technologies and solutions in larger infrastructure projects, including the capability to address deep uncertainty over decades-long lifecycles. This capability is crucial for the green transition because green transition projects often work with long lifecycles (Žužek et al., 2021). However, we do not see this trend of capabilities in traditional PD, which typically focus on a shorter period. (Maier et al., 2016; Marchau et al., 2019; De Neufville, 2011; De Weck, 2022). Our working hypothesis is that also product development portfolio management would benefit from building increased capability to address long-term uncertainties to support the green transition, as this would allow, for example, the development of adaptable product platform concepts that are not locked into specific pre-assumptions of future developments or market demands and thus can accommodate the volatile uncertainty landscape of the green transition (Taebi et al., 2020).

Research questions and contributions of this paper

This paper focuses on better understanding and categorizing the uncertainties in green transition to support decision-making in product development portfolio management. Specifically, we investigate frameworks relevant to addressing the increased medium and long-term uncertainties in product development portfolio management due to the increasing global implementation of green transition agendas. This paper addresses this topic by focusing on two specific research questions:

- RQ1: What are the specific sources of uncertainty for product development portfolio management that are amplified by the implementation of the green transition agenda? RQ1 will collect the current state-of-practice, as described in the literature, regarding the sources of uncertainty in product development portfolios.
- RQ2: How can we conceptualize portfolio level uncertainties to assist decision-making in product development portfolios?
  Following RQ2, we will discuss what empirical research is necessary to complement the findings in the literature, providing a fundament for improved product development portfolio and risk management practice in companies.

2 RESEARCH METHOD

We utilized a literature review (Bryman and Bell, 2015) to identify gaps and state of the art (Section 3, RQ1). Uncertainty sources within the green transition are poorly understood (Messerly et al., 2019; Taebi et al., 2020); therefore, we chose an exploratory approach (Cash, 2018).

Based on the literature review, we conceptualized a model of sources of uncertainty (K.E., 1995) (Section 4, RQ2). To validate our conceptual model, we identified larger organizations that indicated

https://doi.org/10.1017/pds.2023.369 Published online by Cambridge University Press

active engagement in the green transition. Through introduction interviews, we identified and set up interviews with key stakeholders. The selection criteria for interviewees included the senior role in the organizations with responsibilities concerning ongoing projects and sustainability (Section 5, Interviews study). We conducted semi-structured interviews using the sources of uncertainty as a guide but remained open for additional categories (Bryman and Bell, 2015). We utilized ways of asking questions utilizing direct and indirect questions. Each interview lasted around one hour, varying between general processes and activities in portfolio management into a very detailed introduction of case-specific topics. The interviews continued until the direct and indirect questions stopped revealing new content of the addressed topics.

Table 1: Overview of interview partners (Section 5 / RQ2)

Stakeholder	Role of Interviewee	Green transition projects	# of interviews
Production company (PC)	Portfolio management	Some	2
Regulatory body (RB)	Management, VP	Some	2
NGO	Portfolio management, Program management	Many	2

3 CURRENT KNOWLEDGE AND STATE OF THE ART

3.1 Risk and uncertainty in product development portfolio management

PM activities are central to the continuous development of a company and its products and innovation outcomes. These activities include defining and governing new product development projects, projects to support existing products, and projects to remove or consolidate the product portfolio (Gupta et al., 2022; PMI, 2017). Dealing with uncertainty and risk is central to portfolio management and involves uncertainties with multiple aspects (Cooper, 2017; Gupta et al., 2022; PMI, 2017), briefly discussed in the following:

Portfolio strategy development involves understanding medium-term uncertainties and translating them into the company's strategy, analysing the existing portfolio, and identifying new project opportunities in alignment with the company's purpose (Cooper et al., 2001; Gupta et al., 2022). This strategic management concentrates on three elements; strategic objectives, strategic goals, and strategic vision. The range of the strategic objectives is typically 1-2 years. The strategic goals are to be achieved usually within 3 or more years, whereas the strategic vision ranges from 5 years or more (PMI, 2017)

Analysing the existing portfolio to ensure the strategic fit (Cooper, 2017; PMI, 2017) requires awareness of uncertainties within technology, usage of resources, and evaluation of the current progression and results for existing products and projects. Here the portfolio manager collects information from various sources for preparing the evaluations of business cases evaluating the benefit and risks.

Business case management involves data collection and presentation, enabling the manager to decide on funding and resource prioritization and how uncertainties could impact the business case. Further activities include preparing and assessing the business case to highlight assumptions, ignorance, and uncertainties. The content of the business case should, as a minimum, include the resources needed, including the cost, schedule, and risk assessment (Gupta et al., 2022). The purpose of this step is to prepare portfolio decision-making and relies heavily on adequate short and long-term uncertainty assessment.

Portfolio decision-making structure is the process of terminating and/or holding projects. This decision should consider the uncertainties in projects' assessed values, portfolio priorities, and project performance, which is a combined evaluation of all the previous steps.

Management of new products and services focuses on allocating resources, implementing stage-gate management, and post-launch tracking (Cooper, 2017; Gupta et al., 2022). Risk evaluations happen at toll gates and are part of assessing and forecasting resource needs.

Allocating resources is an ongoing process where the PM manager scans, reviews, and manages the ongoing activities, continuously monitoring for risks and uncertainties. The purpose is to ensure optimal usage of resources to achieve the best possible portfolio in alignment with the company's strategy and objectives. Here the prioritization of the project can change as well as the relocation of resources (PMI, 2017).

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Stakeholder management crosses all the above-mentioned activities management and can address uncertainties and risks related to stakeholders. Both the company's internal and external stakeholders are relevant to consider and manage when managing the portfolio (Gupta et al., 2022).
Risk management is discussed in depth in the following section:

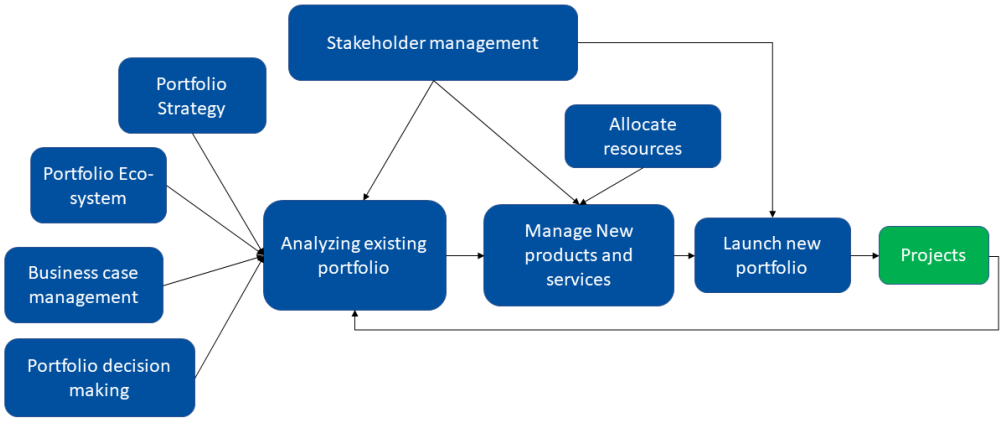

Figure 1: Aspects of portfolio management affected by uncertainties and risk.

3.2 Sources of uncertainty in product development portfolio management

For the purpose of this paper, we understand risk as the effect of uncertainty on objectives following ISO 31000 (ISO, 2018). A literature review indicated that in the context of PD organizations, uncertainty is generally categorized into four types of uncertainty (see Table 2).

Table 2: General sources of uncertainty in PD organizations, following (Jaafari, 2001; Kreye et al., 2022; Martinsuo, 2013; O'Connor and Rice, 2013)

Sources of uncertainty	Coverage
Technological	Existing technological knowledge, new products, complex engineering,
Market	Customer needs, market dynamics and size, price
Organizational	Strategic commitment, organization structure, knowledge, internal politics
Resource	Competencies and technological knowledge, finance (internal and external), materials from an external supply,

These four sources of uncertainty provide a general, high-level understanding, but do not reach the level of specificity required for product portfolio planning. A second major constraint is the four sources provide a "here and now picture" of the current uncertainty landscape, but do not explicitly consider the long life cycles relevant in portfolio planning (easily reaching multiple decades when considering an entire product life cycle) (Gupta et al., 2022). Third, they do not address the relations between uncertainties. Extending the literature review specifically to cover these aspects, (Kreye et al., 2022) provide an in-depth study of the causation of uncertainty and identified an additional root or symptomatic uncertainty type. This is also proven to influence the conditions for complex engineering projects (Kreye et al., 2022). One study (Martinsuo et al., 2014) focuses on how portfolio managers frame uncertainties towards their portfolio, three major categories of uncertainty were recognized each with subthemes (see Table 3).

Table 2: Uncertainty categories based on (Martinsuo et al., 2014)

Categories	Subcategories	Examples of uncertainty types
Environment	Society	Legal developments, regulations, safety, global economy downturn
	Markets	Customers, market development, price erosion, difficulties to estimate project business impact
	Industry	Competitors, technological development
Organizational complexity	People	Organizational politics, competences
	Company	Organizational structure, technology push, function interaction, strategy

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	Inter-project relations	Resource allocation, project scheduling, project priorities
Single project	Evaluation	The business impact of one project, failure, learning from single projects, goal complexity
	Project characteristics	Special and large customer supply projects, product development site relocation decision
	Scope	Product-, component features, platform development
	Cost	Budget, cost
	Schedule	Project duration

This further categorization addresses the complexity of how uncertainty is perceived in the organization together with which area of product development they relate to. Another branch of decision-making is related to deep uncertainty, which often appears in relation to environmental or infrastructure projects where the project execution and life span of the final solution stretch several decades into the future (Maier et al., 2016; Marchau et al., 2019). Instead of types (or sources) of uncertainty, the authors focus on the degree of uncertainty. This is particularly relevant for long-term planning activities, such as product portfolio management. Four levels of uncertainty are identified (see Table 4). These levels of uncertainty are also appropriate for strategies to recognize and evaluate risks and uncertainties (Geraldi et al., 2019; Oehmen et al., 2020).

Table 3: Levels of uncertainty, deterministic to ignorance (Marchau et al., 2019; Walker et al., 2003)

Levels of uncertainty				
Level 1	*Level 2*	*Level 3*	*Level 4*	
A clear idea of the future deterministic	A plausible future	A few plausible futures	Many futures	Unknown futures
Statistical uncertainty	Scenario uncertainty	Recognized ignorance	Total ignorance	

The existing framework for portfolio management to acknowledge uncertainty, especially deep uncertainty shows multiple limitations. First, the process of collecting, analysing, and then deciding on the future portfolio mix, leaves the impression that portfolio managers' decisions are deterministic based on fully informed business cases. However, as both (Walker et al., 2003) and (Marchau et al., 2019) indicate, the world is far from deterministic. Many plausible future scenarios may emerge through both predicted and unknown futures, especially when predicting the effects of the environment as part of the green transition. This asks for a model that invites different levels of uncertainties to be identified and evaluated alongside the more predictable scenarios in the portfolio management process.

4 A CONCEPTUAL FRAMEWORK FOR SOURCES OF UNCERTAINTY AMPLIFIED BY A GREEN TRANSFORMATION AGENDA

We aim to extend existing portfolio management practices from their deterministic focus towards approaches that can accommodate and leverage significant degrees of uncertainties from various sources and to different levels (as discussed in the previous section).

The conceptual framework draws from prior research on uncertainty and Portfolio Management (Kreye et al., 2022; Martinsuo, 2013; O'Connor and Rice, 2013; Walker et al., 2003). In addition to the general literature review of the previous section, for the conceptual model we also specifically reviewed the literature for uncertainties introduced by the green transition. This led to a total of 6 categories of sources of uncertainty, which will be discussed below.

4.1 Technology

There is a high level of uncertainty related to potential technical solutions that come from research and innovation to solve issues related to the green transition (Ma et al., 2021). Technology is a vital influencing factor for green transition projects (European Commission, 2019) because it introduces uncertainties to the portfolio in multiple ways (Cooper, 2017; Martinsuo, 2013). First, the level of uncertainty is low related to the current technologies and portfolios and how these impact the market

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conditions. In incremental innovation projects, uncertainties related to technology increase concerning future market conditions (De Weck, 2022). The level of uncertainty increases in development projects but also the needed technologies for future development. Envisioning future perspectives on a technological view leaves multiple parallel solutions open for technologies to exist within the companies and their environments (Haasnoot et al., 2013). The level of uncertainty related to competitive technologies, both from competitors and from innovative solutions, is medium to high yet still relevant to include in the analysis since they will influence market conditions for existing technologies.

4.2 Finance and insurance

Financing and insurance are challenging for the green transition because of the uncertainties involved. It can be difficult to insure when utilizing a new material or new technologies or having a long implementation time (Pawlak et al., 2018; Stricker et al., 2022). Portfolio managers should pay attention to finance and insurance in their portfolios because of how financial streams influence the upcoming project planning (Mazzucato, 2018). Time can be long for implementation and in alliance with the funded project. For example, the application process for the first round of EU funds for large-scale innovation projects lasted from 3 July 2020 until grant awarding in March 2022 (European Commission, 2022). Economic alliances and distribution of the risk over multiple stakeholders. Finance and cost structure is still the central elements for portfolio managers to deal with and leaving is reaching through the organization, technology, resources, etc. (Korhonen et al., 2014; Martinsuo et al., 2014)
Certain guarantees and safety measures must be considered when evaluating the solutions for their environment. Typically, part of reducing risk is to involve insurance companies (ISO, 2018), or to distribute the investment risk to multiple stakeholders and actors (Mazzucato, 2018) and these can be particularly challenging for green transition projects (Quatrini, 2021).

4.3 Market and consumer

Market and consumer behaviour can be extremely volatile regarding green transition projects as they can shape the competitive landscape technologies and market opportunities (Patterson, 2005). (Gupta et al., 2022) connect the investigation of trends to the market insight and relate to customers' behaviour, technological trends, and trends within the industry highlighting the importance of following tightly this source of uncertainty. Consumers are for example moving towards more sustainable choices at an accelerating pace, creating new markets for sustainable products (Pinkse and Bohnsack, 2021). Consumer and market behaviour can be particularly difficult to predict in green transition projects (Pinkse and Bohnsack, 2021).

4.4 Regulation and legislation

The regulatory landscape keeps changing and thus is a volatile uncertainty dimension for the green transition. For example with the introduction of the CSRD and EU taxonomies for ESG new uncertainties and risks emerge for companies because of high requirements and the necessity of compliance (Parris, 2006). Regulation and Law are impacting the portfolio from many different angles.
One of the largest uncertainties when working with the green transition and portfolio is the regulative environment. The current regulatory can have conflicting interests when reviewing the product lifecycle from different angles. This can be regulatory changes into the system, which the products eventually will be a part of, that suddenly changes and therefore change the product properties etc. The heightened focus on climate change has further sped up the lead time on regulation and added to the uncertainty for this uncertainty source. Not only for new products but also the viability of old products as increasing demands are put on to document and ensure the whole supply chain (Dumrose et al., 2022).

4.5 Business model

We have chosen to highlight business models as they represent a particular challenge for green transition projects (Trapp and Kanbach, 2021). The connection between the business model and the portfolio is linked through the aligned activities between the value-creating element of the value proposition from the business model to the business logic from the portfolio management (Cooper, 2017; Osterwalder, 2010). Certain challenges are also introduced by the introduction of new business models; e.g., the Circular Economy (European Commission, 2019). This also invites a high level of uncertainty covering all fields of the organization (technology, resources, and market). Finally,

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strategy and the company's business model should align throughout the full development cycle. In case any change in direction is made in top management, this should be implemented through the business model, and thereby into the portfolio.

4.6 Organizational context

The organisational context is a significant source of uncertainty because the strategy, decision-making processes and management heavily influence the commitment and direction the organisation takes (Martinsuo et al., 2014; O'Connor and Rice, 2013). Given the length of the product development life cycle uncertainties related to organizational context, the transformation from the mainstream organization process to adopting new means for development, internal resistance, changes in strategic focus, internal battles for resources, internal communication, requirements clarification across the organization, introduces several different uncertainties towards the portfolio (Kreye et al., 2022; Martinsuo et al., 2014; O'Connor and Rice, 2013).

In addition to the sources of uncertainty, it is also crucial to consider the level of uncertainty for the portfolio manager to decide which strategies are to be used to deal with the knowledge in each factor. Each factor must be addressed on the level of uncertainty from statistical knowledge to total ignorance.

We have combined the sources of uncertainty which are particularly relevant for the green transition with the level of uncertainty and conceptualized the following model depicted in figure 2:

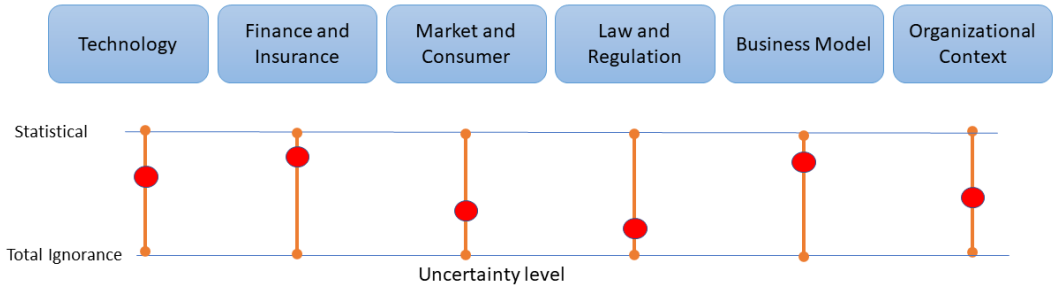

Figure 1: Conceptual framework, 6 factors of uncertainty

Our review also shows that the categories are interdependent. Financing for example, is influenced by regulatory bodies as well as market demands. Another example is that technology choice can be influenced by consumer behaviour or by the ability to get a loan. Recently regulatory bodies in the EU, for example, are introducing the CSRD and ESG taxonomies which mandate supply chain sustainability and provide favourable investment options for green transition projects thus influencing both financing options and supplier and technology choices (Dumrose et al., 2022). It is key to understand the different trends within each uncertainty source and understand how volatile the dimension is regarding the level of ignorance. Trends need to be investigated and monitored across all categories. For example, technology trends and solutions to work patterns may drastically change when put into a different environment with different historical trends (Maier et al., 2016). In addition, regulatory and consumer trends greatly influence a company's decisions when investigating new markets. Moreover, it can be challenging to commit to green solutions because of the ignorance and volatility of uncertainty. Considering the long-term perspective and the trends holistically and in different dimensions will be a crucial influence on the portfolio and how it is governed (Marchau et al., 2019).

To illustrate the interdependencies of the findings in section 2, an interview study was conducted to give preliminary results of the conceptual model.

5 INTERVIEW STUDY

A Preliminary Validation of Uncertainty Framework with Product Portfolio Practitioners

In total six semi-structured interviews were conducted to validate the appropriateness of the uncertainty framework, evidence is presented to illustrate each factor and their interdependencies.

Business model – The PC are adjusting their business model considering future legal requirements of the of the future context for their products. The current marketplace is regulated both national and international, which brings additional uncertainty to the business model. The NGO stated that business models are particularly uncertain but a key aspect of the green transition this includes the willingness to pay and carbon footprint as two major uncertainty categories. The regulatory body had a focus on

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the uncertainty of how to enable business models within the green transition and found industry reluctance or acceptance as a key uncertainty source within business models.

Technology – The NGO highlighted that due to the longtermism of the green transition some of the technologies that will be used have not even been invented yet, thus pointing to an extreme degree of uncertainty. Both the NGO and regulatory body highlighted that some technologies need regulation before they can be used and thus are linked to other uncertainty sources. In addition, the technologies are often immature and represent also potential ignorance concerning adoption and performance, according to the NGO. The company also identified technology as the main source of uncertainty within the green transition. The PC addresses uncertainties in development and implementing new material variants with lower environmental impact. Technological challenges product, requirements interfaces towards contextual environment both internal and external to the company.

Regulatory – Current part of the data needed for production of products is by law required to be documented and reported. It is expected that the regulatory requirements in this area will increase in the coming years, and therefore this report is already being made. There is a business potential for the company in the expected regulations and laws there will be on the customer's products. Since the company already has the documentation in place, is expecting to continue or increase its market share, while competitors establish this process. The company identified a regulatory trend in turning towards more documentation of the whole including detailed documentation of the environmental impact, but also saw a high level of uncertainty and ignorance within this domain as it is difficult to predict the legislative outcomes.

Market and Consumer – The NGO stated that changes in the market and consumer behaviour have the power to turn the whole industry and make a particular direction favourable or worthless, thus making this a highly relevant and volatile source of uncertainty. The regulatory body had found many challenges in determining consumer behaviour and saw this as a volatile dimension of uncertainty.

Finance and insurance – The NGO found that financing highly affects the ability to do green transition projects. Due to their uncertain nature, it is difficult to get financing and insurance, thus highly affecting other sources of uncertainty such as business models. The regulatory body stated that incentives and financing could provide some effect. However, the insurance aspect was difficult to affect for them.

Organizational Context - Introducing sustainability and increased focus on the green transition forces the organisation to break the traditional mindset and historical traditions. The PC found the need to establish new internal mechanisms to manage and interpret data to be used in PD and as input in various places in the portfolio management lifecycle. The organizational uncertainties have interdependencies with the remainder of the factors. Due to the high level of uncertainty related to the green transition, organizational uncertainty increases with the need for internal competencies toward technologies, which relates to both regulatory uncertainties and market and consumer uncertainties. These uncertainties then influence the selection of a business model, affecting the need for finance and insurance.

As visualized through the illustrative example, uncertainties related to the green transition are highly interdependent. None of the factors alone is responsible for any of the identified uncertainties. It is merely the interdependencies that create the uncertainty. Therefore, we suggest that these interfaces and interdependencies undergo further study, to investigate their effect on the portfolio while tossing light on how this dynamic is dealt with in product development portfolio practices.

6 DISCUSSION AND FUTURE RESEARCH

Accommodating Uncertainty Interactions and Levels of Uncertainty

This paper investigates how product portfolio management practices the manage the uncertainties introduced by the green transition. The literature study showed a gap a current PM practice fail to address long-term uncertainty introduced by the green agenda. Non of the the current uncertainty-types propperly addresses long-term uncertainties or the impact of the green transistion. The conceptual framework with the six factors introduced in this paper ties together the theoretical gap between PM activities and uncertainties. Hence, the factors seem to collect the required elements to inform portfolio managers as part of their management activities, the conceptual framework needs to be tested through real-world case examples (Cash, 2018). This need for further justification fits well with the description of case study research (Yin, 2018). The purpose is to understand the complexity related to the uncertainties, from where they emerge, and how they are connected to other factors than the primary. To test the validity of the conceptual framework, we want to conduct an empirical study. The method selected is

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case study research to collect data through interviews and collection of other data types; e.g., portfolio charter, roadmaps, etc. to triangulate our findings to verify our theory (Eisenhardt, 1989; Eisenhardt and Graebner, 2007; R. K. Yin, 2018). We will select multiple mid and large-sized industrial companies that operate with product development and innovation. Here, we will identify leaders, managers, and executives to conduct semi-structured interviews to investigate how uncertainties enter the company and through which channels. Evidence from the first interviews when triangulated with other sources of data, will be documented in systems maps. These systems maps will construct the basis for further semi-structured interviews where the mapping will be incorporated as a boundary object to set the context and inspire discussion. Furthermore, we will do both individual and cross-case analysis of our finding, to identify and code critical infrastructure and interfaces, which addresses internal and external uncertainties that influence the PM process and construct allies for further research. The research presented in this paper is adding four contributions to the. The firs contribution consists of the literature review, (RQ1, section 3). The second contribution is a conceptual framework for addressing uncertainty in product PM (RQ 1, section 4). The third contribution is an application example of the usage of the proposed conceptual framework, (RQ2, section 5). The Fourth contribution, consist of preparing the research methodology to test the framework in a contextual setting, (RQ2, section 6).

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https://doi.org/10.1017/pds.2023.369 Published online by Cambridge University Press