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**The role of
Public-Private
Collaboration
in advancing
the transition
towards cleaner
and sustainable
energy systems**

Cultural contexts, ecosystem orchestrations agency,
and the role of hybrid schemes



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Tiivistelmä

Tässä väitöskirjassa tarkastellaan julkisen ja yksityisen sektorin välisen yhteistyön (PPC, Public-Private Collaboration) roolia kestäviin energiajärjestelmiin siirtymisessä. Neljästä artikkelista koostuva väitöskirja syventää ymmärrystä PPC:stä kriittisenä tekijänä julkisten ja yksityisten ponnistelujen yhdenmukaistamisessa energiasiirtymän nopeuttamiseksi. Laadulliseen lähestymistapaan perustuen tutkimuksessa tarkastellaan sitä, miten sosiokulttuuriset tekijät vaikuttavat PPC:n muodostumiseen sekä julkisten ja yksityisten tahojen välisen yhteistyön dynamiikkaan. Väitöskirjassa yhdistetään keskeiset teoreettiset näkökulmat, mukaan lukien ymmärryksen rakentuminen, sosiaalisen vaihdannan teoria, käyttäytymisen mikroperusteet ja käytännön teoria, joiden kautta analysoidaan onnistuneen yhteistyön taustalla olevia mekanismeja. Nämä käsitteelliset lähestymistavat tarjoavat näkökulman ymmärtää, miten toimijat antavat merkityksen yhteistyösuhteille niiden erityisten kontekstien perusteella, ja miten luottamus, vastavuoroisuus ja yhteiset tavoitteet edistävät ongelmanratkaisua ja innovointia. Väitöskirjassa selvitetään myös sitä, miten julkisten ja yksityisten toimijoiden yhteistyökäytännöt synnyttävät uusia sosiaalisia rakenteita, kuten ekosysteemejä.

Tapaustutkimusten, kuten kestävä energia Suomessa sekä julkisen ja yksityisen sektorin ekosysteemi akkupohjaista energian varastointia varten Länsi-Suomessa, keinoin tämä väitöskirja osoittaa, kuinka PPC toimii 'sidoksena' uusille yhteiskuntarakenteille mahdollistaen eri kumppaneiden kokoamisen yhteiseen ponnistukseen heidän vahvuuksiensa pohjalta. Tässä mielessä havainnot osoittavat, kuinka toimijat kehittävät alkuvaiheen ekosysteemejä itsetietoisuuden ja arvojen löytämisen kautta, jotka ovat sopusoinnussa sosiokulttuurisen kontekstin kanssa. Tämä väitöskirja korostaa myös PPC:n potentiaalia vastata sosioteknisen muutoksen haasteisiin, josta esimerkkinä voidaan käyttää tulevaa ilmiötä liittyen käytöstä poistettaviin aurinkosähköjärjestelmiin kehittyvissä talouksissa.

Tämä tutkimus tarjoaa käytännön oivalluksia päätöksentekijöille ja ammattilaisille innovoinnin edistämiseksi PPC:n avulla auttaen luomaan energiasiirtymää tukevia verkostoja. Tulevaisuuden tutkimuksessa tulisi tarkastella PPC:tä edistäviä mekanismeja erilaisissa konteksteissa sekä sosiaalisen pääoman roolia energiainnovaatioiden ekosysteemien edistämisessä.

Asiasanat: julkisen ja yksityisen sektorin välinen yhteistyö, energiasiirtymä, hybridijärjestelmät, kestävä kehitys, kulttuurinen konteksti, ekosysteemien synty, toimijuus, käytännön teoria, ymmärryksen rakentuminen, sosiaalisen vaihdannan teoria, käyttäytymisen mikroperusteet, orkestrointi

Abstract

This dissertation explores the role of Public-Private Collaboration (PPC) in shaping the transition to sustainable energy systems. Comprising four papers, it deepens understanding of PPC as a critical factor in aligning public and private efforts to accelerate the energy transition. The research employs a qualitative approach to examine how socio-cultural factors influence PPC formation and the dynamics of collaboration between public and private entities. The dissertation integrates key theoretical perspectives, including Sensemaking, Social Exchange Theory, Microfoundations, and Practice Theory, to analyze the mechanisms underlying successful collaboration. These conceptual approaches provide a lens to understand how actors assign meaning to collaborative relationships based on their specific contexts and how trust, reciprocity, and shared objectives foster problem-solving and innovation. The dissertation also investigates how collaborative practices among public and private stakeholders induce the creation of new social structures, such as ecosystems.

From case studies such as sustainable energy in Finland and the public-private ecosystem for battery-based energy storage on the West Coast of Finland, this dissertation shows how the PPC acts as a 'binder' for the new social structures, enabling the assembly of the different partners in a joint effort from their strengths. Findings indicate, in this sense, how actors develop early-stage ecosystems through self-recognition and value discovery in line with the socio-cultural context. This dissertation also emphasizes the potential of PPC to address the challenges of socio-technical change, such as the upcoming phenomenon of end-of-life photovoltaic systems in developing economies.

This research offers practical insights for policymakers and practitioners to promote innovation through PPC, helping to establish supportive networks for the energy transition. Future research directions include exploring mechanisms to promote PPC across contexts and the role of social capital in fostering ecosystems for energy innovation.

Keywords: public-private collaboration, energy transition, hybrid schemes, sustainable development, cultural context, ecosystem emergence, agency, practice theory, sensemaking, social exchange theory, microfoundations, orchestration

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Looking back in time on this journey, I am amazed by how everything has changed compared to the original plan. When I set out, my plan seemed straightforward—a clear path in a new context. Perhaps at that moment, I did not realize how different it would be. Beyond academic learning, this journey has been a deep exploration of my own life, challenging me to understand myself in diverse situations and guiding me toward my own path. As I approach this final stage, with the future still uncertain, I find myself carrying a lighter load. Paradoxically, though, this "lighter suitcase" is filled with valuable tools for life. Among these are the habit of self-reflection as a practical means of building knowledge and the mindful use of observation, listening, sharing, reading, and feeling to create meaning and draw purposefully from experience.

As this dissertation is the compilation of my doctoral research work, it also serves as a kind of traveler's diary. It is important, therefore, to acknowledge those whose contributions helped me progress step by step along the way. In the first place, I thank God for allowing me to marvel at the coexistence of simplicity and complexity together in each thing and circumstance, ratifying perfection, transcendence, and unity. I thank my family, who, despite the distance, I have always felt by my side. To my Mom, Gloria Amparo, my Dad, Braulio, my sister, Diana Carolina, and my nephew Gerónimo. Their unwavering belief in me has supported me in pursuing my dreams and overcoming challenges. I carry my family and my homeland, Cali, Colombia, within me—embedded in my skin, my eyes, and my soul—as a constant reminder that true strength lies at one's roots; as Juan Ramón Jiménez's paradox states, "the one who has roots, has wings".

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Abbreviations

PPC	Public-Private Collaboration
PPP	Public-Private Partnership
SET	Social Exchange Theory
CSF	Critical success factor
EOL	End-of-life
PV	Photovoltaic
HPPP	Hybrid public-private partnership
PPI	Public-private innovation partnership
EU	European Union

kW	Kilowatt
MW	Megawatt
kWp	Kilowatt peak
ICT	Information, Communication, and Technology
SDG	Sustainable Development Goals
CO ₂	Carbon Dioxide
GHG	Greenhouse gas
OECD	Organization for Economic Co-operation and Development
IPP	Independent Power Producer
PPA	Power Purchase Agreement
ESCO	Energy Service Company
ESPC	Energy Saving Performance
EPC	Energy Performance Contract
TES	Thermal Energy Services
PPP-BR	Green renovations
VA	Voluntary agreements
5Ps	Pro-poor PPPs
GNI	Gross National Income
EVA	Ethylene Vinyl Acetate
WEEE	Waste Electrical and Electronic Equipment
EPR	Extended Producer Responsibility
REMP	Ghana Renewable Energy Master Plan
c-Si	Crystalline silicon
CdTe	Cadmium telluride
PFI	Private Finance Initiative
UK	United Kingdom
PFI	Private Finance Initiative
Gt	Gigatonne
°C	Degree Celsius
ESS	Energy Storage System
SMEs	Small and medium-sized enterprises

Publications

[P1] Pinilla-De La Cruz, G. A., Rabetino, R., & Kantola, J. (2022). Unveiling the shades of partnerships for the energy transition and sustainable development: Connecting public–private partnerships and emerging hybrid schemes. *Sustainable Development*, 30(5), 1370-1386. <https://doi.org/10.1002/sd.2288> Copyright notice. Permission statement. Reprinted with permission from Wiley.

[P2] Pinilla-De La Cruz, G. A., Rabetino, R. (2024) Eliciting the anchor link for building public-private collaboration in sustainable energy: insights from the Finnish context. *Journal of Cleaner Production*, 143670 <https://doi.org/10.1016/j.jclepro.2024.143670>. Copyright notice. Permission statement. Reprinted with permission from Elsevier.

[P3] Pinilla-De La Cruz, G. A., Rabetino, R. & Kohtamäki, M. (2024). Unfolding ecosystem emergence: The role of actor's agency and public-private collaboration practices. A revised version of the paper will be submitted to a journal.

[P4] Ndzibah, E., Pinilla-De La Cruz, G. A., & Shamsuzzoha, A. (2022). Collaboration towards value creation for end-of-life solar photovoltaic panels in Ghana. *Journal of Cleaner Production*, 333, 129969. <https://doi.org/10.1016/j.jclepro.2021.129969>. Copyright notice. Permission statement. Reprinted with permission from Elsevier.

1 INTRODUCTION

1.1 Background

The global shift toward cleaner and more sustainable energy systems is a complex and multifaceted challenge requiring collaboration across various sectors and stakeholders (Cherp, Vinichenko, Jewell, Brutschin, & Sovacool, 2018). According to IRENA (2023), to restrict global warming to 1.5°C, it is crucial to reduce carbon dioxide (CO₂) emissions by approximately 37 gigatons (Gt) from 2022 levels and achieve net-zero emissions in the power sector by 2050. However, the gap between current progress and the required targets grows yearly. This ongoing shortfall will result in greater future investment needs and higher costs due to the escalating impacts of climate change. Furthermore, most energy transition efforts have concentrated on technological, institutional, and regulatory aspects, with less stress on the relevance of social dialogue and the crucial role various stakeholders play in reshaping economic and social structures (IRENA, 2023a).

Advancing the energy transition requires viewing it as a social phenomenon with both social and environmental objectives. The primary aim of the energy transition is indeed to ensure future conditions for life, using clean technologies as tools to achieve this goal. Therefore, the transition must focus on fostering societal adoption of these changes, recognizing people at the core of the shift. For cleaner energy solutions to emerge and scale, social structures must evolve towards new socio-technical systems (Kanger & Schot, 2019). This change is driven by various public and private agents, such as businesses, public authorities, users, academia, investors, and communities in diverse socio-cultural contexts (Geels, 2018; Schot & Kanger, 2018).

IRENA (2023) emphasized that global collaboration at all levels is needed to bridge the gap between climate goals and current outcomes. The growing diversity of public and private actors involved in the transition to cleaner energy systems stresses the need to recognize their roles, leverage their strengths, and align their efforts toward decarbonizing energy systems (IRENA, 2023a). For collaboration to materialize in the transformations of energy systems, it is necessary to rethink the rigid social structures that traditionally positioned public and private actors on opposing edges. This dichotomy not only hinders collaboration but also undermines the purpose of the energy transition in tackling climate change.

As climate change affects the planet's sustainability in the medium and long term, strategies must be devised to address this complex challenge without division or distinction of sectors. Therefore, public and private actors play equally essential and indispensable roles in the energy transition as critical contributors to the configuration of new social structures. For instance, emerging technologies and energy settings depend on public stakeholders to create favorable conditions through public funding and public legitimation of innovations. Private stakeholders are fundamental in the energy transition, given their role in incorporating low-carbon solutions in the industry, the market, and society. Undeniably, it is not possible to consolidate the energy transition only with unilateral or dispersed efforts since collective efforts must be channeled toward achieving socio-technical transformations for the decarbonization of energy systems (Kivimaa, 2023; Tan, Wang, Zhang, & Li, 2020).

Research endeavors in Public-Private Collaboration (PPC) are essential to responding to the challenges of climate change. For example, electrification with renewable energies, the development and adoption of new energy carriers, and energy storage systems to increase the flexibility and resilience of energy systems require significant collaborative efforts from a wide range of stakeholders (IRENA, 2023a). The PPC can function as a 'scaffold' to support the development of innovations to achieve desired technological readiness levels. It also plays a significant role in integrating value chains and promoting sector coupling. Collaboration between different stakeholders is essential for the decarbonization of the energy sector and through innovative solutions across relevant industries such as manufacturing, transportation, and maritime (Johnson & Pinilla-De La Cruz, 2024; Quélin, Kivleniece, & Lazzarini, 2017; Vangen, 2017).

PPC pursues achieving outcomes beyond individual interests by creating and utilizing social capital (Caldwell, Roehrich, & George, 2017; Quélin et al., 2017; Vangen, 2017). This is particularly relevant for providing suitable conditions for co-creation among heterogeneous stakeholders in alignment with the Sustainable Development Goals (United Nations, 2023), as the environmental and economic dimensions and societal implications in community development need to be considered. In addition, PPC promotes mutual learning among partners and strengthens collaborative advantages by combining resources, knowledge, and expertise.

Furthermore, PPC performs as a 'binder' that enhances the integration of actors in joint initiatives based on shared values and beliefs. Therefore, in this sense, understanding the characteristics of socio-cultural contexts is essential. As PPC can vary according to the context, ranging from formal, contract-based

arrangements to more flexible and relational arrangements, hybrid PPC schemes have recently emerged in the energy transition involving diverse governance dimensions (Klijn, Koppenjan, & Warsen, 2021). These new aspects include various coordination, incentives, and agency mechanisms relevant to the energy transition challenges (Bowen & Taillieu, 2004; Smith & Thomasson, 2018; Tan et al., 2020).

Although PPC aligns with the objectives of decarbonizing energy systems and represents a central element for high-growth strategies in our increasingly globalized world, it remains complex to build, sustain, and last over time. Hence, understanding the underlying mechanisms that prompt actors to embrace or reject collaboration as a practice is crucial to achieving successful and lasting collaborations. It is essential to identify the incentives for different stakeholders to direct their organizational practices toward more collaborative approaches. This common ground is central to converging efforts towards decarbonizing energy systems. To effectively study the PPC for the energy transition, it will be relevant to apply conceptual and theoretical frameworks that achieve two objectives: keeping a broad perspective on the phenomenon and, at the same time, providing detailed information on the specific dynamics of collaborative relationships between public and private organizations.

The Microfoundations heuristic framework provides the means to generate explanations from the micro level about social outcomes by studying the mechanisms that influence individual actions (Contractor, Foss, Kundu, & Lahiri, 2019; Felin, Foss, & Ployhart, 2015). At this point, the principles of Sensemaking are beneficial for studying the nature of PPC from the factors exerting influence in the socio-cultural context (Fellows & Liu, 2016; Harris, 1994; Weick, Sutcliffe, & Obstfeld, 2005). Sensemaking also provides a framework for understanding how actors operate as collective agents that assign meanings to collaborative relationships according to the context. These mechanisms explain the construction of the mental schemas that actors use to evaluate and integrate the various forms of collaboration. Likewise, key elements such as reciprocity and trust are fundamental to successful collaborations.

The Social Exchange Theory mainly provides a suitable approach for analyzing the underlying mechanisms that influence mutual interdependence, the culture of trust, and joint problem-solving (Blau, 2017; Malmström & Johansson, 2015). From the perspective of constructing new social structures, such as ecosystems, the Practice Theory offers a framework to study the roles of agency of public and private stakeholders and collaborative practices (Bourdieu, 2005). Thus, building social structures that support the need for the decarbonization of energy systems

requires a deeper understanding of the rationales of PPC and the underlying mechanisms. In that sense, this dissertation explores this phenomenon from the conceptual approaches of Social Exchange Theory, Sensemaking, Microfoundations, and Practice Theory. A detailed discussion of these theoretical perspectives is provided in the Theoretical Background section of the dissertation.

1.2 Purpose of the dissertation

In line with the need to address actions to address climate change from a social perspective, in which PPC appears as a central factor to align efforts to produce forceful actions in energy transition, the purpose of this dissertation is to expand the understanding of how the joint effort between public and private entities have a central role in driving the change towards the development of sustainable energy systems. As mentioned in the previous section, since PPC is an essential element to advance in the energy transition, it is therefore of great relevance to understand the mechanisms behind the construction of collaborative relationships. However, the literature is limited in exploring PPC as a fundamental aspect of evolving new social structures in the socio-technical change towards cleaner and more sustainable energy systems. Currently, studies on PPC appear dispersed with little cohesiveness between them; usually, they appear to be conducted from different approaches or under some other concepts; therefore, it is not easy to find clear lines of research and even generate an academic dialogue. In addition, published studies usually lack a defined theoretic approach and are limited in contributions to the literature.

Therefore, PPC for the energy transition requires structured scientific efforts and empirical evidence that contributes solid steps to constructing this field of knowledge. Additionally, the approach of PPC must maintain the necessary balance to enhance theory building without losing the connection with current phenomena and with the actions that must be taken by public policies and practitioners in the field. Above all, it is necessary to provide the literature with scientific production using theoretical approaches to build the contributions on solid foundations and create pathways for future studies. Furthermore, research efforts are required to provide up-to-date information to be used by policymakers and practitioners in creating and executing policies to scale energy innovations at industrial levels and integrate value chains through collaboration between public and private actors.

1.3 Research questions and intended contributions

Following the purpose of this dissertation of deepening the understanding of how the joint effort between public and private entities plays a role in driving the change toward the development of sustainable energy systems, an overarching research question has been developed to address the research gap illustrated previously:

RQ: How does public-private collaboration outline the transition to sustainable energy systems?

This dissertation comprises four scientific papers (Papers 1-4) to answer the research question. First, Paper 1 started with a broad approach to PPC that includes exploring the diverse spectrum of schemes worldwide found in the literature. Here, a conceptual review was conducted on the wide spectrum of PPC, from the most formal and contractual bonding partnerships to more informal schemes, and it also approached emerging hybrid collaboration schemes. A systematic literature review was conducted to find evidence from different worldwide contexts regarding current schemes for progressing in the transition in energy systems. The research question that Paper 1 answered is: *how do public-private partnerships and hybrid schemes differ in addressing the challenging transition toward cleaner and more sustainable energy systems?* Findings in Paper 1 exhibit the presence of six common elements in the concept of public-private partnerships according to the literature as (i) form, (ii) purpose, (iii) timeframe, (iv) stakeholders, (v) risk and reward, and (vi) critical success factors.

Second, Paper 2 uses an empirical approach to specific aspects of collaborative relationships. This paper focuses on exploring the effect of the socio-cultural context on collaboration schemes. Specifically, Paper 2 examines *how cultural context at the country level influences individuals' perception of public-private collaboration toward more sustainable energy systems and defines the nature of the prevalent type*. For that purpose, the Social Exchange Theory (Blau, 2017; Malmström & Johansson, 2015), Individual sensemaking (Fellows & Liu, 2016; Harris, 1994; Weick et al., 2005), and the Microfoundations approach (Contractor et al., 2019; Felin et al., 2015) were applied as the underpinnings for building the theoretical framework. A qualitative case study was built where Finland as a country is the unit of analysis. The selection of Finland as a case study allowed me to establish the connection between widely accepted forms of collaboration for the energy transition and the cultural background. Findings in Paper 2 provide information about how the sociocultural context crafts PPC, with trust and national culture influencing flexible, horizontal relationships. Additionally, the

study indicates that the public sector supports private innovation, playing a pivotal role in energy transition.

Third, Paper 3 continues narrowing down the subject by exploring the case study of the emergence of an early-stage ecosystem for battery-based stationary energy storage systems on the West Coast of Finland. Paper 3 examines *how the ecosystem actors' agency and collaboration practices define the emergence of the early-stage ecosystem*. The conceptual approaches used here were Practice Theory (Bourdieu, 2005) and Microfoundations (Contractor et al., 2019; Felin & Foss, 2015). The findings suggest that the energy transition requires the collaboration of key public and private actors at the ecosystem level. Likewise, it was identified how public and private actors have different roles, including the role of the orchestrator of the ecosystem. Here, agency and practices in the emergence of ecosystems are influenced by the specific context, as discussed in Paper 2.

Four, in Paper 4, the phenomenon was examined in a different context; this is the case of end-of-life solar photovoltaics panels in Ghana. Paper 4 answered the following questions: *RQ1: how have sustainable practices for EOL PV panels been encouraged on a global scale and specifically in Ghana? RQ2: what are the value creation propositions for EOL PV panels from a public-private partnership perspective? And RQ3: what are the roles of stakeholders in advancing sustainable practices for EOL PV panels in Ghana?* This case study was built as an integrative review based on secondary data. The findings indicate the potential for developing a strategy for the upcoming phenomenon of end-of-life solar PV panels in developing economies through value creation, hybrid public-private partnerships, and collaboration strategies for knowledge transfer via educational platforms. This study presents a stakeholders map across the supply chain into strategic, operational, and support levels and identifies key skills for sustainability-focused education. The study also highlights future research areas.

Next, Table 1 displays a summary of the papers included in the dissertation.

Table 1. Summary of the papers in the dissertation

Feature	Paper 1	Paper 2	Paper 3	Paper 4
Title	Unveiling the shades of partnerships for the energy transition and sustainable development: Connecting public-private partnerships and emerging hybrid schemes	Eliciting the anchor link for building public-private collaboration in sustainable energy: insights from the Finnish context	Unfolding ecosystem emergence: The role of actor's agency and public-private collaboration practices	Collaboration towards value creation for end-of-life solar photovoltaic panel in Ghana
Specific research questions of the papers	How do public-private partnerships and hybrid schemes differ in addressing the challenging transition toward cleaner and more sustainable energy systems?	How does cultural context at the country level influence individuals' perception of public-private collaboration? And, how does the cultural context define the nature of the prevalent type of public-private collaboration towards more sustainable energy systems?	How do the ecosystem actors' agency and collaboration practices define the emergence of the early-stage ecosystem?	RQ1: How have sustainable practices for EOL PV panels been encouraged on a global scale and specifically in Ghana? RQ2: What are the value creation propositions for EOL PV panels from a public-private partnership perspective? RQ3: What are the roles of stakeholders in advancing sustainable practices for EOL PV panels in Ghana?
Theoretical groundings		Social Exchange Theory (Blau, 2017; Malmström & Johansson, 2015), Individual sensemaking (Fellows & Liu, 2016; Harris, 1994; Weick et al., 2005) Microfoundations (Contractor et al., 2019; Felin et al., 2015)	Practice theory (Bourdieu, 2005). Microfoundations (Contractor et al., 2019; Felin et al., 2015)	
Research approach	Conceptual review	Single-case study: empirical qualitative research	Single-case study: empirical qualitative research	Integrative review (applied to a case study)
Status	Published	Published	In process	Published

1.4 Structure of the dissertation

The core of this dissertation is structured into six sections. The *Introduction* summarizes the background and identifies the knowledge gap that this research addresses. It outlines the research question and the intended contributions and offers insights into the essential concepts, the current state of research, and the purpose of this dissertation. Additionally, it introduces readers to the overall dissertation structure.

The *Theoretical Background* section reviews the literature, exploring the relationship between Public-Private Collaboration and Social Exchange Theory, Sensemaking, Microfoundations, and Practice Theory frameworks.

The *Methodology* section places this dissertation within its philosophical research framework by addressing the fundamental ontological, epistemological, and axiological assumptions, the chosen perspective on the intrinsic nature of humans, and the selected approaches. It outlines the decisions regarding the research's conceptual and empirical components, including the research strategy and design and the data collection and analysis methods. Additionally, the section reflects on and discusses the evaluation of qualitative research.

The fourth section, related to the *Research Papers: Summaries of Findings*, presents summaries of the results from Papers 1–4 that make up this dissertation. These summaries focus solely on restating the findings without offering theoretical or methodological background or discussing the research's significance.

The *Discussion* section provides an in-depth analysis of the contributions to theory and this dissertation's implications for practitioners and society. It highlights this research's unique value to the literature on Public-Private Collaboration. Additionally, the section addresses the study's limitations and offers recommendations for upcoming research.

The *Conclusion* section offers a synopsis of the core points of the dissertation and synthesizes its main arguments. The complete texts of Papers 1–4 are included at the end of the document.

2 THEORETICAL BACKGROUND

The study of PPC in the energy transition context has traditionally lacked a unified theoretical framework, with existing approaches spanning a broad spectrum. Principal-Agent theory has been one of the most common and traditional approaches to literature based on dyadic formal arrangements from Anglo-Saxon schemes. However, the evolution of PPC at a global level has given rise to the emergence of usually hybrid and relational collaborations that, although they have not been clearly reflected in the literature, have played a relevant role in the development of innovation from local levels to international instances.

In this dissertation, four conceptual frameworks have been used to fill the existing gap in the literature and improve the understanding of PPC for the transition toward cleaner systems: Social Exchange Theory, Sensemaking, Microfoundations, and Practice Theory. First, the Social Exchange Theory provides a suitable framework to explore the foundations of collaborative relationships connected to the spirit of mutual support that is materialized with exchanges of resources based on relationships of trust and reciprocity. Second, the Sensemaking approach allows us to understand the meanings that collaborative relationships acquire according to the conditions in which they occur, including the socio-cultural context. Notably, the approach is especially relevant for exploring meanings from the relationship between public and private actors in specific socio-cultural contexts and their connection with commonly accepted collaborative schemes.

Third, the Microfoundations framework provides a holistic approach to the phenomenon. Here, PPC to the energy transition can be explained as a result of the mechanisms taking place at the micro-levels. This approach allows for the connection of the needs of the energy transition with the socio-technical dimensions. Fourth, the Practice Theory provides the frame for continuing to explore the phenomenon, this time from the practices that give rise to collaborative structures such as ecosystems. This conceptual approach is particularly relevant in identifying the factors that lead to new social structures for the energy transition with the participation of public and private actors to evolve and consolidate over time.

These conceptual frameworks help to find solid explanations of the PPC phenomenon for the energy transition and create a path for future studies. Below is a summary of the previous works related to the theoretical approach to PPC and the connection to the energy transition, as well as an introduction to the four conceptual approaches chosen in this dissertation.

2.1 How PPC has been approached in previous studies

Efforts in academic research on PPC have focused mainly on exploring the factors that facilitate and hinder the relationship between public and private agents (Vangen & Huxham, 2003). This aspect has been approached from different theoretical angles, including social, economic, and institutional sciences (Gray & Wood, 1991; Vangen & Huxham, 2003). Thus, PPC literature includes a broad spectrum of relationship schemes, from the most formal to those based on relational approaches. The notion of PPC is diverse and takes different forms according to the administrative traditions of the region and experience in collaboration with the private sector. One of the obstacles to understanding this phenomenon is the fragmentation of the literature between different notions of PPC and the scarcity of studies on integrating and recognizing all the dimensions of this phenomenon. Klijn (2010) points out that the concept must be broad and hybrid to absorb divergent approaches, the complexity of relationships, and even existing ambiguity.

The history and evolution of PPC seem to be written alongside social and political transformations. Indeed, in Northern Europe and the Netherlands, PPC resembles collaborative relationships between actors to develop products and services jointly (Greve & Hodge, 2011; O'Flynn & Wanna, 2009; Wanna, 2008). For instance, the Dutch notion of PPC is a bit far from the British financial instrument, and it is increasingly oriented towards being applied as a collaborative governance scheme (Greve & Hodge, 2011; O'Flynn & Wanna, 2009) as there are diverse views about public-private relationships, new hybrid schemes arise in different contexts (Warsen, Greve, Klijn, Koppenjan, & Siemiatycki, 2020). At the same time, approaches in the literature also emerge from various edges. Although numerous studies lack an explicit theoretical approach, traditional approaches to PPC have been traditionally explained by the 'principal-agent theory' following the Private Finance Initiative (PFI) model in the United Kingdom (Achim & Borlea, 2013; Alchian & Demsetz, 1972). However, this theoretical approach proposes a limited scope for a mechanism that involves a broader range of relationships. Indeed, the 'principal-agent theory' cannot fully explain emerging forms of collaboration. Scholars agree that traditional 'principal-agent' models and tight contractual forms make developing and incorporating innovation difficult.

In Nordic countries, hybrid schemes commonly correspond to horizontal relations between public and private actors to achieve win-win conditions (Klijn & Koppenjan, 2016; Koppenjan, 2012; Warsen et al., 2020). PPC in the Nordics can be described by the rational of 'principal-principal' as indicating a non-hierarchical and tight collaborative relationship between public and private actors for projects

or initiatives of public interest (Ansell & Gash, 2008; Klijn, 2010; Osborne, 2009; Warsen et al., 2020). Some collaboration schemes in the Nordic countries appear with the label of public-private innovation partnerships (PPIs) as a response to the need for cooperation between social actors to develop innovation projects (Brogaard, 2021; Weihe et al., 2011). These cooperation schemes are primarily used in the healthcare and eldercare sectors in the Netherlands and Denmark and correspond to ‘principal-principal’ relationships based on trust between public and private actors (Brogaard, 2021; Weihe et al., 2011).

Overall, PPCs in the Nordics rely on the common ground of collaborative relationships. In this vein, Benítez-ávila, Hartmann, Dewulf, & Henseler (2018, p. 432) highlighted the relevance of relational governance elements in public-private collaborative relationships as “*informal rules of social exchange such as flexibility, solidarity, communication and problem-solving through consultation*” (Benítez-Ávila et al., 2018; Kaufmann & Dant, 1992; Macneil, 1982; Xue, Yuan, & Shi, 2016). In this sense, PPC aims to construct close and synergistic links between stakeholders (Grimsey & Lewis, 2004; Klijn & Koppenjan, 2016; Warsen et al., 2020).

As PPC has been adapted according to the historical moment and the context in which it is applied, it would be relevant to briefly explain key terms central to understanding PPC. For instance, regarding the concept of ‘collaboration’, its meaning stems from the Latin ‘collaborare’, referring to labor that is developed together (Lewis & Short, 1879; Stout & Keast, 2021). This term has been adopted in multiple disciplines to refer to the action of two or more people working together to achieve a common goal, for example, creating or co-creating something new (Cambridge University Press, 2019; Innes & Booher, 2010; Stout & Keast, 2021). In the same vein, related to the term ‘co-creation’, it is broadly understood as the outcome of multiple organizations or entities that create together an idea or solution (Elkjær, Horst, & Nyborg, 2021).

Given the diverse schemes of PPC that arise according to the context, hybridity is a pivotal concept. In this sense, scholars such as Quélin et al. (2017) approached the notion of ‘hybridity’ in governance as multi-organization collaborative arrangements, where there is a combination of different organizational traits. Likewise, the ‘ecosystem’ concept is associated with PPC as a collaborative social structure. Scholars have defined this term as a self-organizing multilayer social network where actors bring different traits (Tsujimoto, Kajikawa, Tomita, &

Matsumoto, 2018). According to Valkokari & Hyytinen (2021), ecosystems serve as niches for co-creation between heterogeneous stakeholders. Lastly, the ‘value networks’ concept appears to be associated with PPC, commonly understood as structures of interconnected partners creating value for end users (Valkokari & Hyytinen, 2021).

2.2 Theoretical approach to studying PPC for the energy transition

PPC is conceived as a flexible approach that is more participatory and inclusive; it suits the contemporary challenges of the energy transition. In the recent report by Kivimaa (2023), PPC performs a critical role in the transition to cleaner energy systems by facilitating the pooling of public and private stakeholders’ strengths, resources, and expertise to drive progress toward a shared objective. Likewise, it is crucial to emphasize the need to apply conceptual frameworks to the study of PPC to attend to the urgency in unblocking the shift in socio-technical systems (Kivimaa, 2023), as it involves creating a vision with new forms of configuration based on a synergy between the leading agents of the changes from the institutional, political and technological arenas.

The current research agenda places the exploration of the energy transition from the socio-technical approach at the center of academic endeavors worldwide (Köhler et al., 2019; Markard & Truffer, 2008; Truffer et al., 2022). The transition towards the decarbonization of energy systems requires the recognition of the relevant social challenges that it implies, particularly in terms of the change in the established concept of energy resources at the societal level and its relationship with these resources (Köhler et al., 2019). Furthermore, the shift towards new socio-technical systems is required to achieve the expected transformations towards sustainability in energy production and consumption patterns (Grin, Rotmans, & Schot, 2010; Köhler et al., 2019). As Geels (2005, 2011) and Köhler et al. (2019) stated, transitions towards sustainability are multidimensional and complex; therefore, their study needs to delve into the construction of meanings and prevalent practices to understand the interrelation between the technological, political, social and market dimensions.

Moreover, the energy transition is understood in research as a co-evolutionary process involving multiple interdependent developments over an extended period. Typically, it takes decades to reach a stable rate of progress and eventual stabilization (Köhler et al., 2019; Rotmans, Kemp, & Van Asselt, 2001). As the

transition inherently involves change, numerous innovations are expected, though their development, performance, and adoption are subject to uncertainty.

Notably, beyond these characteristics, the energy transition is recognized as a multi-actor process. While sustainability is a public concern, and private actors may have limited incentives to engage actively in specific processes, public efforts alone are insufficient for a successful transition. As Kivimaa (2023) points out, achieving climate neutrality requires enhancing the resilience of energy systems by reconceptualizing the integration of supply chains, infrastructure, institutions, and business models through strengthened PPC. The same study outlines the capabilities needed for the carbon neutrality transition, highlighting that specific actions—such as creating spaces for PPC—are essential to implementing transformative innovation policies (Kivimaa, 2023).

2.2.1 Social Exchange Theory

Social relationships are anchored in the interaction between agents and their continuous iterations of giving and receiving (Kaynak & Marandu, 2006; Wang, Han, & Yang, 2022). Therefore, collaboration is closely linked to social relationships in its essence, connected to the principle of reciprocal exchange of resources for rewards (Homans, 1974; Stafford, 2008; Wang et al., 2022). Social Exchange Theory is based on this principle to explain resource exchanges by social actors, thus facilitating the study of the mechanisms underlying PPC. In particular, by the use of this conceptual framework was possible to reveal how collaborative behavior is led from the expectations of rewards and benefits of public and private social agents (Kankanhalli, Tan, & Wei, 2005; Shalley, Gilson, & Blum, 2009; Wang et al., 2022).

Furthermore, this conceptual approach places trust and reciprocity at the core of collaborative relationships (Dalenogare, Dain, Ayala, Pezzotta, & Frank, 2023). Additionally, the theory enabled us to connect the specificities of socio-cultural contexts with the nature of collaborative exchanges and the collaboration schemes that emerge between agents from the public and private sectors.

2.2.2 Sensemaking

Sensemaking as a conceptual approach reveals how the elements of socio-cultural contexts provide cognitive frameworks for evaluating the stimuli perceived by agents at an individual level. These frameworks create specific narratives adapted to the environment that explain different situations (Fellows & Liu, 2016; Maitlis,

2005; O’Leary & Chia, 2007). These narratives allow individuals and societies to deal with the uncertainty of unexpected or novel events. The meanings created in a particular sociocultural context have individual and collective implications since they add personal experiences and narratives of common knowledge for the members of a specific context (Fellows & Liu, 2016; Scott, 2013).

Sensemaking is especially relevant for the study of PPC for cleaner energy systems as it performs as a ‘vehicle’ to connect the collective dimension within socio-cultural contexts with the intrinsic motivations of public and private agents to create a collaborative nexus (Fellows & Liu, 2016; Harris, 1994; Ott, 1989). Furthermore, Sensemaking as a heuristic framework contributes to the study of PPC for the energy transition as it enables the exploration of factors exerting influence on collaborative relationships. In particular, Sensemaking helps explore how culture frames the nature of interactions between public and private agents as it performs as an informal institution on a collective level (Dunning & Bansal, 1997; Fellows & Liu, 2016).

2.2.3 Microfoundations

Microfoundations presents a pragmatic approach to the search for plausible explanations for social phenomena. It is not considered an independent theory since it is essentially a perspective that converges various elements facilitating the process of theory building (Contractor et al., 2019; Winter, 2011). The multidimensional lens of Microfoundations focuses on the causal relationship that effects at the macro level have with the interactions, behaviors, and actions that take place at the micro or individual level (Coleman, 1994; Contractor et al., 2019; Felin et al., 2015).

In studying PPC for the decarbonization of energy systems, Microfoundations offers a helpful framework to explore the dynamics of public and private stakeholders in collaborative relationships, which have historically been perceived as dichotomous relationships. Hence, this approach supports the relevance of heterogeneity in collaborative efforts to achieve collective outcomes (Contractor et al., 2019; Felin & Hesterly, 2007). Notably, the Microfoundations heuristic framework provides a pragmatic approach to discovering how socio-cultural configurations influence individuals regarding motivations, actions, and behaviors and the acceptance of PPC schemes for decarbonizing energy systems. Therefore, the socio-cultural context becomes relevant in interactions for collaboration and the corresponding collective outcomes (Contractor et al., 2019).

2.2.4 Practice Theory

One of the core premises of Practice Theory, as highlighted by Jarzabkowski, Balogun, & Seidl (2007), is that actors do not operate in isolation; somewhat, their behavior is shaped by socially defined patterns rooted in the institutions and contexts to which they belong. The socio-cultural context comprises knowledge, norms, values, and frameworks transferred to individuals as practices. At the same time, individuals act as agents within this context, possessing a degree of autonomy to influence and modify it over time. Thus, practices shape both individual actions and collective behaviors (Jarzabkowski et al., 2007; Johnson, Melin, & Whittington, 2003).

From a Bourdieusian perspective, the social world comprises created microcosms where agents interact through concepts such as habitus, field, capital, and practice (Bourdieu, 1990, 2000; Bourdieu & Wacquant, 1992; Gomez, 2015). This view of Practice Theory is particularly valuable for examining PPC in the energy transition. This conceptual approach provides a framework to analyze how the PPC can perform as a scaffolding for emerging and consolidating new social structures, such as emerging ecosystems, to promote innovative solutions to decarbonize energy systems.

2.3 The interplay between theories to approach Public-Private Collaboration for the energy transition

In the study of PPC for the transition towards cleaner energy systems, which is the subject of this dissertation, the use of the conceptual approaches of Social Exchange Theory, Sensemaking, Microfoundations, and Practice Theory provides the possibility of analyzing and delimiting the phenomenon within a logical framework that can solidly guide the development of research in this specific field. First, regarding Social Exchange Theory, this approach allows us to investigate the mechanisms that influence PPC from the conception of social relations grounded in the expectation of reciprocity and mutual benefit. The strength of the collaborative relationship would depend on the intensity and frequency of the exchanges. Additionally, the robustness of the relationship and the existing basis of trust between partners makes it possible to mitigate the risks involved in innovation for energy decarbonization.

Second, the conceptual approach to sensemaking helps to elucidate the formation of meanings about PPC, considering the mental schemes that shape this process. In particular, Sensemaking provides insights into how elements of the socio-cultural context, such as beliefs, norms, and values, influence mental schemas and

determine the dominant forms of PPC in that context. Third, the Microfoundations are heuristic frameworks for theory building through a pragmatic approach, enabling causal explanations for the PPC phenomenon for the energy transition by understanding the factors that take place at the individual level and whose aggregation produces a result at the macro level. Fourth, from the Bourdieusian perspective of Practice Theory, the PPC phenomenon for the energy transition could find plausible explanations from the connection with existing practices in a given context. Additionally, the use of Practice Theory facilitates the identification of the role of PPC as social capital, which is a decisive move forward in the decarbonization of energy systems.

3 METHODOLOGY

3.1 Research philosophy

As research philosophy comprises the systems of beliefs and assumptions about knowledge development, revealing the underlying assumptions underpinning methodological decisions becomes decisive. The discussion about research paradigms and assumptions is relevant to provide a clear lens for readers to understand the author's philosophical position concerning the research work (Saunders, Lewis, & Thornhill, 2019). Notably, by sharing the chosen research paradigm, the author can recognize the perspective from where the social phenomenon has been studied as well as the theoretical approaches used to provide the explanations of the findings and the applied methods (Carlson & Hatfield, 2004; Rabetino, Kohtamäki, & Federico, 2021). It includes explanations of the research work's meta-theoretical assumptions regarding ontology, epistemology, and axiology.

This dissertation could be positioned under the umbrella of the *Interpretivism* paradigm as, in this research work, the phenomenon has been studied considering it as a social construction through culture and nature, which is framed in a specific context (Michael Lynch & Garfinkel, 2022; Saunders et al., 2019). One of the rationales of *Interpretivism* is related to the unique meanings and experiences of social reality that individuals in different cultural settings generate (Saunders et al., 2019). *Interpretivism* seeks to develop deeper understandings and interpretations of social realities in socio-cultural contexts (Saunders et al., 2019).

Interpretivism as a research paradigm offers an appropriate approach to explore the complexity and multidimensionality of PPC for the energy transition. As common public policies and organizational practices overlook the underlying mechanisms to build collaboration among public and public stakeholders under specific contexts, *Interpretivism* is needed to reach a deeper level of analysis in this endeavor. Overall, this research paradigm guides the research towards interpreting reality considering socio-cultural richness (Crotty, 1998; Saunders et al., 2019).

3.1.1 Ontological and epistemological position

Ontological assumptions indicate how the researcher sees the world. These assumptions craft how the researcher perceives the nature of reality and how it is reflected in the study of objects. In *Interpretivism*, reality is perceived as socially

constructed through history, language, and culture (Michael Lynch & Garfinkel, 2022; Saunders et al., 2019). Understanding reality is possible by digging into experiences and practices in specific contexts. Collecting multiple elements from socio-cultural contexts makes it likely to understand the meanings and interpretations generated by individuals and collective actors (Blaikie, 2007). Therefore, the view of the world is nominalist by nature, as meanings are connected to the contexts; they do not correspond to independent entities (Rabetino et al., 2021).

Concerning epistemological assumptions, which refer to acceptable and legitimate knowledge, this dissertation follows the interpretive approach that seeks new understandings of the social phenomenon based on perceptions and interpretations (Burrell & Morgan, 2016; Saunders et al., 2019). The multidisciplinary field of PPC includes different data sources to build solid case studies, which are considered legitimate knowledge (Saunders et al., 2019). Reality under this approach is regarded as symbolically and socially constructed (Blaikie, 2007; Rabetino et al., 2021). Here, knowledge is an interpretation of the world that occurs as virtual images as symbols produced by individuals and amplified in collective groups (Blaikie, 2007; Chia & Rasche, 2010; Rabetino et al., 2021). The contributions are made through the theoretical interpretations of the meanings in socio-cultural contexts revealed through the research work (Gephart, 2004; Rabetino et al., 2021).

3.1.2 Methodological decisions

Methodological decisions are made with the specific goal of addressing the research question in this dissertation. The research design contains methodological choices for data collection and analysis strategies (Saunders et al., 2019). Notably, in this dissertation, an effort was made to keep coherence between the dissertation's objective, philosophical assumptions, and selected research methods. As mentioned, this dissertation follows the interpretive research paradigm; therefore, qualitative methods were found suitable for exploring the social phenomenon and understanding meanings and mechanisms in-depth (Denzin & Lincoln, 2011; Saunders et al., 2019).

Qualitative methods facilitate the discovery of meanings through interaction with participants or using diverse secondary data sources, keeping a naturalistic and interactive focus (Saunders et al., 2019). In this dissertation, two research designs using qualitative methods were employed. First, a conceptual approach was applied by conducting a literature review in Paper 1 and an integrative review of the literature and public reports in Paper 4, focusing on a specific case study.

Second, an empirical approach was used by adopting a case study research design in Papers 2 and 3. Combining conceptual and empirical research methods provides a solid methodological framework that aligns with the underlying philosophical assumptions while using diverse data sources to generate meaningful theoretical contributions to the field.

Next, Table 2 summarizes the research strategy and methods used.

Table 2. The research methods in this dissertation

Research approach	Conceptual research		Empirical research	
	Paper 1	Paper 4	Paper 2	Paper 3
Research design	Conceptual review	Integrative review (applied to a case study)	Case study qualitative research	Case study qualitative research
Unit of analysis	Publications in Web of Science and Elsevier's Scopus electronic databases	Publications in Web of Science and Elsevier's Scopus electronic databases	Country as a case study	Ecosystem emergence as a case study
Data sources	101 records included in the analysis	The analysis included 131 records, and nine official reports and information were from four websites	30 semi-structured interviews and ten official reports	15 semi-structured interviews, two observations, and 28 documents

3.2 Conceptual research: conceptual and integrative literature reviews

3.2.1 Research strategy and design

In qualitative studies, the conceptual approach as a research strategy provides the opportunity to access the latest knowledge in studies conducted by scholars worldwide. The literature review as a conceptual approach contributed crucially to this dissertation, particularly in Papers 1 and 4, because it allowed us to obtain a peripheral vision of the PPC study and identify the predominant research aspects. The conceptual approach using peer-reviewed academic articles facilitated the understanding of the evolution of PPC for the energy transition.

Paper 1 examines existing findings in previous research to identify gaps in knowledge and new alternatives to approach PPC. In doing so, the study follows the guidelines for conducting conceptual reviews in studies conducted by Hulland (2020). The paper focused on comparing traditional public-private partnerships with emerging hybrid public-private partnership models in the literature, where the substantial challenges in collaboration schemes that affect progress in the energy transition were identified.

For Paper 4, the methodological choice was the integrative review approach based on the guidelines of Cronin and George (2023) and Torraco (2005). This method enabled us to synthesize the latest academic literature alongside official reports to understand the subject comprehensively. Therefore, the research work could produce valuable insights from the knowledge in different communities of practice. Paper 4 approached the case of the upcoming end-of-life solar photovoltaics panels in Ghana. The case was studied from the latest scientific literature and from the perspective of international and national public organizations, where collaboration appears to be a key factor for developing suitable strategies for creating value and reducing environmental impacts.

3.2.2 Data collection

The decisions regarding data collection in conceptual research are crucial for ensuring the quality of the results. This process started with the definition of scientific databases and specific criteria for the delimitation of the scope of the study. Subsequently, the criteria for screening the records were defined to be able to use a suitable data set for answering the research questions. In Paper 1, the systematic search was conducted using Scopus and Web of Science. The number

of records obtained was 853 (as of February 8, 2021). During the screening process, abstracts were examined to assess their relevance to public-private partnerships in the energy sector. For the remaining articles, a full-text analysis was conducted using two criteria: (1) emphasis on the energy sector and (2) the centrality of partnerships throughout the article's structure. After completing this screening process, 101 articles were included in the final sample.

In Paper 4, a systematic search was done using Elsevier Scopus and Web of Science scientific databases. Initially, 379 records were retrieved, and 335 unique records remained after removing duplicates. These were screened by reviewing their abstracts to assess their relevance to end-of-life solar photovoltaics panels, resulting in 127 records being included for further analysis. Considering the relevance of collaboration in creating solutions for the end-of-life solar photovoltaics panels in emerging economies, an additional systematic search was carried out in the Scopus database applying the terms "hybrid partnership" OR "hybrid public-private partnership". This search, focused on articles in English from 2001 to 2021, yielded 135 results. Four articles on hybrid partnerships in sustainable development and innovation were identified during the screening process. Considering the significance of this topic from multiple dimensions, reports developed by international renewable energy agencies and supplemented our dataset with official documents and information from public agencies' websites in Africa and Ghana were also incorporated. Our dataset included 131 academic studies from systematic searches, reports from international agencies, and information from selected websites.

3.2.3 Data analysis

After the data collection, the data analysis process requires several steps to capture the key insights from the data set. Paper 1 followed a process of five stages described by Hulland (2020) as i) defining the local domain and scope, ii) capturing and synthesizing extant information, iii) identifying and resolving contradictory explanations, iv) highlighting gaps, and iv) outlining a further research agenda.

The data analysis in Paper 1 began with an outline of the literature on public-private partnerships in the energy sector to assess their relevance to the energy transition. The first explicit definitions of "public-private partnership" in the literature were identified to capture and synthesize existing knowledge because precise definitions are foundational to any discipline (Ronda-Pupo & Guerras-Martín, 2012). The NVivo 12 software was used to qualitatively analyze the sample articles to identify the characteristics of public-private partnerships. This process

involved coding recurring constructs and patterns in the texts, which were then grouped into higher-order categories.

Paper 4 followed eight steps recommended by Cronin and George (2020) for conducting integrative reviews: (i) define the topic within its local context, (ii) identify other different communities of practices that are studying the same topic, (iii) connect these identifiable communities around the subject, (iv) synthesize the primary findings from each community of practice, (v) abstract the findings into overarching themes, (vi) examine the connection between themes, (vii) integrate the themes into a cohesive framework, and (viii) refine and refocus as necessary. Once the dataset was finalized, a thematic synthesis was conducted through holistic data triangulation. This process began by identifying central constructs and grouping commonalities into overarching themes. The findings were then integrated into a complete overview of global practices for managing end-of-life solar photovoltaics panels, along with a proposal for a collaborative value-creation strategy for end-of-life solar photovoltaics panels in Ghana. The alternative principles for systematic reviews outlined by Denyer and Tranfield (2009) were adhered to ensure rigor in the study.

3.3 Empirical research: case studies using qualitative research

3.3.1 Research strategy and design

Empirical research in qualitative research allows the researcher to get closer to real situations to better understand the phenomenon (Eisenhardt, 1989; Eisenhardt & Graebner, 2007; Yin, 2018). In particular, using real case studies as an empirical research strategy is considered one of the most effective ways to produce insights in terms of detailed empirical descriptions and theoretical contributions (Dubois & Gadde, 2002; Eisenhardt, 1989; Saunders et al., 2019). With this in mind, the empirical approach in Papers 2 and Paper 3 case studies was carefully planned and executed.

In Paper 2, a research strategy based on qualitative methods was employed to examine how cultural context shapes individuals' perceptions of PPC for decarbonized energy systems at the national scale. Qualitative methods were selected due to the lack of consistent approaches in the literature for exploring the role of culture in PPC, from individual actions to broader societal outcomes. A single-case study was conducted to examine the perspectives of critical actors in the energy and sustainability sectors, using Individual Sensemaking and Social

Exchange Theory as the foundation for understanding this specific, hard-to-replicate phenomenon. As the case study, Finland was the decision for this paper given its strong history of collective industrial development and its current status as a worldwide proving substrate for developing energy technologies (Business Finland, 2021). The decision to emphasize a single country was supported by the "ecosystem architecture" concept, which frames the study within defined territorial and cultural boundaries (Ma, 2019; Ma, Christensen, & Jørgesen, 2021).

Regarding Paper 3, a qualitative research approach was applied to examine how observable mechanisms related to orchestrators' roles and PCC influence the interaction between agency and structures during forming a public-private ecosystem. The study employs a single case study to provide detailed evidence of the orchestration mechanisms within Finland's emerging ecosystem for battery-based stationary energy storage systems. In its early stages, the public-private ecosystem serves as the primary unit of analysis. The research is grounded in Practice Theory, particularly from a Bourdieusian perspective, to explore the dynamics of agency, structure, and collaboration in the ecosystem's development (Bourdieu, 2005; Gomez, 2015; Jarzabkowski et al., 2007; Jarzabkowski, Kaplan, Seidl, & Whittington, 2016).

3.3.2 Data collection

For data collection, the main sources of primary data in Paper 2 and Paper 3 were semi-structured interviews. This technique is aligned with the interpretive philosophical paradigm and allows us to obtain a realistic approach to the phenomenon. The decision to use semi-structured interviews is due to the need to approach the phenomenon from the very source of knowledge in public and private actors in the energy context. Additionally, in Papers 2 and 3, the results of the interviews were compared with each other and contrasted with other data sources, such as official reports, among others, to ensure the solidity of the contributions of the investigative work.

In Paper 2, the primary data source consisted of 30 interviews with public and private sector experts engaged in PPC for the energy transition in Finland. These informants were selected through official publications from Finnish energy associations, authorities, and organizations. Semi-structured interviews conducted online between June and October 2021 lasted between 42 and 71 minutes and were transcribed verbatim for analysis. Additionally, secondary data from publicly available sources was incorporated to enhance the study's validity.

Concerning Paper 3, a qualitative research strategy was applied in this article to examine how orchestrators' roles and PPC shape the interaction between individual agency and broader structures while forming a public-private ecosystem. The study focuses on a single case in Finland, exploring the early-stage development of an ecosystem for battery-based stationary energy storage systems. Guided by Practice Theory from a Bourdieusian perspective, the research highlights the collaborative efforts between public and private sectors that have been in progress since 2016, forming the foundation for this emerging ecosystem. Finland was selected for the case study due to its advanced experience in electrified systems and a strong commitment to battery technology, reflected in its Battery Strategy (Ministry of Economic Affairs and Employment of Finland, 2021). The initiative, which started in response to the European Tesla Gigafactory in 2016, has focused on developing energy storage solutions. Data collection included 15 semi-structured interviews with key stakeholders, panel discussions with public authorities and international partners, and observations and secondary sources like official reports and media articles from 2017 to 2024, which were used in this research work. Together, these data sources provided a comprehensive understanding of the ecosystem's development and role in advancing Finland's green transition.

3.3.3 Data analysis

Analyzing the data from the semi-structured interviews becomes a unique source of insights into the phenomenon of PPC for the energy transition. Since the perspectives of public and private stakeholders in the energy sector allow us to have a genuine and close connection with reality. For this purpose, a conceptual tool such as the Sensemaking heuristic framework was used in Paper 2 to examine the public-private partnership for the transition towards sustainable energy systems. The study combines semi-structured interviews and archival data, whereas an open coding approach was adopted to discern themes and patterns in the data. Assisted by NVivo 12 software, the sensemaking model proposed by Weick, Sutcliffe, and Obstfeld (2005) was followed, asking four guiding queries: *How did it become important? What does it mean? What is the story here? What should I do?*

Systematically answering these questions, it was identified how stakeholders interpret and construct meaning around PPC, mainly focusing on how they perceive its relevance and their roles in facilitating or hindering collaboration. Through this iterative process, first-order concepts were grouped into second-order topics and, ultimately, into broader aggregated dimensions. This helped us

uncover interdependencies and patterns in how actors make sense of PPC for energy innovation. Additionally, our findings align with the Social Exchange Theory to understand the dynamics of these collaborations. A conceptual match was found by comparing our results with archival data related to PPC and energy innovation in Finland, reinforcing our interpretations and providing a comprehensive view of sensemaking in the context of sustainable energy systems.

Particularly in Paper 3, the data analysis involved examining semi-structured interviews and archival materials following the methodologies of Eisenhardt (1989) and Gioia, Corley, and Hamilton (2013), with additional guidelines from Cloutier and Ravasi (2021) to ensure the trustworthiness of the findings. Relevant data segments were identified and coded to capture their meaning, and these codes were then categorized into second-order themes through an iterative process, continuing until no new themes emerged. The interrelationships among these themes were analyzed and grouped into broader aggregate dimensions. In total, 338 pages of interview transcripts were analyzed to create a structured data model. Additionally, notes from observations and reviews of official and press publications were used to support and enhance the empirical findings.

3.4 Critical assessment of the methodological decisions

Qualitative research demands a thorough execution of methods and techniques to ensure the reliability of findings. It provides a broad perspective on the phenomenon and a detailed, granular analysis to identify focal mechanisms. This dissertation integrates conceptual approaches (in Papers 1 and 4) and empirical approaches (in Papers 2 and 3) to offer a comprehensive, current, and realistic examination of the topic. As noted earlier, the four papers are philosophically aligned, each exploring the phenomenon from different perspectives with clearly defined methodologies. Below is a critical evaluation of the research choices regarding quality and trustworthiness.

3.4.1 Quality assessment

The evaluation of the quality and trustworthiness of conceptual research has been done by addressing the principles of transparency, inclusivity, explanatory, and heuristic research in conceptual research (Denyer & Tranfield, 2009). Additionally, validity and reliability were assessed using the empirical research approach.

Regarding quality in conceptual research, data collection and analysis transparency are crucial to producing the findings and contributions (Saunders et al., 2019). Therefore, in Paper 1 and Paper 4, this process has been presented with details to guarantee transparency. Specific search strings were designed and used to capture the papers on the topic of interest in scientific databases with the broadest range of scholarly journals in conceptual and integrative reviews to ensure inclusivity. Regarding the explanatory principle, contrasting positions in the literature about the topics were shown, and details of the research process were presented to reach the conclusions of the studies. Finally, the close connection between the context and results was underscored to guarantee that the heuristic principle is adhered to.

In empirical research, construct validity is adhered to in Papers 2 and 3 by selecting key informants to cover public and private organizations in the energy field and producing a set of interviews as the primary data source. Additionally, secondary data from publicly available sources was used to contrast the insights from primary sources. Regarding internal validity, the research process in Paper 2 and Paper 3 was carefully outlined by following clear conceptual frameworks. To ensure external validity, a comprehensive literature review was conducted to support the empirical work. Finally, regarding reliability, secondary sources were used to validate the results and document the research process and findings, including power quotes supporting the conclusions.

3.4.2 The subjectivity of the researcher

For researchers approaching contemporary phenomena, exploring the socio-cultural contexts in which these phenomena unfold is essential to fully understanding the factors influencing behaviors (Saunders et al., 2019). As stated by Rabetino et al. (2021, p. 156), the interpretive philosophical approach requires the researcher to adopt the role of an “empathetic observer” and language mediator, facilitating the capture of concepts and meanings that emerge from social interactions with interviewees. Therefore, from my background as a project researcher, I have been involved in energy projects coordinated by the Vaasa Energy Business Innovation Center (VEBIC) platform at the University of Vaasa. Additionally, I have actively attended events related to the energy field at the national and regional levels in the last few years. This experience has enabled me to enhance my observation skills and improve my ability to interpret phenomena when engaging with social actors in the field.

4 RESEARCH PAPERS: SUMMARIES OF FINDINGS

The present dissertation is a compilation of four papers investigating how Public-Private Collaboration can outline the transition to sustainable energy systems. This section serves to give a brief introduction to the papers and outline their findings. It does not intend to present methodological or theoretical background details or examine the research contributions, as these topics are addressed in separate sections of this document. The implications of the research findings are approached in the *Discussion* section. The complete texts of the papers are available in the Appendices of this dissertation (Paper 1, Paper 2, Paper 3, and Paper 4). The author's contributions are acknowledged in the dissertation's Appendices under "Author Contributions".

Paper 1 is a co-authored review study called “Unveiling the shades of partnerships for the energy transition and sustainable development: Connecting public–private partnerships and emerging hybrid schemes,”. The first author is Giovanna Andrea Pinilla De La Cruz. The second author is Professor Rodrigo Rabetino from the School of Management, University of Vaasa (Finland). The third author is Professor Jussi Kantola from the University of Turku (Finland). This paper has been published in the peer-reviewed Sustainable Development journal (Publications Forum -JUFO- 2) in 2022.

Paper 2, “Eliciting the anchor link for building public-private collaboration in sustainable energy: insights from the Finnish context,” is a co-authored empirical study. The first author is Giovanna Andrea Pinilla De La Cruz. The second author is Professor Rodrigo Rabetino from the School of Management, University of Vaasa (Finland). This paper has been published in the peer-reviewed Journal of Cleaner Production (Publications Forum -JUFO- 2) in 2024.

Paper 3, “Unfolding ecosystem emergence: The role of actor’s agency and public-private collaboration practices,” is a coauthored empirical study. The first author is Giovanna Andrea Pinilla De La Cruz. The second author is Professor Rodrigo Rabetino from the School of Management, University of Vaasa (Finland). The third author is Professor Marko Kohtamäki from the School of Management, University of Vaasa (Finland). An earlier version of Paper 3 was presented at the R&D Management Conference in June 2024 in Stockholm. When writing the dissertation introduction, Paper 3 is in progress.

Paper 4, “Collaboration towards value creation for end-of-life solar photovoltaic panel in Ghana,” is a coauthored review study. The first author is University lecturer Emmanuel Ndzibah from the School of Technology and Innovations, University of Vaasa (Finland). The second author is Giovanna Andrea Pinilla De

La Cruz. Associate Professor Ahm Shamsuzzoha from the School of Technology and Innovations, University of Vaasa (Finland) is the third author. This paper has been published in the peer-reviewed Journal of Cleaner Production (Publications Forum -JUFO- 2) in 2022.

Next, Table 3 presents a summary of the findings of each paper.

Table 3. Summary of findings by paper

Paper	Summary of findings
Paper 1	The literature review identified 65 distinct definitions of Public-Private Partnerships. A substantial number of these are based on definitions provided by relevant international entities. Our analysis reveals that six elements are commonly included in these definitions: (i) form, (ii) purpose, (iii) timeframe, (iv) stakeholders, (v) risk, reward, resource and responsibility-sharing, and (vi) critical success factors.
Paper 2	The analysis identified six dimensions of individual sensemaking related to Public-Private Collaboration (PPC) in transitioning to cleaner, more sustainable energy systems. These dimensions were divided into two stages: (1) the progression from the socio-cultural context to introspection, which initiates individual sensemaking, and (2) behavioral decisions regarding PPC as a social outcome. The findings highlight the foundational link between the socio-cultural context and PPC as a social outcome by examining the Microfoundations and deeper trajectory layers. Trust, shaped by national cultural contexts, fosters collaboration among public, private, and hybrid organizations. The public sector supports private innovation through financial tools and plays a vital role in the energy landscape. Cultural context influences the nature of PPC relationships, favoring flexibility and horizontal structures.
Paper 3	The case study of an emerging public-private ecosystem for battery-based stationary energy storage systems in Finland demonstrates the gradual process of self-recognition and value discovery that leads to the formation of a new social structure, such as an ecosystem (Bourdieu, 2005; McAdam, Harrison, & Leitch, 2019). Within this evolving ecosystem, tensions arise from conflicting trajectories and interests, providing insight into micro-level phenomena and practices within a broader context (Bourdieu, 2005; Jarzabkowski et al., 2007). In this ecosystem, the orchestrator acts as a collective entity, representing both individual agency and the cultural background's inertia. The orchestrating team and public and private organizations have created the ecosystem's framework, becoming a tense field. Agents within this space compete to exchange value propositions,

Paper	Summary of findings
	aiming to maintain or improve their position within the ecosystem. The case study identifies specific categories as mechanisms shaping the orchestrating team's agency within this ecosystem.
Paper 4	This study offers a contemporary perspective on global photovoltaic panels waste management, drawing from the literature, specifically focusing on developing economies, particularly Ghana. Using Ghana as a case study emphasizes the potential for value creation from end-of-life photovoltaic panels in such economies. The research comprehensively analyzes end-of-life solar photovoltaic panels across three areas: examining value creation, forming hybrid public-private partnerships among stakeholders, and developing collaboration strategies for knowledge transfer via educational platforms. Regarding hybrid partnerships, the study maps out current stakeholders and presents an approach for stakeholders across the supply chain, categorized into strategic, operational, and support levels. Additionally, it identifies the technical, business, and marketing skills necessary for a sustainability-focused educational platform. Lastly, the study outlines research areas for further studies.

5 DISCUSSION

This dissertation addresses the following umbrella research question: *How does Public-Private Collaboration outline the transition to sustainable energy systems?* In doing so, this research identified the broad spectrum of PPC arrangements, from formalized contractual public-private partnerships to voluntary arrangements (Leminen, Rajahonka, Westerlund, & Hossain, 2021). It underscores the importance of recognizing hybrid schemes as highly context-dependent (Quélin et al., 2017). The research emphasizes the role of cultural context in enhancing the capacity of public and private stakeholders to be involved in social exchanges and collaborate on energy innovation (Johnson & Pinilla-De La Cruz, 2024). It underscores the importance of complementarity of both sectors in achieving common objectives (Lingens, Seeholzer, & Gassmann, 2022). It also emphasizes the necessity of collaboration to drive innovation and facilitate socio-technical change. Drawing on the Microfoundations approach and Social Exchange Theory, the research demonstrates that consensus and trust strengthen the relationships among public and private stakeholders, reinforced by a shared cultural foundation (Steinbruch, Nascimento, & de Menezes, 2022). This dissertation shows that horizontality, influenced by the cultural context, echoes the power dynamics between actors and impacts social exchanges in PPC (Klijn & Koppenjan, 2016; Warsen et al., 2020).

Furthermore, this dissertation reveals how ecosystem actors' agency and collaborative practices shape early-stage ecosystems' development. Using the case of a public-private ecosystem for battery-based stationary energy storage systems in Finland, the study illustrates how self-recognition and value discovery among actors lead to the formation of a new social structure—an ecosystem (Bourdieu, 2005; McAdam et al., 2019). This dissertation also enriches the literature on PPC by demonstrating how these relationships are embedded in social structures, mainly underpinned by high levels of trust (Khalid & Ali, 2017; Malmström & Johansson, 2015). Furthermore, it explains how unaligned actors collaborate to build collective identity, new governance structures, and contextual integration (Jarzabkowski et al., 2007; Thomas & Ritala, 2022). This approach brings new insights into the creation and evolution of ecosystems, explaining shifts in the agents' micro-actions over time (Jarzabkowski et al., 2016). Overall, this dissertation shows how PPC can play a crucial role in adopting sustainable practices to face the upcoming phenomenon of end-of-life photovoltaics in developing economies.

Aligned to this research question as a backbone, each paper included in this dissertation also answers specific guiding questions as follows:

[P1]: *How do public-private partnerships and hybrid schemes differ in addressing the challenging transition toward cleaner and more sustainable energy systems?*

Paper 1 underscores the varying perspectives in the literature on the scope of public-private partnerships in the PPC range, which significantly influence how collaborations are formed. These divergences present challenges, particularly when addressing the cross-sectional transformations in energy systems aimed at sustainable development. The study identifies notable differences in partnership structures, ranging from formalized contractual public-private partnerships to voluntary arrangements. It underscores the importance of spotting hybrid models and ensuring their institutional orientation, as the effectiveness of public-private partnerships and hybrid schemes is highly context-dependent (Leminen et al., 2021; Quélin et al., 2017). Given that the transition is moving to more distributed and inclusive energy systems, the study stresses the need to establish pathways for diverse social actors to collaborate effectively in the energy transition (Köhler et al., 2019). From the public-private partnership in energy literature, the study reveals the challenges to progress toward the energy transition arising from existing ambivalences between public-private partnerships and hybrid public-private partnerships. It illustrates the growing innovative responses from diverse edges of society coming together to tackle the energy transition.

[P2]: *How does cultural context at the country level influence individuals' perception of public-private collaboration? And, how does the cultural context define the nature of the prevalent type of public-private collaboration towards more sustainable energy systems?*

Paper 2 underscores the significant influence of cultural context on PPC, particularly in fostering relationships characterized by horizontality and flexibility without rigid schemes (Podrug, 2011). This environment encourages the social exchange of information, capabilities, and resources, driven by the close connection among institutions and the niches where new ideas emerge (Malmström & Johansson, 2015). The study uses individual sensemaking to explore how cultural context shapes social facts, transitioning from interpretations at the individual level to broader social outcomes in PPC (Contractor et al., 2019; Felin et al., 2015; Ivanova-Gongne & Törnroos, 2017).

The research emphasizes the role of cultural context in enhancing public and private agents' ability to be involved in social exchanges and collaborate on energy innovation. It underscores the importance of complementariness among the public and private spheres in achieving common objectives. Additionally, the study highlights the necessity for collaboration to drive innovation and facilitate socio-

technical shift. Drawing on the Microfoundations approach and Social Exchange Theory, the research exposes that consensus and trust strengthen the link between public and private entities, reinforced by a shared cultural foundation (Khalid & Ali, 2017). Moreover, the study shows that horizontality, influenced by the cultural context, echoes the power dynamics between agents and impacts social exchanges in PPC (Can Saglam, Yildiz Çankaya, Golgeci, Sezen, & Zaim, 2022).

[P3]: *How do the ecosystem actors' agency and collaboration practices define the emergence of the early-stage ecosystem?*

In Paper 3, the practices connected to collaboration between public and private stakeholders and the agency of actors are explored regarding the craft of the emergence of early-stage ecosystems. Using the case of a public-private ecosystem for battery-based stationary energy storage systems in Finland, the study illustrates how self-recognition and value discovery among actors lead to the forming of a new social structure—an ecosystem (Bourdieu, 2005; McAdam et al., 2019). Within this evolving space, tensions arise from differing trajectories and interests, helping to reveal micro-level phenomena within a broader context (Bourdieu, 2005; Jarzabkowski et al., 2007). The orchestrator, acting as a collective agent, plays a principal role in structuring the ecosystem, navigating tensions as actors compete to enhance their value propositions while maintaining or improving their positions within the ecosystem. This study enriches the literature on PPC by demonstrating how these relationships are embedded in social structures, mainly underpinned by high levels of trust (Khalid & Ali, 2017; Malmström & Johansson, 2015).

The paper explains how unaligned actors collaborate to build collective identity, new governance structures, and contextual integration. It contributes to the ecosystem emergence literature (Jarzabkowski et al., 2007; Thomas & Ritala, 2022). From a Practice Theory perspective, it explores how various forms of capital influence agents' behavior and how cultural inertia ('habitus') affects the orchestrator's agency (Bourdieu, 2005; Gomez, 2015; Whittington, 2010). This approach provides insights into the creation and evolution of ecosystems, explaining shifts in the agents' micro-actions over time (Jarzabkowski et al., 2016).

[P4]: RQ1: *How have sustainable practices for EOL PV panels been encouraged on a global scale and specifically in Ghana?*

Paper 4 illustrated how, as in many developing economies, establishing an effective and sustainable photovoltaic waste management system is a critical challenge in Ghana. A relevant aspect of encouraging end-of-life photovoltaic panels' sustainable practices is to foster hybrid partnerships among stakeholders

(Ndzibah, Pinilla-De La Cruz, & Shamsuzzoha, 2021; Yamoah, Kaba, & Adolf, 2020). A robust regulatory and financial framework must underpin these efforts. Therefore, it is essential to focus on strategic-level initiatives in designing policies and regulations and creating incentives to encourage active stakeholder participation in photovoltaic waste management (Salim, Stewart, Sahin, & Dudley, 2019b, 2019a).

[P4]: RQ2: *What are the value creation propositions for EOL PV panels from a public-private partnership perspective?*

In Paper 4, the propositions for value creation from end-of-life photovoltaics panels emphasize the need to identify stakeholders across the entire value chain, acknowledging the complexity of Hybrid Public-Private Partnerships due to the diverse actors involved. The study highlights the importance of defining the roles of stakeholders at different levels (Fischer, Alimi, Knieling, & Camara, 2020; Yamoah et al., 2020). Despite budget constraints, infrastructure needs, and logistical challenges, there are possibilities to foster end-of-life photovoltaic panels' second life and recycling. Fostering synergies between stakeholders in the solar photovoltaics business and the waste management industry can enhance value-creation processes.

[P4]: RQ3: *What are the roles of stakeholders in advancing sustainable practices for EOL PV panels in Ghana?*

This study presents an initial stakeholder map for the photovoltaics industry and a proposed updated map that classifies stakeholders based on their roles in the end-of-life photovoltaics waste management system. While creating synergies among these stakeholders is critical for achieving adequate photovoltaic waste management, practical collaboration predominantly relies on a robust institutional agenda that ensures fair conditions and commitment within hybrid partnerships.

Notably, this dissertation contributes to the literature on PPC from several edges. First, PPC is recognized as a complex and multidimensional phenomenon, following studies by Wanna (2008). Therefore, the study of PPC is focused on unveiling the different layers of this phenomenon. In particular, the findings of this doctoral research are aligned with the studies by Wanna (2008) in the idea that the presence of actors of heterogeneous nature and contrasting visions can give rise to significant challenges to achieving the success of collaborative relationships.

Likewise, the studies conducted by Quélin, Kivleniece, and Lazzarini (2017) are complemented, particularly concerning the connotation of PPC as a phenomenon beyond the scope of relationships between suppliers and customers, where collaborative relationships include hybrid forms that combine economic and social interests. Here, the PPC phenomenon is explored from a conceptual and empirical approach, including the explanations for accepting specific collaborative schemes linked to the socio-cultural context. Thus, the findings of this doctoral research complement previous studies by Caldwell, Roehrich, and George (2017) and Vangen and Huxham (2003), revealing the mechanisms behind PPC from the micro-level.

Moreover, in line with studies by Caldwell et al. (2017) and Tan, Wang, Zhang, and Li (2020), the crucial role of public actors in the PPC to support the development and scaling of emerging energy technologies is underscored in the present work. Additionally, this dissertation offers insights into how PPC becomes an essential pillar of new social structures for innovation, such as ecosystems, from an empirical approach. Finally, following Wanna (2008), the potential of the PPC as an instrument of public policies is presented here, given the advantages that the PPC offers to provide new policies with a realistic, concerted vision adjusted to the energy transition needs are highlighted.

5.1 Theoretical contributions

This dissertation offers theoretical contributions from four perspectives, delimited by three specific boundaries: policy, industry, and organizational (Figure 1). First, regarding *Policy innovation*, the energy transition represents a profound transformation involving restructuring energy processes and their social structures. Consequently, it becomes essential to evaluate how well existing regulations align with the needs of this transition (Geels, Turnheim, Asquith, Kern, & Kivimaa, 2019; Schot & Steinmueller, 2018). At the macro level, sustainability goals are increasingly embedded in the agendas of governments worldwide, influencing national policies and cascading down to regional and local levels (Geels et al., 2019). This shift needs a redefinition of roles, regulatory adaptations to incorporate new actors and activities, and the creation of policies that foster energy innovation (Laatsit, Grillitsch, & Fünfschilling, 2022). This dissertation stresses the fundamental role of PPC in moving towards cleaner energy systems.

As emphasized in recent reports like IRENA (2023), policies promoting the energy transition must adopt a socio-technical approach. Fragmented efforts weaken the

transition momentum, making it crucial for policies to position PPC as a fundamental element in the shift towards cleaner, more sustainable energy systems.

Second, in terms of *Industry innovation*, the transformation of the electricity sector is central to the transformation of the energy systems (Schot & Steinmueller, 2018). The energy industry is undergoing a significant shift, with innovation increasingly focused on cleaner energy sources and technologies to reduce dependence on fossil fuels (Geels et al., 2019). As a result, renewable energy solutions at various stages of maturity are being adopted and expanded by the industry. At the same time, efforts are underway to scale up new energy carriers, improve electricity conversion, enhance energy storage, and advance the digitalization of energy systems and services, among other technological innovations that promote flexibility and reliability (IRENA, 2023b; Kivimaa, Claire, Jayaram, Hakala, & Siddi, 2022). Furthermore, the energy transition demands a broad integration of the value chain, extending beyond the energy sector itself. It is essential to establish connections with adjacent sectors serving consumers and producers of energy resources, such as agriculture, transportation, and maritime industries. This dissertation underscores the critical role of PPC in driving innovation within the energy industry. The interconnectedness of actors and sectors necessitates a multidimensional approach, which can be effectively facilitated through PPC.

Third, related to *Organizational innovation*, the transformation of the energy sector and the integration of value chains would inevitably drive significant changes within organizations (Dall-Orsoletta, Romero, & Ferreira, 2022). Internal practices and processes must adapt to align with the evolving demands of the energy transition. Organizational innovation would be critical for ensuring that businesses survive and capitalize on the opportunities presented by this transition (Malmström & Johansson, 2015). Additionally, organizations must recognize the advantages of PPC when operating within emerging social structures like emerging ecosystems (Steinbruch et al., 2022; Valkokari & Hyytinen, 2021). This dissertation highlights PPC as a form of social capital organizations can leverage for growth and expansion (Malmström & Johansson, 2015).

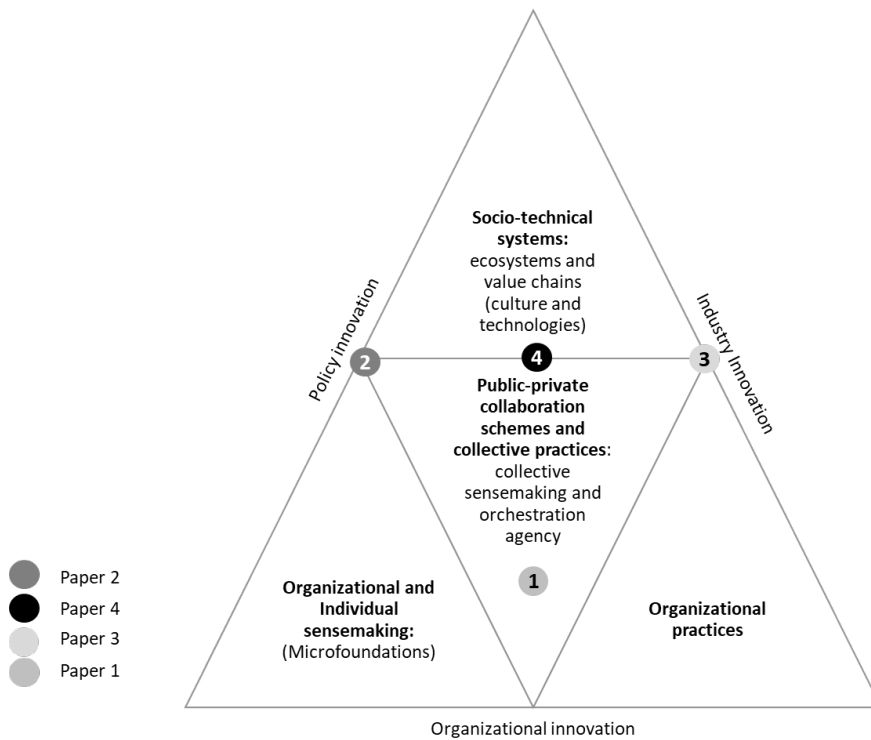


Figure 1. Diagram of theoretical contributions of the dissertation

Concerning the specific contributions, this dissertation brings several conceptual implications to the field of PPC, notably in terms of *Public-Private Collaboration schemes and collective practices*, *Socio-technical systems*, *Organizational and individual sensemaking*, and *Organizational practices*.

5.1.1 Conceptual contributions on the role of alternative PPC schemes and collective practices for the energy transition

Socio-cultural contexts significantly influence the prevalent *PPC schemes and collective practices*. The nature of relationships between public and private actors is shaped mainly by the characteristics of the specific context in which they operate (Autio, Kenney, Mustar, Siegel, & Wright, 2014). Collaboration models are influenced by beliefs, norms, values, and practices widely accepted within a context (Moonen, 2017; Vitell, Nwachukwu, & Barnes, 1993). As such, efforts to introduce collaboration practices or models that fail to account for the unique aspects of the local context may struggle to take root. For collaboration schemes to be effective, they must align with the social and cultural foundations of the society in which they are implemented (Johnson & Pinilla-De La Cruz, 2024).

This dissertation highlights the relevance of recognizing the central role of collaboration in social development and strengthening, which emerges from the

collective practices that have defined a socio-cultural context over time (Gomez, 2015). Achieving successful collaboration between actors with different incentives—such as those in the public and private sectors—requires identifying common values that unite them as individuals and members of a broader community beyond their organizational roles and formalities (Asplund, Björk, Magnusson, & Patrick, 2021; Kola, Koivukoski, Koponen, & Heino, 2020; Valkokari & Hyytinen, 2021). For that purpose, Paper 2 explored the motivations and reluctance factors that enhance or hinder PPC, how socio-cultural contexts lead to an individual's perception of PPC, and determined the prevalent schemes.

The energy transition demands working teams to be able to operate in complex situations because this shift often involves high levels of technical and commercial risk, rapid decision-making, flexibility, and adaptation. This level of collaboration can only be sustained through a shared commitment to working toward common goals, regardless of challenges. The degree of formality in PPC schemes would differ according to the need for control and the level of trust within a specific context (Steinbruch et al., 2022; ter Bogt & Tillema, 2016). The balance between formal and informal collaboration must reflect the established norms and collective practices of the relationships in that context. Paper 4 discussed the need for hybrid collaboration schemes to approach upcoming phenomena such as the end-of-life of solar photovoltaic panels in developing economies.

Notably, the energy transition, as previously discussed, fosters the emergence of new social structures, such as ecosystems, which begin at niche levels (Geels, 2011; Schot & Geels, 2007). These ecosystems serve as incubators for innovative ideas that can gradually be scaled to industrial and commercial levels through collaboration between diverse organizations. Achieving the goal of scaling innovation, particularly in emerging energy technologies, implies significant risk investment—something no single sector can bear alone—and multi-level discussions to enable necessary regulatory changes (Geels et al., 2019; Köhler et al., 2019). These changes can fundamentally affect the energy sector's operation, particularly in energy storage and new energy carriers.

Moreover, engaging citizens in dialogue will be essential to build consensus around the potential implementation of these changes. Public sector involvement is crucial within ecosystems to ensure that solutions are aligned with the social, political, and financial landscape. It is also vital that the public sector provides adequate support to facilitate these transformations. Alongside this, the participation of key actors—such as research institutes, development companies, and industries willing to adopt innovations—would be necessary (Asplund et al., 2021). Effective orchestration of these actors is critical to creating a robust ecosystem, ensuring

that innovations reach the level of maturity needed for their adoption in society. Within ecosystems, the orchestrator plays a vital role, acting as a collective agent capable of making strategic decisions while representing the collective interests of all members. The orchestrator ensures that the ecosystem stays focused on achieving its overarching goals, fostering collaboration, and driving innovations to their full potential (Autio, 2022; Valkokari, Seppänen, Mäntylä, & Jylhä-Ollila, 2017). Therefore, Paper 3 explores the mechanisms for ecosystem emergence behind the orchestration's agency and the role of PPC along the early stages of emergence.

5.1.2 Conceptual contributions on the role of PPC in transforming Socio-technical systems

Addressing climate change requires decisive action, such as the shift to cleaner energy systems (Sovacool, 2016). This transition extends beyond developing and scaling new energy technologies, as illustrated in Paper 3; it also demands profound social transformations alongside technological advancements (Kivimaa et al., 2022). Public and private stakeholders are the main drivers of this shift toward new *Socio-technical systems*. These actors include supranational, national, and regional government authorities, publicly funded organizations, universities, research institutions, energy facilities, industries that consume energy resources, and technology development companies. Notably, these stakeholders also play a dual role as users of the technologies alongside the general public.

Given the social dimension of the energy transition, key stakeholders must collaborate to advance the necessary actions for decarbonizing energy systems (Geels et al., 2019). PPC emerges as a pivotal mechanism for pooling resources and efforts to achieve the global goal of tackling climate change through mitigation and adaptation measures (Kivimaa, 2023). The shift toward sustainable socio-technical systems occurs at multiple levels and involves the integration of energy value chains, as explored in Paper 4. This includes linking actors and processes associated with energy activities and sectoral integration with industries. The relationships between sectors, organizations, and authorities would be crucial in ensuring that PPC is a tool for finding common ground, enabling actors to aggregate efforts (Wanna, 2008). In this process, it is vital to consider the cultural dimension in building strong collaborative relationships based on trust and reciprocity, as examined in Paper 2.

5.1.3 Conceptual contributions on the role of Organizational and Individual sensemaking for fostering PPC

As PPC is a social phenomenon that can be explained by links between actors at the micro level, understanding the underlying mechanisms requires exploration of both *Organizational and Individual sensemaking*. Over time, established practices in socio-cultural contexts shape organizational practices and become the next point of reference for reacting to environmental stimuli. In turn, contextual practices affect the perceptions and interests generated at the individual level (Fellows & Liu, 2016; Harris, 1994).

Therefore, studying PPC for the energy transition requires exploring organizational and individual sensemaking in socio-cultural contexts, providing insights into the perceived distance between partners. For instance, in those contexts where high trust and lower distance are prevalent, the gap between partners may seem smaller, and collaborative endeavors would be based on a lower need for control (Hofstede, 1983; Hofstede, 1979; Vitell & Barnes, 1993). Mainly, Paper 2 offers valuable information about the sensemaking process related to the concept of PPC within specific contexts by applying the organizational and individual sensemaking approach. Additionally, this approach enabled the identification of key factors to build collaboration between heterogeneous stakeholders for the decarbonization of energy systems.

5.1.4 Conceptual contributions on the role of Organizational practices in enabling PPC

Regarding the conceptual contributions to *Organizational practices*, this dissertation highlights the role of collaboration for industries and public organizations to capitalize on opportunities for value creation and value capture from the energy transition (Caldwell et al., 2017). Given their significant impact on transforming energy systems—ranging from large corporations to SMEs—organizations contribute meaningfully to this shift, highlighting the value of working together. Specifically, as illustrated in Paper 3, organizations find their place by collectively pursuing goals that benefit individual entities and a diverse group of stakeholders in the emergence of new social structures like ecosystems (Valkokari et al., 2017).

PPC for the energy transition can create both social and organizational value (Caldwell et al., 2017; Quélin et al., 2017). Beyond the intrinsic benefits tied to the technology or energy services that the ecosystem supports, member organizations gain exposure to different work practices, industry standards, and the potential for

synergies within the value chain. Collaboration enhances soft skills and increases visibility within industrial and commercial networks (Kola et al., 2020). These outcomes contribute to resource optimization and broaden the organization's market perspective, fostering innovation and growth.

5.2 Implications for practitioners and society

The dissertation provides useful insights for policymakers and practitioners in the energy and sustainability sectors. Policymakers can find insights in this dissertation to develop policies focusing on multi-actor collaboration that facilitates the assimilation of the technological, policy, and regulatory changes implied by the decarbonization of energy systems (Köhler et al., 2019). Likewise, this dissertation presents arguments for incorporating contextual factors and promoting social learning between public and private agents in innovation policies (Köhler et al., 2019).

The findings of this dissertation align with the need to promote and provide support for collaboration between public and private agents as one of the key capabilities for the energy transition addressed in the report by Kivimaa (2023). Likewise, the transformation of new policies for innovation requires spaces provided for experimentation with emerging energy technologies by multiple actors and new public funding mechanisms oriented to public-private co-creation (Geels et al., 2019; Matschoss & Repo, 2020; Schot & Steinmueller, 2018).

This dissertation also argues the need to issue policies for innovation according to the financial resources and expertise of different actors in initiatives to transform energy systems (Kivimaa, 2023). Furthermore, a call is made for innovation policies to include PPC within the framework of public policies. Likewise, this dissertation offers inputs for industries to identify opportunities for value creation from the energy transition through collaboration with public actors to integrate value chains and create new ecosystems (Kivimaa, 2023).

Collaboration could reveal new untapped opportunities to create industrial and social value while reducing resistance to change by promoting flexible, trust-based relationships (Steinbruch et al., 2022). In the organizational context, the findings are expected to inspire companies and public organizations to recognize their internal strengths while identifying gaps in capabilities and resources that can be addressed through PPC (Malmström & Johansson, 2015). The work also encourages reflection on the organizational changes needed to navigate the energy transition, helping reduce the risks posed by evolving regulatory and normative frameworks (Dall-Orsoletta et al., 2022).

5.3 Limitations and future research recommendations

This dissertation has several inherent limitations. First, related to the conceptual research approach in Paper 1 and Paper 4, the data capture and analysis are constrained by the systematic search, which may have led to the omission of some relevant studies. Although two of the most comprehensive bibliometric databases were used, there is a possibility that specific articles available in other databases were missed, though further reviews did not reveal any missed relevant studies.

Regarding the empirical approach, using single case studies in Papers 2 and 3 limits the generalizability of the findings, although the cases were selected based on their specific relevance. In Paper 2, Finland was chosen as the unit of analysis due to its unique institutional, cultural, and regulatory framework, which presents noteworthy characteristics in terms of collaborative relationships among public and private stakeholders in energy innovation. In Paper 3, the focus on Finland's early-stage ecosystem for battery-based stationary energy storage systems highlights the crucial role of PPC in fostering ecosystems for critical aspects of the energy transition, such as energy storage. This dissertation's interpretive approach also benefits from using single cases, allowing for a detailed exploration of the phenomenon to uncover the meanings and mechanisms that drive collective outcomes.

Future research could expand in several important directions. First, exploring suitable mechanisms to promote PPC across contexts is possible, especially in cleaner energy systems. Additionally, further studies could investigate the roles and drivers of public and private organizations within these collaborations. Other potential research areas include examining how social capital can foster emerging ecosystems and understanding how disruptions in current trajectories can create turning points in the evolution of these ecosystems. These efforts would help deepen the understanding of PPC in addressing energy transition challenges.

6 CONCLUSIONS

This dissertation has studied how public-private collaboration (PPC) can play a central role in outlining the transition to cleaner energy systems. This research addresses gaps in the literature to highlight the fundamental role that PPC plays in accelerating the transition toward the decarbonization of energy systems. The four papers in this dissertation compilation provide valuable and up-to-date information on the mechanisms underlying collaborative relationships and conceptual approaches and applications in case studies.

In this dissertation, four conceptual approaches are used to explore the factors that influence the creation and effectiveness of PPC for the energy transition: Social Exchange Theory, Sensemaking, Microfoundations, and Practice Theory. The findings of this dissertation present the socio-cultural context, trust, and reciprocity as elements that significantly influence collaborative relationships. Additionally, it is emphasized that successful collaborative relationships appear as a collective effort strengthened by shared values such as mutual trust, which goes beyond contractual ties.

Furthermore, this dissertation stresses the role of hybrid PPC schemes, often shaped by the specific cultural, political, and economic contexts in which they operate. This dissertation reveals the potential of PPC in creating new social structures, such as ecosystems. The case study of battery-based stationary energy storage systems in Finland demonstrates how agency and collaborative practices among actors can promote emerging ecosystems that enable sustainable energy innovation. Such ecosystems can evolve through collective identity formation, the development of governance structures, and contextual integration.

From a managerial perspective, this dissertation offers valuable insights for policymakers and practitioners. Notably, the significance of promoting collaborative synergies between public and private organizations, for instance, enables joint work between different actors for the energy transition. Policymakers should consider the socio-cultural context when crafting innovation policies and promoting social learning between stakeholders. This approach would help establish the support networks necessary for scaling energy innovations and achieving long-term sustainability goals.

While this research offers new insights into PPC and its role in energy transitions, several avenues for future research remain. There is a need to explore mechanisms that enable PPC to be applied effectively across diverse contexts, particularly in cleaner energy systems. Additionally, further studies should investigate the drivers and roles of different organizations within these collaborations and examine the

role of social capital in fostering ecosystem development. Future research could also examine how disruptions in current energy systems could create opportunities for the evolution of new, more resilient collaborations.

Overall, this dissertation enriches the understanding of PPC by demonstrating its essential role in driving the transition to sustainable energy systems. Through theoretical and empirical contributions, it establishes a foundation for future studies on the socio-technical transformations required to address the pressing challenges of climate change. By recognizing PPC as a key mechanism for collaboration, this work provides essential insights for policymakers and practitioners to navigate and support the energy transition effectively.

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Appendix: Author contributions to Papers 1-4

Paper 1

Giovanna Andrea Pinilla De La Cruz is the first and corresponding author of the paper. Contributions of Giovanna Andrea Pinilla De La Cruz are related to the writing – review & editing, writing – original draft, methodology, formal analysis, data curation, and conceptualization. Rodrigo Rabetino, the second author, contributed to the writing –review & editing, validation, supervision, project administration, and conceptualization. The third author, Jussi Kantola, contributed to the supervision and project administration paper.

Paper 2

Giovanna Andrea Pinilla De La Cruz is the first and corresponding author of the paper. Contributions of Giovanna Andrea Pinilla De La Cruz are related to the writing – review & editing, writing – original draft, methodology, formal analysis, data curation, and conceptualization. Rodrigo Rabetino, the second author, contributed to the writing –review & editing, validation, supervision, project administration, and conceptualization.

Paper 3

Giovanna Andrea Pinilla De La Cruz is the first author of the paper. Contributions of Giovanna Andrea Pinilla De La Cruz are related to the writing – review & editing, writing – original draft, methodology, formal analysis, data curation, and conceptualization. Rodrigo Rabetino, the second author, contributed to the writing –review & editing, validation, supervision, project administration, and conceptualization. Marko Kohtamäki, the third author, contributed to the writing –review & editing, validation, supervision, and conceptualization.

Paper 4

The first author, Emmanuel Ndzibah, worked on conceptualization, methodology, formal analysis, writing the original draft, writing review, and editing. The second author, Giovanna Pinilla De La Cruz, worked on conceptualization, methodology, formal analysis, writing the original draft, writing review and editing, and visualization. The third author, Ahm Shamsuzzoha, worked on conceptualization, methodology, and writing review and editing.



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REVIEW ARTICLE



Unveiling the shades of partnerships for the energy transition and sustainable development: Connecting public–private partnerships and emerging hybrid schemes

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Abstract

The transition to cleaner energy technologies and sustainable development requires the commitment and collaboration of the public and private sectors. Among such collaborations, public–private partnership (PPP) refers to the convergence and complementarity between public and private actors and represents an organizational arrangement for addressing strategic sustainability challenges such as reducing carbon emissions and plays a relevant role in transforming the sector after energy reforms. The rigidity of PPP schemes introduces certain limitations in adapting to the energy transition and sustainability needs. As a result, several hybrid schemes have emerged from PPPs, which are focal points in this paper. This article aims to contrast PPPs with emerging hybrid PPPs to facilitate their understanding. It contributes to the academic dialog on recognizing the relevance of emerging forms of collaboration in tackling contemporary issues. The review's primary outcome is a framework of PPPs and hybrid PPPs and the critical challenges for advancing the energy transition and sustainable development. The contributions from this study may help policymakers to design suitable tools for incorporating hybrid PPPs in climate change policies and institutional frameworks. The findings suggest developing mechanisms through which PPPs and hybrid PPPs foster cleaner technologies, thus improving energy efficiency and access and strengthening energy security strategies. Further work is needed to address key research issues related to (i) mechanisms for the institutional alignment of hybrid PPPs, (ii) assuring reciprocity and commitment, (iii) knowledge management, and (iv) capacity-building.

KEYWORDS

energy transition, environmental policy, hybrid, innovation, public–private collaboration, public–private partnership, public–private partnership, stakeholder engagement, sustainable development

1 | INTRODUCTION

Climate change requires urgent actions, including the transition toward cleaner technologies and sustainable development (Fleta-

Asín & Muñoz, 2021). Current challenges involve technological, environmental, social, and economic disruptions (Sovacool, 2016; Wang & Ma, 2021). Forging alliances and cooperation networks is essential in pursuing this goal (Cruz & Sarmento, 2017; Pinilla-De La

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Cruz et al., 2020). Accordingly, public–private partnerships (PPPs) are the point of convergence and complementarity between public and private actors (Jumbe & Mkondiwa, 2013; Morse & McNamara, 2009; Shahbaz et al., 2020). In particular, scientific research on the role of PPPs in energy has attracted attention with the advent of global reforms in the energy sector (Pinilla-De La Cruz et al., 2021; Sovacool, 2013). Thus, the private sector's involvement in the energy domain has been propelled since the economic recession of 1970 (Fleta-Asín & Muñoz, 2021; Sovacool, 2013), wherein PPPs became widely used as part of electricity reform process strategies around the world (Araquistain Portela, 2020; Gao & Zhao, 2020; Southard, 2010).

The energy transition and evolution of related energy systems have significantly broadened the role and scope of PPPs to support the transition toward cleaner technologies and sustainable development (Chen et al., 2019; De Carvalho, 2018). Per Thomas et al. (2018), the energy transition requires “scalar lenses” to comprehend and connect the different contexts in which it occurs (Broto & Baker, 2018; Harrison & Popke, 2018; Smith & High, 2017; Thomas et al., 2018, p. 184). Recognizing the multidimensionality of the energy transition is critical for understanding the needed transformation in cooperation between actors due to technical reconfigurations and the social and economic implications of this phenomenon (Smith & High, 2017; Thomas et al., 2018). It involves the transition toward creating more sustainable systems for the access and use of energy resources (Sanderink, 2020; Thomas et al., 2018; Turner et al., 2003) including the exploration of the circular economy, industrial ecology, ecological economy and political ecology (Bettencourt & Kaur, 2011; Seager, 2008; Thomas et al., 2018). Consequently, it is imperative to identify the current limitations of traditional systems to incorporate alternative responses where cooperation in pursuit of the transition is effective (Broto & Baker, 2018; Thomas et al., 2018).

Although the relevance of PPPs for reducing carbon emissions is shown (Raza et al., 2021), and they can play a determining role as a shortcut for the transformation of the energy sector (Somma & Rubino, 2016), it would seem that the current PPP schemes have certain limitations in their formats for the energy transitions. In this sense, Chaurey et al. (2012) and colleagues argue about the limitations against the incorporation of innovative technological and institutional solutions for access to energy aligned to the sustainable development goals (SDGs) given by the absence of sustainable partnerships adapted to the new scenarios (Chaurey et al., 2012). In their study on electric vehicle charging infrastructure, Wang and Ke (2018) highlight that PPPs require specific adaptations to the new contexts proposed by the energy transition, which differ from the experiences of infrastructure sectors. Cruz and Sarmiento (2017) indicate that PPP models based on deterministic planning models on costs, risks, and revenues have proven unsuitable for uncertainty scenarios. Additionally, typical contract-based models appear incompatible with incorporating radical innovations and the interaction of different social actors (Cruz & Sarmiento, 2017; Gunawansa, 2011).

Moreover, these authors further expose the need for reforming PPPs to provide them with greater flexibility in facing smart infrastructure challenges in the transport, water, energy, and information, communication and technology (ICT) sectors (Cruz & Sarmiento, 2017). Likewise, Klijin and Koppenjan (2016) have studied the

influence of contract length and flexibility on innovativeness in projects. Notably, from the need of developing innovation, a new field within the PPP umbrella is under construction and is of great interest as it provides opportunities to develop and adopt innovative solutions through collaboration (Weihe et al., 2011). These hybrid schemes are emerging in the Nordic countries as public–private innovation partnerships (PPIs) (Brogaard, 2015, 2017, 2019; Weihe et al., 2011). PPIs encompass a broad assemblage of formal alliances and collaboration based on networks between public and private organizations to innovate technologies, processes, and services (Brogaard, 2015).

An ongoing discussion is needed regarding the adequacy of PPP schemes to face the energy transition challenges and sustainable development. Indeed, relevant international forums have emphasized the need to align PPPs with SDGs to improve their broad implementation in projects for access to clean energy, new energy infrastructure, and energy innovation (Hancock et al., 2018). SDGs offer a broad vision that requires the collaborative participation of all social actors. For instance, Goal 17 seeks to promote new effective forms of collaboration and recognizes partnerships as vehicles to mobilize and share resources and knowledge to achieve the SDGs (Hassan et al., 2019; Oliveira-Duarte et al., 2021; Tremblay et al., 2020). Inexorably, the complex nature of sustainability requires additional efforts by governments, industry, and communities in aligning collaboration to achieve higher impacts (Owusu-Manu et al., 2020).

In the same vein, the energy transition and sustainability require systemic approaches beyond the traditional bilateral collaboration since it is not a confined or linear problem but interconnects multiple actors in multiple layers with a global impact (Svendsen & Laberge, 2005). As Heldeweg et al. (2015) point out, this change process includes “gray areas” that have not yet been regulated and of which there is no total clarity at the institutional level, in addition to the overlapping and competing roles among public and private actors. It is necessary to identify what exists and works for specific contexts and their limitations. Further, in specific and complex scenarios, such as the energy sector, alternative PPP schemes have emerged for the energy transition but do not seem to be entirely recognized as such in the previous literature. This group includes many new forms of collaboration typically referred to as “hybrid PPPs,” which do not have a clear space within the framework of PPPs (Nel, 2018; Ungureanu et al., 2018; Vikkelsø et al., 2021; Zhu & Sun, 2020). Indeed, new forms of collaboration can generate social value in the form of innovative solutions, development, and transfer of new knowledge, building trust and mutual commitment (LaBerge & Svendsen, 2000; Svendsen & Laberge, 2005). It is appropriate to expose this phenomenon to speed up the energy transition and safeguard the principles in which energy governance is framed when incorporating alternative models of collaboration within PPPs (Heldeweg et al., 2015).

Against this backdrop, this article aims to contrast PPPs with emerging hybrid PPPs in the literature to understand emerging forms of collaboration and their key challenges. In doing so, this article does not intend to take a normative stand to determine what should or should not be included within the scope of PPPs. Instead, it aims to understand, based on a conceptual literature review, what kind of schemes have been classified as PPPs in the existing papers concerning the

energy sector, as well as the fundamental features of and differences between these schemes and the critical challenges for advancing the energy transition and sustainable development. Thus, following the methodology for conceptual reviews proposed by Hulland (2020), the present study addresses the following research question: *How do public-private partnerships and hybrid schemes differ in addressing the challenging transition toward cleaner and more sustainable energy systems?* The primary outcome of the study is a framework for understanding PPPs and hybrid PPP schemes. Thus, this paper contributes to the academic dialog on recognizing the relevance of emerging forms of collaboration in tackling contemporary issues by exploring the role of PPPs and emerging hybrid PPPs as well as key challenges of the transition toward cleaner and more sustainable energy systems.

2 | RESEARCH METHODS

The value of conceptual review papers derives from their ability to sense the voids requiring urgent recognition and updating current frameworks. As Hulland (2020, p. 31) states, “Conceptual reviews are most effective when they synthesize existing findings, identify gaps and generate new insights, and propose novel ways of thinking about a phenomenon.” Accordingly, this review takes this reference for the design of the research work.

Figure 1 shows the research outline for conducting this conceptual review following a five-stage process proposed by Hulland (2020, p. 28), that is, (i) defining the focal domain and scope, (ii) capturing and synthesizing current knowledge, (iii) identifying and resolving contradictory explanations, (iv) identifying gaps, and (v) setting research agenda, further explained in the text below (Sections 2.1–2.3).

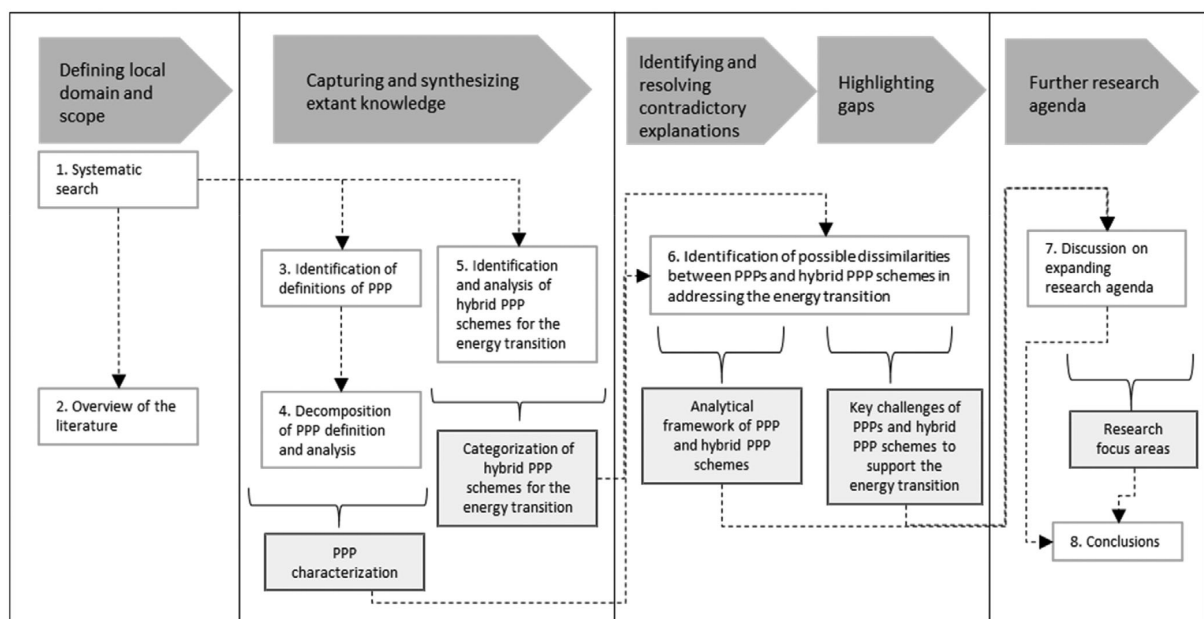


FIGURE 1 Research outline

2.1 | Data collection

A systematic search was conducted in Web of Science and Elsevier's Scopus databases to locate scholarly articles in English, using a search string that includes “ppps” OR “public private partnership” OR “public-private partnership” AND “energy.” Since the acronyms PPP and PPPs are widely used in other disciplines, we included exclusions to the search string such as “pentose phosphate pathway,” “purchasing power parity,” “Poisson point process,” among others. We retrieved 853 records (as of February 8, 2021), resulting in 676 unique items after eliminating duplications. By performing a screening process, we first assessed the connection between abstracts with PPPs in energy. After disregarding irrelevant articles by screening the abstract, the full texts of the remaining articles were analyzed applying two criteria: (1) focus on the energy sector, (2) centrality in partnerships reflected in the whole structure of the article. At the end of the screening process, 101 articles had become part of the final sample (see systematic search and screening process in Figure A1).

2.2 | Data analysis

The data analysis started with an overview of the literature in PPPs in energy as a first approach to observing the sample's connection with the energy transition. Subsequently, for *capturing and synthesizing current knowledge*, we proceeded to identify the explicit definitions of “public-private partnership” or “PPP” in the literature based on the premise that definitions are the central pivot of any discipline (Ronda-Pupo & Guerras-Martín, 2012). We identified the key characteristics of PPPs by carrying out a qualitative analysis of the articles in the

sample using the NVivo 12 software package. This process included identifying constructs that shared commonalities or patterns in the texts, denoted as codes (see Table B1 and Figure C1) and later combined in higher-order categories. The systematic literature review by Kohtamäki et al. (2018), the Gioia et al. (2013) methodology was used as a reference for the analysis. The first outcome of the study at this instance was the characterization of the concept of PPPs. We described different categories of hybrid PPPs in the literature via content analysis. Later, based on the characterization of PPPs and identification of hybrid PPPs, we analyzed the current limitations of PPPs and hybrid PPPs to advance the energy transition. We obtained three outcomes in identifying and resolving contradictory explanations and identifying gaps as (1) a categorization of hybrid PPPs for the energy transition, (2) an analytical framework of PPPs and hybrid PPPs, and (3) a summary of key challenges of PPPs and hybrid PPPs to support the energy transition. In the final step, we suggested some future avenues for further research.

2.3 | Quality assessment

The study follows the premises to promote rigor proposed by Sovacool et al. (2018). It also adheres to the four alternative principles, that is, transparent, inclusive, explanatory, and heuristic, to produce systematic reviews, as described by Denyer and Tranfield (2009) and used as quality criteria by scholars (Rojon et al., 2021). First, transparency is ensured with the open presentation of the research process. In so doing, we described the research design, including the process of data collection and data analysis. Therefore, readers can relate the data, findings, and conclusions. Second, we used as data sources two of the electronic databases with the highest spectrum of academic journals (Scopus Elsevier and Web of Science) to guarantee the inclusiveness of the relevant literature for the study.

Additionally, the search string was designed to capture studies focused on the topic of interest. Based on the exclusion criteria, a screening process was used to obtain the final sample for analysis. Third, the explanatory principle is presented by contrasting and juxtaposing the literature and transparent ways of analyzing data, for example, the decomposition of PPP definitions and subsequent analysis of hybrid PPPs. Finally, the heuristic principle is adhered to by presenting the connection with the context when describing different hybrid PPPs for the energy transition.

3 | RESEARCH FINDINGS

3.1 | Overview of the literature in public-private partnerships in energy

The literature on PPPs in energy has its antecedents in the economic recessions of the 1970s and the following growth in public debt (Sovacool, 2013). These events led to the transformation of contracting models in the energy sector. Over the next two decades, the

former natural monopolies progressively gave way to new actors and competitive forces. In the 1990s, a global reform process was consolidated, and at least 60 countries have included PPPs in their governance schemes (Komendantova et al., 2012; Sovacool, 2013). After that, and in connection with the growing concern about climate change and sustainable development (Faulkner, 1995; Zhang & Maruyama, 2001), the scientific literature compiled this transformation phenomenon and prepared the ground for the development of a new stream of research separate from those on the application of PPPs in other infrastructure sectors. From 2015 onward, the volume of scientific production in PPPs in energy has intensified in energy efficiency and agro-energy applications in Europe and waste-to-energy and electric vehicle charging infrastructure in China (Manos et al., 2014; Xu et al., 2015; Yang et al., 2016). A key aspect in the literature is the persistence of sustainability (Arbulú et al., 2017; Bougrain, 2012; Sheng et al., 2020), clean energy (Atmo & Duffield, 2014; Feng et al., 2021; Raza et al., 2021), and the energy transition (De Carvalho, 2018; Koengkan, 2020) as the motivation for research.

An interesting aspect of the literature is how the concept of PPP has been used over time. It should be noted that the current approaches differ from the studies published in early 2000. In the early studies, PPP appears to strengthen the electricity supply and facilitate energy access. Over time, several studies focused on identifying critical success factors (CSF), while others discussed the role of PPPs within new energy efficiency schemes. The latest studies show PPPs as a mechanism for developing emerging technologies such as hydrogen applications, and a substantial change occurred in discourse toward a discussion on the explicit role of PPPs in reducing CO₂ emissions and climate change. It reveals how PPP plays a relevant role in moving toward sustainable development.

3.2 | Analysis of definitions of public-private partnerships

Scholars have highlighted the lack of consensus in the literature on a universal definition of PPPs (Ahmad & Raza, 2020; Araquistain Portela, 2020; Di Liddo et al., 2019; Rossi et al., 2019; Shahbaz et al., 2020). According to Heldeweg et al. (2015, p. 3), based on Bloomfield (2006), some ambiguities emerge from what is known as the “container concept” attributed to PPPs. However, analysis of the previous definitions brings a better understanding of the central characteristics of PPPs. We identified 65 explicit definitions of PPPs in the literature (see studies in Table D1). A significant number of them are derived from the definitions proposed by international organizations such as the World Bank, European Commission, the Asian Development Bank, United Nations, and the Organization for Economic Co-operation and Development (OECD). Our analysis indicates the presence of six elements in the definition: (i) form, (ii) purpose, (iii) timeframe, (iv) stakeholders, (v) risk, reward, resource and responsibility-sharing, and (vi) critical success factors (Figure 2).

Form	<ul style="list-style-type: none"> - Contract - Cooperation - Collaboration - Agreement - Legally binding contract - Broad assortment of relationships
Purpose	<ul style="list-style-type: none"> - Public assets/infrastructure and/or services - Funding, construction, renovation, management, maintenance of infrastructure or service
Timeframe	<ul style="list-style-type: none"> - Long-term
Stakeholders	<ul style="list-style-type: none"> - Public and private entities
Risk, reward, resource and responsibility sharing	<ul style="list-style-type: none"> - Sharing responsibilities, risks, revenue and costs
Critical success factors	<ul style="list-style-type: none"> - Engagement of private sector - Focus on specific goal - Goal alignment

FIGURE 2 Characteristics of public–private partnerships from the definitions. Source: See sources in Appendix D

Each of the six elements in Figure 2 encompasses the key characteristics of PPPs. From this analysis, it is possible to observe how the “form” of PPPs is mainly described as a “contractual,” “cooperative”; further, several authors refer to a PPP as an “agreement,” “collaboration,” and “broad assortment of relationships”. There are also other “forms” identified in the analysis, such as “hybrid” (one time) (Nel, 2018) and “voluntary effort” (one time) (Fecondo & Moca, 2015), mainly originated from authors approaching hybrid PPPs. On the other hand, in terms of the “purpose,” the finding indicates that PPPs are oriented to provide public assets, infrastructure and/or services, and activities related to financing, construction, renovation, management, and maintenance infrastructure or service. Concerning the timeframe, PPPs lean substantially toward long-term relationships. In terms of “stakeholders,” there is consistency in the convergence of public and private actors. Regarding the “risk, reward, resource and responsibility-sharing” in PPPs, most agree that the relationship involves sharing responsibilities, risks, revenue, and costs. Only some definitions refer to “critical success factors,” where scholars highlighted the relevance of private sector’s engagement, focusing on a specific goal, and goal alignment.

3.3 | Hybrid public–private partnership schemes: Developing a categorization

Although there is no clear border between PPPs and hybrid PPPs, we searched for hybrid schemes in the literature. Surprisingly, almost 30% of the literature reviewed refers directly or indirectly to variants of PPPs, although our search string does not include any explicit keyword concerning the hybrid schemes. Those hybrid PPPs appear with different labels and descriptions; however, they pursue the ultimate goal of the energy transition from diverse approaches. Based on the findings, we gathered those examples of hybrid PPPs and classified them according to their approach or purpose (Table 1).

In Table 1, we described 15 examples of hybrid schemes classified into five categories. These hybrid PPPs correspond to specific approaches contributing to the energy transition. Those categories are energy security (Arbulú et al., 2017; Heldeweg et al., 2015; Nel, 2018), energy efficiency (Bougrain, 2012; Martiniello et al., 2020; Zhang et al., 2018), energy technology development (De Carvalho, 2018; Foley et al., 2011; Hancock et al., 2018; White, 2004), energy access, and promoting and supporting energy initiatives (small-scale and bottom-up; Otsuka & Cheng, 2020; Sanderink & Nasiritousi, 2020; Figure 3).

Figure 3 illustrates how the five categories of hybrid PPPs can be articulated to achieving energy transition goals. There are different motivations for hybrid PPPs to emerge; for example, the so-called Type II partnerships have originated from international events such as the Johannesburg Conference in 2002 as an instrument to fulfill Agenda 21 (Abbott, 2012, p. 548). Type II partnerships are transnational partnerships providing financial or regulatory support for initiatives oriented toward sustainable development and energy transition (Abbott, 2012; Sanderink & Nasiritousi, 2020).

3.4 | Public–private partnerships and hybrid schemes: How do they differ in addressing the challenges of the energy transition and sustainable development?

As mentioned above, we found that most of the studies in our sample are related to the transition toward cleaner and more sustainable energy systems. However, since partnerships can have different origins, some could be derived from government strategies closely aligned with infrastructure practices, others can be bottom-up initiatives or a combination of both. As a result, there may be variations between how PPPs and hybrid PPPs respond to the energy transition. Based on the characterization of PPPs and the identified categories of

TABLE 1 Hybrid public–private partnerships for the energy transition

Example		
Energy security	IPP—independent power producer	It focuses on new generation infrastructure projects. IPP is the label of the private energy producer, but it is also recognized as such as a hybrid scheme of collaboration (Nel, 2018). The significant distinctions of IPP is that they do not provide a service on behalf of the public authority, and the public authority does not have direct or indirect control over the private entity in this hybrid form (Nel, 2018, p. 42).
	PPA—power purchase agreements	It is a contractual figure between the state electricity companies and the private IPP, which is generally oriented toward a long-term relationship (Baylis, 2000; Lesser, 2008; Salci & Jenkins, 2018; Tobey & McGinnis, 2018; Weiss & Sarro, 2013; Weisser, 2004; Wisser, 1998).
	Environmental partnerships	The main goal is to guarantee environmental quality and, at the same time, can be a complementary strategy of energy supply—for example, waste-to-energy projects (Arbulú et al., 2017, p. 917).
	Private–private partnerships	Form of collaboration in areas that are not fully regulated yet due to the energy transition. One example is private companies such as biogas suppliers, energy companies, and network operators in the Netherlands (Heldeweg et al., 2015). At first glance, they may appear to be private partnerships; however, after an exhaustive analysis of official documents, they should be labeled as “hybrids” or a “particular type of PPP” (Heldeweg et al., 2015, p. 11) because they are governed by the rules for the provision of public services and comply with the principles of energy governance.
Energy efficiency	ESCO—Energy Service Company, ESPC—Energy Saving Performance Contract, EPC—Energy Performance Contract	The EPC is widely used in the European market to carry out energy efficiency programs, including energy savings, energy audits, and technology modernization projects. This scheme pursues a long-term relationship in essence (Martiniello et al., 2020). EPCs are organized by a private company, generally an energy services company (ESCO) (Martiniello et al., 2020). The energy-saving performance contract (ESPC) is a type of structure used in PPP projects related to energy efficiency, refurbishment or upgrades (Tobey & McGinnis, 2018). Although several authors state that these schemes can be classified as PPP, this notion is not totally shared in the academic arena (Burger & Hawkesworth, 2011; Dastig, 2009; Martiniello et al., 2020, p. 2).
	TES—thermal energy services	Here, public energy service companies act as energy providers to partner with an institution or company to improve heating systems. For example, many TES in infrastructures belong to British Columbia school districts (Jensen & Dowlatabadi, 2018).
	PPP-BR green renovations	PPP-BR aims to reconstruct existing building infrastructure to achieve green quality and green standards, including improved energy savings and reduced emissions and waste (Yang et al., 2019).
	City-level partnerships	City-level partnerships focus on initiatives related to energy efficiency and clean technologies (Andonova et al., 2009; Galli & Fisher, 2016; Jänicke & Jörgens, 2009).
	VA—Voluntary agreements	VA aims to achieve energy efficiency flexibly and cost-effectively (Zhang et al., 2018). VAs are typically bottom-up approaches mobilizing potential energy savings that would be difficult to achieve with traditional command-and-control approaches. The operating mechanism is based on a negotiation between the government and individual private companies or industry associations to determine individual energy-saving targets (Zhang et al., 2018). The parties join in a relationship by signing a “non-mandatory type of VA” (Zhang et al., 2018, p. 282).
	Energy access	5Ps—pro-poor PPPs

(Continues)

TABLE 1 (Continued)

	Example	
Energy technology development	Technology development partnerships	Collaborations between universities, public institutions and private companies to develop research on energy efficiency at a technical level and financial models, intellectual property, and all aspects for adopting technologies in a specific context (Foley et al., 2011).
	Voluntary technology development	These schemes seek to achieve technological innovation, for example, the development of clean technologies through collaboration among those organizations interested in the same issue (White, 2004). These collaborative initiatives often use decentralized decision-making models.
Promoting and supporting energy initiatives	Deliberative partnerships	Stakeholders, such as civil, market, and government work on problems related to a local need, such as adopting cleaner energy technologies (Forsyth, 2005).
Type II partnerships	Multi-stakeholders partnerships	This scheme can vary in terms of scale, functions, setting, structure, funding and effectiveness (Andonova & Levi, 2003; Hale & Mauzerall, 2004; Pattberg et al., 2012; Sanderink & Nasiritousi, 2020; Sovacool & Van de Graaf, 2018; Szulecki et al., 2011). One of the most successful examples is the renewable energy and energy-efficiency partnership (REEEP). This scheme started in 2002 to finance clean energy and energy-efficiency projects developed by small to medium companies in emerging markets and developing countries (Sanderink & Nasiritousi, 2020). In REEEP, more than 300 members of public and private entities intervene (Sanderink & Nasiritousi, 2020). Country governments and donations back the financing mechanism for supported projects from private contributors (Sanderink & Nasiritousi, 2020).
	Global partnerships	Voluntary initiatives to respond to challenges such as energy and sustainability goals (Otsuka & Cheng, 2020). Otsuka and Cheng (2020) show the United Nations Environment Program (UNEP) partnerships as an example of global partnerships.

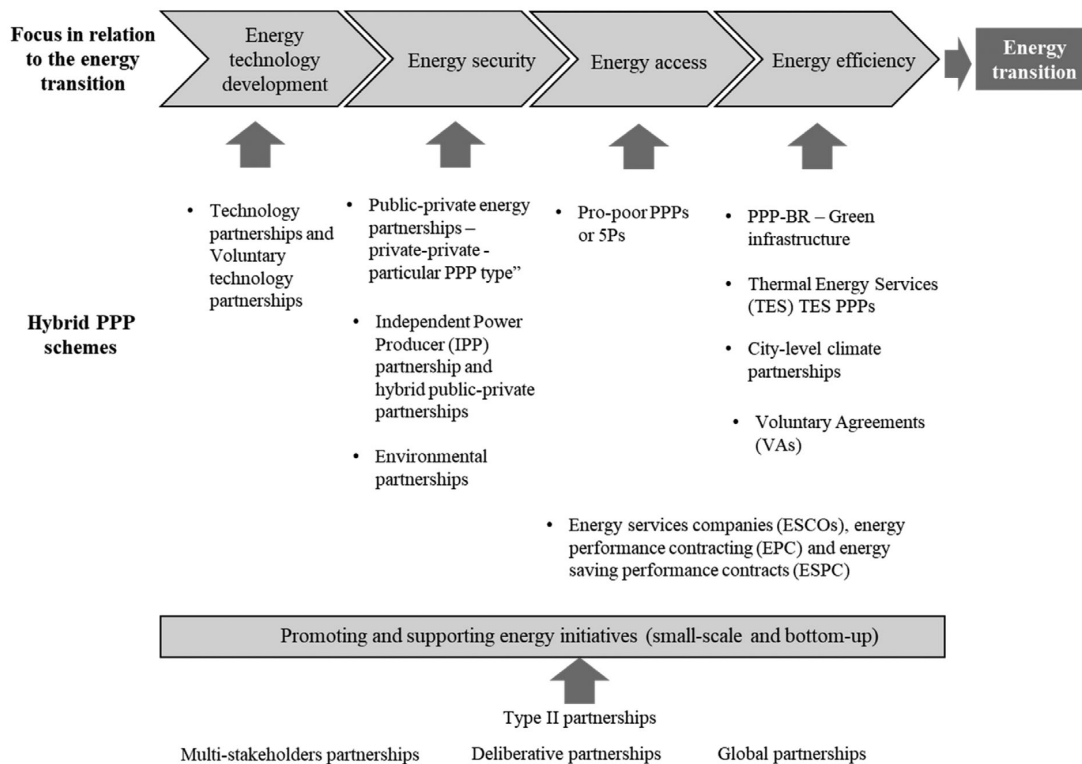


FIGURE 3 Articulation of hybrid public-private partnerships to achieve the energy transition

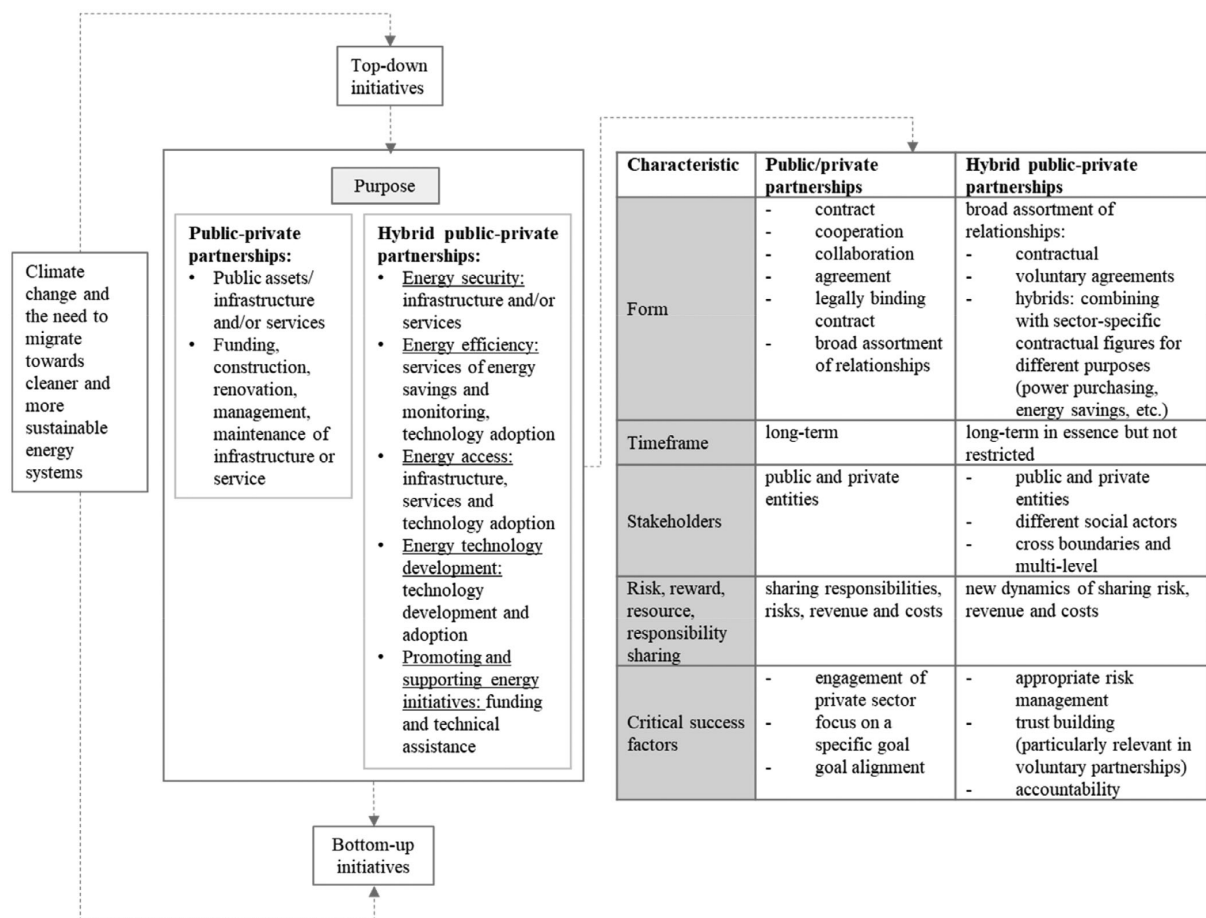


FIGURE 4 Framework for analyzing public-private partnerships and hybrids public-private partnerships

hybrid PPPs, we created a framework showing these two parallel approaches (Figure 4).

This framework in Figure 4 does not intend to arrange hybrid PPPs as a homogeneous group but make some relevant aspects from the literature visible and pave the way to identify their current challenges. In doing so, the six characteristics presented are discussed below (Sections 3.4.1–3.4.6) based on the commonalities and differences identified in the literature between PPPs and hybrid PPPs.

3.4.1 | Form

Scholars argue that PPP contracts are not flexible in incorporating changes during a project's life cycle, which leads to costly renegotiations and could be an obstacle against innovations (Bougrain, 2012). However, the energy transition is opening an avenue for enhancing community participation in energy markets; further, new energy scenarios include the implementation of both top-down and bottom-up initiatives (Dinica, 2008a; Grotenbreg & van Buuren, 2017). In contrast, hybrid schemes rely more on negotiated forms or even

voluntary forms, based on the premise of building a solution from collective efforts (Galli & Fisher, 2016). Zhang et al. (2018) and White (2004) refer to these new PPPs as voluntary agreements. Nevertheless, inexorably, a PPP formed to support the energy transition will face challenges relating to the implications of voluntary and bottom-up approaches, particularly in the risk of lack of reciprocity and commitment of parties involved (Heldeweg et al., 2015). Therefore, PPP depends on a solid institutional foundation; otherwise, the legitimacy of the relationship can be undermined.

3.4.2 | Purpose

The response to the challenges of sustainability and the particularities of the energy sector have led to creating customized partnerships for these purposes. Hancock et al. (2018) stated the relevance of aligning PPPs with SDGs. In particular, new forms of PPPs can be crucial to achieving Goal 7 related to promoting access to energy and new energy solutions, as well as Goal 9, in terms of ensuring energy security through building resilient, inclusive and innovative systems

(Hancock et al., 2018). While there are guidelines for implementing PPPs in infrastructure, these new forms of collaboration in the energy sector also require knowledge management for satisfactory implementations.

3.4.3 | Timeframe

PPPs, per se, have a prominent orientation toward long-term relationships. Indeed, PPPs have durability for several reasons: (i) the private actor is expected to carry out activities on behalf of the public authority during the project's life cycle (Martins et al., 2011; Yang et al., 2019); (ii) large-scale projects are characterized by slow pay-back; and (iii) a long-term relationship guarantees energy-purchasing conditions to reduce the uncertainty of renewable-energy projects. Overall, hybrid PPPs are also aimed at building relationships that last over the long term. However, in some hybrid PPPs, financial sources pose difficulties in ensuring lasting relationships, for example, schemes depending on subsidies, grants, or donors.

3.4.4 | Stakeholders

Unlike PPPs, hybrid schemes tend to be more decentralized, participatory and inclusive (Forsyth, 2005). Different social actors will inevitably enter the energy arena during the transition toward cleaner and more sustainable systems, such as small private enterprises, citizen organizations, research institutions, academia, non-profit organizations and consumers (Forsyth, 2005). As Grotenbreg and van Buuren (2017) note, the energy sector is a rapid technological evolution scene featuring bottom-up initiatives, leading to building partnerships. In particular, public authorities assume facilitating roles and transfer leadership positions to actors outside the public sphere (Grotenbreg & van Buuren, 2017). The distinction between public and private actors is blurred since their roles intersect and overlap. In this context, public entities without a statutory power mandate and even private actors can perform as functional public authorities (depending on the specific case and regulation; Heldeweg et al., 2015). One of the most significant challenges in encouraging the participation of new stakeholders is to clarify who can exercise public authority and how new actors are institutionalized within PPPs.

3.4.5 | Risk, reward, resource, and responsibility-sharing

Innovation is the central axis of the energy transition, as the development and adoption of new technologies can provide growth opportunities (Phang, 2020). However, overcoming technical and commercial barriers requires flexibility and adaptation. Although technological risk takes on major significance in these contexts, the literature on PPPs shows that new risk management approaches involving different levels of innovation incorporations seem scarce. As Phang (2020) highlights,

innovation in the energy transition context requires recognizing technological risks and adopting new business models, and hybrid PPPs, particularly schemes where the source of funding includes grants or donations, present challenges to ensuring the sustainability of partnerships over time, given the significant financial risk (Chaurey et al., 2012).

3.4.6 | Critical success factors

For hybrid PPPs, in addition to the CSFs mentioned in Section 3.2, other factors are also crucial for successful implementations. For example, in EPC, ESPC, and ESCOs, an adequate accounting framework and institutional capacity for risk allocation purposes

TABLE 2 Key challenges of public–private partnerships and hybrid public–private partnerships for the energy transition

Characteristic	Key challenges to support the energy transition
Form	<p>There is no complete alignment of PPPs and hybrid PPPs. Legitimacy and institutional alignment are key challenges.</p> <p>In hybrid PPPs, the key challenge is guaranteeing reciprocity and commitment, particularly in voluntary schemes.</p>
Purpose	<p>There is no clear space in PPPs not strictly related to infrastructure and associated services.</p> <p>A strategy for structuring the information related to sector-specific practices in PPPs and hybrid PPPs is relevant for further successful implementations</p>
Timeframe	<p>The durability of hybrid PPPs is a challenge considering the financial constraints of new business models in hybrid PPPs.</p>
Stakeholders	<p>There is no clear space for the participation of different social actors in PPPs.</p> <p>Defining the representative authority in hybrid PPPs when activities are not fully regulated is a key challenge.</p>
Risk, reward, resource, and responsibility-sharing	<p>PPPs' risk management approaches could be limiting when dealing with technological innovations and/or multiple PPPs stakeholders.</p> <p>In hybrid PPPs, a key challenge is to achieve a well-balanced risk allocation when meeting current institutional frameworks.</p>
Critical success factors	<p>Building trust in hybrid PPPs is a challenge, particularly in voluntary schemes.</p>

Abbreviation: PPPs, public–private partnership.

TABLE 3 Overview of the research work

Stage	Outcome	Key aspects
Defining local domain and scope	Literature on PPPs in energy	
Capturing and synthesizing extant knowledge	<div style="border: 1px solid black; padding: 5px; width: fit-content; margin-bottom: 10px;">PPP characterization</div> <div style="border: 1px solid black; padding: 5px; width: fit-content;">Categorization of hybrid PPP schemes for the energy transition</div>	Characteristics of public-private partnerships PPPs from definitions: <ul style="list-style-type: none"> • Form: contractual relationship • Purpose: providing public infrastructure and/or services • Timeframe: long-term • Stakeholders: public and private entities • Risk, reward, resource and responsibility sharing: sharing responsibilities, risks, revenue and costs • Critical success factors: engagement of private sector, focus on specific goal and goal alignment • Energy security • Energy efficiency • Energy access • Energy technology development • Promoting and supporting energy initiatives
Identifying and resolving contradictory explanations	<div style="border: 1px solid black; padding: 5px; width: fit-content;">Analytical framework of PPP and hybrid PPP schemes</div>	Hybrid PPPs emerge as top-down and bottom-up initiatives as a result of the need to migrate toward cleaner and more sustainable energy systems. <ul style="list-style-type: none"> • Broad assortment of relationships including voluntary agreements, hybrids and contractual. • Multiple social actors participate in these arrangements. • New approaches for risk sharing and business models. • Critical success factors are appropriate risk management, trust building and accountability.
Highlighting gaps	<div style="border: 1px solid black; padding: 5px; width: fit-content;">Key challenges of PPPs and hybrid PPP schemes to support the energy transition</div>	<ul style="list-style-type: none"> • Lack of flexibility in PPPs as well as a lack of clear space for other purposes not strictly related to infrastructure and associated services, for example technology development, and the participation of different social actors. • Lack of alignment of PPPs and emerging hybrid PPPs.
Further research agenda	<div style="border: 1px solid black; padding: 5px; width: fit-content;">Research focus areas</div>	<ul style="list-style-type: none"> • Mechanisms for the institutional alignment of hybrid PPPs. • Mechanisms for assuring reciprocity and commitment. • Knowledge management • Capacity building

Abbreviation: PPPs, public-private partnership.

are critical for achieving win-win conditions (Carbonara & Pellegrino, 2018). Moreover, in environmental partnerships, a solid institutional framework and strategic vision are crucial to reducing risk significance (Arbulú et al., 2017). Regarding bottom-up initiatives and voluntary agreements, it is essential to guarantee accountability and transparency (Muleya et al., 2019) and high levels of trust to facilitate the decision-making process (Zhang et al., 2018).

4 | DISCUSSION ON EXPANDING RESEARCH AGENDA

How do public-private partnerships and hybrid schemes differ in addressing the challenges of the transition toward cleaner and more sustainable energy systems? This study highlights the neglected role of PPPs and emerging variants of PPPs, so-called by scholars as “hybrid

PPPs" in the energy transition context. As noted in the literature, existing divergences on the scope of PPPs have profound effects on how collaborations occur, and propose relevant challenges when facing cross-cutting changes in energy systems toward sustainable development (Table 2). However, to the extent that this phenomenon becomes visible, research efforts can be oriented to explore it. Notably, the dissimilarities in the partnership's form (e.g., contractual vs. voluntary) reflect how, alongside the top-down initiatives formalized in contractual PPPs, there are also bottom-up initiatives from multiple social actors. Furthermore, some partnerships emerge in incomplete institutional frameworks, posing ambivalences related to their adherence to PPP schemes, even when they comply with energy governance principles. Hence, PPPs and hybrid schemes are highly dependent on the specific context where they are applied.

As described in Table 2, the first challenge of PPPs and hybrid PPPs is recognizing hybrid forms and their institutional alignment. This aspect can significantly influence the risk aversion in projects. Since emerging hybrid PPPs do not present visible incorporation into institutional frameworks and current PPP guidelines, there is a call for research on developing adequate mechanisms to address this issue and strategies that guarantee reciprocity and commitment. Such a study would require the participation of practitioners, policymakers, multilateral organizations, civilians, and the scientific community in reconciling ideas and conceptions about how PPPs is adapted to current collaboration needs. Research efforts should also focus on developing strategies for knowledge management of PPPs and hybrid PPPs in the energy sector, providing project-implementation guides according to the particularities of this sector. Since the energy transition is oriented toward increasingly decentralized and participatory systems, it is necessary to find paths for different social actors to collaborate in the energy transition. One of the critical aspects is to clarify the representativeness of public and private stakeholders in PPPs and hybrid PPPs.

Regarding the operationalization of risk-sharing principles, it is necessary to reconcile hybrid PPPs with the institutional frameworks in accounting forms to achieve a win-win relationship that encourages private actors' participation. Simultaneously, the development of alternative approaches to risk management is required for high technological, market, and regulatory risks in the energy transition context. Finally, a fundamental aspect in PPPs and hybrid PPPs is how to build trust for decision-making, taking into account that technological progress, as well as changes in the market and regulations, require agile adaptation, stakeholders' alignment and, above all, a high level of trust. In summary, the research agenda should include the following:

- *Mechanisms for the institutional alignment of hybrid PPPs:* Alignment of bottom-up initiatives with institutional frameworks, accounting approaches and public repressiveness of social actors.
- *Mechanisms for assuring reciprocity and commitment:* Development of frameworks for assuring legitimacy in hybrid PPPs.
- *Knowledge management:* Developing a knowledge management strategy for PPPs and hybrid PPPs in sector-specific features as well as new risk management approaches, sustainable business models and CSFs.

- *Capacity building:* Capacity building in achieving goal alignment, trust-building, accountability, stakeholders' engagement and value creation.

5 | CONCLUSIONS

This article attempts to unveil an overlooked phenomenon in the literature, such as the existing differences between PPPs and hybrid PPPs in addressing the energy transition. Our analysis examines the definitions of PPPs used by the authors. In this analysis, six conceptual elements emerged in the definitions: PPP form, purpose, timeframe, stakeholders, risk, reward, revenue and responsibility-sharing, and CSFs. Alongside the decomposition of the definitions, several examples of hybrid PPPs were also identified in the literature targeting various purposes related to the energy transition, such as energy technology development, energy access, energy security, and energy efficiency. The definitions of PPP and hybrid PPPs were used to develop an analytical framework to contrast similarities and differences. Overall, we found the need for research on the institutional alignment of PPPs and hybrid PPPs, mechanisms for assuring reciprocity and commitment in hybrid schemes, and developing a strategy for knowledge management and capacity building public-private collaboration in energy. Table 3 provides an overview of the research work regarding the primary outcomes and key aspects of the five-stages process approached in this conceptual review paper.

5.1 | Conceptual contributions and policy recommendations

The value of this paper is threefold. First, it clarifies the concept of PPP and offers a guide for understanding the differences between the various related concepts used in the literature. Second, it exposes the challenges to advancing the energy transition from existing ambivalences between PPPs and hybrid PPPs. Third, it shows the increasingly innovative responses from various social sectors to join forces to face energy transition and sustainability challenges. This paper is the first study that directly approaches this phenomenon from the literature of PPPs in energy to the best of our knowledge. Several scholars have made other efforts along the way in exploring hybrid PPPs based on empirical evidence (Heldeweg et al., 2015; Nel, 2018). Additionally, this article points out the critical research areas to focus on advancing the energy transition from collaboration schemes.

The present study is not limited to summarizing the extant literature. It also identifies, analyzes, and presents a relevant research gap with a potentially significant impact on contemporary social issues such as the energy transition. Furthermore, this research work provides several research outcomes that may be useful for future research, for example, (i) characterization of PPPs; (ii) classification of hybrid PPPs; (iii) analytical framework of PPPs and hybrid PPPs; (iv) synopsis of the key challenges for the energy transition; and (v) identification of research focus areas.

Besides, this study points to several implications for managers and policymakers. Concerning the managerial implications, the study summarizes how various hybrid PPP schemes have emerged to face challenges such as expanding access to energy, energy technology, energy efficiency, transnational cooperation, and initiatives on a smaller scale. In this study, practitioners can directly connect PPP and hybrid PPP as collaboration schemes with energy sector experiences. Similarly, the six criteria derived from the PPP definitions can characterize control items for new PPP energy projects.

As in every study, this article has inherent limitations. First, the data capture and synthesis process have inherent limitations arising from the systematic search. Second, although two of the most comprehensive databases for bibliometric studies were used, a few articles that can only be found in other databases may have been missed. Therefore, other databases were reviewed to identify missed studies, but no relevant articles were found. Finally, although the data selection and analysis were exhaustive, some data may have been omitted.

Regarding the implications for policymakers, first, the study provides an avenue to design appropriate mechanisms for the formal alignment of hybrid PPPs in climate change policies and institutional frameworks. Second, a clear picture of PPPs and hybrid PPPs helps one understand opportunities from bottom-up initiatives. Third, the findings could lead to new mechanisms for PPPs to foster emerging technologies and business opportunities in the energy transition context. Last, this article's contributions could help policymakers facilitate access to funding schemes and broader collaborations.

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APPENDIX A

SYSTEMATIC SEARCH AND SCREENING PROCESS

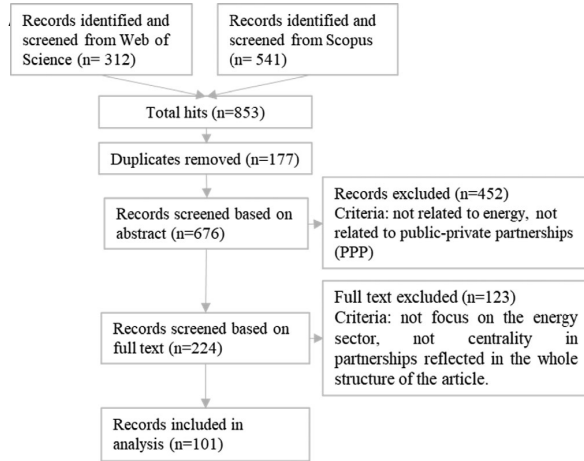


FIGURE A1 Systematic search and screening process. Adapted from Moher et al. (2009)

CODING PROCESS OF PUBLIC-PRIVATE PARTNERSHIP DEFINITIONS

TABLE B1 Example of coding process

Code	Text
Public assets-infrastructure and-or services	“delivering infrastructure or public services” “delivery of services or facilities for public use”
Legally binding contract	“Legally structured partnership” “Legally-binding contract”
Long-term	“long-term relationship” “long-term”

APPENDIX C

DATA STRUCTURE

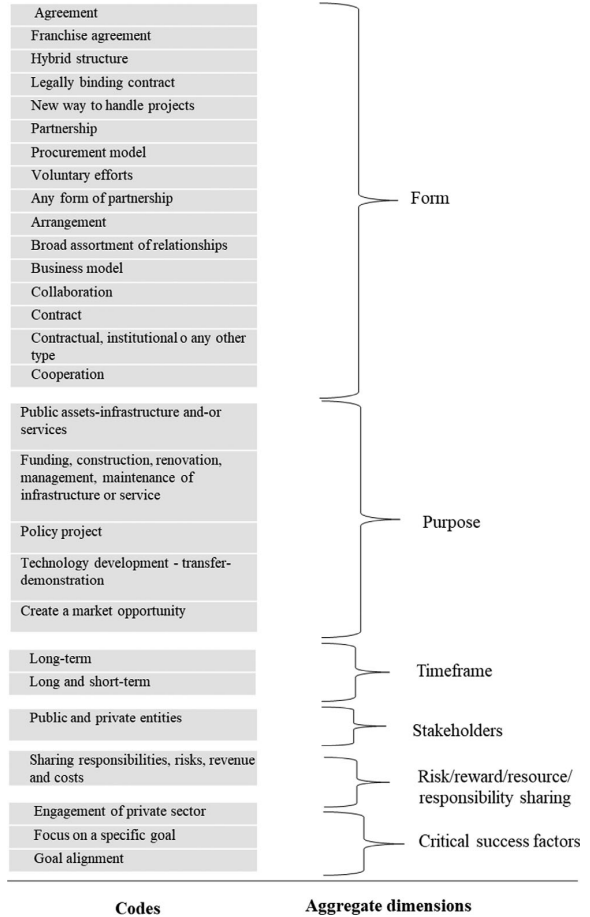


FIGURE C1 Data structure of public-private partnership definitions: From codes to aggregate dimensions

APPENDIX D

LIST OF STUDIES OF PUBLIC-PRIVATE PARTNERSHIP DEFINITIONS

TABLE D1 List of studies where public-private partnership definitions were identified

List of studies
Fleta-Asín and Muñoz (2021)
Raza et al. (2021)
Araquistain Portela (2020)
Sheng et al. (2020)
Panteli et al. (2020)
Bai and Zhang (2020)
Wang et al. (2020)
Ahmad and Raza (2020)
Koengkan (2020)
Martiniello et al. (2020)
Khan et al. (2020)
Shahbaz et al. (2020)
Gao and Zhao (2020)
Di Liddo et al. (2019)
Fang et al. (2019)
Wang and Zhang (2019)
Tang et al. (2019)
Saadeh et al. (2019)
Rossi et al. (2019)
Lugaric et al. (2019)
Cui et al. (2019)
Muleya et al. (2019)
Tobey and McGinnis (2018)
Wang and Zhang (2018)
Jensen and Dowlatabadi (2018)
Gao and Zhao (2018)
Liu and Wei (2018)
Carbonara and Pellegrino (2018)
Wang and Ke (2018)
Nel (2018)
Stritzke (2015)
Akcay et al. (2017)
Rehman et al. (2017)
Arbulú et al. (2017)
Owusu-Manu et al. (2017)
Somma and Rubino (2016)
Heldeweg et al. (2015)
Xu et al. (2015)
Fecondo and Moca (2015)
Copiello (2015)
Wentworth and Makokera (2015)

TABLE D1 (Continued)

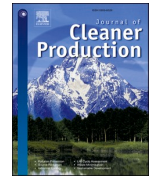
Fantozzi et al. (2014)
Sovacool (2013)
Jumbe and Mkondiwa (2013)
Benkovic et al. (2013)
Chaurey et al. (2012)
Martins et al. (2011)
Dinica (2008b)
Lukamba-Muhlya and Uken (2006)



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Eliciting the anchor link for building public-private collaboration in sustainable energy: insights from the Finnish context

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ABSTRACT

This article interrelates social, environmental, and technological aspects concerning public-private collaboration. The aim is to decipher the motivations and reluctance factors that prompt or limit building synergies between actors with divergent incentives and better understand the connection between the individual-level sensemaking and macro-level constructs regarding public-private collaboration in a specific socio-cultural context. Following the microfoundations movement in strategy and Organizational Theory, the study combines insights from sensemaking research and Social Exchange Theory to delve into how cultural context influences individuals' perception of public-private collaboration for the energy transition and ultimately defines its nature. Drawing from a case study in Finland based on 30 interviews, we identify six critical dimensions in the actors' discourse: 1) the role of trust in decision-making, 2) consensus and competition, 3) horizontality, 4) boosting innovations versus the challenges of public and private sectors, 5) acceptability of arrangements and public funding, and 6) the role of public-private collaboration in the decarbonization. These dimensions shed light on the influence of the socio-cultural context in enhancing trust and consensus as drivers of social exchange in public-private collaboration. Future studies should explore 1) enabling mechanisms for cross-context collaboration and 2) the roles and motivations in collaborative approaches.

1. Introduction

Transitioning to cleaner and sustainable systems requires Public-Private Collaboration (PPC) for directing efforts toward effective actions (Ndzibah et al., 2022; Pereno and Eriksson, 2020; Pinilla-De La Cruz, Rabetino and Kantola, 2022). PPC is a broad concept that is not limited to the Anglo-Saxon model of public-private partnerships (PPP) (Ferraris et al., 2018). For example, Klijn et al. (2021) presents a continuum of five paths of collaboration of public and private actors, including principal-agent and principal-principal type relationships with organizational forms ranging from tight to loosely coupled. Existing research suggests that PPC facilitates the development of public-oriented projects in complex environments (Kwak et al., 2009; Lassen et al., 2015; Satheesh, 2023) and the convergence of capacities, resources, and perspectives between public and private actors in co-creating innovative solutions (Asplund et al., 2021; Azagra-Caro et al., 2019; Guan and Zhao, 2013). Thus, understanding the motivations and mechanisms behind the collaboration is crucial, as socio-technical systems involve social structures at various levels,

including public institutions representing a common voice and individual or private perspectives (Mossberg et al., 2018; Palm and Gustafsson, 2018).

Despite its relevance, current PPC initiatives often lack the necessary scale and effectiveness, hindered by a limited understanding of factors shaping connections between actors. Moreover, implementing PPC encounters obstacles in the form of disparities in sensemaking across diverse cultural contexts. The principles governing the public and private actors and their pursued interests, along with the cultural context in which the relationship operates, significantly affect the new collaborative endeavors sought (Autio and Thomas, 2014). Furthermore, collaboration has implications at the individual level of public and private actors that affect one's tendency to trust others or exert control to prevent opportunistic behavior. Yet, the academic literature in the field does not provide conclusive information about the factors that link the cultural context of actors in PPC. Indeed, the existing literature falls short in exploring the broad collaborative spectrum from different perspectives and its connection to the cultural context, with culture being overlooked in PPC studies (Starik and Kanashiro, 2020; Wang et al.,

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2022). Consequently, the lack of explicit distinctions of collaborative relationships in different cultural contexts emphasizes the need for a more nuanced approach to collaborative models in energy system decarbonization decisions.

Against this backdrop, this study aims to understand the relevance and influence of cultural context in building collaborative relationships between public and private actors, which is a crucial aspect to advance in the energy transition. Thus, our goals are twofold. First, we examine the collaborative relationships between actors with divergent incentives, as public and private actors, to decipher the motivations and reluctance factors that prompt or limit building synergies. Second, we study the connection between individual-level sensemaking and macro-level constructs regarding public-private collaboration in a specific socio-cultural context. We decided to use the logic from the micro-foundations movement (Felin and Foss, 2015) and using the theoretical lens of individual sensemaking (Fellows and Liu, 2016; Harris, 1994) and Social Exchange Theory (SET) (Blau, 2017; Malmström and Johansson, 2015) to analyze this phenomenon and addressing the following research questions: *How does cultural context at the country level influence individuals' perception of public-private collaboration? And, how does the cultural context define the nature of the prevalent type of public-private collaboration towards more sustainable energy systems?*

We conducted a case study at the country level in Finland to explore a context that exhibits similar geographic, cultural, institutional, and regulatory factors. Finland was chosen as a suitable case due to its remarkable evolution in recent decades towards an economy founded on promoting technological development with a social vision of equality and trust. The country is the top-ranked supporter of the global energy innovation system (Smith and Hart, 2021) and is considered one of the world's 'most cooperative' countries (Kuisma et al., 1999; OECD, 2017). Additionally, Finland is widely recognized for its strong commitment to carbon neutrality by 2035, showing significant reductions in CO₂ emissions from a strategic focus on public-private collaboration and innovative solutions (Business Finland, 2023).

As its main contributions, the paper spotlights the patterns of PPC sensemaking among individual actors, including the influence of cultural context, experiences, motivations, and reluctance factors. This paper also reveals the agency's key role in explaining social outcomes from the individual level. Furthermore, the article unveils the influence of the socio-cultural context in enhancing trust and consensus as drivers of social exchange in PPC. While the study underscores the difficulties related to 'importing' or transferring PPC frameworks from one context to another, it suggests that incorporating the specific nuances of the cultural context of implementation is essential to building successful public-private collaborations. Policymakers can use the findings to promote the emergence of PPC by activating public funding instruments. These insights may stimulate social learning and encourage stakeholder interaction to facilitate solid interventions.

2. Theoretical background

Viewing PPC as a social phenomenon underscores the relevance of understanding links between macro-level constructs, notably the impact of cultural context on such collaborative endeavors. Since PPC is socially constructed based on the values, practices, and norms individuals are embedded in, this shapes the understanding of reality (Quélin et al., 2017). Hence, the potential implications of socio-cultural context and power dynamics among parties in PPC are significant. This entails exploring the meanings and motivations driving individual and collective behaviors at the micro-level. In other words, relationships between macro-level constructs find their origin and functionality through the actions and interactions of individuals (Contractor et al., 2019). Following the logic from the microfoundations movement (Felin and Foss, 2015), scrutinizing such interactions provides insights into the dynamics of social exchange within PPC, constituting a social outcome in its own right.

The microfoundations approach suggests that macro-constructs originate and are activated by the actions and interactions of individuals (Contractor et al., 2019). The microfoundations approach is not a theory but a 'lens' to analyze the relationship between social phenomena at multiple levels, including the micro level (Felin and Foss, 2015). Consequently, the exploration of the trajectory from macro-level social facts, such as cultural context, to macro-level social outcomes, such as PPC, implies a first step in delving into the individual interpretations and meanings ascribed by both public and private actors (Felin and Foss, 2015; Palmié et al., 2023). Supported by the premise of microfoundations of finding an approximation to the causal root of the phenomenon in the meaning of the motivations of individual behavior, we then turn to the theoretical approach of individual sensemaking to approach the base layers of the phenomenon.

Here, we used individual sensemaking as a 'vehicle' to explore the distinct attitudes and behaviors around PPC. While adopting the above lens, we combined sensemaking research and Social Exchange Theory (SET) to understand PPC's complexity; given the interactive nature of the elements that intervene in socio-technical systems, culture influences sensemaking at different levels, including the individual level (Aguinis and Glavas, 2019; Clegg et al., 2017). SET explains how collaboration oriented to innovations occurs as interactions between organizations for exchanging knowledge and experiences, which are built on the foundations of values such as trust and reciprocity (Khalek and Chakraborty, 2023; Malmström and Johansson, 2015; Santos et al., 2023).

2.1. Individual perception to make sense of the socio-cultural context

From the micro-level, individual sensemaking is intricately linked to a mental dialogue between different motivations and reluctance factors, which is especially relevant to understanding the challenges behind PPC (Kudesia, 2017; Leung and Morris, 2015). Indeed, individuals' decisions result from a mental dialogue in which their attitudes are reconciled with the normative expectations perceived by the cultural context. Since the cultural context influences individual sensemaking, behavioral decisions tend to be congruent with the cultural dimensions of the society to which the members belong (Ivanova-Gongne and Törnroos, 2017).

It is, therefore, relevant to explore what underlies the actors' sensemaking at the individual level to understand the nature of future decisions and concrete actions around collaborative relationships between the public and private actors (Yström et al., 2019). Participants within a PPC 're-create' meanings based on their memories and reshape their sense of belonging to a community (Yström et al., 2019). This process encompasses the individual motivations and nuanced operational logics of the public and private entities represented by the actors involved, along with the preconceived notions regarding these organizations within the socio-cultural context. Consequently, these factors may engender tensions in creating value within the PPC.

2.2. Social action and interaction instigating public-private collaboration

PPC occurs when intricate interdependencies arise within social structures, influenced by each party's interests and influence (Quélin et al., 2017). In essence, PPCs are based on patterns of mutual interchanges that affect and are affected by the public and private partners involved in the relationship (Caldwell et al., 2017). Notably, the Theory of Social Exchange (SET) is valuable in delineating the key factors that instigate and preserve collaboration, such as trust and reciprocity (Santos et al., 2023). Indeed, trust and the expectation of reciprocity in collaborations positively relate to the cultural similarities between partners (Malmström and Johansson, 2015; Robson et al., 2019). Furthermore, commitment and power structures are also patterns of social exchange (Santos et al., 2023). In this vein, Wyleżalek (2021) posits that social exchange in collaborations is a dynamic process that triggers organizational and power-related social relationships.

The social exchange and features of the collaboration are shaped by the cultural context and cultural similarities between partners (Johnson & Pinilla-de La Cruz, 2024; Khalid and Ali, 2017). Culture acts as a framework for evaluating stimuli and endowing them meaningfully since it is built as a structure of shared knowledge schemes (Fellows and Liu, 2016).

2.3. PPC as a collective outcome

According to Vangen (2017), similarities and differences between individuals are recognized and articulated at a macro level regarding the cultures they belong to, such as the national culture. Different scholars suggest four key cultural dimensions that distinguish different national cultures and would provide insights into understanding how the cultural context influences the perception of PPC: individualism, masculinity, power distance, and uncertainty avoidance (Cui et al., 2019; Moonen, 2017).

Considering PPC as a collective outcome, according to the study by Klijn et al. (2021) based on the perceptions of professionals from Denmark, the Netherlands, and Canada, Dutch professionals showed a preference for horizontal collaboration between public and private partners, while Canadian professionals are more associated with relationships based on performance indicators and contractual compliance. Likewise, in a multiple-case study in six cities in Nordic countries, Leminen et al. (2021) explored the wide range of collaboration models

supporting innovation for sustainability. The findings reveal a diversity of models ranging from dyadic to multifold-stakeholder relationships (Leminen et al., 2021).

3. Research strategy and method

The present paper follows a qualitative research strategy to explore how cultural context influences individuals' perception of public-private collaboration toward cleaner and more sustainable energy systems at the country level. Qualitative methods were chosen because we addressed unexplored topics, and the existing literature lacks consistent approaches to investigate the role of culture in PPC from the individual level to the social outcomes (Felin and Foss, 2015). Here, we conducted a single-case study as a research strategy to delve into the bottom layers of actors of the energy industry and sustainability at the country level (Piekkari and Welch, 2018; Welch and Piekkari, 2011; Yin, 1994). In particular, we used individual sensemaking and the principles of the Social Exchange Theory (SET) to build this case study addressing a relevant phenomenon whose characteristics are highly specific and hard to replicate (Dubois and Gadde, 2002; Eisenhardt and Graebner, 2007; Siggelkow, 2007).

3.1. Case selection and research context

Finland was selected as the research context and case study. The

Table 1
Data sources.

Source	Total	Characteristic	Interview code	Time (min.)	Gender (W: woman, M: man)	Age range
Interviews	30	Energy segment				
Public organizations: 9		Cooperatives	A1	59	M	55 <
Private companies: 11			A2	71	M	45–54
Hybrid organizations: 10		Energy authorities	B1	53	W	45–54
			B2	66	W	35–44
			B3	60	M	45–54
		Energy clusters	C1	55	M	55 <
			C2	56	M	45–54
		Energy offices at municipalities	D1	59	M	45–54
			D2	57	M	55 <
			D3	51	W	35–44
		Energy services companies	E1	58	M	45–54
			E2	51	M	25–34
			E3	54	M	45–54
		Engineering companies and project developers	F1	46	M	45–54
			F2	44	W	35–44
			F3	42	M	45–54
		Funding agencies in energy	G1	56	M	45–54
		Integrators and platforms	H1	50	W	35–44
			H2	47	W	35–44
			H3	59	M	45–54
		Renewable energy associations	I1	56	W	35–44
			I2	64	M	35–44
		Research, academia, and experts	J1	58	W	35–44
			J2	56	M	35–44
			J3	45	M	35–44
		Utility companies	K1	70	M	45–54
			K2	70	M	45–54
			K3	52	M	35–44
			K4	49	M	35–44
		Venture capital and financing companies	L1	62	M	45–54
Archival sources		Source titles				
10 documents		Ministry of Economy Affairs and Employment of Finland, 2022 Ministry of Economic Affairs and Employment of Finland, 2022 Finnish Government, 2021 Ministry of Education and Culture Finland, 2020 Ministry of Economic Affairs and Employment Finland, 2019 Koski et al. (2019) Ormala (2019) Ministry of Economy Affairs and Employment of Finland, 2018 Research and Innovation Council Finland, 2017 OECD (2017)				

decision to focus on one country relies on the conceptual framework of 'ecosystem architecture' (Z; Ma, Christensen, & Jørgesen, 2021; Z. Ma, 2019) to set the scope of territorial and cultural boundaries within a specific context. The country's history is marked by the strength of its collective efforts in developing and modernizing its industries. Furthermore, the country is currently recognized as a global testing ground for emerging energy technologies (Business Finland, 2021).

3.2. Data collection

The primary source was a set of 30 interviews with a selected group of public and private experts from the different edges of the PPC for the energy transition in Finland. Informants were identified in official publications of Finnish energy associations, authorities, and primary organizations (see Table 1).

The online semi-structured interviews were conducted between June and October 2021 and ranged from 42 to 71 min and were transcribed verbatim for analysis. Secondary data was also collected from publicly available sources, strengthening the study's validity. The conceptual model that emerged from the study was evaluated against updated country-level records to provide a realistic perspective.

3.3. Data analysis

We adopted a research framework that drew on the principles of previous sensemaking studies (Bien and Sassen, 2020; Weick et al., 2005). It included analyzing semi-structured interviews and archives as a triangulation strategy (Williams and Shepherd, 2016). Our first step was to employ an open coding approach, *in vivo*, to identify codes in the data (Gioia et al., 2013; Strauss, A., & Corbin, 1998). The NVivo 12 software package was used to assist with this process. Next, we mapped our findings according to the research framework presented in Fig. 1. We developed this approach based on Weick et al. (2005, p. 410), capturing sensemaking by answering four guiding questions: i) *How did it become important?* ii) *What does it mean?* iii) *What is the story here?* Also, (iv) *what should I do?*

The first question, "How did it become important?" provided instructions for identifying sensemaking clues from an initial open coding. Then, we note parentheses and labels and categorize the distinctive features of the phenomenon's sense construction. Next, we analyze whether those categorized codes provide information to answer "What does it mean?", "What is the story here?" and "What should I do?" (Weick et al., 2005, p. 410). Concerning the question of "What does it mean?", we discerned similarities and discrepancies in how informants interpret the PPC for the transition towards sustainable energy systems. Additionally,

we identified significant features of how these stakeholders perceive themselves.

When tackling the question, "What is the story here?", we followed a similar approach to the first question. Still, we emphasized exploring the interplay between past and present experiences in the sensemaking process of individual actors. We sought to uncover the key factors that either facilitate or hinder collaboration. As for the last question, "What should I do?", we used the same procedure as the previous questions. Still, we aimed to reveal how the actors comprehend and integrate the concept into their cognitive and behavioral decision-making processes. Ultimately, we used all the insights from the above analyses to interpret the patterns of meaning construction and individual sensemaking of the PPC for energy innovation in Finland.

After carefully analyzing similarities, we identified first-order concepts from the information gathered in the data and categorized them into second-order topics. This analysis was conducted until we reached a point where no new categories were identified. By grouping the second-order topics, we gained insights into component interdependencies, which aided us in interpreting meaning formation. We grouped the second-order themes into aggregated dimensions, involving an iterative process between the second-order and higher-order topics. By understanding these dimensions, we could put together the pieces of sensemaking. A visual representation of the aggregated dimensions of second-order topics and first-order concepts is presented in Fig. 2.

Subsequently, we analyzed how the empirical results fit into the Social Exchange Theory (SET) theoretical framework. We also reviewed the empirical results with the archival sources referring to the PPC for innovation in the Finnish context of sustainability, finding a match at the conceptual level.

3.4. Quality assessment

To ensure the validity and reliability of our study, we employed various strategies during the data collection and analysis. To establish construct validity, we used primary data from interviews with a diverse range of actors from the Finnish energy context and cross-checked it with secondary data from public records. We also ensured internal validity by thoroughly outlining our research process and using the individual sensemaking approach framework (Fig. 1). To bolster external validity, we conducted a comprehensive review of existing literature on PPC from the theoretical approach of the SET to support our work. Regarding reliability, we meticulously documented our research process and findings for future reference while triangulating primary and secondary data sources to validate our results. Additionally, we shared our research findings with some interviewees to confirm our main

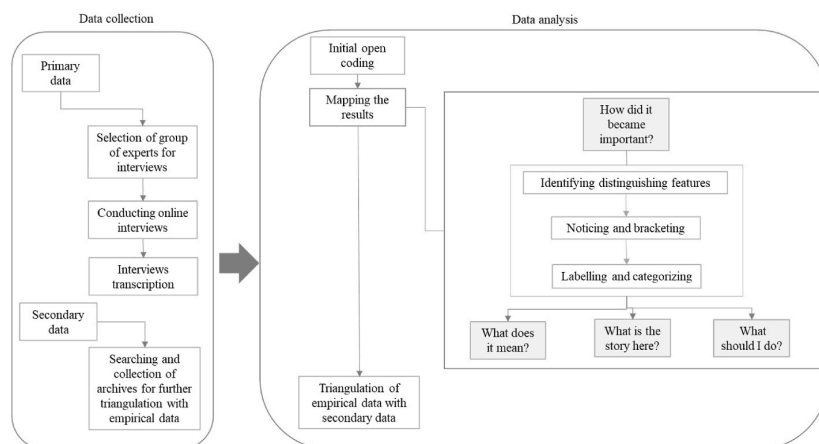


Fig. 1. Research framework.



Fig. 2. Data structure.

conclusions.

4. Findings

From the data, six dimensions of individual sensemaking emerged regarding the concept of PPC for migration towards cleaner and sustainable energy systems. They were categorized into two significant moments: from the socio-cultural context to the *Introspection* (which gives rise to individual sensemaking) and *Behavioral decisions* on the role of PPC as a social outcome. The disaggregation of each dimension is presented below and supported by powerful quotes and proof quotes in Appendix A following the guidance of Pratt (2008, 2009).

4.1. From the socio-cultural context to an individual introspection

The process of introspection provides insights into how individuals make sense of the concept of PPC based on their personal experiences

and internal simulations of potential responses from the relevant actors in the cultural context. Individuals construct mental frameworks from their recollections of past events and their understanding of the community's values and norms.

'Yes, it is because it is so everyone understands it, and then when we talk about the partnership, it means that both parties must gain something. But if you think about buyer and seller, but someone is selling something to another, the other party does not care if the other one is gaining or not.' [F3]

4.1.1. Perception of the cultural context by the individual: the role of trust

Stakeholders revealed distinct aspects of their self-conception as Finnish individuals, significantly impacting collaboration-building efforts. Interviewees refer to most people in the energy sector, whether in the public or private domains, knowing one another due to Finland's relatively 'sparsely populated country'. Consequently, there is a sense of

comfort in establishing collaborative relationships with individuals already known or referenced.

'We are a small country with quite a high degree of transparency. Even if people complain about our regulations, they are still pretty good and solid, so we have this kind of nice small circle of people and institutions who know each other and can talk to each other. There is a low threshold to going and talking to each other.' [G1]

Within the energy sector in Finland, the actors recognize themselves as individuals who hold trust as a key value in establishing collaborative relationships. Trust emerged as a central factor in Finnish society, contributing to forming personal connections and enduring business relationships informally. Stakeholders associate trust in their partners with the critical element that enables them to take risks, make challenging decisions, or tackle complex issues. Trust as a value is essential in building new frameworks with risks and uncertainty, such as transitioning to sustainable energy systems.

'I really think it starts with trust because without trust, you cannot share the risk, and without trust, you are not willing to take the same risk as if you trust each other.' [K3]

4.1.2. Experiences: the role of consensus and competition in innovation

Informants indicate that the most successful collaborations result in developing and demonstrating something new. Remarkably, the parties involved have shown a greater interest in collaboration than competition, which has emerged as a crucial factor in facilitating effective partnerships between actors of different natures.

'History here is a good teacher. If you think that we are now in the middle of a revolution and you are thinking that, or you are taking from the past, the previous revolution that was the IT revolution, when the IT revolution, companies there were willing to do their stuff. (...). Then so that, there was no need for the competition. There was absolutely no need for the competition. It was rather like, let's collaborate and, you know, build up this revolution together because that will benefit us all, and some people will make money, and those technologies that are worth surviving, they will survive.' [C2]

Informants underscore the significance of joint efforts by public and private actors in introducing new energy technologies to the market. For instance, some interviewees referred to the lessons from introducing wind power technology in Finland, which has transformed the energy sector and educated stakeholders in collaboration. Another example cited is the case of the electric vehicle, which necessitated the concerted efforts of actors from the public and private domains and is gradually gaining momentum.

'(...) I think there are so many levels of collaboration, and taking wind power now as an example, so what was done in Finland back in maybe it was 2008 when we have this feed-in tariff system for wind power, back then wind power was not economically viable, so you need it. Yeah, you need to have feed-in tariffs, and the government sets this feed-in tariff. But then, for these projects to actually wind power investments to start, they would be up to the municipalities.' [J2]

Representatives from the private sector contend that PPC facilitates the resolution of issues through dialogue without the interference of emotions or political debates. Private representatives also argue that consensus is necessary to have greater flexibility on the part of public partners in collaborative relationships.

4.1.3. Meaning creation: public-private collaboration arrangements and degree of horizontality

Stakeholders generally linked the concept of PPC for energy innovation with an interactive mechanism between public and private actors that yields mutual benefits. Interestingly, some stakeholders drew analogies between the relationship dynamics of family members to

illustrate how collaboration differs from other types of relationships.

'I take an example from family life. The parents are partners, but kids, children, and parents are not kind of partners because they have all the power and responsibilities for them; yes, they are on a different level.' [F3]

Informants perceive the PPC for innovation in energy as a multifaceted process that lacks uniformity or a unified approach. Instead, it encompasses a broad spectrum of nuances where public and private actors converge in collaborative ventures. Among the diverse range of PPC arrangements mentioned by stakeholders, we observed local and international schemes with a long-standing tradition. Of interest, we discovered some overlap and divergence in the perspectives of various stakeholders on PPCs. We have summarized the key themes of the PPC arrangements in Table 2.

As previously mentioned, diverse viewpoints on public-private collaboration are evident, linked to various mechanisms and institutionalized instruments by governmental entities. Specifically, from a private standpoint, it is acknowledged that major energy companies remain under public ownership in the energy market. Consequently, collaboration with the public sector plays a strategic role in energy transition, influencing policy and operational aspects.

4.1.4. Tensions between motivations and reluctance factors: boosting innovations versus the challenges of public and private sectors

Informants emphasized the relevance of complementarity between the public and private sectors to achieve common goals. In particular, interviewees emphasized the significance of collaboration among companies, universities, and research centers to drive innovation in the energy sector.

Table 2
Public-private collaboration arrangements.

PPC arrangements	Key themes: cues of sensemaking
Co-creation and co-innovation schemes	Most actors identified PPC with collaborative projects oriented toward energy innovation, where European and Finnish public institutions provide public funding involving companies, research centers, and universities.
Ecosystems and clusters	Ecosystems work as open innovation platforms to build collaboration with different partners in co-creation. Ecosystems also support building further closer PPC. Clusters also appear as a form of PPC that works in a similar technical area; these relationships are closer to the business than ecosystems.
Mankala principle	Typical arrangements in the Finnish energy field aimed at public or private utility companies sharing resources and responsibilities. Here, all the involved utility companies can buy energy at cost.
Energy cooperatives	Local communities with a significant role in the decision-making process for energy projects.
Energy Services Companies ESCO projects	Informants related ESCO with projects where a private company offers energy services to public institutions. However, according to the actors, ESCO is not commonly applied in the Finnish context.
Public-private partnership	Five different ideas of PPP were found: <ul style="list-style-type: none"> - PPP is associated with PPC as a collaborative and horizontal relationship where partners create value for each other. - PPP is identified holistically, including soft versions based on relationships without rigid agreements and hard versions of formalized PPPs. - PPP is associated with the Anglo-Saxon approach, highlighting that it is unsuitable for the Finnish context. - PPP appears as a mechanism for high-scale investment projects. - PPP is related to the so-called people-public-private partnerships. Here, stakeholders provide services or public infrastructure with citizens' participation.

(...) So when all these are together, with funding from the Finnish government, the research institutions, and the private sector, I think we have great opportunities to develop new technologies there. [B1]

Informants also highlighted that all parties may not fully understand technical and commercial complexities, further hindering collaboration. Working with public entities is mainly seen as a challenge for private actors due to the need to disclose private company information.

'The parties are not necessarily very comfortable opening up the full structures and full way of working and full financing set up in the projects because that contains a lot of confidential information and strategic choices.' [F1]

From the public sector standpoint, collaboration with the private sector serves as a means to foster the development of new technologies. Furthermore, they acknowledge that partnering with the public sector promote the presence of companies in international markets. Private sector representatives assert that energy innovation need local or regional government entities as initial leaders. Regarding the reluctance factors to collaborate, the private representatives stated that the public sector may be a bit rigid and some offices work in silos. Representatives of hybrid organizations believe that the public sector's involvement facilitates innovation development. However, the intensity of the role of the public sector in collaboration drops when energy technologies reach maturity.

4.1.5. Acceptability and individual sensemaking: acceptability of arrangements and public funding

The stakeholders acknowledged the current application of PPC in the energy industry in Finland for research and development, emphasizing the relevance of communication and mutual understanding. They also noted the unique characteristics of the energy sector in Finland, such as its high level of regulation, which needs specific collaboration agreements. While a diverse range of PPC arrangements was identified, stakeholders perceive their acceptance differently. Divergent interpretations of these arrangements among the interested parties suggest that the operationalization of PPC for innovation in practice is not entirely clear to them.

'I think it is a, there are many different ways [to collaborate between public and private actors], but one is to have these dialogues to creating common visions and understandings where to go (...) [D3].

As previously mentioned, accepting a PPC agreement is contingent on the meaning ascribed to it by interested parties. Specifically, related to public-private partnerships (PPP) within the PPC spectrum, acceptance appears lessened in cases where stakeholders associate PPPs with the traditional PFI model, or what some refer to as 'hard versions of PPPs'. Conversely, acceptance increases when actors associate PPPs with implicit, informal, and spontaneous versions of PPPs.

'So that is why I think the public-private partnership has been very popular in Finland for a long time. But now, even more, because the aim is that the small and medium-sized companies will go to the international market and be active there, they also need support from the universities and research organizations.' [H1]

The primary motivation for establishing PPCs is the potential for developing and scaling energy innovation. However, private actors denote concerns about collaborating with public actors, as it may limit their ability to maneuver within projects. Collaboration with public actors is seen as potentially slowing decision-making, increasing uncertainty around obtaining public funding, and adding rigidity and formality. Consequently, PPC arrangements based on horizontal relationships with a certain level of formality, such as 'co-creation' and 'co-innovation' schemes with public funding, ecosystems, and clusters, are the most widely accepted by actors. The Mankala principle framework is also commonly accepted in the Finnish energy sector.

'The collaboration structure is called the Mankala structure, as I mentioned. It can be done so that there is a mix of private players and community or state and players. So there, the ownership structure between the players does not matter. You can do it independently of the ownership structure.' [F1]

In contrast, 'hard versions of PPPs', such as the traditional PFI model, are not widely accepted in Finland. Some actors argue that this type of PPP is more easily applied in other sectors and possibly in countries where public finances require it. Some actors have considered the ESCO model a version of PPP, but its application is still limited in the Finnish context.

The acceptability of some of the most popular mechanisms found suggests the presence of public funding as a catalyst for PPC in the context of national energy innovation. In this regard, private sector perspectives indicate that solutions not yet fully established in the market benefit from public support, with public funding being crucial. Public funding is vital in making projects related to new energy technologies feasible. Nevertheless, accessing public funding instruments is perceived as complex for private actors. Similarly, representatives of hybrid organizations view public funding as a risk buffer for emerging technologies in power-to-x, hydrogen, and similar fields, where the payback time is long.

The sensemaking about the concept of PPC for energy innovation gains traction based on how convincing and acceptable the idea is for stakeholders in their contexts. This begins with stakeholders' introspection and is also shaped by the cultural context surrounding them. Stakeholders' motivations for engaging in collaborative energy transition efforts balance possible factors of reluctance as they reflect on past experiences to support or refute the idea of PPCs. Moreover, stakeholders evaluate the different PPC arrangements according to the current application in the context and compatibility with their collaborative sense.

4.2. Behavioral decisions: public-private collaboration as a social outcome

The informants perceived that PPC is aligned with the transition to sustainable energy systems. Still, they also highlight inconsistencies between daily activities and the decarbonization goals. Informants emphasized the relevance of establishing a clear vision of Finland's role in the global energy transition and developing collaboration strategies.

'But then I am all quite often thinking of a higher level of this public-private collaboration in energy transition, not just those mainstream investment activities, but also how to steer the whole sector to some desired direction, for example, towards cleaner investments from fossil fuels, etc.' [G1]

4.2.1. Connection with forthcoming actions: public-private collaboration in decarbonizing energy systems

Informants related the concept of PPC with a broader goal of decarbonizing energy systems on a global scale and underscored its relevance in this endeavour.

'I think that is key [collaboration] to all of this. Because I think in Finland but globally as well, or if you think about Europe or any other country, what we are trying to achieve now as humans is that we will, we are trying to in, well, we have to, if we want to reach these targets in 30 years, we will have to decarbonize the whole global economy, we have to decarbonize the energy sector, of course. (...).' [J2]

Given the relevance of the energy transition, stakeholders recognize the potential of the PPC on multiple levels, not only at a local level but also on a European and global scale.

'(...) I think it is very important that they were able to develop something that others can then use, that it is not just the one project and over. But

they have developed something very useful in the future for the whole energy system so that we can also use it in other places.' [B1]

5. Discussion

This study uses the case of Finland to explore *how cultural context at the country level influences individuals' perception of public-private collaboration and how the cultural context defines the nature of the prevalent type of public-private collaboration towards more sustainable energy systems*. The findings reveal the anchor link by exploring the microfoundations and trajectory's bottom layers from the socio-cultural context to the PPC as a social outcome. The specific national cultural context encourages the bonds of trust (Ybarra and Wiersema, 1999). Trust is the link to building collaboration between public, private, and hybrid organizations (Klijin et al., 2021). Thus, the perception of closeness, trust, and consensus promotes the social exchange between actors of heterogeneous nature (Malmström and Johansson, 2015; Santos et al., 2023). The public sector appears as a relevant figure as it provides multiple financial instruments to support the private sector in developing innovation (Tan et al., 2020). Likewise, the public sector plays a substantial role in the national energy landscape, encompassing purely public entities and hybrid structures unique to the country (Kivimaa, 2023). The private sector perceives the public sector as a key stakeholder, especially in promoting emerging energy technologies (Tan et al., 2020). The reluctance factors are generally related to the apprehension towards sharing confidential information, lack of understanding, and delays in decisions (Oskam et al., 2021).

Overall, the cultural context influences the PPC, the type of relationships in which horizontality prevails, and the absence of rigid formats or templates (Podrug, 2011). The social exchange of knowledge, support, and resources for PPC for energy innovation is fostered here, possibly due to the closeness between the institutions and the niches where innovation is generated (Malmström and Johansson, 2015). Individual sensemaking has been used to explore the social facts as the cultural context from the individual level to the social outcomes as PPC

(Contractor et al., 2019; Felin and Foss, 2015; Ivanova-Gongne and Törnroos, 2017). We formulated a conceptual model from the data structure, elucidating the interdependencies between the aggregate dimensions and the second-order themes (Fig. 3). Subsequently, this model was examined under the Social Exchange Theory (SET) to determine its theoretical fit. Our model offers a dynamic framework that unveils the cultural context's influence on PPC in energy innovation.

The process begins when individuals use mental schemas to review collaboration-related experiences (Harris, 1994). The perception of the cultural context and experiences interconnect with the meaning creation and the initial categorization regarding PPC (Tukiainen, 2015). The outcome of creating individual meaning is the concept of PPC as a horizontal relationship (Lotfi et al., 2022). Similarly, the individual engages in an internal dialogue emphasizing the motivation and reluctance factors. Here, the individual goes from a tension between these opposing forces towards a state of reconciliation, eventually leading to a unique understanding of their stance on PPC for energy innovation (Yström et al., 2019). Furthermore, individual sensemaking is closely linked to behavioral decision-making (Fellows and Liu, 2016). Drawing upon the insights gained from our case study, we have formulated a series of propositions that explain the interrelationships among the aggregated dimensions.

Proposition 1a. *the higher the level of trust in a given cultural context, the higher the degree of consensus.*

In a socio-cultural context, trust facilitates collaborative relationships among both public and private entities. Trust enables open dialogue and negotiation and the emergence of mechanisms based on relational ties. Furthermore, a strong level of trust among parties involved in collaboration facilitates consensual decision-making, reducing the risk of opportunistic behavior. Drawing from the SET framework, trust bonds foster collaboration surpassing the capabilities of individual entities. Connected to the influence of trust, we propose the following.

Proposition 1b. *the higher levels of trust in a given cultural context, the lower the need for competition in promoting innovation.*

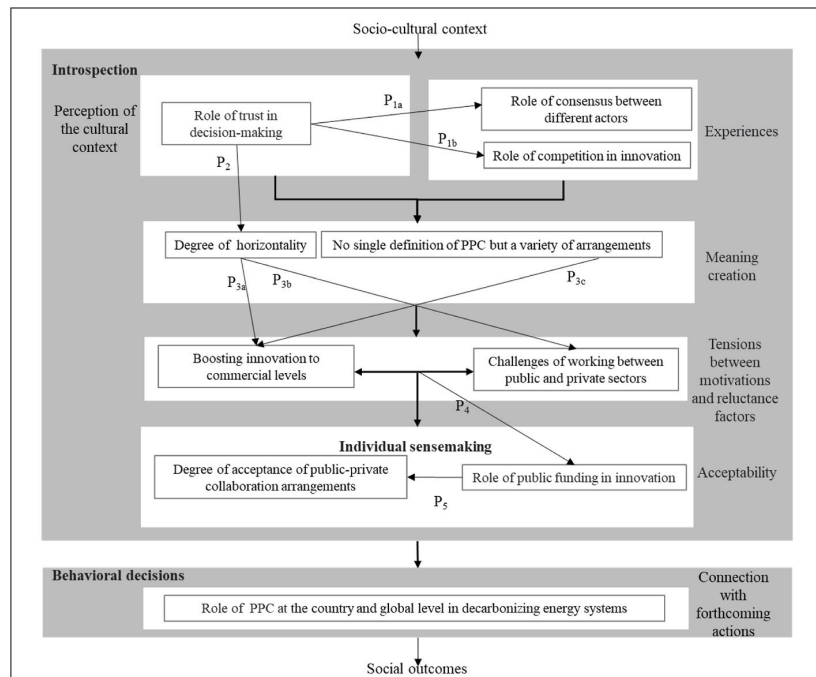


Fig. 3. Conceptual model of individual sensemaking of public-private collaboration towards cleaner and sustainable energy systems.

Instead of competing, stakeholders would join efforts when there is a high level of mutual trust. Indeed, trust helps share risks among parties when there is high uncertainty about the innovative solution. Here, the role of trust in the SET appears as the basis of collaboration to accelerate learning and promote innovation (Malmström and Johansson, 2015; Malmström and Wincent, 2012; Malmström et al., 2013). Likewise, high trust enhance the exchange of information, knowledge and capabilities for value creation, leaving aside the need to compete in innovation (Malmström and Johansson, 2015; Santos et al., 2023). Additionally, Antunes et al. (2022) stated that collaboration is appreciated more than competition in sustainability transitions. Concerning the influence of trust in PPC, we propose the following.

Proposition 2. *the higher levels of trust in a specific cultural context, the more positively it influences the horizontal nature of public-private collaboration*

A high level of trust facilitates the organic strengthening of ties between actors, thereby reducing power distance and promoting horizontal collaboration. In line with the SET perspective, trust is a multifaceted concept encompassing reliability and predictability (Khalid and Ali, 2017; Robson et al., 2019). Scholars have articulated trust as a continual anticipation held by one partner regarding the predictable and mutually agreeable conduct of another. This understanding of trust prevents the intentional imposition of one partner's will on others or the development of uneven power dynamics (Blau, 2017; Wyleżalek, 2021). Remarkably, one of the strengths of the Finnish innovation system, according to the document 'Review of Innovation Policy Finland' was the sense of being "all in one boat" (OECD, 2017, p. 22). Considering the implications of horizontality in collaboration, we propose the following.

Proposition 3a. *the more horizontally structured public-private collaboration, the more positively it enhances innovation scaling to commercial levels.*

A high degree of horizontality could lead to less power distance among partners. Here, stakeholders could feel more comfortable assuming higher risks of innovative processes. Furthermore, stakeholders can increase the intensity of resources for activities to reduce technical and commercial barriers to innovative solutions. Within collaboration, power dynamics play a crucial role in shaping how exchanges of knowledge or resources are conducted (Wyleżalek, 2021). To continue deepening the influence of horizontality in PPC, we propose the following.

Proposition 3b. *the more horizontally structured public-private collaboration is, the more positively it influences the mitigation of challenges between public and private actors.*

According to the SET, power relationships could determine the dynamics of interaction and influence among partners in collaboration (Khalid and Ali, 2017). Notably, increasing the level of horizontality in collaboration may aid in reducing power distance between partners and promoting better alignment. Moreover, a horizontal structure facilitates a better understanding of diverse partner perspectives and realities, enabling more efficient conflict resolution. When actors cannot collaborate on an equal footing, the governance process could be susceptible to being controlled by stronger actors (Douglas et al., 2020; Pinilla-De La Cruz et al., 2022).

Proposition 3c. *varied configurations within PPC positively contribute to tailoring relationship-building to meet the demand of scaling innovation to commercial levels.*

The dichotomy between public and private dimensions does not cover the rich variation of organizational forms within PPC (Quélin et al., 2017). Indeed, a standardized definition might not capture the multidimensional nature of the phenomenon; instead, it is the adaptable nature of collaboration that facilitates essential conditions for co-creation and the scaling of new energy technologies. In this case, SET is a pertinent conceptual framework for elucidating diverse intersections manifest at various levels (Wyleżalek, 2021). SET enables a nuanced understanding of how relationships and contexts shape the diverse ways organizations engage in innovation,

contingent upon drivers and nature (Can Sağlam, Yıldız Çankaya, Golgeci, Sezen, & Zaim, 2022). The reconciliation of motivations and reluctance factors is connected to the role of public funding in PPC. Thus, we propose the following.

Proposition 4. *aligning motivations and overcoming reluctance factors in public-private collaboration has a positive influence on the role of public funding.*

Local, national, and even regional public policies articulate public funds for innovation. Consequently, public authorities actively advocate for and promote programs and policies that foster collaboration. Here, public and private actors should be willing to align on expectations and motivations to work on innovation. Hence, alignment between public and private actors can increase the impact of public funding on the development of innovation (O'Kane et al., 2020). Specifically, a motivation for private entities to engage in collaborative innovation is the availability of public funding, underscoring its significance. To further analyze the role of public funding, we propose the following.

Proposition 5. *Public funding influences the acceptance of public-private collaboration arrangements characterized by equal standing and a defined level of formality.*

Public funding can influence the acceptance of the type of PPC arrangements on a relational base but with some formality and equal standing, as it serves as an incentive to establish collaboration. Furthermore, public funding is critical in shaping multi-stakeholder collaborations and their alignment with sustainability objectives. Also, it facilitates tailored linkages with academia and research centers. In particular, European programs and national agencies, such as Business Finland, highlight the role of public funding for ecosystems and partnerships in energy innovation (Ministry of Economic Affairs and Employment Finland, 2019; Ministry of Economy Affairs and Employment of Finland, 2018; 2022). However, some informants stated that handling public funding implies strict rules for using taxpayers' money and long waiting times for public decisions. Notably, the type of arrangements where the tightness of the collaborative structure is less would rely more on public funding or co-funding to keep stakeholders engaged. Indeed, according to Brostro (2012), the pressure of international competition and rapid technological advances push the industry to connect research efforts to networks and then public co-funding works by strengthening the incentives to build collaborations for research and development.

6. Conclusions

This study underscores the crucial role of PPC in advancing cleaner and more sustainable energy systems. To address the research questions, we developed a case study using the SET framework and individual sensemaking to explore culture's impact on PPC in energy innovation at national level in Finland. Our findings indicated six main dimensions in the actors' discourse: 1) perception of the cultural context, *the role of trust in decision-making*; 2) experiences, *consensus, and the role of competition in innovation*; 3) meaning creation, *the role of horizontality, arrangements*; 4) tensions between motivations and reluctance factors, *boosting innovations to commercial levels versus the challenges of working between public and private sectors*; 5) acceptability and individual sense-making: *acceptability of public-private collaboration arrangements and the role of public funding*; and 6) connection with future actions: *the role of public-private collaboration in decarbonizing energy systems*.

6.1. Theoretical contributions

The findings of this study provide insights into several contributions to the literature. Firstly, our study explores the impact of cultural context on the ability of both public and private actors to engage in social exchanges and collaboration for energy innovation. In this sense, those interviewed emphasized the relevance of complementarity between the public and private sectors to achieve common goals.

Moreover, the study underlines the need for collaboration to foster innovations and instigate socio-technical change. Second, in line with the microfoundations approach and the Social Exchange Theory (SET), our study reveals that factors such as trust and consensus enhance the connection between public and private actors. These factors are further strengthened by the common foundation provided by the cultural context (Khalid and Ali, 2017). Here, informants emphasized that trust is a key value in collaborative efforts within Finnish society. Similarly, horizontality stemming from the cultural context, reflects the power distance among actors and influences the social exchange in PPC (Can Saglam et al., 2022). This paper elucidates the relevant role of the agency in offering explanations for social outcomes at the individual level.

6.2. Policy implications

Based on the findings, our study provides valuable contributions for policymakers in driving actions toward more sustainable energy systems. Firstly, it presents an updated understanding of the motivations of public and private actors to build PPC in the Finnish energy context, which informants indicated as the opportunity to develop and scale energy solutions. These insights could encourage social learning and stakeholder interactions to foster relevant interventions (Köhler et al., 2019).

Secondly, our study highlights the significance of trust, consensus, and horizontality for decision-making in the Finnish context and the relevant role of public funding in helping energy innovation gain full traction in the market. Therefore, policymakers can leverage these context-specific features to promote the emergence of solid grassroots PPC by activating public funding mechanisms. Third, this study emphasizes the challenges of ‘importing’ or transferring PPC frameworks from one context to another. Successful instruments in specific cultural settings may not yield the desired outcomes if the nuances of the cultural context of implementation are not considered.

Appendix A

Table A1
Representative proof quotations

Aggregate dimension second-order theme	Representative quotes
Socio-cultural context Introspection Perception of the cultural context: <i>the role of trust in decision-making</i>	- <i>It [trust] is key in our culture. It is key</i> . [B2] - <i>(...) But to my understanding, it is informal and easy-going, and, of course, there are. They make contracts and sign understandings under responsibilities, etc. So, of course, they take care of the legal basis. But, as a small country, and I said, everybody knows everybody in the kind of sector</i> . [J3] - <i>Well, if I think about those projects with whom I have worked, these energy support projects, I would say that the most successful are those they have been able to develop and demonstrate something new</i> . [B1]
Experiences: <i>consensus and the role of competition in innovation</i>	- <i>Well, I think we should try to make them discuss with each other so that they can tell us how they normally work and compare their working methods and issues. And maybe bring some new ideas to the discussion and decide how to collaborate</i> . [H1] - <i>But I would say, it [decision-making] is horizontal, but it is also formal</i> [B2] - <i>So there are various ways to create this relationship, and they are all tailor-made more or less; there is no one size fits all</i> . [E3]
Meaning creation: <i>the role of horizontality, variety of arrangements</i>	- <i>How much more powerful you are if you do things together</i> [B2] - <i>I think if we would be better at cooperation, then we create it much more. Always says that 1 + 1 is more than two; it is three or four (...)</i> [D2] - <i>I think it is very fruitful if this kind of network and collaboration exists, so I think we can do more quickly good things</i> [H1] - <i>(...) If you have a political interest in and want to steer it in a certain way, the companies have their interests, which might differ. And I noticed that these different parties have difficulties understanding each other's position</i> . [F2] - <i>EU horizon projects are a good example where these energy transition innovations or demonstrations in Finland (...)</i> . [J1]
Tensions between motivations and reluctance factors: <i>boosting innovations to commercial levels versus the challenges of working between public and private sectors</i>	
Acceptability and individual sensemaking: <i>acceptability of public-private collaboration arrangements and the role of public funding</i>	

(continued on next page)

6.3. Limitations and future research opportunities

As with any research endeavor, our study has its limitations. Specifically, using a single case study may restrict the generalizability of the findings. Nonetheless, the decision to employ the single case study was informed by the case's relevance and its value. Future research efforts should focus on two key areas: (1) enabling mechanisms for fostering cross-context public-private collaboration and 2) the roles and motivations of public and private actors in collaboration toward cleaner and sustainable energy systems.

CRediT authorship contribution statement

Giovanna Andrea Pinilla-De La Cruz: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Rodrigo Rabetino:** Writing – review & editing, Validation, Supervision, Project administration, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data that has been used is confidential.

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Table A1 (continued)

Aggregate dimension second-order theme	Representative quotes
Behavioral Decisions and social outcomes	- 'ESCO model, I would say. It is part of this partnership. It is a wider viewpoint from the ESCO model (...)'. [E3]
Connection with forthcoming actions: the role of public-private collaboration in decarbonizing energy systems	- 'Yeah, we can contribute something big at the European or even global level, but it needs more collaboration and common understanding (...)'. [B3] - '(...)all the collaboration between the public sector and research, like universities and research centers and the private sector, is very efficient because if the universities only study something by themselves, maybe they are not developing something too important for the companies. So, where all these are funded by the Finnish government, research institutions, and the private sector, we have great opportunities to develop new technologies.' [B1] - '(...) then they all could collaborate instead of trying to be good in everything and then competing, and then there is kind of overlapping because there are so few resources for this kind of research that it would be better to kind of focus in a better way and coordinate this'. [B3]

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UNFOLDING ECOSYSTEM EMERGENCE: THE ROLE OF ACTOR'S AGENCY AND PUBLIC-PRIVATE COLLABORATION PRACTICES

Abstract

This study explores the ecosystem emergence for battery-based stationary energy storage systems, focusing on the collaboration among actors to support integrating new technologies and the agency and efforts driving its growth and consolidation. We use processual analysis to understand the micro-level activities stemming from the agency of ecosystem actors, particularly the orchestrators' role, unveiling the mechanisms that lead to the ecosystem's emergence in a specific context. In our single case study, we interviewed key ecosystem stakeholders from public and private organizations in an emergent ecosystem in Finland. Anchoring our research on the practice theory, we provide novel insights into practices and mechanisms of ecosystem formation and the role of public-private collaboration along the early stages of emergence. Policymakers and practitioners could find valuable information to understand better the influence of social structures on the evolution of ecosystems, including the mechanisms behind the orchestration's agency.

Keywords: ecosystem emergence, public-private collaboration, practice theory, orchestration, green batteries, green electrification

1. Introduction

As a central element for green electrification, energy storage has become a priority to tackle climate change and move towards sustainable energy systems. Yet, the pace of electrification of renewables and the development of efficient storage systems must accelerate to meet the rising global energy demand by 2050 (IRENA, 2022). To promote and accelerate the development of clean and innovative solutions, such as energy storage systems social structures, such as ecosystems, must be established to enable interactions between key stakeholders. Ecosystems perform as niches where the necessary support is provided to innovation to overcome technical and commercial risks. However, building robust ecosystems is complex because they often lack articulation and cohesion.

From the agents' perspective, the emergence of ecosystems involves a collective discovery and progressive exploration that is enhanced or hindered by their ability to collaborate to achieve a common goal and build legitimacy in a specific context (Thomas, Autio, & Gann, 2022). It involves generating a cohesive value proposition and a collective identity at the ecosystem level (Adner, 2017; Jacobides, 2018).

The emergence of ecosystems is a process of forming new social structures from the exchanges of agents in a specific field (Bhaskar, 2008; Sawyer, 2005). The collaborative iterations and the expertise of actors strengthen ecosystems. The intensity of interactions contributes to the consolidation of the ecosystem, enabling the scaling and adoption of new energy technologies. Heterogeneous actors in emerging ecosystems are sometimes aligned, but at other times they contrast. Indeed, given that public and private actors often act based on their rationality and decision-making within their operational structures, divergent incentives could affect ecosystem emergence under specific conditions (Tsujiimoto, Kajikawa, Tomita, & Matsumoto, 2018).

Ecosystem consolidation might slow if efforts are not focused on a shared objective. In particular, ecosystems for the decarbonization of energy systems in their initial stages are particularly complex because they require the participation of public actors, both as guarantors and as active supporters. In parallel, emerging ecosystems require a foundation within private companies where innovations and valuable contributions from academia and other stakeholders can develop and grow. Therefore, public-private collaboration is needed to address emerging challenges. Indeed, public-private collaboration (PPC) plays an increasingly crucial role in promoting the emergence of ecosystems as new social structures and enhancing the value creation (Pinilla-De La Cruz, Rabetino, & Kantola, 2022;

Taillard, Peters, Pels, & Mele, 2016). Furthermore, PPC within emerging structures enables the alignment of efforts toward the common goal of scaling clean energy technologies, ensuring that the ecosystem advances in line with its value proposition while maximizing its momentum to reach higher levels of development (Brogaard, 2019a; Ndzibah, Pinilla-de La Cruz, & Shamsuzzoha, 2022; Ndzibah, Pinilla-De La Cruz, & Shamsuzzoha, 2021).

In particular, the ecosystem orchestrator is crucial in aligning participants and fostering a collective identity. Orchestrators connect the micro level of individuals and collective levels but are also influenced by various tensions derived from their cultural background and past experiences and the social structures surrounding them (Bourdieu, 1990; Gomez, 2015; Jarzabkowski, Balogun, & Seidl, 2007). Orchestrators also guide public and private actors to collaborate effectively by defining roles and establishing governance rules. However, research focused on the emergence of public-private ecosystems for the transformation of energy systems and the role of orchestrators remains limited, although the urgency of prioritizing research in this field is recognized due to the high failure rate observed in emerging stages (Freeman, Carroll, & Hannan, 1983; Thomas, 2022). The literature offers little exploration of the relationship between the emergence of new social structures, such as ecosystems, and the impact of orchestrator agency and collaborative practices. Accordingly, it is necessary to have a better understanding of the mechanisms that influence the emergence of public-private ecosystems from the identification of the connection between the micro-actions of the agents as orchestrators with the practices socially defined and transferred throughout time (Felin & Foss, 2015; Taillard et al., 2016; Thomas, 2022).

Against this backdrop, our study seeks to reveal how collaborative practices and the agency of the orchestrator drive the emergence of a public-private ecosystem for green electrification and stationary energy storage systems (Bourdieu, 1990; Gomez, 2015). Specifically, we apply the theoretical lens of Practice Theory to identify PPC as rooted in social structures, which can facilitate the concentration of agents's efforts toward achieving a stronger position within the industry context. Our article answers the following research question: *How do the ecosystem actors' agency and collaboration practices define the emergence of the early-stage ecosystem?* We conducted an in-depth single case study based on primary data and archival sources since 2016 to examine the early stages of one emerging ecosystem in Finland. This study provides evidence-based information on the practices that give rise to the emergence of a public-private ecosystem and its development and evolution dynamics (Jarzabkowski, Kaplan, Seidl, & Whittington, 2016). Policymakers and practitioners could find valuable insights to better understand the interplay between agency, habitus, capital, and field by

studying the process of ecosystem emergence. Furthermore, The ultimate goal of this study is to unravel the emergence of a public-private ecosystem through microactions of self-recognition and value discovery over time, leading to its configuration as a new social structure (Bourdieu, 2005; Jarzabkowski et al., 2007).

2. Conceptual framework

2.1. Emergence of public-private ecosystems

Ecosystems emerge as new social structures shaped by the influence of existing frameworks and the dynamic interplay of ascending and descending forces (Polese et al., 2021; Taillard et al., 2016). Thomas et al. (2022) state that ecosystem emergence occurs in three stages until maturity: *launch, expansion, and establishment*. Ecosystem emergence is evolutionary by nature, as it gains strength through repeated interaction among its members (Kola, Koivukoski, Koponen, & Heino, 2020). This iterative process leads to the development of more resilient and stable structures over time (Valkokari, Seppänen, Mäntylä, & Jylhä-Ollila, 2017). As ecosystems emerge, new rules, roles, and governance structures are created from the diverse institutional logic of their members (Bhaskar, 2008; Taillard et al., 2016).

Mainly, public-private ecosystems for the energy transition cope with the differing actors' incentives to achieve cooperation and address the technical, regulatory, and commercial risks of novel energy technologies (Dedehayir, Mäkinen, & Ortt, 2018; Ozgur Dedehayir & Seppänen, 2015; Susur, Hidalgo, & Chiaroni, 2019). Here, Asplund et al. (2021) revealed the need for research related to the emergence or *genesis* due to the challenges of building foundations of collaboration between actors promoting divergent economies. During the emergence, the new ecosystem evolved from an initial idea to become an aligned structure of actors able to deliver a system-level value proposition (Adner, 2017; Jacobides, 2018; Sjödin, Parida, & Visnjic, 2022).

2.2. Orchestration of public-private ecosystems

The orchestrators' role is crucial to align the diverse actors' perspectives towards a shared goal while delineating the path to developing a collective identity (Jarzabkowski et al., 2007; Thomas, 2022). Undeniably, the alignment between individual contributions and the system's overall value proposition would impact

the potential success of the emergence process. This alignment strengthens the coherence between ecosystem objectives and actions (Tsujiimoto et al., 2018). The scope of orchestrators extends to critical activities, such as influencing actors and coordinating actions to collaboratively define the ecosystem's architecture and the roles of individual members (Augusto et al., 2022; Thomas et al., 2022).

Since orchestrators embody individual and collective perspectives, they act as dynamic agents navigating interconnected structures that influence ecosystems' emergence (Kohtamäki et al., 2021; Seidl & Whittington, 2014; Vaara and Whittington, 2012). Their role becomes crucial in mobilizing the ecosystem towards a more stable structure during emergence. However, public-private ecosystem members and the orchestrators' agency do not occur in isolation as the sociocultural context exerts significant influence (Klessova, Engell, & Thomas, 2023). Therefore, the cultural background, values, norms, and regulations define a path or trajectory for the ecosystem to evolve (Pinilla-De La Cruz & Rabetino, 2024). Additionally, the ecosystem's value proposition could be highly influenced by whether it has been driven and supported by the public or private sectors (Asplund et al., 2021).

2.3. Agency, collaboration, and the role of the orchestrator in public-private ecosystems

The orchestrator's agency could reflect the ecosystem's prevailing 'modus operandi' as socially accepted practices and existing forces in a given context (Gomez, 2015; Jarzabkowski et al., 2016; Seidl & Whittington, 2014). The orchestrator's agency serves as a catalyst, connecting diverse forces within a specific context to enable a new ecosystem structure where different agents can operate going forward (Bourdieu & Wacquant, 1992; Gomez, 2015). The orchestrator benefits from these tensions to direct movements towards better positions in the field. These forces correspond to resources -often called 'capital' in the literature- and provide fundamental elements for the emergence of the ecosystem (Pratap & Saha, 2018). The potential of capital lies principally in the competitive advantage it offers.

In some cases, cultural capital corresponds to specific technical skills or mastery in critical areas for the consolidation of the ecosystem. Likewise, social capital can arise from the strength of social networks and the capacity of regional actors to join efforts to pursue a common goal. Symbolic capital is generated through the legitimacy and recognition that entities possess within the specific context of the ecosystem (Bourdieu, 2005).

As mentioned above, their personal and cultural backgrounds determine the orchestrator's agency. Accordingly, their inherent proclivity and trajectory would affect the orchestrators' decisions and behavior. Scholars such as Bourdieu (2005) and Gomez (2015) refer to this concept as 'habitus'. Agents' habitus somewhat influences how the orchestrator would steer the ecosystem's system-level value proposition. Thus, agency operates in the intersection between the tension exerted by the various capitals and the trajectory provided by the habitus in the new field that has been created corresponding to the ecosystem in emergence (Gomez, 2015; McAdam, Harrison, & Leitch, 2019) (Figure 1). The ecosystem as a new field is transformed in response to the agent's actions, and in turn, the ecosystem also exerts influence over the orchestrator's agency (McAdam et al., 2019). However, due to its inherent maneuverability, the orchestrator's agency and other agents cannot be precisely measured or quantified (Bourdieu, 2005; Gomez, 2015). This capacity for maneuver allows agents to implement changes that are difficult to predict from the recombination or adaptation of different components (Jarzabkowski et al., 2007).

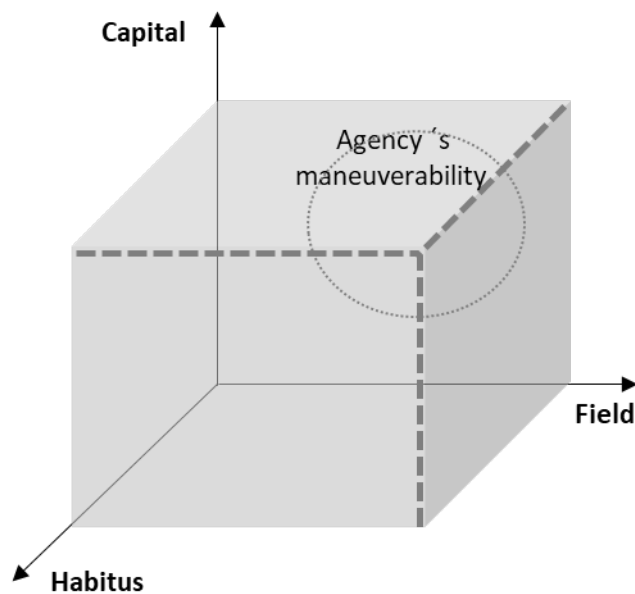


Figure 1. A preliminary conceptual framework based on the Bourdiesian's standpoint (Bourdieu, 2005)

The emergence of the ecosystem is an innovative process in itself. The orchestrator may explore new areas of knowledge and, in turn, take advantage of their existing

knowledge (Audretsch, Belitski, & Caiazza, 2024; Gretsche, Salzmänn, & Kock, 2019). Moreover, the orchestrator might progressively guide the integration of actors, expertise, and resources previously disconnected within the new field (Gherardi, 2012; McAdam et al., 2019). In doing so, the approach will leverage the capacity to connect elements, transitioning from the individual actions of agents to foster a collective agency that supports the emergence of the ecosystem (Jarzabkowski et al., 2007; Russo-Spena, Tregua, Amitrano, & Bifulco, 2020; Taillard et al., 2016). In this case, social capital's collaboration can potentially increase the "permeability" between these structures and the orchestrators' agency (Jarzabkowski, 2008). This, in turn, leads to a greater capacity for adaptation and development (Gomez, 2015; Pratap & Saha, 2018).

In particular, collaboration between public and private actors, a coordinated effort between actors driven by opposing incentives, can either empower or limit individual agency (Corsi, Fu, & Külzer-Sacilotto, 2021). Additionally, when public-private collaboration works appropriately, it facilitates progressively mobilizing ecosystems toward upper levels as more complex and robust social structures (Halley & Winkler, 2008; Taillard et al., 2016).

3. Research design

This paper follows a qualitative research strategy to examine how observable mechanisms associated with the orchestrators' roles and public-private collaboration (PPC) impact the interaction between agency and structures during the emergence of a public-private ecosystem (Asplund et al., 2021; Gomez, 2015; Richard Whittington, 2010). We conducted a processual analysis of a single case study to provide in-depth qualitative evidence on the patterns and mechanisms related to the orchestration agency in the emergence ecosystem for battery-based stationary energy storage systems in Finland (Eisenhardt & Graebner, 2007). Our qualitative single case study considers the public-private ecosystem in the early stage as the primary unit of analysis. Notably, we anchored our research on the principles of the Practice theory from the Bourdieusian's standpoint (Bourdieu, 2005; Gomez, 2015; Jarzabkowski et al., 2007, 2016).

3.1. Case study

The case study selection followed a purposeful sampling (Patton, 2022) based on the nation's extensive experience in electrified systems and applications and its robust commitment embodied in the Battery Strategy for Finland (Ministry of Economic Affairs and Employment of Finland, 2021). Primarily, the choice is

driven by the resilience of the battery value chain and the collaborative efforts among diverse actors from both public and private sectors since 2016, leading to the emergence of a public-private ecosystem.

The case study takes place on the West Coast of Finland, where this initiative was proposed to build and integrate a green battery value chain (Business Finland, 2017, 2019). This initiative emerged at the end of 2016 from the announcement of the European Tesla Gigafactory of batteries for electric vehicles (Yle, 2017). Over time, after self-recognition of the region's capabilities, a strategy focused on producing stationary energy storage systems based on batteries was incorporated (EnergyVaasa, 2019). From 2016 up to date, the ecosystem's initiative has progressed in the emergence process in early stages (Figure 2). Despite some obstacles, the initiative has promising potential to form a public-private ecosystem that contributes to the green transition in the Nordic countries (Business Sweden, 2023; Ministry of Economic Affairs and Employment Finland, 2019; Ministry of Economic Affairs and Employment of Finland, 2021).

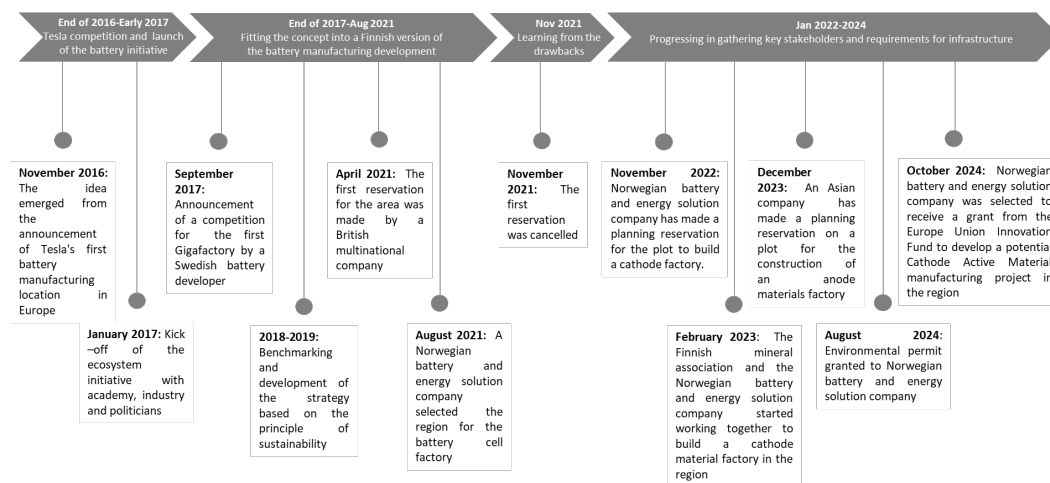


Figure 2. Timeline of the ecosystem from 2016-2024 based on the City of Vaasa (2023) and information from public available sources

3.2. Data collection

Data was collected using primary and secondary sources (Table 1). First, between April and May 2024, a set of 15 semi-structured surveys focused on regional actors were carried out. Informants were identified through reports and publications of relevant organizations in the context. These actors are widely recognized for their role in public and private organizations in the regional energy sector. All

informants were contacted by email, and interviews were conducted via Microsoft Teams. Each interview ranged from 26 to 53 minutes. We structured the interview using a questionnaire developed from a literature review to address key themes critical to answering the research question (Appendix A). Likewise, in 2024, we observed two-panel discussions with the participation of national and regional public authorities and potential international partners. Similarly, secondary data was collected from publicly available sources such as official plans and reports, press releases, websites, and media articles issued in Finland and Nordic countries during 2017-2024 to understand the historical context of the ecosystem emergence comprehensively.

Table 1. Data sources

Interviews (15)	Informant's roles:	Interview code	Time (min.)
	Managing directors, public authorities, and experts from key public and private organizations related to the energy field on the West Coast of Finland	A1	53
		A2	47
		A3	45
		A4	42
		A5	40
		H3	30
		H4	42
		B1	31
		B2	26
		A6	38
		A7	52
		H1	30
		A8	44
		H2	35
		A9	30
Observations (2)		Panel discussion August 2024	90 min
		Panel discussion October 2024	270 min
Archive sources (28)	Data type:	Official plans and reports	15
		Press releases	4
		Websites	6
		Media articles	3

3.3. Data analysis

Data analysis included data from semi-structured interviews, observation notes, and files (Williams & Shepherd, 2016). This analysis was performed following Eisenhardt (1989), Gioia, Corley, and Hamilton (2013), and Cloutier and Ravasi (2021). Data analysis involved identifying key data segments and assigning codes to capture their meaning, then grouping them into categories as second-order themes through an iterative process until no new categories emerged. Subsequently, the interdependencies of these categories were identified to group them into aggregate dimensions. The volume of data analyzed corresponded to 338 pages of interview transcripts to create a data structure (Figure 3). Furthermore, observation and review notes from official and press publications were used to complement and substantiate this empirical approach.

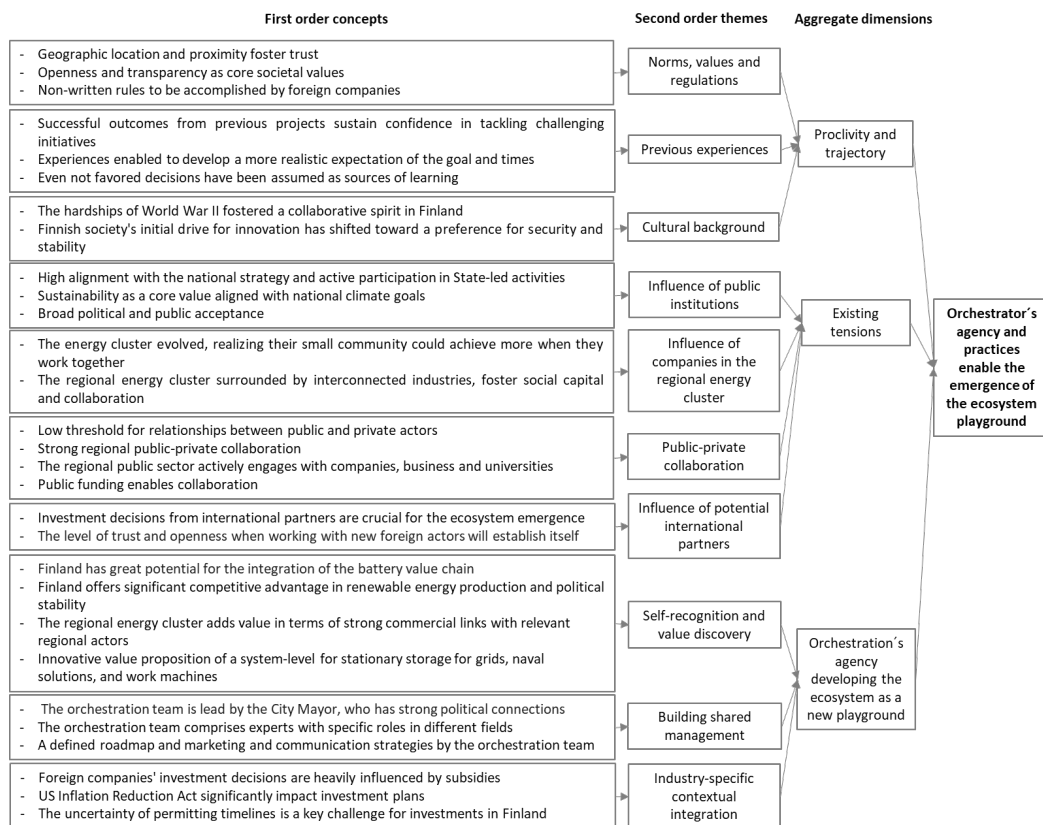


Figure 3. Data structure based on the empirical work

3.4. Quality assessment

Validity and reliability are ensured in this study at all stages. In particular, to ensure construct validity, the primary source for data collection corresponded to a set of interviews. Here, informants were carefully selected to cover the different edges of the regional energy organizations. Primary data was contrasted with secondary data from publicly available sources. Moreover, internal validity was reinforced by carefully outlining our research process and using Cloutier & Ravasi's (2021) guidelines. Regarding external validity, an exhaustive review of the literature on public-private collaboration in the emergence of ecosystems was conducted based on Practice and Agency theories. Finally, to support the reliability of our work, we documented the research process and findings for future reference, including supporting quotes (Appendix B); we also provided information about data sources and the questionnaire used for semi-structured interviews (Table 1 and Appendix A).

4. Findings

The data analysis identified ten categories as mechanisms influencing the orchestration team's agency. The categories have been grouped into *proclivity and trajectory*, *existing tensions*, and *orchestration's agency developing the ecosystem as a new playground*. The explanation of each dimension is detailed below and is supported by powerful quotes. Additional supporting quotes are in Appendix B, per Pratt's (2009) guidelines.

4.1. Proclivity and trajectory

The first aggregate dimension corresponds to *proclivity and trajectory*, which trace a congruent and regular line of motion. These mechanisms explain the origins of regularities in the daily actions of agents. We identified three mechanisms in this category that significantly influence the direction and trajectory guiding the ecosystem's emergence. First, we identified a set of *norms, values, and regulations* that, according to the interviewees, correspond to characteristic elements of Finnish society. For instance, Finland has been described by those interviewed as a high-trust society whose geographical location and low population density make it easier to meet and interact with people within the same region.

“Now trust is really the foundation for everything. It's kind of what this all this triangle, you know, so it's the foundation for everything, and I will say it has been a really good level between all the players in Vaasa”. [B1]

Some interviewees have described Finland as a “country club” to highlight the relevance of personal relationships. Trust extends beyond institutional and organizational boundaries and leads to practices characterized by transparency and openness within and outside organizations.

“I think that we are a high-trust society, somebody often has, or many people have said that Finland is not a country; it's a Country Club”. [H4]

The second category within this dimension corresponds to *previous experiences*. The informants emphasized the relevance of earlier projects as a knowledge base for structuring the work plan and defining the required competencies for the orchestrating team of the emerging ecosystem for battery-based stationary energy storage systems. The experience of the orchestration team in previous projects at the regional level gave them the confidence to be part of this project, which, because it is a highly novel idea in the country, includes important challenges. The expected consolidation of the ecosystem would significantly impact the economy and the region's country. Additionally, regardless of future results, addressing the obstacles encountered in the emergence of this new ecosystem has resulted in fruitful learning opportunities for the regional actors. Even negative decisions have been taken as turning points to refine and adjust the strategic direction of the ecosystem.

“A ship project was on target to get the new baseline ship between Umeå and Vaasa, so the similar kind of, let's say, a way of working to have, let's say, different experts from different areas”. [A1]

Lastly, the *cultural background* category presents helpful information to explain the cultural dimension from the Finnish perspective. In this regard, the informants referred to the devastating effects of the Second World War on the Finnish economy, including the war penalties paid to the former Soviet Union over the next decade. This situation forced Finnish society to endure the most difficult circumstances and discover the value of perseverance and hope for a better future. The strengths that allowed Finland to reconstruct its economy and notable industrial development rapidly are based on its creative, cooperative capacity and discipline. In this context, trust and integrity became the essential pillars of uniting efforts to reconstruct the country. As a result, since the war, strict codes of conduct and social sanctions have been established against opportunistic behavior that

have resulted in adopting social practices oriented towards transparency and accountability.

“Because after the Second World War, we were in a tough situation because the economics was tight, and we were in that kind of situation that nobody in the world believed that we could be anything else but part of Russia after two decades. So, but we all of a kind of a like a bumblebee with a huge corpse and little wings and quite impossible against the physical law that it flies. But Finland is like a bumblebee. Yeah, we fly”.
[A6]

Regarding industrial development, informants suggest that the region's notably high per capita exports and the formation of the regional energy cluster, where the ecosystem is emerging, can be attributed to Finnish emigration to North America in search of opportunities, especially concerning engine technology.

“We usually also discuss why our region is so international and why the level of exports is so high per capita in this region. We have always been looking outwards. (...) The great story about the energy cluster more or less started because of John Wickström going over to America and then being friends with Henry Ford and taking back the knowledge that they gained there to start building the engines; you can see it like on a historical level in my opinion that you have been open to, you know, trading collaborating”.
[H1]

4.2. Existing tensions

Existing tensions from various sectors of the public arena influence the orchestration of the emerging ecosystem. These tensions define the momentum to drive a shift from one position to another by ecosystem orchestrators. On one side, public institutions exert significant tension, which is related to the *influence of public institutions* and the members of the orchestrating team.

“Let's say, business trips to try to advance the Finnish battery industry investments, and we were also part of the delegation almost when was, let's say, going to Asian countries or the US” [A1]

The second category refers to the *influence of companies in the regional energy cluster*. At the regional level, the energy cluster is a technical platform that joins key private actors in the energy sector. This regional cluster has promoted large-scale energy initiatives, including the battery-based storage ecosystem initiative,

which is the subject of this study. Interviewees reveal that the regional network of actors offers implicit quality assurance to new investors and represents a potential market for stationary battery-based energy storage systems. The technical cluster has acquired validation and legitimacy in the regional context, where the advantages of taking advantage of its collective strengths to promote initiatives for regional development are recognized.

“We are seeing that, of course, energy Vaasa and the cluster have played a great role over time in facilitating many different collaborations between stakeholders in the ecosystem”. [H1]

The third category is central to the regional panorama: *public-private collaboration*. Interviewees indicate that the country and the region have a low threshold for interactions between public and private sector actors, leading to frequent public-private collaboration initiatives. Low hierarchical barriers and shared backgrounds make this collaboration a strength. According to informants, the success of the regional energy cluster is primarily attributed to its foundation in public-private collaboration and the trust among its members. Furthermore, the public sector also functions as an articulator by mobilizing companies, universities, and other organizations to participate in regional development initiatives. Given the complexity of the ecosystem value proposition, it relies on the collective efforts of several sectors, where collaboration becomes a fundamental component to developing a solution for stationary battery-based energy storage systems.

“If you talk about the public sector here, you want to be involved with the companies, so sometimes the public sector might be the driver that they want to meet with some companies and universities. (...) But I wouldn't say there's a barrier between the private and the public”. [H2]

The fourth category refers to the *influence of potential international partners*. Here, the investment decisions of new international stakeholders would significantly influence the ecosystem's future. New international partners in the battery industry substantially impact the pace of the ecosystem's development. Interviewees emphasized that shared values, especially trust, facilitate collaborative relationships with investors from similar sociocultural backgrounds, such as those from the Nordic countries.

“This is the culture, and, of course, we kind of expect them to be somehow able to operate in this kind of environment, and then we have to remember always that this is not necessarily taking alter back home, so this is kind of a learning

curve where the level of trust and where the level of openness will settle itself”.
[A6]

4.3. Orchestrator´s agency developing the ecosystem as a new playground

The development of a solution for battery-based stationary energy storage systems, as an emerging ecosystem, represents a nascent social structure within the broader context of the global battery industry in the power sector. The development and consolidation of the ecosystem depend on regional efforts and the dynamics of the international market. According to interviewees, three key categories can be identified as elements influencing the development of this emerging ecosystem: *self-recognition and value discovery, building shared management, and industry-specific contextual integration.*

The first category is connected to *self-recognition and value discovery*, where interviewees have described the ecosystem initiative as a learning process for a new branch within the energy industry. The self-recognition and self-discovery process has provided the opportunity to identify previously overlooked strengths that now become fundamental elements to develop a value proposition aimed at sustainable energy storage systems. While the initial impetus was the search for a European location for Tesla's upcoming Gigafactory, self-discovery has created an innovative solution to address renewable energy challenges. This initiative incorporates the technological and social capabilities of the region and benefits from the political stability and the country's commercial opportunities.

“But if we take Vaasa as an energy cluster, it is the biggest energy cluster in the Nordics, so we have the know-how. We already have employees who understand energy and energy technology. We have had the chemical industry involved as well. (...) We have, on average, affordable energy prices and not only affordable but also clean energy compared to central Europe”. [A2]

Interviewees reveal that a transformation was generated in the strategic orientation when knowing the specificity of the battery industry as a new field in the regional context. Additionally, some unfavorable investment decisions also produced changes in strategy. These ‘turning points’ led to rethinking the value proposition and focusing on developing a system-level solution for stationary storage aimed at electrical networks, the naval industry, and work machines, in contrast to the market of electric vehicles. The interviewees also point out that the regional energy cluster has continued to serve as a platform for innovative initiatives, promoting collaborative work as in previous projects.

“The revolution of EVs that are coming, but as the market has changed dramatically during these years, we saw, and we also learned during all these years that EVs batteries are highly competitive market and the margins for those who produce EVs batteries are very small. So there's a much bigger cake to take in margin sense if you go for ESS for the stationary storage, for grids, if you go for work machines, if you go for naval solutions, and so on”. [A5]

In the second category, concerning *building shared management*, informants acknowledge the significant leadership role of the City's Mayor in the ecosystem. The orchestrating team is widely recognized in the context of the broad experience of its members in various development companies and energy public services in the city. Each member of the orchestration team has strong connections with industries, academia, political actors, and social organizations. Roles have been defined within the team based on individual competencies, and work plans and routines have been established. Additionally, the team has implemented a specific communication strategy with external stakeholders and the general public.

“We have made yearly plans where we think about the actions needed this year, and then we execute them and follow up. Then we have weekly meetings with the GigaVaasa team”. [A5]

The third category refers to *industry-specific contextual integration*, which, contrasting the previous two categories, relates to the formation of the ecosystem within a new industry for regional players currently dominated by major global players in the field of battery manufacturing. Regional players have primarily applied comprehensive benchmarking and targeted efforts to attract international players with battery industry experience and financial resources to invest in the region. These efforts aim to assemble the various components of the ecosystem. These efforts aim to assemble the multiple components of the ecosystem. However, the global economic dynamics regarding the direction of investments have not favored the consolidation of the decisions of international actors, mainly due to more attractive subsidies for investments offered elsewhere and with which Finland cannot compete.

“I would have to say that the Inflation Reduction Act was an important milestone, but not important as a good thing. But it slowed down the development of GigaVaasa, and if you haven't heard about the Inflation Reduction Act, it's governed by the US, and investment aid should be provided to set up factories inside the US to reduce emissions. (...) So, we talk about the billions in subsidies they are bumping into the industry, and, unfortunately, we don't have that kind of possibility in Finland”. [A2]

5. Discussion

This study sheds light on how the ecosystem actors' agency and collaboration practices define the emergence of the early-stage ecosystem. The case study of an emergent public-private ecosystem for battery-based stationary energy storage systems in Finland illustrates the genesis of a process of self-recognition and value discovery over time that leads to the configuration of a new social structure such as an ecosystem (Bourdieu, 2005; McAdam et al., 2019). In this new playground, tensions converge, shaped by trajectories and divergent interests, enabling the understanding of microphenomena and practices within a broader context (Bourdieu, 2005; Jarzabkowski et al., 2007). In this analysis of an ecosystem emergence, the orchestrator, as an agent, acts as a collective individual, embodying the individual but simultaneously endowed with the inertia of the cultural background. The orchestrating team, accompanied by public and private organizations, have created the space of the ecosystem to which they have given a structure, which becomes a field of tensions in which the agents who confront each other to access from a value proposition exchange and in turn, preserve or improve their position in the playground. In this case study, we identified ten categories that serve as mechanisms within the ecosystem, shaping the agency of the orchestrating team. These categories have been assembled into three aggregate dimensions: *proclivity and trajectory, existing tensions, and orchestration's agency developing the ecosystem as a new playground.*

In Figure 4, the diagram depicts the emergence of the ecosystem through the interplay of the aggregate dimensions, where the tensor agents in the playground interact with the orchestration agency. The tensions observed in the case study have been identified as originating from four edges: from *companies within a regional technical cluster in energy*, from *public institutions*, from *potential international partners*, and the tension exerted by the existing *public-private collaboration* in the regional energy context. The forces that govern this structure are based on the individual weight exerted by the agents. In short, agents with greater economic, social, and symbolic capital will generate greater tension and, therefore, have a greater influence on the agency of the orchestrator and on the direction in which the ecosystem is oriented. Existing tensions are mediated by their *historical trajectory and background*, formed by *past experiences, norms, values, regulations, and cultural backgrounds*. Therefore, recognizing their *trajectory and proclivity* will offer valuable information to produce plausible explanations about reactions and movements on the playground (Bourdieu, 2005; McAdam et al., 2019).

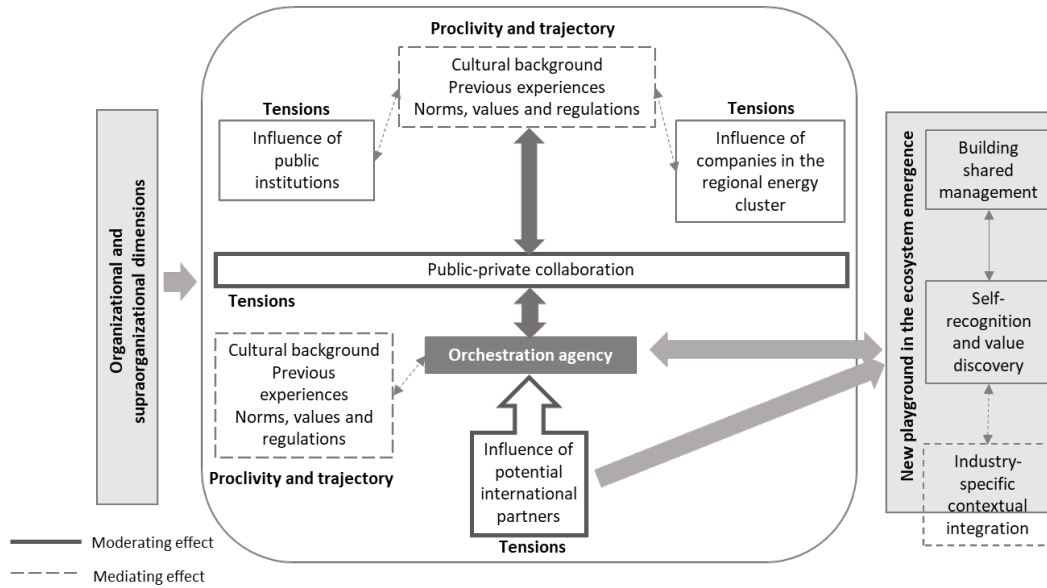


Figure 4. Diagram of the existing agents tensoring in the playground of a public-private ecosystem emergence and the orchestration agency

Among the existing tensions, *public-private collaboration* (PPC) is a moderating agent that affects the strength and direction of the tensions exerted by regional public and private actors. The influence of the PPC lies in the ability to concentrate the volume and weight of the tensions exerted by public organizations and companies in the regional energy cluster at a single point, providing a greater boost to gain a better position in the playground. By concentrating the tensor agents of public organizations and companies, the PPC appears in the playground as a figure of greater weight, whose 'gravity effect' can result in the attraction of other tensor agents, such as international players in the battery industry and the strengthening of the structure of the ecosystem as such. The efficiency of the moderating effect of the PPC lies in harmonizing different incentives of public and private actors in a common setting (Brogaard, 2019b; Pinilla-De La Cruz et al., 2022; Russo-Spena et al., 2020). Here, the orchestrating team's agency is influenced by the intensity of the public-private collaboration (PPC) and other tensions in the playground. The orchestrator team, made up of individuals from the tensor agents of the regional sphere, is also mediated by the trajectory and proclivity of these agents.

Notably, the orchestrator team plays a crucial role in the emergence of the ecosystem, for which it must be able to create a virtual projection of the ecosystem and direct efforts towards its materialization from processes such as *self-recognition and value discovery*, *building shared management*, and ensuring *industry-specific contextual integration* (Thomas, 2022; Thomas et al., 2022). In

particular, contextual integration is built into the emergence process, but at the same time, it has a mediating influence on the ecosystem since it depends on the dynamics of the specific context of the global battery industry. Indeed, the balance of tensions from the regional level may not be sufficient to exert a sufficiently robust structural effect in the global context to produce its leap to the next stage in the emergence; hence, the orchestrating team needs to be able to identify the existing gaps in the types of capital. In this case study, cultural capital encompassing specific technical and technological resources in battery manufacturing appears particularly as a relevant strategic market asset (McAdam et al., 2019). Thus, the uneven distribution of tensions in the playground can restrict the ability of the orchestrator and the other regional agents to maneuver and, therefore, slow down the ecosystem's emergence (Bourdieu, 2005).

Incremental and significant changes drive ecosystem emergence (Thomas et al., 2022). Each change represents an opportunity to improve its position and strengthen the structure or, conversely, to hinder expansion and weaken consistency, depending on how effectively the agents leverage divergent tensions. Using the Bourdiesian perspective as a basis for the historical analysis, we show in Figure 5 the multidimensional function of practices to unveil the mechanisms that underlie the ecosystem as a new structure and that build the process of emergence over time (Bourdieu, 2005). Since the ecosystem's genesis at the end of 2016, with the initial idea fueled by the regional ambition to venture into the field of energy storage, the ecosystem has progressively gained traction and strength. Furthermore, as seen in the model, tensions and proclivity are linked to the current position in the ecosystem, in which singular positive interactions such as public-private collaboration appear. The agency is part of the ecosystem and is bounded by the influence of tensor agents and the load of trajectory inertia (Bourdieu, 2005). However, the agency can generate 'turning points' that have not been forecasted that result in strategic movements for the evolution of the ecosystem (Jarzabkowski et al., 2007). An example of the turning points in this case study occurred from the refusals to the calls for gigafactories and the withdrawal of the first reservation; these events catalyzed a new process of self-recognition and value discovery that gave rise to an adjusted system-level value proposition (Jarzabkowski, 2008). Thus, the process of ecosystem emergence for battery-based stationary energy storage systems on the West Coast of Finland will continue its evolution until it reaches its consolidation due to the effect of the interplay between the agency and the structures in this new playground.

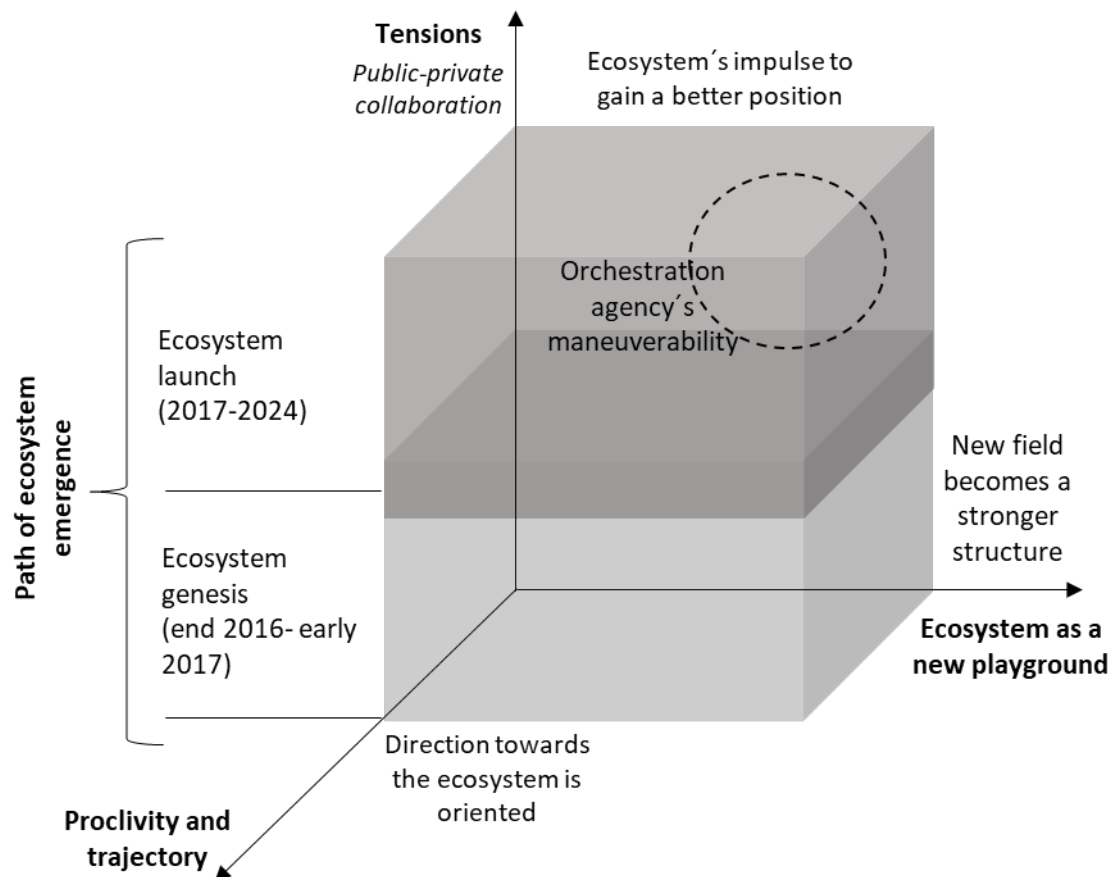


Figure 5. Three-dimensional model of the ecosystem emergence

6. Conclusions

6.1. Theoretical contributions

The study makes several contributions in different fields, such as the literature on public-private collaboration, ecosystems, and Practice Theory. First, the study revealed the critical role of PPC in facilitating the mobilization of the emerging structure of the ecosystem toward a better position in the industry-specific context (Taillard et al., 2016; Thomas et al., 2022). Similarly, this study adds to the literature on PPC by offering evidence of how these bonds are rooted in social structures, particularly related to the high levels of trust (Khalid & Ali, 2017; Malmström & Johansson, 2016). Concerning the contributions to the ecosystem emergence literature, our paper analyzes how different actors, initially lacking alignment structures, collaborate to form a collective identity, new governance

forms, and build contextual integration (Jarzabkowski et al., 2007; Thomas, 2022).

Regarding the contributions to the Practice Theory, we use this heuristic lens to identify the influence of the force exerted by the various types of capital on the tensor agents, as well as the hysteretic loading in the 'habitus' on the orchestrator's agency (Bourdieu, 2005; Gomez, 2015; Richard Whittington, 2010). This exercise of historical analysis facilitated the finding of plausible explanations for the genesis of the ecosystem as a new field and its evolutionary process and changes in the direction of the agents' micro actions (Jarzabkowski et al., 2016).

6.2. Practical implications

Policymakers and practitioners could find valuable insights to better understand the interplay between agency and social structures by studying the process of ecosystem emergence (Halley & Winkler, 2008; Whittington, 2018; Whittington, 2010). Policymakers could use this study as input to guide the transformation of innovation policies for the energy transition that integrate the promotion of the creation of ecosystems as new social structures (Kivimaa, 2023). Additionally, this work could offer valuable insights to identify opportunities for value creation through public-private collaboration.

Practitioners could also find input for enhancing self-recognition actions in public and private organizations that foster internal competencies in diverse types of capital and agility in turning strategic directions when necessary.

6.3. Limitations and future research opportunities

Like any research effort, our study has certain limitations. Here, using a single case study may limit the generalizability of the findings. However, this case proposes crucial elements for the energy transition from the collaborative spectrum in forming new social structures; therefore, the case's decision corresponds to the significant value of the research objectives. Future research could explore (1) how to use social capital in public-private collaboration to enhance the economic capital in emerging ecosystems and 2) how to produce ruptures in trajectories and proclivity to generate turning points in the evolution of ecosystems.

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Appendix A: Interview Questions

Table A1. Interview Questions

Introduction	Description of the purpose of the study and asking about the current interviewee's role
Questions	<ol style="list-style-type: none"> <li>1. How did the idea of the battery-based stationary energy storage initiative come about, and how is it related to the regional energy cluster? <li>2. How has the battery-based stationary energy storage initiative developed over time? <li>3. How do you historically describe the strategic orientation of the battery-based stationary energy storage initiative? <li>4. How has the battery-based stationary energy storage initiative been run? <li>5. How do different actors take on the role of orchestrator? <li>6. How has the teamwork and collaboration been going between the public and private actors of the orchestration team and with other actors in the battery-based stationary energy storage initiative? <li>7. What practices and routines are commonly implemented by the organizing team as a group and individuals representing the various stakeholders within the ecosystem? <li>8. How do these practices come to be accepted and validated by the different actors in the local area? <li>9. How have local institutional, regulatory, and cultural frameworks influenced practices? <li>10. What differentiates the battery-based stationary energy storage initiative from similar initiatives? <li>11. What are the key investments needed in the future? <li>12. What is the history of the battery-based stationary energy storage initiative, and how does it continue?

Appendix B: Supporting quotes

Table B1. Supporting quotes

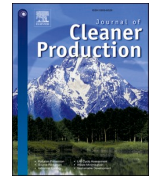
Aggregate dimension and second-order theme	Supporting quotes
Proclivity and trajectory	
Norms, values, and regulations	<p><i>"I would say that this Finnish mentality is that basically you have the trust, and you can only lose it". [B2]</i></p> <p><i>"We are open and transparent. That's our value". [A3]</i></p>
Previous experiences	<p><i>"Well, I mean that kind of failure. It wasn't. We couldn't do anything about it. Yes, it was a company decision to leave the battery manufacturing. I think we learned a lot".[A2]</i></p> <p><i>"Aurora Bothnia is a good example of how the different companies, even though they are competitors in some fields and some businesses, can still nicely collaborate with big projects". [A8]</i></p>
Cultural background	<p><i>"World War Two shaped, I think, many industries profoundly and created various significant innovations, but the Finnish industry did get quite the boost from the war penalties and paying for them that created, I think, a number of industries, and it created a spirit of achieving together". [H4]</i></p> <p><i>"Traditionally, in Ostrobothnia, you are quite good at that because you have had social sanctions on opportunistic behavior. (...) Because overprices would have been remembered for generations that you got rich". [A7]</i></p>
Existing tensions	
Influence of public institutions	<p><i>"Strategically, it is very important to have close cooperation with the leading politicians in Finland, so they understand also from our side how they can help to get the investments to Finland".[A2]</i></p> <p><i>"They are really positive. We have, of course, discussions with them, the Ministry of Economics, and with them, we are discussing future possibilities and state funding possibilities". [A4]</i></p>
Influence of companies in the regional energy cluster	<p><i>"There is a big impact because the EnergyVaasa is like what, well, you know, but it's like 180 companies, like 13,000 experts. So, we have some expertise here. It's very important. I've at least understood now that some of the new companies that have come into the region come here because they know that there is knowledge about the energy industry in our region". [H2]</i></p> <p><i>"It's a loser connection that creates social capital. Since the geographical connections, people know each other, enabling collaboration in other forms now". [H4]</i></p>

Aggregate dimension and second-order theme	Supporting quotes
Public-private collaboration practices	<p><i>“But if you think about how you end up with different structures, so if you and I think that collaboration fundamentally changes the strategic paradigm. So, while companies or organizations used to focus on competing alone at the moment, the value propositions are so complex that collaboration is kind of the let's say, it's almost mandatory”. [H4]</i></p> <p><i>“So, I think this is a really great level, the public-private kind of partnership and doing things together, moving forwards and a really great level”.[H1]</i></p>
Influence of potential international partners	<p><i>“It's important to get started with at least one of these big batteries with the investment decision”. [B1]</i></p> <p><i>“The kind of issue in the battery industry is that China is leading from a technological point of view, in that they have built the kind of competencies and many of the European players they have that they need to learn from the Chinese. They have the factories, and a new kind of battery chemistry is already ready, and in the production and so on”. [A8]</i></p>
	Orchestrator’s agency developing the ecosystem as a new playground
Self-recognition and value discovery	<p><i>“So I think overall now if that they've of this kind of battery factories would come to what I think the big benefit would be that it would it attract people on and competencies to so Finland on the people, but also companies around that business, not only the battery manufacturing companies but everything will cost around that one like engineering companies or R&D companies, etc.”. [B1]</i></p> <p><i>“I see many players in the energy cluster of Vasa that would need this kind of company, like chemical and battery cell manufacturing, but not battery module manufacturing. I mean, we see a need”. [B2]</i></p>
Industry-specific contextual integration	<p><i>“The US response; so the Inflation Reduction Act, of course, had a huge impact on the already, let's say, planned European investments and because this is anyway a new business area”. [A1]</i></p> <p><i>“The biggest difference between if this is happening somewhere else, one point is that we all know that Germany is getting this kind of investment. They are putting a lot of money to the table and from the state and get this kind of investment”. [A4]</i></p>
Building shared management	<p><i>“The project team is led by The Mayor, Tomas Häyry, and then in the project team, we have different persons from, let's say, the city umbrella. (...) So different rules have been picked from the umbrella governed by the City of Vaasa”. [A2]</i></p> <p><i>“I think the team has been almost the same from the beginning, and we are having weekly meetings. We all have different responsibilities in this team”. [A4]</i></p>



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Collaboration towards value creation for end-of-life solar photovoltaic panel in Ghana

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ABSTRACT

This paper identifies value creation strategies and the role of stakeholders in advancing sustainable practices for end-of-life (henceforth EOL) solar photovoltaic panels (solar PV) in Ghana. This is preceded by an overview of the global outlook of sustainable practices for EOL solar PV as well as how these can be promoted in a developing country like Ghana. The framework discusses and promotes efficient collaboration towards value creation by stakeholders in advancing sustainable practices for end-of-life solar PV in Ghana. The methodology centers on an integrative review aimed at identifying the different aspects leading to a value creation framework for EOL solar PV. The paper discusses a hybrid public-private partnership (HPPP), which includes the types of synergy between different actors as well as their clear roles. The core options available to government, businesses and end-users in the value creation includes the provision of a technical solution, improved logistics and innovative business opportunities. The aforementioned options will achieve reduction, reuse, repair and/or recycling, targeted at promoting a unique collaboration between all relevant stakeholders. Furthermore, such options present an opportunity to promote awareness utilizing education in sustainability, thus promoting the need for extending the useful lifecycle of the products.

1. Introduction

Value creation is an essential concept and process that sets a business apart from its competitors, helps in securing long-term customers, and promotes branding. This paper looks at value creation from a new perspective, with a core relationship from the context of public-private partnership (PPP) and a well-designed framework of the roles of stakeholders in PV waste management. Value creation from a PPP perspective focuses on the role required from all stakeholders from government, businesses and households in any given economy (Regenfelder et al., 2017). Furthermore, value creation in this context should be measurable based on realistic targets linked to realistic objectives for a solution-focused action plan (Tsanakas et al., 2020). Value creation in this context does not focus on any short term profitability of the proposed framework to either reduce, reuse, recycle or repair a solar PV panel (Mahmoudi et al., 2019). Rather, value creation seeks to enhance awareness of what the consequence will be if the right proactive measures are not taken now to help mitigate any future e-waste and other supplementary derived waste from solar PV panels (Corwin, 2018;

Regenfelder et al., 2017). Thus, the concept of value creation is on the basis of the role and responsibility of all stakeholders enshrined in a societal policy framework aimed at promoting awareness and enforcing the accountability of stakeholders in a way that helps to uphold the principles for the appropriate management of EOL solar PV panels (Mahmoudi et al., 2019; Tsanakas et al., 2020).

Solar PV power technology has been demonstrated to be a mature technology with a large potential market on a global scale (Song et al., 2020; Xu et al., 2018). The huge deployment of solar PV has contributed to the reduction of prices by around 50% since 2010 (Sharma et al., 2019). Currently, solar PV is adding more capacity than fossil fuels and is positioned as the third renewable energy technology after hydro and wind power (Chowdhury et al., 2020). One of the key factors of solar PV is its contribution to the energy transition towards cleaner and more sustainable energy systems (Domínguez and Geyer, 2019). "EOL" as a term is employed in end-of-life products descriptions, particularly from a supplier' perspective (Ndzibah et al., 2021). Generally, this term refers to the period of time beyond which a product does not officially receive any form of support or after-sales service, gradually making the product

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obsolete (Ndzibah et al., 2021; Salim et al., 2019a). Until recent years, EOL PV panels have been attracting more attention since the first PV installations have already reached the decommissioning stage. Moreover, the EOL of PV panels has become a phenomenon of public interest on a global scale, considering that the rapid spread of solar PV capacity is directly connected to the generation of PV waste (Chowdhury et al., 2020; Su et al., 2019). According to IRENA and IEA-PVPS (2016), PV waste could reach around 20 million tonnes by 2050. PV waste requires the attention of national governments and supply chain stakeholders due to its potential significance for the environment and human health (Corcelli et al., 2018; Guo et al., 2019). Furthermore, proper PV waste management brings considerable environmental benefits. Recycling 185 tons of PV panels affords savings of about 1480–2220 ton CO₂ equivalent (Cucchiella F, D'Adamo I, 2015; Ndzibah et al., 2021). In developing countries in Africa, Latin America and the Middle East, despite the high influx of solar PV installations, there are no apparent initiatives to deal with the phenomenon of EOL PV panels. As stated by Okoroigwe et al. (2020), unless strong action is taken in a timely manner, PV waste will be taken to commercial landfills and incinerators, or manual component removal practices will continue to be applied. Along the same lines, Hansen et al. (2021) argue that in the countries of sub-Saharan Africa electronic waste is taken to landfills, and there is a lack of adequate infrastructure and legislation for PV waste management in this regard. To this may be added the informal, poorly coordinated and decentralized nature of waste management schemes (Hansen et al., 2021). In developing economies, solar PV power and EOL solar PV waste are strongly linked to energy access strategies. The large gap between the supply of and demand for electricity services has driven the creation of innovative opportunities for the adoption of solar PV systems in rural and off-grid areas (Rehman et al., 2017; Sovacool, 2013). By 2014, African countries reached a cumulative solar PV capacity of 1344 MW (IRENA, 2014). According to the Africa Clean Energy Technical Assistance Facility and Coffey International Development Ltd (2019), the implementation of off-grid solar installations has benefited more than 100 million people with improved energy access. In these scenarios, energy access strategies should be implemented under a multidimensional approach, including EOL PV waste management. Since one of the central constraints in developing economies is their limited public budget, it is imperative that public and private actors join with efforts to provide innovative solutions to energy and environmental challenges (Pinilla-De La Cruz et al., 2020; UNU-INRA, 2019). Here, public-private partnerships (PPPs) appear as an alternative that can connect and complement resources and capacities among the different stakeholders (Pinilla-De La Cruz et al., 2021). In particular, in recent years, "hybrid" approaches to PPPs have emerged to enable a diversity of stakeholders to intervene in creating hybrid and innovative business models (Chaurey et al., 2012; Rehman et al., 2017). It is noteworthy that, despite the relevance of the EOL PV waste management phenomenon and its prevalence in developing economies, the literature presents few studies addressing this issue (Tsanakas et al., 2020). Therefore, the primary focus of our study is on value creation for EOL solar PV panels in developing countries through collaboration based on the conceptual framework proposed by Ndzibah et al. (2021). In so doing, we have followed the guidelines for integrative reviews proposed by Cronin and George (2020) in order to answer three research questions:

RQ 1. *How have sustainable practices for EOL PV panels been encouraged on a global scale and specifically in Ghana?*

RQ 2. *What are the value creation propositions for EOL PV panels from a public-private partnership perspective?*

RQ 3. *What are the roles of stakeholders in advancing sustainable practices for EOL PV panels in Ghana?*

Although there is no universal consensus classification of a developing country, according to the database of World Development Indicators provided by the World Bank and its member countries, Ghana is

classified for the fiscal year 2022 as a lower-middle-income economy with a GNI per capita of between \$ 1046 and \$ 4095 (World Bank, 2021). Another factor which has influenced Ghana being recognized as a developing country is its high population growth of 2.21% per year (CIA, 2021), with high rates of unemployment (Manhart et al., 2019), high dependence on the primary sector, especially agriculture, and high dependence on exports of primary unprocessed commodities (Ingco et al., 2001; UN and FAO, 2017).

Ghana is selected here as a case study for two fundamental reasons: (i) its favorable solar radiation due its geographical conditions (average solar irradiation of 4–6.5 kWh/m²/day: (EC Ghana and UNDP, 2015; IRENA, 2015) make it suitable for extensive development of solar PV projects, and (ii) according to the Ghanaian Energy Sector Strategy and Development Plan, the Government of Ghana will focus on "supporting the use of decentralized off-grid alternative technologies (such as solar PV and wind) where they are competitive" (EC Ghana and UNDP, 2015, p. 4). Approximately 30% of the Ghanaian population live in remote and often inaccessible locations where a suitable alternative to provide access to electricity would be isolated grids and mini grids. Currently, the government is testing various initiatives for the dissemination of solar energy systems, including the Solar Lantern Promotion Program (2 million lanterns in remote/off-grid locations), a photovoltaic solar energy installation with 715 kWp and 25 network-connected PV solar systems through private sector initiatives (EC Ghana and UNDP, 2015). Additionally, the Ghana Renewable Energy Master Plan (MoEn Ghana et al., 2019) established among its objectives for the year 2030 that approximately 20% of the electricity generation capacity from renewable energies will come from distributed generation (i.e. solar home systems, solar street lighting systems, mini-grids, etc.). Ghana represents developing economies with, on the one hand, high potential for solar PV capacity, and therefore for generating significant amounts of PV waste in the future, and, on the other hand, logistical challenges due to highly distributed PV installations (ACE TAF and Coffey International Development Ltd, 2019). The rest of the paper is organized as follows: Section 2 outlines the methodological approach. Section 3 details the results and discussion, which includes sustainable practices for PV panels on a global scale and the outlook for these in Ghana, and additionally the issue of value creation for EOL PV panels for Ghana is discussed. Section 4 presents the conclusions of the study.

2. Methodology

This study followed the guidelines for integrative reviews described by Cronin and George (2020) and Torraco (2005). The integrative review makes it possible to gather and synthesize knowledge across different communities of practice (Brown and Duguid, 1991; Cronin and George, 2020). The holistic triangulation of the data provides a better understanding of the phenomenon to produce unique insights and contributions. By following this methodological approach, it was possible to integrate the latest scientific articles exploring EOL PV panels, the data from international environmental agencies related to EOL PV, as well as official reports from public agencies in Ghana. In particular, Cronin and George (2020) recommend the following eight steps for conducting integrative reviews: (i) articulate the topic locally, (ii) find other communities of practices studying the same topic, (iii) bind identifiable communities around a topic, (iv) refine primary findings from each community of practice, (v) abstract the findings into common themes, (vi) explore how the themes relate to each other, (vii) integrate themes into a coherent whole, and (viii) refine and refocus.

First, we identified the EOL solar PV power as the focus of our study. Subsequently, we captured the latest studies on the subject by conducting a systematic search in Elsevier Scopus and Web of Science electronic databases using the search string ((TITLE-ABS-KEY ("solar panel*" OR photovoltaic) AND ("end-of-life" OR "circular economy" OR "extended producer responsibility" OR "product stewardship")) AND (LIMIT-TO (DOCTYPE,"ar") OR LIMIT-TO (DOCTYPE,"re") OR LIMIT-

TO (DOCTYPE,"English")). We retrieved 379 records. After removing duplications, we obtained 335 hits. Those records were screened based on abstracts by assessing their relation to EOL solar PV panels, where 127 records were included in the analysis. Afterwards, given the relevance of collaboration in building a suitable scheme for EOL solar PV panels in developing economies, we conducted one additional systematic search in the Scopus database, using the search string ""hybrid partnership" OR "hybrid public private partnership" to look for articles in English. Here, we obtained 135 hits, including publications from 2001 to 2021. In the screening process, we found four articles that showed a relation to hybrid partnerships in sustainability and innovation. Given the relevance of the phenomenon in the energy, environmental and social dimensions, we included reports from international agencies in renewable energy and complemented the data set with official reports and information in websites published by African and Ghanaian public agencies. In total, our data set encompassed 131 academic studies from the systematic searches, five reports from international agencies, four official reports from public agencies in Africa and Ghana, and information from four websites. After the data set was defined, we proceeded to conduct a thematic synthesis through a holistic triangulation of the data. Initially, we identified constructs and later arranged the commonalities among the data into common themes in order to finally integrate all the findings into a comprehensive summary of global practices for EOL solar PV panels and a proposal for building value creation for EOL solar PV panels through a collaboration strategy for Ghana. In order to promote rigor in conducting this study (Yadav and Desai, 2016; Yadav et al., 2017), we followed the alternative principles for producing systematic reviews proposed by Denyer and Tranfield (2009). Fig. 1 summarizes the research outline.

3. Results and discussion

3.1. Sustainable practices for end-of-life photovoltaic panels on a global scale

Although solar PV panels are considered to be relatively reliable, failures may occur that affect their operation. According to Chowdhury et al. (2020), some manufacturing defects in design or light erosion can affect electricity generation (Chowdhury et al., 2020; Smith and Bogust, 2018). However, most failures occur during the productive stage (Chowdhury et al., 2020; Komoto et al., 2018). The most common failures involve cracks and microscopic failures. Furthermore, other factors that could affect the solar PV operational condition are the degradation of the ethylene vinyl acetate (EVA) anti-reflective layer on the glass, degradation by constant exposure to pollution or by changes in temperature, problems in the connections of both of the cells with other

components of the system, and glass and frame breaks (Chowdhury et al., 2020; Cubukcu and Akanalci, 2020). Once PV panels reach the EOL stage, appropriate management is needed to avoid environmental and health impacts. Improper EOL PV waste disposal can lead to significant negative environmental effects from metals such as cadmium, amongst other materials (Corcelli et al., 2018; Deng et al., 2019). Some potential effects from long exposure to cadmium could be neural diseases, cancer, and kidney dysfunction (Cyrs et al., 2014). At the same time, it should be taken into account that some semiconductors in PV panels offer only a limited supply due to the geopolitical conditions of their reserves (Augustine et al., 2019). Therefore, recycling solar PV waste is a *sine qua non*.

3.1.1. Recycling process

Recycling practices can generate significant economic and environmental benefits by reducing the need for new materials and the cost of new products. When solar PV panels cannot be reused or repaired, they should be recycled (Ndzibah et al., 2021). Presently, different recycling techniques are applied, some with greater development and maturity than others, and the environmental impacts and financial costs can, in turn, have high variability. Commonly, these techniques encompass chemical, thermal, and mechanical processes for delamination and materials recovery (Maani et al., 2020; Song et al., 2020a). Some scholars have made focused their efforts on comparing the possible environmental impacts of various techniques for EOL PV waste management. In particular, the study conducted by Maani et al. (2020) analyzed the management of c-Si and CdTe. The authors found 10 different delamination techniques, of which six are applied to c-Si, and four to CdTe. When comparing the recycling techniques of c-Si with CdTe for delamination, quite similar results were found in relation to the use of thermal and mechanical treatments (Maani et al., 2020). In particular, the c-Si recycling process presented more significant impacts than those of CdTe, given the use of chemical treatments to separate the components (Maani et al., 2020). According to the above mentioned study, recycling methods should aim to recover the most expensive materials with the greatest impact on health and the environment such as tellurium, silicon, aluminium, silver, and copper (Maani et al., 2020). The economic sustainability of photovoltaic waste recycling programs faces important barriers due to high recycling costs and the lack of specific infrastructure for this type of waste (Cucchiella F, D'Adamo I, 2015; D'Adamo I, Miliacca M, Rosa P, 2017). According to Corcelli et al. (2018), based on Global Data. (2012), the value per watt of a recycled module will reach approximately 0.6 US dollars in 2025, with an increase of 1.21 per watt US dollars by 2035.

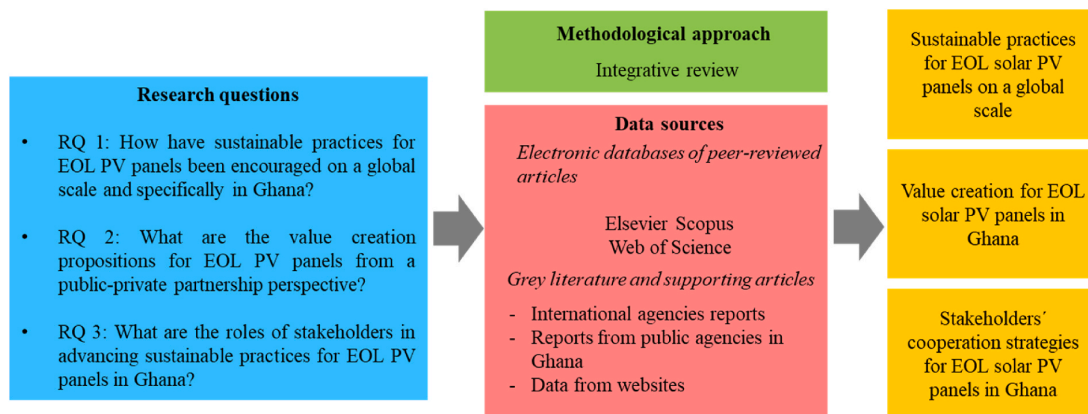


Fig. 1. Research outline.

Table 1
Value creation processes for end-of-life solar photovoltaic panels: reuse, refurbishment, recycling, and recommissioning

Value creation process	Contributions with references
Reusing	<ul style="list-style-type: none"> • Implementation of circular economy based reuse of PV cells (Brenner & Adamovic, 2017; CABRISS, 2021). • PV- waste as a source for raw materials and other valuable components (IRENA & IEA-PVPS, 2016; Tasnia et al., 2018). • The PV waste management focuses towards sustainability among different stakeholders (Azeumo et al., 2019; Mahmoudi et al., 2021). • Integrating social to techno-economic factors in a model provides a more realist scenarios of circularity potential of reusing and recycling PV panels (Walzberg et al., 2021). • At the end of life PV panels can be reuse as recycled materials (Chowdhury et al., 2020; Shin et al., 2017).
Repairing refurbishment	<ul style="list-style-type: none"> • The repair of PV panels can be managed efficiently by coordinating the stakeholders with respect to design, production, collection and recovery of the panels (Besiou & Wassenhove, 2015; Chowdhury et al., 2020). • Value creation goes beyond the economic dimension to involve environmental dimension. Remanufacturing and refurbishment of EOL solar PV panels are included in the sustainable innovation strategy (Regenfelder et al., 2017). • Identification of potential economic benefits of circularity in in different stages of the supply chain of EOL PV (Deng et al., 2020). • The repair and maintenance of end-of-life PV panels can be a useful aspect in the circular economy and can recommend research and development to reduce cost and environmental impact (Heath et al., 2020).
Recycling	<ul style="list-style-type: none"> • Recycle of PV panels after macro and micro analysis of crystalline silicon offers significant financial benefit (Shin et al., 2017). • Recycle of EOL PV modules focuses on the maximum recovery of materials to ensure the optimum benefit (Farrell et al., 2020) • The recycling of PV panels can be improved by the ease-of-disassembly of valuable components. It has significant impacts to reduce environmental impacts (Tao & Yu, 2015; Tasnia et al., 2018). • Challenges for creating value are the current high impact of energy consumption in mechanical treatment in the recycling of EOL photovoltaic panels. The energy resources used for recycling could be higher than the consumption of materials and energy used for construction (Del Pero et al., 2019). • PV wastes if appropriately recycled after decommissioned can bring substantial economic advantages to the renewable energy business (Mahmoudi et al., 2019). • Recycling and management of EOL PV panels as a "second mining" alternative from the consumer countries (Mahmoudi et al., 2019). • Advanced thermal treatment is explored to separate different materials from Silicon PV panels (Fiandra et al., 2019). • Value creation through the use of thermochemical process such as pyrolysis provides an alternative for recycling EOL c-Si PV modules (Farrell et al., 2021). • The value creation and value capture in EOL photovoltaic panels could be increased by maximizing the recovery of silver and copper, as well as recycling the aluminium frame and preserving the purity of the low Fe glass fraction. (Dufflou et al., 2018). • Thermal delamination provides an alternative for removal of polymers crystalline silicon (c-Si) photovoltaic (PV) modules to facilitate materials recovering (Dobra et al., 2021). • Implementation of recycling policies and the use of technologies for data acquisition and treatment offers an alternative for the recycling of thin-film thermal process (Aravelli & Ramavathu, 2021). • Value creation and value capture from EOL PV panels could become a multi-billion USD industry. The challenge is to reduce recycling costs (Vargas et al., 2021). • The application of hexane offers an environmental alternative approach for expanding the lifespan of recycled PV panels (Tembo, 2021). • Value creation through the recovery of valuable materials resourced from waste crystalline-silicon PV module (Si, Ag, Cu, Sn) (W. Chen et al., 2021). • Recycling EOL PV panels to recovery FTO coated glass substrate could be an alternative to take advantage of one of the most expensive components in PV panels (Chowdhury et al., 2021). • Value creation from recycling through the coarse tellurium extraction from photovoltaic waste (H. Chen et al., 2021). • Quantification of material flux recovery from recycling process using mechanical and manual dismantling techniques (Padoan et al., 2021). • A systematic analysis of different material alternatives to recycle dye solar cells (Miettunen & Santasalo-aarnio, 2021).
Recommissioning	<ul style="list-style-type: none"> • Recommissioning is an important decision to give a second-life to PV solar panels decommissioned but show functional conditions. This is one of the alternatives to maximize the benefits across the whole PV value chain (Tsanakas et al., 2020).

3.1.2. Global landscape of end-of-life photovoltaic waste

Currently, most countries do not have specific regulations for PV waste management, which generates inadequate disposal of this waste, with adverse effects on health and the environment (Mathur et al., 2020; Venkatachary et al., 2020). So far, the European Union and a few other countries have set up specific protocols for PV waste (Xu et al., 2018). The fast dissemination of solar PV technology has forced the European Union to create reactive policies to avoid possible impacts from waste generated at the EOL of PV panels (IRENA and IEA-PVPS, 2016; Sander, 2007). In 2012, the European Union issued the Waste Electrical and Electronic Equipment (WEEE) Directive, forcing manufacturers and suppliers of PV panels in the European market to cover the expenses of collection and recycling of EOL PV panels (Chowdhury et al., 2020; Sharma et al., 2019). The WEEE directive includes extended producer responsibility (EPR), whereby producers would collect and recycle at least 85% of their PV panels free of charge (ISE, 2018; Venkatachary et al., 2020). Along with the WEEE directive and national policies, voluntary initiatives to recycle photovoltaic panels have been established among different actors in the solar photovoltaic supply chain. The two most recognized waste recycling entities are First Solar and PV Cycle. First Solar offers recycling services, and uses almost 90% of the glass for reuse and 90% of the semiconductor materials for new modules (Sharma et al., 2019). PV Cycle is a public-private partnership integrated by stakeholders of the solar PV industry and European governments,

which originated as a voluntary initiative for recovery and recycling (Sharma et al., 2019). At the moment, research efforts are shifting towards adopting sustainable strategies that broaden the scope of EOL solar PV panel management (Tsanakas et al., 2020). Here, different stakeholders can be involved to create value and business opportunities not only from recycling activities but also from reusing, repairing/-refurbishment, and recommissioning of solar PV panels. It is worth mentioning that although studies focusing on different forms of value creation from EOL have increased in recent years, the information is very diffuse (Tsanakas et al., 2020). In Table 1 we summarize the main studies focusing on value creation for EOL solar PV panels.

3.2. Outlook for end-of-life solar photovoltaic panels in Ghana

In the particular case of Ghana, the abundance of solar energy resources (in a range of 4–6.5 kWh/m²/day) provides a suitable scenario for the emergence of new solar PV projects (EC Ghana and UNDP, 2015; IRENA, 2015). Ghana, like most countries in Africa, has a beneficial geographical situation, resulting in high solar radiation throughout the year (Aboagye et al., 2021). Notably, one of the key aspects of the expansion of solar PV technology in Ghana is the need to increase access to electricity (EC Ghana and UNDP, 2015). Currently, approximately 17% of the population have no access to electricity (US AID, 2020). Official information on the currently installed capacity of solar PV

panels in Ghana is limited. In fact, there are significant differences regarding the solar PV installed capacity reported by different sources. For example, the Energy Commission reported the figure of 7.99 MW from solar PV by 2015 (EC Ghana and UNDP, 2015, p. 26), whilst non-official sources such as ESI Africa (2021) indicate a solar PV installed capacity of 64 MW. Regarding plans for new solar installations, information is provided by MoEn Ghana et al., (2019), which describes the new Ghana Renewable Energy Master Plan (REMP). The specific objectives of the REMP are enlarge the share of renewable energy in Ghana's energy mix to 1363 MW by 2030. In particular, the goal for solar PV is to reach around 692.5 MW of capacity by 2030 through three investment cycles that include utility scale, distributed PV, standalone PV, solar street lighting, and solar traffic signs, among other applications. Considering the difficulty of finding unified and official information on installed capacity, as well as the additions of new capacity every year since the first installations, estimation of the dismantling or dismantling projections of EOL photovoltaic solar panels is significantly complex. This would require an empirical approach in conjunction with the Government of Ghana and key stakeholders. At the moment, whenever it is possible to collect the data on annual capacities and on photovoltaic solar energy in the market, it is possible to use these in accordance with the model proposed in the IRENA and IEA-PVPS(2016). This model makes it possible to quantify the future flow of waste from photovoltaic panels using the conversion data and the probability of loss during the life cycle of the photovoltaic panel (IRENA and IEA-PVPS, 2016). The model uses two waste flow scenarios (regular loss and anticipated loss) using the Weibull function (IRENA and IEA-PVPS, 2016).

Although Ghana has adopted the Hazardous and Electronic Waste Control and Management Act of 2016, which includes provisions for the management and disposal of hazardous electrical and electronic waste and its related purposes, with guidelines and prohibitions on the import and export of hazardous and other wastes, it does not clearly include the country's informal e-waste sector in the process (Republic of Ghana, 2016, p. 3). Therefore, it is clear that Ghana and most other developing economies urgently need to define a clear 'roadmap' for PV waste management, even though the solar PV industry is relatively young in this particular country. According to the guidelines developed by the Africa Clean Energy Technical Assistance Facility and Coffey International Development Ltd (2019), the most important challenges for PV waste management in African countries are the entrenched informal sector, lack of stakeholder engagement, limited capacity (personal and technical), lack of enforcement, and insufficient data on electronic waste stocks and flows. Taking into account the relevance of cooperation between stakeholders, and the need to develop skills, knowledge and infrastructure, we have proposed a value creation option for EOL PV panels in developing economies like Ghana.

3.3. Value creation from end-of-life solar photovoltaic panels in Ghana

The strategy for the creation of value for EOL solar PV panels proposed for Ghana is derived from the conceptual framework developed by Ndzibah et al. (2021), which takes into account as key factors the technical solutions, logistics and innovative business models for activities, not only limited to recycling, but also including the reuse and repair of EOL solar PV panels. This conceptual framework is aligned with the global sustainability strategies for innovation supported by the environmental, economic and social pillars. The creation of value for EOL solar PV panels is not limited to a single side of the value chain, but integrates multiple associated actors in partnerships and business networks (Regenfelder et al., 2017). This strategy is detached from the traditional business models focused on a single product or service in the first phase of the life cycle, because, on the contrary, the creation of value emerges precisely from the exploration of all the possibilities of taking advantage of the product *per se*, and different components and all possible revenue streams. Therefore, technical-economic knowledge of

the alternatives is essential for the development of value propositions, as well as the identification of the stakeholders at the different levels of the value chain. Furthermore, to ground a sustainable strategy for value creation, it is necessary to identify the skills needed for companies and for the people involved in different processes. Above all, it is crucial to customize the strategy to the reference context, considering the possible opportunities and limitations. Our study focuses on Ghana, a country that is emerging as a consumer of solar PV panels in the medium and long term.

In recent years, some African countries have been structuring policies for electronic waste management focused on preventing the impacts derived from hazardous materials (ACE TAF and Coffey International Development Ltd, 2019). However, most of these political frameworks are not oriented toward value creation from waste; moreover, the specific management of PV waste is not clearly laid out (ACE TAF and Coffey International Development Ltd, 2019; Hansen et al., 2021). Although value creation from EOL solar PV is particularly challenging in developing economies because of budget constraints, the lack of infrastructure for PV waste management, and the logistical complexity of transportation and collection in off-grid PV, it is undeniable that opportunities can be generated from reuse, repair/refurbishment and recycling (ACE TAF and Coffey International Development Ltd, 2019). The option of recycling solar panels after decommissioning activities would allow the unlocking of a wide stock of raw materials and other components (IRENA and IEA-PVPS, 2016; Ndzibah et al., 2021). PV waste can be a source of new revenue streams after appropriate recycling as well as reducing environmental and health impacts (Mahmoudi et al., 2019). In this sense, authors such as Sajjad Mahmoudi et al. (2019) have pointed out the potential of the recovery of materials as the "second mining industry" of the PV value chain. PV waste can lead to new products an opening a room on the global commodity markets. In a scenario of low PV penetration, the value creation and capture could reach around one US\$ billion from the fabrication of approximately 50 million new solar PV panels from the recovered materials (Mahmoudi et al., 2019). However, three fundamental aspects must be taken into account to foster recycling in developing economies: (i) the logistics of collection, transport and transfer; (ii) the financial viability of implementing technical solutions for the recovery of materials; and (iii) the promotion of innovative business opportunities (ACE TAF and Coffey International Development Ltd, 2019; Augustine et al., 2019). Logistics is perhaps one of the most complex aspects to address (ACE TAF and Coffey International Development Ltd, 2019; Hansen et al., 2021; IRENA and IEA-PVPS, 2016). The high dispersion of solar PV installations and the proliferation of medium- and small-scale projects must be taken into account when planning EOL PV waste management (EC Ghana & UNDP, 2015; IRENA, 2015). Here, the costs of collection and transportation can dominate the overall costs of waste management (Augustine et al., 2019; Deng et al., 2019). At the same time, it will be crucial to bring in qualified workers (electricians and roofers), as well as personnel trained in collecting and transporting PV panels in the appropriate conditions (IRENA and IEA-PVPS, 2016). Furthermore, recycling infrastructure is fundamental to achieving the optimal recovery of materials (ACE TAF and Coffey International Development Ltd, 2019).

Currently, most PV waste recycling is carried out in conventional recycling plants, given the moderate amount of waste at the moment and the lack of economic incentives (IRENA and IEA-PVPS, 2016). However, it is desirable that recycling plants dedicated to PV waste be established in the long term, which could increase recovery capacity and maximize revenues, especially because the recycling industry in Ghana has a large proportion made up of the informal economy (ACE TAF and Coffey International Development Ltd, 2019; Manhart et al., 2019). As has been stated by Balde et al. (2017), electronic waste management in Africa is controlled by collectors and recyclers from the informal sector in most countries, recycling infrastructure are either non-existent or extremely limited. One of the examples cited in this report is the site known as "the Agbogbloshie" in Ghana, which has raised international concern.

Therefore, the implementation of synergies to formalize and qualify people and companies in the proper management of PV waste is relevant.

3.3.1. Second life of solar photovoltaic panels through recommissioning

One of the options that should be considered in developing countries like Ghana is the possibility of providing a 'second life' for PV panels by recommissioning, either by being replaced after 25–30 years of use by more efficient equipment, or by being repaired and returned to an operational state. Before any decommissioning process, there should be a testing and assessment of individual units to establish whether the PV panels can be reused, repaired or recycled. PV panels in operational conditions can be given a 'second life' as in new installations in rural communities, educational centers or other third parties. Equipment, the evaluation of which indicates that they are still in operational condition, even with efficiency reductions, will still be very useful to meet the needs of multiple communities to have access to energy services. In this regard, [Tsanakas et al. \(2020\)](#) argue that a significant number of solar PV panels are decommissioned even if they do not show operational failures for reasons related to insurance claims, or the overhauling of solar infrastructure, amongst other technical reasons. These solar PV panels or arrays of PV panels could be considered in the first instance to be recommissioned after a testing and labelling process is completed.

Currently, to our knowledge, no official estimates of PV waste quotas have been published for disposal, recycling or reuse/repair/retrofit/recommissioning. However, Ghana's Renewable Master Plan recognizes that along with increasing solar PV capacity, PV waste will also increase, requiring proper management. The plan considers that REMP resources will support the expansion of the recycling infrastructure and the construction of new locations for the appropriate use and disposal of photovoltaic waste ([MoEn Ghana et al., 2019](#)).

3.3.2. Reuse, repair and refurbishment

Similarly, EOL PV panels found in non-functional conditions should be subjected to a quality inspection to identify the origin of the failure and possible alternatives to fixing it ([ACE TAF and Coffey International Development Ltd, 2019](#); [IRENA and IEA-PVPS, 2016](#)). Value creation in this case includes prolonging the value chain towards a circular economy business, where PV solar panels can be repaired or refurbished ([Kazancoglu and Ozkan-Ozen, 2020](#); [Regenfelder et al., 2017](#)). Repaired PV panels can be sold at a price of about 70% of that of new panels ([IRENA and IEA-PVPS, 2016](#)). As an example, in countries like India, the reuse industry includes maintenance, repair, resale and refurbishment and reassembly, and the remanufacturing of electronic waste ([Corwin, 2018](#), p. 19). The growing market for electronic waste for the above mentioned purposes has enhanced the development of industries specialized in different aspects of the process, producing significant positive impacts in the economy ([Corwin, 2018](#)). With the proliferation of PV installations, the market for second-hand PV panels and components is also increasing in developing economies. The second-hand market industry can provide a new eco-friendly variant for entrepreneurs in Ghana. To achieve a well-developed market for second-hand PV panels, it is necessary to establish technical tests and qualification to guarantee the operating conditions of the PV panels returning to the market ([IRENA and IEA-PVPS, 2016](#); [Tsanakas et al., 2020](#)). At the moment, most repair or refurbishment activities of PV solar panels in developing countries are not performed under formalized or standardized schemes ([Tsanakas et al., 2020](#)). This aspect may hinder business opportunities at the medium and large-scale level. It is difficult to provide an economic estimation for implementing value creation strategies for EOL photovoltaic solar panels in Ghana due to the limited and unreliable information currently available. However, it is important to mention that the REMP contemplates an estimated investment of US \$ 5.6 billion during the period 2019 to 2030. This amount includes investment in infrastructure for the recycling and disposal of photovoltaic waste. Under the plan, successful implementation could generate more

than 200,000 jobs, including those related to recycling ([MoEn Ghana et al., 2019](#)).

3.3.3. Ghana as an importing country of solar photovoltaic panels

The phenomenon of EOL solar PV panels has been overlooked in consumer countries ([Mahmoudi et al., 2019](#)). To foster value creation from EOL PV waste management, it is imperative to take into account that countries such as Ghana are importers of PV panels ([Hansen et al., 2021](#)). Since the production of this equipment takes place outside the country, the recycling costs are, in practice, being assumed by the importing country. Furthermore, the recovered semiconductor materials do not have developed markets within the importing country. This is possibly one of the most complex aspects in promoting value creation from EOL PV panels in countries like Ghana. In addition to the costs of the logistics of collecting highly dispersed PV panels and their treatment, there is the barrier of the commercialization of the components recovered in recycling processes. Ghana, in its role as an importer of PV panels, will not develop a demand for materials that will achieve a positive balance between recycling costs and revenues from the marketing of materials ([Hansen et al., 2021](#)). Viable options for the recycling of EOL PV panels in Ghana would be the establishment of policies to extend responsibility for the costs of recycling and disposal of hazardous materials to the producer ([ACE TAF and Coffey International Development Ltd, 2019](#); [Hansen et al., 2021](#)), whereby companies would be compelled to recycle PV panels after decommissioning. This would require the alignment of the solar PV value chain in Ghana so that the quantities of equipment on the market can be both controlled and the logistics of recovery ensured. Regardless of the strategy for creating and capturing value of EOL PV panels, alignment of the actors in the value chain is required. Regarding the value creation from second life through the recommissioning, reusing, repairing, refurbishment or recycling of EOL solar PV panels, it is imperative to build collaboration networks among stakeholders of the whole value chain ([Regenfelder et al., 2017](#)).

3.3.4. Public-private partnerships: stakeholders' collaboration strategies

Synergies among stakeholders from the solar PV industry and the waste management sector are crucial for an effective EOL PV waste management system ([Hansen et al., 2021](#); [IRENA and IEA-PVPS, 2016](#)). Partnerships in the global landscape of PV waste management indicate some successful examples, such as PV CYCLE, but more evidence is needed related to the formation and consolidation of cooperation between the PV solar industry and waste management. Similarly, some recent studies present public-private partnerships as a possible alternative to encourage both the public and private sectors to assume and share responsibilities in the management of EOL photovoltaic solar panels and the creation of value ([Khawaja et al., 2022](#)). The first step in creating a collaborative strategy, for example public-private partnerships, is to identify groups of stakeholders in the solar PV industry. Information from official agencies in Ghana ([EC Ghana and UNDP, 2015](#); [MoEn Ghana et al., 2019](#)) indicates five groups: (i) public agencies in energy issues, (ii) actors in the solar PV industry, (iii) financial institutions, (iv) end-users, and (v) research and educational institutions ([Fig. 2](#)). Since the guidelines for electronic waste in Ghana do not include specific norms for PV waste management ([EPA, 2018](#)), there are no visible synergies between the solar PV industry and the waste management sector.

Here it would be relevant to mention that the ownership of the major on-grid solar PV installations in 2015 are related to the Volta River Authority (2500 kW), Noguchi Memorial Institute for Medical Research (715 kW), Trade Works Company Ltd (10 kW) and the Energy Commission (4.25 kW) ([EC Ghana and UNDP, 2015](#), p. 26). Additionally, there is also a significant presence of private companies in solar power installations: for example, in private office buildings and private residences, and also there are more than 90 installations in rural communities ([EC Ghana and UNDP, 2015](#)). Along with these stakeholders, there is also international coordination with financial institutions such as

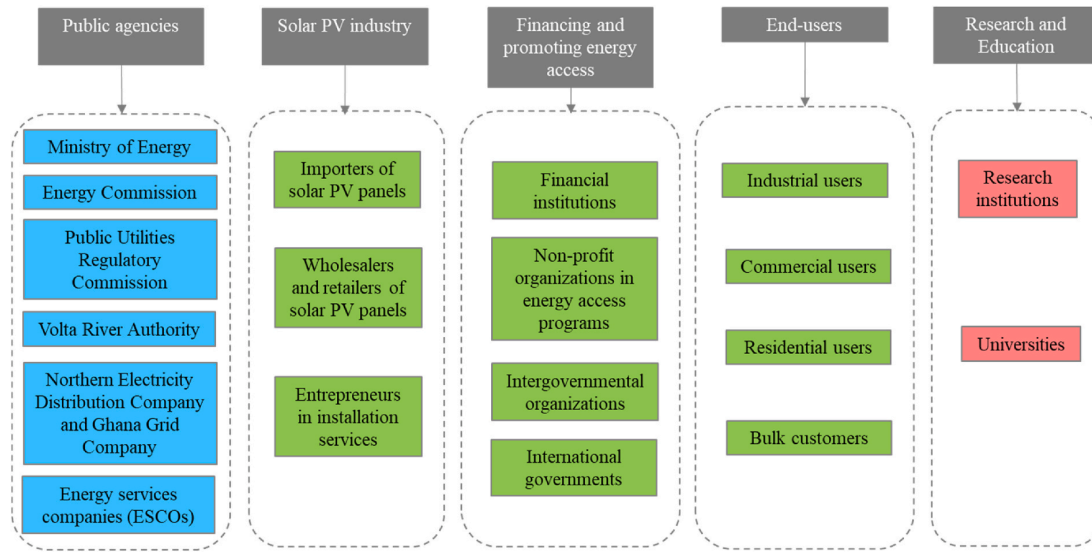


Fig. 2. Stakeholder map of the solar photovoltaic industry in Ghana.

multi-development banks, research institutions, non-profit organizations, intergovernmental organizations and international governments to support actions aimed at changing to renewable sources in Ghana. Some examples are the African Development Bank, World Bank, European Union, United Nations, Agence Française de Développement, Dutch Ministry of Foreign Affairs, German Federal Ministry for Economic Cooperation and Development, Norwegian Ministry of Foreign Affairs, Australian Agency for International Development, UK Department for International Development, and Swiss Agency for Development and Cooperation (EC Ghana and UNDP, 2015, p. 26).

To elucidate the path to building solid collaboration in PV waste

management, we propose a new map of stakeholders based on a systemic approach (Fig. 3). Here, stakeholders are classified into three levels: (i) the strategic level, which includes policymakers, regulators and legislators in Ghana (IRENA, 2015; MoEn Ghana et al., 2019); (ii) the operational level, encompassing stakeholders such as those participating in current solar PV projects (upstream stakeholders), end-users, and those actors who create value from PV waste (downstream stakeholders); and finally, (iii) the supporting level, including institutions related to research and development and to education, as well as consultants and civil organizations. This map locates new actors that can intervene in the energy arena by offering services related to repair,

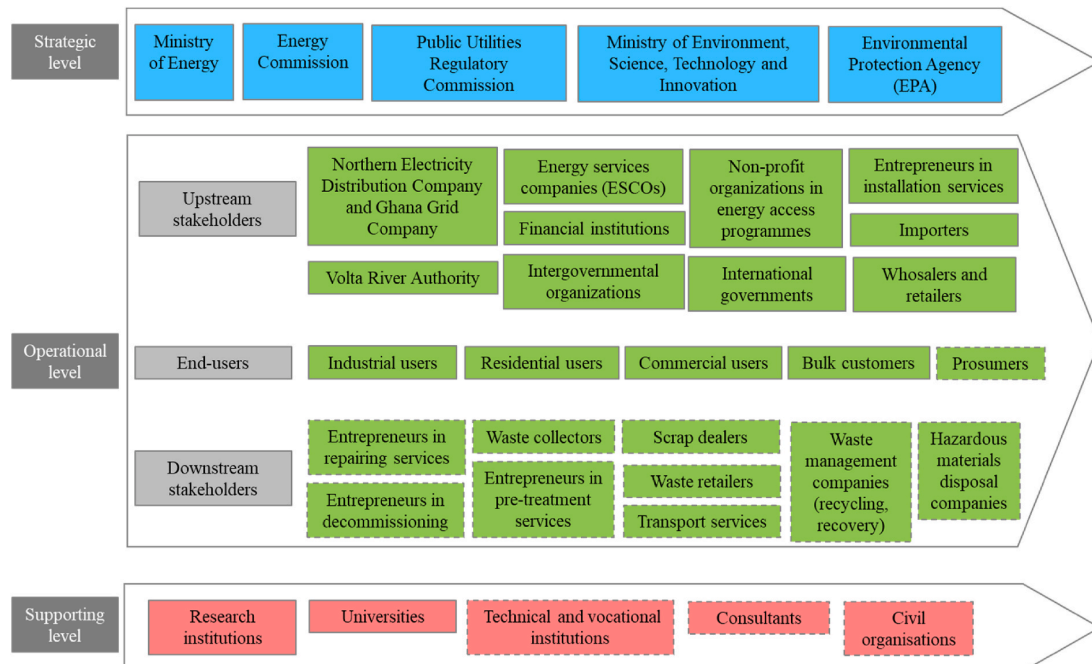


Fig. 3. Stakeholder map adapted to solar end-of-life solar photovoltaic panels management for Ghana.

installation, recycling, transport, storage, and consulting in EOL PV management, as well as users who can become "prosumers" in the medium term: that is, producers and consumers at the same time.

The collaboration strategy for the Ghanaian context should consider the possible barriers, drivers and enablers. Since 2011, the Ghana Ministry of Finance initiated a national policy on PPPs for the development of infrastructure and services projects (EC Ghana and UNDP, 2015; MoEn Ghana et al., 2019). At the moment, PPPs have proven to be a suitable option for thermal power plant projects in Ghana. At the same time, PV solar power in Ghana and in other developing economies is characterized by decentralized, off-grid, rural use, in large proportion in smaller-scale projects, where conventional cooperation approaches can be highly limiting (EC Ghana and UNDP, 2015; IRENA, 2015). In fact, PV systems and off-grid solar PV have very specific characteristics for cooperation initiatives in PV waste management, such as the great variety of stakeholders in the value chain (ACE TAF and Coffey International Development Ltd, 2019). Taking into account the complexity of addressing collaboration between cross-sectoral stakeholders for a 'meta-problem' such as the implementation of a sustainable innovation strategy and value creation for EOL solar PV panels, we found a basis in the application of the concept of 'hybrid public-private partnerships' (HPPPs) (Ungureanu et al., 2018; Vikkelsø et al., 2021). According to Ungureanu et al. (2018) and Zhu and Sun (2020), hybrid partnerships encompass a broad assortment of organizational arrangements between cross-sectoral stakeholders, combining resources for sustainable business. Hybrid partnerships should be designed according to the specific context because they comprise diverse goals, values and institutional logics (Nel, 2018; Vikkelsø et al., 2021). Based on a HPPP approach, we propose to build cooperation among stakeholders at the strategic level, the supporting level, and the operational level to achieve a suitable EOL PV waste management system. For instance, HPPPs can be built by public agencies with upstream stakeholders such as retailers, importers and ESCOs, and with downstream stakeholders such as entrepreneurs in repairing, decommissioning, pre-treatment, transport and waste management services. These HPPPs can assist in compliance with policies of extended producer/supplier responsibility to undertake PV waste management (ACE TAF and Coffey International Development Ltd, 2019; IRENA and IEA-PVPS, 2016). One of the most important challenges of the HPPPs for PV waste management will be financing the infrastructure and developing the technical and business competencies in the downstream stakeholders (Manhart et al., 2019). Overall, building new HPPPs should start with a clear definition of their possible revenue stream(s) and cost(s), identification of possible risks, and appropriate mechanisms for ensuring transparency, commitment and accountability. The financial viability of EOL PV waste management depends not only on the development of the national value chain (Hansen et al., 2021), but also on the interaction with international actors (Hansen et al., 2021). Therefore, simultaneously with the consolidation of HPPPs in the national value chain of Ghana, work should also be done in cooperation with international actors, such as PV panel producers, international dealers and suppliers in commodity markets, governments and other associated international organizations. Stakeholders at the strategic level of the Ghana national value chain should work on building HPPPs with international governments from where the PV panels are mainly imported. These alliances will help to make it easier for producers and suppliers to assume the extended responsibility of the producer in the collection and management of EOL PV waste. Furthermore, strengthening synergies with international actors could facilitate the transfer of knowledge to Ghana on emerging technologies to create value from recycling, repair, refurbishing, and recommissioning of EOL solar PV panels, as well as research and development and education and training activities.

3.3.5. Collaboration in transferring knowledge: a platform for education in sustainability

As mentioned before, one of the most important barriers in the

implementation of a sustainable PV waste management system at a global level is the lack of technical and business capacities in PV waste management (IRENA & IEA-PVPS, 2016). According to Tsanakas et al. (2020), the activities related to reuse, repair and refurbishment of EOL solar PV panels are currently developed under informal or non-standardized procedures. The case of Ghana deserves particular attention due to its high potential in the solar industry, and, at the same time, informal economy in the waste management sector (ACE TAF and Coffey International Development Ltd, 2019; Hansen et al., 2021). Therefore, it is essential to create an educational platform for capacity-building. The role of this platform is documenting the needs in terms of technical competencies as well as business, management and marketing competencies, and developing suitable programs to support the EOL PV waste management system (EPA, 2018; Salim et al., 2019b) (Fig 5). The platform should provide certified programs to prepare citizens to meet the requirements of PV waste management in cooperation with stakeholders in the value chain (EC Ghana and UNDP, 2015; Salim et al., 2019b). To establish this platform requires the agreement between different stakeholders to determine the demand for people both in the upstream and downstream side and the skills required in each case (Fig. 4). It is necessary to liaise with the national government to determine the needs for skills and demand. The academy needs to prepare programs according to the needs of the upstream and downstream stakeholders in the value chain. The establishment of HPPPs between stakeholders will provide competent personnel to carry out activities aimed at value creation and the adequate disposal of EOL PV panels, and additionally, it will foster the expansion of the renewable energy industry in Ghana. Moreover, the consolidation of this platform will contribute to compliance with national policies and international norms in solar PV waste management, and also with the reduction of CO₂ emissions and acknowledgement of the significance of the environmental and health aspects associated with PV waste.

3.4. Discussion of key insights from the research work

This study offers an innovative proposal on value creation for EOL solar PV panels. Our research work integrates data from the most relevant and up-to-date studies and official reports. This phenomenon has been approached using three research questions. The first asks *how have sustainable practices for EOL PV panels been encouraged on a global scale, and specifically in Ghana?* At a global level, although there is concern about the need to deal with the PV waste problem, only the European Union has implemented a specific regulation for PV waste management. The European Union has incorporated PV waste in its Waste Electrical and Electronic Equipment (WEEE) Directive, which involves specific targets in terms of collection, recovery and recycling. This directive also introduces the principle of extended producer responsibility for PV panel producers participating in the EU market. The proper management of hazardous materials contained in PV waste is encouraged, as well as the exploitation of business opportunities from the recovery of valuable materials. Several voluntary initiatives of public-private partnerships have shown positive results in facilitating compliance with extended producer responsibility and material recovery. However, it is necessary to extend cooperation networks among stakeholders from the solar PV industry, public agencies and the waste management sector. Additionally, reliable data is required regarding the number of solar panels that enter the market at the level of each country, which would serve as the basis for designing adequate regulatory instruments (IRENA and IEA-PVPS, 2016). In particular, this is a barrier for developing economies, where it would be necessary to implement mechanisms to unify the data referring to PV panels that enter the market and to those that reach the decommissioning stage. The second part of the same question focuses on *how to encourage or promote sustainable practices for EOL PV panels in a developing economy like Ghana.* In Ghana, as in most developing economies, the challenge of implementing a robust sustainable PV waste management system is paramount. The proposal is

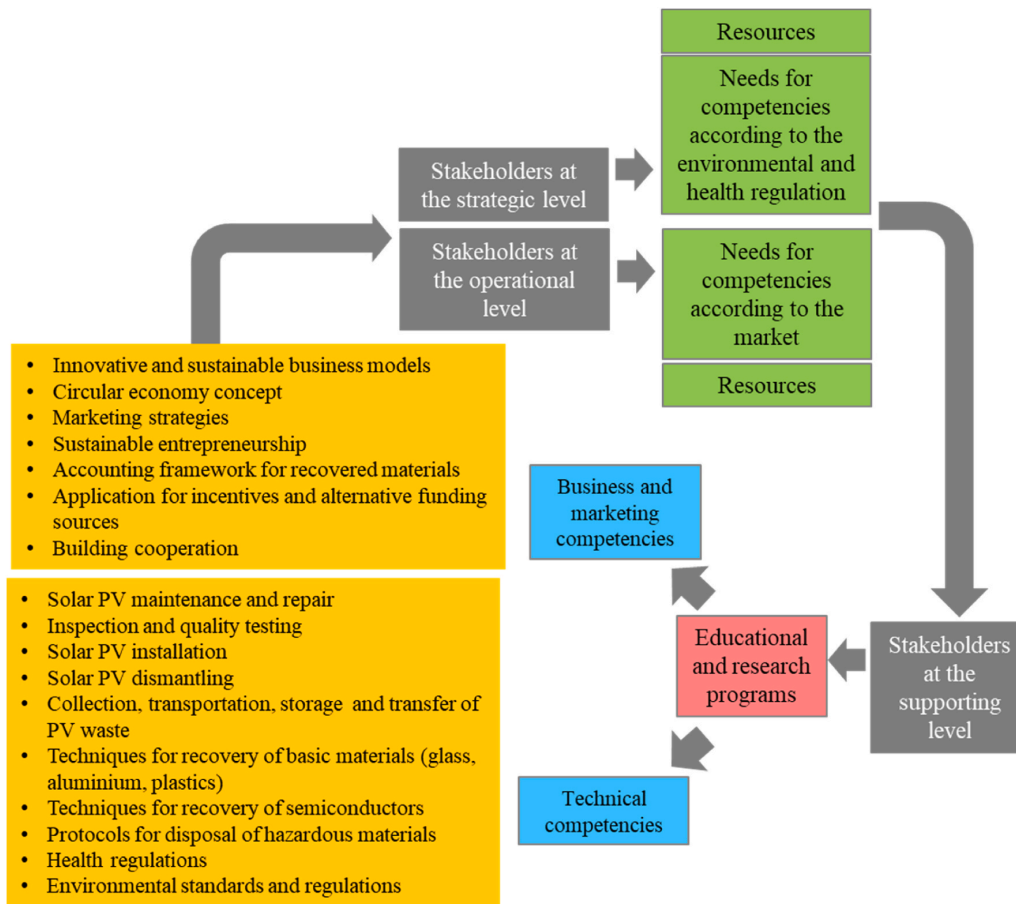


Fig. 4. Cyclical scheme of the technical, business and marketing competencies to address in a platform for education in sustainability and the stakeholders at the strategic, operational and supporting level.

based on three factors according the study conducted by Ndzibah et al. (2021): (i) exploration and strengthening the value creation from PV waste in terms of reuse, repair/refurbishment, recommissioning and recycling; (ii) building hybrid partnerships among stakeholders at the strategic, operational and supporting levels; and (iii) the creation of a platform for capacity-building. These factors must be supported by an adequate regulatory and financial framework. Therefore, it will be necessary to focus work at a strategic level not only on designing policies and regulation, but also on the appropriate incentives to motivate stakeholders to actively participate in PV waste management. Additionally, intensive work is needed to develop innovative business models, reducing the risk aversion of stakeholders in a nascent industry and ensuring the economic sustainability of the system. Building sustainable EOL PV waste management in developing economies also involves high up-front costs in infrastructure, personal training, and operation costs. Moreover, the emerging markets for PV by-products and second-hand PV panels may not provide the expected economic returns in the short and medium term. Governmental support is needed to address the challenge of applying the principle of extended producer responsibility (EPR) to leverage the cost of PV waste management. The second research question discusses the value creation propositions for EOL PV panels from a public-private partnership perspective, and the proposal

involves identifying the stakeholders in the whole value chain, considering the complexity of HPPPs from their multiplicity of actors. Additionally, our study presents the relevant role of stakeholders in the strategic, operational and supporting levels of the value chain, where their core responsibilities are clearly beyond politicizing waste management. In addition, despite budget constraints, inadequate infrastructure, as well as an ongoing logistical complexities there are opportunities to promote the reuse, repair, recommissioning and recycling of EOL PV panels. Furthermore, in the context of developing countries and specifically Ghana, the basis of encouraging such value creation includes a clear protocol to ascertain: (i) the logistics of collection, transport and transfer; (ii) the financial viability of implementing technical solutions for the recovery of materials; and (iii) the promotion of innovative business opportunities. A constructive synergy among stakeholders from the solar PV industry and waste management sector will strengthen a better value creation process. The third research question related to the roles of stakeholders in advancing sustainable practices for EOL PV panels in Ghana. We present a map of current stakeholders of the PV industry as a baseline. Additionally, we propose a new map, where stakeholders are classified according to their role in the EOL PV waste management system. The creation of synergies among those stakeholders would be crucial for the success of PV waste

management. However, cooperation depends largely on a solid institutional framework for ensuring the principles of transparency, accountability, power balance and commitment in hybrid partnerships. Once PV waste management is established, benefits can be obtained from the three dimensions of sustainability, namely the environmental, social and economic dimensions (Ndzibah et al., 2021; Salim et al., 2019a). The incorporation of the circular economy concept can help in reducing GHG emissions and the use of landfill for PV waste disposal as well to the proper disposal of hazardous materials (Ndzibah et al., 2021; Salim et al., 2019a). In the social sphere, there are relevant opportunities, such as the creation of new jobs, new sustainable entrepreneurship, and enhancing cooperation and participation of social actors in the EOL PV waste management system (Ndzibah et al., 2021; Salim et al., 2019a). Regarding economic benefits, the value creation from PV waste can stimulate the economy through new ventures, the development of new markets and technology transfer. It should be noted that this article does not intend to rule out the existence of uncertainty about the implementation of different strategies for the creation of value of EOL solar PV panels in Ghana (i.e. waste volume uncertainty, material uncertainty, demand for recovered material uncertainty, etc.) (Besiou and Wassenhove, 2015), but rather to expose the technical, logistical and social aspects involved. As mentioned above, international experience indicates the relevance of country-level strategies based on value chain alignment and collaboration among stakeholders, and strong policies related to the responsibility of producers, importers, and users among involved stakeholders. Additionally, support should be given for research and development to create internal infrastructure and to take advantage of the opportunities of EOL solar PV panels after decommissioning. Therefore, it is undeniable that one of the critical steps towards reducing risk will be the implementation of policies and associated regulation and incentives for managing EOL solar PV panels in Ghana.

4. Conclusions

This study provides a contemporary viewpoint on PV waste management on a global scale based on the most salient studies (Salim et al., 2019a; Song et al., 2020). But the central goal is to approach this phenomenon in developing economies, in particular in the context of Ghana. Our study puts emphasis on the value creation of EOL PV panels for developing economies, using Ghana as a practical example. The study thus offers a comprehensive outlook on EOL solar PV panels on three fronts, namely the exploration of value creation, building HPPPs among stakeholders, and collaboration strategy for knowledge transfer through an education platform. Particularly regarding building hybrid partnerships, this study provides a map of current stakeholders and a roadmap with all the stakeholders of the supply chain, organised at the strategic, operational and supporting levels. Furthermore, the paper provides information regarding the technical, business and marketing competencies needing to be addressed in a platform for education in sustainability. Finally, our study highlights the research area focus for further studies.

4.1. Future prospects

Efforts in future research work to structure and implement strategies oriented towards value creation and value capture through collaboration of EOL PV panels in developing countries should focus on:

- A review of results of international experiences in programs of extended producer responsibility, reverse logistics, emerging recycling technologies and public-private partnerships to structure

strategies oriented to the closed cycle and the creation of value and the capture of value of EOL solar PV panels;

- Focusing research efforts on building extended producer responsibility schemes, in which the network of services and sales at different levels (national and international) is used to collect the EOL solar PV panels (Yu and Tong, 2021);
- Structuring of voluntary participation schemes in collaboration programs that generate synergy between the actors in the value chain, and whose results contribute to the development of adequate regulation and incentives (Besiou and Wassenhove, 2015);
- Focusing research efforts on the potential market for equipment and materials recovered from EOL photovoltaic solar panels leading to reduced uncertainty for stakeholders;
- Developing information systems related to photovoltaic solar panels in the market that provide realistic projections on the amounts of photovoltaic waste in Ghana;
- Building an EOL PV waste management regulatory framework for developing economies that focuses on value creation from PV waste, builds cooperation networks and structures a platform for education in sustainability.
- The creation of innovative business models that reduce the risk aversion of stakeholders in a nascent industry that guarantee the economic sustainability of the system.

4.2. Managerial implications

The present study is not limited to summarizing the existing literature. Compared to previous studies on EOL PV waste, in addition to providing an outlook on the world landscape of PV waste management, our study also proposes a value creation process for building EOL PV waste management systems in developing economies. The research outcomes of our work include (i) an identification of value creation strategies for Ghana, (ii) a stakeholder roadmap for building PV waste management partnerships in developing economies and specifically in Ghana, and (iii) information regarding the technical, business and marketing competencies needed to be addressed in a platform for education in sustainability.

Concerning the managerial implications and recommendations for policy-makers, our study provides a synthesis of the key factors in PV waste management in a global outlook and in the context of developing economies. Practitioners can find useful information regarding their possible participation and articulation in the construction of PV waste management, in addition to the possibilities of value creation from waste. Policy-makers will find a roadmap for working on strategic aspects such as the building of a regulatory framework aimed at promoting the attempt not only to reduce the environmental and health impacts of waste, but also to create value, promote cooperation, and energize the economy.

CRediT authorship contribution statement

Emmanuel Ndzibah: Conceptualization, Methodology, Formal analysis, Writing – original draft, Writing – review & editing. **Giovanna Andrea Pinilla-De La Cruz:** Conceptualization, Methodology, Formal analysis, Writing – original draft, Data curation, Writing – review & editing. **Ahm Shamsuzzoha:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix 1

Table A1
Table of Abbreviations/Nomenclatures

Acronym	Full text
EOL	End-of-life
PV	Photovoltaic
HPPP	Hybrid public-private partnership
PPP	Public-private partnership
GNI	Gross national income
EVA	Ethylene vinyl acetate
c-Si	Crystalline silicon
CdTe	Cadmium telluride
WEEE	Waste Electrical and Electronic Equipment
EPR	Extended producer responsibility
REMP	Ghana Renewable Energy Master Plan
CO ₂	Carbon dioxide
EU	European Union
GHG	Greenhouse gas
kW	Kilowatt
MW	Megawatt
UK	United Kingdom
kWp	Kilowatt Peak
ESCO	Energy service company

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