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From use cases to business cases: I-GReta use cases portfolio analysis from innovation management and digital entrepreneurship models perspectives

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Abstract

This study provides a detailed exploration of how innovation management and digital entrepreneurship models can help transform technical use cases in smart grid contexts into viable business cases, thereby bridging the gap between technical potential and market application in the field of energy informatics. It focuses on the I-GReta project Use Cases (UCs). The study employs methodologies like Use Case Analysis, Portfolio Mapping of Innovation Level, Innovation Readiness Level, and the Tech Solution Business Model Canvas (TSBMC) to analyse and transition from technical use cases to viable business cases. This approach aligns technological solutions with market demands and regulatory frameworks, leveraging digital entrepreneurship models to navigate market challenges and foster energy management, sustainability, and digitalization.

Keywords: Smart grid, Use case, Business case, Digital entrepreneurship models

Introduction

The global shift towards renewable energy sources, driven by the urgency to mitigate climate change and the depletion of fossil fuels, leads to a growing need for energy systems that are not only flexible but also possess substantial energy storage capabilities (Gielen et al. 2019). As renewable sources like solar and wind are inherently intermittent, the ability to store energy during peak production times and release it on demand is critical to maintaining grid stability and ensuring a consistent energy supply (Denholm and Mai 2019). This transition is further motivated by the aim to enhance energy security, reduce greenhouse gas emissions, and foster economic growth through sustainable energy industries (Jacobson et al. 2017). The development of such flexible energy systems is pivotal in supporting the integration of renewables into the existing infrastructure, making storage technologies and smart grid solutions essential components of the future energy landscape (Burrett et al. 2009). Aligning the technical and functional aspects of these systems with their business cases is paramount, ensuring that the market alignment complements the technical feasibility, thus enabling scalable, economically sustainable solutions that address market needs and regulatory compliance (Gregory 2015). This strategic alignment underpins the successful integration of renewable energy into the grid, leveraging technical innovations to meet real-world demand and supporting the broader goals of energy policy and economic development (Kober et al. 2020).

The selection of the I-GReta project for a Use Cases portfolio analysis from the perspectives of innovation management and digital entrepreneurship was motivated by its unique positioning at the intersection of advanced energy technologies and market-oriented solutions (I-GReta website 2023). I-GReta as a project focuses on smart grid and renewable energy innovation which results in a rich and complex array of use cases. The I-GReta project aims to develop strategies for the planning and operation of flexible energy systems, utilizing storage capacities and integrating a high proportion of renewable energy sources into regional and local power grids community. This integration involves demand flexibility, building-level forecasting, and large-scale optimization for controlling electrical, heating, and cooling consumption. The project envisions creating a digitalized and decentralized energy system, connecting trial sites across four countries through an ICT platform that incorporates FIWARE components. FIWARE is an open-source initiative that aims to provide a universal set of standards for developing smart applications in various sectors (FIWARE website 2023). It is designed to ease the development of smart solutions by offering a curated framework of cloud-computing components that can be assembled like building blocks in a construction set. FIWARE's mission is to drive the adoption of open standards that ease the development of smart applications in multiple vertical sectors. I-GReta's key stakeholders are occupants, building owners, and energy system operators, who are invited to actively participate in a Virtual Smart Grid (VSG) facilitated by this platform. One of the research dimensions is the trading of storage capacities through the platform, with individual storage solutions offering significant value and impact at a local level. This setup presents an opportunity for exploring various digital entrepreneurship models, particularly in the domain of energy trading, storage management, and energy informatics.

The integration of digital entrepreneurship models serves as an intermediary step in transitioning from use case development to business case realization, ensuring that the technological advancements are not only technically robust but also primed for market acceptance and success. This alignment is critical in bridging the gap between innovation and market adoption, providing a framework within which technologies can be evaluated against their commercial potential and market fit. The analysis of digital entrepreneurship models offers insights into potential revenue streams, business scalability, and user adoption strategies, thereby enhancing the value proposition of the use cases to stakeholders and investors. Including this analysis ensures that R&D initiatives are designed with a clear understanding of the market dynamics and customer needs, ultimately fostering a smoother transition to viable business cases. This approach is underpinned by literature that emphasizes the importance of integrating market analysis in the early stages of technological development, such as the work of Chesbrough on open innovation (Chesbrough 2003) and the business model canvas by Osterwalder and Pigneur (2010). Both studies are instrumental in mapping out the business potential of new technologies.

The research question of this study is "What role do innovation management and digital entrepreneurship models play in enhancing the development of business cases from use cases in the I-GReta R&D portfolio?". It centres on understanding the transformative impact of strategic innovation and digital business strategies on the progression from technical use cases to commercially viable business cases within the smart grid context. The research objectives are multi-faceted:

- *Mapping Use Cases:* To map out the I-GReta UCs portfolio, ensuring the alignment of technological innovations with the structural requirements of smart grid architectures.
- *Conducting a Portfolio Analysis for Innovation Potential:* Conduct I-GReta UCs portfolio analysis, as informed by (Vandaele and Decouttere 2013), to assess the innovation potential of I-GReta UCs from both technological and market perspectives.
- *Evaluating Innovation Readiness Levels:* To evaluate the Technology Readiness Level (TRL), Market Readiness Level (MRL), and Regulatory Readiness Level (RRL) of each use case, pre-estimating their maturity and market viability.
- *Creating a Tech Solution Business Model Canvas:* To create and utilize a tailored Tech Solution Business Model Canvas (TSBMC) for I-GReta, analysing solution functionality, infrastructure, security, value proposition, and stakeholders.
- *Proposing Digital Entrepreneurship Models:* Based on the intersection of market and technology analysis, propose relevant digital entrepreneurship models and specific business cases for each use case in the I-GReta portfolio.

Through these objectives, the study seeks to illuminate how innovative management practices and digital entrepreneurship can effectively bridge the gap between the technical potential of smart grid solutions and their practical market applications.

To effectively prioritize project activities within the I-GReta initiative, consortium members have decided to underpin all upcoming technical and user-focused developments with a suite of well-defined Use Cases (UCs). These use cases are tailored to the specific needs of the partner organizations overseeing field trials in Austria, Romania, Sweden, and Germany. Collectively, the project has documented 13 use cases within the Smart Grid UCs Repository, conforming to the IEC 62559-2:2015 standard (Kuchenbuch et al. 2023).

Table 1 lists various UCs along with their field trial locations, spanning Austria, Romania, Sweden, and Germany. Use cases like "Flexible Charging Tariffs" and "Smart Home" originate from Austria, focusing on dynamic pricing and home automation, respectively. Romania's use cases involve investment strategies and optimization of prosumer operations, while Sweden's use cases emphasize building energy management and solar energy utilization. Germany's use cases include power shifting and sector coupling, demonstrating the project's comprehensive approach to enhancing energy efficiency and integration across different levels of the energy supply chain. The initial phase of the project entails gathering an array of potential use cases, encompassing both thermal and electrical flexibilities, as depicted in Fig. 1. These are subsequently categorized into three distinct sectors: Building, Community, and Public Energy System. The Building sector focuses on flexibilities within a structure's thermal or electrical system. The Community sector

Table 1 I-GReta use cases list

Field trial location	Use case ID	Name of use case
Austria	AT_UC1	Flexible charging tariffs
	AT_UC2	Smart Home
	AT_UC3	Bidirectional charging
Romania	RO_UC1	Deferral investment within student campus
	RO_UC2	Optimal planning for a prosumer investment to extend its flexibilities
	RO_UC3	Optimal operation of prosumers with flexibilities (generation, storage, loads)
	RO_UC4	Optimal operation of prosumers within an energy community
Sweden	CHA_UC1	Flexible usage of solar energy
	CHA_UC2	Energy management with multiple flexible sources
	CHA_UC3	Integration of multiple energy storage systems
Germany	DE_UC1	Shift of power consumption/production in time
	DE_UC2	Coupling of electricity and heat sectors
	DE_UC3	Flexibility market

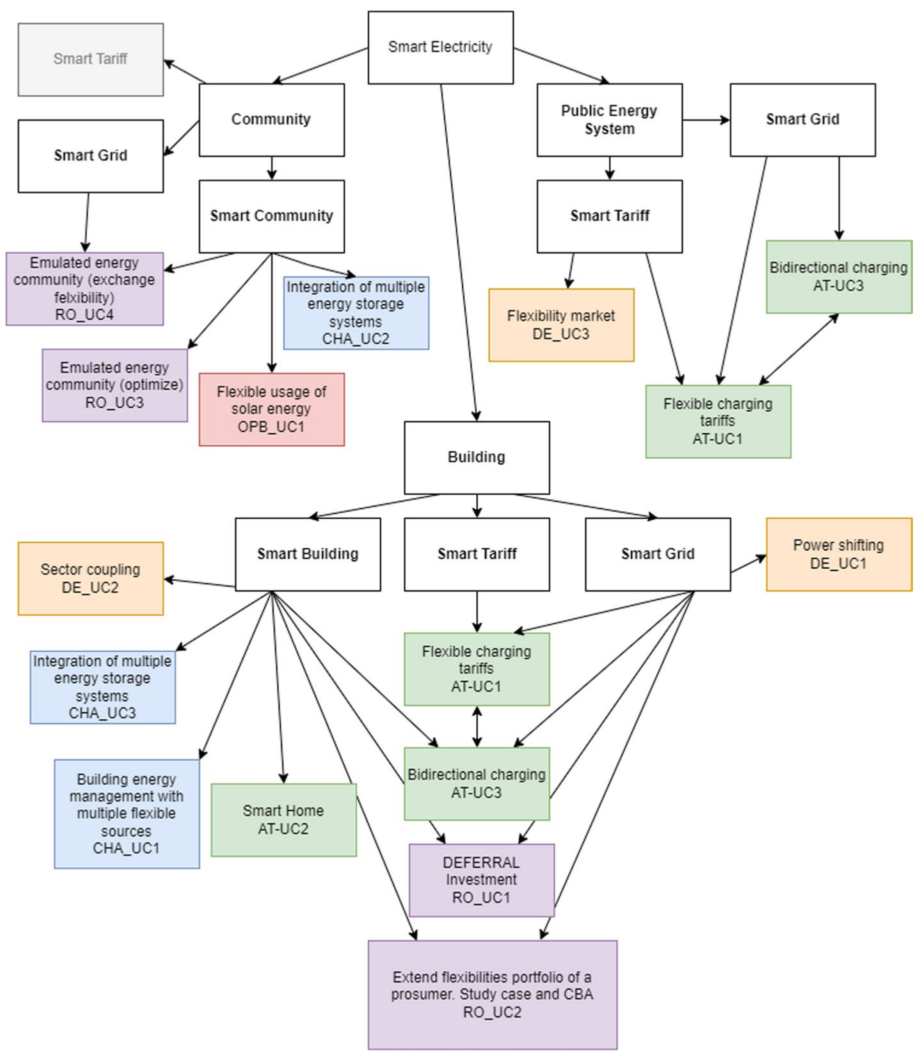

Fig. 1 Clustering of use cases in I-GReta (use cases of one colour are undertaken at the same field trial location)

pertains to small-scale energy systems where resources are communally shared. The Public Energy System represents an expansive version of the Community sector, facilitating resource exchange beyond community confines, necessitating compliance with the public power grid's regulations. Each sector is divided into two general categories—Smart Grids and Smart Tariffs—and a sector-specific category. Smart Grids capture UCs that leverage advanced Smart Grid features, such as smart tariffs and demand response. This classification aims to pinpoint synergies between UCs and their interconnections. Notably, some UCs span multiple sectors and subdivisions. From this comprehensive set, a subset of use cases is selected based on technical feasibility at trial sites. A prime area of focus within the project is Smart Buildings, which are instrumental in linking heat and electricity, thereby unlocking new flexibility exchange opportunities. Subtopics within the Smart Buildings category address the integration of renewable energy sources into building energy management systems, incorporating smart charging for alternating current (AC) and direct current (DC), and fostering Smart Energy Communities.

Analysing UCs individually is essential to grasp the distinct complexities and opportunities each presents, ensuring they meet their unique technical specifications, regulatory requirements, and stakeholder expectations (Bittner and Spence 2003). When considered as a collective portfolio, these use cases enable a strategic overview, highlighting how they align with overarching organizational goals and identifying potential synergies, which can lead to more efficient resource utilization and improved risk management strategies (Cassiman et al. 2005). Furthermore, a portfolio perspective encourages innovation through the cross-fertilization of ideas and ensures the suite of use cases is robust against market fluctuations and responsive to customer needs, ultimately fostering a holistic and resilient approach to smart grid development (Curley and Salmelin 2017). Moreover, the adoption of FIWARE and the implementation of a cross-national platform for energy systems facilitate standardized data exchange and interoperability across use cases, enhancing the overall efficacy of the smart grid ecosystem.

For simplification and focused study within this paper, we have distilled the full spectrum of the I-GReta UCs portfolio into four generalized use cases. The selected UCs are: UC1, "Upscaling of Battery Storage," which explores the enhancement of energy storage capabilities; UC2, "Energy Flexibility, Renewable Sources and Building Energy Management System," which involves integrating smart technologies for building management systems; UC3, "Planning of Energy Communities for Flexibility Scenarios," which aims to develop cooperative models for energy sharing and management; and UC4, "Bi-Directional Charging," which tests the capacity for electric vehicles to contribute to grid stability through bidirectional energy flows. These cases represent the diverse yet interconnected facets of the I-GReta project and provide a comprehensive overview for analysis.

The paper presents a comprehensive structure beginning with an introduction that sets the stage for discussing renewable energy, smart grids, and the I-GReta project's use cases. The background section reviews relevant literature and theoretical frameworks in energy technology research, particularly the innovation management, R&D portfolio analysis and technology and market alignment techniques. Methodologically, the paper describes the transition from the I-GReta project use cases to business cases, employing various analytical tools. It then delves into an in-depth analysis of these use cases, their market readiness, and innovation levels, followed by a detailed look at the application of a tailored business model canvas. The paper culminates with a synthesis of digital entrepreneurship models suited to these use cases, a critical discussion of the findings and methodologies, and a conclusion summarizing the project's key contributions to energy management and sustainability.

Background

In the realm of energy technology R&D projects, the alignment of use case and business case development from the conceptual level to the implementation phase is a topic that has garnered significant attention in the literature. This is particularly relevant in the context of integrating renewable energy sources and advancing smart grid technologies. At the conceptual stage, the literature emphasizes the importance of feasibility studies and stakeholder analysis. As noted by (Smith and Woodworth 2012), early-stage assessments should consider technical feasibility, market demand, and regulatory landscapes to ensure that proposed solutions are viable. This stage often involves extensive modelling and simulation to predict system behaviour and potential challenges. The use of TRLs, as discussed by (Mankins 1995), is a common approach in energy grid projects to assess the maturity of a technology. This method helps in systematically progressing from concept (low TRL) to implementation (high TRL), ensuring that each stage of development is grounded in reality and technologically feasible. A more recent study focusing on the assessment of district heating and cooling systems, where it evaluates their technical feasibility, market demand, and regulatory landscapes, also highlights the need for early-stage alignment between UC and BC (Yang et al. 2022).

As projects advance, the focus shifts towards market analysis and business modelling. Priem highlighted the need for developing comprehensive business models that align with the technology's capabilities and market needs (Priem et al. 2018). This includes exploring different revenue streams, cost structures, and market positioning strategies. The literature also underscores the significance of regulatory and policy considerations in the development process. As argued by (Reyna and Chester 2017; Rajavuori and Huhta 2020), navigating the complex regulatory environment is crucial for the successful deployment of energy grid technologies. This involves understanding and influencing policy decisions that affect market entry and technology adoption. Finally, the role of stakeholder engagement and the formation of strategic partnerships are critical in bridging the gap between use cases and business cases. According to (Meijer et al. 2019), collaboration with industry partners, regulatory bodies, and end-users helps in tailoring solutions to market needs and enhances the likelihood of successful technology adoption and implementation. The Smart Grid Architecture Model (SGAM) is increasingly recognized in the literature as a pivotal framework for aligning the use case and business case development process in energy grid R&D projects, from conceptualization to implementation (Albano et al. 2014; Panda and Das 2021). SGAM provides a multi-layered, structured approach for the design and development of smart grid technologies. It encompasses various aspects of the smart grid, from physical components to business and market considerations, allowing for a holistic view of project development. According to (Mashlakov et al. 2019), SGAM facilitates interdisciplinary collaboration by providing a common language and reference model for stakeholders from different domains, including engineers, business developers, and policymakers. This is crucial for ensuring that technical solutions are aligned with market needs and regulatory frameworks. A literature review from (Rip and Kemp 1998) emphasizes the importance of aligning technical solutions with viable business models, ensuring that the developed technologies are economically sustainable and market-ready. The use case and business case development process under the SGAM model involves transitioning from high-level conceptualization to detailed implementation. This structured approach ensures alignment with strategic objectives and regulatory compliance throughout the development process.

The focus of this study is limited to Use Case (UC) and Business Case (BC) layers only (Fig. 2). Developing the business layer within the SGAM model involves considerations like stakeholder interests, economic viability, regulatory compliance, and market dynamics (Mashlakov et al. 2019). Important aspects include clear value propositions, scalable business models, and a thorough understanding of the energy market's regulatory landscape. For more in-depth insights, the works of Giordano et al. on the importance of business models in the smart grid sector provide valuable guidance (Giordano et al. 2011). In the context of emerging energy markets, it means overseeing and fostering new technologies, strategies, and business models that can effectively cater to the growing and often unique needs of these markets.

The digitalization of the energy sector, characterized by the integration of advanced technologies such as IoT, big data analytics, and blockchain, has opened new avenues for entrepreneurial ventures (Bumpus 2019). These technologies facilitate the creation of innovative business models like Energy-as-a-Service (EaaS) and peer-to-peer energy

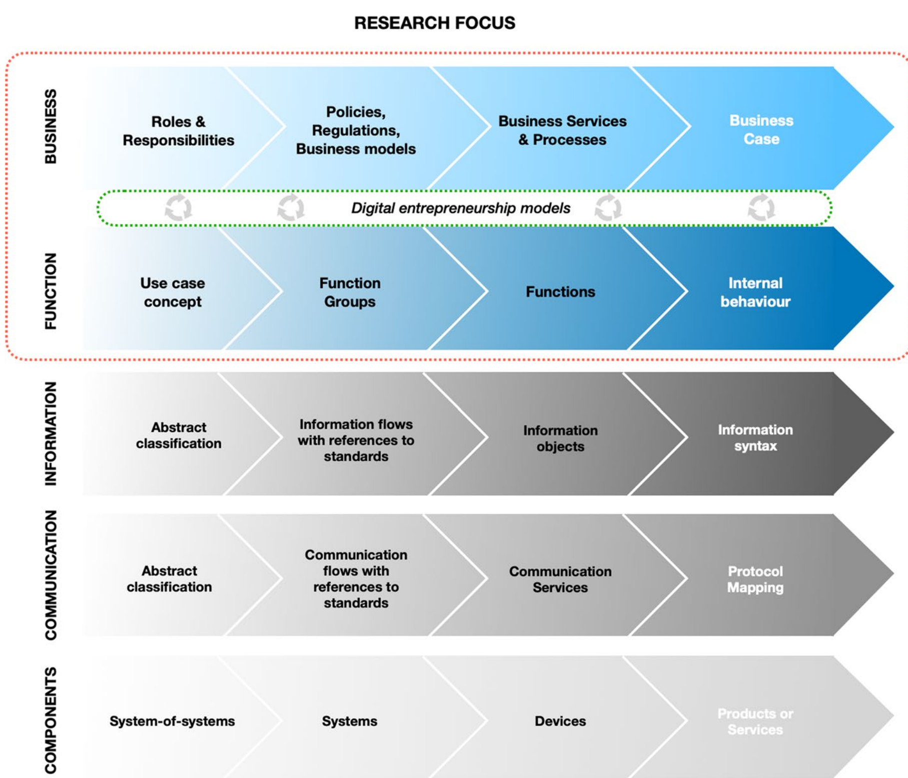

Fig. 2 Research focus is based on the SGAM framework, (Adapted from Mashlakov et al. 2019)

trading platforms, which are reshaping traditional energy market structures (Iria and Soares 2023). Digital entrepreneurship, characterized by the utilization of digital tools, platforms, and technologies, plays a pivotal role in innovating business models, products, and services (Bican and Brem 2020). In the context of emerging energy markets, this form of entrepreneurship manifests in diverse forms (Nambisan 2017). Digital entrepreneurship in the energy sector not only accelerates the transition towards more sustainable and efficient energy systems but also fosters economic growth by spawning new market opportunities and business models (Bocken et al. 2014). This is particularly evident in the growing trend of decentralized energy systems, where digital platforms enable consumers to become prosumers, actively participating in energy production and consumption (Parag and Sovacool 2016). Thus, the role of digital entrepreneurship in the energy sector is multifaceted, driving innovation, market restructuring, and contributing to the broader objectives of energy sustainability and resilience.

In the context of the SGAM, the application of digital entrepreneurship models facilitates the alignment of technological use cases with market-oriented business cases. Platform-based business models are instrumental in enhancing stakeholder collaboration across different SGAM layers, ensuring the integration of diverse smart grid technologies (Menci and Valarezo 2024). The adoption of agile and lean methodologies aids in the rapid prototyping and iterative development of smart grid solutions, allowing for flexible adaptation to changing market needs (Duc et al. 2019). Furthermore, a user-centric design approach ensures that the technologies developed are marketable and meet end-user requirements (Jin et al. 2017; Shafqat et al. 2021).

The intersection between UC and BC through the lens of digital entrepreneurship models, suggests a conceptual bridge facilitated by digital innovation. Digital entrepreneurship models can act as a conduit between the technical and functional aspects of UC and the strategic and economic dimensions of BC (Wang and Shao 2023; Satalkina and Steiner 2020). At this intersection, digital entrepreneurship models apply innovative digital tools and platforms to translate the technical solutions and functionalities defined in UC into market-ready products and services within BC (Bumpus 2019). This includes leveraging digital platforms to define roles and responsibilities, utilize data from smart grid technologies to inform policies and regulations, and reshape traditional business models to align with new market demands. By doing so, digital entrepreneurship ensures that the technical innovations are not only aligned with strategic business goals but are also designed with market adoption and regulatory compliance in mind. This intersection is pivotal for ensuring that the smart grid solutions are economically viable, socially acceptable, and technologically feasible, fostering a seamless transition from concept to commercialization.

This study highlights the essential integration of renewable energy sources and smart grid technologies in energy R&D projects. It emphasizes early-stage assessments involving technical feasibility, market demand, and regulatory landscapes. However, existing studies often lack a holistic approach that combines these elements systematically. The study addresses this by advocating for the Smart Grid Architecture Model (SGAM) and digital entrepreneurship models. These models not only align technical and market considerations but also foster flexibility and user-centricity in smart grid solutions. The study thus fills a gap in the existing literature by providing a more integrated and dynamic framework for energy technology development. The summary of the background is presented in Table 2, where the key elements and a critical comparison with existing frameworks are highlighted.

Methodology

The study methodology for transitioning from use cases to business cases within the I-GReta UCs portfolio involves an approach that incorporates various innovation management and business analytical tools. It begins by deploying a UCs analysis. Following this, a Portfolio Analysis informed by (Vandaele and Decouttere 2013) assesses the innovation potential of various I-GReta UCs from a market and technological perspective. The study then evaluates the innovation readiness levels, which include Technology Readiness Level (TRL), Market Readiness Level (MRL), and Regulatory Readiness Level (RRL), to estimate the maturity of each use case. In the framework of the project, we have developed a Tech Solution Business Model Canvas (TSBMC) tailored for the I-GReta project, which analyses the solution's functionality, infrastructure, and security features, alongside its unique value proposition and stakeholders involved, including beneficiaries, operators, and potential synergies with SMEs and start-ups.

The outcomes of the previously described analysis of various intersection between market and technology is the proposal of digital entrepreneurship models and specific business cases for each use case within the I-GReta portfolio. The aim of this

Table 2 Summary of the background studies

Key aspects	Reflection	Authors
Early-Stage Assessments	The study progresses to market analysis and business modelling, highlighting the need for comprehensive models that align with technology capabilities and market needs	Smith and Woodworth 2012; Yang et al. 2022; Meijer et al. 2019;
Policy and regulation landscape	Navigating the complex regulatory environment is crucial for the successful deployment of energy grid technologies	Reyna and Chester 2017; Meijer et al. 2019; Rajavuori and Huhta 2020;
Use case and Business case levels (SGAM)	This model appears to be more comprehensive compared to traditional R&D models, which may not have integrated technical, business, and policy layers as effectively	Priem et al. 2018: Albano et al. 2014; Mashlakov et al. 2019; Panda and Das 2021; Giordano et al. 2011;
Digitalization and Digital Entrepreneurship	This aspect marks a significant evolution from earlier models that did not fully incorporate the transformative potential of digital tools and platforms in energy sector innovation	Bumpus 2019; Iria and Soares 2023; Bican and Brem 2020; Nambisan 2017; Parag and Sovacool 2016;
Agile and Lean Methodologies	This approach, focusing on flexibility and user-centric design, is more dynamic compared to some traditional R&D methodologies that might be more linear and less adaptive to market changes	Duc et al. 2019; Jin et al. 2017; Shafqat et al. 2021;
Intersection of UC and BC through Digital Entrepreneurship	The study suggests that digital entrepreneurship models act as a bridge between technical-functional aspects of UC and strategic-economic dimensions of BC	Wang and Shao 2023; Bumpus 2019; Satalkina and Steiner 2020

methodology is to facilitate a strategic move from a technology-centric analysis to a business-centric evaluation. This reflects a multidisciplinary approach, encapsulating technical, economic, and strategic dimensions, and it demands a thorough understanding of both the theoretical frameworks and the practical implications of such an integration within the energy sector. The overall methodology of this study is presented in Fig. 3.

The methodology used in this study is specifically tailored to the needs of the I-GReta project, which focuses on integrating renewable energy sources and advancing smart grid technologies. The use of Use Case Analysis, Portfolio Mapping, Innovation Readiness Level assessment, and Tech Solution Business Model Canvas (TSBMC) is appropriate for this project because it allows for a comprehensive evaluation of technical, market, and regulatory aspects essential in the energy sector. The benefits of this methodology include its holistic approach, which integrates multiple dimensions of analysis, ensuring that the solutions are viable across technical, market, and regulatory landscapes. This is particularly important for the I-GReta project, which operates in a complex and rapidly evolving field. The selection of methods occurred under a specific work package where both technical and business experts from the I-GReta consortium proposed various tools and methods. The final selection of methods was based on their clarity and comprehensibility to both groups. This collaborative approach ensured that the chosen tools were accessible and understandable to all parties involved. However, potential improvements could include incorporating more quantitative data analysis to complement the qualitative assessments, providing a more robust empirical foundation for the conclusions. Additionally, case studies or pilot projects could be integrated into the methodology to test theories and models in real-world scenarios, thereby enhancing the practical applicability of the research findings.

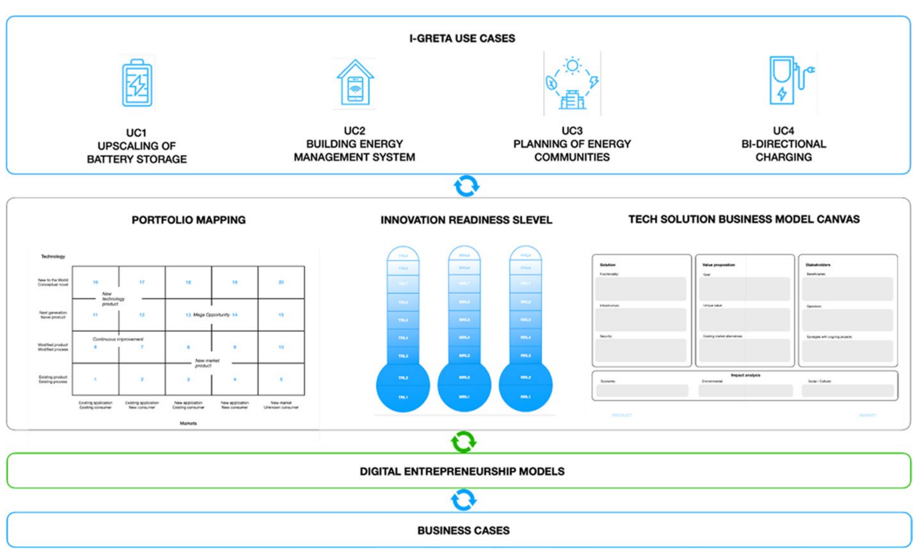

Fig. 3 Overall methodology of the study

Use case analysis

Standardized Use Case Methodology (UCM), as specified in (Schäfer, et al. 2018), is a critical step in enhancing smart grid analysis by providing a structured approach to describe use cases. It relies on detailed narratives to comprehensively capture the essence of each use case. In Step 1 of the Use Case description, according to (Schäfer, et al. 2018), each use case is assigned a unique identifier, a specific field of application, and a characteristic name. This step includes version management with the goal and boundary conditions of the use case. Key performance indicators and necessary conditions, such as assumptions and preconditions, are outlined, with the option to add further classification details like relationships to other use cases or priorities. In SGAM, a UC is a scenario detailing the interaction between entities, such as users and systems, within a smart grid to achieve specific objectives (Albano et al. 2014). Key elements include actors (the interacting entities), scenarios (descriptive narratives of interactions), requirements (technical and functional needs), constraints (regulatory or technological limitations), and expected results (anticipated outcomes or benefits). The I-GReta UCs portfolio employs a UCM approach to ensure that technological solutions are developed with the end-user in mind. This strategy involves creating narratives that encapsulate typical user behaviours, facilitating the understanding of objectives and supporting technical solution development that meets users' needs. This user-centric approach, integrating Use Case Scenarios (UCS), is foundational for aligning technical development with user requirements and market demands. In this study, we will limit ourselves to Use Case descriptions, which will include the name of the Use Case, scenario and technical requirements.

Portfolio mapping of innovation level

Portfolio Mapping of Innovation Level, as discussed by (Vandaele and Decouttere 2013), provides a framework for evaluating R&D projects based on technological innovation and market readiness. This methodology categorizes innovations within a portfolio, assessing their position in terms of development stage and market potential. Applying this to the I-GReta UCs portfolio involves evaluating the technological maturity and market viability of each use case. By evaluating UCs based on their technological maturity and market readiness, it facilitates a preliminary understanding of where each UC stands in terms of development and market potential. An adopted form (Vandaele and Decouttere 2013) template was used in our study (Fig. 4).

Innovation readiness level

Understanding the maturity levels of each use case in the I-GReta project is vital not only for individual project assessment but also for ensuring effective cross-use case communication and data exchange, especially when utilizing a cross-national platform like FIWARE. The readiness of each use case in terms of technology, market, and regulatory aspects influences how well these systems can interact and share data across different national contexts. This impacts the overall efficacy and integration of

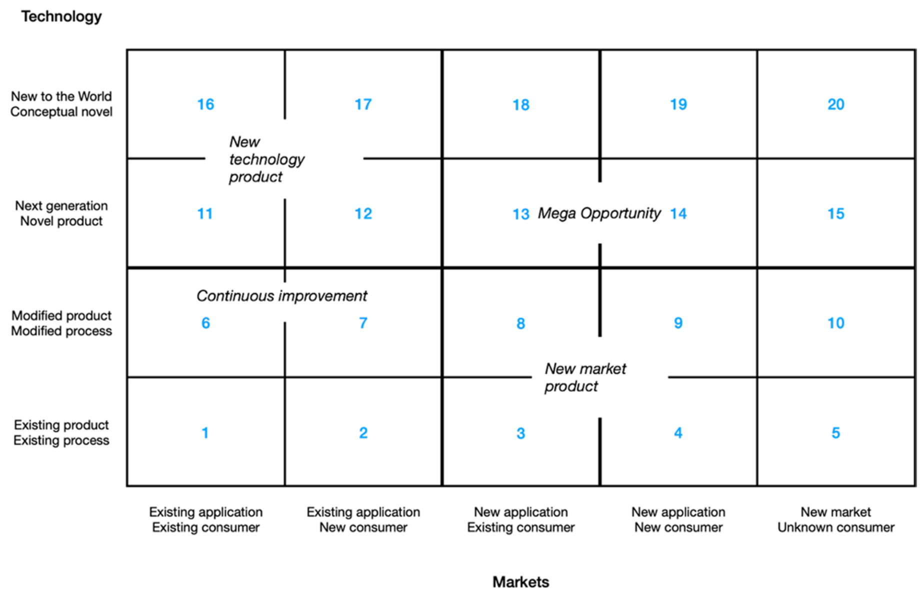

Fig. 4 Portfolio Mapping of Innovation Level, adopter from (Vandaele and Decouttere 2013)

the smart grid solutions within the project. This holistic view is crucial for achieving seamless interoperability and efficient energy management across borders.

Incorporating IRL analysis with the Portfolio Mapping of Innovation Level methodology offers a comprehensive approach to evaluating UCs in terms of their technological and market readiness. This combined methodological approach enhances strategic decision-making by providing a multifaceted view of a project's maturity, encompassing technology, market, and regulatory readiness aspects (Borgefeldt and Svensson 2022). IRL analysis complements the innovation and market assessments of Portfolio Mapping, allowing for a more nuanced understanding of potential risks, gaps, and the overall readiness of a project. The IRL is dissected into three key dimensions:

- *TRL:* Evaluating the maturity of the technology, from conceptualization to full-scale deployment.
- *MRL:* Analysing the extent to which the technology is prepared to meet market demands and the challenges it might face.
- *RRL:* This indicates the technology's compliance with existing regulations and identifies potential regulatory barriers.

The description of each Level of the IRL dimensions is presented in Fig. 5.

Tech Solution Business Model Canvas

In the context of this study, a synthesis of various business model canvases is undertaken to construct a comprehensive Tech Solution Business Model Canvas tailored for the project's R&D needs. This integration incorporates the holistic business operation perspective from (Osterwalder et al. 2015), the start-up-centric problem–solution focus of (Maurya 2022), and the customer-oriented design of the Value Proposition Canvas (Osterwalder et al. 2015). Additionally, it involves elements from the Digital Policy

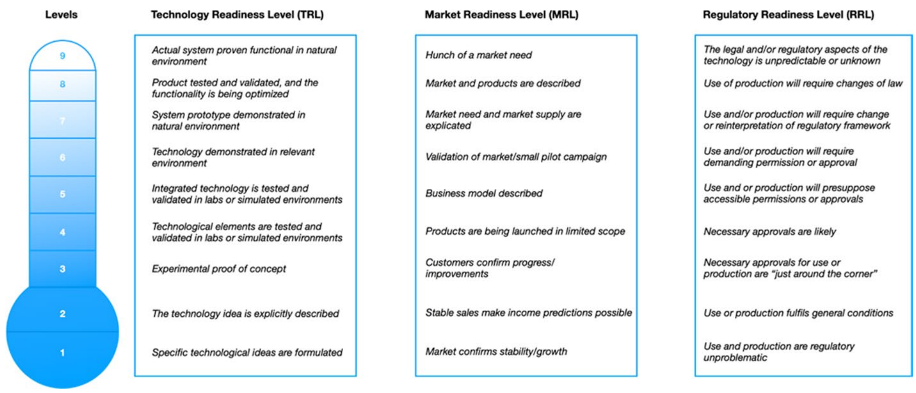

Fig. 5 The Innovation Readiness Scale and the three dimensions of readiness level assessment, adapted from (Borgefeldt and Svensson 2022)

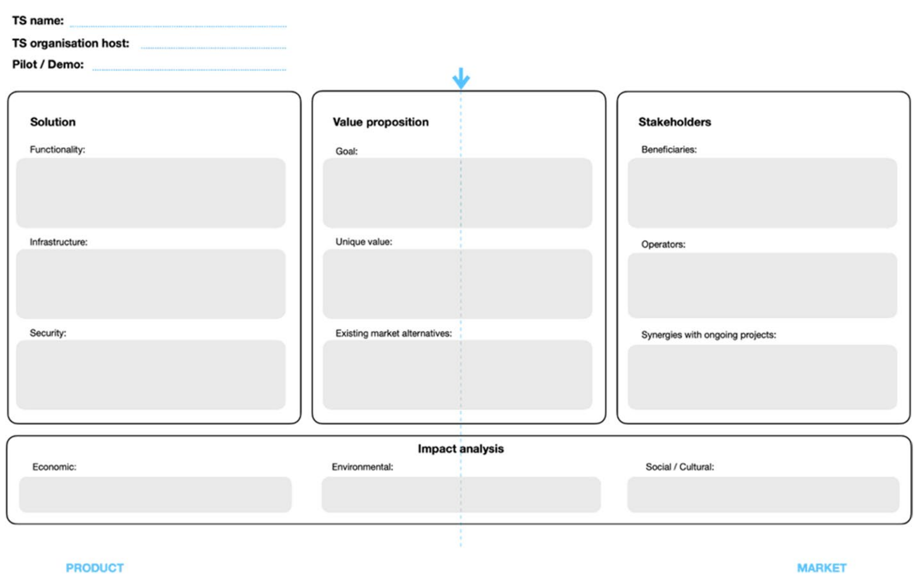

Fig. 6 Technical Business Model Canvas template

Model Canvas, which contextualizes digital policy development within the stakeholder and ecosystem framework (Beagrie and Greenstein 1998), and the Sustainable Business Model Canvas (Joyce and Paquin 2016), which infuses environmental and societal considerations into business strategy. The resultant Tech Solution Business Model Canvas (TSBMC) for the I-GReta project features dedicated sections on Solution, Value Proposition, Stakeholders, and Impact Analysis (Fig. 6). This canvas aims to facilitate discussion related to a strategic move from technical use cases to market-ready business cases. The TSBMC ensures a holistic analysis, considering the technical nuances, economic viability, and broader impacts of the I-GReta UCs. Through this structured approach, the study aims to offer valuable insights and actionable recommendations to stakeholders and decision-makers. The Tech Solution Business Model Canvas methodology is employed through a collaborative and interactive half-day workshop. During this session, leaders of each Use Case (UC) work closely with their respective teams to fill out the canvas, detailing aspects such as the solution's functionality, infrastructure, security, value proposition, stakeholders, and the environmental, social, and economic impacts. Following the individual team activities, a collective discussion round is conducted. This process not only fosters a deeper understanding of each UC unique and shared attributes but also encourages cross-pollination of ideas, leading to a more integrated and coherent approach to innovation within the R&D portfolio.

Results

This section will provide a detailed analysis of the use cases developed within the I-GReta project. Each use case will be assessed for its functionality, economic viability, and stakeholder engagement potential and innovation readiness.

I-Greta use cases analysis

The I-GReta project encompasses an innovative portfolio of UCs that aim to foster advancements in smart grid and energy management technologies. This analysis delves into the practical applications and technological integrations offered by the project, highlighting the synergy between various components aimed at enhancing energy efficiency, flexibility, and sustainability.

UC1 engages in the analytical observation of photovoltaic (PV) and battery systems to understand their charging and discharging behaviours, with a specific concentration on the efficiency of energy storage within batteries. The approach involves a set of scenarios where PV profiles during diverse seasonal conditions, such as summer and autumn, are used to illustrate the dynamic behaviours of battery systems as they interact with the power grid. In an empirical progression of these scenarios, a standard 30 kW battery system is experimentally scaled to a more robust 100 kW system, allowing for an assessment of scalability and performance. This use case necessitates the integration of PV systems, battery and battery management systems, alongside automation systems critical for communication processes, highlighting the technical intricacies required to achieve the desired outcomes in energy storage efficiency. UC1 exemplifies the project's commitment to energy conservation and management. By analysing the charging and discharging patterns of PV-battery systems, this use case explores the potential for improved energy storage solutions, focusing on the efficiency of batteries and their integration into the grid. The application of this use case in different seasonal profiles underlines its adaptability and scalability in real-world scenarios.

UC2 focuses on the innovation of the Home Energy Management Systems (HEMS) towards more energy flexibility features and functions. The initiative aims to provide end users with optimal time recommendations for energy-consuming appliances and electric vehicles (EVs). A practical scenario involved tenants from multiple residential buildings engaging with HEMS in a real-life setting to adapt their daily activities and energy usage to coincide with times of lower demand or peak solar generation. The technical infrastructure supporting this use case comprises PVs, energy storage solutions, EV charging units, home appliances sockets' smart meters and the HEMS itself, all equipped with interfaces designed for ease of use. Thereby facilitating user interaction and promoting efficient energy consumption patterns in a user-centric way. UC2 addresses the integration of smart home systems with advanced energy management platforms. This use case underscores the role of user engagement and behavioural adjustments in energy consumption, facilitated by HEMS that align usage patterns with optimal energy production times.

UC3 employs the FIWARE open-source platform to strategically plan and optimize investments in photovoltaic (PV) systems and battery storage, with a focus on operational flexibility. The use case is exemplified through a public building that has the potential for maximum PV energy production yet exhibits a highly variable and inflexible electric load profile. This scenario uncovers the necessity for additional local storage capacity, facilitated by appropriate power conversion units, which serves to reduce the financial burden on the local electricity grid infrastructure, including aspects managed by Distribution System Operators (DSO). The technical underpinnings of UC3 include the deployment of smart meters, Raspberry Pi 3 boards as control units, and the requisite hardware servers, alongside Ethernet cables and network switches, to construct a robust and responsive network infrastructure. UC3 utilizes the capabilities of the FIWARE platform to plan for smart investments in energy infrastructure. This use case presents a model for energy communities where flexibility and operational efficiency are paramount, particularly in public buildings with variable energy demands.

UC4 explores the innovative practice of bi-directional charging for electric vehicles (EVs), assessing their capacity not only to charge but also to discharge their batteries back into the power grid. This dual functionality of EVs holds the potential for enhancing grid stability and optimizing energy management. The practical application of this use case is demonstrated through the deployment of two bi-directional EV charging stations within a laboratory environment that is integrated with RES energy generation and management systems. Here, EVs serve as both energy consumers and potential storage solutions, as they can return electricity to the grid, thereby facilitating more efficient energy consumption and utility for users. The technical infrastructure required to realize UC4 encompasses EV charging stations with bi-directional charging capabilities and vehicles equipped to handle such bidirectional energy flows. UC4 brings to the fore the transformative potential of electric vehicles (EVs) as both energy consumers and providers. By exploring the bi-directional charging capability, this use case serves as an important exploration for smart energy management, where EVs can contribute to grid stability and offer innovative solutions for energy storage and distribution.

The UCs within the I-GReta project form a cohesive portfolio that exemplifies the integration of technical innovation with pragmatic execution. Each UC transcends its function as an isolated inquiry to become an essential component of the overarching aim to transform the energy sector. The detailed examination of each case provides valuable perspectives on practical viability, involvement of stakeholders, and the technological expertise that characterizes the I-GReta initiative. This collective approach not only drives the project's mission forward but also contributes to setting new standards in energy management and sustainability. The utilization of the FIWARE open-source platform plays a crucial role in all the UCs, underpinning the seamless integration of various smart grid components and facilitating a connected digital ecosystem. It exemplifies how a unified digital platform can act as a catalyst in advancing the future of smart grids, enhancing operational efficiency, stakeholder engagement, and overall grid management.

I-GReta use cases Portfolio Mapping

In the I-GReta project, the Portfolio Mapping of Innovation Level has been applied to categorize the UCs based on their technological novelty and market readiness (Fig. 7). UC1 is positioned within the quadrant of existing technologies and applications for current consumers, indicating an incremental improvement on current market offerings. UC2 occupies a space indicating new market products, suggesting a more innovative approach within familiar consumer segments. UC3 and UC4 are both placed in the sector indicative of next-generation technology for new applications and consumers, highlighting their pioneering status in terms of technology and target market. Each UC's positioning reflects its strategic direction: UC1 is focused on enhancing and optimizing existing solutions, UC2 on introducing new products to established markets, and UC3 and UC4 on developing breakthrough technologies that create new markets and consumer segments, driving forward the R&D portfolio's innovative edge. By situating each use case on a matrix that cross-references technological novelty against market readiness, the method provides clarity on the innovation trajectory and commercial potential of each use case. For example, UC1's position suggests a focus on incremental innovation, optimizing existing technologies for current markets, which may require a business model cantered around process improvement and cost efficiency. Conversely, UC3 and UC4, positioned as next-generation technologies for new markets, point towards the need for robust digital entrepreneurship models that can navigate uncharted market territories, spearhead customer education, and build new revenue streams.

I-GReta use cases innovation readiness level

For UC1 the technology appears to be at a mature stage, indicated by a high TRL, suggesting it has been validated in relevant environments. Its MRL positioning reflects an early market introduction with a validated business model, while its RRL indicates that

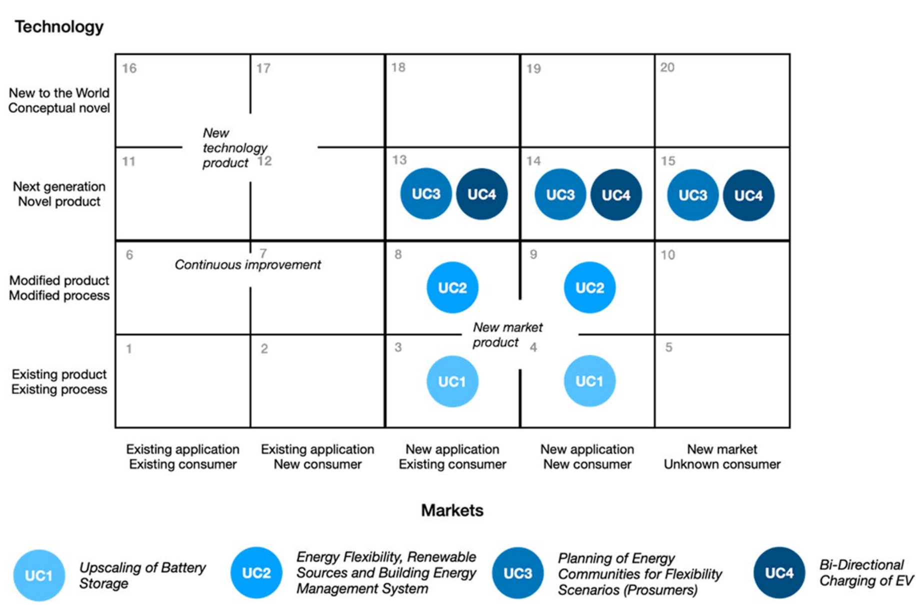

Fig. 7 Portfolio Mapping of Innovation Level applied to I-GReta UCs

the use or production will require some form of permission or approval, hinting at a need for further engagement with regulatory bodies. UC2 shows a robust TRL with proven system functionality in a natural environment. The MRL is at a stage where products are being launched in limited scope, and the RRL suggests that regulatory changes or reinterpretations are anticipated, which could imply potential legislative tailwinds or headwinds. UC3 displays a TRL indicative of prototype demonstration in natural settings, implying readiness for pilot studies or early adoption. The MRL is at the level where the market confirms progress or improvements, and the RRL is optimistic, with necessary approvals likely in place, suggesting a smoother path to market entry. Lastly, UC4 is positioned at a similar TRL to UC3, with a prototype demonstrated in real-world conditions. Its MRL suggests that it is still at the validation or small pilot campaign stage, indicating initial market tests are underway. The RRL is the most advanced among the use cases, with necessary approvals for use or production perceived to be imminent.

Overall, the IRL analysis provides a nuanced picture of where each UC stands in terms of development, marketability, and regulatory engagement (Fig. 8). This assessment is pivotal for strategic planning in the I-GReta project, as it identifies potential barriers and facilitators in the journey from concept to market realization within the EU's dynamic energy sector.

I-GReta use cases Tech Solution Business Model Canvas

This sub-chapter provides an overview of four UCs, conceptualized through the TSBMC, addresses different aspects of energy flexibility, management, and storage, demonstrating a commitment to integrating advanced technologies with market needs and regulatory frameworks (Fig. 9).

In UC1, the TSBMC illustrates a strategic approach to enhance energy flexibility. The solution central to this use case involves connecting stationary energy storage systems to FIWARE platforms, offering a digital twin of local energy systems. This innovative integration promises a unique value in allowing customers to integrate their storage systems with existing FIWARE systems. The canvas identifies energy prosumers as the primary beneficiaries and housing associations or building owners as the key operators. Furthermore, it acknowledges synergies with ongoing projects like the Battery Loop project in Gothenburg, suggesting a collaborative effort in the energy sector. From an economic

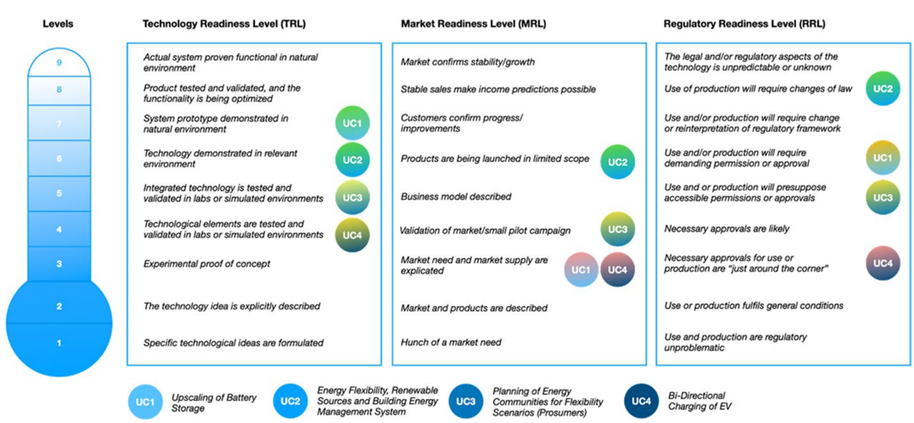

Fig. 8 Innovation Readiness Level applied to I-GReta UCs

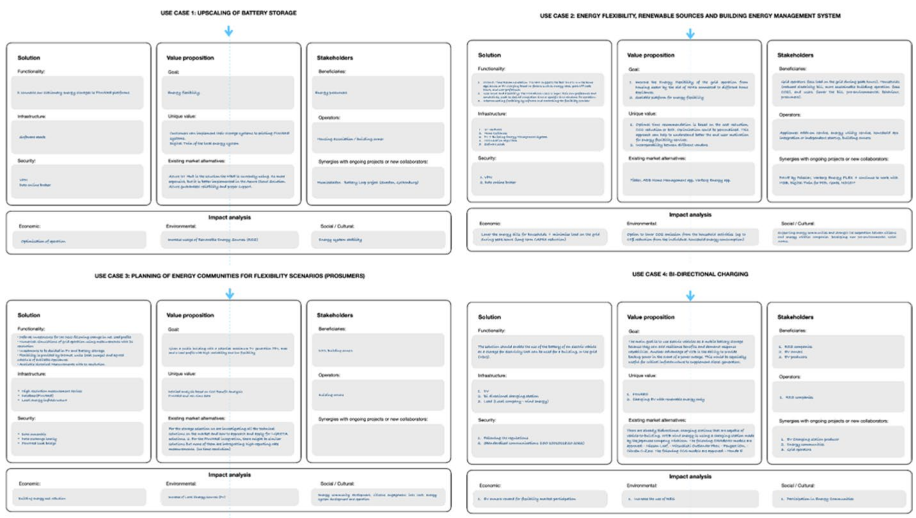

Fig. 9 Tech Solution Business Model Canvas applied to I-GReta UCs

perspective, the use case focuses on optimizing operations, which includes improving efficiency and reducing costs. The environmental impact analysis foresees an increased use of Renewable Energy Sources (RES), aligning with broader sustainability goals. Socially and culturally, the projected outcome is the stabilization of the energy system, which could translate into a more reliable energy supply for consumers. In summary, UC1 addresses the critical need for energy flexibility by proposing a solution that not only integrates with existing smart platforms but also provides a framework for future enhancements in energy management, usage, and stability.

UC2, as detailed by the TSBMC, explores the optimization of energy flexibility within the grid, specifically within the housing sector. This use case aims to utilize HEMS connected to various home appliances and EV charging stations to enhance energy flexibility and integrate PV Demand Side Management (DSM) and a scalable platform for other Demand-Response Management (DRM) energy services. The unique value proposition lies in its dual focus on cost reduction and CO2 emission reductions through personalized optimization, which is expected to foster user motivation for adopting energy flexibility services. Beneficiaries of this use case include grid operators, who will benefit from reduced load during peak hours, and households, who will see reduced electricity bills and more sustainable building operations. The operators listed are appliance add-on services, energy utility services, and building owners, among others. The use case also draws on synergies with EU projects like DigitalTwin4PED and Gente. From an economic standpoint, the use case seeks to reduce long-term capital expenditure by lowering energy bills for households, minimizing load on the grid during peak hours and integrating energy generated by PV. Environmentally, it provides the option to reduce CO2 emissions and energy cost from household activities. Socially, the use case supports the development of energy communities and encourages pro-environmental social norms by involving citizens and energy utility companies in the energy management process. UC2 addresses the need for enhanced energy management through innovative and personalized home automation systems that offer economic and environmental benefits, while also supporting social and cultural shifts towards more sustainable energy consumption behaviours.

The UC3 is focused on the strategic planning of energy communities with an emphasis on flexibility scenarios tailored for prosumer involvement. The Tech Solution Business Model Canvas for this use case delineates a multifaceted approach where the solution involves high-resolution measurement devices and local energy infrastructure integrated with FIWARE platforms to enable precise tracking and control of energy production and consumption. The value proposition of this use case hinges on the detailed cost–benefit analysis and real-time data utilization to maximize PV generation potential and load profile variability, thereby offering a unique analytical advantage over existing market alternatives. The target beneficiaries include Distribution System Operators (DSOs) and building owners who are positioned to benefit from enhanced energy management and cost savings. Economic benefits are projected in terms of direct energy cost reductions for buildings, while the environmental impact is anticipated to increase the use of local energy sources, particularly photovoltaics. Socially and culturally, the use case contributes to the development of energy communities and fosters citizen engagement in local energy system development and operations, which aligns with broader sustainability and participatory goals. Collaboration and data security are underscored through partnerships with ongoing projects and adherence to data ownership and exchange protocols, ensuring that the solution not only advances technical objectives but also aligns with regulatory and community-centric frameworks. In summary, UC3 represents an integrative model that leverages technological innovation and community engagement to foster sustainable energy ecosystems, offering economic and environmental benefits while promoting social inclusion in energy management practices.

In UC4, the TSBMC outlines the deployment of bi-directional EV (Electric Vehicle) charging stations as a dual-purpose solution: providing energy storage and contributing to grid stability through demand-response capabilities. The solution leverages EV batteries as mobile energy storage units, enabling them to contribute power back to the building or grid during peak demand or power shortages, which not only aids in energy management but also provides a backup in emergencies, augmenting resilience. The value proposition centres on utilizing renewable energy sources for charging. This approach offers a distinct advantage over existing market alternatives by integrating renewable energy sources and smart technology, positioning it as a forward-thinking model in line with contemporary environmental objectives. Beneficiaries of this use case include renewable energy service companies, EV owners, and manufacturers, all of whom stand to benefit from the increased utilization and efficiency of EVs as energy storage solutions. Operators of these systems would primarily be the renewable energy service companies responsible for implementing the charging stations. Economic incentives are provided to EV owners for their participation in the flexibility market, promoting the adoption of this innovative charging approach. The environmental impact is significant, with an increase in the use of renewable energy sources, while socially and culturally, the model supports participation in energy communities, facilitating collective engagement in sustainable practices. This model represents an integrated approach that enhances energy systems' sustainability while offering economic incentives and social engagement, showcasing a progressive step towards a more resilient and renewable energy infrastructure.

Digital entrepreneurship models and potential business cases

The final part of this study analysis is synthesis of previous results and proposal of the strategic digital entrepreneurship models and corresponding potential business use cases for the I-GReta project use cases (Fig. 10).

For UC1, the entrepreneurship model identified is "Energy Storage as a Service (ESaaS)." This model could facilitate business use cases like "Commercial Battery Solutions," focusing on providing battery storage systems to commercial entities, and "Energy Storage Integration Consultancy," which would offer expert advice on integrating energy storage solutions into existing systems. In UC2, the "Building Automation Platform" model is proposed. Potential business cases under this model include "Smart Home Energy Optimization," which involves optimizing energy use in homes for efficiency and cost savings, and "Demand-Response Aggregation," which could enable the collective management of consumer energy demand in response to supply conditions. UC3 aligns with the "Peer-to-Peer Energy Trading" model. This facilitates business use cases such as "Prosumer Network Expansion Services," aiming to expand networks of energy producers and consumers who trade energy, and "Community Energy Management Systems (CEMS)," which manage the energy usage of a community to optimize consumption and costs. For UC4, the "Vehicle-to-Grid (V2G) Services" model is suggested. This model could create business use cases like "EV Energy Storage Solutions," which would use electric vehicle batteries as temporary energy storage, and "Renewable EV Charging Networks," which would establish networks for charging electric vehicles using renewable energy sources. Each digital entrepreneurship model is tailored to

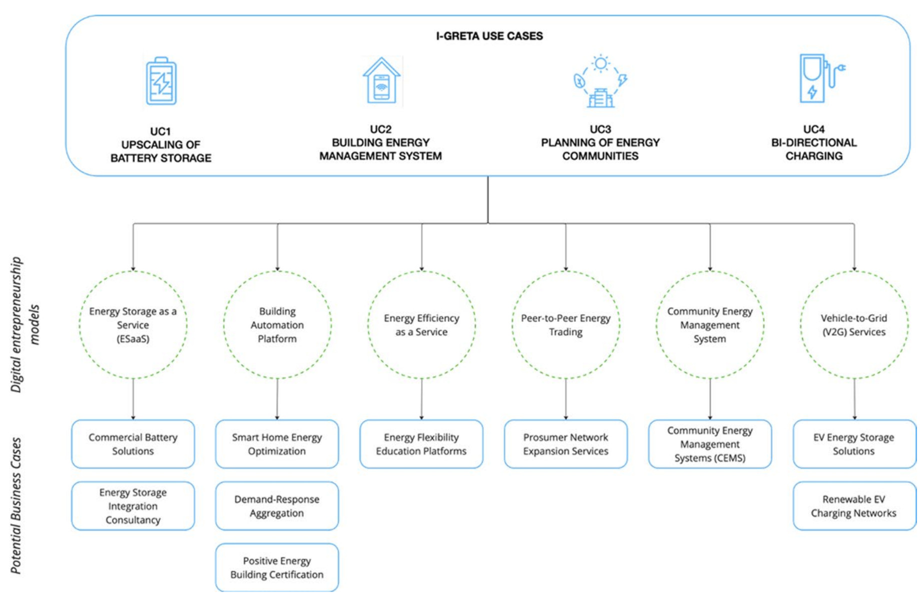

Fig. 10 Digital entrepreneurship models and potential business use cases for I-GReta UCs

address the specific needs of the use cases, proposing innovative business use cases that could drive forward the goals of the I-GReta project. These models and business cases collectively reflect a commitment to leveraging technology for sustainable energy management, community engagement, and the creation of new market opportunities within the energy sector. The selected digital entrepreneurship models within the energy sector hold significant potential for reshaping the industry landscape. These models offer various economic, social, and regulatory implications that warrant closer examination. In the Table 3 there is a summary of Economic, Social and Regulatory implications from TSBMC workshop.

Discussion

This study has provided a nuanced analysis of the I-GReta project's R&D portfolio through various methodological lenses, including use case mapping, innovation readiness levels, and the development of a tailored Tech Solution Business Model Canvas. Through the systematic categorization of use cases, a trajectory of innovation and market alignment has emerged, suggesting distinct pathways for each use case from technological readiness to market penetration and regulatory compliance.

For UC1, we see the potential for a service-oriented approach, aligning with business models such as Energy Storage as a Service (ESaaS). This resonates with trends towards service-oriented business models in the energy sector (Shafqat et al. 2021), which emphasize customer value over product ownership. The commercial viability of battery storage integration consultancy suggests a demand for expertise in integrating advanced energy storage solutions with existing infrastructures, a trend supported by the increasing complexity of energy systems (Richter 2013). UC2 reveals the importance of smart home energy optimization and demand-response aggregation in enhancing energy efficiency. These potential business cases reflect a growing market for home

Table 3 Economic, Social and Regulatory implications summary

Digital Entrepreneurship Models	Economic Implications	Social Implications	Regulatory Implications
Energy Storage as a Service (ESaaS)	Reduced upfront costs, revenue opportunities for service providers	Energy sustainability, energy independence, resilience	Address ESaaS agreements, fair pricing, data privacy, grid impact
Building Automation Platform	Cost savings through improved efficiency, lower operational costs	Improved indoor comfort, well-being	Data privacy, security, energy efficiency standards
Energy Efficiency as a service (EEaaS)	Cost Savings, Energy Efficiency Incentives, Revenue for Service Providers	EEaaS can make energy-efficient technologies more accessible to a wider range of customers	Energy Efficiency Standards, Measurement and Verification (M&V)
Peer-to-Peer Energy Trading	Cost savings for consumers, revenue for prosumers	Community engagement, empowerment, decentralized energy	Grid access, fairness, transparency in energy trading
Community Energy Management Systems (CEMS)	Cost savings, economies of scale in energy procurement	Community resilience, sustainability, reduced environmental impact	Community-level energy management, grid integration
Vehicle-to-Grid (V2G) Services	Revenue streams for EV owners, offset EV ownership costs	Integration of renewable energy, reduced carbon footprint	V2G technical and operational standards, grid compatibility

energy management solutions (Iria and Soares 2023) and the increasing role of digital platforms in energy consumption management (Duch-Brown and Rossetti 2020). The peer-to-peer energy trading model proposed for UC3, highlights the emerging paradigm of prosumer-centric energy markets. This model aligns with the shift towards decentralized energy systems, where digital platforms empower consumers to engage in energy production and consumption (Burger et al. 2020). Lastly, UC4 demonstrates the intersection of transportation and energy sectors, with vehicle-to-grid (V2G) services showcasing an innovative use of EV batteries for energy storage. The proposed business case for renewable EV charging networks aligns with current drives towards sustainability and renewable energy integration (Madina et al. 2016).

The proposed digital entrepreneurship models in this study carry economic, social, and regulatory implications potential for the future UCs development. Economically, these models offer avenues for cost reduction and revenue generation; for instance, Energy Storage as a Service (ESaaS) and Vehicle-to-Grid (V2G) services provide reduced upfront costs and new revenue streams, respectively. Socially, the implications are equally transformative, with models like Peer-to-Peer Energy Trading fostering community engagement and empowerment, and Building Automation Platforms enhancing indoor comfort and well-being. These models promote energy sustainability, independence, and resilience, contributing to reduced environmental impact and the integration of renewable energy sources. Regulatory implications are intricate, as they must address the balance between innovation and compliance. ESaaS requires careful consideration of fair pricing and data privacy, while V2G services pose challenges in establishing technical and operational standards. The regulatory landscape must adapt to these emerging models, ensuring grid compatibility and energy efficiency standards are met without stifling innovation. This study showcases the interwoven nature of these implications, emphasizing the need for a coherent strategy that aligns technological advancement with economic incentives, social benefits, and a flexible regulatory framework to support sustainable growth in the digital energy marketplace.

The mapping of use cases to smart grid architectures revealed challenges in aligning complex technological innovations with existing systems. The portfolio analysis highlighted notable innovation potential, but also underscored the need for a more nuanced understanding of market dynamics. Evaluating readiness levels proved an understanding of different projects readiness for the market deployment, but also the variability in market and regulatory environments suggests that a one-size-fits-all approach might be limiting. The Tech Solution Business Model Canvas offered comprehensive insights, yet the adaptability of these models in varying market conditions requires further exploration. The proposed digital entrepreneurship models are innovative, but their real-world applicability may face hurdles such as stakeholder resistance and technological integration challenges. Overall, the study makes significant strides in understanding the transition from technical use cases to business cases but also reveals areas requiring deeper investigation and strategic refinement.

The interdependency of technology, market, and regulation presents both challenges and opportunities. While technological readiness can be achieved through rigorous R&D and pilot testing, market readiness requires a robust understanding of customer needs and competitive positioning. Regulatory readiness, perhaps the most unpredictable, necessitates a proactive and responsive approach to policy changes and legislative developments. Unexpected findings, such as the variable stages of regulatory readiness among the use cases, open new avenues for discussion. For example, the imminent regulatory approval for UC4's bi-directional charging suggests a conducive legislative environment, while the anticipated changes for UC2 may introduce both opportunities for influence and risks of non-compliance. These findings suggest the need for a flexible, adaptive approach to innovation management and digital entrepreneurship within the energy sector. As the sector continues to evolve, the capacity to anticipate and respond to market and regulatory shifts will be crucial. Additionally, the role of digital platforms and tools in facilitating new business models, such as Energy-as-a-Service and peer-to-peer energy trading, cannot be overstated. These models offer the potential to disrupt traditional energy markets, creating new value for consumers and providers alike.

The literature reviewed in the Background section suggests a shift toward more comprehensive and digitally integrated models in energy informatics, focusing on the early-stage assessment, regulatory considerations, and the intersection of use cases (UC) with business cases (BC) through digital entrepreneurship. These scholarly perspectives can be connected to our results and findings by demonstrating how our study adopts these evolved approaches. The advancements in early-stage assessments and policy landscapes as highlighted by Smith and Woodworth (2012) and Reyna and Chester (2017) resonate with our findings on the criticality of aligning technological capabilities with market needs and regulatory requirements. The comprehensive approach of integrating use case and business case levels, as discussed by Priem et al. (2018), is reflected in our study's methodology that interweaves technical, business, and policy aspects. The evolution towards digitalization and agile methodologies emphasized by Bumpus (2019) and Duc et al. (2019) is mirrored in our research outcomes, showcasing how digital tools and flexible design contribute to the adaptability and success of energy solutions. Lastly, the intersection of use case (UC) and business case (BC) through digital entrepreneurship, as suggested by Wang and Shao (2023), is demonstrated in our findings where digital entrepreneurial models serve as a linchpin connecting technical functionality with strategic-economic viability, reinforcing the holistic nature of our study's insights. Our findings provide a fresh perspective on the interplay between technology and market dynamics, offering a new paradigm for how energy-related R&D can evolve to meet the challenges of digital transformation and sustainable development. This connection enriches the academic discourse with practical examples and solidifies our contribution to the field, emphasizing the relevance and timeliness of our work in light of these recognized scholarly advancements.

While this study provides valuable insights, it also acknowledges certain limitations. While the current methodology offers significant insights, however it could benefit from a more balanced approach between qualitative and quantitative analysis. The inclusion of quantitative data would provide a stronger empirical basis, lending statistical weight to the qualitative observations. This dual approach could deepen the understanding of the complexities involved in the research. Furthermore, the application of case studies or pilot projects would serve as a practical test bed, allowing for the evaluation of theories and models in real-world settings. This would not only validate the research findings but also enhance their relevance and applicability to actual industry scenarios, bridging the gap between theory and practice. Another limitation is the dynamic nature of technological innovation and market forces, which requires ongoing analysis to stay current. Future research could explore longitudinal studies to track the progression of these use cases as they navigate market entry and scale-up. To delve deeper into the application and effectiveness of the proposed models, involving stakeholders in empirical studies would offer critical insights into the real-world challenges of adoption and implementation. Further, a thorough investigation into how these business models perform under diverse market conditions would add valuable understanding to their scalability. Equally important is a more comprehensive exploration of the legislative landscape, which could illuminate both potential regulatory hurdles and opportunities, significantly affecting the models' success and feasibility.

Conclusion

The I-GReta project's approach to integrating advanced technologies with market and regulatory frameworks demonstrates the potential for significant contributions to the field of energy management and sustainability. The project's four cornerstone use cases—Upscaling of Battery Storage, Building Energy Management System, Planning of Energy Communities, and Bi-Directional Charging—each contribute uniquely to the energy sector's transformation. These cases collectively illustrate the potential for scalable, economically sustainable solutions that not only meet immediate market needs but also align with broader sustainability goals. UC1 has shown the potential for service-oriented business models like Energy Storage as a Service (ESaaS), which capitalize on the growing complexity of energy systems. UC2's Building Energy Management System has highlighted the growing market for smart home solutions and demand-response aggregation, emphasizing the role of user engagement in energy efficiency. UC3's Planning of Energy Communities has aligned with the decentralized energy paradigm, empowering consumers to become prosumers. UC4's Bi-Directional Charging has merged the transportation and energy sectors, expanding the utility of EV batteries. The I-GReta project represents a concerted effort to navigate the complex interplay of technology, market, and regulatory frameworks within the energy sector. In conclusion, this study marks an advancement in energy informatics and digital entrepreneurship by demonstrating how digital tools and agile methodologies can be harmonized to drive innovation in the energy sector. Our research provides novel insights into the development of sustainable business models that potentially can be economically viable and technologically advanced. Furthermore, the practical implications of our work, such as the enhanced adaptability of energy systems to market changes and the facilitation of regulatory compliance, pave the way for real-world applications, offering a roadmap for industry stakeholders to implement cutting-edge energy solutions effectively. The study highlights its limitations, suggesting a balanced approach and inclusion of both qualitative and quantitative data to improve empirical strength and industry applicability, while recommending future research to explore the dynamics of technology and market forces through longitudinal studies and stakeholder engagement for better scalability and adoption insights.

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Author contributions
EM—wrote the main manuscript, facilitated the workshops MP—wrote the main manuscript, participated in the worksop MaM—wrote the main manuscript, participated in the worksop MoM—analysed UCs, participated in the worksop RP—analysed UCs, participated in the worksop CS—analysed UCs, participated in the worksop TP—analysed UCs, participated in the worksop H.W—study supervision DM—funding AM—funding.

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Data availability
The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

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Not applicable.

Consent for publication
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