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D7.5 MiniStor Business Model

Marco Rocchetti (R2M)

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Summary

This report outlines the business strategy developed to ensure the replicability of the project after its conclusion, and to facilitate market entry for the MiniStor thermal energy storage system and other Key Exploitable Results (KERs).

As an introduction to business modelling, the report provides an overview of the Energy Performance Contract (EPC) market in the EU and describes consolidated business use cases related to the circular economy, such as PV systems and lithium batteries. These two concepts are considered key pillars for developing an innovative MiniStor business model to ensure replicability.

The Canvas methodology was used to analyse customer segments and draft business models. The document explores five business strategies, one for each KER, detailing the value proposition and customer segment analysis, as well as providing a complete business template indicating key partners and activities, and offering a preliminary financial assessment.

Emphasis is placed on the MiniStor integrated solution (KER #1), presenting the business approach of a Newco composed of consortium partners and external stakeholders. This is considered the optimal strategy for entering the market once TRL9 is reached.

In this way, the MiniStor consortium and its partners could benefit from the Intellectual Property Rights (IPR) and knowledge generated in the project and participate in a synergistic manner in the commercialisation of the MiniStor integrated system in the residential sector as the initial market target, while also exploring future customer segments. This approach is based on circularity and extended producer responsibility applied to the MiniStor system. Three business strategies are considered: direct selling, product as a service, and shared platform.

The circular business model was presented at a dedicated workshop for the MiniStor partners and external experts to collect information and suggestions for its validation.

The report concludes with a SWOT analysis of the applicability of the MiniStor system in the residential sector, considering the current TRL level (TRL7).

Deliverable Number		Work Package	
D7.5		WP7	
Lead Beneficiary		Deliverable Author(S)	
R2M Solution		Marco Rocchetti (R2M); GianMarco Gatti (R2M); Yanich Herve Bang (R2M); Mario Cortese (R2M); Sander Smith (R2M); Lorenzo Elia (R2M)	
Beneficiaries		Deliverable Co-Author (S)	
CARTIF EndeF IEREC Psyctotherm		Alberto Belda Yolanda Lara Carlos Ochoa, Gustavo Sousa Apostolos Gkountas	
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Type of deliverable	R	Report	X
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Abbreviations

AEPC	Active Building Energy Performance Contract
API	Application Programming Interface
APS	Announced Pledges Scenario
BC	Business Case
CAPEX	Capital Expenditure
CBM	Canvas Business Model
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
D.	Deliverable
DHCN	District Heating and Cooling Network
DHW	Domestic Hot Water
BMC	Business Model Canvass
EEA	European Environmental Agency
EED	Energy Efficiency Directive
EESS	Electrical Energy Storage System
EoL	End of Life
EMDE	Emerging Market and Developing Economies
EPBD	Energy Performance Building Directive
EPC	Energy Performance Contract
EPR	Energy Performance Ratio
ER	Exploitable Result
ESC	Energy supply Contracting
ESCo	Energy Service Company
ESI	Energy Service Insurance
EU	Europe
EV	Electric Vehicle
GHG	Green House Gas
HEMS	Home Energy Management System
HP	Heat Pump
HVAC	Heating Ventilation & Air Conditioning
IEA	International Energy Agency
IEQ	Indoor Environmental Quality
IoT	Internet of Things
IP	Intellectual Property
IPR	Intellectual Property Right
LCA	Life Cycle Assessment
LCOS	Levelized Cost of Storage
LFP	Lithium Ferro Phosphate
LHS	Latent Heat Storage
LIB	Lithium Ion Battery
NZEB	Net Zero Building
OEM	Original Equipment Manufacturers
OPEX	Operational Expenditure
KER	Key Exploitable Result
PCM	Phase Change Material
PLC	Programmable Logic Controller
PV	Photovoltaic Panel
PVT	Photovoltaic Thermal Panel
R&D	Research & Development
RES	Renewable Energy System
RGB	Red, Green Blue
ROI	Return Of Investment
SHS	Sensible Heat Storage

SME	Smal and Medium Enterprise
SoA	State of Art
SWOT	Strengths, Weaknesses Opportunities and Threats
TES	Thermal Energy Storage
TESS	Thermal Energy Storage System
TCM	Thermochemical Materials
TRL	Technology Reediness Level
UNEP	United Nation Environmental Programme
VAT	Value Added Tax
VP	Value Proposition
VPC	Vale Proposition canvas
WEEE	Waste Electrical and Electronic Equipment

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Disclaimer

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This deliverable has been conceived using R2M's exploitation and business modelling methodology, which has been developed across time as R2M has fulfilled this role in several EU projects. Although continuous improvements happen, the core of the methodology is common to other deliverables and, for this reason, the table of contents, some pictures and some text modules are similar to other business model deliverables developed in the framework of previous projects.

The contents here are project-specific and are the main result of R2M's and all contributors' effort in creating this report.

Executive Summary

This report outlines the business strategy for the commercial exploitation of the MiniStor results, based on an evaluation of the value propositions and business modelling using the Business Canvas methodology.

Five main Key Exploitable Results were selected during the project exploitation activity (detailed in the Deliverable 7.8), taking into consideration characteristics that bring them closer to the market and make them more likely to meet customer needs in the short to medium term.

These results are reported in Table 1 and can follow either a single exploitation and commercialisation strategy or a joint strategy, which would make the MiniStor solution a breakthrough innovation for the market.

Table 1. KER table - compact version

KER #	ER Name	Type	Owner (O) or Partner (P)
1	MiniStor compact Energy Storage System	Product, System	CNRS (O), CARTIF (O), CERTH-ITI (O), ENDEF (O), HSLU (P), PSYCTO. (P), SOFRIGAM (P)
2	MiniStor Home Energy Management System (HEMS)	Product, Software	CARTIF (O), CERTH-ITI (P)
3	Novel PVT System	Product	ENDEF (O)
4	Thermochemical Units (TCM storage)	Product	CNRS (O), PSYCTO. (P), SOFRIGAM (P)
5	Visual Interface IoT platform for user interaction	Software	CERTH-ITI (O)

The project partners from the MiniStor consortium can follow either a single exploitation strategy, considering only the results for which they are owners, or a joint exploitation strategy, forming a collaborative approach.

The joint exploitation strategy defined to meet the needs of the residential segment, should be considered the MiniStor compact integrated system that can provide multiple benefits, such as heating, cooling, DHW production, energy flexibility, and smart management of a building's energy needs. No similar technology developed by a single company is currently available on the market. To meet market demand, the joint exploitation strategy defined here is implemented through a newco[1] in which MiniStor partners (IPR and innovation owners and partners) and additional stakeholders participate, completing the entire value chain and providing a tailored solution for building end users.

The MiniStor business model is based on circularity, which guarantees a low environmental impact and additional economic benefits from the recycling process. Extended product responsibility, which

[1] NewCo or Newco is a term used to describe a corporate spin-off, startup, or subsidiary company before they are assigned a final name, or to proposed merged companies to distinguish the to-be-formed combined entity with an existing company involved in the merger which may have the same (or a similar) name. In a handful of cases the new company may retain the name "Newco" (Wikipedia).

is applied in Europe to products such as lithium batteries and PV systems, guarantees a relationship with the customer segment until the system is retired.

In conclusion, the circular business model can be applied to customer segments in three models: (i) direct selling, (ii) product as a service, and (iii) shared platform. The third model, the Shared Platform, can be implemented alongside the first two.

1. Introduction

1.1 Objective of the Report

The integration of Thermal Energy Storage System (TESS) in residential buildings is considered one of the pillars for the European decarbonization roadmap that had set the target of 40% of greenhouses gas emission by 2030.

This efficiency measure has been recognised fundamental to guarantee a high penetration of Renewable Energy Systems (RES) in the local energetic context like smart grids and local energy communities and guarantee an efficient use of the energy produced providing a direct impact to the heating, cooling and production of Domestic Hot Water (DHW).

This report provides an analysis of the business strategy identified during the project to facilitate market entry for the MiniStor results and bridge the gap between research and the market. It identifies the key stakeholders, resources and strategies required to reach the customer segment and defines a circular business strategy that can strengthen EU competitiveness in the energy sector.

1.2 Relationship with the MiniStor Activities

This deliverable represents the final output for the task 7.4 that worked supporting the IP management generated by the MiniStor, harmonizing the results of the project with the business vision of the consortium partners. As part of the exploitation roadmap, this activity collects information and feedback from all the WP7 tasks, with the purpose to identify the Key Exploitable Results (KERs) through the characterisation of the Exploitable Results identified in the task 7.3 and listed in the D7.4 "Exploitable Result Table".

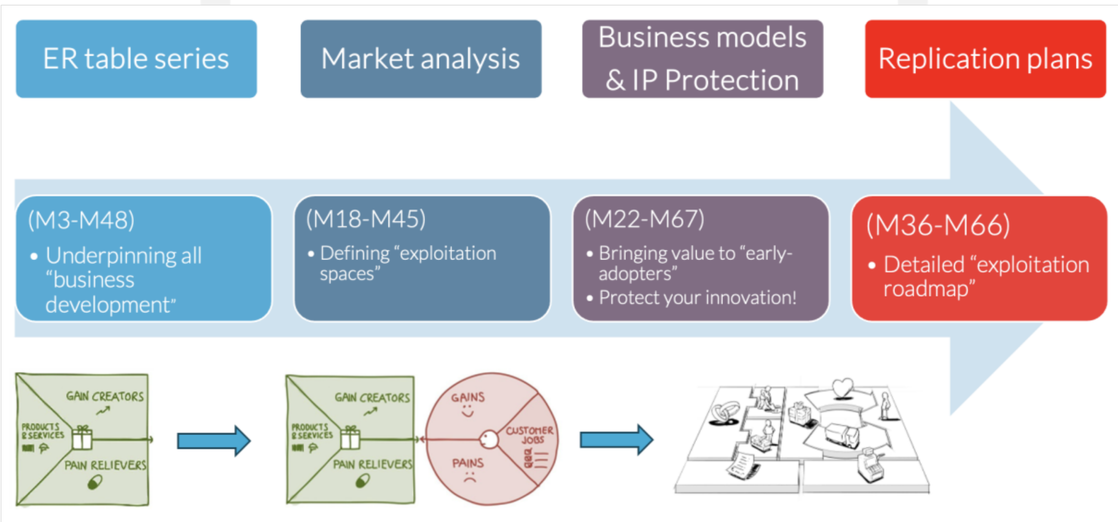

Figure 1. MiniStor Exploitation roadmap

The KERs can be considered as a *commercial-ready ERs which has been selected and prioritised due to its high potential to be "exploited" – meaning to make use and derive benefits downstream the value chain of a product, process or solution, or act as an important input to policy, further research, or education.* The selection process of KERs is well described in first part of the D7.8 "Replication Plan"

The business model analysis based on KERs have been strongly influenced also by the task 7.5 "Market analysis, cost and effectiveness assessment. In the first part the MiniStor Market Analysis reported in the D7.5 provided a detailed review of the strengths and the weaknesses of the MiniStor results compared with the main competitors technologies and products available into the market. Secondly, the cost-benefit analysis, with the main outputs included in the D7.7 identified economic bottlenecks for the future commercialisation phase.

Respect to the other project activities, the identification of innovative types of business models, takes also in consideration the issues and bottlenecks encountered by this innovative solution in the process of drawing, commissioning and installation, represented by the activity of the WP6 "Demonstration and evaluation".

1.3 Deliverable Structure

This document is structured in order to describe the context where the MiniStor business model is drafted, presenting at the beginning a brief description of the terminology, the methodology and the tools used in this analysis in the chapters one and two.

It continues, in the chapter 3, with an introduction of the EU energy market trend and the description of the main energy performance contracts that can facilitate the market entrance to the MiniStor solution in a context of an ESCo approach.

The context assessment is finalized in the chapter four with a description of the circular economy and some examples of consolidated use cases.

The chapter 5 represent one of the two main contents of the report providing a detailed approach to the business modelling through the Canvas methodology.

The chapter 6 contains the treatment of the business modelling assessment that is explained in detail in relation to the circular economy.

The last chapter, the number 7, describes the SWOT analysis done for the Platform as a Service and the Shared platform.

2. Business Model methodology

This chapter describes the main concepts, terminology and methodology used to identify, develop and validate the MiniStor business model. The Business Model Canvas was used as the tool and methodology in the exploitation work package. It is a useful visual approach for drafting new ideas, products and services, as well as new business ideas. It is based on the terminology listed in Chapter 2.1 and the structure described in Chapter 2.2.

2.1 Terminology

Business Models: A Business Model describes the rationale of "*how an organization creates, delivers, and captures value, in economic, social, cultural or other contexts. The process of business model construction and modification is also called business model innovation and forms a part of business strategy. The term business model is used for a broad range of informal and formal descriptions to represent core aspects of a business, including purpose, business process, target customers, offerings, strategies, infrastructure, organizational structures, sourcing, trading practices, and operational processes and policies including culture*" [1].

Business Case: The business Case "*captures the reasoning for initiating a project or task. For example: a software upgrade might improve system performance, but the "business case" is that better performance would improve customer satisfaction, require less task processing time, or reduce system maintenance costs. A compelling business case adequately captures both the quantifiable and non-quantifiable characteristics of a proposed project. Business cases can range from comprehensive and highly structured, as required by formal project management methodologies, to informal and brief.*
Information included in a formal business case could be the background of the project, the expected business benefits, the options considered (with reasons for rejecting or carrying forward each option), the expected costs of the project, a gap analysis and the expected risks. Consideration should also be given to the option of doing nothing including the costs and risks of inactivity. From this information, the justification for the project is derived" [2].

Business Model Canvas (BMC): The Business Model Canvas is the tool used to assess the MiniStor business approach. It "*is a strategic management template used for developing new business models and documenting existing ones. It offers a visual chart with elements describing a firm's or product's value proposition, infrastructure, customers, and finances, assisting businesses to align their activities by illustrating potential trade-offs* [3].

Value Proposition (VP): *A value proposition is the full mix of benefits or economic value which a company promises to deliver to the current and future customers (market segment) who will buy their products and/or services. It is part of a company's overall marketing strategy which differentiates its brand and fully positions it in the market. A value proposition can be set out as a business or marketing statement, called a "positioning statement", which summarizes why a consumer should buy a product or use a service* [4[2]].

2.2 The Canvas Business Model

The Business Model Canvas tool facilitates the systematic contribution for the MiniStor partners thanks to the visualisation approach.
The BMC is represented by a template composed by nine building-blocks as shown in the Figure 2. It was proposed initially in 2005 by Alexander Osterwalder, based on his

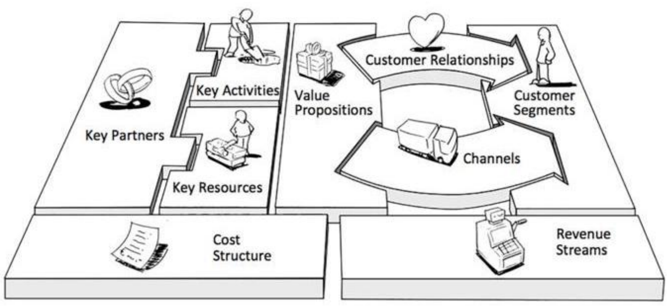

Figure 2. Business Model Canvass Template (Source Strategizer)

[2] Source https://en.wikipedia.org/wiki/Value_proposition

earlier work on "business model ontology" [3].

2.2.1 The Canvas Template

The nine Business Model Canvas blocks indicated in the Figure 2 and Figure 3, contain the key points to be developed in order to build the business strategy. Here each one is described:

- Key Activities: Actions key partners take to create and offer value propositions, reach markets, maintain customer relationships and earn revenue.
- Key Partners: Actors with a fundamental role in value proposition creation or delivery.
- Key Resources: Assets or services necessary to realize and deliver the value propositions.
- Value Proposition: The outcome being purchased through sales of the products & services.
- Channels: Means of communications, value proposition delivery, and user support.
- Customer Relationships: Strategies to attract/retain customers and encourage (re)purchase.
- Customer Segments: Profiles with common needs, behaviours, or other attributes.
- Cost structure: Most important expenses incurred in delivering value propositions, maintaining customer relationships and generating revenues.
- Revenue Streams: Sources and frameworks that generate turnover and subsequent profits.

Three are three areas coloured in the Figure 3 representing three main concepts. From the BMC literature it is possible to see: "*When you sketch out a business model with the Business Model Canvas you actually make assumptions about desirability, feasibility, and viability*" [3]:

Feasibility groups the three blocks related to the execution of the business model (key partners, key activities, and key resources). It represents the infrastructure necessary to execute your business model. If this part is not well sketched, there will be a poor execution.

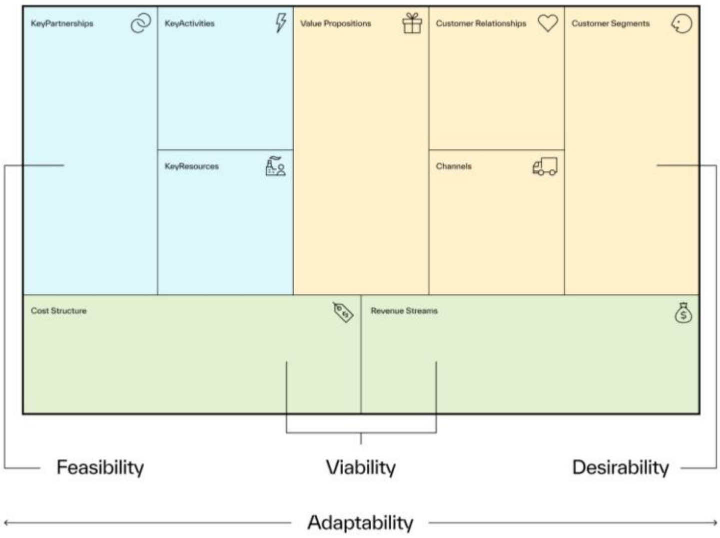

Figure 3. Areas of BMC (Source Strategizer)

Desirability represents the customer-side area. This area contains assumptions that will create the customer value and the relation with the customer segments. An unsatisfactory sketch in this zone, can produce an added value solving an irrelevant customer job. So, it could not satisfy the market needs.

Viability zone contains financial assumption that generate profits from the business. It is important to signal in place a profitable and perfect business.

Adaptability represents the entire BMC (feasibility + viability + desirability) and is about the assumptions that a balanced business model is chosen within the context of external factors, such as competition, technology change, or regulation (considering the risk of external threats).

2.2.2 The Value Proposition template

The Value Proposition Canvas (VPC), shown in the Figure 4, forms the core of the Canvas methodology. It comprises two zones that work together to report the characteristics of the value proposition (product or service) for sale, and the customer segment with its specific needs that must be met by the market.

[3] Source Strategyzer "Why companies fail & How to prevent" [Link]

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The VPC helps to ensure that a product or service is positioned around what the customer values and needs, and to ensure that there is a fit between the product and market. It is an outlook at the relationship between two parts of the BMC, customer segments and value propositions.

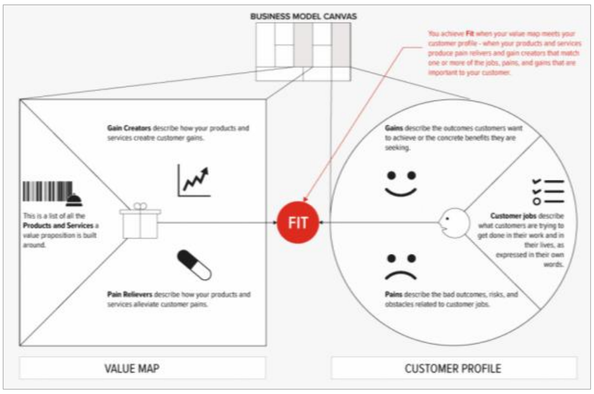

Figure 4. Reference from Value Proposition and BMC

The customer profile representing the market sectors and the potential customers to which productors or sellers of goods and services are oriented to sell. The meeting point of the two parts, indicated by the red point in the Figure 4, represents the market balance when the value proposition satisfies the request from the customer profile.

Value map (zoom in from value propositions block):

- Product and Services describe the market offer that value propositions are built around.
- Gain Creators describe how products and services create customers gains.
- Pain Relievers describe how product and services alleviate customer pains.

Customer Profile (zoom in from customer segments block):

- Customer Jobs describe what customers are trying to get done in their work and their lives.
- Gains describe the outcomes customers want to achieve or the benefits they are seeking.
- Pains describe bad outcomes, risks, and abstractions related to customer jobs.

The BMC is cantered around its value proposition(s): The Business Model can be considered well developed when there is a connection between the value map and the customer profile as show in the Figure 4[4]. It means that the value proposition can satisfy the needs of the identified customer profile, so the business model is able to transform the value proposition in monetary value. In the MiniStor project the value proposition is represented by the MiniStor System and the KERs and the customer segment is represented by the residential sector.

2.2.3 Ad-Lib value

'Ad lib', short for the Latin 'ad libitum', usually means speaking or performing without preparation or rehearsal. It implies improvisation or spontaneous speech/performance, often in response to a situation. In business, 'ad lib' can refer to the quick prototyping of alternative value propositions by filling in a template, which forces one to articulate how value is created, according to Strategyzer [3].

Value Proposition Ad-Libs: Ad-Lib value proposition template[5] is presented in Figure 5Error! Reference source not found. [6]. Ad-Lib VPs have been constructed for each value proposition to be used as an "elevator pitch" for validating business model assumptions throughout the MiniStor lifecycle.

[4] https://www.garyfox.co/value-proposition-canvas-guide/
[5] Bland D. and Osterwalder A., (2020) Testing Business Ideas
[6] https://assets.strategyzer.com/assets/resources/ad-lib-value-proposition-template.pdf

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Preliminary competitive advantages: The competitive advantage will be considered in the MiniStor project for each KER. Taking in to account a comparative competition set assessment that looks at the market alternatives and how the MiniStor solutions shall meet the stakeholder needs and hopefully surpass their expectations. Completing this activity will enable KER owners to use the final line of the Value Proposition Ad-Libs, thereby strengthening their elevator pitches.

Figure 5. Value Proposition ad-lib template

3. Market Trend driving MiniStor Business Models

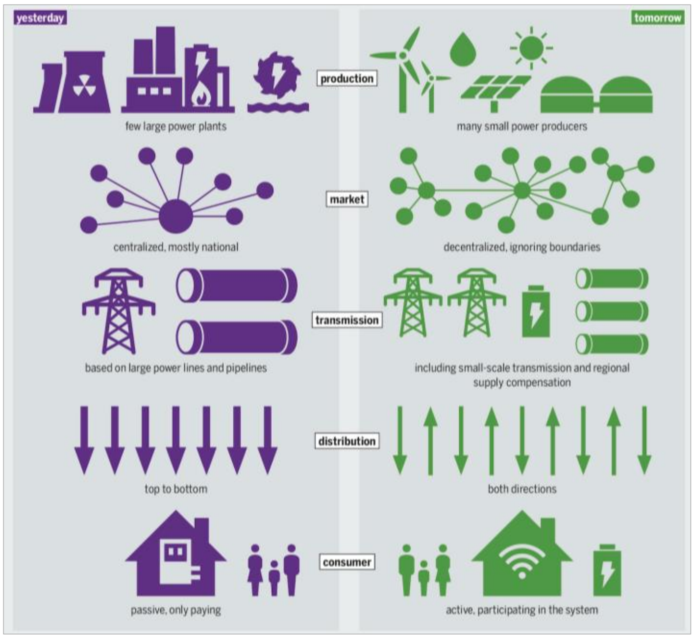

Figure 6. Decentralised energy model versus centralised model [4]

The evolution of the European energy context is characterised by the transition from the centralised system to the distributed generation and by the integration of RES plants into the energy networks, see Figure 6[7].

In the new concept, the energy system is moving towards the concept of a smart grid which includes new stakeholders and new players (prosumers) in the energy market. This poses a significant challenge to the entire energy which is becoming bidirectional and where the aleatorily of the RES productions impose an improved grid balance model.

In this context, the role of energy storage, become fundamental as it can support energy saving and increase the flexibility and the resilience of the system.

The second market driver impacting with the MiniStor project is the context of energy prices. Over the last five years, the energy market has been characterised by a significant price volatility for both electricity natural gas as illustrated in the Figure 7 and Figure 8. Apart from some situations, the EU trend shows a marked increase in energy prices, which has a direct impact on household management costs and in the other market sectors. This is due to a combination of factors, such as the energy situation post-Covid which brought new energy use habits (e.g. work from home), but mostly due to political instability in countries responsible for energy export (e.g. Russia, North Africa, etc.). This context could generate instability throughout the EU market, affecting the entire economy.

The third driver analysed here for MiniStor project is the household renovation market.

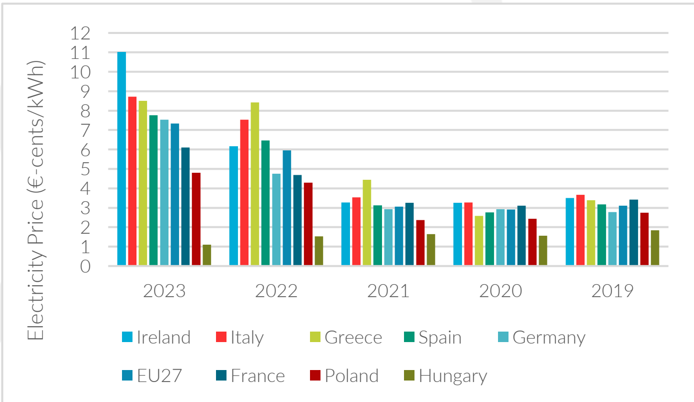

Figure 7. Household Electricity Prices period 2023-2019 (Eurostat)

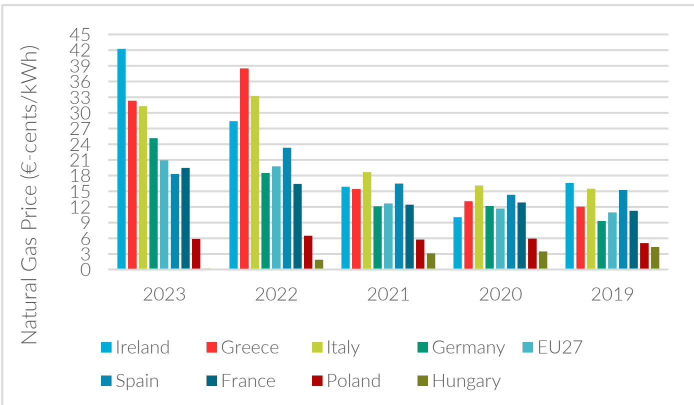

Figure 8. Household Natural Gas prices period 2023-2019 (Eurostat)

[7] https://it.wikipedia.org/wiki/Smart_grid

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This decade is characterised by significant investment in building renovation programmes, supported by European and national policies and regulation, primarily to reduce the environmental impact of buildings and the greenhouse gas emissions. In this process, innovative technologies that can reduce energy consumption while guaranteeing the same (or improved) living conditions for citizens, play a key role. Moreover, the most significant barrier to renovation remains the initial investment, which represents an obstacle for many building owners.

3.1 The Market of the Energy Performance Contracts

Energy Performance Contracts (EPCs) are a type of contract used in both the public and private sectors. They are based on energy efficiency and the performance of a system or plant compared to a baseline. Improved performance is reflected in terms of energy and cost savings, as well as a reduced environmental footprint (CO_2 reduction).

According to the IEA [5], EPCs are long-term contracts, ranging in duration from two to 20 years. They provide clients with a programme of practical engineering and energy efficiency measures implemented in buildings (residential or industrial), delivering real energy savings through the installation of renewable energy systems (RES), HVAC systems, lighting, controls, and building envelope improvements. Building occupants can also receive training in energy efficiency practices to minimise total energy consumption by way of demand-side energy efficiency methods.

Key actors in EPCs are Energy Service Companies (ESCo), which carry out investments to improve energy efficiency and assume the risk of the initiative, thereby freeing the end customer from any organisational or investment burden. The EPC contract regulates the collaboration between the ESCo and the client, as well as general matters including property rights, system usage and partnership length. It also stipulates the amount and structure of the investment, how it is to be implemented and overseen, and how the implemented energy-saving measures are to be maintained.

It specifically establishes how the annual savings are distributed. These payments are usually linked to performance and savings obtained during a reference period, as measured by the International Performance Measurement and Verification Protocol.

In the market of EPC contract, normally there are three main categories of figures that have a different role in the process, depending on the type of EPC implemented. The Table 2 describes the three categories.

Table 2. EPC contract key players

	Beneficiary / End User The beneficiary in the EPC contract is the end user. He is normally the building owner that benefits from the energy service and the cost reduction. He can represent the private of public sector, from a simple homeowner from the representative of a municipality. His objective is to reduce the energy costs and improve the technological level.
	Financial Provider (Bank / Investors) The financial provider is a third party that invest the loan in the project. It can be a commercial bank, a private institution or, sometimes the ESCo itself. Sometimes, this role is covered totally of in part by the beneficiary.
	Energy Service Company (ESCo) The ESCo is the company responsible for the financial risk. It takes part in the installation and management of the efficiency measures and is remunerated by the cost saving (all or a share) for the contract period.

Below some common typologies of EPC contracts are described in the main aspects. Each model has advantage and disadvantage, and the choice depend essentially on the type of project, the typology of the client and the access to the capital. Sometimes the national constraints and regulation determine the choice of the EPC contract.

3.1.1 Capital performance contracts - First out contracts

The *first out* EPC contract is characterised by a short contract period (normally 3–5 years) and the main objective is to end the contract quickly. The initial investment for plants or efficiency measures is fully funded by the ESCo and becomes the property of the customer at the end of the contract. Therefore, the return on the initial investment must be achieved within a few years. In this case, the full amount of the savings achieved (cost savings) for the selected period is guaranteed to the ESCo in order to repay the loan, including finance charges and profit.

In this model, increased savings allow for faster payback on the investment, thereby shortening the contract duration rather than providing an additional source of revenue for the ESCo.

3.1.2 Shared saving contracts - First in contracts

The *First in* EPC contract is quite similar to the *First out* model but covers a longer period (5-10 year) where the savings (cost savings) are divided between the ESCo and the client in a percentage defined at the beginning, on the basis of a feasibility study and considering the repayment period, the risk assumed, and the capital committed. A typical agreement of cost saving sharing is 70% to the ESCo, 30% to the user.

The client befits from a reduction energy costs and the ESCo benefits from a longer period of licence fee. The ESCo maintain the ownership of the system until the end of the contract, after which ownership passes directly to the customer (Figure 9). This is probably the most used EPC contract mostly applied in Asian countries such as Philippines and Japan [5].

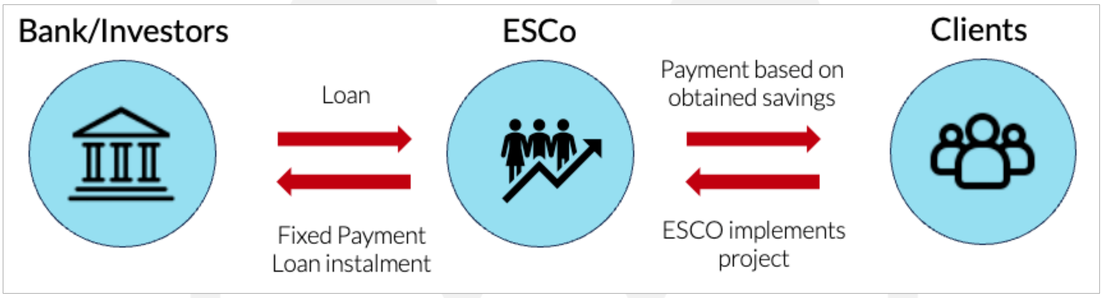

Figure 9. Shared saving EPC model

3.1.3 Pay for Performance Contact

This model is a sort of shared saving contract but characterised by a different payment model. Here the client pays on the base of an indicator set on real results (energy saving) achieved in the reference period. Therefore, the payments can vary in every period. Property and management of the property remains the same of the shared saving contract.

3.1.4 Guarantee saving Contract

In this EPC contract, the initial financing and its management is in the responsibility of the end client (bank loan), but the energy saving is guarantee by the ESCo.

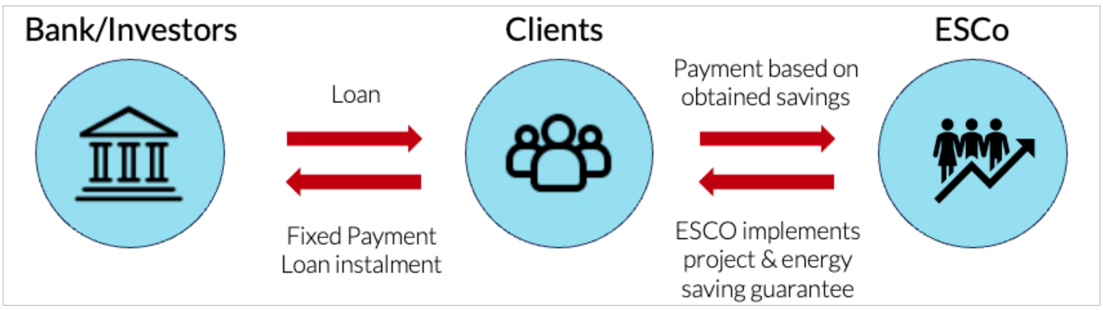

Figure 10. Guarantee saving EPC model

Therefore, the EPC contract covers the risk to reach lower performances. In case the energy (cost) saving is not sufficient to cover the loan instalment, the ESCo itself will cover the difference. The ESCo remuneration covers system management and maintenance service. The ownership oversees the client from the beginning of the contract. This is the most widespread model in the European, USA, African and Australian markets [6].

3.1.5 Guaranteed savings with risk sharing contract

This EPC model is a mix of the Guarantee saving contract, but it has also a share of shared saving. Therefore, the risks and benefits are divided between the ESCo end the is client based on an initial agreement.

Sometimes small ESCo with limited access to credit can use Energy Saving Insurance (ESI). The ESI is offered by some financial institution, insurance companies or private companies, to cover the risk of the uncertainty associated with the performance efficiency and the methodology used to measure the efficiency. The ESIs cover two types of events:

(i) Technical Insurance: ESI covers the risk where the promised energy performances are not obtained by the efficiency measures
(ii) Credit Insurance: This ESI covers the case where the customer fall in credit default.

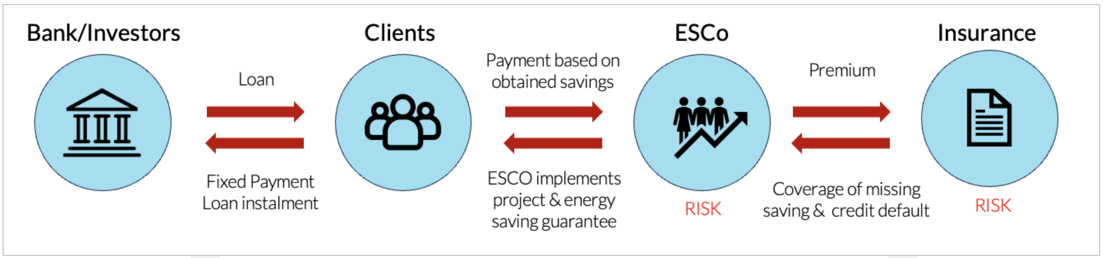

Figure 11. Energy Saving Insurance model

3.1.6 Energy Service Contract

This EPC model takes in consideration as well as the initial investment (technology installation), also services provided by the ESCo to the client such as operation & maintenance of systems, monitoring and management.

This typology of EPC contract follows the Active Energy Performance Contract that incorporates the management of some customer energy loads (consumptions). Active-EPCs enable adjusting use or operation processes (e.g. running appliances at off-peak hours) or onsite energy production to further energy and cost savings managing the building flexibility. In this context, it becomes fundamental the building digitalisation level to allow automatic energy management by iteration with smart meters and energy management systems.

Another EPC model that takes in consideration the services is the EPC Energy Supply Contracting (ESC). In this contract, the ESCo is responsible for the technological upgrading, the energy saving and the energy supply. It is a common contract for the heating and cooling supply by District Heating and Cooling networks (DHC) with CHP systems or for electrical energy production by RES (PV and Wind turbines). This contract is most popular in European countries such as France and Germany [6].

“Public Super ESCos” have been also created in several countries to kickstart an energy efficiency market. A Super ESCo is an entity that operates at a higher level than a traditional ESCo, often functioning under government or large institutional oversight. The objective of a Super ESCo is to drive large-scale energy efficiency projects and initiatives across various sectors, including public buildings, industrial facilities, and infrastructure. The African Development Bank (AfDB) launched in February 2023 supports for the establishment of public Super ESCo in nascent markets such as Rwanda, Senegal and South Africa [7].

3.1.7 Active Building Energy Performance Contract (AEPC)

The *"active"* component typically refers to the use of real-time monitoring, data analytics, and adaptive systems to optimize energy performance dynamically.

The Figure 12 highlights how the new concept, AEPC, is linked to the EPC and describes its ecosystem from a business model perspective. The first inner ellipse shows the core stakeholders that are directly involved in the AEPC service delivery. The second ellipse shows those stakeholders that are more generally involved in the ESCo business and in delivering EPC or other energy contracting services. The final outer ellipse shows a third range of stakeholders that are only indirectly involved or influence the activity of the first two categories [9].

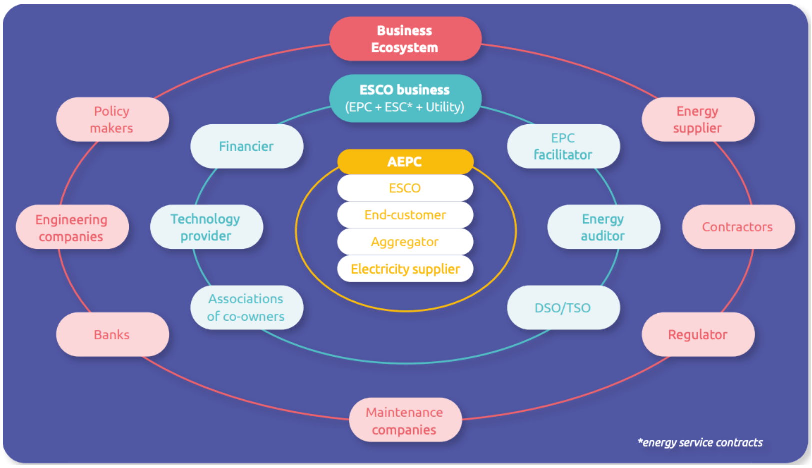

Figure 12. AEPC most relevant stakeholders' business ecosystem (from AmBIENCe report,2022)

The Figure 13 shows the business model associated to AmBIENCe EPC contract that can be generated by the AEPC parameters in consideration as type of building, building occupation by owners or rented. The AEPC business model is an evolution of the basic EPC contract, but it takes in consideration benefits and revenues generated by energy flexibility as demand response programmes available into the energy market.

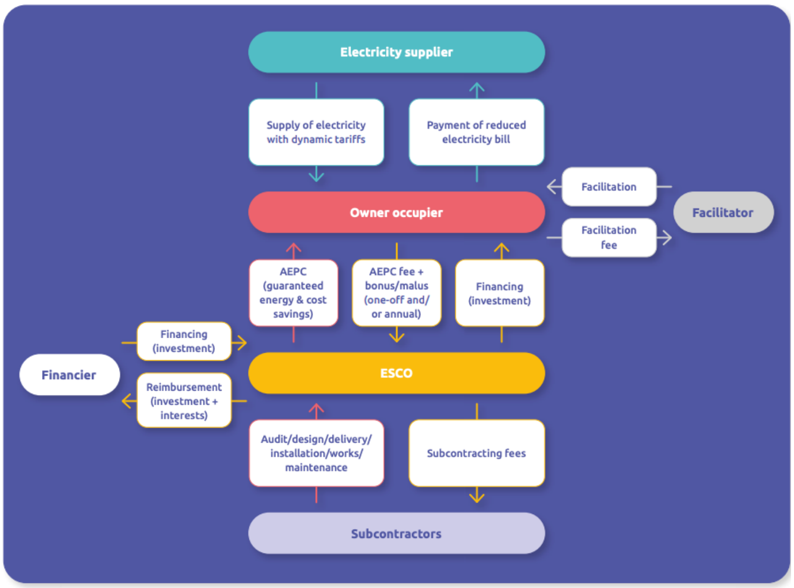

Figure 13. AmBIENCe EPC Business models

3.2 The ESCo European market trend

In recent years, the most relevant market sector for the ESCo has essentially been building renovation. According to the European Environment Agency (EEA), buildings account for 42% of the EU's annual energy consumption, 35% of its annual greenhouse gas emissions, and around one-third of all materials consumed in the EU each year. Despite this significant environmental impact, however, only around 1% of buildings are renovated for energy efficiency each year. This highlights the critical need for increased efforts and policies to promote sustainable building practices to meet climate targets by 2050. The EEA also notes that the construction industry is estimated to be worth €1.7 trillion and could generate over 20 million jobs [10].

This challenge underscores the importance of initiatives such as the European Union's Renovation Wave project (released in 2020 by the European Commission)[8] and the involvement of ESCo in facilitating these essential upgrades. Recently, the EU has further strengthened the Energy Efficiency Directive (EED), setting a target of 4% improvement in energy efficiency per year and an 11.7% annual reduction in energy consumption by 2030.

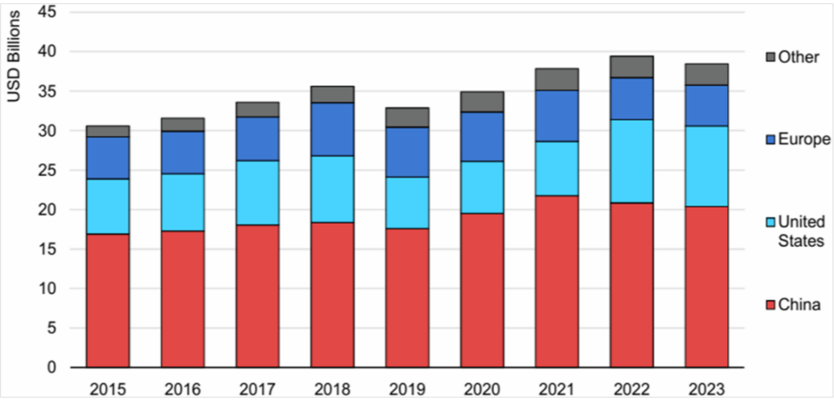

Figure 14. Total investment by energy service companies, 2015-2023 (IEA: Energy efficiency 2024)

The EED is complemented by a strengthened Energy Performance of Buildings Directive (EPBD) on 28 May 2024 [11], which is necessary to realize the Renovation Wave and to boost the energy performance of buildings and requires new buildings to be solar energy ready. The EPBD aims to reduce the primary energy use of residential buildings by 16% by 2030 and by 20% to 22% by 2035 [12].

The IEA-UNEP 2024 Global ESCo Survey has observed that the ESCo market decreased by 2.2 % in 2023 (see Figure 14). However, according to IEA, this comes against the backdrop of strong growth in recent years, and the total market size remains above USD 35 billion. The slight decline in 2023 is partly driven by public budget cuts, given that the sector is a significant client of ESCo. To date, the global market is dominated by China, the United States and Europe, which together account for more than 90% of all ESCo investment [13].

3.3 The Circular Business Model

In the context of MiniStor, it is important to pay attention to sustainability, both in terms of the solution and the business model defined to support the commercialisation of the results. One interesting approach is the circular business model, which is becoming increasingly popular.

Figure 15. Circular Economy Business Model

The circular business model is a sustainable evolution of the traditional economy where an organization create value and participate in its value chain minimizing the ecological footprint and reducing the social costs. Unlike the linear model, which is based on a 'production-distribution-consumption-disposal' life cycle, the circular approach aims to maximise the value of resources by minimising waste and promoting the reuse, recycling and regeneration of materials as shown in the Figure 16.

This approach is at the heart of the European Commission's strategies for addressing the environmental, economic and social challenges of our time and sustain the economic growth and the EU competitiveness.

The European Commission has identified this model as crucial to achieving the goals of the European Green Deal[9] and transitioning to a climate-neutral, resilient economy. Through the Circular Economy Action Plan[10], the EU is promoting policies and instruments that incentivise companies to innovate

[8] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/renovation-wave_en
[9] https://ec.europa.eu/stories/european-green-deal/
[10] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0098

products, processes and services according to the principles of eco-design, durability and reparability. This approach contributes to environmental protection and opens new opportunities for economic growth and employment, thereby stimulating the competitiveness and resilience of the European production system.

This project has received funding from the European Union´s Horizon 2020 research and innovation programme under the grant agreement No 869821

4. Circularity Business Models

To meet the Sustainable Development Goals[11] reported in the Figure 16, renewable energy systems are currently in the spotlight. Solar and wind energy are the primary drivers of the renewable energy market, whereas biomass and geothermal energy only make a minor contributor [14].

Figure 16. Sustainable development Goals

The most promising business model for the sustainable energy transition with potentiality to reach the SDG goals is the circular business model.

This Business Model is an innovative approach to sustainability, focussing on creating a closed-loop system in which resources are reused, recycled, or regenerated instead of being discarded. It is a key component of the circular economy, which minimise waste, extend product lifecycles, and reduce the environmental impact of production and consumption.

In order contribute to the European goals in terms of energy and material sustainability the MiniStor business model has been developed based on the common circular best practices and models already in place in Europe.

4.1 PV Circular Economy Business Model for PVT collector

Starting from 2010, the annual capacity added by photovoltaic installations has gone up significantly, resulting in an annual installed photovoltaic (PV) capacity of 240 GW in 2022 (Figure 17), accumulating a total installed PV capacity of 1.185 GW worldwide [14].

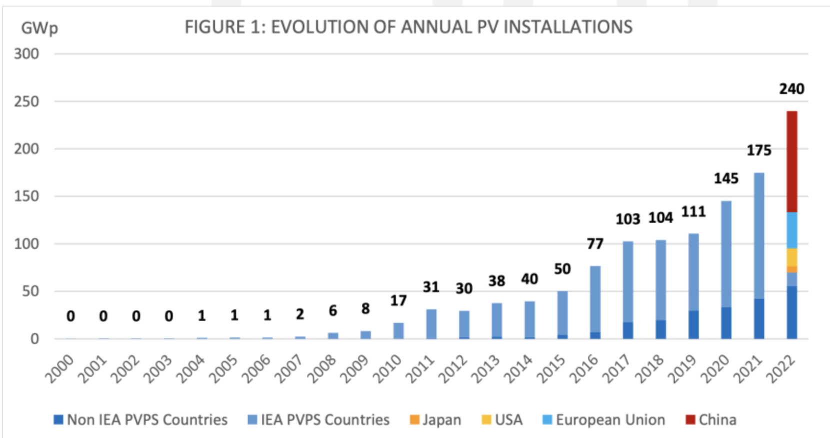

Figure 17. Evolution of PV annual installation (IEA PVPS)

The International Renewable Energy Agency (IRENA)'s Remap analysis shows that solar PV power installations could grow almost six-fold over the next ten years, reaching cumulative capacity of 2.840 GW globally by 2030 and rising to 8.519 GW by 2050.

The solar PV capacity added in 2023 (347 GW, 73% more than the previous record 200 GW set in 2022) almost equals all such capacity added in the eight years from 2010 to 2017. In the 1.5 °C scenario, installed solar PV capacity would exceed 5.400 GW by 2030 and 18.200 GW by 2050 [15].

[11] https://sdgs.un.org/goals

This project has received funding from the European Union´s Horizon 2020 research and innovation programme under the grant agreement No 869821

In recent years, there has been an increase in attention towards the management of end-of-life (EoL) PV modules, also known as PV waste. If the decommissioning of PV systems is not handled properly, the growing number of EoL PV modules could present a new environmental challenge.

The rapid growth of installed capacity has led to an increase of PV waste. IRENA has projected the cumulative global waste of 1.7 to 8 million metric tonnes in 2030 and will increase to 15 to 32 million tonnes in 2040 before reaching 60 to 78 million tons in 2050. IRENA defines two categories of cumulative global waste: (i) regular loss that assumes solar panels will last 30 years (PV lifetime) without early attrition or decay and (ii) early loss instead, that takes account of "infant", "mid-life" and "wear-out" failures before the 30-year lifespan. (Figure 18) [16].

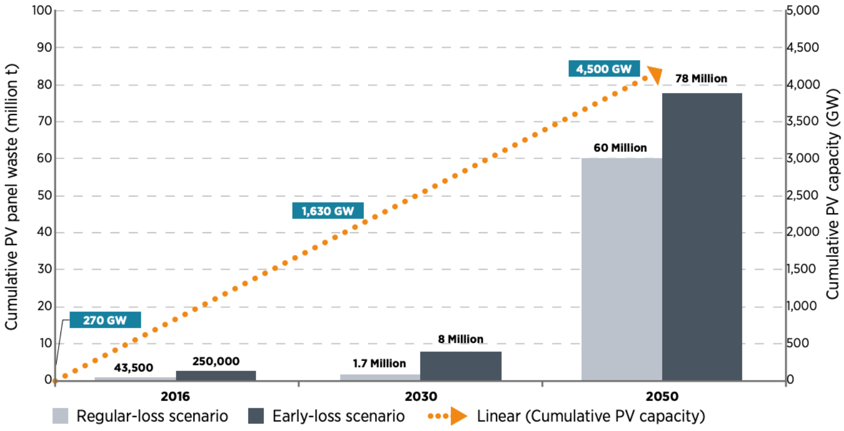

Figure 18. Overview of Global PV panel waste projection, 2016-2050 – IRENIA

In recent years, there has been an increase in attention towards the management of end-of-life (EoL) PV modules, also known as PV waste. If the decommissioning of PV systems is not handled properly, the growing number of EoL PV modules could present a new environmental challenge.

Preeti Nain et al. point out that the average lifespan of crystalline solar modules is 25–30 years, creating the impression that there is currently a low volume of waste, which can result in delays or the non-inclusion of EoL PV waste in legislation [17]. A broader vision of production and consumption is necessary to address this issue and establish a renewed circular economy.

The circular economy is a holistic production model that translates into a new way of designing and using products and services [18]. It implies moving from a linear to a circular model, considering waste at all stages of the production process [19]. Holistic planning is required for the EoL management of PV modules, considering not only the environmental aspect, but also the financial perspective. Two examples in this area are the recovery of raw materials and the creation of new end-of-life solar PV industries [20].

4.1.1 International policy

The Eco-design for Sustainable Products Regulation, which entered into force on 18 July 2024, is the cornerstone of the Commission's approach to more environmentally sustainable and circular products. There is no international standard for recycling photovoltaic modules now [21]. For instance, the European Union has created policies and instructions for

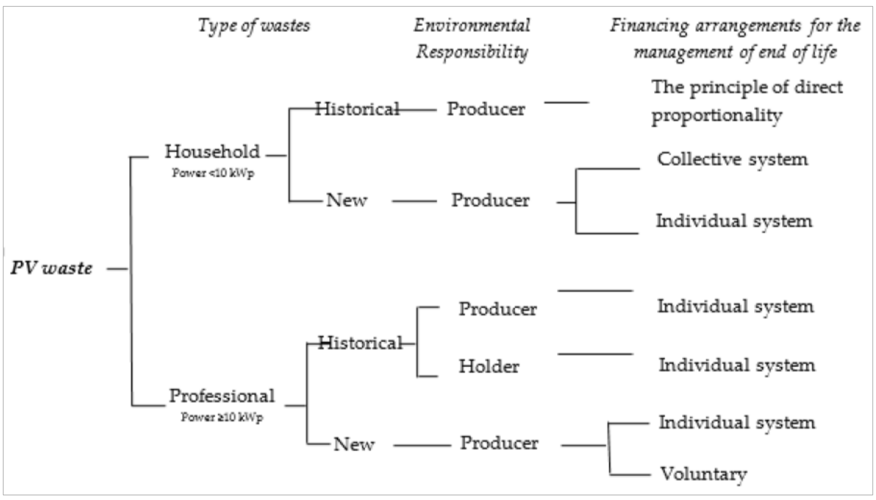

Figure 19. Diagram of photovoltaic (PV) waste types and modalities of financing

the management of PV modules at the EoL. Extended producer responsibility (EPR), introduced by the European Directive on Waste Electrical and Electronic Equipment (WEEE) [17], has obliged producers and importers in each European member state to organize the collection, transport, recycling and financing of these operations for their PV equipment since 2014. This now represents one of the most important meta-principles of environmental policy (Figure 19) [22].

In the USA, some states have laws that specifically address the EoL of PV systems. In China, the development of equipment and legislation related to the recycling of PV equipment is being rapidly developed (see Table 3) [20].

Table 3. Status of photovoltaic end-of-life management in several photovoltaic leading countries

Country	End-of-life photovoltaic module quantity in 2050 (million tonnes)	Photovoltaic end-of-life approach	Specific regulation on photovoltaic end-of-life	Remarks
Germany	4.3 to 4.4	Extended producer responsibility	ElektroG	N/A
Italy	2.1 to 2.2	Extended producer responsibility	Legislative Decree No. 49	N/A
United Kingdom	1 to 1.2	Extended producer responsibility	United Kingdom WEEE Legislation	N/A
China	13.5 to 19.9	N/A	N/A	-E-waste management is established but photovoltaic is not included. -Research and development on photovoltaic end-of-life has started.
United States	7.5 to 10	Extended producer responsibility (Washington)	N/A	-California has been working on photovoltaic end-of-life regulation within its border. -State and industrial-led policies on photovoltaic end-of-life have started to emerge.
Japan	4.4 to 7.5	Treated under general regulation for industrial waste management	N/A	-Research and development projects on photovoltaic end-of-life recycling.
India	4.4 to 7.5	Treated as general waste	N/A	-Government has issued a message for developers to follow WEEE waste rules.
South Korea	1.5 to 2.3	Included as industrial waste	N/A	-Initiated discussion on photovoltaic end-of-life management.
Australia	0.9 to 0.95	N/A	N/A	-Research and development on photovoltaic end-of-life by industry.

N/A is not applicable; WEEE is waste from electrical and electronic equipment; e-waste is electronic waste; ElektroG is Germany's Electrical and Electronic Equipment Act.

Removing the encapsulation from the laminate used in modules (the most widespread is ethyl vinyl acetate, ethylene vinyl acetate) is the most challenging steps in the recycling of crystalline silicon PV panels due to the high-energy consumption of thermal processes at high temperatures, for the use of solvents, and for the treatment of the fumes in the process [22]. Furthermore, according to Nain P. et al., the current EoL PV regulations have no regulations of emerging contaminants such as PFAS (per- and poly-fluoroalkyl substances) and microplastic [17].

4.1.2 A path to sustainable decarbonization of PV

In order to create a circular economy for PV systems, changes must be made across the entire supply chain. This includes promoting the circular design and manufacturing of high-quality systems, maximising product lifetimes through maintenance, repair and reuse, establishing high-value recycling and reducing landfill.

This project has received funding from the European Union´s Horizon 2020 research and innovation programme under the grant agreement No 869821

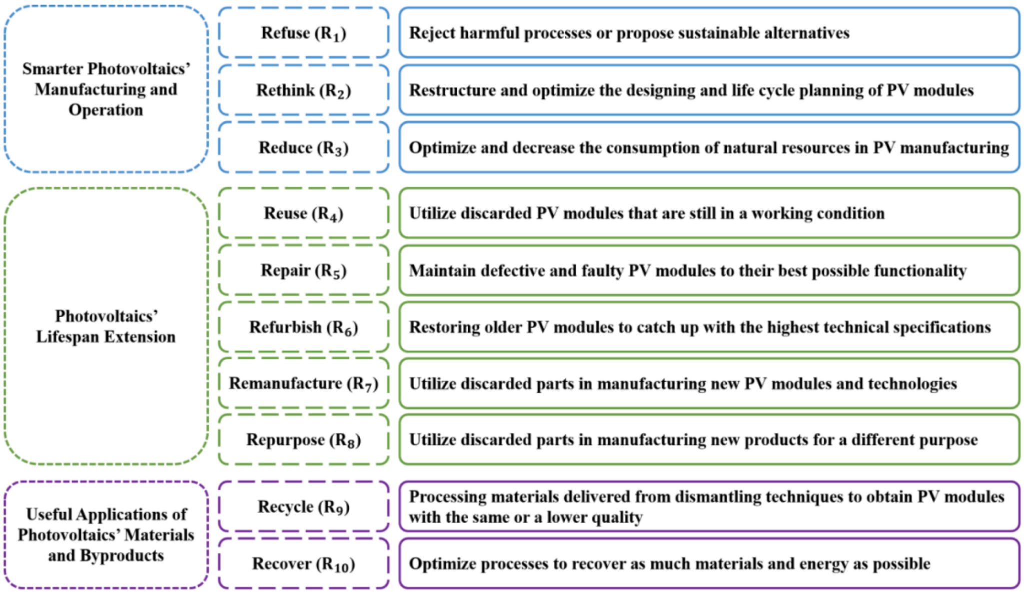

Figure 20. 10R principles of sustainability and the targets of Photovoltaics' Circular Economy

According to Hussein et al., the implementation of the best circular economy, not only focuses on the 3Rs sustainability principles (Reduce, Reuse, and Recycle) but also the entire 10Rs of sustainability as shown in the Figure 20 [23]. Figure 21represents the steps necessary to put in place the 10Rs process. From the beginning (Design phase) it is fundamental to take in consideration the circular economy, not only to guarantee the use of recycled materials but also to facilitate the disassembling at the end of life. The crucial of circular models' step is placed at the end of the product life with the dismantling facilities, in most of the case this step is done in dedicated factories that extract from the used PV panels, all the material that can be recused in the production, not only of PV panels but also of other goods (Step 6 shown in the Figure 21) [24].

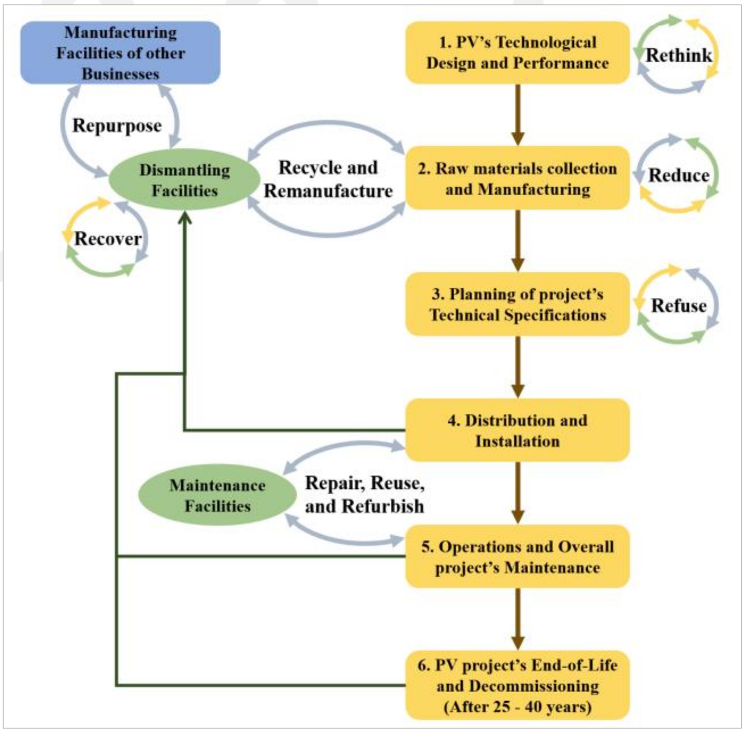

Figure 21. Applicable areas for the 10Rs of sustainability within the Photovoltaics industry

4.1.3 PV Circular Economy

Several articles report on studies and models of circular economy for PV modules. One of the most useful is the scientific article "*Review on feasible recycling pathways and technologies of solar photovoltaic modules*" published in 2015 by Jing and Tao.

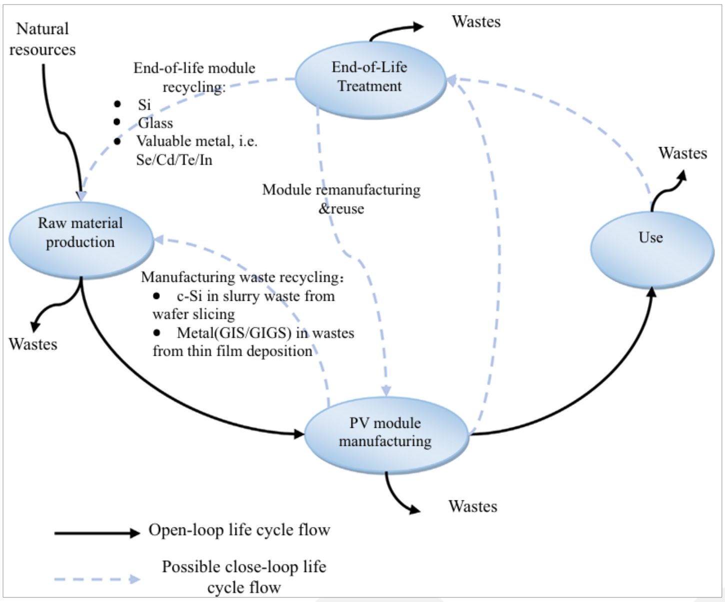

Figure 22. PV Loop life cycle flow

The model is based on an open-loop cycle flow presented in the Figure 22. In an ideal closed-loop life cycle, the volume of material moving around in the cycle is maximized.

To put it simply, the waste that leaves the life cycle at every stage is usually minimized compared to reality. Consequently, the use of natural resources is also minimized, resulting in minimal environmental impacts but in reality, is more burdensome [25].

In the pursuit of sustainable energy solutions, the photovoltaic industry has made significant strides towards optimizing the lifecycle of PV modules. This involves not only the efficient production of solar panels but also the responsible management of their end-of-life phases. An integral part of this approach is the implementation of a closed-loop life cycle, which prioritizes the reduction/reuse of waste at every stage and the conservation of natural resources.

Other studies focus the attention on the recycling processes techniques, as illustrated in the Figure 23[12]. The picture reports main three dismantling phases:

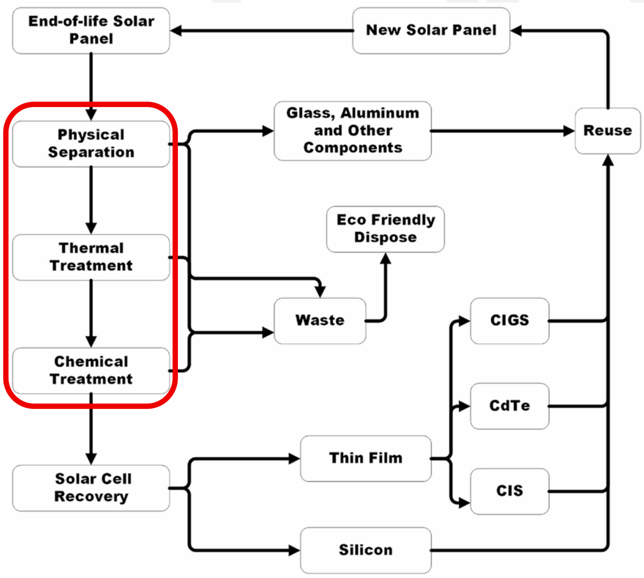

Figure 23. Types of solar PV recycling processes

Physical: in this process, panels are primarily dismantled by removing the surrounded aluminium frame, as well as the junction-boxes, glass and embedded cables.

Thermal: This process can effectively recover waste materials like poly crystalline silicon and other metals. Additionally, thermal treatment can decompose organic materials, such as encapsulants and polymeric layers, which can be disposed without damaging the environment

Chemical: by applying specific chemicals and solvents, the different layers (such as Ethylene Vinyl Acetate) of the solar panel can be selectively dissolved, allowing for the recovery of individual components to be reused.

[12] Chowdhury, M.S., et al., An overview of solar photovoltaic panels' end-of-life material recycling. Energy Strategy Reviews, 2020. 27.

4.1.4 Recommendation

Based on practices followed by Europe and the United States, Nain P. et al. outlines the following recommendations illustrated in the picture below.

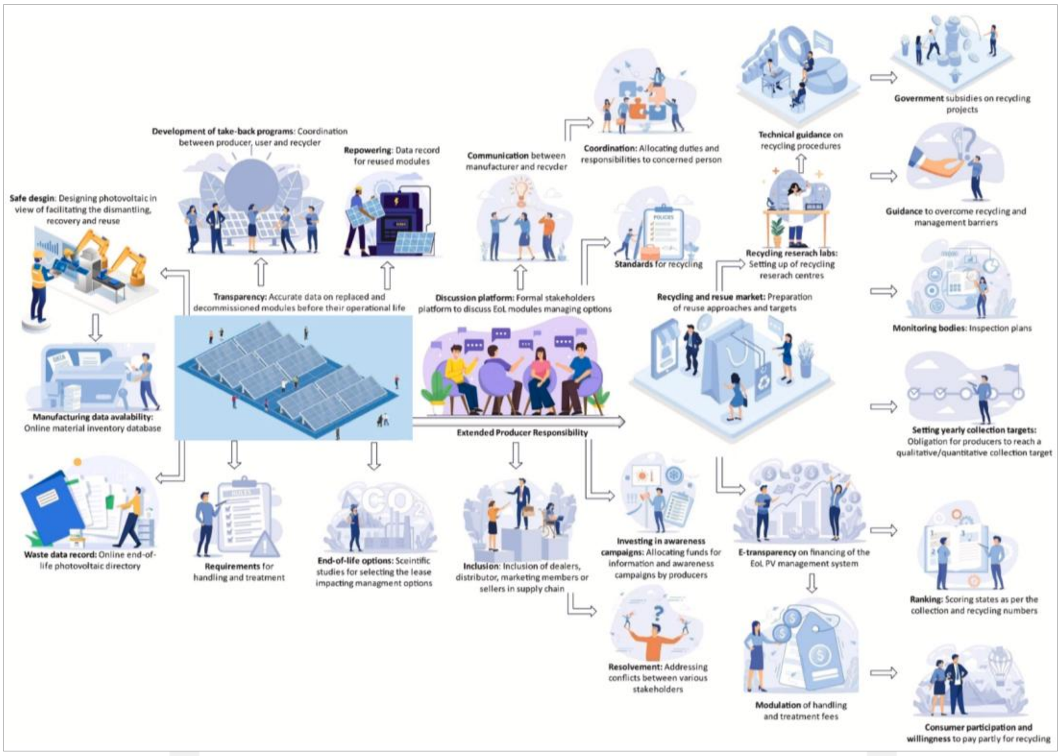

Figure 24. Recommendation for end-of-life solar photovoltaics management

The scheme in the Figure 24 and the studies can be summarised in three levels of recommendation that are pillars to put in place an efficient circular economy for PV technology:

Product level:

- Reuse and recycling market: It may be beneficial to create centres for re-use and recovery that employ operators who are nationally certified.
- Promote and increase transparency: At every stage, it is important to report materials and data to enhance waste management.
- Monitoring process and collection targets: By creating collection targets for manufacturers and states, the collection rates of all modules can be enhanced.

Stakeholder and productor level:

- Communication and coordination: Speeding up all processes is possible by providing sufficient communication channels, but conflicts can also arise due to unclear roles and responsibilities between different parties.
- Consumer participation: Accurately understanding the willingness of consumers to participate and pay for dismantling and recycling.
- Roles and responsibilities: By clearly defining responsibilities for stakeholders involved efficient operation of PV waste management can be achieved.

Regulation level:

- Implementation of EPR principle: Both public and private partners are involved in EPR in the European Union, with coordination being done through a central authority or a common platform for discussion.
- Information availability: Regulations that promote manufacturers to provide descriptions of the module material composition to avoid the need for hazardous waste characterisation.

- State or Regional Waste Plans: Decentralized collection and recycling are necessary.
- Economic Incentives: To promote the safe handling and design of easy-to-recycle processes, grants from state or private organizations are required.

4.2 Lithium battery Circular Economy

The rapid adoption and integration of lithium-ion batteries into various sectors underscore their pivotal role in modern technology. Their versatility extends beyond just consumer electronics; they are instrumental in powering electric vehicles (EV), thereby supporting the global shift towards cleaner transportation.

The integration of these batteries into power grids further enhances their significance, providing grid stability and aiding in the management of renewable energy sources, supporting energy flexibility and enhancing energy security by mitigating the risk of supply disruptions. As countries strive to reduce their carbon footprints, battery storage systems become critical in balancing intermittent renewable energy with grid demands, ensuring a steady flow of electricity even when natural conditions are not ideal [26].

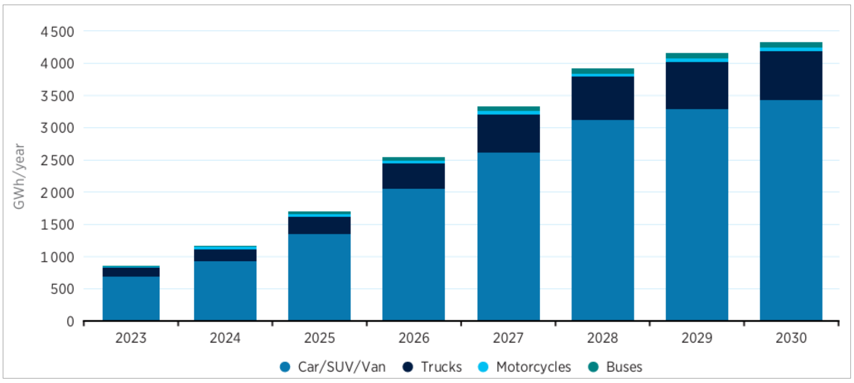

Figure 25. Estimated battery demand for EV in 2023-2030

The 1.5 °C Scenario sees battery storage offering significant flexibility to the power system, reaching almost 360 GW by 2030, and 4.100 GW by 2050 [27] (see Figure 25 [13]).

In addition, according to the IEA, battery demand growth can be predicted by three scenarios (Global Energy and Climate Model scenarios [27]):

1. Stated Policies Scenario: demand is set to grow four-and-a-half times by 2030 compared to 2023, and more than seven times by 2035.
2. Announced Pledges Scenario (APS): demand is significantly higher, multiplying by five times in 2030 and nine times in 2035.
3. Net Zero Emissions by 2050 Scenario (NZE): Demand grows even more, up 7 times in 2030 and 12 times in 2035.

The Announced Pledges Scenario (APS) approach suggests that there will be an increase in battery demand per week in 2035 compared to the whole year of 2019. If countries reach their announced climate and energy pledges in full. [29].

Research indicates that buildings slowly transform from energy consumers to prosumers [30]. Therefore, an interactive building-electric vehicle energy network can tackle the intermittency of renewable energy with high renewable energy self-consumption [31].

Although, they are not yet cost-competitive with fossil fuels, battery storage costs have decreased by almost 90% from 2010 to 2023 (from USD 2.511 to USD 274 per kWh) and reaching the absolute lowest cost of 115 kWh in 2024 [32].

China remains the primary battery market, accounting for around 55% of global demand in 2023, with Europe and the United States each accounting for about 15% [29].

As the demand for battery becomes increasingly significant, recycling and reutilization are essential to address the growing volume of used batteries, which contain valuable materials such as lithium, cobalt, and nickel. Efficient recycling processes can reduce the environmental footprint of battery

[13] IRENA, Critical materials: Batteries for electric vehicles, International Renewable Energy Agency, Abu Dhabi. 2024.

production and contribute to a circular economy, minimizing waste and promoting the sustainable use of resources.

Methods of battery recycling processes:

As shown in Figure 26[14], there are two main traditional methods of battery recycling processes techniques: pyrometallurgy and hydrometallurgy (respectively, red and green colours; the blue refers to the battery start and end life) [33].

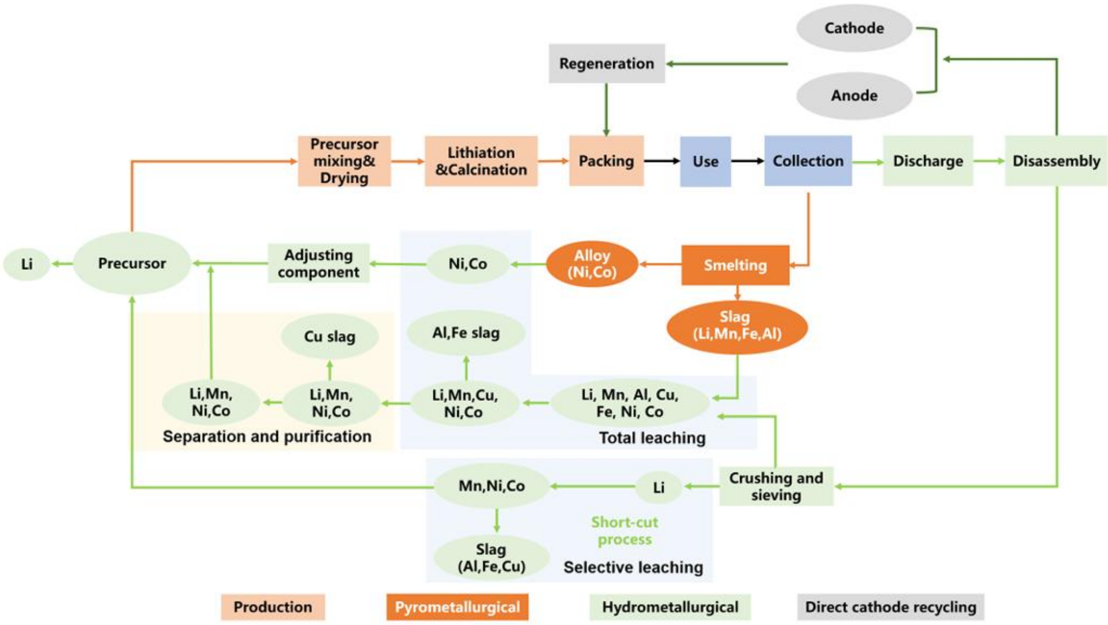

Figure 26. LIBs processes including manufacturing and three recovery methods

Pyrometallurgy involves high-temperature processes where batteries are smelted to recover valuable metals like cobalt, nickel, and copper. This method, while effective, can release harmful emissions and lead to the loss of some materials [34].

Hydrometallurgy, on the other hand, uses aqueous chemistry (by leaching process [35]) to dissolve and separate metals from the battery material [36]. This method is generally more environmentally friendly, allowing for the recovery of a broader range of materials with less energy consumption [37]. However, it requires careful handling of chemicals and generates waste that must be managed properly.

In other recycling processes, like biohydrometallurgy, which is one of the branches of hydrometallurgy, microbes are employed to extract metals from minerals. The lack of adaptability, long processing times, and leaching requirements make it less suitable for industrial use [38].

The third innovative approach in battery recycling, to overcoming the drawbacks of conventional lithium-ion battery (LIB), is direct cathode recycling (Figure 26). In this method, individual battery components are recovered from spent batteries and reused in new battery fabrications without significantly altering their structure or morphology [39]. This process allows the preservation of the cathode material quality, making it a highly effective method in maintaining the performance and longevity of new batteries. Direct recycling not only minimizes waste but also reduces the need for raw material extraction, contributing to a more sustainable and eco-friendly battery production cycle [40]. The advantages and disadvantages of the various recycling processes for batteries are highlighted in Table 4 [41].

Table 4. Advantage and disadvantage of conventional recycling process compared with direct recycling technology

Methodology	Advantages	Disadvantages
Pyrometallurgy	- Applicable to all battery types	- Higher energy input and capital investment

[14] Ren, Z., et al., Comprehensive evaluation on production and recycling of lithium-ion batteries: A critical review. Renewable and Sustainable Energy Reviews, 2023. 185: p. 113585.

This project has received funding from the European Union´s Horizon 2020 research and innovation programme under the grant agreement No 869821

	- No generation of wastewater - No pretreatment after sorting - Direct melting allows for obtaining master alloys - Hight recovery metals	- Cannot recycle/treat Li, Al, and LFP batteries - Hazardous gases emission - Additional cost for gas clean-up
Hydrometallurgy	- Applicable to any battery chemist - High sustainability - High extraction efficiency and purity of metals - Low energy consumption and capital cost - Little hazardous gas emission	- Pretreatment necessary to obtain black mass - Complex operational steps - Produce a large quantity of acid waste - Hazardous gases emissions: Cl_2, SO_3, NO_x - Additional expenses for disposal of hazardous gases, acids - Morphology and structure defects in cathode material
Biohydrometallurgy	- Applicable to all battery types - Low operational costs - Minimal use of chemicals - High efficiency and low metal concentration - No toxicity issues	- Slow kinetics and long processing time - Electrolytes and binders are toxic to microbes - At high pulp density, efficiency is lower - No potential for altering the metal valence state
Direct Recycling	- Applicable to all battery types - All other battery materials can be recovered including anode, electrolyte, binder, and foils - Suitable for LFP batteries and batteries scraps - Energy efficient	- Complex mechanical retreatment and separation steps - Recovered material may not perform as well as virgin material - Binder removal is crucial - Cathode materials of different origins reduce the value of the final product - Regeneration process is necessary

LIBs are processed by more than fifty companies worldwide. China and South Korea are the primary locations for most companies [42] where hydrometallurgy is mainly utilized for industrial purposes (for example, Brunp, Soundon New Energy, GEM, Huayou Cobalt, Ganpower, etc.). In fact, China accounts for the vast majority of current global battery recycling capacity, with 80% of capacity for battery pretreatment and almost 85% of material recovery [29]. The Figure 27 shows the forecasting of battery capacity for different use as well as the projection of grow rate for the recycling in Europe, China and USA.

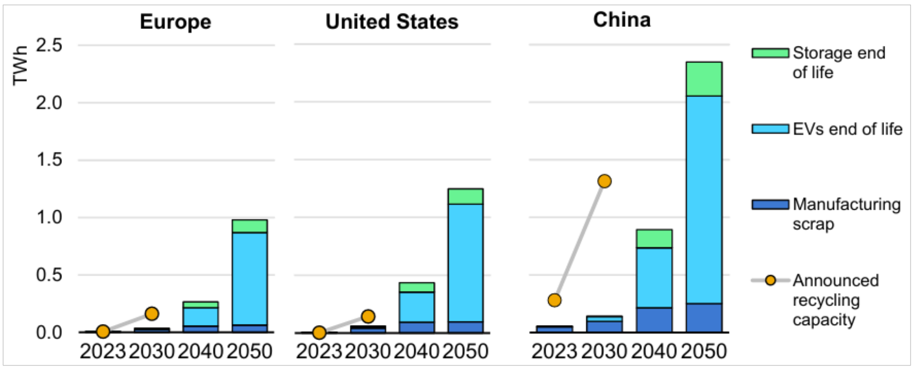

Figure 27. Battery recycling feedstock and capacity by region (Source: IEA 2024)

Battery recycling companies:

In the European Union, the most common recovery methods are pyrometallurgy, hydrometallurgy, and combinations of both. Many battery manufacturers are investing in new battery recycling technologies. To give an example, in Italy EnelX and MIDAC are working together to construct the first significant recycling plant for lithium batteries used in electrical vehicles, industrial systems, and stationary systems. In fact, for a long time, MIDAC S.p.A. has been manufacturing storage systems for the automotive, stationary battery, and industrial traction battery industries. For the past decade, it has been manufacturing lithium batteries. MIDAC is creating a "second life" project that recycles and produces innovative battery cells and packs to complete the lithium battery value chain with the IPCEI project [43].

Recycling Regulations: Recycling capabilities in other regions are also expanding, driven by increasing environmental regulations and the growing demand for sustainable practices in battery production and disposal.

In the recycling regulations, an important concept is the extended producer responsibility (EPR), which assigns the responsibility for the treatment of EoL products to the producer[51].

In the EU, present regulations include the Battery Directive (Directive 2006/66/EC) and the Waste Electrical and Electronic Equipment (WEEE) Directive (Directive 2012/19/EU). In addition, the EU Batteries Regulation introduced in 2023 [44] aims to reduce the carbon footprint of batteries, increase the number of batteries recycled, incentivise more sustainable battery designs and foster responsible materials sourcing as shown in the Table 5 and Table 6 [29].

Table 5. EU Battery Regulation – Minimum material recovery efficiency by material

Material	By 31st December 2027	By 31st December 2031
Cobalt	90%	95%
Copper	90%	95%
Lithium	50%	80%
Nickel	90%	95%

Table 6. EU Battery Regulation – Minimum quota of recycled content by material

Material	18th August 2031	18th August 2036
Cobalt	16%	26%
Lithium	6%	12%
Nickel	6%	15%

Compared to U.S., Neumann J. et al. point out that, the only federal policy regarding battery recycling is the Battery Act of 1996, which primarily focuses on facilitating the recycling of nickel–cadmium (Ni–Cd) and small sealed lead-acid (SSLA) rechargeable batteries, as well as phasing out the use of mercury in batteries. In China, the first legislation concerning battery products was introduced in 1995, Subsequently, in 2016, the Policy on Pollution Prevention Techniques of Waste Batteries by the Ministry of Ecological and Environment.

Furthermore, the development of a monitoring system for waste batteries is encouraged, an EPR is introduced for EV and battery manufacturers and specific recycling targets of 40% by 2020 and 50% by 2025 [42].

The global distribution of critical materials [45], often concentrated in specific regions, poses challenges for equitable access and sustainable extraction. Countries with significant deposits of rare earths are presented in Figure 28[15], cobalt, and nickel (for cathode) wield considerable influence over the battery supply chain, leading to potential supply bottlenecks and price volatility.

Consequently, regulations and policies are evolving to address these issues, promoting innovation in recycling technologies and alternative materials to mitigate dependency on scarce resources. For instance, advancements in solid-state batteries and the use of less critical materials are being explored to enhance sustainability and reduce environmental impact.

Currently being investigated are a variety of non-Li chemistries, such as batteries that use naturally abundant elements like sodium, zinc, magnesium, and calcium. The sodium ion technology, which is

[15] Li, Y., et al., Recycling of spent lithium-ion batteries in view of green chemistry. Green Chemistry, 2021. 23(17): p. 6139-6171.

the most like commercial LIBs, is the most common non-Li battery solution among these non-Li batteries [42].

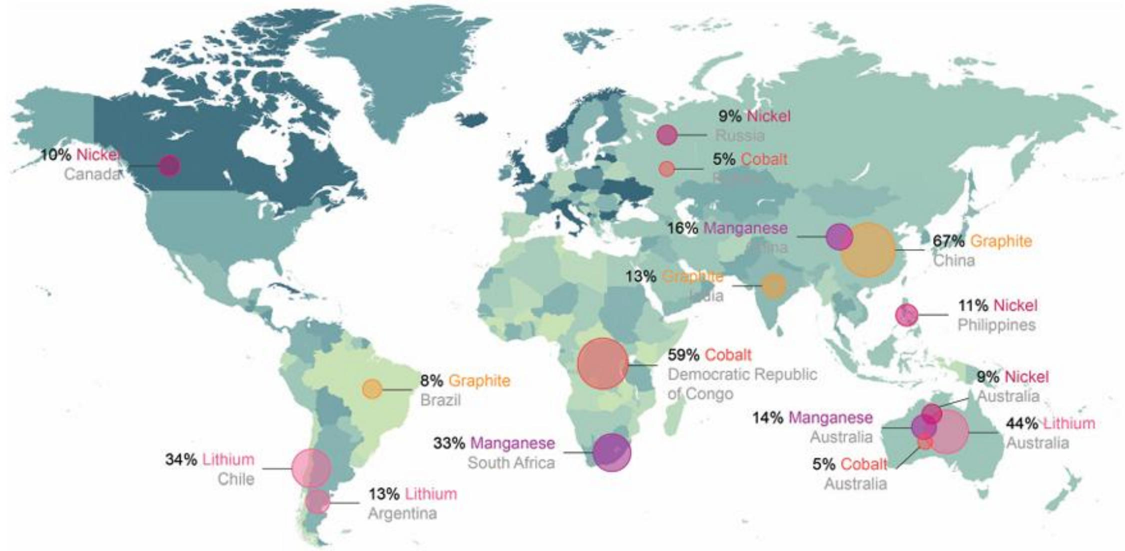

Figure 28. Worldwide distribution of criticality of raw materials (CRMs)

Besides the EU battery regulation introduced in 2023 and the global battery passport program, the IEA suggests policies that promote the sustainability and circularity of batteries. These actions include:

- Embrace a holistic approach: Not only improve batteries for EV, but also increase in domestic battery production
- Enhance transparency, traceability, and environmental, social and governance considerations
- Strengthen co-operation to facilitate second-hand EV trade: Stronger co-operation between advanced economies and EMDEs (merging markets and developing economies) could help facilitate trade in second-hand EVs while ensuring that end-of-life strategies are adequate.

4.3 Thermochemical Storage System Circular Economic Business Model – Ammonia production

Ammonia (NH_3) is commonly used as a refrigerant, fertilizer and chemical feed stock. It is increasingly recognized as an important, sustainable fuel for global use in the future. In the project, it is used as the medium to achieve the reversible thermochemical reaction. The use of ammonia as a sustainable energy carrier for global use in the future is becoming increasingly recognized. Ammonia applications in heavy transportation, power generation, and distributed energy storage are actively being developed.

It is well known that over 90% of the world's production of ammonia, made by the Haber-Bosch (H-B) synthesis process developed in 1913 [47], depends largely on fossil fuels, and the current production process is not environmentally friendly. In fact, the process generates H_2 from natural gas or coal, through steam reforming and combines it with N_2, which has been separated from air by a cryogenic process, to produce ammonia. The reaction between N_2 and H_2 requires temperatures more than 400 °C and pressures above 200 bar. This growth trajectory is forecasted to elevate the production from 185 million metric tons in 2021 to 230 million metric tons by the year 2050 [48].

Therefore, production of ammonia from renewable resources will help to decrease the environmental impacts of the ammonia synthesis process. Ammonia production accounts for 2% of global fossil energy use and 1.2% of global GHG emissions, which correspond to approximately 420 million MT of CO_2 equivalent (CO_{2e}) annually [49].

4.3.1 Ammonia production technologies

In order to achieve a carbon-neutral society, several alternative ammonia production pathways have been investigated. For instance, Boyce J. *et al.* classified three different ammonia pathways (despite the existence of innovative techniques in progress), starting from the conventional one : *(i)* "grey" (70%) and "black/brown" (30%) ammonia as conventional ammonia produced from fossil resources, natural gas and coal respectively ; *(ii)* "blue" ammonia, to reduce the carbon intensity of ammonia based coal or natural gas, is produced by capturing and using CO_2 emitted from conventional production processes ; *(iii)* "green" ammonia, to synthesize ammonia from carbon-free sources including water electrolysis ("yellow" ammonia, when the electrolysers are powered by the region-specific electricity grid), air, and zero carbon or near-zero carbon electricity such as solar, wind, biomass and nuclear power (Figure 29)[16] [50].

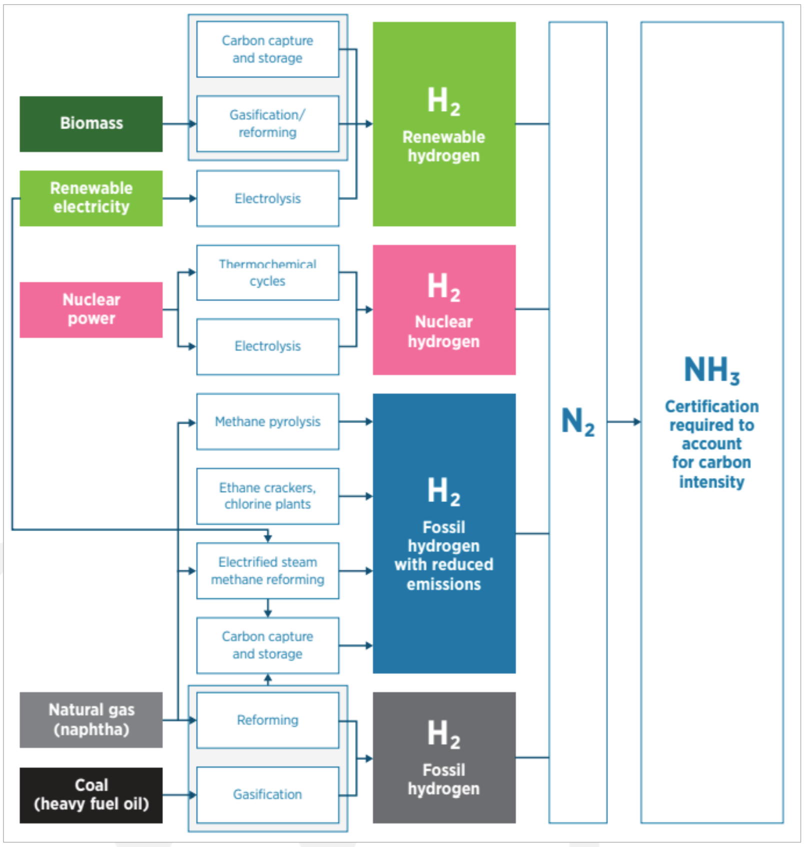

Figure 29. Production pathway of ammonia from various feedstocks

Hydrogen from methane pyrolysis is *(iv)* "turquoise" hydrogen, not yet ready for industrial use but considered a tool for a more sustainable hydrogen economy by scientists, due to the solid carbon by-product [51]. While the previous processes can be categorized as the first and second generation, MacFarlane D. *et al.* speaks about a third generation of processes that do not utilize H-B technology [52].

Generally, the IEA Roadmap distinguishes the following ammonia production routes in the Sustainable development Scenario and in the Net Zero Emission 2050 Scenario (Figure 29)[17] [48]: Electrolysis, Pyrolysis, Coal, Coal with CCS (carbon capture and storage), Gas, Gas with CCS, Oil, and Fossil with CCU (carbon capture and utilisation).

[16] Bicer, Y., et al., Comparative life cycle assessment of various ammonia production methods. Journal of Cleaner Production, 2016. 135: p. 1379-1395.
[17] IRENA, Innovation Outlook: Renewable Ammonia, 2022 [Link].

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5. MiniStor Key Exploitable Resoults business modelling

The exploitation activity started at M3 and identified 23 exploitable results (ERs), which are presented in deliverable D7.4, 'MiniStor exploitable results table'. D7.4 presented the situation at the beginning of the project, when the research and development activities had just begun.

The list of ERs has changed in line with the evolution of the project and its activities. Some ERs were removed from the initial list due to evolution in the composition of the MiniStor consortium. The characterisation of the ERs and the risk and impact assessment that will be integrated into D7.8, 'Replication Plan', reduced the list of ERs to 19.

At the end of the MiniStor project, five Key Exploitable Results (KERs) were defined by applying selection criteria and considering their advancement into MiniStor, as presented in Table 7.

A KER is a commercially ready ER that has been selected and prioritised due to its high potential for exploitation, meaning making use of and deriving benefits from a product, process or solution downstream in the value chain, or acting as an important input for policy, further research or education. Therefore, the business model analysis will be applied only to the KERs.

Table 7 . Key Exploitable Results Table

KER #	ER Name	Type	Owner (O) or Partner (P)	Exploitation strategy
1	MiniStor compact Energy Storage System	Product, System	CNRS (O) CARTIF (O) CERTH-ITI (O) ENDEF (O) HSLU (P) PSYCTO (P) SOFRIGAM (P)	Application at residential level. After the TRL upscaling, this resoult can be exploited by joint strategies. The definition of a newco or an ESCo partecipated by the MinisTor partners and additional investors repsesent an interesting strategy.
2	MiniStor Home Energy Management System (HEMS)	Product, Software	CARTIF (O), CERTH-ITI (P),	Application in the MiniStor solution and commercialisation in other froms. Scientific dissemination
3	Novel PVT System	Product	ENDEF (O)	Commercialisation and direct selling by the IP owner. Integration in the MiniStor applications.
4	Thermochemical Units (TCM storage)	Product	CNRS (O), PSYCTO. (P) SOFRIGAM (P)	TRL upscaling and integration in different sectors as industrial to demostrate the technology scalabitiy.
5	Visual Interface IoT platform for user interaction	Software	CERTH-ITI (O)	Copiright and integration in the HEMS and in the MiniStor solution

5.1 MiniStor KER#1: MiniStor compact energy storage system

The KER#1 - MiniStor Compact Energy System is an innovative energy heating, cooling and storage solution designed specifically for residential properties. This cutting-edge solution enables homeowners to store both electrical and thermal energy generated from renewable sources, such as PVT panels. The system's primary objectives are to maximise the use of RES reduce dependence on natural gas and the electrical grid, and lower energy costs by using stored energy during peak demand periods. It also enables energy flexibility through advanced energy management strategies. By integrating thermal energy storage to their residential building, users can utilise excess energy that would otherwise be lost, thereby reducing their environmental impact compared to fossil fuels and improving the utilisation of intermittent renewable energy sources such as solar energy.

Figure 30 shows the MiniStor system configuration installed at the EMI pilot in Hungary. It is positioned in a dedicated enclosure to reduce fire risk, to comply with industrial regulations imposed by standard EN378. The figure also shows the connection scheme of the sub-components.

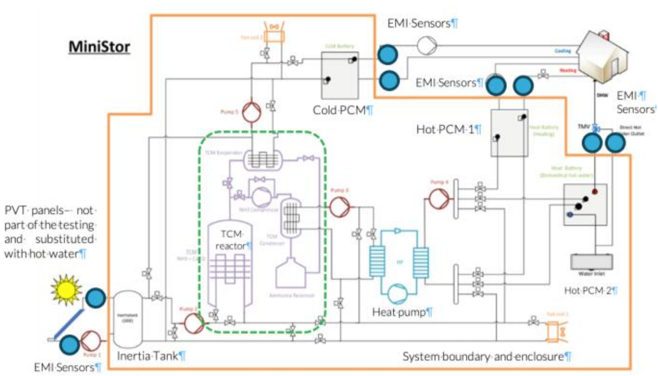

Figure 30. MiniStor system installed at EMI pilot and system scheme

Key Features and Components: The MiniStor compact energy storage system can be considered more than a simple storage system as it incorporates three integrated storage technologies (two thermal and one electrical) to ensure year-round functionality and efficiency:

1. Thermal Storage: The thermal storage unit provides the building heating and cooling needs, combining advanced technologies developed by consortium partners to optimize heating and cooling capabilities:
   - ER 13 Thermochemical Unit (TCM): It uses a proprietary thermochemical reactor with ammoniated salts (Ca_2Cl_2-NH_3) with enhanced functionality in terms of reaction kinetics, reversible reaction, high durability with high capacity thermo-physical and mechanical properties.
   - ER 14 Latent Heat Storage (LHS) Units: Equipped with phase change materials (PCMs), designed to store and release heat efficiently that has been generated by the TCM reactor, supporting both heating and cooling applications.
2. Electrical Storage: A commercial lithium-ion battery system forms the core of the electrical storage unit, providing high flexibility and consistent performance. Lithium-ion technology ensures reliable energy storage and efficient discharge, making it ideal for daily use in residential settings.

The system is also equipped with other components, such as a Programmable Logic Controller (PLC) control system, a HEMS connected to the PLC for managing building consumption, a user IoT interface for interacting with end users, a heat pump to increase efficiency of the output heat generation, and a PVT plant for producing thermal and electrical energy.

This configuration can be seamlessly integrated into residential buildings, enabling it to work with renewable energy systems such as solar panels.

The MiniStor Compact Energy Storage has a functional design with an energy density of 180 kWh/m^3, which is more than 10.6 times higher than that of water-based energy storages of the same volume, guaranteeing its innovativeness[18].

Finally, the entire system is engineered to meet a household's net energy consumption needs, ensuring high energy conversion and storage efficiency. The MiniStor can easily satisfy the energy needs of a typical 80–100 m^2 dwelling.

5.1.1 MiniStor compact energy storage value proposition

Value proposition: The KER#1 value proposition is represented by the integrated MiniStor Compact Energy Storage system. In this configuration, the MiniStor considers different KERs and results, such as the TES (KER#4), the PVT system (KER#3), the HEMS (KER#2) and the Visual Interface for the IoT platform (KER#5), providing an integrated solution that represents a significant leap forward in residential energy heating and cooling systems. This solution combines the capacity to store energy, enabling flexible energy storage services and sector coupling. By addressing both electrical and

[18] MiniStor Deliverable D3.1 "Initial dimensioning of the system according to the general use typology"

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thermal energy needs, it enables homeowners to embrace a more sustainable and cost-effective energy future, whereby thermal energy storage is still a novel proposition in the market.

This solution is designed to provide heating, cooling and domestic hot water (DHW) for residential applications such as single houses or apartments, small villas and family homes. It exploits RES integration as an alternative to traditional systems such as gas boilers, biomass boilers or heat pumps. Depending on the external environmental conditions, it can integrate PV and PVT systems, as well as an additional heat pump. The innovative HEMS system can manage energy consumption, minimise annual costs and enable energy flexibility for other buildings or interaction with a flexibility aggregator.

Customer profile: The main customer profile is represented in the right-hand side of Figure 31. MiniStor Compact Energy Storage Value Proposition comprises the residential sector (owners of single and family houses, flats, and small villas), who benefit directly from MiniStor energy savings as end users. This profile also includes building managers, building energy operators, and figures involved in building design, such as architects, designers, and system engineers, who can benefit from innovative technologies and propose more efficient residential solutions in the retail market.

Another interesting customer segment is represented by energy retailers and the ESCo sector, who can participate in economic investment at a building and local level by collecting revenues from savings generated, energy reduction, and flexibility services through EPC contracts and building renovation programmes (governmental incentives).

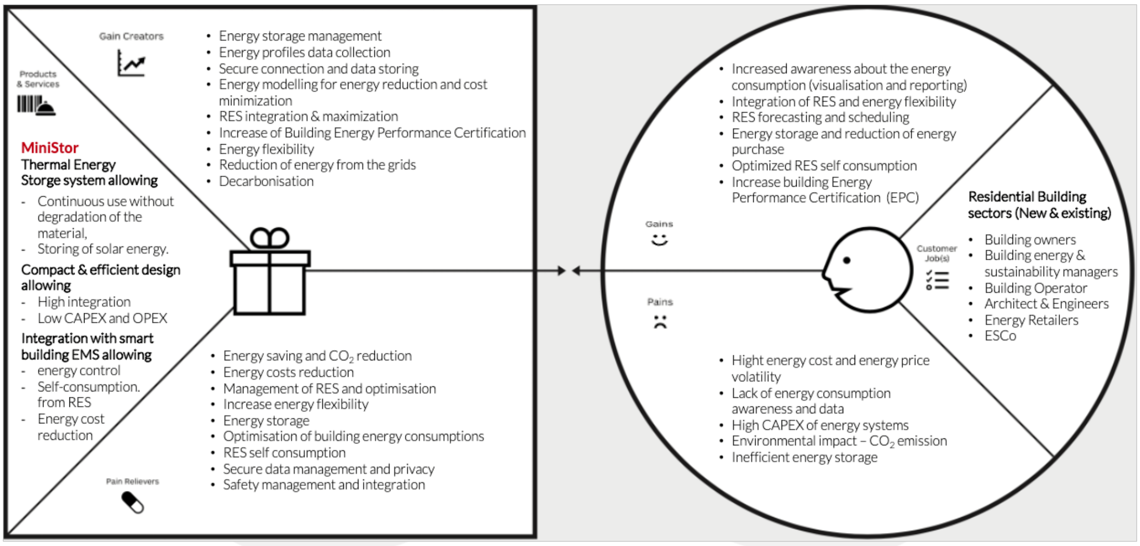

Figure 31. MiniStor Compact Energy Storage Value Proposition

At this development level (TRL7), the residential customer profiles are limited by ammonia regulations (EN 378, as detailed in D2.3), which limit the maximum volume for a single application and identifies specific safety conditions and safeguard system for installation in technical rooms, which can add to the final cost and maintenance of the system as they are used mostly in large-scale industrial settings. Due to these restrictions, the system cannot be scaled up or used in a modular way, which represents a bottleneck for its integration into larger structures, such as multifamily buildings, accommodation facilities, hospitals, and sports centres, which have similar energy consumption requirements (heating, cooling, and DHW), and where MiniStor could benefit from cost-efficient integration.

Compact and functional design: At the heart of the system is the ammonia thermoelectric storage (TES) system. With a footprint of just 0.72 m^2, the MiniStor Compact Energy Store is designed to integrate seamlessly into residential spaces, providing an energy capacity around ten times higher than that of water-based solutions on the market. Its compact size enables it to be installed and connected to a home's thermal distribution systems, allowing it to work with renewable energy systems, such as PVT panels and heat pumps (HPs). The system's functional design encompasses the performance of more traditional systems, such as heating and cooling systems, thermal and electrical storage systems, and efficient HEMS, providing a unique, tailored solution to a building's needs. This means that, with the MiniStor, a building can become energy efficient and sustainable by increasing the share of renewable energy resources instead of fossil fuels.

Energy efficiency and performance: The system is engineered to operate with high efficiency. By dynamically managing stored energy, the MiniStor Compact Energy system reduces reliance on external energy sources based on fossil fuels and optimises renewable energy use throughout heating and cooling periods.

Benefits to Homeowners:

- Increase RES penetration: MiniStor can support the penetration of RES increase the self-consumption, enabling energy flexibility and reducing the dependency for the electrical and thermal grids on fossil fuels as natural gas.
- Cost Savings: Reduces energy costs by the exploitation of self-consumption strategies and utilizing stored energy during peak hours.
- Environmental Impact: Maximizes the use of renewable energy, minimizing carbon footprint.
- Flexible Integration: Compatible with solar panels and other renewable energy systems MiniStor can generate energy flexibility at building and local level. It could participate in the electrical flexibility market in accordance with aggregators and local distributors.

Benefits to architect, building designer and ESCo:

- Design efficient and green solutions: Architect and designer can propose the MiniStor solution as a sustainable alternative respect to gas boilers and traditional heating and cooling systems, participating in the renovation of the building sector supporting the realisation of high-level EPR buildings.
- EPC contracts: The ESCo can participate in the financial investments for new buildings realisation and renovation processes of inefficient buildings, collecting revues from the generated efficiency, the energy flexibility market and green incentives.

5.1.2 MiniStor compact energy storage business model

The MiniStor Compact Energy Storage System has been specifically designed to meet the needs of building owners by providing a reliable solution for storing electrical and thermal energy generated from renewable sources. This energy can be stored during periods of high-RES production, such as sunny days with low demand, and utilised during periods of high energy demand when solar panels are not producing sufficient power or during grid outages. This ensures continuous energy availability and enhances self-sufficiency.

Our innovative business model focuses on leveraging the entire value chain by connecting key stakeholders, such as technological developers and system integrators, who can connect the MiniStor solution to homeowners. Other players are represented by partners who can commercialise the integrated MiniStor solution, as well as investors who can participate in the financial business model. By combining technical expertise with practical commercial applications, our business model offers a seamless, all-inclusive solution.

A core objective of the MiniStor initiative is to foster the development of a robust energy ecosystem for entry into the market following a period of TRL upscaling. This ecosystem will engage potential stakeholders, including battery and lithium storage manufacturers, recycling companies and private equity firms seeking new investment opportunities. The MiniStor Compact Energy Storage System is offered as an all-inclusive solution, eliminating the need for customers to purchase additional components or services. It enhances usability and ensures a seamless experience by providing a single point of contact for all customer service needs.

This approach could be well represented by a new company or spin-off founded by MiniStor's key partners, opening the possibility for new stakeholders to enter the business and compete within the business value chain. This approach is based on the idea that some academic partners and research centres, who possess the key knowledge and intellectual property rights (IPRs) or key enabling technologies (KERs), are unable to operate directly in the market or have limited experience in commercial activities.

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At the same time, to guarantee the circularity of the business model, forming a business partnership or an external collaboration with a recycling company will be fundamental to provide end of-life support and reuse.

Building partnerships with business operators across the value chain and engaging directly with end users will be essential for successful commercialisation. Utilities, system operators, and energy service companies (ESCo) will benefit from expanding their service offerings and actively participating in the shift towards decentralised energy systems. By integrating this pioneering storage solution, these operators can improve grid resilience and efficiency while minimising the need for costly grid expansion projects.

Collaborating with supply chain key actors, such as solar panel and lithium battery manufacturers, ammonia producers, compressor manufacturers, heat exchanger suppliers, etc., will enhance product quality while leveraging established sales channels, a critical factor for successful market scaling.

A preliminary revenue models has been formalized in the canvas template shown in the Figure 32, allowing complementary products and services to be marketed together, further boosting value creation and customer acquisition.

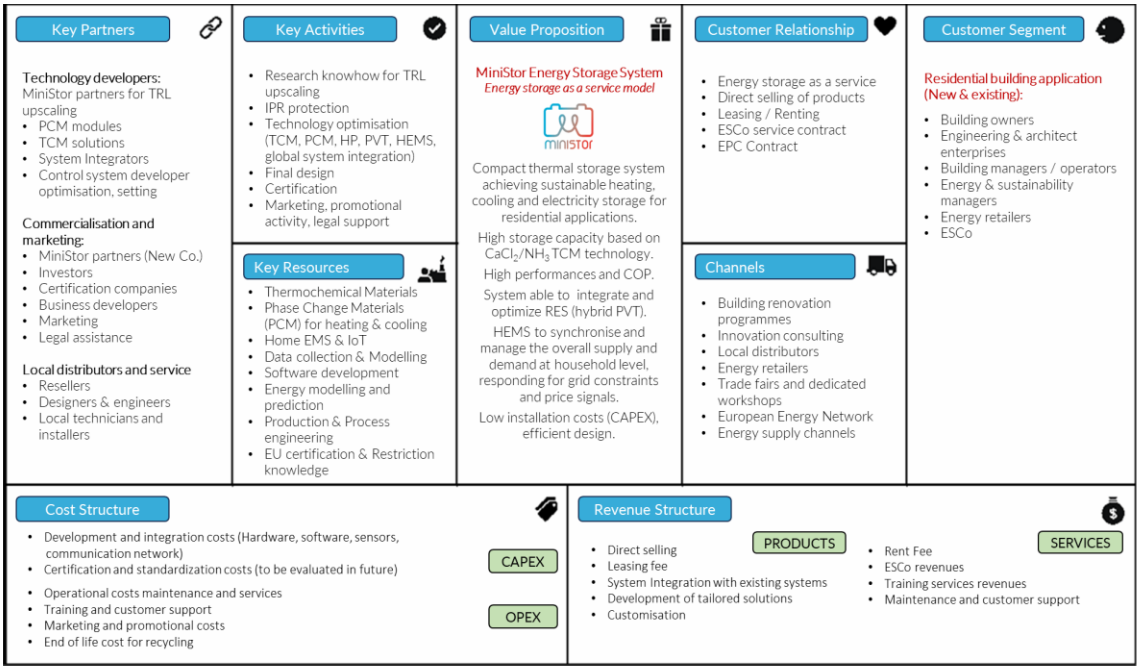

Figure 32. MiniStor Compact Energy Storge Canvas template

The cost structure of the MiniStor Compact Energy Storage System is divided into capital expenditure (CAPEX) and operational expenditure (OPEX).

1. CAPEX includes two primary categories:
   - System production costs: Costs for the system building and engineering that consider the costs for the technologies, the system dimensioning and realisation as well as the initial costs for the certification. This category collects all the costs needed to produce a marketable system and bring it into the market. The main components of CAPEX are the TES and the PCM modules, the piping, the lithium-ion battery, the inverter, the PLC management system, the HEMS and any additional components such as sensors, meters, controllers, wiring, switches, and other supporting equipment.
   - Installation costs and equipment or service costs: The costs for the system integration to the building and the additional equipment that must be installed to provide a full-service solution in operation mode under the safety regulations.
2. OPEX primarily covers:

- System maintenance & replacement or refurbishment costs: Those costs are related the annual maintenance of the system and the substitution of demerged parts. This voice reparents a cost for the company in the case of EPC agreement applied by an ESCo that provide a full-service operational contract. In the other cases, if the system is directly sold by the homeowner, this voice represents a potential incoming for the MiniStor company that can sell new components and assistance for the maintenance.
- Training and customer support: As the previous cost, this voice is a cost only in the case of EPC and is an incoming in the other cases. It represents the cost for organise and do training campaigns for the personnel involved in the entire value chain, from the end-user (utilisation training), the resellers, to the operators responsible for the installation and maintenance (technical skill training).
- Marketing and promotional campaigns: Common cost for place the system into the market and guarantee a good level of visibility to guarantee and increase the market penetration.
- End-of-life management and recycling: This voice is related to the circular economy approach and the extended producer responsibility detailed in the chapter 6. It represents the cost for the system withdrawal and the dismissing of the exhaust components until the recycling of raw materials.

Installation, maintenance, training and replacement costs are influenced by factors such as customer location, since regulations, labour costs and VAT rates vary from country to country. These geographic variations necessitate tailored cost considerations in order to provide accurate and competitive pricing for customers in different regions.

The cost and benefits assessment will be detailed in Deliverable 7.7, which will also include an estimation of the return on investment (ROI) from the perspective of residential customers.

A key factor in the cost-efficiency of the system is its commitment to circularity, which plays a pivotal role in managing the replacement of TES (TCM and PCM), as well as lithium batteries and refurbishment costs. Circularity is not only integral for minimising environmental impact, but also for enhancing economic viability and sustainability. Promoting strategies such as direct reuse, refurbishment, remanufacturing and recycling of technologies and raw materials significantly reduces the Levelised Cost of Storage (LCOS). This approach aligns with global sustainability goals and strengthens the economic case for adopting the MiniStor solution.

The primary revenue streams will come from direct sales, backed by a robust marketing campaign. Additionally, cross-selling opportunities will be maximized through strategic partnerships across the MiniStor energy storage supply chain, including collaborations with PV, PVT and lithium battery manufacturers. These collaborations will not only enhance the market reach but also provide added value to customers by offering integrated solutions.

Furthermore, the MiniStor Compact energy system offers customization options, ensuring a versatile and adaptable product tailored to meet diverse customer needs. This potential adaptability will position the product as a versatile and customer-centric solution in the energy storage technology sector.

The second part of the revenue streams is composed by selling of services as training for end-users and operators or the operation and maintenance service.

Revenue streams are further enhanced by offering the product as a service, establishing a "storage-as-a-service" business model. This innovative approach facilitates the creation of local energy communities, empowering members to actively participate in energy production and become "prosumers"—both producers and consumers of energy. To effectively implement this model, the establishment of an Energy Service Company is a strategic must. The ESCo will manage energy storage systems and other RES assets on behalf of energy communities, acting as a flexibility aggregator and intermediary that bridges the gap between investors, power generators, and energy consumers. This model represents at the same time the concept of “Shared product”.

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The Green Deal Industrial Plan for the Net-Zero Age[19], introduced in Europe, offers incentives such as tax credits to encourage renewable energy projects, including energy storage systems and building renovation initiatives. These incentives vary across EU countries and play a vital role in enhancing the economic viability of storage-as-a-service projects. By leveraging these incentives, the ESCo can attract investors who benefit from tax credits, thereby ensuring a financially sustainable business model. In turn, energy communities can access storage services via subscription or usage fees, eliminating the need for upfront capital investment or operational management. This model also improves the overall efficiency of renewable energy usage and heat recovery from other end users (e.g. industrial companies). By enabling energy communities to share excess, unused renewable energy, the storage system maximises clean energy usage while minimising reliance on grid-supplied power and fossil fuels. This reduces costs for the communities and contributes to broader sustainability goals by optimising renewable energy (RES) penetration and management.

The ESCo could adopt the structure of an open joint-stock cooperative, enabling energy community members to play an active role in the company's administration. This participatory approach enables members to invest directly in their energy needs, strengthening their position as prosumers. This cooperative framework fosters a sense of ownership, collaboration and shared responsibility within the energy community, aligning economic incentives with environmental sustainability and local empowerment.

5.2 MiniStor KER#2: Home energy Management System

The MiniStor KER#2 is an advanced, smart, interoperable digital energy system designed to efficiently manage residential energy supply and demand. This innovative system, shown in Figure 33, integrates various capabilities to provide seamless control over energy resources, ensuring optimal utilization of the MiniStor storage system. By dynamically responding to heating requirements, the system ensures an intelligent balance between consumptions, energy storage, and energy supply with a clear focus on adaptability and performance.

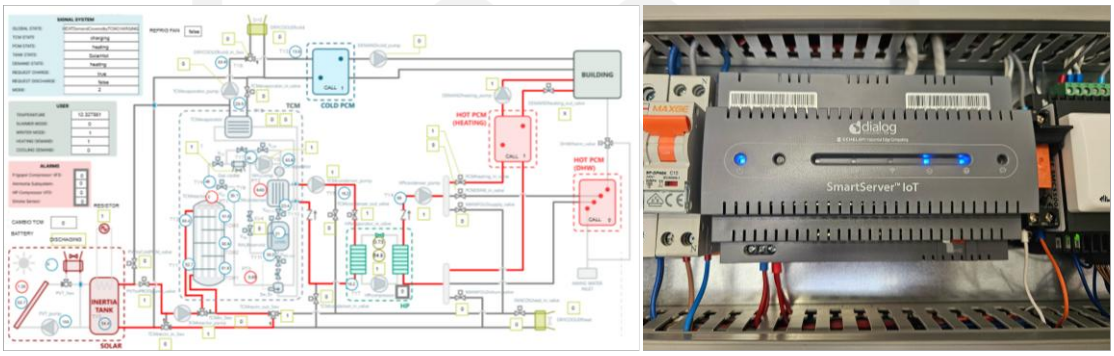

Figure 33. HEMS control scheme (a) and hardware (b)

Key Features and Components:

1. Continuous real-time Monitoring and Intelligent Controls: the system incorporates non-intrusive, intelligent controls seamlessly integrated with various devices and home appliances. These controls ensure secure and efficient communication with the MiniStor software, which collects, analyses, and displays (in synergy with the KER#5 – Visual Interface IoT platform for user interaction) energy usage data, providing useful energy performance feedback, helping them make informed decisions.
2. Advanced prediction services and User-Centric interaction: Leveraging the power of IoT middleware and machine learning algorithms, the system processes raw data to deliver accurate forecasts of critical operational parameters, such as heating demands and energy production. This predictive capability allows the system to dynamically manage the overall

[19] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/green-deal-industrial-plan_en

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residential energy supply and demand, aligning energy delivery with the unique needs of each household.

In addition, the HEMS IoT platform enhances the user experience through highly customizable settings that ensure maximum comfort and energy efficiency. By adapting energy supply to individual preferences, the system not only optimizes performance but also enhances indoor environmental quality (IEQ), improving the comfort level of tenants.

The MiniStor HEMS aims to set a new standard for energy management in residential buildings, offering homeowners a robust solution to minimize energy waste, lower costs, and enhance sustainability, all while maintaining comfort and reliability.

5.2.1 MiniStor Home Energy Management System value proposition

Value Proposition: The KER#2 value proposition if represented by the Home Energy Management System owned by CARTIF and developed with the collaboration with CERTH-ITI. It controls the entire MiniStor system during its operational model.

By seamlessly integrating renewable energy sources and prioritizing user comfort, the system offers a reliable and forward-thinking approach to modern energy management enabling energy flexibility strategies.

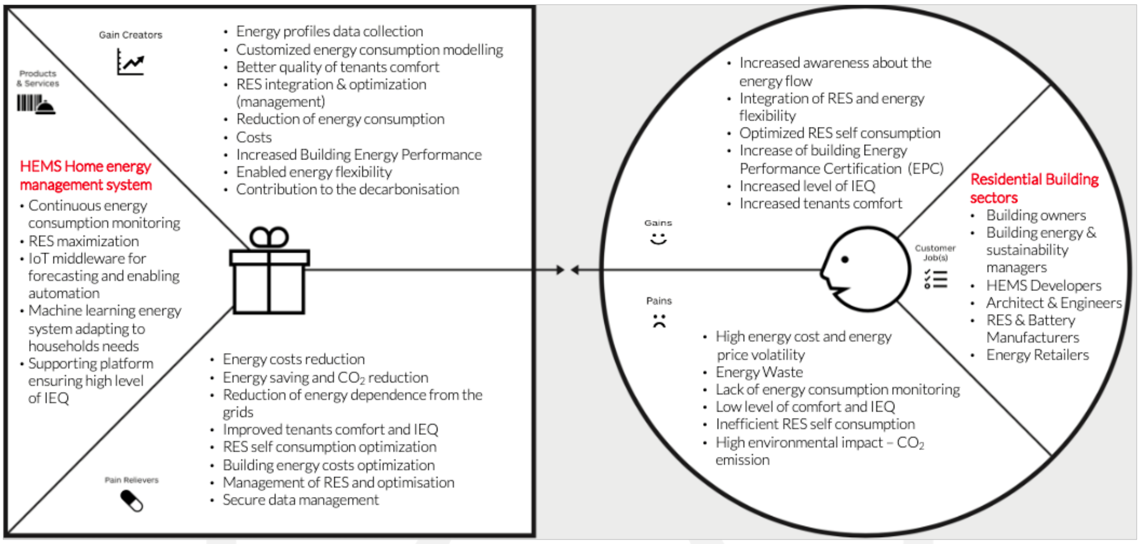

Figure 34. HEMS Value Proposition

Customer Segment: As it works strongly in connection with the MiniStor integrated solution, the main customer segment is here again represented by the residential sector. Designer and architects can exploit the HEMS by integrating home automated appliances as well as the energy saving strategies. Other customer sectors that could be interested to the HEMS are IoT and software companies working in the development of HEMS than can be interested to collaborate or acquire the results from MiniStor.

Benefits to Homeowners:

- Real time Energy Consumption Monitoring: Tenants have a continuous and accurate control over their energy consumptions, enabling smarter decision-making to enhance efficiency.
- RES Maximization: the system optimizes the use of renewable energy sources (self-consumption), such as solar panels and other RES. By maximizing the utilization of these resources, the MiniStor system reduces dependency from the grid.
- Cost Savings: Through intelligent energy management strategies, the system synchronizes heating or cooling demands. By efficiently balancing consumption and integrating renewable energy, homeowners can experience substantial savings on their energy bills.
- Reduced Environmental Impact: By maximizing renewable energy usage, it helps reduce the household carbon footprint.

- **Customized energy management:** The MiniStor system adapts to the unique needs of each household. Advanced algorithms account for parameters such as individual comfort preferences, ensuring a tailored energy management experience that maintains optimal living conditions for all occupants.

5.2.2 MiniStor Home Energy Management business model

The primary function of the **MiniStor Home Energy Management System (HEMS)** is to manage the overall energy supply and demand of a building, taking into account heating, cooling and electricity requirements.

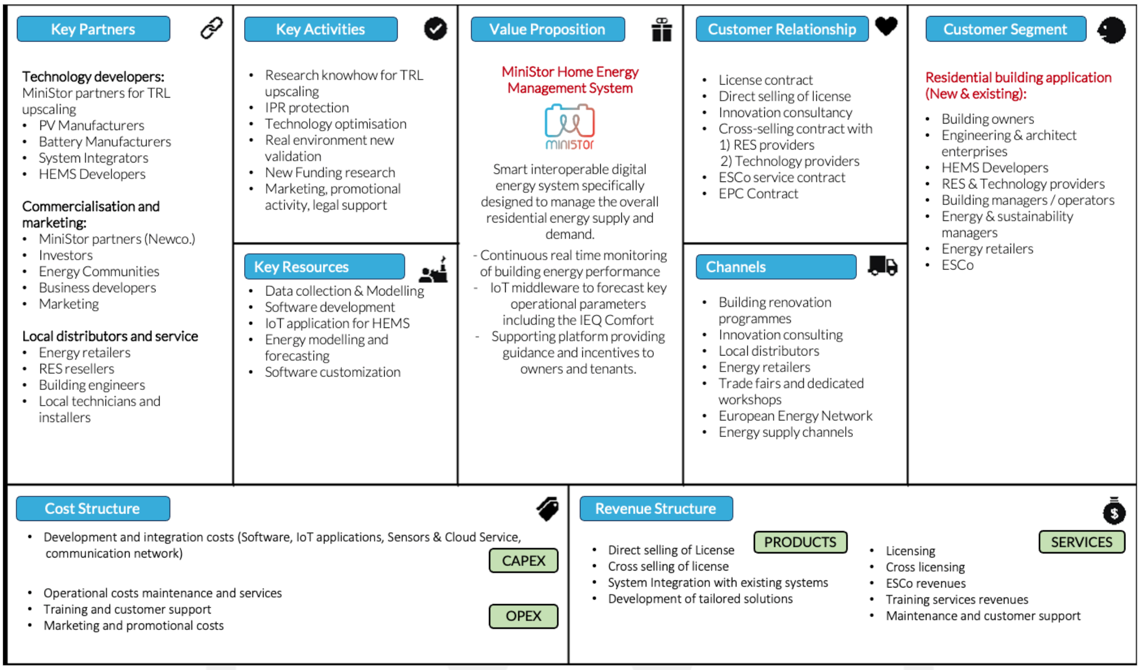

Figure 35. HEMS Business Model Canvas

The HEMS operates in synergy with the Visual Interface IoT platform for user interaction (Table 1- KER5), enabling seamless connectivity between building appliances and the HEMS itself. To ensure full integration and optimal performance, it will be commercialised in partnership with the IoT platform interface of CERTH. Given the fragmented nature of the energy systems market, the business model is designed to provide a comprehensive, integrated solution connecting various home energy components, such as photovoltaic systems, energy storage units and heat pumps, as well as smart building appliances. We believe this is key to successful market scale-up. Previously, these systems were sold as standalone products, but the convergence of today's value chains drives sector coupling and enhances the customer experience. The MiniStor HEMS plays a fundamental role in this process. At its core, the MiniStor HEMS manages the efficient interplay between household energy consumers and generators. By coordinating the distribution of self-generated energy, it ensures optimal usage and reduces overall consumption.

Our business model recognises the value of strong partnerships in a fragmented market. Collaborating with building sensor manufacturers, suppliers and other energy ecosystem players, such as solar panel and battery manufacturers, energy retailers and service providers, is fundamental to effective market scaling up and success. These partnerships will enhance product quality and streamline market access by leveraging established sales channels.

By integrating MiniStor HEMS, all stakeholders in the value chain benefit:

- **ICT Manufacturers and Original Equipment Manufacturers (OEMs)** can offer an expanded portfolio of integrated solutions to their customers.

- Energy service providers can simplify the customer experience without increasing technical complexity.
- End-users gain a seamless, user-friendly product that enhances energy efficiency and reduces costs.

This alignment of interests not only accelerates adoption but also creates new revenue streams and competitive advantages for all participants.

MiniStor HEMS's cost structure is divided into two primary categories: CAPEX and OPEX:

1. CAPEX: Includes costs associated with development and integration of the hardware and software, such as:
   - Software management systems components.
   - IoT applications and sensors.
   - Cloud infrastructure and associated services.
   - Supporting equipment, including controllers, wiring, and switches.
2. OPEX: Covers ongoing operational expenses, including:
   - System integration updating and maintenance, which could be performed online, requiring users to have internet connectivity.
   - Customer support and training services.
   - Marketing and promotional activities to drive customer acquisition.

Main target customers are:

1. Engineering firms involved in energy system design and integration.
2. Manufacturers of PV systems, heat pumps, and energy storage solutions.
3. Manufactures or Suppliers of building sensors and smart appliances
4. Energy retailers seeking to expand their offerings and improve customer loyalty.

Potential applications are relevant within Smart building and districts context, due to the nature of management of the municipal buildings (retirement homes, sport centres, universities) but also include residential houses or autonomous detached houses.

Commercialization Strategy:

The commercialization of HEMS is structured around a strategic collaboration between CARTIF (HEMS owner) and CERTH (IoT visual platform owner), in conjunction with the broader MiniStor Consortium in the case of the integrated solution (KER#1). Several potential commercialization pathways are under consideration:

1. Creation of a New Business Entity (NewCo):
   - A dedicated company could be established to lead the commercialization of MiniStor HEMS, bringing together key stakeholders from the consortium.
   - This entity would oversee product deployment, business development, and customer engagement, ensuring streamlined market entry and scalability.
2. Spin-Off from CARTIF:
   - CARTIF, as the knowledge and exploitation rights owner, could initiate a spin-off company specifically focused on the commercialization of HEMS.
   - This new entity would assume control of the HEMS technology, driving its market adoption and integration into smart energy ecosystems.
3. Direct Commercialization through Subcontracting:
   - In this approach, CARTIF would retain ownership of HEMS, while its commercialization would be subcontracted directly to CERTH or other stakeholders.
   - This model leverages CERTH's expertise in IoT platforms to enhance cross-selling initiatives and expand market penetration.

Revenue Model: MiniStor HEMS's primary revenue stream will come from selling hardware and licensing software, which will give customers access to the platform in exchange for a recurring subscription fee. This model ensures sustainable, long-term revenue generation while fostering customer retention.

Cross-selling initiatives will also play a vital role in maximising value creation. By offering complementary products and services as bundled solutions, MiniStor HEMS will enhance customer acquisition and increase its competitiveness in the market. This strategy boosts adoption and drives growth for all partners involved, thereby reinforcing the MiniStor ecosystem within the energy management sector.

Leveraging these commercialisation strategies and revenue streams positions MiniStor HEMS to become a key player in smart communities, districts, and residential energy management, driving efficiency, sustainability, and innovation.

5.3 MiniStor KER#3: Novel PVT system

The MiniStor PVT Water Collector is an advanced liquid-based solar panel that seamlessly integrates photovoltaic and thermal energy production into a single module. This potential breakthrough technology, developed during the MiniStor project, builds upon the current liquid-based PVT collector models manufactured by EndeF. They include an unglazed model (known commercially as Ecovolt) and a glazed model (known commercially as Ecomesh). Several modifications and improvements were implemented in the current PVT collector models, including design of the thermal absorber, incorporation of a PV laminate with higher nominal electrical power and use of an adhesive to improve integration between the PV laminate and the thermal absorber.

Figure 36. PVT installation (a): Glazed panels in Sopron Hungary, (b): Unglazed panels in USC

The second-generation of the glazed hybrid solar panel stands out due to its patented CTA (Transparent Insulating Cover – Patent P201200571) technology developed by EndeF (Figure 36-a). This advanced front cover enhances thermal performance by reducing energy losses caused by reflection, making the panel particularly well-suited for cold climates.

In contrast, the unglazed hybrid panel utilizes highly efficient monocrystalline silicon cell laminates without a front cover (Figure 36-b) and a newly designed heat absorber. This design facilitates heat dissipation, addressing the common issue of reduced electrical efficiency in photovoltaic panels as temperatures rise. As a result, the panel is ideal for warm climates, maintaining high electrical performance.

Key Features and Components:

1. Glazed CTA (Transparent Insulating Cover) Technology: it is a patented innovative cover system that incorporate a specialized front layer that efficiently captures the sunlight, while minimizing energy losses from reflection. By leveraging this advanced design, it is possible to significantly improve the thermal performance of the panel, maximizing its production of hot water.
2. Unglazed panel with new heat absorber: This innovative design allows excess heat to dissipate effectively, addressing the common problem of loss in electrical performance at higher temperature. By enabling heat to escape through the absorber, the unglazed panels maintain optimal functionality, even in the hottest climates.

The glazed solution is best suited to applications that prioritise thermal energy output, while the unglazed panels are more effective in environments that focus on maximising electricity production.

For the MiniStor project, which involves storing heat generated by the PVT system, critical operation occurs during winter, spring and autumn.

Table 8. KER#3 PVT installations at MiniStor demo sites

Demo site	New Solar field	PVT type
Thessaloniki (pre-demo) - Greece	Yes	Glazed
Kimmeria - Greece	No (already available)	n/a
Santiago de Compostela -Spain	Yes	Unglazed
Sopron - Hungary	Yes	Glazed
Cork - Ireland	Yes	Glazed

Table 8 shows the configuration of the PVT installation at the five MiniStor demonstration sites.

5.3.1 Novel PVT system value proposition

Value Proposition: The MiniStor KER#3 value proposition is represented by the Novel PVT system owned by EndeF. It is a compact, safe and reliable solution converting solar energy in both electrical and thermal energy. The technology is perfectly designed to operates under the most adverse conditions, always ensuring optimum energy performance in various climatic conditions. This is a real step forward in the current SoA, since a common problem with photovoltaic panels is the loss of electrical performance when the panel increases in temperature. At the same time, in cold weather, current solar panels show thermal loss due to sun ray reflection.

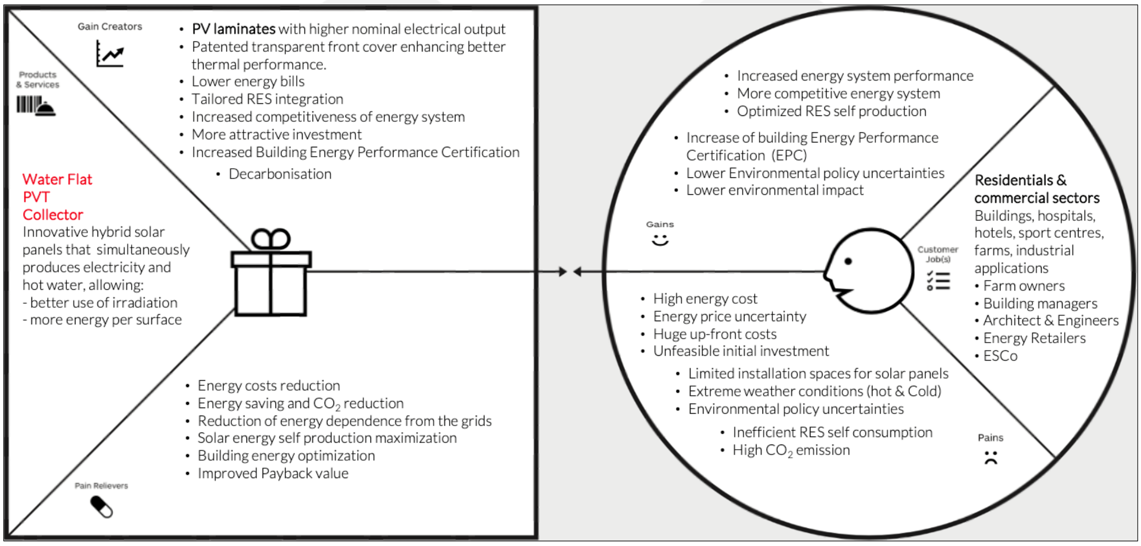

Figure 37. EndeF PVT panels value proposition

By using a new heat absorber and do not incorporating the cover on the front, the unglazed solution allows the excess heat to escape. This configuration guarantees a good operation of the panel even in the warmest climates. In addition, by using the patented CTA technology, which incorporate a layer on the front of the panel, the glazed version significantly maximizes the irradiation, improving therefore, the thermal performance of the panel.

Customer Segment: Although MiniStor analysed the application of PVT systems in the residential sector, PTVs can be used by a wider range of customers. They can be used in various sectors, including residential buildings, hospitals, sport centres, tertiary buildings to farms and the industrial facilities, where the heating and cooling requirements align with the temperature produced by the system. In essence, it can meet the needs of sector requiring heating at temperature below 40°C, while also providing and additional benefit of electrical energy supply.

Benefits to building owners:

- Simultaneous production of heat and electricity: the combination of photovoltaic and thermal technologies into a single system, enables the simultaneous production of

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electricity and heat. This dual functionality allows a better use of solar irradiation offering a more efficiency compared to other solar systems. The water circulation produces the cooling on the panel increasing the PV efficiency.

- Optimization of energy production per m^2: by optimizing the energy output per available surface area, compared to the use of singular photovoltaic and thermal systems, the MiniStor PVT panel is an excellent solution for buildings with limited roof area, as they enable efficient utilization of available space without compromising energy needs.
- Reduced Environmental Impact: by generating energy more efficiently and requiring fewer resources, PVT systems help to lower the associated CO_2 emissions compared to separate photovoltaic and thermal installations and represent a valis alternative to fossil fuels heating. This contributes to a smaller carbon footprint and aligns with sustainability goals.
- Cost Saving & improved Return of Investment: by maximizing the overall efficiency of the energy system, also reducing the reliance from the grid, by simultaneously producing and maximizing the heat and electricity, the PVT panel reduces the monthly energy bills translating into significant long-term cost savings. This makes the investment more attractive, shortening payback periods and improving ROI, therefore making the PVT panels more financially viable solution to different customer segments.

In summary, the MiniStor PVT panels offer a highly efficient, eco-friendly, and cost-effective way to meet the energy demands of modern buildings. All of these enhancing better financial returns on their energy investments.

5.3.2 Novel PVT system business model

As the EU and governments worldwide strengthen policies and standards to accelerate the transition to renewable energy, solar power is making progresses, emerging as a cornerstone of sustainable building strategies. Thanks to advancements in efficiency enabling reliable performance in diverse weather conditions with minimal power loss, EndeF's innovative PVT panels are poised to redefine energy systems, setting new benchmarks within the building sector. Designed to maximize energy production, these panels offer homeowners customized solutions adapting to different weather conditions—overcoming one of the biggest challenges in the PVT panel industry.

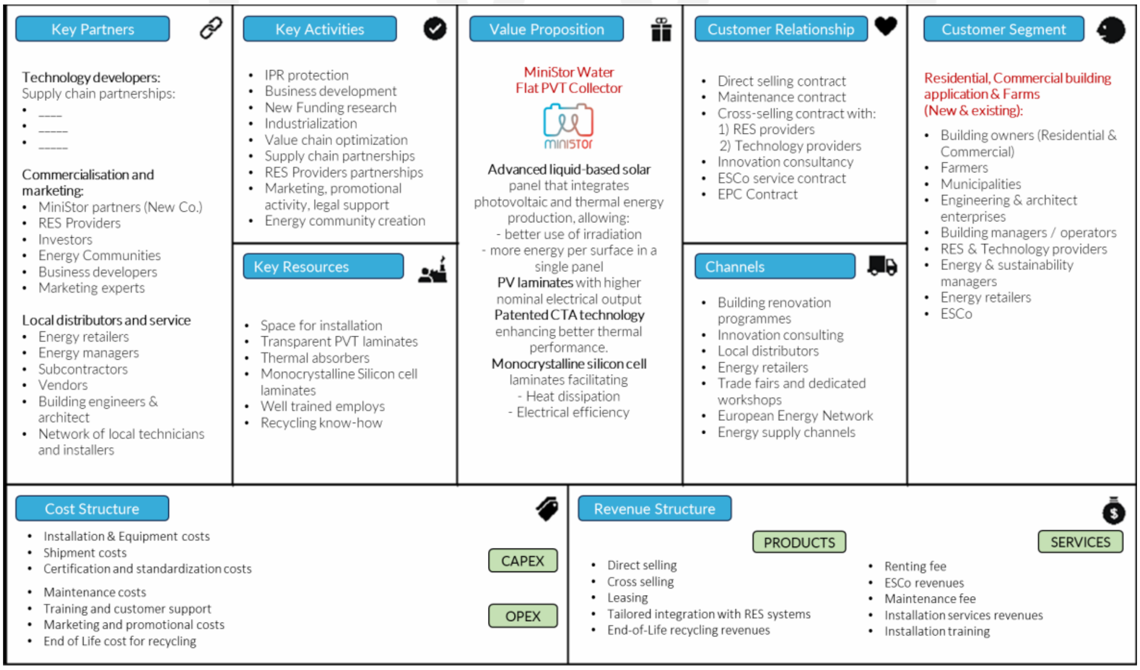

Figure 38. PVT Business Model Canvas

EndeF is an innovative company dedicated to developing and delivering pioneering, sustainable energy solutions that make renewable energy more accessible. The company specialises in solar energy systems, focusing on accessibility for all.

The building and construction energy sector is still highly fragmented, with energy systems such as heat pumps, solar panels, PVT collectors and thermal storage units often being sold separately. This lack of integration limits efficiency and scalability. EndeF recognises that combining technologies is key to optimising energy usage and enhancing system performance overall. The MiniStor PVT panel can be effectively integrated with heat pumps. By contributing directly to thermal demand, PVT panels improve heat pump performance, leading to increased efficiency and reduced energy costs. Additionally, the surplus electricity generated by the PVT system can support the heat pump further, ensuring a more sustainable and self-sufficient energy ecosystem within buildings. Beyond heat pumps, the MiniStor PVT panel can be combined with other solar technologies to increase market scalability.

Pilot projects have demonstrated that combining PVT panels with advanced energy storage solutions significantly increases the contribution of solar thermal energy to domestic hot water (DHW) and heating demands. Furthermore, integrating PVT panels with advanced energy storage solutions, such as the MiniStor system, enables optimised utilisation of solar resources, thereby maximising contributions from renewable energy sources and reducing reliance on conventional energy sources. A business model centred on sector coupling is fundamental to successful commercialisation. Integrating PVT technology with heat pumps is a particularly strategic approach to the electrification of thermal demand in buildings. In the context of growing space constraints in urban construction, compact, multifunctional solutions such as PVT panels offer a significant advantage by maximising energy production per available surface area. Finally, to ensure seamless integration and efficiency, combining PVT technology with other energy systems requires digitalisation and smart energy management. EndeF has developed its own energy management system to enable optimised control and monitoring of energy flow. However, EndeF's PVT panels are also compatible with third-party energy management systems, such as the one provided by CARTIF. This flexibility enhances interoperability, making PVT technology a valuable and adaptable solution for various energy ecosystems. For the business model to be effective, strategic collaborations are essential. By partnering with key players in the energy sector, product quality can be enhanced, market access can be streamlined, and established distribution channels can be leveraged. These partnerships are crucial for accelerating the adoption of PVT technology and ensuring its successful deployment in a variety of applications.

Since PVT panels maximize the use of solar irradiation, generating more energy per unit area than traditional solar and thermal technologies combined, they are particularly beneficial in settings where space is limited, and thermal demand is high as indicate in the customer segment in the Figure 38. The ideal applications for MiniStor PVT panels include:

- Hotels: Continuous demand for hot water and heating makes PVT technology a cost-effective solution for energy efficiency.
- Nursing Homes: Providing a stable and sustainable hot water supply for elderly care facilities.
- Sports Centres: Supporting high water heating requirements for showers, pools, and other facilities.
- Hospitals: Meeting extensive energy needs while ensuring a sustainable and resilient power supply.
- Residential Buildings: Enhancing the energy efficiency of multi-unit complexes.
- Single-Family Homes: Providing homeowners with a sustainable and cost-effective energy solution.
- Industrial sectors: Industrial processes with hot water needs under the level of 100°C (food and beverage sectors) of pre-heating in processes with temperature level under 100°C.

By offering a high-performance, integrated, and scalable energy solution, EndeF is driving the transition towards a cleaner, more sustainable future, reducing Europe's dependence on gas and other fossil fuels.

Some costs can be considered relevant for the marketability and the TRL upscaling The cost structure, divided into CAPEX and OPEX costs can be the following:

1. CAPEX: Includes costs associated with the installation & equipment costs, such as:
    - Customized panels infrastructure.

- PVT panels.
- Integration with other technologies and building integration.
- System certification and standardisation.

2. OPEX: Covers ongoing operational expenses, including:
    - System set up and maintenance.
    - Customer support and training services.
    - Marketing and promotional activities.
    - End of life cost of recycling.

Commercialization Strategy: The PVT panels will be commercialized directly by Endef, leveraging its existing customer base, at the beginning in the Spanish market and later, analysing the possibility to extend the commercialisation to other countries, by sales channels and resellers. Additionally, the system—when integrated into the MiniStor storage unit or other MiniStor ERs can also be marketed by partnership and through subcontracting agreements.

Furthermore, EndeF is actively exploring additional commercialization pathways, including:

1. Creation of a Business network:
    - A dedicated business networks abler to cover EU country markets could be established to extend the commercialization of PVT panels outside the Spanish market.
    - This entity would oversee product deployment, business development, and customer engagement, ensuring streamlined market entry and scalability following the countries market condition.
2. Collaboration with the MiniStor Newco:
    - In the case of creation of a dedicated company for the commercialisation of the MiniStor integrated solution (KER#1), EndeF could participate as a partner, contribution to bring the knowledge about the PVT and as a technology provider.
3. Direct Commercialization through subcontracting:
    - In this approach, EndeF would retain ownership of the PVT panel, while its commercialization would be subcontracted to local installers and ESCo companies.
    - This model could leverage cross-selling initiatives and expand market penetration.

Revenue Model: EndeF is committed to delivering innovative and accessible solar energy solutions, making renewable energy practical and affordable for a wide range of customers. The company specialises in developing and commercialising solar panels and related energy products and offers comprehensive installation and maintenance services. Understanding the diverse energy needs of its clients, EndeF provides customised solutions tailored to the specific requirements of each customer's property, energy consumption patterns and budget. Beyond its commercial offerings, EndeF actively participates in national and EU-funded renewable energy projects, leveraging these initiatives to enhance and promote its pioneering PVT technology. Through continuous research, development and pilot implementations, EndeF is refining its solutions to improve efficiency, scalability and integration with other energy systems. These projects also raise awareness of the potential of PVT technology within the industry, accelerating its adoption across European markets.

The company's primary revenue streams include solar panel and related hardware sales, as well as consultancy. The company also generates income from installation and maintenance services. To enhance accessibility and affordability, EndeF is exploring alternative business models, including leasing programmes. Under this model, customers can lease solar panels for a set period and benefit from immediate energy savings, avoiding the need for upfront costs. This approach secures a steady, recurring revenue stream while making the adoption of solar energy more financially viable for a broader customer base. A key element of EndeF's commercialisation strategy is cross-selling and forming strategic partnerships with other energy system providers. This strategy boosts the adoption rate and drives business growth for all partners involved through shared market access, thereby reinforcing the MiniStor ecosystem within the building and construction sector.

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5.4 MiniStor KER#4: Thermochemical Units storage

The MiniStor thermochemical unit storage (TCM) is designed and owned by CNRS, in collaboration with SOFRIGAM, responsible for the ammonia reactor and PSYCOTHERM, responsible for the realisation of the ammonia circuit (compressor, evaporator, condenser, valves, etc.) and its connection. It is a cutting-edge thermal energy storage solution designed specifically for residential applications (Figure 39).

Figure 39. TCM unit installed (a) and detail (b)

This innovation redefines how heat can be stored and utilised, offering a more efficient and compact alternative to traditional thermal storage technologies. It exploits the storage capacity of the ammonia cycle, which is around ten times higher than that of water-based solutions.

Thanks to its small, space-efficient design, the TCM MiniStor unit is ideal for homes with limited space, making it suitable for new constructions and retrofitting projects alike. Its effectiveness is maximised when integrated with renewable thermal energy systems, such as heat pumps and PVT panels, ensuring the full exploitation of renewable energy.

By capturing and storing excess thermal energy during sunny periods, the system ensures heat is available during periods of high demand, thereby enhancing overall energy efficiency and reducing reliance on fossil fuels.

Key Features and Components: At the core of the MiniStor system is an advanced thermochemical storage technology, utilizing a calcium chloride ($CaCl_2$)–ammonia (NH_3) reaction. This next generation approach significantly improves reaction kinetics, thermo-physical performance, and mechanical stability, making it a highly efficient and durable solution for thermal energy storage. Unlike traditional sensible heat storage (SHS) and latent heat storage (LHS) systems, which rely on temperature changes or phase transitions to store heat, the MiniStor unit leverages sorption and thermochemical reactions to achieve superior energy storage density. By utilizing the reversible reaction between ammonia and salt, the system can store and release heat with a remarkably high energy density of approximately 250 kWh/m^3 of TCM material for heating and 120 kWh/m^3 for cooling—a significant improvement over conventional water-based storage solutions (approximately 5 to 10 kWh/m^3). One of the major advantages of this technology is its chemical stability, allowing for multiple charge and discharge cycles without material degradation. This ensures long-term reliability and minimal maintenance, making it an economically and environmentally viable option, contributing to a more sustainable energy future by reducing CO_2 emissions and enhancing the efficiency of renewable energy systems.

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5.4.1 Thermochemical Units storage value proposition

Value Proposition: The KER#4, MiniStor's thermochemical unit (TCM), can be considered the heart of the system because it is responsible of the high energy storage capacity and provide significative innovation to the entire MiniStor solution. The successful large-scale adoption of RES technologies is strictly correlated to the ability to manage the energy produced during the day exploiting the self-consumption of heating, cooling and electrical demands, particularly during peak periods minimising the energy loss and the grid injections that are not cost -efficient (not remunerate in some countries or remunerated with low tariffs).

A key enabler in achieving energy flexibility is energy storage, which plays a vital role in harnessing and optimizing renewable energy production while minimizing overall energy losses. To bridge the gap between energy generation and consumption effectively, thermal and electrical storage solutions must be cost-efficient and capable of retaining excess energy for later use.

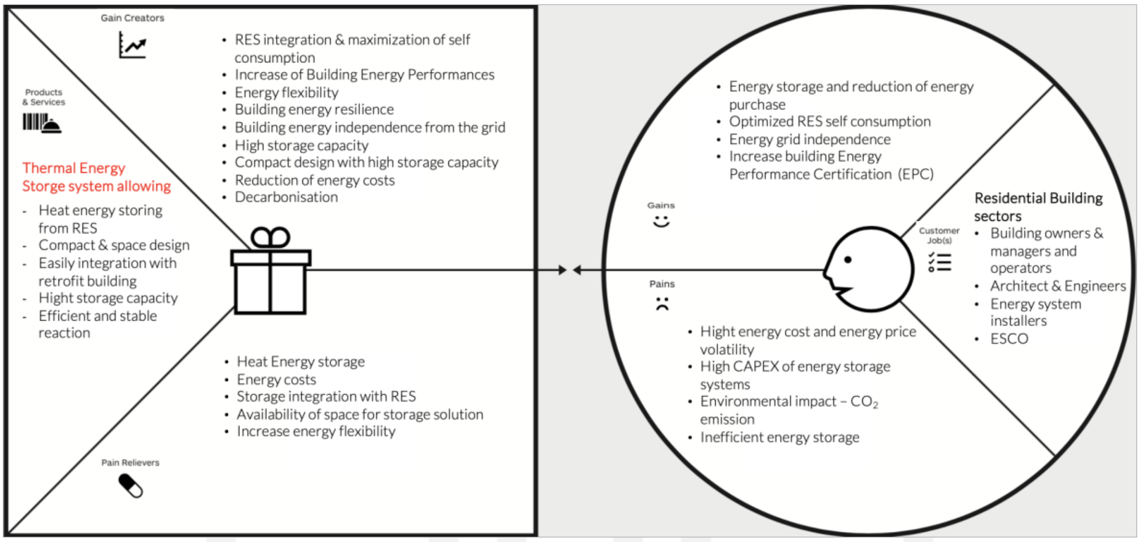

Figure 40. TCM Unit Value Proposition

The MiniStor Thermochemical Unit is a groundbreaking, high-performance thermal energy storage solution designed to enhance energy efficiency in homes. This innovative technology not only reduces carbon emissions but also maximizes the utilization of renewable energy sources, making buildings more sustainable and energy grids more resilient.

The Figure 40 shown the canvas value proposition analysis for the TCM solution. As deeply analysed in the D2.3 "Analysis of relevant legislation and standards for system operation", the ammonia-based solution must respect country standards and regulations for its integration in the residential sector that, at the current state of the regulations, limits the maximum volume of ammonia for a building. This is the reason way in the MiniStor project, only certain types of building have been considered in the customer segment assessment. Nevertheless, the applicability of TCM ammonia solution has less restriction in industrial sector, this means that industrial processes where the heating temperature is lower than 100°C could represent a great potential for replicability.

Key Benefits for building owners:

1. Cost Reduction: The MiniStor Thermochemical storage system is engineered to be affordable, offering a market competitive CAPEX cost and minimal annual maintenance. These features significantly reduce operational expenses, lowering the levelized cost of heat (LCOH) and making the system cost-competitive with fossil fuel-based heating solutions.
2. Compact & Space saving design: Unlike conventional water-based storage solutions, the MiniStor TCM module is up to four times smaller, making it ideal for both new builds and retrofit projects, where space is often a constraint. Its compact nature allows seamless integration into residential and commercial environments without requiring excessive room for installation.

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3. Enhanced Energy Independence & resilience: By efficiently storing RES heat, the MiniStor's unit enhances the renewable energy resilience, ensuring uninterrupted heating and power supply.
4. Carbon Footprint reduction: By optimizing the use of renewable energy, MiniStor TCM unit directly contributes to reduce the dependency from fossil fuels, lowering greenhouse gas emissions.
5. Seamless Integration with Renewable Energy Systems: the MiniStor's Thermochemical storage unit is highly adaptable and designed for easy integration with various renewable energy technologies and heating and cooling systems, including:
   - Solar PV and PVT panels: efficiently storing excess solar energy for heating purposes.
   - Heat pumps: improving the overall efficiency and effectiveness of heating systems.
   - Other renewable energy solutions: enabling a holistic and sustainable energy approach for buildings.

By combining efficiency, affordability, and sustainability, MiniStor's Thermochemical Unit storage is shaping the future of renewable heating solutions, making energy independence a reality for both residential and commercial properties

5.4.2 Thermochemical Units storage business model

The MiniStor Thermochemical Storage Unit introduces a compact, cost-effective, and highly efficient solution for storing heat and integrating seamlessly with renewable energy systems such as PVT panels, and heat pumps. By enhancing energy independence and with minimal space requirements, MiniStor's innovative storage technology is poised to transform heating systems in the building and construction sector.

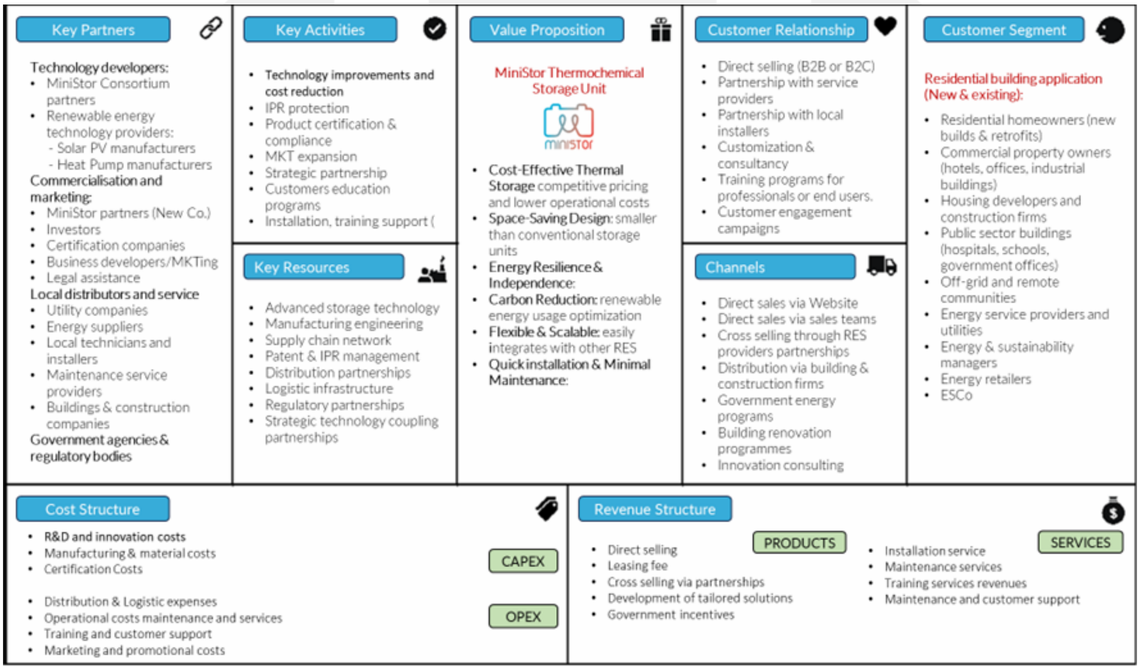

Figure 41. TCM Unit Business Model Canvas

The business model presented in the Figure 41, focused on sector coupling, is key to the successful commercialization of this technology. The strategic integration of MiniStor's TES solution with other RES ensures that buildings can efficiently meet their thermal demand while maximizing the use of RES energy. Given the growing space constraints in urban construction—especially in retrofitting projects—the compact and scalable nature of MiniStor's storage unit provides a significant market advantage but the regulation about the use of ammonia limits the maximum building thermal capacity.

To drive innovation and capitalize on the expanding energy sector, TCM's business model leverages a strong network of strategic partnerships for engineering the technology development and the building integration, including:

- MiniStor partnership: As previously indicated, this KER has seen the collaboration of three fundamental partners, CNRS for the design, Sofrigam for the TCM storage reactor realisation and Psyctotherm for the ammonia circuit connection. Considering that contribution to guarantee the TCM value chain sustainability, the collaboration from those three partners becomes fundamental.
- Renewable energy technology providers *(Heat Pumps, PVT Panels, and Other thermal RES Technologies):* The seamless integration of MiniStor's TCM storage unit with other thermal renewable technologies enhances overall system efficiency, providing customers with a more comprehensive, optimized energy solution. Apart from the partnership with the owners and contributors described at the previous point, new partnerships could create a synergy leveraging other's sales channels and expanding the market. Cross-selling revenue models will be established, allowing bundled sales of complementary products and services, increasing value creation and customer acquisition
- Building and construction firms: Incorporating MiniStor's TES storage unit into building projects allows construction firms to offer higher-value solutions to the market. The compact size and easy installation of the unit make it an ideal fit for both new developments and retrofits, where space limitations are a major challenge. By partnering with construction firms, CNRS, Sofrigam and Psyctotherm can scale adoption across residential, commercial, and municipal projects. Cross-selling initiatives will facilitate joint commercialization efforts, further expanding market penetration.
- Research Institution & Universities: Ongoing R&D collaboration with academic and research institutions is crucial for continuous technology scale-up and improvement, performance enhancement, and breakthrough innovations in thermochemical storage.
- Government agencies and regulatory bodies: Collaboration with regulation bodies and standardisation categories will facilitate the integration of ammonia systems in the residential sector where at the current state, promoting advanced safety regulations.
- Utility companies, energy providers and flexibility aggregators: MiniStor TCM storage unit offers market opportunities for utilities and energy providers, to support the transition towards sustainable energy solutions. By integrating thermal storages with grid management, utilities can enhance demand response strategies, optimize local renewable energy integration and reduce the fossil fuels. DHCN can represent an interesting customer segment for the TCM technologies.
- Installation and maintenance service providers: Strong partnerships with qualified installers ensure efficient deployment and long-term support for customers. This direct connection to end-users streamlines adoption and enhances customer satisfaction, contributing to the smooth market expansion.

By fostering these collaborations, CNRS, Sofrigam and Psyctotherm can accelerate the TRL upscaling, the market entrance and the creation of distribution channels, enhance customer connections, ensuring a win-win strategy for all stakeholders involved in the TES value chain. To be feasible and economically competitive, the MiniStor Thermochemical Storage Unit must maintain a cost-efficient structure while ensuring high-quality standards. The cost structure is divided into:

- CAPEX: including:
  - R&D costs for continuous innovation.
  - Manufacturing and materials costs.
  - Regulatory compliance and certification costs.
  - Market entrance costs and structure organisation.
- OPEX: including:
  - Logistic and distribution expenses.
  - Marketing and promotional costs to boost awareness and customer retention.

- Training and education programs supporting professional installation and customer know-how.

In addition, a key consideration in the long-term success of the MiniStor storage solution is end-of-life management. Circularity is central to the business model, not only for reducing environmental impact but also for enhancing economic feasibility by:

- Recycling materials to minimize waste and extend resource utility.
- Developing take-back programs for responsible disposal and reusability.
- Exploring second-life applications for storage units beyond their initial lifespan.

Target Market: The MiniStor Thermochemical Storage Unit is particularly suited for residential homeowners, both for new builds and retrofits. Therefore, potential end-customers are building and construction firms, energy systems engineering firms, sustainability manager consultants, all of these seeking innovative energy solutions. In addition, beyond individual households, MiniStor's storage technology can plays a key role in local community's initiatives and DHCN, revolutionizing urban energy management.

Commercialization Strategy: The TCM storage unit knowledge is owned by Sofrigam, Psyctotherm and CNRS. It means they have all the capacity and knowledge to produce the TCM solutions and develop a commercialisation plan independently from the other MiniStor partners, leveraging the existing customers and established sales channels.

Nevertheless, the TCM system can reach its main customer segment, when integrated into the MiniStor compact energy storage system and it can be commercialized through a joint exploitation strategy with other MiniStor partners.

Summarising, the potential exploitation can be organised in the following strategies:

1. TCM NewCo between CNRS, Sofrigam and Psyctotherm:

   CNRS, Sofrigam and Psyctotherm could participate in a NewCo or spin-off, specifically focused on the commercialization of the TCM units without the collaboration of others MiniStor partners. This approach can use the existing commercial structure of Sofrigam and Psyctotherm and penetrate different sectors respect to the residential, for example the industrial sectors. In this model the TCM unit is not dependent from the other MiniStor contributions but need additional improvement a customisation to meet the industrial applicability.

2. Creation of a MiniStor new business entity (Newco): This strategy represents the joint exploitation in collaboration with other MiniStor partners. A dedicated NewCo could be established to lead the commercialization of the MiniStor innovativeness (PVT, TCM, HEMS, and other KERs and ERs) involving the collaboration of multiple KER owners. Additional stakeholders as private investors and recycling companies can bring added value in the newco. This entity would oversee product deployment, business development, and customer engagement, ensuring streamlined market entry and scalability. Due to the characteristics of the MiniStor solution, this strategy is mostly indicated to meet the residential customer segment.

This first strategy requires strong collaboration between the three companies. This does not preclude their inclusion in the second strategy; for example, the three companies could establish a joint entity for TCM development and participate in MiniStor NewCo together.

Revenue Model: The revenue model is built on multiple income streams, with direct product sales serving as the primary source of revenue, supported by a strong marketing strategy to drive customer adoption. Additionally, the company generates revenue from installation and maintenance services, which can be delivered either in-house or through a network of certified partners, ensuring seamless deployment and ongoing support.

A key revenue driver is the cross-selling strategy, which leverages strategic partnerships within the energy system value chain. By collaborating with renewable energy providers, construction firms and technology integrators, Sofrigam and Psyctotherm can expand their market reach and deliver added value to customers in the form of fully integrated energy solutions. Customisation options

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will also be offered, allowing for versatile and adaptable configurations tailored to diverse customer needs.

5.5 MiniStor KER#5: Visual Interface IoT platform for user interaction

The MiniStor KER#5, presented in the Figure 42, is an advanced IoT platform designed to deliver a comprehensive, end-to-end, multi-sensorial framework for smart residential environments.

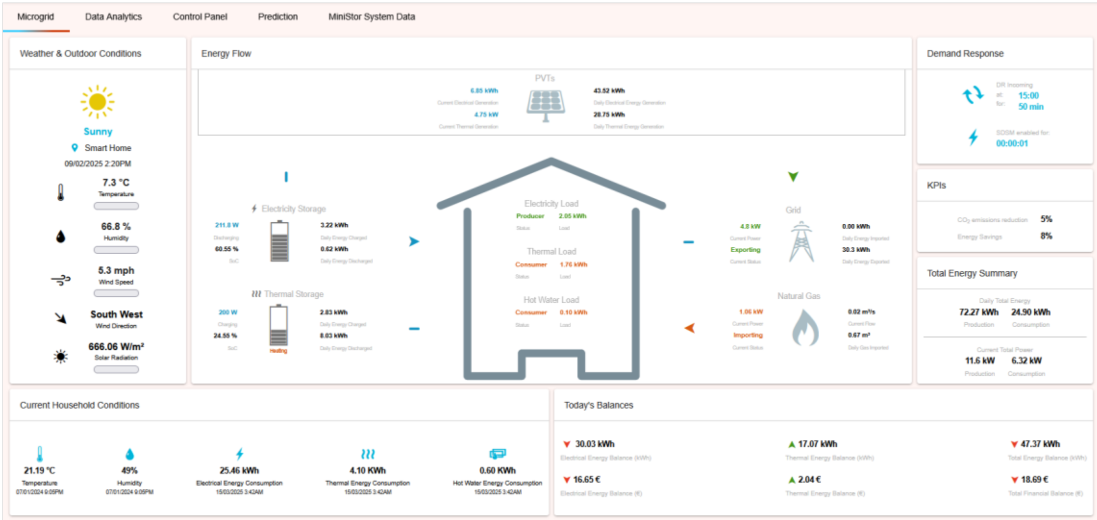

Figure 42. Visual Interface IoT platform

It represents the end-user interface for communicating with MiniStor and allows building parameters to be set at end-user level by collecting, processing, analysing and visualising data gathered from a wide array of installed hardware components.

The platform goes beyond simple data acquisition by seamlessly integrating with HEMS to enhance energy optimisation and automation across various home subsystems. These include renewable energy systems (RES), heating, ventilation and air conditioning (HVAC) systems that detect environmental conditions in the home, lighting and water systems, and imaging and vision systems that collect data from thermographic and red, green and blue (RGB) sensors, as well as sensors that can detect occupancy or movement within the household. Furthermore, users can remotely manage smart appliances connected to the platform, enabling real-time monitoring and control of domestic operations.

At the same time, the platform can manage demand response flexibility with the grid or a flexibility aggregator.

Key Features and Components:

1. High Integration: The IoT platform ensures seamless integration with various data sources and systems through an open API, enabling efficient data sharing and interoperability. Multiple communication protocols are supported on top of the platform's core layer, allowing third-party platforms within the ecosystem to securely access and retrieve relevant data. This openness fosters ecosystem expansion and ensures compatibility with a wide range of smart technologies and services.
2. High Customization: The IoT platform offers a highly adaptable user experience, through highly customizable settings. It allows users to personalize the system based on their unique needs, habits, and preferences. Advanced customization can be tailored on the end-user needs.

5.5.1 Visual Interface IoT platform value proposition

The IoT platform is owned and developed by CERTH-ITI and serves as a powerful enabler for next-generation smart appliances and interconnected home management systems. The canvas value proposition is presented in the Figure 43.

Designed for versatility and scalability, the platform enables seamless communication between devices, sensors, and centralized control systems within a residential environment. Its core functionality lies in collecting, processing, and analysing diverse data streams sourced from a broad array of in-home systems and sensors.

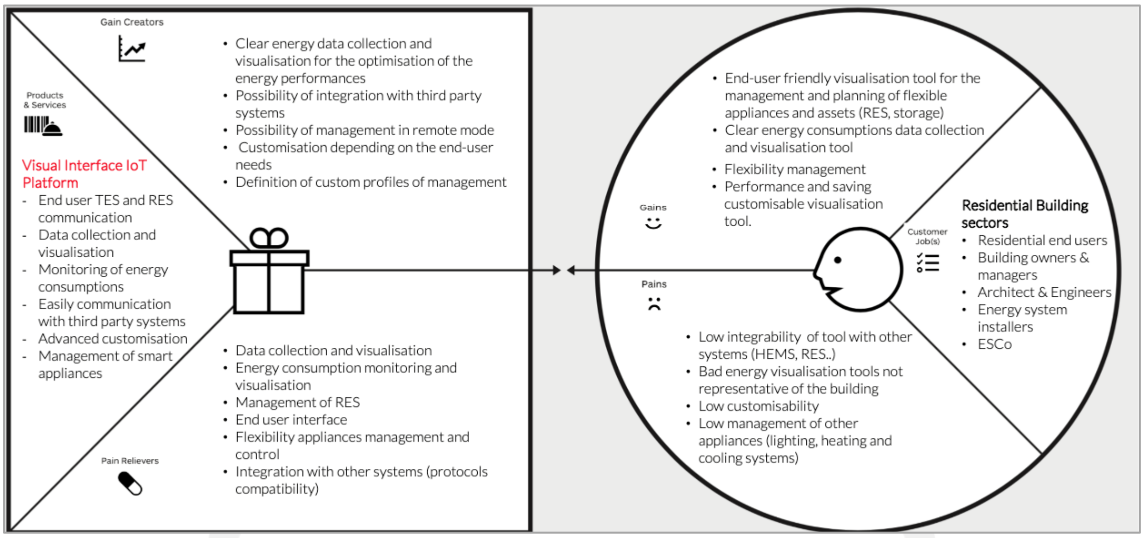

Figure 43. Visual Interface IoT platform

Benefits to Homeowners and end MiniStor end user: The integration of CERTH-ITI's IoT platform into smart homes delivers a range of practical benefits to residents, enhancing comfort, convenience, and enabling the iteration with RES for the control and management of the energy efficiency:

1. Real time Energy Consumption Monitoring: Tenants have a continuous and accurate overview over their energy consumptions, empowering them to make informed decisions that improve efficiency and lower utility costs.
2. Remote Management of Smart Appliances: By integrating various household devices into a unified platform, users can remotely control smart appliances via a mobile app or web interface. This includes scheduling tasks, turning devices on/off, and receiving alerts, which enhances convenience and safety, especially when away from home.
3. Advanced Customization setting: The system offers high levels of personalization, allowing users to adapt the behaviour of their smart home according to their routines, lifestyle, and comfort preferences.
4. Easy integration with third-party platform: Thanks to its open architecture and support for multiple communication protocols, the CERTH-ITI IoT platform ensures compatibility with third-party systems and services.
5. Flexibility market: The IoT platform enable energy flexibility services and permits the iteration with the grids and the flexibility aggregators.

The system is highly adaptable, making it possible to tailor the data acquisition and analysis to suit the specific needs and preferences of users. In the context of the MiniStor project, this IoT platform has been successfully integrated with the innovative thermal storage system, creating a smart, self-regulating energy ecosystem.

5.5.2 Visual Interface IoT platform business model

The MiniStor IoT platform offers a robust infrastructure designed to digitally replicate the house collecting data and generating key performance indicators. It enables seamless communication between domestic appliances and smart management systems, empowering tenants to monitor and manage their overall energy consumption more efficiently.

Figure 44 shows the drafting of the business models in the Canvas template and identifies the customer segment and the key partnership required.

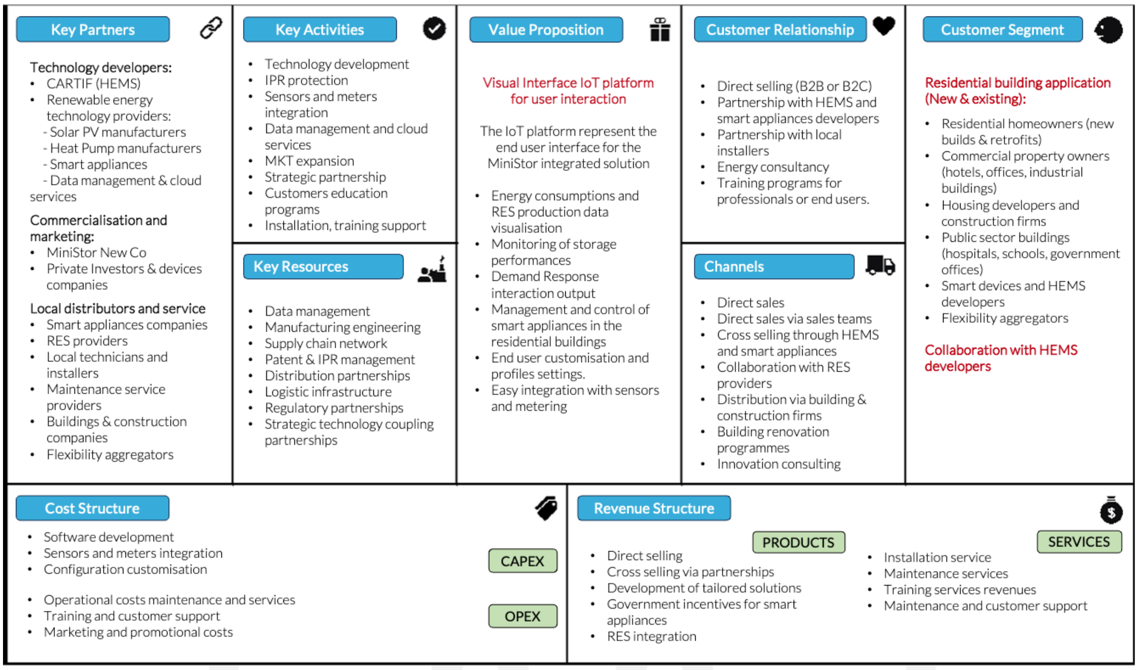

Figure 44. IoT visual Interface Canvas Business Model

The IoT platform market is currently highly fragmented, characterized by numerous players and a lack of interoperability standards. This fragmentation creates a significant challenge to integrate the various hardware into a single platform, but also a strategic opportunity to introduce a scalable, standardized solution. The MiniStor IoT platform developed by CERTH-ITI stands out as both a commercial and innovation hub, capable of integrating and coupling third-party technologies with market-ready solutions. The platform is designed to foster collaboration with external stakeholders, allowing the integration of diverse technologies to create a unified, intelligent ecosystem. This open collaborative approach positions CERTH-ITI's platform as a pivotal enabler in the transition toward smarter, more energy-efficient environments.

CERTH-ITI's strategy is to engage directly with key stakeholders across the building and ICT value chains. These stakeholders are not only collaborators but also target customers. Specific partnership agreements will be established with:

- Manufacturers of sensors, meters, HVAC, RES systems, storages, heat pumps, smart plugs, and even non-smart device producers seeking to digitalize their offerings.
- HEMS providers, essential for offering a fully integrated solution that maximizes energy efficiency.
- Energy service providers and flexibility aggregators looking to enhance their services with smart home or smart building capabilities.
- Architectural and engineering firms, who can embed the IoT platform into new construction or renovation projects.
- ESCOs, which serve as effective channels to reach end-users by integrating energy efficiency services with digital technologies.

In addition to B2B partnerships, CERTH-ITI also aims to reach end customers directly, offering tailored solutions that meet the specific needs of stakeholders or individual users. This can be achieved through three distinct approaches:

- In-house solutions: Fully developed internally by CERTH-ITI, encompassing both hardware and software components. This approach could be applied to the MiniStor newco in the case of KER#1 commercialisation strategy.
- Inside-out solutions: CERTH-ITI identifies and collaborates with external commercial partners to complement in-house technologies (for example CARTIF).
- Outside-in solutions: External providers bring their technologies to CERTH-ITI for integration with the IoT platform, creating a consolidated product offering for the end-user.

These models offer market flexibility and allow CERTH-ITI to address diverse market demands.

Target Applications: The MiniStor platform is versatile and scalable, making it suitable for a range of applications, including but not limited to:

- Residential buildings and autonomous houses
- Local communities and smart districts
- Municipal infrastructure and public buildings
- Commercial offices
- Industrial facilities

Additional customer segment can be represented by smart devices manufactures that could be interested to by the IoT licence know-how or a licence service.

Cost Structure: The platform's cost structure is divided into two main categories:

- CAPEX: These include the upfront investment in developing the IoT platform and the costs associated with integrating domestic hardware.
- OPEX: These are ongoing costs related to system maintenance, updates, customer support, training, marketing, and promotional activities aimed at customer acquisition and retention.

Commercialization Strategy: As a non-profit research center, CERTH-ITI will not directly commercialize the MiniStor platform. Instead, the go-to-market strategy involves the establishment of new business entities or parentships dedicated exclusively to the commercialization and further development of the platform. CERTH-ITI could sell or license the rights for commercial exploitation to new entities or other companies, which will take ownership of product evolution and market growth.

In addition, a commercial Newco or a spin-off can be established in partnership with the MiniStor consortium partners in the case of the commercialization of the integrated MiniStor solution (KER#1). The structure can focus on different verticals or market niches, leveraging shared business models while utilizing the unique technologies and commercial networks of their founding partners.

Revenue Model: The primary revenue stream for the IoT Visual platform could be generated through licensing agreements. These contracts will include subscription-based models, creating a stable and recurring revenue flow.

CERTH-ITI will also encourage cross-selling initiatives in collaboration with complementary technology providers (example: CARTIF- KER#2), enhancing the overall value proposition and driving stronger market penetration.

Additional revenue will come from:

- Service contracts for clients who require technical development, customization, or full digital transformation services.
- Consulting and integration services for stakeholders integrating the platform into their operations.
- Training and consultant services.

This project has received funding from the European Union´s Horizon 2020 research and innovation programme under the grant agreement No 869821

6. MiniStor approach to Circular Economy

The MiniStor project has considered the circular business model as a key pillar for exploiting the project results and a solid model for the replicability.
This model has been considered not just a way to follow the EU environmental guidelines, but it also gives the business a real advantage over competitors in an energy segmented market populated by different technologies.
With this strategy, the MiniStor consortium aims to develop a market strategy that consolidates relationships with customer segments throughout the product's life cycle ensuring a continuative benefit from both parts.
At the same time, the circular business model reduces the purchase of raw materials from foreign countries, which exposes businesses to cost fluctuations and supply uncertainty.

6.1 Consolidated circular business modelling use cases

To draft the Circular Business Model for MiniStor in the most useful way possible and guarantee the best possible market entry, this process took into consideration the most successful existing circular business models as a reference point.
Two important sectors investigated were PV panels and lithium batteries, as these are the sectors most influenced by the need for critical raw materials, most of which come from outside the EU.

6.1.1 PV System Circular Business Model

One of the circular business models in place from more than 10 years is the recycling process of the PV systems. This concept is based on the management of PV panels for the entire lifecycle of the modules, starting from the design and production phase that is done promoting an easy disassembling process at the end of life. The approach aims to maximise the value of raw materials and minimise waste.

Innovative know-how generated in the research project Photorama [54], where ENEA participated[20], demonstrated a recovery rate of about 98% of the raw materials. The most important PV companies now have recycling processes integrated into their production and are currently working with second-life or recycling.

The second life program takes into consideration used PV panels near the end of life that are still working with lower performances, but which can generate benefits in other contexts. In this regard, the second life approach uses PV panels from dismissed plants.

An example of PV efficient circular business model comes from the First Solar Company is presented in the Figure 45.

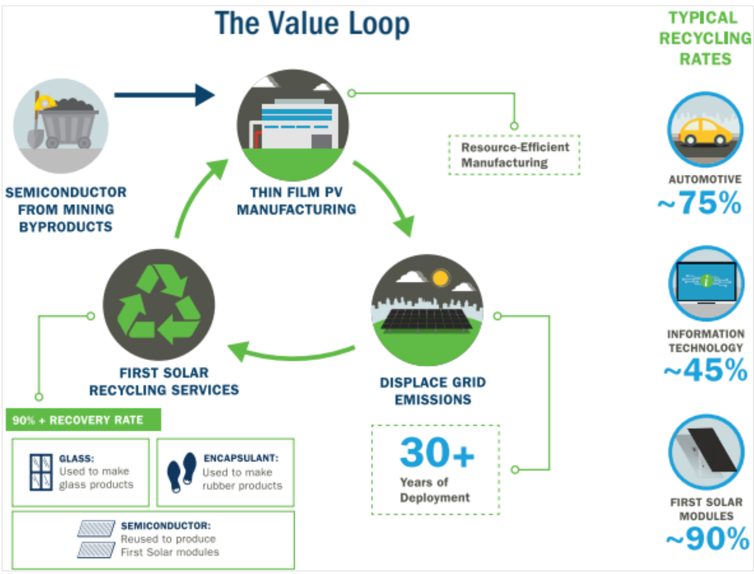

Figure 45. First Solar Circular Business Model

"Responsible Solar minimizes environmental life cycle impacts and transforms waste into resources to provide solutions to climate change, energy security, water scarcity, and a resource-constrained world. While focusing on maximizing material recovery through

[20] https://www.enea.it/en/

our industry leading high-value PV module recycling services, First Solar is committed to responsible sourcing and continuing to exclude deep sea mining minerals until scientific findings are sufficient to assess the environmental risks" [21] .

First Solar covers a leadership role in this sector with a consolidated experience of over 15 years at world level. The market approach has been based on the Extended Producer Responsibility 8 years before the introduction of it as an obligation for the PV companies

The approach of First Solar differs from other PV companies because their process recovers over 90% of semiconductor material which is reused to produce new PV panels, reducing raw materials from mining. It is reflected in less energy and water used in the LCA.

Other materials as glass and metals frame are recovered with the same rate (90%) and reused in other products such as glass, rubber and aluminium products [55].

6.1.2 Lithium battery Circular Business Model

The circular business model in the lithium battery sector has taken importance due to the large use and market growth of lithium storages in the electric mobility and in RES storage applications that places new environmental and economic challenges in from of the European economy, with particular emphasis for the supply of critical raw materials.

The application of the CBM in this sector is like the PV sector and starts from the design and production phases that promote modular design and production.

Also, in this sector the second life is an important approach because the lithium batterie, used in the electrical vehicles and with reduced performances can be used for stationary application, such as energy storage for buildings, electricity grids or photovoltaic systems, where the performances have less importance than the capital costs of the storage. This strategy still allows 70-80% of the residual capacity of batteries to be utilised, extending their use before their final recycling.

The second life approach can also open the door for a different business model of consumption as the "battery as a service" where the customer pays not for the product but for the service generated by the storage.

Recycling is another key component of the circular model. Advanced technologies such as hydrometallurgical and pyrometallurgical recycling enable critical materials such as lithium, cobalt, nickel and manganese to be recovered. However, for recycling to be economically viable, it must be part of a collaborative value chain in which producers, users and recyclers share data, standards and infrastructure.

An interesting example of application of CBM comes from the Italian company MIDAC[22]. MIDAC is one of sixty European battery companies involved in the IPCEI programme[23], which aims to develop a complete lithium battery supply chain in Europe. Through a circular economy approach, MIDAC plans to reuse, recycle, and produce new batteries from recycled materials. To achieve this, it will invest €130 million over seven years in new recycling and lithium battery production facilities in Italy.

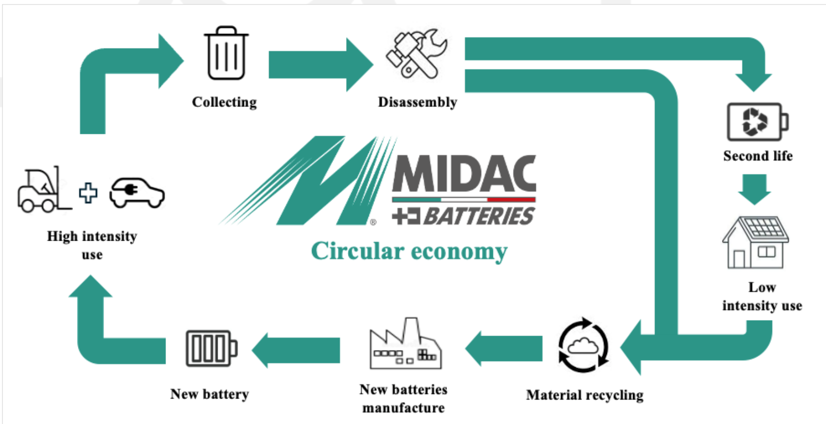

Figure 46. MIDAC Circular Business Model

[21] https://www.firstsolar.com/
[22] https://midacbatteries.com/
[23] https://www.ipcei-batteries.eu/about-ipcei

As shown in Figure 46, the collection of used lithium-ion batteries is the first step of the process. MIDAC is responsible for the disassembly phase of the battery packs to obtain the modules, which are selected using a proprietary protocol to assess their suitability for second-life applications.

The modules selected for a second life will be used to produce second-life batteries for standby storage. Those that are not suitable will be used to recover secondary raw materials for new cells and produce new first-life industrial batteries through the construction of a recycling plant [56].

6.2 MiniStor Circular Business Model

The circular economy business model, as presented in Section 5.1.2, is based on the MiniStor integrated system. It aims to maximise the use of underutilised assets.

The MiniStor consortium uses this strategy to enter a market not overtaken by TES system. It considers MiniStor's multiple characteristics, which enable it to meet a residential building's entire energy needs. As described in Section 5.1.1, the solution considers several technical aspects and targets the residential sector in principle, but not exclusively.

The strategy for entering the market with this innovative solution involves sharing knowledge and ownership between multiple entities, including academic partners, SMEs, research institutes and large enterprises. This strategy can be implemented through a new company (Newco), which comprises MiniStor partners and additional external stakeholders who can contribute missing knowledge or financial capital to the value chain. This enables the future MiniStor Newco to operate in the market as a unique entity representing different partners and investors.

The business model canvas drafted for KER#1 was optimised and used in a dedicated workshop organised towards the end of the project as part of Task 7.6: 'Stakeholder Design Workshops for User Involvement and Validation' (Figure 47). Partners from the MiniStor consortium, as well as external experts from relevant technological sectors such as PV, lithium batteries, TES and PCM, and research centres, participated in the workshop.

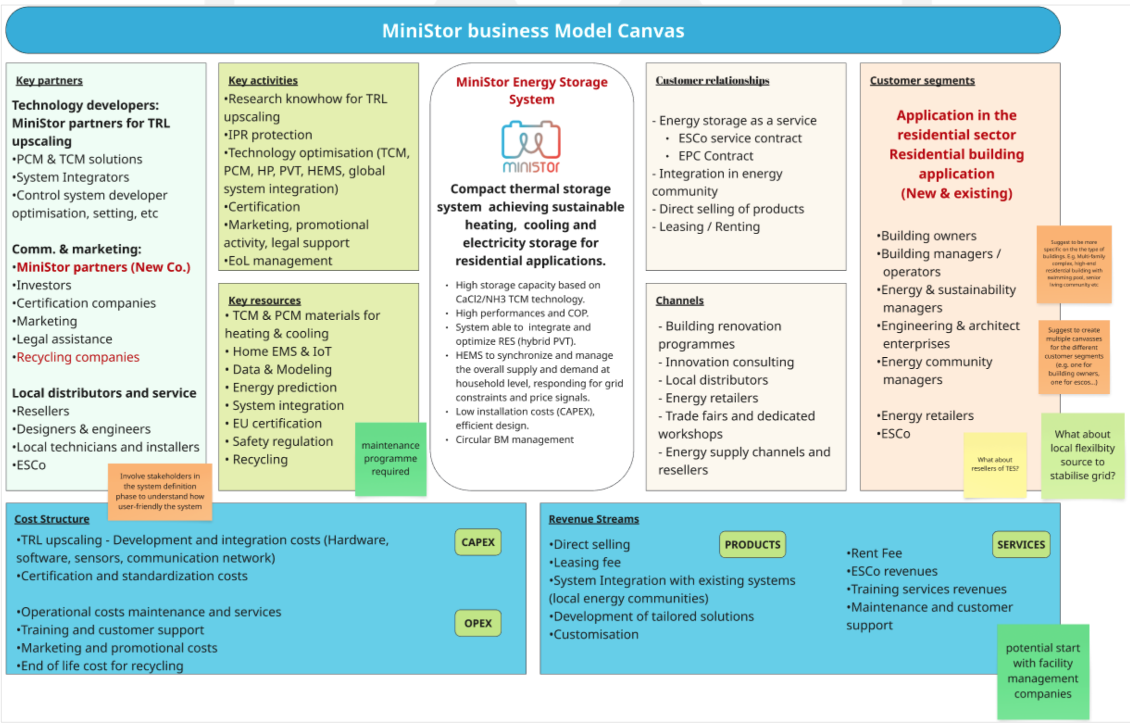

Figure 47. MiniStor Canvas Model on MIRO board

Technology providers are well represented by the MiniStor partners, who form the core group of Newco. They will be responsible for producing the TCM unit, the HEMS and the HP in a tailored way, and for connecting all the systems. Some technological components, such as the EESS and the PCM unit, could be sourced directly from the market via supply agreements with the producers.

Other systems, such as the PVT panels, could be produced by the owners (EndeF) and sold within the MiniStor business.

Other potential partners of the Newco are listed in the left side of Figure 47 In this list, particular attention is reserved to recycling companies (evidenced in red) because they have to cover the recycling knowledge that are missing in the MiniStor consortium and are at the base of the circular economy approach.

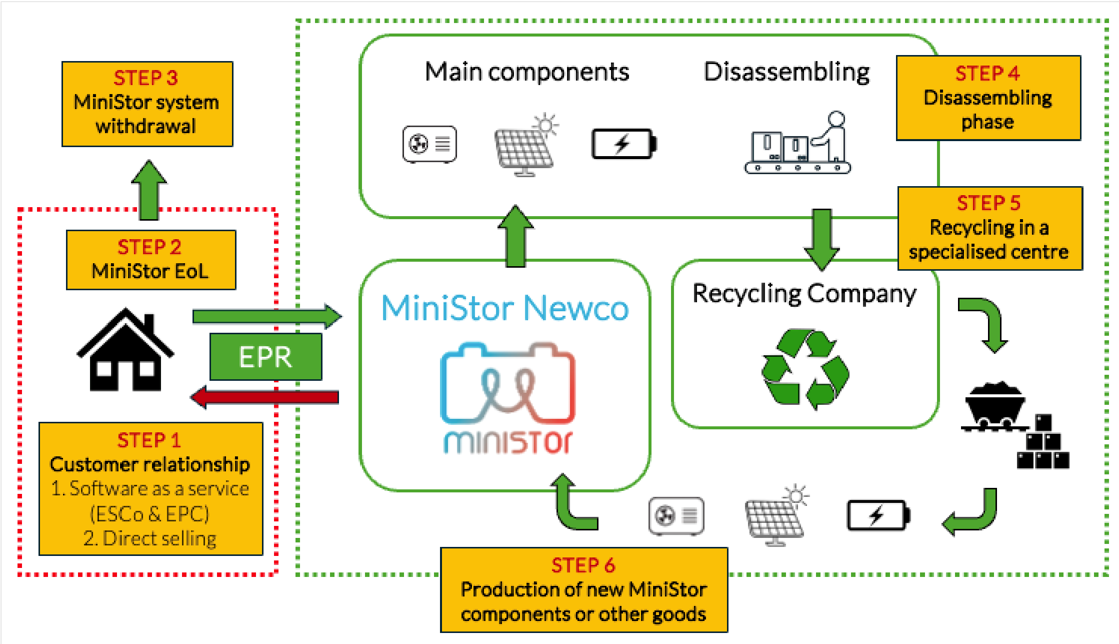

Figure 48. MiniStor Circular Business Model

During the virtual workshop, the main concept of MiniStor was presented to facilitate understanding of the business model and encouraged contributors to provide useful feedback.

The business model has been presented in the MIRO platform[24], to create a collaborative framework where the attenders contributed with comments and suggestions in form of sticky notes.

The final business model, result of this analysis if presented in the Figure 48 where the MiniStor Newcos is positioned in the center of the scheme near the recycling company that plays a principal role in the business.

Step#1– Customer relationship: The first step of the CBM shows the relationship with the customer segment, here represented by the residential sector. It is based on the extended producer responsibility standard that guarantee to the MiniStor newco, a continuative relationship with the customers for the entire life of the product life until the substitution. This customer relationship could follow three different approaches:

1. The direct selling model: where the customer pays the CAPEX cost and all the services requested during the MiniStor life (installation, O&M, training, etc.). This model is the easiest and like the most technological assets assailable into the market. This model guarantees the entire cash flow at the beginning of the relationship, less risks for the MiniStor newco, but probably reduce the economic benefits for seller.
2. The Product as a service model: This second approach is based on the selling of the benefits/services produced by MiniStor and not from the property of the goods. Relevant use cases of product as a service are: a. Philips: the light as a service business model where the customer pays for the light, not for the lamps. b. Michelin: with the provision of tyres for company fleets.
3. This approach follows the EPC contract (detailed in chapter 3.1) that are contracts based on the economic benefits generated by the system, during its application at building level. EPC contracts

[24] https://miro.com/index/

are typical contract used by ESCo. In this model the ESCo finances the CAPEX and some OPEX costs and receives economic benefits from the service generated to the customer segment.

With the software as a service approach, the MiniStor system must be maintained and able to provide heating, cooling and DHW as requested by the building users.

4. Sharing Platform: This concept is based on the applicability of the MiniStor solution in a group of buildings rather than to a single building. In this way, users can benefit from shared assets, reducing CAPEX and OPEX costs. The sharing platform is effective in local energy districts and smart grids. Due to limitations in the use of ammonia in the residential sector, the system is currently limited to supporting a single building application and this approach has not been analysed in depth. Nevertheless, this remains the most promising business concept because, alongside the product-as-a-service EPC approach, it can facilitate economic integration in the residential sector. Any future assessment of this business model must take national ammonia regulations into account.

Step #2 – MiniStor EoL: This step marks the end of the system's life when withdrawal and replacement are necessary. Reasons for system replacement include reduced system efficiency or need to replace expensive system components where repair is less cost-effective than replacing the entire system. At this point, due to the extended responsibility, the MiniStor newco is responsible for the withdrawal.

Step #3 – MiniStor withdrawal: The system withdrawal will be done by the MiniStor technicians or by a company working in the name of MiniStor. The deinstallation will be done in all the parts included in the selling contract during the selling step (TCM unit, PCMs, HP, etc).

If the selling has been done in direct selling, the system will be simply deinstalled and all the components will be collected in the MiniStor factory.

It the customer relationship has been done with an EPC contract, the ESCo could evaluate if some technical components (i.e. the PV panels the HEMS or other parts) are already working with a good level of performances. In this second case, the ESCo could decide to change only the parts not working and provide an extension of the EPC contract.

Step #4 – Disassembling phase: The disassembly phase is the first step that requires collaboration with the recycling company. Initially, all the technical parts are disassembled in the MiniStor laboratories, and the components are divided (HP, TCM, PCM, etc.). At this stage, the technical components are checked and selected for 'second life' installations in locations where performance is less important than initial cost. Technical parts not used for second-life installations will be fully disassembled; the ammonia will be removed from the TCM as well as other working fluids in accordance with all safety requirements. The output of this process is the preliminary step for the recycling process.

Step #5 – Recycling process: the recycling process, started in preliminary phase in the step #4, will continue in specialised departments or companies, where the materials will be recovered by tailored processes depending on the materials. The know-how for this step will come at the beginning from a partnership with a specialised company, but when the business will be fully operative those competences could be acquired by the MiniStor company. It is important to underline that this process, even if planned at the beginning of the business model, could start when there are enough MiniStor units disassembled. This can happen from 10-15 years from the first installations. Until the volume of disassembled MiniStor systems is higher, this process could be done by subcontracting to reduce costs.

Step #6 - Production of new MiniStor systems: The material recycled from the step 5 will be reused in the production of new MiniStor components to provide a substantiable product with low LCA rate and at the same time to reduce the cost for raw materials. As indicated in the previous point, this process can start once there are a relevant volume of dismissing systems to sustain the circular economy. It means that the new MiniStor system built with recycled raw materials from previous systems will be available in a middle to long period.

Nevertheless, at the beginning the acquisition of raw materials for the MiniStor construction will guarantee a percentage of recycling materials from other products. In conclusion, the recycling materials that will be not usable in the MiniStor reconstruction, but with market value, will be used to fill other circular economies.

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7. MiniStor SWOT Analysis

The final assessment done in relation to the MiniStor integrated solution business model is the SWOT analysis that describe Strengths, Weaknesses, Opportunities and Threats of the MiniStor "Product as a Service" business model and the "Shared platform" business model.

The SWOT assessment has been started during the "'Stakeholder design workshops" included in task 7.6, where the external experts added comments and suggestions in form of electronic post-its in relation to the MiniStor integrated platform as value proposition (Figure 49).

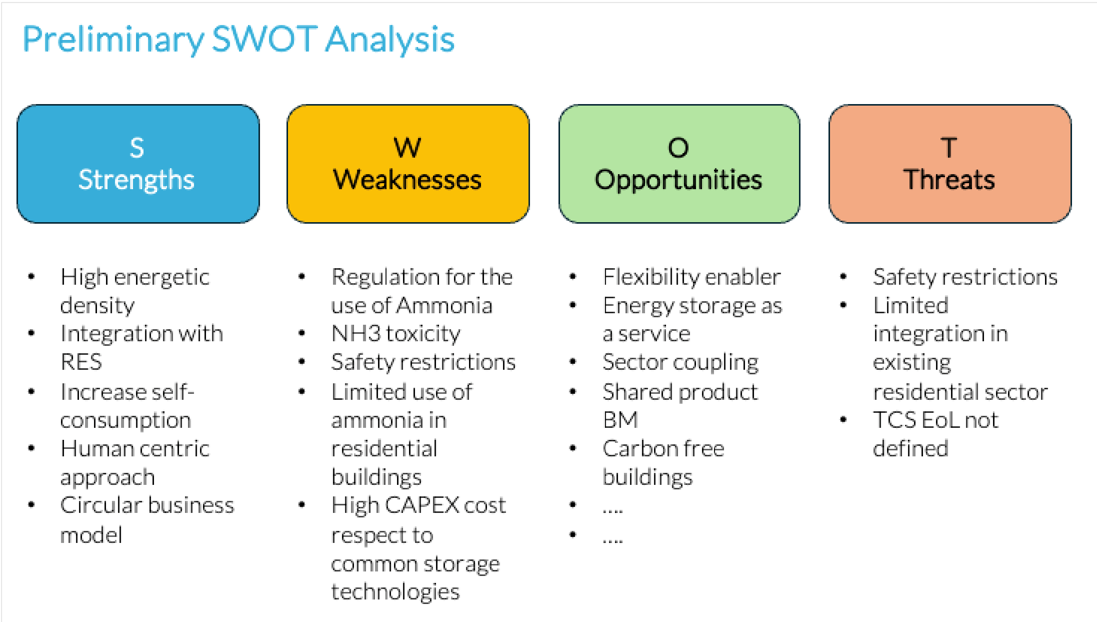

Figure 49. Preliminary SWOT analysis feedback from MIRO

Table 9 present some characteristics of the two potential business models that are not mutually exclusive, but can be applied together in some cases, complementing each other. They can be applied in a complementary way in certain situations, depending on country legislation and customer segment.

In general, Product as a Service is best suited to contexts where product quality, maintenance and durability are important, and where there is a strong relationship between suppliers and customers. It is likely that the MiniStor circular business model will have to be based on this concept from the outset in order to penetrate the market and achieve success.

Sharing platforms are successful in contexts with high usage frequency and high urban density, which is typical of smart urban districts with a high share of renewable energy sources (RES), where optimising spare capacity through the community is crucial, and where integration with distributed resources can facilitate this. This characteristic could form the second level of the MiniStor business model once the technology is more mature and affordable.

Table 9. MiniStor business model SWOT analysis

	Product as a Service Business Model	Sharing Platform business Model
Strength	• Long-term customer retention: This model enables the MiniStor newco to maintain the relationship with the client throughout the system's lifetime. This involves the application of an EPS contract by an ESCo. Continuous customer monitoring enables the development of tailored solutions that optimise the MiniStor system for real building and end-user behaviours. • More control over the product life cycle: This model guarantees control over the product life cycle. This approach is well described in the circular business model, in which the company (Newco) is responsible for withdrawing the system under the extended producer responsibility scheme. This model is also preferred when the relationship is based on an EPC contract. To maintain profitability, the EPC contract must control the system and maintain all functionality to reduce O&M costs. • Recurring revenue: In the case of an EPC contract, the revenues of this approach are represented by the end user's economic savings and the benefits produced by the product. This ensures a continuous revenue flow rather than a one-off payment. • More durable solutions and better quality: With this model, the products remain the property of the company that signs the EPC contract with the end user. This means that the ESCo has a greater incentive to design and produce durable, repairable goods with lower maintenance costs. This model guarantees better product quality.	• Cheaper access to goods and services: This model reduces CAPEX and OPEX costs for end users and facilitates market entry for businesses where production costs are not yet fully optimised. On the other hand, this model works well where the product can be shared easily and effectively. This means that the size (capacity) and performance of the MiniStor system must guarantee its use by end users when it is shared. This model is most likely not applied in countries where ammonia is limited by internal regulations that restrict the system's capacity. • Positive network effect in smart districts: This model facilitates the development of local communities and smart districts where assets are distributed among multiple users. A good example of a shared application could be in PV local communities or at the DHCN level. • Efficient utilisation of system capacity: With this approach, users with a low utilisation ratio can share a MiniStor unit between multiple buildings, reducing costs while maintaining the system's benefits. With the same approach, MiniStor units with oversized capacity for small buildings can be installed in shared mode. This means a smaller product size for a wider range of building installations. • High scalability with low marginal costs: This model allows for system scalability while limiting development costs. This works well with a modular approach, where the size (capacity) of the system can be customised and multiple units of the same system can be installed. This approach is the opposite of a tailored solution.

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Weaknesses	• High initial investment required to maintain product ownership: In products and services, the main part of the initial investment is overseen by the ESCo. This means having high financial exposure at the beginning, with income generated over the years depending on the efficiency of the system applied at building level. This characteristic is intrinsic to the ESCo business model, making it quite sustainable for this type of company. • Operational risk for maintenance and logistics: As with the previous point, this characteristic is typical of the ESCo business; therefore, a structured ESCo can support this kind of risk. O&M must be carefully considered at the beginning of the contractualization phase because a poor assessment can result in financial exposure (costs). ESCo companies also need to be well organised with efficient logistics to respond quickly to requests for technical assistance in the event of problems. • More complexity in management and contractualization: The EPC contract must take into account all possible situations that could arise during the customer relationship in order to reduce O&M costs.	• Dependence on the number and trustworthiness of users: Multiple ownership of a shared asset must be based on a well-dimensioned process to ensure all users are satisfied. Energy consumption must remain at the level of the design phase to enable the system to provide all users with the same level of comfort. • Regulatory and liability issues (e.g. damages): Regulations are sometimes complex, particularly in the energy sector. In the case of the MiniStor system, damage caused by one user is reflected in the service for all users connected to the system. • Less controllable service quality: As with the first weakness, users cannot use the system as they wish but must usually respect certain restrictions that could affect the service quality. In the MiniStor system, this essentially depends on the system's capacity and operational mode, which must be balanced during the design phase.

Opportunities	• More opportunities for business expansion: This business model creates more opportunities for expansion with specific customer segments, such as municipalities and industrial sectors, which are more oriented towards EPC contracts. For MiniStor, this could open the tertiary building market (hotels, sports centres, small hospitals, etc.) and then the residential sector. • Remote monitoring and integration with smart technologies: MiniStor has been developed to integrate easily with RES and smart technologies to provide a range of smart services that can fully satisfy the energy needs of building users while providing high-quality internal comfort. In this way, the MiniStor HEMS developed by CARTIF can play a key role. • Synergies with circular economy models (recycling, reuse): This approach forms the basis of the MiniStor business, as described in Chapter 6. Extended product responsibility will play a pivotal role.	• Growth in urban and young markets: This model facilitates RES integration at a local level, an area in which the MiniStor system operates. Applications in local and smart grids represent the target market, as does the situation where space is limited (at urban level), which presents an opportunity for MiniStor as a shared TES. • Integration with digital solutions: The shared TES model will be supported by an innovative digital solution that will permit management and control of the system. The system is already equipped with an open-source HEMS that can be integrated with existing systems. This feature will facilitate acceptance and integration of the system. • Potential in emerging sectors: As mentioned in the first point of opportunity, the MiniStor system is designed for integration with smart grids and to support the integration of RES at a local level. Energy decentralisation will facilitate MiniStor's market entry as well as the development of new generations of DHCN.
Threats	• Regulatory complexity: This business model is more complex and is sometimes not well accepted by certain customer segments. In some situations, it is difficult to integrate due to country regulations regarding energy systems and an energy market that is not fully open. • Cultural resistance to use versus possession: As an innovative business approach, it must convince customers who are sceptical of disruptive innovations. • Financial risks associated with asset management: The main threat to an ESCo is financial management due to the initial investment and revenues spread over several years.	• Restrictive local or sectoral regulations: As with other energy systems, the sharded TES model sometimes conflicts with local regulations and standards that do not permit the easy sharing of energy. • Risk of opportunistic behaviour among users: The multiple ownership of an energy asset must be supported by robust regulations and well-defined contracts to ensure that all owners receive the same benefits. Sometimes a user cannot obtain the desired benefits.

This project has received funding from the European Union´s Horizon 2020 research and innovation programme under the grant agreement No 869821

8. Conclusion and next steps

As a conclusion of the business model assessment, the MiniStor solution can be defined as a disruptive innovation with the potential to revolutionise the thermal energy systems market.

The MiniStor integrated system, presented here as KER#1, is a multiple system that is not yet available on the market and has no competitors. It is able to provide thermal self-sufficiency to a family home or small building, but storage capacity can be limited due to current standards and regulations that restrict the use of ammonia at a residential level by requiring industrial safety systems.

The main technological innovation is the thermochemical ammonia-based unit, which has an energy capacity more than ten times that of common water-based thermal storage systems. This reduces the required space and facilitates urban integration where regulations align with the system's characteristics.

The MiniStor integrated system represents a joint exploitation from the MiniStor consortium, which acquires IPR and knowledge. While the joint exploitation strategy is not the only way to disrupt the market, it is the most important and straightforward way to achieve a significant share of the residential market.

Considering the configuration of the consortium, the best market entry strategy has been evaluated as a NewCo, with participation from MiniStor partners and additional stakeholders to cover missing competencies and technology that could boost competitiveness. Relevant stakeholders could include PV and EESS companies, as well as a recycling company, which would be fundamental in guaranteeing the circularity of the business model.

The circular business model developed in this task is based on extended product responsibility, which puts the NewCo in direct contact with customers throughout the entire lifecycle of the system, including the withdrawal and recycling phase. The business model can be based on three concepts: (i) Direct selling, (ii) Product as a Service, and (iii) a Shared Platform.

The first model is the simplest and guarantees revenue from sales from the outset.

The second model is based on Energy Performance Contracts (EPCs) applied by an Energy Service Company (ESCo). This model guarantees lower economic exposure for customers but probably offers a smaller long-term economic advantage.

The third model, the shared platform, can be applied to the first two models and differs from them in that it can be applied to multiple consumers (i.e. more buildings served by a single system).

In terms of environmental impact, this model is probably the most efficient, but it is more appropriate for energy districts and local communities with a high level of building smartness and RES penetration.

To reach marketability, the next steps for the MiniStor system will be to upscale the technology readiness level (TRL) and conduct additional testing over medium to long periods, covering entire years of heating and cooling.

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