D7.7 Cost-benefit analysis

Lead Author - Marco Rocchetti (R2M)

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Summary
This report details the final exploitation activity and provides an economic assessment of the application of MiniStor in five different use case scenarios. The analysis follows the technical results and simulations carried out in D6.7, taking into consideration some of the main use cases. It presents costs for prototyping and market competitor prices, detailing the services that MiniStor can provide at the level of residential buildings.
The economic simulations for the five use cases take into account the reverse approach for calculating the simple payback time. This reverse approach is employed because it is not possible to have a defined market price for the MiniStor solution at TRL 7. This approach identifies the economic benefits of the MiniStor scenario in relation to the baseline, considering literature data on end-of-life technologies and the PBT commonly accepted by the residential building customer segment. A range of possible market prices accepted by customers is analysed.
The final assessment provides interesting data on the preliminary reduction in costs of the MiniStor subcomponents, which are presented in the final comments.

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Lead Beneficiary	Deliverable Author(S)
R2M Solution	Marco Rocchetti (R2M) – Lead Author Yannick Bang Harve (R2M) Gianmarco Gatti (R2M) Roberta Roffi (R2M) Mario Cortese (R2M) Marcella Del Vecchio (R2M)

Beneficiaries	Deliverable Co-Author (S)
ENETECH	Konrad Zdun (Enetech)

Beneficiaries	Deliverable Reviewer (S)
CERTH	Paschalis A. Gkaidatzis
HSLU	Louis Schibli, Philipp Schutz

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Abbreviations

AUX	Auxiliary
CAPEX	Capital Expenditure
COP	Coefficient of Performance
D.	Deliverable
DHN	District Heating Network
DHW	Domestic Hot Water
EoL	End of Life
ESS	Energy Storage System
EESS	Electrical Energy Storge System
EER	Energy efficiency Ratio
EPC	Energy Performance Certification
FPC	Flat Plate Collector
FSP	Fresnel Solar Panel
HEMS	Home Energy Management System
HP	Heat Pump
HVS	Hight Voltage Storge
IA	Innovation Action
KPI	Key Performance Indicator
LFP	Lithium iron Phosphate battery
OEL	Optimal Environmental Lifespan
OPEX	Operative Expenditure
O&M	Operation and Maintenance
PBT	Pay Back Time
PCM	Phase Change Material
PV	Photovoltaic Panel
PVT	Photovoltaic Thermal Panel
RES	Renewable Energy System
T.	Task
TCM	Thermochemical
TRL	Technology Readiness Level

1. Introduction

1.1   Objective of the report

This deliverable is the second report as an output from T7.5 and presents the cost-benefit analysis of the MiniStor system applied to the residential sector.

In this context, the MiniStor system is compared to traditional systems available into the market, by simulating environmental conditions and services to cover the building's energy needs and provide services to end users comparable in selected scenarios.

In this regard, it is important to note that the MiniStor system is not just a thermal energy storage system, but rather a system composed of different subsystems that can satisfy a building's energy needs and additional services, in a single solution.

The MiniStor system can provide basic energy services such as heating, cooling and the preparation of domestic hot water (DHW), as well as advanced services such as thermal and electrical energy storage, integration of renewable energy systems (RES), participation in the flexibility market and the advanced management of building consumption in relation to the energy produced by RES.

These characteristics make it unique in the market, with some competitors originating from research projects that have not yet been fully developed and not yet commercialised, as reported in the D7.6 'MiniStor market analysis'.

Therefore, the comparative assessment is supported by an analysis of the MiniStor components and a market review with the scope to identify current commercial prices for competing subsystems such as heat pumps (HP), electrical energy storage systems (EESS), etc.

The final output represents and assessment of the economic conditions that MiniStor aims to achieve for its marketability at residential level once the technology will be fully developed and commercialised.

1.2   Structure and connection with the other deliverables

This report is structured from the beginning to provide information needed to clearly investigate the parameters that effect the MiniStor market price considering competitors technologies, market conditions and energy tariffs available in the EU context.

The first part (chapter 2) summaries the general information about MiniStor to define the characteristics which will be compared to other common technologies. This part of the report collects general information from other deliverables and document developed and shared during MiniStor.

The chapter 3 describes the subcomponents of MiniStor that are needed to provide energy services as well as additional services connected and not common to commercial heating and colling systems. This document D7.7 takes in consideration competitors' technologies as indicated in the D2.1 and in the document T7.5 "Market competitors and European market replicability assessment" where it is placed too.

For the description of the system components, the report uses information collected in technical deliverables as:

- D3.1 - "Initial dimensioning of the system according to general use typologies".
- D3.2 – "Design of peripheral thermal equipment".

The cost assessment is presented in the chapter 4 that represents the core concept of this report. The treatment follows the technical replicability assessment done in the D6.7 "Feasibility analysis" in some of the scenarios selected through the obtained results. This chapter descries prototypes costs sustained in MiniStor, market conditions in the selected scenarios and provided a final assessment defining a range of price that can be accepted by the residential sector.

The conclusion of the report, chapter 5, summarise the result and identify where price reduction can be identified from TRL7 in order to meet the expectations selected in the previous assessment.

2. Overview of the MiniStor system

This chapter reports information collected from D3.1 "Initial dimensioning of the system according to general use typologies" to facilitate the understanding of the techno-economic assessment, the definition of the subsystems with their commercial costs and its different configurations applied in the pilots use cases.

The MiniStor system has been developed with the primary objective to provide an innovative, economic and sustainable solution for the thermal energy storage of RES energy, in support to the decarbonisation process of the residential sector.

At the same time, MiniStor can support basic services such as heating and cooling and DHW production, common to commercial technologies as gas or biomass boilers, HP, etc. Combining additional innovative services such as energy storage, energy consumptions and flexibility management provides characteristics more related to smart technologies.

As shown in the Figure 1, the MiniStor system can be considered composed by different sub-systems. This configuration is innovative because it is not yet available from any other company in this unique form.

MiniStor is characterised by two different innovative thermal energy technologies, a thermochemical unit (TCM) and two units with phase change material (PCM) that guarantee high storage capacity. The ammonia based TCM solution has an even higher energy density, 10 times over the energy density of water-based technology (water storage) [1].

The system is easily feasible for the integration with thermal RES like photovoltaic thermal panels, solar thermal collectors and heat pumps, characteristics that make it a very promising solution for the market penetration in a context even more oriented towards distributed energy configurations. MiniStor is also able to store electrical energy produce by photovoltaic thermal panels (PVT).
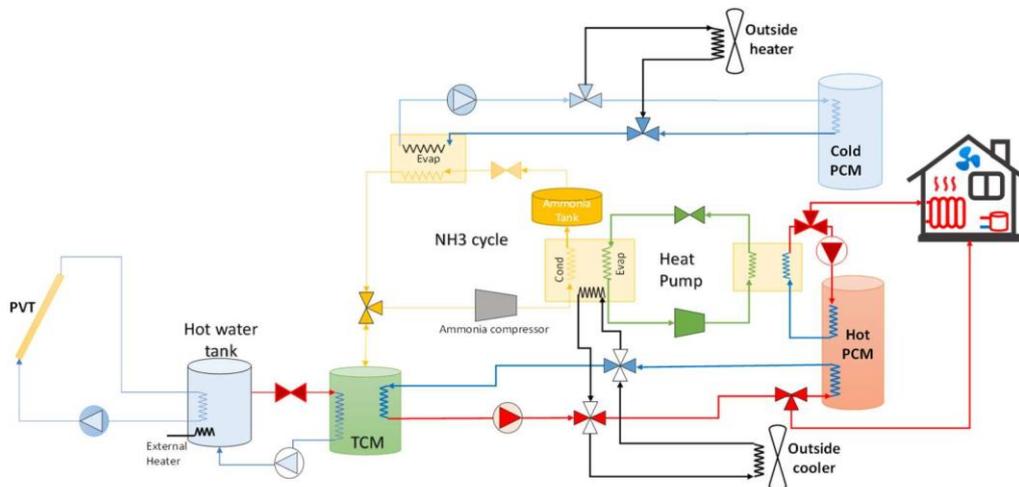
Figure 1. Overview of the MiniStor system (source: MiniStor D3.1)

The system is managed by an innovative human centric Home Energy Management System (HEMS) that optimise the RES production exploiting the self-consumption.

2.1   MiniStor pilot configurations

MiniStor follows a tailored approach optimised to the building's characteristics where it is installed (space available, distribution system, etc.) and on the environmental context (latitude, external temperature, type of RES integrated, etc.). Nevertheless, it is possible to define a basic configuration which is used in the four pilot installations (Table 1).

The basic configuration can be considered composed by a PVT system for the RES heat conversion, a TCM unit connected to two PCM units by a HP, a lithium battery EESS and a HEMS for the system management.

Table 1. MiniStor pilot configurations

Demo site	Type of building	New PVT field	Add. Heat pump	PVT type	Electrical storage	Electricity feed	Enclosure type
Thessaloniki (Greece) pre-demo	Smart home	Yes	No	Glazed	Yes	Tri-phase	Same size
Kimmeria (Greece)	University residential demo	No (FPC existing)	No (Biomass Boiler)	FPCs	No	Tri-phase	Same size
Santiago de Compostela (Spain)	University residence	Yes	Yes	Unglazed	Yes	Tri-phase	Same size
Sopron (Hungary)	NZEB family house	Yes	No	Glazed	Yes	Tri-phase	Same size
Cork (Ireland)	Semi-detached building	Yes	No	Glazed	Yes	Bi phase	Smaller for shipping

Two MiniStor pilot prototypes vary with respect to the basic configuration:

- **Kimmeria - Greece**: In the system installed in Kimmeria, the RES integration is represented by a biomass boiler and Flat Plane Collectors (FPC) already installed in the building, in substitution of the PVT plant.

- **Santiago De Compostela - Spain**: In the system installed in Santiago de Compostela, due to the winter conditions, the PVT plant is assisted by an additional HP to integrate the heat produced that otherwise would not have been sufficient.

The MiniStor system collects and store heat energy from a combination of four subsystems as shown in the Figure 1:

(i)   the PVT panes which convert the solar irradiation in hot water in input to the system.
(ii)   the TCM units responsible for the storage of energy.
(iii)   the HP system responsible to elevate the released heat at the ammonia condenser.
(iv)   the PCM units (hot and cold) which deposit the heat and cold received and through heat exchangers provide it to the building distribution.

The sub systems of the MiniStor solution will be considered in the cost and benefits assessment defining a baseline solution that can be created assembling the market components. The Table 2 lists the subcomponents connection to technologies which can be considered a baseline competitor for residential applications.

Table 2. MiniStor configurations and subsystems

Component	Basic Configuration	Baseline technology competitors
TCM reactor	Yes	Traditional residential system composed by gas boiler, biomass boilers or HP + water vessel storage + chiller for the cooling mode
Heat pump	Yes	
Cold PCM	Yes	
Hot PCM	Yes	
PVT panels	Yes	Commercial PVT, FSP + PV
EESS	Yes	Commercial lithium EESS
HEMS	Yes	Commercial HEMS

The MiniStor subsystems have commercial competitors indicated in the D7.5 "MiniStor Market Analysis", which can be assembled to provide similar services and benefits to the building end users.

The next chapter will analyse the MiniStor subcomponents and commercial systems, which can be used as a reference for common residential systems.

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3. MiniStor Components and Technology Competitors

This chapter follow the treatment started in the D7.6 "MiniStor market analysis" and focusses to the MiniStor subcomponents presenting some market competitor technologies with the scope to define the market prices and the target for MiniStor's future development.

3.1   Photovoltaic Thermal Pannels (PVT)

The PVT collectors produce renewable thermal and electrical energy from solar radiation. The heat is transferred in the form of hot water to the TCM unit. The PVT panels can also produce electrical energy by the PV solar cells, as an input to the EESS.

This system represents the alternative to the fossil fuel technologies, as the common gas boilers installed in many residential buildings are responsible for their CO_2 emissions and the environmental impacts. PVT technology has been present in the market for several years, but it is not widely used as the PV technology. The PVT models produced by Endef and used in MiniStor are described in the Table 3.

Table 3. PVT characteristics

PVT Prototype 2: Glazed PVT collector	
General Feature	
Type of panel	Glazed
Dimensions L x W x H (m)	1.645 x 978 x 93
Gross area (m^2)	1.61
Electrical Connection	MC4 connectors
Hydraulic connection	4 x 22 mm fittings (lateral side)
Thermal specification	
Adsorber Area (m^2)	1.55
Fluid content (l)	1.2
Number of tubes	9
Total tube length (m)	16.34
Electrical specification	
Power MPP (W)	270
Voltage MPP (V)	31.19
Current MPP (A)	8,67
Open circuit Voltage (V)	
Short circuit Current (A)	9.19
Efficiency (%)	16.60

3.1.1   PVT market competitors

The market analysis for the PVT systems is included in the D7.4 "MiniStor Market analysis". Table 4 reports some of the solution already available into the market with some reference prices. In the same table, there are also indications of EndeF's solutions, as a confirmation that they are already on the market.

Table 4. PVT market competitors

Manufacturer	Product	Market Price [€]	Photovoltaics characteristics		Thermal Characteristics		Links
			Power [W]	Efficiency [%]	Thermal power* [W]	Area [m^2]	
DualSun	Spring 425 Shingle black	691	425	20.4	418	2.08	https://myshop-solaire

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	Spring 375 Shingle black	815	375	20	660	1.876	https://off-the-grid-solar
Endef	Ecovolt	569	300	18.44		1.55	https://todoen solar
	Ecomesh	839	265	15.98		1.55	https://todoen solar
Solimperks	Powervolt	-	200	15.08	630	1.194	https://archiex po
Fototherm	FT265Cs	-	265	16.5	888	1.59	
SoLink	Cella Fredda HCF300M	1012	300	18.4	703	1.45	https://cambio caldaia
FDE Solar	FDE hybrid 300	-	300	18.75	489.5	1.63	https://enfsola r
Fototherm	FT300As	-	300	18.44	507.3	1.63	https://enfsola r
Sic Solar	EASRA 190	-	190	19.3	721	0.99	https://enfsola r

3.2 Thermochemical Reactor and Ammonia Cycle (TCM)

The ammonia based TCM unit is considered the core innovation of MiniStor with respect to commercial thermal energy storages. To store and provide thermal energy, the TCM reactor utilizes a solid-gas absorption process based on a $CaCl_2/NH_3$ cycle. This characteristic guarantees high-density thermal energy storage, more than 10 times higher than water-based solutions. The sorption process is characterised by a reversible reaction between ammonia and salt that permit to store and release heat with a remarkably high energy density of approximately 250 kWh/m^3 of TCM in heating mode and 120 kWh/m^3 in cooling mode. This is a significant improvement over conventional water-based storage solution that have approximately 5 to 10 kWh/m^3.

The MiniStor TCM unit used in the project is composed by 7 tubes of 1.25 m each one and diameter of 114.3 mm filled in such a way to form 2 sub-reactors. This configuration guarantees 17.5 kWh of thermal storage [1].

The principle of thermochemical reaction processes is highlight on the following reversible reactions:

$$CaCl_2 \cdot 8NH_3 + Heat \leftrightarrow CaCl_2 \cdot 4NH_3 + 4NH_3$$

$$CaCl_2 \cdot 4NH_3 + Heat \leftrightarrow CaCl_2 \cdot 2NH_3 + 2NH_3$$

The ammonia cycle could be divided in two reactor modes of operation: **charging and discharging phases**.

During the charging phase, the thermochemical reactor exploits the heat input, provided by the PVTs or from solar thermal collectors (or by other RES), and releases a gaseous ammonia stream according to the previous endothermic decomposition reactions.

During the discharging mode, the liquid ammonia from the tank is expanded to a lower pressure through the expansion valve and evaporated at temperatures imposed by the ambient conditions, provided that the reactor equilibrium pressure is lower than the evaporation one.

When gaseous ammonia from the evaporator enters the reactor, the following exothermic reaction is occurring:

$$CaCl_2 \cdot 4NH_3 + 4NH_3 \leftrightarrow CaCl_2 \cdot 8NH_3 + Heat$$

$$CaCl_2 \cdot 2NH_3 + 2NH_3 \leftrightarrow CaCl_2 \cdot 4NH_3 + Heat$$
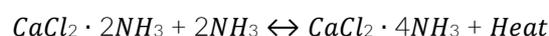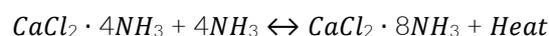
Based on the above equation, the released heat from the TCM synthesis at a temperature of 57-63°C can also be stored in the hot PCM or directly used. Discharging mode takes place mainly in summer and winter nights.

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. TCM units with this configuration (ammonia based) are not available in the market.

3.2.1 TCM Unit Market competitor

Due to the above considerations, market competitors that are already installed in residential applications and can be considered a reference baseline for thermal energy storage can only be hot water vessels. Although they are extremely economical compared to the TCM unit, they have a lower energy capacity and limited flexibility.

3.3 Heat Pump and Phase change material units

A Heat Pump unit is utilized to elevate the released heat at the ammonia condenser from 28°C up to 63°C. The heat pump operates according to a standard refrigerant cycle with R410A, in which heat from the water circuit (NH_3 Condenser-Heat Pump Evaporator) is transferred to the refrigerant in the evaporator, which is evaporated at 21°C/14 bar, and then compressed at 42 bars in the compressor. After that, the compressed refrigerant gas condenses to liquid in the condenser (64°C/42 bar), delivering heat to the hot PCM for storage or directly used for the heating demands. The heat pump cycle closes as the high-pressure liquid refrigerant is expanded to a lower pressure through the expansion valve. Under these operating conditions, the HP COP is estimated at 3.61.

The heating/cooling energy storage system includes two PCM units that store heat and cold at 58°C (Hot PCM) and 11°C (Cold PCM), respectively.

The Hot PCM vessel is connected both to the TCM reactor and to the Heat Pump via two independent water circuits. Its main role is to store the excess heat generated either during the charging phase (through the Heat Pump condenser) or during the discharging phase (TCM synthesis mode) providing this energy to the house when it is needed.

The Cold PCM is exclusively connected to the evaporator of ammonia cycle through a chilled water circuit. Its main role is to store the excess cooling capacity, which is generated during the discharging operating mode from the evaporator of ammonia at 0-10°C.

In summer period, the MiniStor system can provide the house with cold only via the utilization of the ammonia evaporation at the condenser during the discharging phase. Additionally, the heat produced from the TCM synthesis reaction can be released to the ambient or used for DHW production. Instead, during winter period, the MiniStor system can provide the house with heat at temperatures of 63 °C either via the heat pump condenser during the charging mode, or through the TCM reactor during discharging mode.

3.3.1 PCM Unit Market Competitors

The PCM technology, even if innovative, can be considered a technology available on the market with several companies producing PCM units with different characteristics. However, it is not easy to find information about commercial prices because some producers have base in Asia and do not declare prices and performances of the PCM units. The Table 5 presents some information collected from a market overview.

Table 5. PCM unit commercial competitors

Manufacturer	Country	Product name	Capacity [kWh] / Power [kW]	Market Price	Material Type
Heatventors	Hungary	HeatTank 10	10 / 20	~ 6,000 € [1]	Eutectic salt hydrate

[1] Source: https://pcm-ral.org/phase-change-matters-newsletter-november-2023/

Ecolibrium	Australia	Prototype PCM-TB	53,5 / 45	~ 8,600 € [2]	Salt hydrate
Boca	Hong Kong	Tailored solutions	N.A.	0,82,5 USD/kWh	Hydrated salt or Eutectic salt
PCM Energy	India	Latest™ S series	N.A.	N.A.	Inorganic salts

3.3.2   HP Unit Market competitor

The MiniStor heat pump used to increase the released heat at the ammonia condenser to the PCM circuit is a bespoke system built with the MiniStor prototype by partner Psyctotherm. It was developed to efficiently meet the specific temperature requirements of the project, but the concept has many competitors in the market. An overview of some HP competitors with comparable nominal power, available in the market can be found in Table 6. The table is presented with the purpose to indicate an average market value (cost) for the HP used in MiniStor.

Table 6. HP competitors in the EU market

Brand	Product name	Heat power [kW]	COP	Market Price [€]	System / Refrigerant
Daikin Air Conditioning	Altherma 3 R M	4	5.1	3.300	Air - water / R32
Midea	R32 M-Thermal MHC-V5WD2N8-C	5	5.3	1.900	Air - water / R32
Vaillant Group Italia	AroTHERM PLUS VWL 45 / 6	4	4.1	5.000	Air - water / R290
Panasonic 5	Acquarea WH-MDC05J3E	5	4.5	3.500	Air - water / R32
Samsung	EHS Mono R290	5	5	3.700	Air - water / R290
Toshiba	ESTIA	4	5.2	3.500	Air - water / R32
Ariston	Nimbus M universal 50 Net	5	5.1	3.000	Air - water / R32

3.3.3   Baseline technologies used in residential applications

In residential sector, the technologies that can be considered the baseline reference for producing heating and DHW are gas boilers, heat pumps and electric boilers. Other technologies such has biomass boilers and oil boilers have a limited market penetration in EU.

Gas boilers are the most widely used in EU countries due to their low CAPEX and OPEX costs and their quick response when turned on. However, but they are also the main cause for the CO_2 emissions in cities and residential districts.

The Table 7 presents a list of commercial gas boilers comparable to the MiniStor in terms of applicability residential buildings for heating and DHW production. Those products will be used as a reference point for the existing building sector in most of the EU countries.

Table 7. Commercial natural Gas boilers

Manufacturer	Product name	Nominal Power [kW]	Efficiency [%]	Market Price [€]
Ariston	GENUS ONE+ NET	30	98.6	1.400
Ferroli	Bluehelix Alpha 34 C	30	97.7	1.100
Riello	Start 30 KIS	30	93	930
Baxi	Luna IN Plus	30	87.9	1.600

[2] Source: https://theecolibrium.com/2024/07/08/techno-economic-evaluation-of-integrating-a-pcm-thermal-battery-into-cooling-systems-part-2/

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Beretta	Ciao Green29	29	87.6	950
Hermann	Saunier Semiatek 4 Condensing	30	98.2	1.200
Junkers Bosch	Cerapur Compact ZWB	28	94	1.200
Vaillant	EcoTEC pure VMW	28	97	960
Immergas	Victrix 28 TT	28	96.6	1.300
Lamborghini	Alhena 28C	28.5	97.8	1.500

Due to recent EU legislation to contain greenhouse gas emissions in residential buildings, the use of gas and oil boilers is limited by the building EPC standards, which cannot be met with those systems. Consequently, the market is rapidly shifting towards HP and RES systems.

The main EU producers of HPs with some examples of system for residential application (about 100-150 m^2 are presented in the Table 8. The cost indicated sometimes consider the DHW storage system in general but excludes other components needed for installation (piping, expansion tanks, pumps, etc.)

Table 8. Commercial reversible HP air to water

Manufacturer	Product name	Nominal Power [kW]	DHW Storage [l]	COP / EER	Market Price [€]
Daikin	Altherma 3	12	Optional	4,7-5	8,000
Samsung	EHS MonoR290	12	200	4,8 / 4	8,260
LG	Therma V	12	Optional	4,45	5,500
Mitsubishi	ECODAN Hydrotank	9	170-300	4,5	8,500
Ferroli	Omnia ST	12	Optional	4,5-5	5,170
NIBE	S2125	12	Optional	4,33	8,200
Panasonic	Aquarea	12	185	4,8 / 4,17	8,060

In some EU countries with low heating needs, DHW consumption drives the maximum power dimensioning, and the systems results over dimensioned for the heating part. In order to avoid this issue, the DHW production is done with a dedicated system such as electrical boilers.

The Table 9 present a list of commercial electric resistor for the DHW production with their commercial costs.

Table 9. Electric DHW boilers

Type	Brand	Product name	Heat power [KW]	Market Price [€]	Expansion tank capacity [l]
Water Heate (electric)	Ariston	Lydos Plus 100 V/5 EU	1.5	240	100
	COMFEE'	D80-15FGC	1.5	100	80
	Ferroli	Calypso 80	1.2	128	78
	Ariston	Lydos Hybrid (con PDC)	1.2	650	100
Water Heater (Gas)	Ariston	Fast Evo X 14	27	225	N.A.
	Hermann Saunier	Duval Opalia C 11/1 Lix H	22	200	N.A.
Water Heater (Wood-electric)	Ariston	Sle 80	1.2	400	75

3.4 Electrical energy storage and electrical subcomponents

3.4.1 Electrical energy Storage System

The EESS integrated in the MiniStor system is a commercial solution produced by the manufacturer BYD. It is a High Voltage Storage (HVS) with technology LFP lithium battery. Considering the large availability of lithium battery storage systems into the market it is not necessary to list competitors. Table 10 reports the main characteristics directly taken from the BYD company catalogue.

Table 10. EESS datasheet

EESS – LFP battery BYD HVS 5.1	
Modules	2
Energy Stored [kWh]	5.12
Maximum Current in output [A]	25
Peak output Current [A]	50, 3s
Nominal Voltage [V]	204
Operational Voltage [V]	160-230
Dimensions H/W/D [mm]	712 x 585 x 298
Weight [kg]	91
Efficiency [%]	≥ 96
Communication	CAN/RS485
IP Protection	IP 55

As the EESS does not represent an innovation in MiniStor but a technology that helps achieve its aims, it is not necessary to evaluate market competitors. The BYD HVS 5.1 module (with 5.12 kWh capacity) is available to purchase from different marketplaces at prices ranging from €3,279 to €3,750, so it is possible to calculate an average cost of €3,515, representing a cost per kWh of €678. This price is in line with the market cost of other EESS for residential applications.

3.5 Home Energy Management System

The MiniStor HEMS represent an important sub-component managing responsible for the building energy flexibility.

The sector of residential HEMS is a growing sector in the modern era of the smart grid and smart buildings. HEMS can monitor and visualise energy consumption of the home residents to help them adapt their energy usage behaviour based on the feedback they receive from the system. At its core, also the MiniStor HEMS manages the efficient interplay between household energy consumers and generators.

Generally, designer and architects can exploit the HEMS by integrating domotic appliances as well as energy saving strategies. Homeowners can not only save on energy bills but play a valuable part in the sustainability movement. The following table lists some HEMS products that are on the market.

Table 11 reports some examples of competitors prices available into the market. The common costs are from €1,200 to 3,500, depending on the installation and services included.

Table 11. HEMS example of market prices

Producer	Country	Market Price [€]	Link
Smappee	Belgium	249–349	www.digitized.house/smappee
Evergen	Australia	N.A.	www.support.evergen.energy
ABB	Swedish / Swiss	Price on request	www.new.marketplace.ability.abb
Bosch	Germany	Price on request	www.bosch
KNX	Belgium	134 – 469	www.ave.it/catalog
Honeywell	USA	99 – 229	www.homeguide

Solar edge	Israel	1175.3 – 1762.99	www.davesun
Lumin	USA	2,100 - 2,900	www.solarreviews
Carbontrack	Australia	999 installed (3y)	www.choice
Bticino	Italy	1,000 – 2,500	https://professionisti.bticino.it/sites/default/files/2022-05/Guida%20MyHOME_Up%202021%20.pdf

4. MiniStor Cost Assessment

Given the variety of system configurations and sub-components used in the pilot prototypes, defining the commercial cost of the system for innovative technologies developed at TRL7 (demonstration achieved), is very difficult as several steps and iterations are needed to carry the innovation to TRL9 (closer to market introduction).

In this analysis, it is fundamental to take in consideration that innovation technologies have high costs in the market entrance phase due to several critical parameters and costs not defined at commercial scale. Therefore, it is not possible to accurately calculate the MiniStor market price at TRL7.

Starting from the cost sustained for the MiniStor prototypes, this assessment will estimate the market entrance cost on the base of the costs of market competing technologies and the economic benefits that MiniStor can generate in a year period of work at building level. This process will start with the sub-system costs assessment, then will define the economic benefits on the base of the simulation done in the D6.7.

4.1   Methodologies used in the cost and benefit assessment

A cost and benefit assessment aims to define parameters and KPIs to identify the quality of the economic investment, in this case cost of the efficiency measure, in respect to the baseline scenario and its reference performances.

Taking in consideration the customer segment, here defined as the residential sector and the building owners, the economic assessment will be based on the simple Payback Time (PBT). The terminology used in this report is listed below:

Baseline scenario: A baseline scenario is a projection of future conditions assuming no new interventions, or projects are implemented. It represents a "business-as-usual" situation, providing a reference point to assess the impact of new initiatives by comparing them to what would likely have happened anyway. This scenario is crucial for evaluating the effectiveness of sustainability efforts and making informed decisions [2].

Advanced scenario: It refers to a forward-looking evaluation of potential interventions and efficiency measures, considering various uncertain future conditions. It involves analysing a range of plausible scenarios, often including best-case, worst-case, and most likely scenarios, to understand the potential impacts of different economic environments on a project, policy, or investment. This goes beyond simple forecasting by exploring a wider set of uncertainties and longer time horizons [3].

Simple payback time: in financial terms, refers to the length of time (years) it takes for the cumulative cash inflows from an investment to equal the initial investment cost. It's a measure of how quickly an investment breaks even. A shorter payback period generally indicates a more desirable investment, as it means the initial investment is recovered more quickly [4]. The equation 1 define how to calculate it.

$$PBT = \frac{Initial\ Investment\ (CAPEX)}{Yearly\ cash\ flow} \qquad Eq.1$$

Initial investment (CAPEX): The initial investment, in this analysis, is considered the additional cost (difference of cost) the customer segment (building owners) must sustain chousing the advanced scenario respect to the cost of the baseline scenario (Eq.2). This is because however, the owner, has to bear a cost for the installation of the heating and DHW system.

$$Additional\ cost = Cost_{Advanced\ scenario} - Cost_{baseline\ scenario} \qquad Eq.2$$

Yearly Cash flow: The yearly cash flow in a financial assessment represents the total amount of cash that flow into (incoming) and out (costs) over one year-period for a business. In an easiest way here,

it represents the difference between the economic benefits (cost saving) and the costs sustained in a year for the efficiency measure.

Considering those KPIs, the procedure used to estimate the MiniStor price will use the PBT in a reverse mode to estimate the market price that can be sustained by the economic benefit generate.

This process will take on consideration the baseline scenario and the associated costs for heating, cooling and production of DHW for one year, detailed in the deliverable 6.7 "Feasibility analysis for installation replication across Europe" compared with the cost of the same benefits provided by MiniStor /with the same environmental conditions).

Then from the literature review and the consolidated experience of the MiniStor partners in residential building retrofitting, the assessment will consider end of life of competitor systems and PBTs commonly accepted by the residential customer segment, for the estimation of the MiniStor CAPEX (Eq. 1).

4.1.1 Literature assessment for common technology EoL

Heat pumps and gas boilers have comparable service life expectation that can have an impact on long-term investment decisions for residential heating systems.

The lifespan of an Air Source HP is typically 15 to 20 years if operating under normal conditions [5, 6]. However, this lifespan can vary significantly based on several factors such as climate conditions, installation quality, operating conditions and maintenance practices [7-9]. Unlike air source heat pumps, Ground Source HP (although not very widespread) generally have longer lifespans and typically requires replacement after 15 to 25 years. Several studies suggest that, HP systems can experience performance decline over time, with potential reductions in efficiency after 10-15 years of operation, as indicated by some studies [10, 11].

For conventional gas boilers, the lifespan is usually between 15 and 25 years, but some can live up to the upper end of this range if they are properly maintained [6,12]. Similar to the heat pumps, research suggests that boilers are also affected by the maintenance quality, water quality and operating conditions [9].

Modern condensing gas boilers may have similar lifespans to conventional units but condensing systems may require more frequent replacement of specialized components, due to the corrosive conditions of the flue gas flow, even if they are more efficient [13].

Generally, studies analysing heating system lifecycles commonly use 20-year evaluation periods for both systems [9, 12, 14, 15].

The use of 20-year evaluation periods for gas boilers in heating system lifecycle studies is common, which suggests that this is a typical replacement cycle for residential applications, but according to Torsten Hummen et al., it is necessary to consider not only the initial efficiency of the product and efficiency improvements of a potential replacement product but also efficiency degradation of the product in use. Both, continuous technology change and efficiency degradation, tend to shorten the optimal environmental lifespan (OEL) [9] i.e., *"the replacement time where the potential impact savings resulting from using a (more energy-efficient) replacement product are equal or higher than the embodied impacts of that product such that cumulative impacts over a time horizon become minimal"*.

Considering all these factors, we have established a 15-year lifespan assessment's period for competitors' products.

4.1.2 Technology Payback time (PBT) accepted by residential customers

Renovation investments and new building technologies in residential building are commonly analysed with the simple payback time as defined in the chapter 4.

Across Europe, a payback period of 5 to 10 years is generally considered acceptable for households. This depends on factors such as initial costs, annual energy savings, available public incentives and operating expenses.

Gas boilers, whether traditional or condensing, have relatively low initial costs from €1,000 to 3,000 [16] and very short payback periods from 2 to 4 years [17-19], particularly when replacing outdated systems such as oil boilers or non-condensing boilers with low efficiency. However, they incur rising

operational costs due to natural gas price fluctuations and do not contribute to decarbonisation goals. For this reason, in some EU countries, gas boilers cannot be installed in new buildings where high EPC ratings are needed because they don't guarantee minimum performances.

HPs, on the other hand, require a significantly higher initial investment from €7,000 to €15,000 [16] for air-to-water systems, but offer substantial long-term savings, particularly in well-insulated buildings and with low-temperature heating systems (e.g. underfloor heating). The typical payback time for a heat pump is 8–12 years, but this can be reduced to 5–7 years when public incentives are available, such as tax deductions, thermal incentives or renovation bonuses [17-19].

Residential customer' perception of payback time is critical: periods longer than 10 years are often considered too long unless additional benefits are present (e.g. increased property value, improved indoor comfort or environmental benefits). To encourage wider adoption of innovative technologies, financial incentives must be combined with awareness campaigns emphasising the long-term savings and cost stability they offer compared to fossil fuels.

In this context MiniStor will be compared with the PBT accepted by residential customers and the EoL period of HP and gas boiler technologies.

4.2 Definition of MiniStor Prototype Costs

As mentioned in previous chapters, the configuration of the MiniStor system may vary depending on its location of use and the specific conditions of the facility in which it is installed. However, in general, the total cost of building and installing the system is the sum of the costs of the subcomponents it consists of, as presented in chapter 3.

The subcomponents that make up the MiniStor system can be divided into components specially built for the prototyping and commercially available components, procured from the market. Table 12 presents the of subcomponents used the configuration installed in Santiago de Compostela since it contains also the cost of the additional HP used and the solar field which is of a novel type.

The table indicate whether the sub-components are custom-built (dedicated and prototype) or commercially available (commercial).

Table 12. MiniStor sub-components list and costs

MiniStor sub-Component	Type	Partner	Pilot unit cost [€]
PVT panels	Dedicated	EndeF	8,900
Heat pump	Dedicated	Psyctotherm	2,850
Additional Heat pump	Commercial	Psyctotherm (integrator)	3,750
HP control and connection	Dedicated	Psyctotherm / CARTIF	9,650
TCM reactor	Prototype – Dedicated	Psyctotherm / Sofrigam	27,600
Cold PCM	Commercial		1,500
Hot PCM	Commercial		1,500
Inverter	Commercial		2,000
EESS	Commercial		3,400
Piping	Dedicated	Psyctotherm	33,400
Control & Instrumentation	Prototype – Dedicated	Psyctotherm / CARTIF	2,400
Electrical connections	Dedicated	Psyctotherm	4,800
HEMS	Prototype – Dedicated	CARTIF	2,250
Enclosure	Dedicated	Psyctotherm	24,000
Safety equipment	Dedicated	Psyctotherm	8,000
Ancillary equipment	Dedicated	Psyctotherm	4,000
Installation	Prototype – Dedicated	Psyctotherm / Sofrigam	11,000
Total Cost			151,000

The presented list of subcomponents allows for determining the costs of building the MiniStor system. For commercially available components, the cost of purchase is the cost paid for the prototypes. In the case of components specifically manufactured for the system, the cost data comes from individual partners responsible for the development and construction of the components.

From Table 12 is clear that the current MiniStor prototype cost cannot be compared now (TRL7) with a commercial residential system because its cost is much higher than any residential system.

When analysing the costs associated with the construction and installation of the MiniStor system on-site, it is also necessary to consider the costs related to the system's installation and its integration with the existing heating and cooling system in the building. Many of the costs listed, however, can be optimised during the TRL upscaling end the engineering of the production, or deducted because they were particular for a demo site and not needed in general situations.

For example, the cost of the enclosure that in the total cost has a relevant weight can be deleted in case the building has a dedicated technical room that meets the same specifications. Also, the cost for piping and installation can be significantly reduced. In the case of Santiago de Compostela, the piping cost is high because the prototype installation was done outdoor and far from the building, exceeding current norms. This means that optimisation of costs is possible with a relevant impact on the potential commercial price.

Tasks related to the installation of the system with impact on final price include:

- Installation of PVT panels and the corresponding structure if required.
- Preparation of the foundation for the MiniStor system if required.
- Hydraulic and electrical connections of the MiniStor system.

The costs of these activities may vary depending on the location, based on factors such as the distance between the MiniStor system and the building, as well as local conditions, such as soil properties or space for using the PVTs which might require a special structure.

4.3   Definition of Operational and Service Costs

Operating the MiniStor system incurs operational and maintenance costs (O&M), which, like the system cost, depend on the specific configuration. As the definition of the CAPEX cost, the O&M cost (OPEX) can be defined with detail also once a database of historical monitoring data covers 3-4 years measured data. Therefore, the analysis will consider operational cost represented by the energy input to the MiniStor system and estimated cost for the maintenance since long-term historical data are not available at prototyping level.

The primary **operational cost** is the purchase of electricity for the system. The system has its own electricity source in the form of PVT panels and in the EESS. The PVT system also cover the thermal energy needs of the building. It this case the operational costs are zero because the electricity and thermal energy comes from renewable sources (PVT or PV).

In the case of low renewable energy availability, energy must also be supplied from the public power grid, particularly during the winter months when demand for heat is highest and electricity generation from solar radiation is lowest. It this case the HP needs additional energy form the grid and operational costs are represented by the purchase cost for the electricity.

Maintenance costs are related to ensuring the system operates efficiently and safely. Considering MiniStor as a prototype at TRL7, the maintenance costs are not measured during the seasons but estimated from the subcomponent's configuration,

The components that require regular maintenance are listed below:

- **PVT panels**: Maintenance costs for PVT panels are associated with keeping them clean and conducting regular inspections. These costs can be estimated at €30 per glazed panel and €19 per unglazed panel per year[3].

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[3] Source of the data: EndeF

- **HEMS**: The maintenance costs of the HEMS are related to the upkeep of the servers and software used to manage the algorithms and can be estimated between 1-3 % of the CAPEX. This cost depends on the type of data stored and the contract used. At this level MiniStor do not have a detailed cloud, so this analysis considers commercial storage cost estimated around 70 €/y for a 500 GB of cloud service [20]. In total the HEMS maintenance cost is estimated to 100 €/year.

- **TCM unit**: The cost and maintenance for the TCM unit are estimated from literature review. This assumption is needed because there are no data measured or calculated on the pilot prototypes. This value is often defined as a percentage of the CAPEX cost from 1 to 5% of the CAPEX cost. For the estimation of the CAPEX, it is possible to take as reference scientific articles as "Thermal characterization and cost analysis of cement-based composite materials for thermochemical energy storage" [21] defining the CAPEX cost from 100-300 €/kWh. In this calculation a cost of 250 €/kWh is considered for the ammonia-based solution TCM. Therefore, the MiniStor TCM unit of 17.5 kWh can be estimated around €4.500. In consequence the OPEX cost can be estimated between 45-90 €/y.

- **PCM units and other components**: The yearly maintenance costs for PCM units are very low as indicate in literature review [22]. For this reason, the maintenance cost for PCM units and the HP are considered in the other maintenance cost.

The other subcomponents are not subjected to considerable yearly maintenance therefore no other cost will be considered.

Table 13. MiniStor O&M summary table

Component	Operational cost [€]	Maintenance cost [€/y]
PVT panels	0	19-30
TCM Unit	0	45-90
PCM Unit	0	0
HEMS	0	100

The Table 13 reports the O&M costs which will be considered in the economic assessment. The operational costs are defined to be zero because the system is supplied by RES energy (electrical and thermal) from the PVT system. In the period where the RES energy will be not sufficient to cover the building energy needs, the cost of the operational costs will be compared with the electrical energy cost.

4.3.1 European electrical energy, natural gas and district heating tariffs

The costs for the electricity and the natural gas considered in the economic assessment are considered with taxes to consider the real economic impact at end user level as well as the level of cost saving. The costs are considered from EUROSTAT for the year 2024 as reported in the Figure 2 and Figure 3 as a coloured scale.
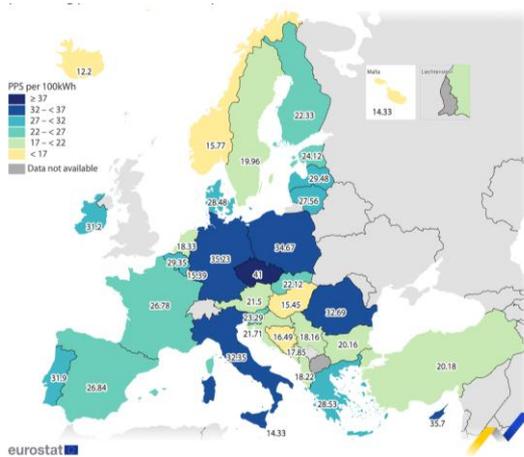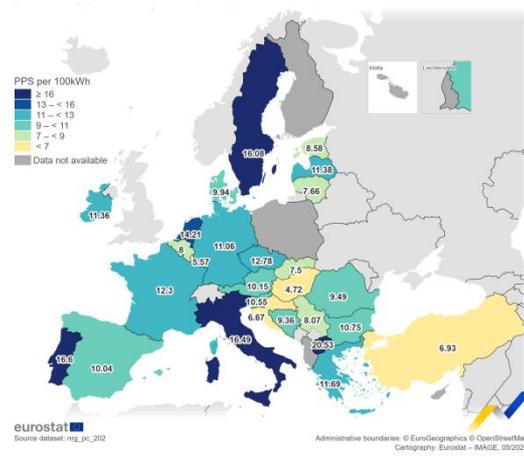
Figure 2. EUROSTAT electricity 2024 prices[4]   **Figure 3. EUROSTAT natural gas 2024 prices[5]**

There are several differences between electricity prices in EU countries that depends on the national energy mix. Also, the price of natural gas present important differences, in particular the price in Hungary that is about 1/3 of the EU average price. In those national prices it is also important take in consideration the share of taxes that vary country by country. In the north EU countries, the taxes level represents a share from 40 to 49%.

The district heating tariffs are more difficult to find at European scale because it is not equally widespread throughout Europe. The district heating network (DHN) tariffs are more used in northern Europe such as in Norway, Denmark Sweden, Finland and Germany, where heating consumption has a relevant impact during the year. In some countries such as in Norway the DHN tariffs are calculated from the prices of the electricity and cannot exceed the prices of electrical energy. From 2024 new regulations limit the maximum price of DHN [23]. Some interesting DHN projects are also developing in Italy in the northern regions.

The energy costs are also reported in from of list of data in the Table 14.

Table 14. EU electricity and natural gas prices

Country	Electricity price [€/kWh]	Natural gas price [€/kWh]	District heating price [€/kWh]
Greece	0,2853	0,1169	N./A.
Norway	0,1577	N.A. – 0,1608 *	0,1135 [6] [7]
Germany	0,3523	0,1106	0,17 [8]
Cyprus	0,3570	N.A. – 0,1169 **	N./A.
Italy	0,3235	0,1649	0,06-0,13 [9]

* Natural gas price in Norway in not available therefore, will be considered the cost in Sweden
** Natural gas price in Cyprus in not available therefore, will be considered the cost in Greece

4.4 Use cases scenarios

The economic assessment done in this chapter complete the technical assessment reported in the D6.7 "Feasibility analysis for installation replication across Europe" therefore the use cases considered in this report are some of the ones considered in the table 13 (page 35) and table 14 (page 37) of D6.7.

In the calculation this report considers the optimal scenario represented by the energy simulation done with the TCM unit and PCM unit fully charged from the beginning since this scenario

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[4] https://ec.europa.eu/eurostat/en/web/products-eurostat-news/w/ddn-20250506-2?
[5] https://ec.europa.eu/eurostat/statistics-explained/index.php?oldid=636298&title=Natural_gas_price_statistics&utm
[6] https://www.hjort.no/en/nve-proposes-new-price-regulation-for-district-heating/
[7] https://www.regjeringen.no/en/aktuelt/norway-price-for-electricity-and-district-heating/id3100201/
[8] https://www.swd-ag.de/pk/heizen-waerme/fernwaerme/fernwaermepreise/
[9] https://www.cdscultura.com/2023/07/i-rincari-del-teleriscaldamento/

represents the best configuration for the residential sector after the technical installation. The Table 15 reports the annual energies consume by the buildings and the PV production (calculated by PVGIS[10])

Table 15. Use case scenarios annual energy demands and PV production

City	Country	Area [m²]	Annual Heating demand [kWh/y]	Annual Cooling demand [kWh th/y]	Electricity production from PVT [kWh el/y]
Athens	Greece	255	13,648	5,484	4,473
Bergen	Norway	184	16,511	0	2,187
Hamburg	Germany	187	19,878	0	2,803
Larnaca	Cyprus	170	9,812	6,477	4,680
Rome	Italy	174	11,146	1,157	4,245

The selected reference use cases represent different EU climatic conditions. In Figure 4 the energy profiles are presented in graphical form.
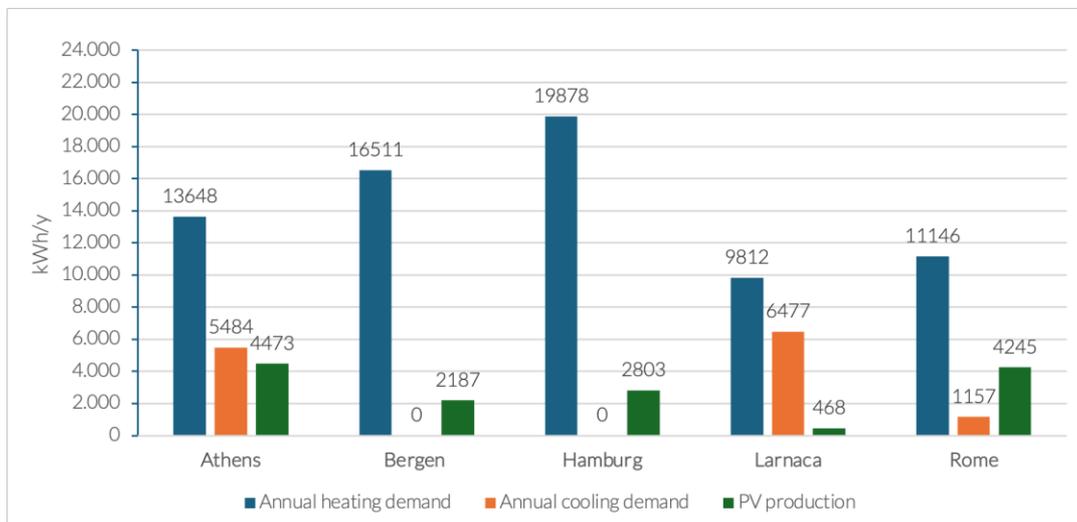

Figure 4. Use cases energy profiles

Considering the common configuration of the building reference baseline in the cities listed in Table 15 it is possible define three different situations.

4.4.1   Baseline Scenario 1: Gas Boiler reference baseline scenario

In the Athens, Hamburg and Rome scenarios, the economic assessment uses buildings with gas boilers for heating as the reference baseline and air to air HP for the cooling during the hot seasons. This is because the gas network in Italy, Germany and Greece is well developed in cities and outside the populated areas and the natural gas represents the most used energy vector for the heating.

In these cases, the baseline configuration is represented by the technological system reported in the Table 16. This system configuration is considered to provide services comparable to those of the MiniStor system, using commercial technologies that can already be installed in these types of buildings.

Table 16. Baseline technological configuration in Rome, Athens and Hamburg

System	Description	Commercial price [€]	Efficiency	Maintenance costs [€/y]
Heating system	Gas Boiler	2,500	0,960	120
Cooling system	Air to air HP	7,200	3,5-4	50
Thermal storage	Water vessel	2,200	N.A.	0

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[10] https://joint-research-centre.ec.europa.eu/photovoltaic-geographical-information-system-pvgis_en

Electric RES	PV system	3,200	N.A.	100
Electric storage	Lithium EESS	3,300	N.A.	0
Management	HEMS	3,500	0,995 regulation	100
Total baseline cost		**21,900**		**370**

In this scenario the O&M costs evidenced in the Table 16 are related to the annual control of the systems and the seasonal cleaning. The HEMS cost is referred to the cloud service and the internet connection that is needed to store and visualise the data collected.

Table 17. Scenario 1 heating costs

City	Annual Heating demand [kWh]	System total Efficiency	Annual energy consumption [kWh]	Natural gas price [€/kWh]	Annual heating costs [€]
Athens	13,648	0,975	13,997	0,12	1,636
Rome	11,156	0,975	11,431	0,16	1,885
Hamburg	19,878	0,975	20,386	0,11	2,255

Table 17 and Table 18 respectively reports the cost for heating (space heating and DHW) and cooling in the case of gas boiler and ait to air HP. The system efficiency in the Table 17 consider both gas boiler efficiency and regulation efficiency.

Table 18. Scenario 1 cooling costs

City	Annual cooling demand [kWh]	Annual PV production [kWh]	EER	HP Electricity consumption [kWh]	Natural gas price [€/kWh]	Annual cooling costs [€]
Athens	5,484	4,473	3,5	1,567	0,12	0
Rome	1,157	4,245	3,5	331	0,16	0
Hamburg	0	2,803	3,8	0	0,11	0

It is important to note that in the case of cooling, the solar production, the HP consumption is considered covered in total by the electricity production in the PV system supported by the flexibility enabled by the HEMS and the EESS.

4.4.2 Baseline scenario 2: Heat Pumps reference baseline

Differently from the previous situations, in Cyprus the gas networks are not developed, and the buildings are not supported by the gas distribution. Some houses use liquefied natural gas (LPG) stored in gas cylinders, but this is not common. The common building heating technology is the air to air or air to water heat pump used to provide heating in the warm winter conditions.

In this scenario, the HP is responsible for the heating and the production of DHW is done with an electric boiler. For this reason, the heating consumption and the DHW consumption are considered divided in 62% and 38% respectively of the total heating consumption reported in Table 15. The Table 19 represents the costs for the baseline reference scenario in Cyprus.

Table 19. Baseline configuration in Larnaca

System	Description	Commercial price [€]	Efficiency COP /EER	Maintenance costs [€/y]
Heating system	Reversible HP	17,800 [11]	3 / 3,5	100
DHW system	Electric boiler	600	0,4	0
Electric RES	PV system	3,200	N.A.	100
Electric storage	Lithium EESS	3,300	N.A.	0
Management	HEMS	3,500	0,995 regulation	100
Total baseline cost		**28,400**		**300**

In this scenario the maintenance costs are as well considered for the cleaning of the systems and small repairs.

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[11] Source: https://www.enpal.com/it/pompa-di-calore/pompa-di-calore-aria-acqua?utm_source=chatgpt.com

The Table 20 and Table 21 present the heating costs and the cooling costs associated to the use of HPs and electric gas boilers. In this situation the PV electricity production is considered optimised by the HEMS and supported by the EESS flexibility with a simple annual summary.

Table 20. Scenario 2 heating costs

City	Annual heating demand [kWh]	Annual DHW*	HP COP	HP Elect. cons. [kWh]	DHW Elect cons. [kWh]*	Elect. from the grid [kWh]	Elect. Price [€/kWh]	Annual heating cost [€]
Larnaca	9,812	3,729	3	2,028	4,056	3,254	0,357	1,162

* Calculated with the electric boiler efficacy 0,5.

Table 21. Scenario 2 cooling costs

City	Annual cooling demand [kWh]	EER	HP Elect. cons. [kWh]	Annual PV prod. [kWh]	Elect. from the grid [kWh]	Elect. Price [€/kWh]	Annual cooling cost [€]
Larnaca	9,812	3,5	1,851	4,680	0	0,357	0

4.4.3 Baseline scenario 3: District Heating reference baseline

The final scenario shows the Bergen building connected to the district heating network (DHN), as this best represents the current situation in Norway. The Table 22 present the cost of the systems needed DHN connection.

Table 22. Baseline configuration in Bergen

System		Commercial price [€]	Efficiency COP /EER	Maintenance costs [€/y]
Heating system	DHN	12,000	0,95	150 [12]
Cooling system	Air to air HP	7,200	3,2 / 5	0
Electric RES	PV system	3,200	N.A.	100
Electric storage	Lithium EESS	3,300	N.A.	0
Management	HEMS	3,500	0,995 regulation	100
Total baseline cost		29,200		300

In this case even if the cooling consumptions are considered zero the system is considered available and installed. The Table 23 reports the annual costs to produce heating and DHW by the DHN.

Table 23. Scenario 3 heating costs

City	Annual heating demand [kWh]	DHW exchange efficiency	Annual heating consumption [kWh]	DHN tariff [€/kWh]	Annual heating cost [€]
Bergen	16,511	0,95*	17,380	0,1135	1,973

* Considered as the efficiency of the building heat exchanger and the internal connections heating losses.

Table 24 reports some information for the cooling consumptions evidencing the possibility to support a small heating load with the electricity produced by the PV system.

Table 24. Scenario 3 cooling costs

City	Annual cooling demand [kWh]	Annual PV production [kWh]	EER	HP Electricity consumption [kWh]	Natural gas price [€/kWh]	Annual cooling cost [€]
Bergen	0	2,187	3,5	0	0,1577	0

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[12] https://1library.net/article/district-heating-substations-techno-economic-projections-smaller-heating.zp7mpg7z?

4.4.4 Advanced scenario: MiniStor

The advanced scenario is represented by the installation of MiniStor in the use case scenarios as an alternative to baseline systems. This approach is well represented by the building renovation process in which owners, or the managers have to decide whether to replace the baseline technology with an advanced system, such as MiniStor.

The Table 25 reports the economic assessment for the heating mode with MiniStor, while electric consumption proportionally increased with the covered heating demand by PVT and auxiliary. * Electric consumption proportionally increased with the covered heating demand by PVT and auxiliary.

Table 26 reports the assessment for the cooling mode. The heating and cooling performance used in this assessment, has been simulated in the D6.7.

In the baseline scenarios, the PVT electrical production is considered to be consumed entirely through self-consumption, supported by the EESS and the HEMS.

The results of the advanced scenarios and the baseline scenario will be summarised in the next chapter, along with the final considerations.

Table 25. MiniStor heating costs

City	Annual Heating demand [kWh/y]	Electricity production from PVT [kWh/y]	Heating demand covered by PVT [kWh/y]	MiniStor Electrical cons. in heating mode [kWh/y]	Heating demand covered by AUX and HP [kWh/y]	HP COP	HP electrical consumption [kWh/y]	Total Electrical consumption [kWh/y]	Electricity from the grid [kWh/y]	Electricity tariff [€/kWh]	Heating costs [€/y]
Athens	13,648	4,473	5,199	1,019	8,449	4,5	1,878	2,897	0	0,2852	0
Rome	11,146	4,245	6,100	846	5,046	4,0	1,262	2,108	0	0,3235	0
Hamburg	19,878	2,803	1,942	3,651*	17,936	3,5	5,124	8,776	5,973	0,3523	2,374
Larnaca	9,812	4,630	7,433	1,005	2,379	4,5	529	1,534	0	0,3570	0
Bergen	16,511	2,187	1,001	4,079 *	15,510	3,2	4,847	8,926	6,739	0,1577	1,063

* Electric consumption proportionally increased with the covered heating demand by PVT and auxiliary.

Table 26. MiniStor cooling costs

City	Annual Cooling demand [kWh/y]	Cooling demand covered by PVT [kWh/y]	Cooling demand covered by HP [kWh/y]	HP EER	MiniStor Electrical consumption in mode [kWh/y]	Electricity from the grid [kWh/y]	Electricity tariff [€/kWh]	Cooling costs [€/y]
Athens	5,484	3,382	2,102	4,5	467	0	0,2852	0
Rome	1,157	1,649	0	4,5	0	0	0,3235	0
Hamburg	0	0	0	5	0	0	0,3523	0
Larnaca	6,477	6,133	344	3,5	98	0	0,3570	0
Bergen	0	0	0	5	0	0	0,1577	0

4.5   Final economic results

Based on the assumptions presented in the previous chapters, the aim of Section 4.5 is the analysis of the annual economic savings that MiniStor could generate under different climatic conditions, as well as in comparative assessment with various baseline technologies such as gas boilers, heat pumps and district heating networks.

The results have been calculating with these assumptions:

1. The building energy profiles and areas identified in D6.7 are representative of existing buildings from 1970s to 1980s.
2. The calculations do not consider flexibility market and peer-to-peer energy exchanges.
3. Electricity grid injection has not been considered as a benefit.
4. Economic incentives and tax recovery schemes have not been considered.
5. The self-consumption of electricity has been considered at 100% through a simple annual sum of the PV/PVT production.

The results of the five baseline scenarios and the advanced scenario presented in the chapter 4.4 are summarised in the Table 27.

Table 27. MiniStor annual economic savings

City	Heating mode [€]		Cooling mode [€]		Maintenance costs [€]		Annual Economic saving [€]
	Baseline	MiniStor	Baseline	MiniStor	Baseline	MiniStor	
Athens	1,636	0	0	0	370	270	1,586
Rome	1,885	0	0	0	370	270	1,985
Hamburg	2,255	2,104	0	0	370	270	251
Larnaca	1,162	0	0	0	300	270	1,192
Bergen	1,973	1,063	0	0	400	270	1,040

The annual economic savings results were used to analyse the maximum market price of the MiniStor system that could be accepted by end users over a 10–15 years reference period.

Even though the systems could have a longer end-of-life period of over 15 years (chapters 4.1.1 and 4.1.2), this analysis considers 10 years as the period during which the system guarantees the same performance. After 10 years, performance degradation is likely. Ten years also represent the accepted PBT for the residential customer segment. The second deadline, considered here as 15 years, is the point at which extraordinary maintenance costs will probably be necessary.

With these assumptions and starting from the annual economic savings generated by MiniStor, the reverse application of the PBT equation (Eq.1) provides indications about the possible market prices accepted in the five scenarios.

This approach provides useful information about the cost reduction that MiniStor has to reach to enter the market and become attractive for the residential customer segment. Table 28 presents the range of prices (minimum and maximum) in comparison with the baseline technology price considered in economic assessment.

Figure 5 shows the sensibility assessment varying the PBT accepted by the market.
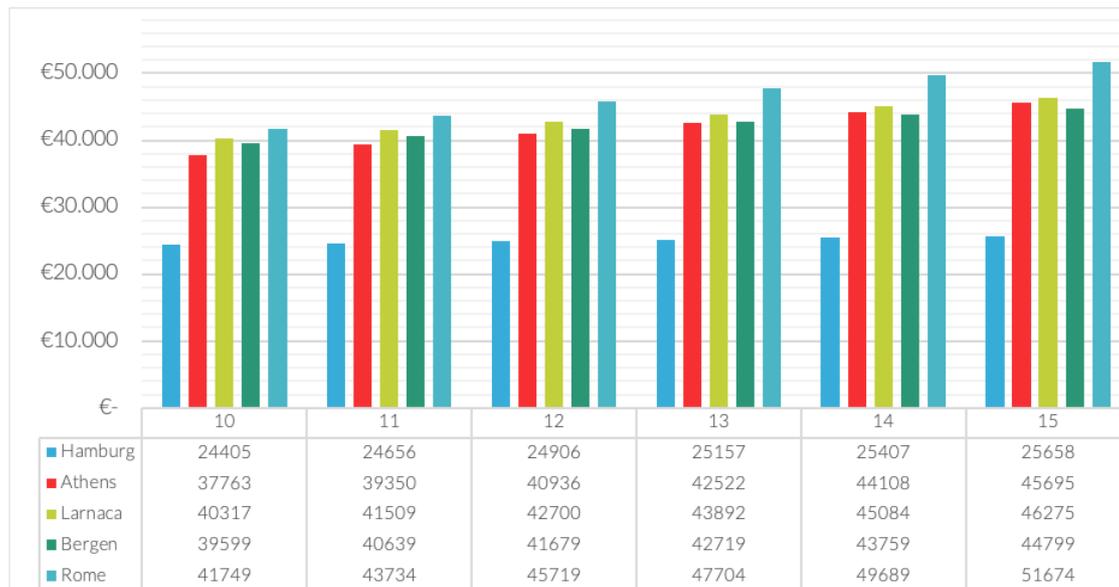
Figure 5. MiniStor accepted market prices in the five reference scenarios

Table 28. MiniStor potential market prices

City	Baseline technology CAPEX [€]	Minimum price [€]	Maximum price [€]
Hamburg	21,900	24,405	25,658
Athens	21,900	37,763	45,695
Larnaca	21,900	40,317	46,275
Bergen	28.400	39,599	44,799
Rome	29,200	41,749	51,674

As final consideration it is possible to have a critical analysis of the five scenarios:

Scenario 1: Renovation of buildings with gas boiler

- **Hamburg:** The integration of MiniStor in Hamburg is the most penalising scenario, despite the market analysis indicating that Germany is the most attractive market. The price range that the residential customer in Germany is potentially willing to pay is between €25,700 and €24,500, which represents a significant reduction in the cost of prototyping the MiniStor technology, unlikely to be achieved in the short term.

  The reasons for this low impact on annual savings are the low solar radiation and the high electricity prices.

  Due to the low solar radiation, the MiniStor system meets the building's energy needs over a short period, with the remainder mostly provided by the electrical HP, which has a high annual electricity consumption. The low solar radiation also impacts the quantity of electrical energy produced. In this scenario, it would be interesting to evaluate integration with other RES (e.g. a biomass boiler) or recovered waste heat.

- **Athens:** In the Athens use cases, the results of the energy simulation showed a range of acceptance, with prices from €37,800 to €45,700. This represents an interesting target for the MiniStor system, even if the price is at the upper end of the range. This is facilitated by the high solar radiation impacting both the thermal and electric energy produced by the RES, even though the tariffs for natural gas and electricity are relatively below the EU average.

- **Rome:** The results presented for the Rome scenario are the most promising of all the scenarios. The accepted price range is from €41,750 to €51,700, which meets the expectations of the MiniStor consortium. In this case too, economic savings are facilitated by the available solar radiation. An interesting aspect to consider is integration into new buildings where gas boilers cannot meet the new EPC performance requirements set out

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in the regulations. This makes it possible to compare MiniStor with other systems, such as HP and hybrid HP, which have higher commercial costs that are like the prices seen here.

Scenario 2: Renovation of building with HP

- **Larnaca:** The scenario in Larnaca represents an interesting solution in context with barriers to connect buildings to energy networks such as gas network and DHN. The high solar radiation available in the Larnaca latitude guarantee the total coverage of the building energy consumptions and interesting cost savings. This is reflected in the range of price for MiniStor from €40,300 to €46,300 that can be considered reasonable targets for the MiniStor technology in a medium long period.

Scenario 3: Scenario of building connected to the DHN

- **Bergen**: The scenario in Bergen even if seems the context with lower interest due to the presence of the DHN, provides an interesting result. The range of price, evidenced by the simulation, is comprised between € 35,600 and € 44,800 even if the latitude of Bergen has scarce solar resources that limits the energy production by the solar field. This result is a consequence of the high CAPEX of the reference technologies (pipers, heat exchangers, excavations, etc.) that permit to MiniStor to become competitive in terms of CAPEX.

As stated in the initial assumptions, these economic results do not take into account the possibility of accessing national incentives. This is a strong assumption that is considered to facilitate the assessment of various scenarios. It is also true that innovative technologies are often supported by incentives, especially if they generate environmental benefits by replacing old, low-efficiency systems.

The data presented here shows that access to incentives, such as feed-in tariffs or decarbonisation, could accelerate the market adoption of the MiniStor solution.

For example, the Ecobonus[13] for building renovations available in Italy in recent years could support the integration of MiniStor as a replacement for gas boilers, providing fiscal savings of between 30% and 50% of the CAPEX cost (up to a maximum cost of €30,000), which could be recovered within a period of 5 to 10 years. This means that the cost of MiniStor in a building renovation programme could be reduced from €10,000 to €15,000, which would have a significant impact on the PBT. Similar incentives are also available in other EU countries, offering comparable economic benefits.

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[13] https://arlettipartners.com/building-bonuses-in-italy-whats-new-in-the-2025-budget-law/

5. Conclusion

The MiniStor project, even if contextualised as Innovation Action (IA), demonstrates a strong research approach for the topic and the results investigated but also for the business approach. Technical and economic simulation demonstrate the applicability of the solution at residential level, even if some current regulatory restrictions could represent potential bottlenecks.

As an innovate product that is not available into the market as a unique solution, but which has been demonstrated at TRL7 at pilot scale, the final commercial price is not yet defined. Some components and subsystems, such as the ammonia TCM unit must be further developed to reach a higher TRL before being introduced to the market.

The residential customer segment identified at the beginning of the project has demonstrated continued technical and economic feasibility in different conditions.

As a main result of the economic assessment, the integration of MiniStor in buildings with well-defined heating and cooling periods and comparable consumptions located in latitudes with good solar radiation can easily meet the market expectation (prices) and the customer prospective (PBT).

The assessment took in consideration the renovation process of 5 different scenarios starting from the technical assessment done in D6.7. Nevertheless, the heating and cooling profile of the selected buildings is more representative of buildings from 1970s and 1980s (in terms of built area and thermal transmittance) respect to new constructions where their energy consumptions are much reduced in comparison.

Considering new buildings with lower area and energy consumptions, MiniStor is able to cover longer heating and cooling periods, and possibly the entire loads with higher economic impact, which can facilitate customer acceptance.

Table 29 presents a proposition to reduce costs beyond the project, by considering engineering processes and subcomponents that could be streamlined in commercial production. The table provides an economic assessment that could easily be matched by residential customers in the event of new building integration.

Table 29. Preliminary cost reductions

MiniStor sub-Component	Type	Pilot unit cost [€]	Preliminary reduction targets [€]
PVT panels	Dedicated	8,900	7,500
Heat pump	Dedicated	2,850	2,500
Additional Heat pump	Dedicated	3,750	3,000
HP control and connection	Dedicated	9,650	3,000
TCM reactor	Prototype - Dedicated	27,600	8,000
Cold PCM	Commercial	1,500	1,500
Hot PCM	Commercial	1,500	1,500
Inverter	Commercial	2,000	1,500
EESS	Commercial	3,400	3,000
Piping	Dedicated	33,400	5,000
Control & Instrumentation	Prototype - Dedicated	2,400	1,000
Electrical connections	Dedicated	4,800	2,000
HEMS	Prototype - Dedicated	2,250	2,000
Enclosure	Commercial	24,000	0
Safety equipment	Dedicated	8,000	3,000
Ancillary equipment	Dedicated	4,000	2,000
Installation	Prototype - Dedicated	11,000	3,500
		151,000	50,000

Other factors that can increase the economic feasibility from MiniStor are the quantification of flexibility services when integrated in a group of buildings enabling peer-to-peer and energy

exchange mechanisms. These were not evaluated in this project, as well as the use of recycled components or potential national incentives for buildings renovation with smart appliances and systems. These were considered as part of the MiniStor business model.

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