H2020-EeB6-2015-680450-CREATE
Compact **RE**trofit **A**dvanced **T**hermal **E**nergy storage

T.2.1 Economic value of heat storage systems

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Executive summary

This work provides an incremental economic assessment of a seasonal compact thermochemical heat storage combined with solar thermal energy for residential retrofit application for various European climates. The energy system supplies heat for individual dwellings for Space Heating (SH) and/or Domestic Hot Water (DHW). The main scenario considers a seasonal thermal storage which allows a 100% solar fraction in order to eliminate the fuel consumption of the back-up system.

This work is included in the European project CREATE as Task 2.1 “Economic value of heat storage systems“ in the Work Package 2[1] and will provide economic recommendations in order to define, with the results of Task 3.1[2], the technical economic key drivers of the system. These findings will then be valued in the project when the business models of the thermal storage will be investigated and refined.

Our results showed that the target price[3] of the thermochemical storage when reaching a 100% solar ratio, is in the range:

- **3080-3531 €/MWh** (855-980 €/GJ) for Domestic Solar Water Heater (DSWHst) in the better cases (very low to negative values for the worst cases) and
- **651-2781 €/MWh** (181-772 €/GJ) for Solar Combined System (SCSst)

which is lower than the projections of the system costs estimated around 5000[4] €/MWh. The evaluated gains come from the savings in fuel consumption and the heat demand naturally impacts them as the battery target price.
Targeting a solar ratio lower than 100% may be an interesting trade-off to investigate.

It must be underlined that, in this deliverable, the considered case study (use of the heat battery in individual households) is not an optimal configuration and therefore the economic viability might be increased with other configurations.

This techno-economic study was carried out by taking into consideration the countries highlighted in the European geographical market analysis issued by FENIX. The latter reveals that the economic feasibility depends not only on technical, thermal and energy market analysis but has to consider the potential evolution of the building stock and its retrofit.

Finally, it appeared that “extra-value” needs to be investigated and defined. The main drivers for the profitability of the system are the heat demand and the weather conditions. Fuel price appears as a key parameter too because according to the different projections (low, medium or high price), it can turn an uneconomic situation (with low gas price) into a profitable situation (with medium and/or high gas price).

A preliminary material cost estimate (based on parametric criteria) points out that the material cost should be in the range 84.4-296.8 €/(GJ.m^3) of energy storage.

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[1] “Cost analysis and planning for future commercial products”
[2] “System requirements definition”
[3] Gas-fired boiler is taken as comparison reference system
[4] This value is given in AD-024 p. 29 (section 2.3.3)

This information is utilized as a starting point for the activities foreseen in task 4.1.
It shall be reminded that this preliminary material cost estimate starts from the assumption that the heat battery system is sold as “ready to market” product, hence Technology Readiness Level (TRL) 9.
The output of CREATE project is to build a demonstrator at TRL 6 level. At this TRL level the material cost range could be increased, the range of **526.8-1852.2 €/unit**.

Table of contents

1. References

1.1 Applicable Documents

	Document	Reference	Issue
AD-01	CREATE Grant Agreement	No. 680450	
AD-02	CREATE Consortium Agreement	No. 0100289706	
AD-03	TNO-CREATE-ECM-26-i1_Preliminary TCM requirements		
AD-04	Annex B (technical) to [AD-01]	H2020-EeB-06-2015	26-06-15

1.2 Terms, definitions and abbreviated terms

CAPEX	CApital EXPenditures
D	Deliverable
DHW	Domestic Hot Water
DSWH	Domestic Solar Water Heater
DSWHst	Domestic Solar Water Heater with storage
GDP	Gross Domestic Product
NPV	Net Present Value
O&M	Operation and Maintenance
OPEX	OPerating EXpenses
RES	Renewable Energy Sources
RDP	(Full) Research Development and Policy
RP	Report
SCS	Solar Combined System
SCSst	Solar Combined System with storage
SH	Space Heating
T	Task
TCM	Thermo-Chemical Material
th	Thermal
TRL	Technology Readiness Level
WP	Working Package

2. Introduction and CREATE context

CREATE is a H2020 project financed by the European Commission whose topic is part of the work program entitled "Integrated solutions of thermal energy storage for building Applications" (Grant Agreement n. 680450).

The objective of the CREATE Project is to develop and demonstrate a heat battery, i. e. an advanced thermal storage system based on Thermo-Chemical Material (TCMs), that enables economically affordable, compact and practically loss free storage of heat in existing buildings, especially for retrofit purposes.

Energy storage is supposed to be one of the key points to achieve nearly-zero energy buildings through the maximization of the use of Renewable Energy Sources (RES) such as solar. Because of the intermittence of the RES, energy storage will serve to couple demand and supply (over a specified time scale). In the framework of this project, the thermal battery is designed to store energy during a long time (up to few months); so the storage capacity will be used inter-seasonally.

The 4-year long CREATE project is subdivided into nine different Working Packages (WP). In this architecture, WP2 called "Cost analysis and planning for future commercial products" appears as the first "operational" task of the project whose results will be forwarded to the other WP as input data especially WP3 "System definition, design and simulation".

EDF is the task leader of the Task 2.1 entitled "Economic value of heat storage system". It takes place at the early stage of WP2 and the present deliverable – D 2.1 – is due 6 months after the beginning of the project that is to say at the end of March 2016.

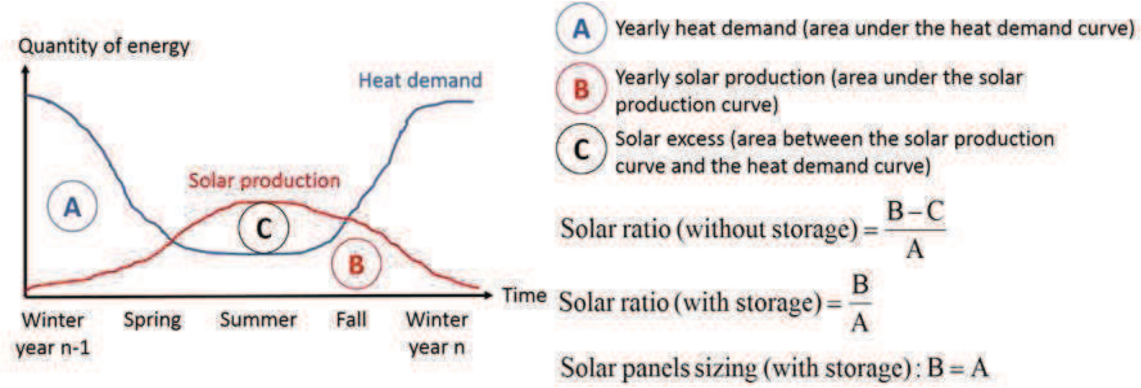
This deliverable (D 2.1) is the result of the Task 2.1 (T 2.1) entitled "economic value of energy storage". It provides an insight for the other tasks of the WP2 addressing economic and market analysis and for the other technical WP of the CREATE project.
According to DoA, task 2.1 is described below:

***Task 2.1 – Economic value of heat storage systems** (Task Leader: EDF; participants: Vaillant, Fenix, D'Appolonia, AEE INTEC)*

- ✓ *Select different local energy scenarios representing combinations of factors that influence the value of energy storage : power load curves, level of electric renewable generation or CHP, electricity price variations, time scale of energy storage...*
- ✓ *Assess the value of thermal energy storage systems according to the most relevant scenario;*
- ✓ *Specify the technical and economic value of thermal storage systems : amount of thermal stored energy, number of cycles, power capacity, maximal cost target, other technical or environmental specifications;*
- ✓ *Investigate lead geographical markets across EU-28 for the proposed system, partially building on the energy scenario simulations to determine the most advantageous markets, as well as identifying key success factors for those markets.*

The heat battery is supposed to be installed in a dwelling located in different places in Europe starting from 2020 (cf. AD-04 p. 25). In this framework, the individual customer point of view was adopted in order to study the economic balance of investing in a heat battery in his dwelling. This battery may be integrated in the existing Space Heating (SH) and/or Domestic Hot Water (DHW) system.

In this study, the energy system supplying the energy to be stored is a solar collector. Depending on the season, weather and heat consumption, the balance between heat supply and demand is positive or negative. The role and the economic value of the heat battery will be to store heat when the supply exceeds demand and to release it in the opposite situation. The time scale of storage may be weeks or months, according to the strong difference of heat supply by solar collectors between winter and summer. Figure 1 summarizes the main principles of the heat battery coupled with solar panels while targeting 100% solar ratio.



$$\text{Solar ratio (without storage)} = \frac{B-C}{A}$$

$$\text{Solar ratio (with storage)} = \frac{B}{A}$$

$$\text{Solar panels sizing (with storage)}: B = A$$

Figure 1 : Main principles of the heat battery

In the CREATE project, the idea of storing excess of renewable electricity is going to be dealt with. In fact, it should provide supplementary financial gains from deferring investments in the electricity grid and it will most probably positively influence the business case of the storage. However, this topic is not considered in this issue of D 2.1 and it will be further investigated as part of Task 2.1.

The fulfilment of T 2.1 was possible thanks to a constructive cooperation between the partners of WP2 and WP3. Discussions, exchanges of experiences and brainstorming were carried out in this framework. Moreover data and market analysis were provided by AEE, FENIX and VAILLANT. These supports facilitated the realization of the cost-benefit analysis and enabled a wider consideration of case studies.

This document was compiled by EDF, whereas different partners within the CREATE program have shared their expertise for this document. AEE Intec and VAILLANT contributed information on heat and domestic hot water need profiles. FENIX provided the preliminary lead geographical market analysis. Preliminary material cost has been performed by D'Appolonia and is reported in appendix 1. All partners advised EDF thoroughly during our work in Task 2.1.

This document has also been reviewed by the partners within the CREATE program before publication.

3. Methodology

3.1 Scope of the study

The cost-benefit analysis of the CREATE project is aimed to estimate the profitability of a heat battery in the residential sector from the individual customer's point of view. Because the choice of investing in such a system mainly depends on the owner of the dwelling/building, our main case studies consider individual housing that is to say private houses.

A heat battery may be interesting in other configurations as for instance in hotels or swimming-pools where the needs of heat are more consequent and less variable during the daytime (because of the diversity effect). However it largely exceeded the scope of the project and it was not studied.

On top of that, heat may be used to operate a cooling system (absorption/desorption air conditioning equipment) which may be another possibility to increase the value of the heat/storage but once again we only considered in this study the Space Heating and Domestic Hot Water needs of a dwelling.

Although the influences of a heat battery on its potential linked networks (electricity and/or local heat network) may be of noticeable importance, we did not consider them in this study.

In this deliverable, the case studies investigated were a thermal solar system supplying heat to be used for SH and/or DHW, coupled with the heat battery in different locations across Europe. We did not consider the installation of a heat battery in an already installed (existing) solar system (DSWH or SCS). The profitability of the battery in these cases may be different from what was identified in this report. The cases of PV and power to heat will be studied later in the WP2 in order to enlarge the market potential evaluation (T 2.3).

3.2 Main assumptions

In this study, the essential thing to consider is the storage function of the battery and the revenues that are generated over its lifetime. So it appeared not necessary to precisely represent the functioning of the thermochemical system and that is the reason why it was considered as a "black box". This black box is able to store energy (charging) when there is a solar production excess (i. e. the instantaneous solar production is greater than the thermal needs) and the battery gives its energy back to the dwelling (discharging) when the solar panels are not able to fulfil the demand.

As this analysis tried to identify the most favourable cases for the heat battery, the following fundamental assumption was chosen and applied in the calculations: the heat battery stores each solar excess production (supply > demand) from the panels without any technical limitation – battery size, possible overheat phenomena… - and gives it back as soon as solar production does not cover the demand (supply < demand) with applying a storage efficiency of 100% (no heat losses).

In order to enhance the profitability of the battery, it is necessary to maximize the fuel savings which is equivalent to maximize the energy savings (i. e. energy efficiency). From this point of view, the best case avoids 100% of the conventional back-up and thus provides a significant CO_2 emissions reduction. This rule is crucial in terms of solar panels dimensioning and heat battery sizing.

In our study, we made the assumption that a solar system equipped with a heat battery is able to provide a 100% solar ratio for SH production and/or DHW depending of the type of the system. Unless contrary mention, solar panels and the need of stored energy were sized according to that.

Data concerning the weather, the heat demand (SH and DHW), the solar production and the battery charge/discharge are considered on a monthly basis. However the energy balance of the battery is carried out on the yearly basis. These assumptions have two consequences:

- It firstly made easier the modelling, the calculations and their verification and according to the deadline of D 2.1 it seemed to EDF and the CREATE project's partners involved in this task the most relevant way to carry out this analysis;
- It secondly gives results that can be considered as the upper boundary in terms of solar excess use/storable part and in the same time it leads to the lower boundary in terms of heat battery and solar panels sizing according to the chosen optimization (100% solar ratio).

In order to know if the heat battery is profitable or not depending on the case study, its Net Present Value (NPV) that is to say the discounted sum over its lifetime of its costs (negative terms) and its revenues (positive terms) was calculated. So even the NPV becomes equal or greater than zero, a system can be considered profitable.

In our analysis, the initial price of the heat battery was taken as (unknown) variable so that the result of the cost-benefit analysis becomes the target price of a heat storage system. This price is estimated so that the system becomes profitable at the end of its theoretical lifetime (20[5] years).

So the objective function of the analysis consists in equalizing the heat battery NPV with zero as Equation 1 underlines.

$$f_{obj} : NPV_{heat\ battery}^{20\ years} = 0$$

Equation 1 : Objective function of the cost-benefit analysis

As our analysis takes place in the first phase of the project, all technical boundaries of the solar thermal system were not taken into account. For instance, we took the assumption that there was no volume limit concerning the battery that could be installed in a dwelling. Another example is that we did not consider the possible overheating phenomena that may arise in the solar panels in case of huge sun radiations. We excluded the electric consumption of the supplementary pumps and/or valves that equip the solar thermal system too.

In order to compare results on a common basis, the heat battery target prices given in this report always are relative to 1 MWh of storage capacity (or 3.6 GJ capacity).

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[5] Cf. AD-024 p. 20

3.3 Data collection

Before starting the cost-benefit analysis, we first made an inventory of the required data to represent the storage and solar thermal system. As thought, technical and economic data was needed for this study. In the two sub-paragraphs below, we will give more insights concerning it.

3.3.1 Technical data

For technical elements concerning the solar thermal system and the heat battery, the data provided in the CREATE Grant Agreement technical annex (AD-04) was used. So the heat battery is supposed to be able to store 417 kWh/m^3, its lifetime is longer than 20 years, there is no energy waste through the storage process (the stored quantity is entirely retrievable) and the battery is operated on a seasonal basis that is to say that the storage and the discharge occur over long periods (seasons).

As the heat battery is compared with conventional heating systems, data concerning gas fired boilers was needed. Public available data from manufacturers' websites (nominal power range, efficiency…) were used.
Other required data concerned:

- per capita and per m² of heated surface consumption:
    - normative elements directly from French and/or European standards
    - measured values from EDF laboratories
    - simulated values from AEE
- DHW input and output temperatures
- solar system technical specifications
- meteorological data

CREATE's partner AEE provided a series of heat demand curves for different countries/cities across Europe. Other sources of data were the literature, private databases or results from EDF laboratories.

Table 1 summarizes the main technical data that was used in the calculations.

Parameter [unit]	Value
Technical lifetime of the heat battery [years]	20
Energy storage density of the battery (on the system level) [kWh/m^3]	417
Heat battery efficiency[6] [%]	100
Dwelling heated surface [m²]	100
Dwelling specific heat demand [kWh/(m².year)]	15-30-60-100
Gas boiler nominal power [kW]	14-22
Gas net calorific value [kWh/m^3]	10.5

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[6] Efficiency describes here the ability to retrieve energy from the battery after a charging process : 100% efficiency means that the storage process is free of energy losses

CO_2 emission from gas combustion [g_{CO_2}/kWh]	234
Gas boiler efficiency [%]	85
DHW tank and tube efficiency [%]	85
Cold water supply temperature [°C]	10
Hot water supply temperature [°C]	55
Number of persons in the dwelling [-]	4
Per capita daily DHW need [litres]	35
DHW supply days per year [days]	330
Simulated geographical locations [-]	Paris-Nice-Davos-Athens-Würzburg

Table 1 : Technical input data of the simulated solar system

3.3.2 Economic data

The economic part of the analysis required a series of prices and costs related to the installation, the use and the maintenance of the thermal systems. For instance, in our analysis we took into account following elements:

- CAPital EXpenses (CAPEX) of the thermal system
- OPerating EXpenditure (OPEX) of the energy (gas price and projections)
- Operating & Maintenance (O&M) of the technical systems
- Initial heat battery investment recovery at the end of the technical system lifetime: we chose 20% as written in AD-04 p. 29.

Once again the consortium and notably VAILLANT and AEE provided us a part of these data.

Table 2 summarizes the main economic parameters of the study.

Parameter [unit]	Value
Duration of the economic study (project duration) [years]	20
Required simple payback [years]	15
Boiler investment cost [€]	1700
Boiler lifespan [years]	15
Yearly boiler O&M [€]	130
Solar investment cost [€/m²]	1000 (for DHW supply) 800 (for SH+DHW supply – scale effect)
Lifespan of solar investment [years]	20
Yearly solar panels O&M [% of initial investment costs]	0.5
OPEX escalation rate [%]	2.2
Discount rate [%]	3
Fuel (gas) price [€/kWh]	3 scenarios on 2014-2040[7] Low price scenario : 0.0767→0.068 Medium price scenario : 0.0767→0.1373 High price scenario : 0.0767→0.184
Heat battery investment recovery at the end of the system lifetime [%]	20

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[7] These scenarios will be described in paragraph 5.

Table 2 : Main economical input data of the cost-benefit analysis

4. Modelling and optimization

As previously said, this preliminary analysis aims to give some insights concerning the profitability of a heat battery installed in a dwelling. This way, our work consisted in developing a simplified simulation tool (excel spreadsheets) to technically represent the system and to economically valuate it according to the chosen scenarios. Both parts of the work – technical and economical modelling – could be further developed and refined compared with our approach[8] but the assumptions we used enabled us to obtain results whose precision seemed to us convenient for the purpose of this analysis.

4.1 Technical modelling

So as to carry out the cost-benefit analysis of a heat battery coupled with solar panels, we took the assumption of considering energy (heat) demand and weather conditions on a monthly basis. This way we elaborated the monthly energy balance of a dwelling in terms of SH and DHW demand mainly according to:

- the geographical location of the dwelling (5 cities across Europe)
- its specific heat demand[9] (or dwelling-type)
- the heated dwelling surface
- the number of people living in the dwelling

This heat demand, SH and/or DWH, may be fulfilled with various possible thermal systems.

To reduce the combinatory cases {system; energy}, we took the assumption that the conventional system (based on fossil fuels) that will serve as comparison reference (with solar systems) is a condensation gas boiler.

Two other system architectures were studied:

- solar system (panels and auxiliary devices) with heat battery and
- solar system without battery

for both types of heat demand: DHW only (the system is called Domestic Solar Water Heater – DSWH) and SH+DHW (in this case, it is a Solar Combined System – SCS).

In parallel we made use of the climatic conditions (in particular solar radiations) and standard performance indicators[10] for solar panels (flat collectors) to calculate the potential solar production per m² of solar system.

In order to define favourable economic conditions for the heat battery, the assumption of a 100% solar ratio (all needs may be covered by solar energy) was firstly adopted for solar system equipped with storage. That is the reason why the optimal sizing of the panels was estimated according to Equation 2 :

$$Solar\ panel\ area = \frac{yearly\ heat\ demand}{per\ m^2\ potential\ solar\ production}$$

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[8] For instance, hourly modelling may have been chosen to represent the technical systems

[9] It is here noticeable to underline that only SH is location dependent. For DHW, location has no influence on the demand

[10] Input data like inclination angle of the solar collectors, azimuth angle, optical efficiency… were chosen under the assumption that the installation is optimal

Equation 2 : Sizing of the solar panels for systems with storage

Equation 2 gives an optimistic point of view in terms of required solar panels. This way, the solar part of the CAPEX of the solar systems with storage is reduced as low as possible. In paragraph 5, we will see that other sizing rules are possible; some of them were applied and the results will be discussed.

4.2 Economical modelling

The cost-benefit analysis carried out with the EDF-developed excel tool is a set of economical calculations for the different technical systems that were defined. More precisely, these are aimed to quantify the differences in terms of CAPEX and OPEX between the conventional gas-fired back-up system and the studied solar systems (without and with storage) over the entire technical lifetime of them. Typical economic parameters such as discount rate or OPEX escalation rate were taken into account.

A solar system would be profitable if its NPV is greater or equal to zero over its technical lifetime. As we forced the NPV to be zero after 20 years of system use, we get the specific target price of the heat battery per MWh (per GJ). According to the obtained prices, the profitability of the heat battery may be estimated:

- if the price is **negative**, the energy savings over the lifetime of the battery cannot compensate the initial CAPEX investment and the required O&M; thus the storage is not economically viable from the customer point of view without any financial support (e. g. subsidy);
- if the price is **zero**, the energy savings just equalize the expenses from the battery ownership; the system is economically profitable for the customer but the heat battery provider has no interest to produce it without being subsided;
- if the price is **greater than zero**, the heat battery is economically profitable from the dwelling inhabitant and the energy savings are sufficient to allow a positive selling price; depending of this value, supplementary subsidies to the heat producer may be necessary to enable the economic viability of the production.

4.3 Use cases

In order to estimate the economical role of the battery in a solar system equipped with it, we calculated “differential” target prices each time between two systems providing the same thermal needs:

- DSWH with storage (DSWHst) vs DSWH without storage (DSWH)
- DSWH with storage vs natural gas-fired boiler (Boiler)
- SCS with storage (SCSst) vs SCS without storage (SCS)
- SCS with storage vs natural gas-fired boiler

Thus, comparing the obtained target prices reveals for each case study which technical configuration (DSWH/SCS, with/without storage) is more profitable from the customer point of view and in the same time it indicates where and under which conditions a heat battery market is possible.

5. Results and discussion

5.1 Domestic Hot Water supply

For Domestic Hot Water, we made the assumption of a unique demand across Europe of 2399 kWh/year[11] (this corresponds to a measured value for south of France). Considering only the DHW supply in a first step, we give in Figure 2 the specific (per MWh) target prices of the heat battery in both comparison cases: DSWHst vs DSWH (hatched blue) and DSWHst vs Boiler (plain blue).

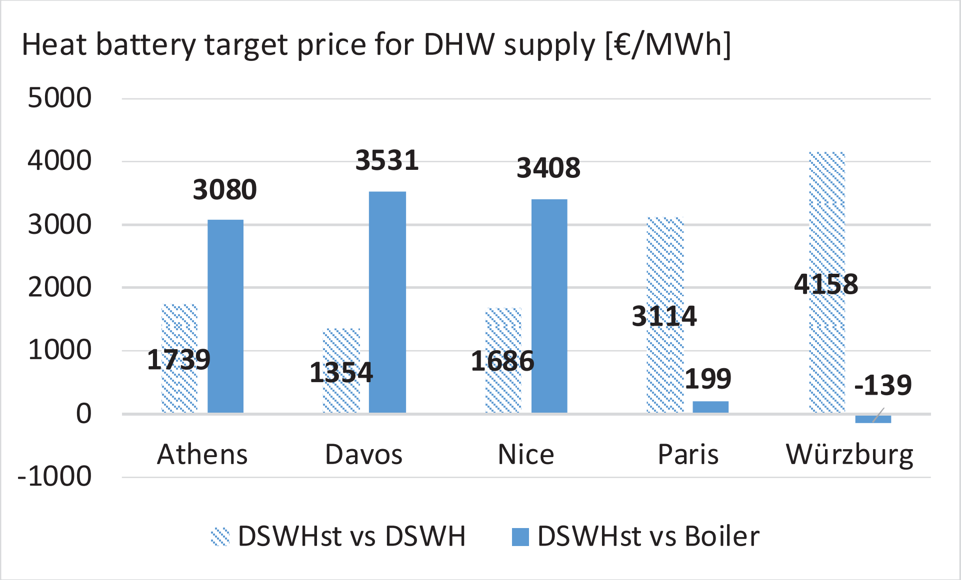

Figure 2: DSWHst heat battery target price in various European cities

As mentioned earlier, the DSWHst is sized so that the solar energy provides 100% of the required needs (no back-up) whereas the DSWH reaches 70% of needs covering. That is the reason why both architectures of systems do not lead to the same required solar collector area. According to the location and the corresponding irradiation, the surfaces vary between 2 and 5.2 m² as it is summed up in Table 3.

	Required solar collector area [m²]	
	DSWHst	DSWH
Athens	2.45	2.32
Davos	2.30	2.01
Nice	2.35	2.18
Paris	3.55	4.35
Würzburg	3.73	5.24

Table 3 : Required solar collector areas for DSWHst/DSWH in different European cities

Two main elements influence the resultant target prices for each system comparison: CAPEX and OPEX. When considering a DSWH which enables 70% of the DHW supply, it

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[11] A standard calculated DHW demand (4 people, 35l/day, 330days/year, T_{feed} = 10°C, T_{output} = 55°C, DHW tank and tube efficiency = 85%) would be 2841 kWh/year

may require an important surface of solar panels depending on the available solar radiation throughout a year (the more the available solar radiation the less the required solar collector area). With the storage, the required surface area of collectors may be less important compared with a DSWH in the same location (under the fundamental assumption of 70% of solar covering for DSWH and the ability of the battery to store each solar excess without limitation). That is the reason why we can notice two groups of target prices in Figure 2 for the comparison DSWHst vs DSWH:

- a low to medium target price group [1354; 1739] €/MWh for Athens, Davos and Nice;
- a high target price group [3114; 4158] €/MWh for Paris and Würzburg.

The low to medium target price group corresponds to cities with high solar irradiation leading to a limited need in terms of collector area in both cases DSWHst/DSWH. The high target price group is representative of cities with lower radiation potential than the other group, so more panels are required to fulfil the demand and these are situations where the surface area of solar panels in DSWHst is lower than in DSWH. The comparison between DSWHst and DSWH is little biased according to that because there is an “artificial” gain in CAPEX (on solar collector costs) when installing a battery compared to a DSWH[12] leading to a high target price.

At the end and according to the general practice, the profitability of the heat battery for DHW supply compared with DSWH is not better in Paris and Würzburg compared with Athens, Davos and Nice.

On the other hand, when considering the comparison DSWHst vs Boiler, we can notice again two groups of battery target prices:

- a high target price group [3080; 3531] €/MWh for Athens, Davos and Nice;
- a very low to negative target price group [-139; 199] €/MWh for Paris and Würzburg.

In this comparison, the heat battery and the solar panels avoid the complete need of back-up which maximize the energy savings. This leads to high OPEX savings. According to the solar radiation of the cities, more or less solar panels are required. Because this potential is high for Athens, Davos and Nice, the required panel surfaces are relatively low (2.45, 2.30 and 2.35 m² respectively) and the installation (solar panels + battery) is **economically profitable from the customer point of view** as target price are positive.

Although the target price still remains under the cost projections of the heat battery (5000 €/MWh), DSWHst may be viable for places with high solar radiation potential like Athens, Davos and Nice.

In Paris, the savings in OPEX (gas consumption) have difficulties to compensate the investment in the solar+battery system leading to a very low (positive) target price. The battery is still economically viable for the customer but not for the manufacturer (as this price is not supposed to cover the costs of construction of the battery). In Würzburg, as the solar potential is very low, a large surface of panels is required (3.73 m²). This situation

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[12] Once again it must be underlined that the heat battery target prices are given under a differential point of view : the target price identifies the advantage/disadvantage of a system compared with another

is not economically profitable for the customer as the calculated target price is negative which indicates that the battery owner loses money while using it.

As the savings in OPEX is one of the main drivers of the results in this study, it clearly appears that the fuel price is a key parameter. That is the reason why we carried out a sensitivity analysis on it. As mentioned in Table 2, we made use of three gas price scenarios[13] over the time horizon 2014-2040. Figure 3 shows the gas price evolution in each of them.

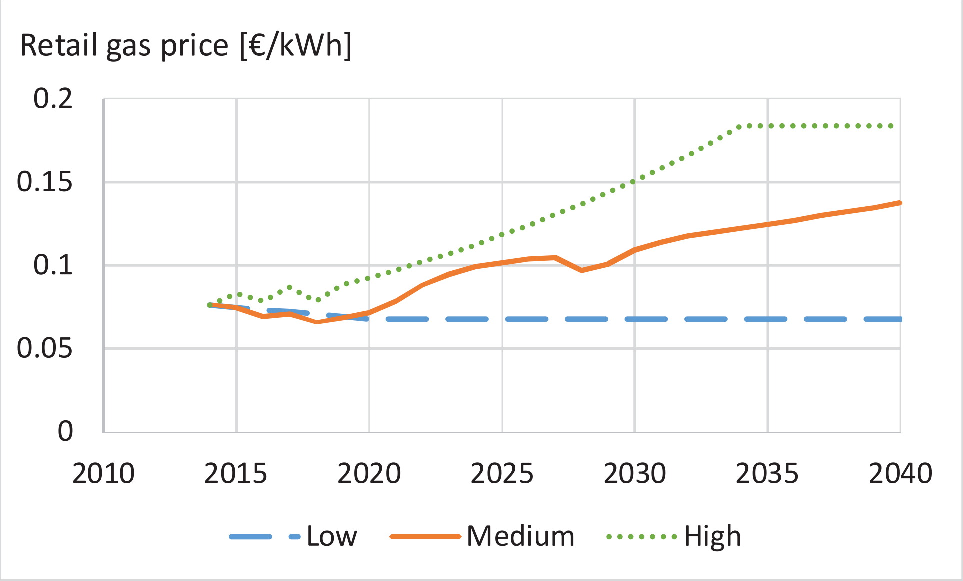

Figure 3 : Gas price trajectories in our scenarios

Applying the different gas price scenarios gave interesting results: situations that are not economically profitable in the low price scenario may be just viable in the medium one and rentable in the high price scenario as can be seen in Figure 4 which shows the case of Paris.

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[13] The medium gas price scenario is based on IHS Rivalry 2014 and the low and high price scenarios are derived from it applying own construction rules. All scenarios concern France and were applied for the other locations without any adaptation

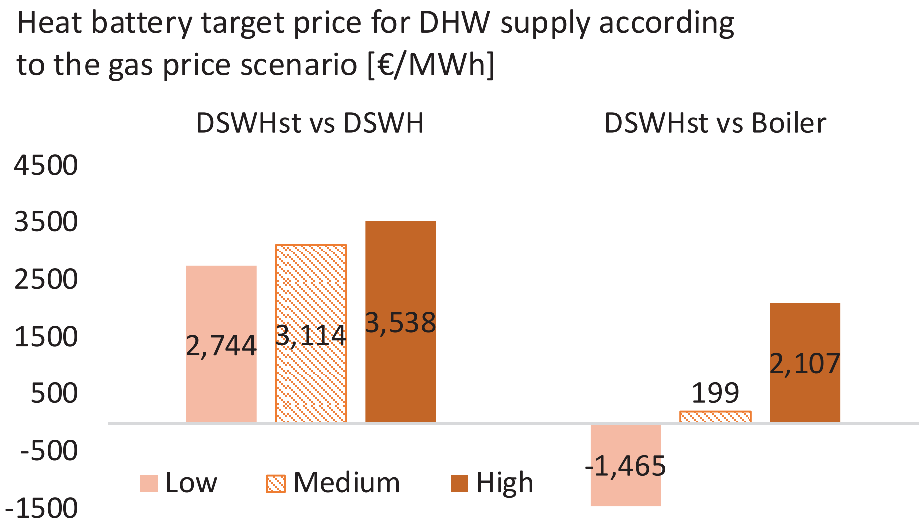

Figure 4: Gas price sensitivity on DSWHst target price (Paris case)

Figure 4 indicates that the target price of the heat battery seems proportional to the gas price. For the comparison DSWHst vs DSWH, the higher is the gas price, the higher is the calculated target price (from 2744 to 3538 €/MWh). Once again, the high target price values must be carefully interpreted with remembering the “artificial” solar collector CAPEX gain between DSWHst and DSWH.

The second comparison – DSWHst vs Boiler – in Figure 4 underlines a turning point in terms of profitability. A low gas price scenario does not allow the viability of the system (the savings do not compensate the initial investment and the lifetime O&M) whereas high price scenario leads to a heat battery target price of 2107 €/MWh.

In the following without any supplementary precision, results will be given while applying the medium gas price scenario.

We summed up in Table 4 the theoretical total gas savings and avoided CO_2 emissions over the technical lifetime of the systems (DSWHst and DSWH).

	DSWHst vs DSWH		DSWHst vs Boiler	
	gas savings [MWh]	avoided CO_2 emissions [t]	gas savings [MWh]	avoided CO_2 emissions [t]
Athens	11.2	2.6	56.5	13.2
Davos	11.0	2.6	56.5	13.2
Nice	11.0	2.6	56.5	13.2
Paris	15.0	3.5	56.5	13.2
Würzburg	16.1	3.8	56.5	13.2

Table 4 : Gas savings and CO_2 emissions reductions thanks to DSWHst/DSWH over their technical lifetime

5.2 DHW and SH supply

The European housing stock is old and because its majority was built before any thermal regulation, the heat demand for domestic buildings is huge. As mentioned before in Table 1, we have selected four building typologies in this study leading to as many specific heat demands per m²: 15-30-60-100 kWh/(m².year). As CREATE is focused on retrofits, we chose to consider as reference case the 100 kWh/(m².year) dwelling type.
As for DSWH, different rules are available for the sizing of the solar collectors that constitute a SCS system (with or without storage):

- the first method for SCSst called **"optimistic"** is related to Equation 2 : the collector surface area that is obtained enables theoretically 100% solar ratio with help of the battery with the minimum of solar panels;
- the second method for SCS called **"solar ratio related"** aims to reach, as its name underlines, precise solar ratios for DHW supply (70% of the demand) and SH (10% of the demand); these figures come from the literature;
- the third method for SCS called **"heated surface ratio related"** is a literature-based sizing rule that is very simple to put into practice: the collector surface area required for a SCS system is equal to 10% of the dwelling heated surface.

Table 5 gives the values of the collector surface areas obtained thanks to the different sizing methods for the five selected cities across Europe. The range of surfaces for SCSst sensitively varies from 4 to 20 m² according to the thermal needs and the solar irradiation. The solar ratio related method gives relatively low surfaces compared to the literature. The heated surface ratio related rule leads to more conventional collector surfaces.

Surface collector area according to the chosen rule and system [m²] Dwelling type 100 kWh/(m².year)			
City	SCSst – "optimistic"	SCS – "solar ratio related"	SCS – "heated surface ratio related"
Athens	4.3	2.8	10.0
Davos	16.0	3.3	10.0
Nice	12.4	4.8	10.0
Paris	20.9	7.1	10.0
Würzburg	19.7	6.6	10.0

Table 5 : SCSst/SCS surface collector area sizing according to the previously defined rules

Firstly in paragraph 5.2.1, we will give some results when applying the optimistic sizing rule to SCSst (SCS will either be solar ratio related or heated surface ratio related sized) and then in paragraph 5.2.2 we will adopt the heated surface ratio related rule for both SCSst and SCS.

5.2.1 Optimistic sizing of SCSst

Figure 5 presents the comparison of heat battery target prices for SCSst when applying the optimistic rule for SCSst and the solar ratio related one for SCS. As previously, for each city, two comparisons are carried out: SCSst vs SCS (red checked pattern) and SCSst vs Boiler (plain red).

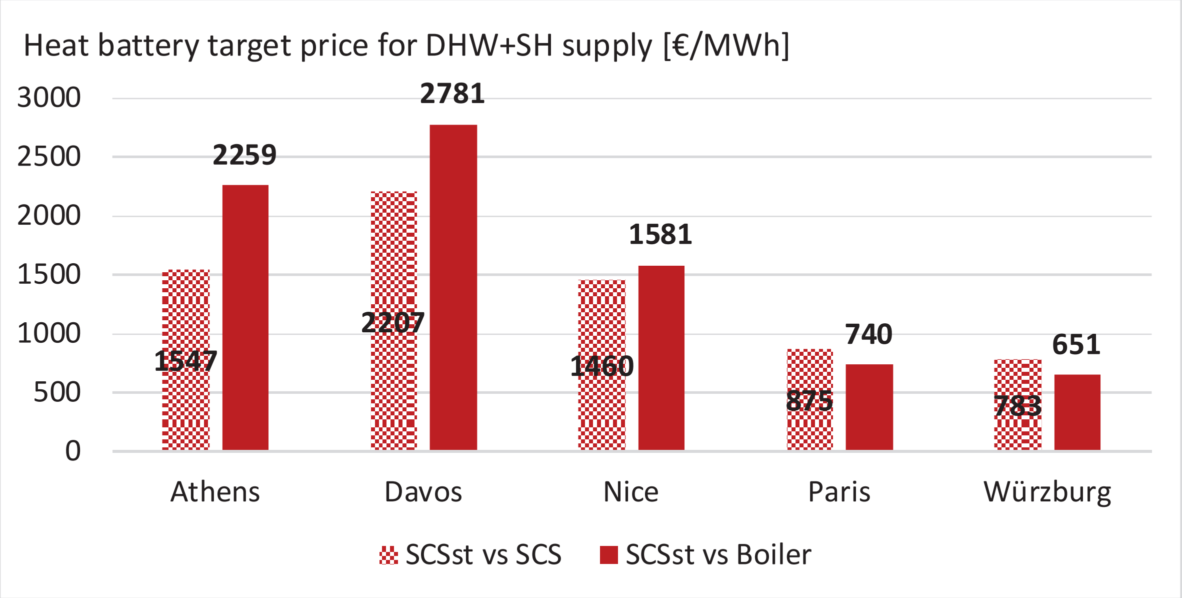

Figure 5 : SCSst heat battery target price for various European cities (dwelling type 100 kWh/(m².year)) – Optimistic sizing for SCSst and solar ratio related sizing for SCS

As we have seen in paragraph 5, two groups of target prices could be noticed for both comparisons SCSst vs SCS and SCSst vs Boiler:

- a medium target price group [1460; 2781] €/MWh for Athens, Davos and Nice;
- a low target price group [651; 875] €/MWh for Paris and Würzburg.

The medium target price group contains cities whose heat demand is low to high and where there is a high solar potential. In these conditions, the required collector surface area is medium to low (4.3 to 16 m²) which implies a limited amount of initial CAPEX. Moreover, there is a noticeable heat battery target price gain from SCSst vs SCS to SCSst vs Boiler.

As for DHW supply, Athens, Davos and Nice are locations where it may be economically viable to install a heat battery coupled with solar panels in order to fulfil the SH and DHW demand.

At the opposite, Paris and Würzburg are locations where the heat demand is high and the solar potential relatively low. In these cases, a consequent surface collector is required (around 20m² for both cities) which penalizes the overall profitability of the system. This one remains economically relevant for the customer (the target price is positive) but it is not the case for the battery manufacturer who would sell it at a very low price level (< 1000 €).

If another dimensioning rule is adopted for SCS as for instance the heated surface ratio related one, comparisons of heat battery target prices between SCSst and SCS slightly evolves as it can be seen in Figure 6.

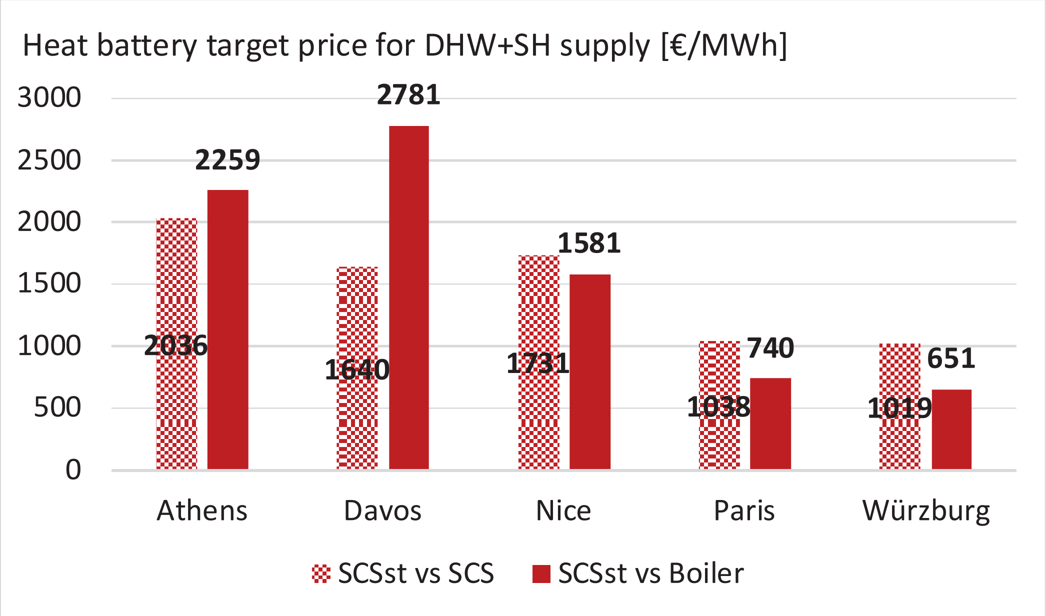

Figure 6 : SCSst heat battery target price for various European cities (dwelling type 100 kWh/(m².year)) – Optimistic sizing for SCSst and heated surface ratio related sizing for SCS

Figure 6 first indicates that changing the sizing rule for SCS has no effect, as expected, on the heat battery target prices of SCSst vs Boiler. So we only will focus on the differential target price SCSst vs SCS.

When the SCS sizing is heated surface ratio related the collector surface raises in each city (see Table 5) making bigger the CAPEX of the SCS system. Thus, the heat battery target price increases between Figure 5 and Figure 6 in each case with the exception of Davos. In this case, the increase in SCS collector surface area from 3.3 m² to 10 m² enables the SCS to fulfil much more heat demand than previously and this gain totally compensates the CAPEX surplus. In this configuration when investing in a SCSst system the specific heat battery target price decreases from 2207 €/MWh to 1640 €/MWh which means a lower profitability.

In Table 6 we summarize the energetic and environmental impacts of SCSst/SCS in terms of gas savings and avoided CO_2 emissions over the entire technical lifetime of the systems.

	SCSst vs SCS		SCSst vs Boiler	
	gas savings [MWh]	avoided CO_2 emissions [t]	gas savings [MWh]	avoided CO_2 emissions [t]
Athens	38.0	8.9	99.4	23.3
Davos	130.3	30.5	392.2	91.8
Nice	170.5	39.9	298.2	69.8
Paris	186.5	43.6	332.5	77.8
Würzburg	156.5	36.6	298.6	69.9

Table 6 : Gas savings and CO_2 emissions reductions thanks to SCSst/SCS over their technical lifetime (dwelling type 100 kWh/(m².year))

As the heat demand is a key parameter of the battery profitability, we also analysed the impact of the type of dwelling. In other words, we estimated the heat battery target price,

the gas savings and the avoided CO_2 emissions for different dwelling typologies (15, 30, 60 and as previously presented 100 kWh/(m².year) of heat demand).
Figure 7, Figure 8 and Figure 9 present the main results[14] of this sensitivity analysis for the comparison case SCSst vs Boiler.

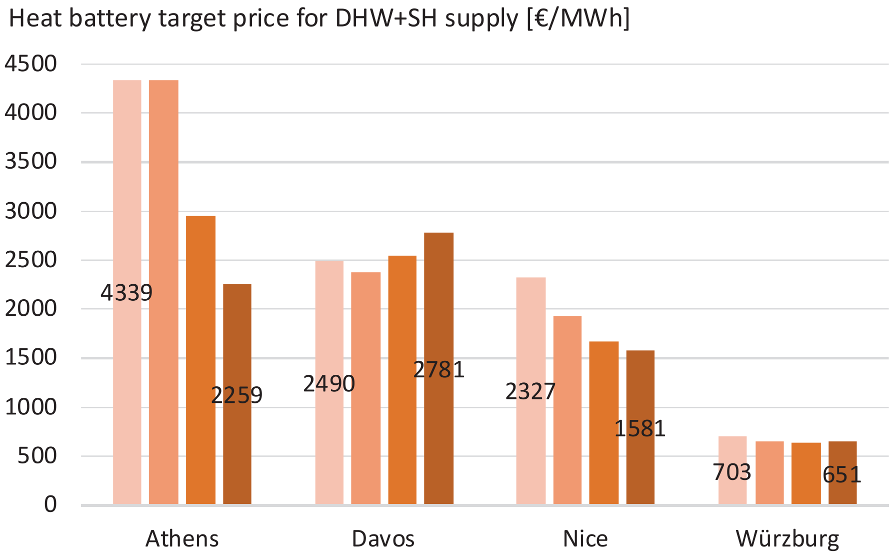

Figure 7 : SCSst heat battery target price for various European cities according to the dwelling type (heat demand in kWh/(m².year)) – Optimistic sizing for SCSst

Interesting to underline in Figure 7 is that the target price differently evolves according to the dwelling type:

- it seems to be a decreasing function of the heat demand for Athens[15] and Nice: the higher is the demand, the higher is the required storage capacity and solar collector area for the dwelling which explains the important role of initial system CAPEX;
- decreasing tendency does not apply for Davos where the heat demand AND the solar potential are high. There seems to be a certain proportionality between per m² heat demand and heat battery target price;
- in the case of Würzburg, the heat battery target price is relatively low (637-703 €/MWh) and remains stable without obvious relation with the dwelling type.

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[14] Results for CO_2 and gas are given over the entire lifetime of the systems

[15] For Athens, as there is no heating demand for both dwelling types 15 and 30 kWh/(m².year) (the heat demand only consists in DHW needs), there is no differences in terms of heat battery target price, gas consumption and CO_2 emissions between both cases

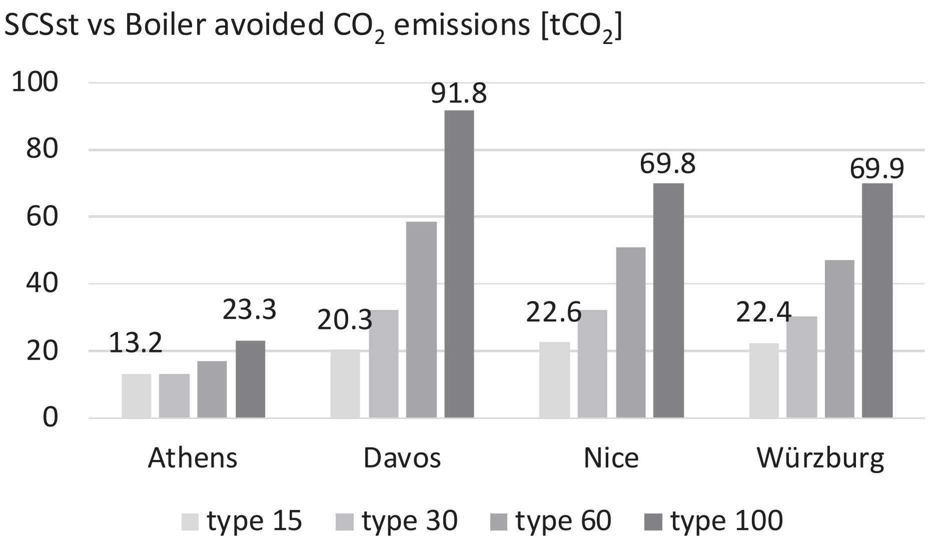

Figure 8 : SCSst vs Boiler avoided CO_2 emissions over the technical lifetime of the systems for different dwelling types (heat demand in kWh/(m².year)) and European cities

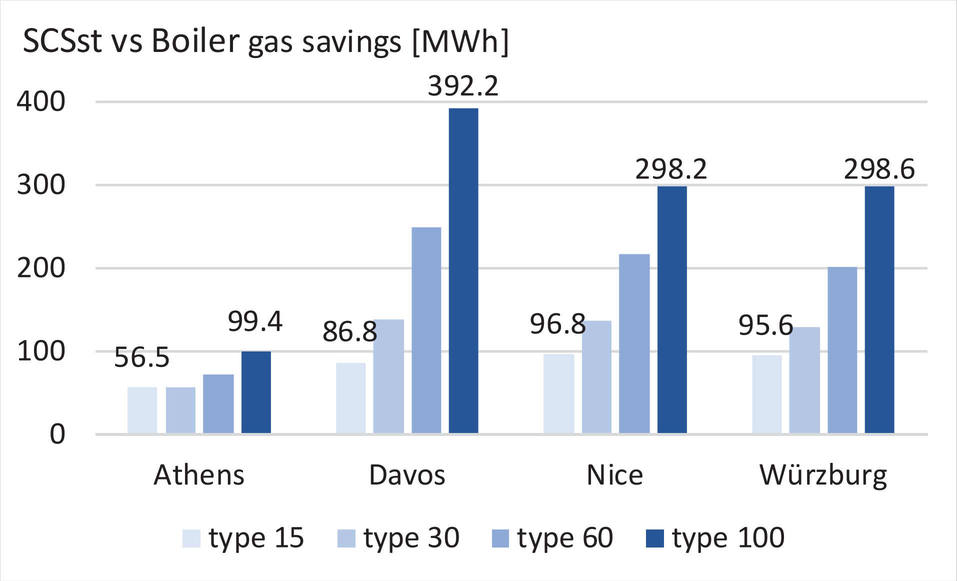

Figure 9 : SCSst vs Boiler gas savings over the technical lifetime of the systems for different dwelling types (heat demand in kWh/(m².year)) and European cities

Contrary to Figure 7, an obvious relationship between dwelling type and gas savings/avoided CO_2 emissions is observable in Figure 8 and Figure 9. The higher is the heat demand, the higher are the gas savings/avoided CO_2 emissions enabled by the SCSst. This was an expected result because the solar+battery system is designed to fulfil 100% of the heat demand. The higher is the demand, the higher will be the theoretical gas consumption from the boiler.

As explained earlier in this report, the optimistic panel collector sizing rule gives favourable results in terms of heat battery target prices. In fact the initial CAPEX of the SCS remains moderate because of the relatively small required collector surface area which is not always representative of the current sizing habits. In an attempt to give more realistic results, we adopted the heated surface ratio related rule for SCS and we present the corresponding results in paragraph 5.2.2.

5.2.2 Heated surface ratio related sizing for SCSst/SCS

In this paragraph, we will study the profitability of a SCSst/SCS when applying the heated surface ratio related rule that is to say that the installed solar collector area is only function of the dwelling heated surface. As the chosen dwelling reference case is an individual housing of 100 m², each system across Europe will be equipped with 10 m² of solar panels.

The first consequence is that this surface may be not enough for SCSst to cover 100% of the heat demand. We remember the reader that Table 5 (second column) contains the minimum theoretical solar collector surface to reach the maximal use of renewable solar energy – 100% solar ratio – for each city. Table 7 gives the solar ratios for SCSst/SCS corresponding to the present sizing rule.

	Solar ratio [%]	
	SCSst	SCS
Athens	232%[16]	91%
Davos	63%	52%
Nice	81%	37%
Paris	48%	28%
Würzburg	51%	31%

Table 7 : Solar ratios related to SCSst/SCS sized with the heated surface ratio related sizing rule – Dwelling type 100 kWh/(m².year)

With the present sizing rule (heated surface ratio related), the initial CAPEX of the SCSst/SCS may be lower than with the optimistic rule (in the case of a decrease of the installed solar collector area) but the savings in OPEX will follow the same trend. Both influences (CAPEX and OPEX) have huge consequences on the heat battery target price as it can be seen in Figure 10.

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[16] The collector surface area for Athens in this case is obviously oversized

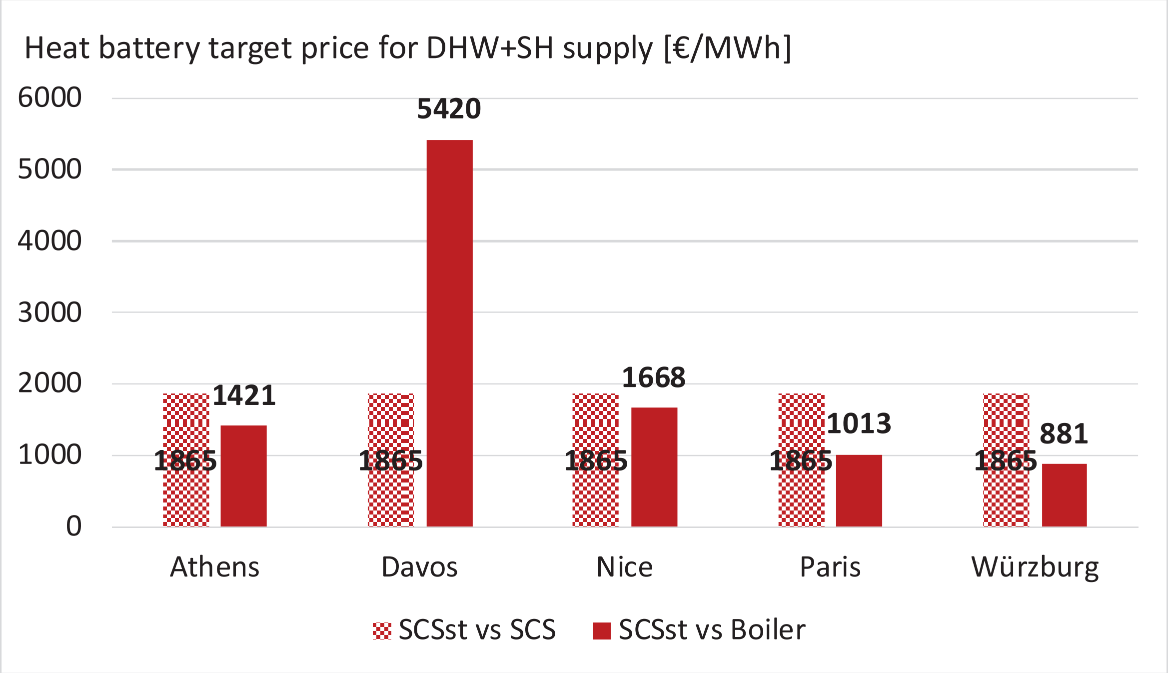

Figure 10 : SCSst heat battery target price for various European cities (dwelling type 100 kWh/(m².year)) – Heated surface ratio related sizing for SCSst/SCS

Two learnings may be drawn from the Figure 10. First of all it can be noticed that the heat battery target price for the comparison SCSst/SCS reaches the same value (1865 €/MWh) for each city. As the systems are all equipped with 10 m² of solar panels, there is no difference between SCSst and SCS in terms of initial CAPEX and solar production for a given city. More interesting is the fact that this target price value is independent from the heat demand.

In fact, 1865 € represents the cost of one avoided MWh of gas consumption discounted over the lifetime of the heat battery with taking into account the recovery of 20% of its Initial CAPEX at the end of its lifetime.

The second learning from Figure 10 is the heat battery target price value reached for Davos in the case SCSst vs Boiler (5420[17] €/MWh) compared with the obtained ones in the other cities (from 881 €/MWh in Würzburg to 1668 €/MWh for Nice). The system panels+battery reaches a higher profitability without reaching 100% solar compared with the case 100% solar ratio (see paragraph 5.2.1 and Figure 5).

According to our modelling and our assumptions it seems to be an optimum for the profitability of the system panels+battery that depends on the heat demand, the available solar irradiation and the targeted solar ratio: it seems that a 100% solar ratio – maximisation of the energy savings – does not necessary correspond with this optimum.

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[17] This target price is greater than the projection of the heat battery costs (5000 €/MWh)

5.3 Cross comparison and analysis

In order to get a global view of the energetic and environmental impacts of DSWHst/DSWH and SCSst/SCS over their technical lifetime, we schematically compiled the data from Table 4 and Table 6 in Figure 11 and Figure 12.

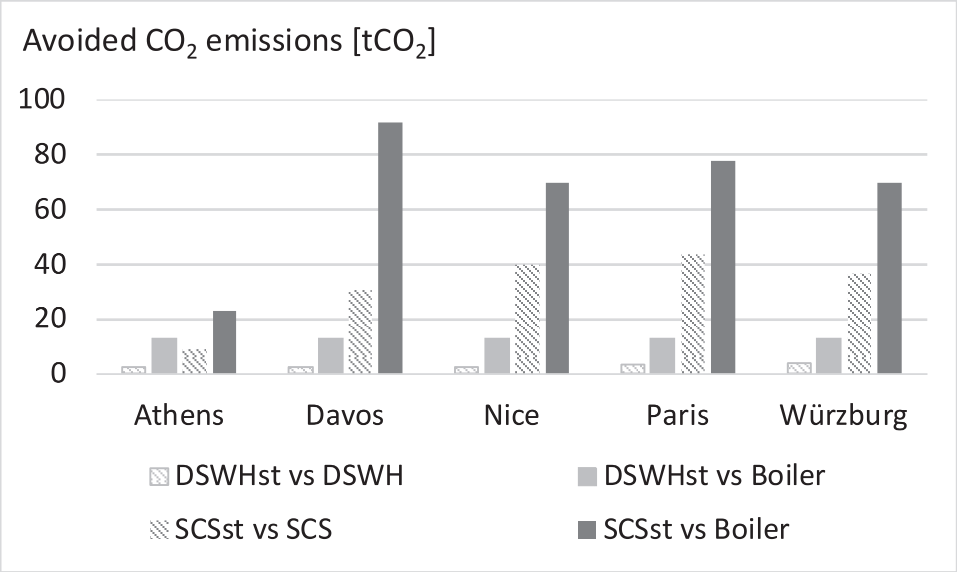

Figure 11 : Avoided CO_2 emissions over the technical lifetime of DSWHst/DSWH and SCSst/SCS (dwelling type 100 kWh/(m².year)) in different European cities

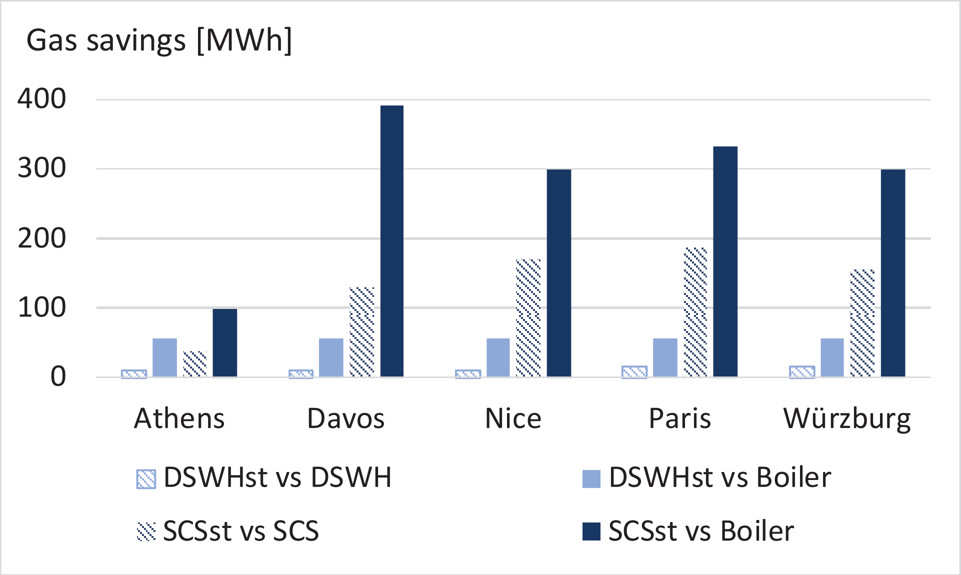

Figure 12 : Gas savings over the technical lifetime of DSWHst/DSWH and SCSst/SCS (dwelling type 100 kWh/(m².year)) in different European cities

As it was previously explained the maximal energetic and environmental gains occur in case of high energy demand. That corresponds to the comparison SCSst vs Boiler. However in the case of Nice where the heat demand is not the highest, the gas savings are relatively high (around 300 MWh). It means a good energy and environmental efficiency of the SCSst system compared to the gas-fired boiler system.

The following tables (Table 8 and Table 9) show the required solar collector areas and the required stored energy quantity depending on the sizing rule for the DHW and DHW+SH supply respectively.

	100% solar ratio sizing (DSWHst)		70% solar ratio sizing (DSWH)
	Panels surface [m²]	Required stored energy quantity [MWh]	Panels surface [m²]
Athens	2.4	0.5	2.3
Davos	2.3	0.5	2.0
Nice	2.4	0.5	2.2
Paris	3.5	0.6	4.35
Würzburg	3.7	0.7	5.2

Table 8: DSWHst and DSWH collector surface area and heat battery sizing depending on the sizing rule

	Optimistic sizing (100% solar ratio – SCSst)		Solar ratio related sizing (70% solar ratio for DHW & 10% solar ratio for SH – SCS)	Heated surface ratio related sizing (SCSst/SCS surface)	
	Panels surface [m²]	Required stored energy quantity [MWh]	Panels surface [m²]	Panels surface [m²]	Required stored energy quantity (for SCSst) [MWh]
Athens	4.3	1.6	2.8	10	6
Davos	16	5.5	3.3	10	1.8
Nice	12.4	7.2	4.8	10	5.5
Paris	20.9	7.9	7.1	10	2.8
Würzburg	19.7	6.7	6.6	10	6.7

Table 9: SCSst and SCS collector surface area and heat battery sizing depending on the sizing rule – Dwelling type 100 kWh/(m².year)

The sizing rules significantly change the required panel surface especially for SCSst/SCS (Table 9). Switching from optimistic to heated surface ratio related rule has for consequence the reduction of the required stored energy quantity with the exception of Athens where the need of SH is very low (the rule switch leads to an increase of panel surface).

With the heated surface ratio related sizing rule, the solar system combined with the heat battery cannot supply the heat demand (cf. Table 7). It is interesting to note that the required stored energy quantity quickly rises with the heat demand. Regarding the CREATE technical annex (AD-04), the heat battery volume for SCSst could reach more than 15 m^3 when remembering that the targeted system battery density is about 2.5m^3/MWh.

The DSWHst heat battery volume requirement (Table 8) corresponds more with the use in individual residential case (0.5 to 0.7 m^3 of required volume for the storage unit).

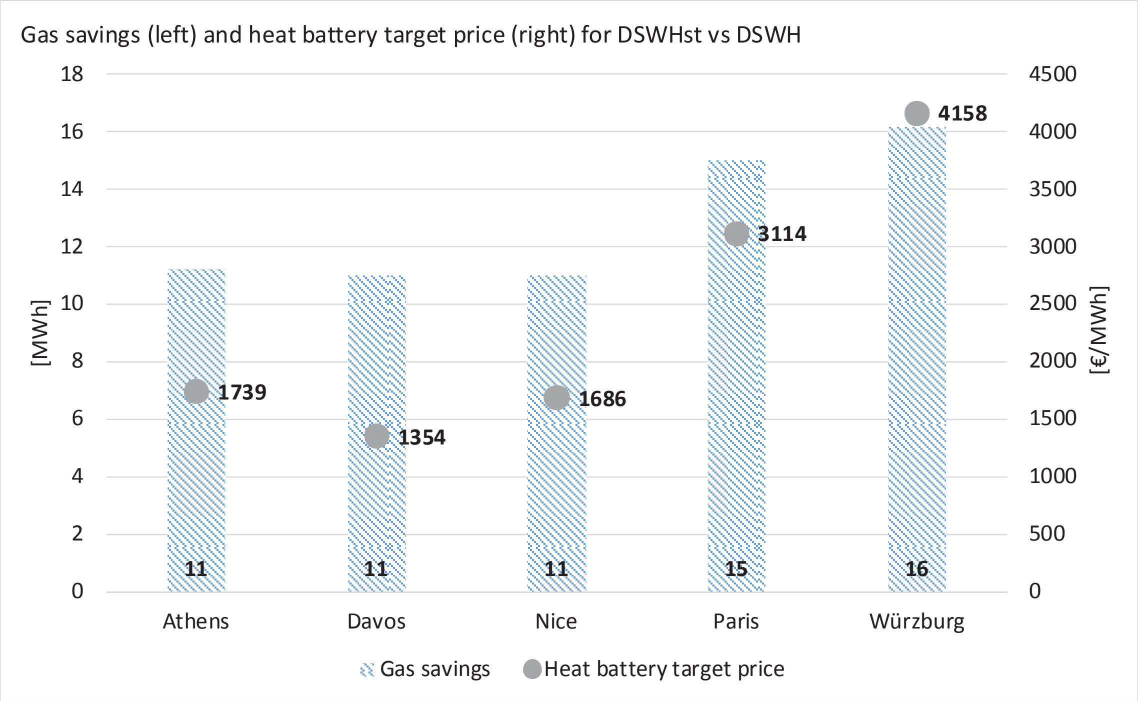

Figure 13 : Gas savings and heat battery target prices for DSWHst vs DSWH in different European cities

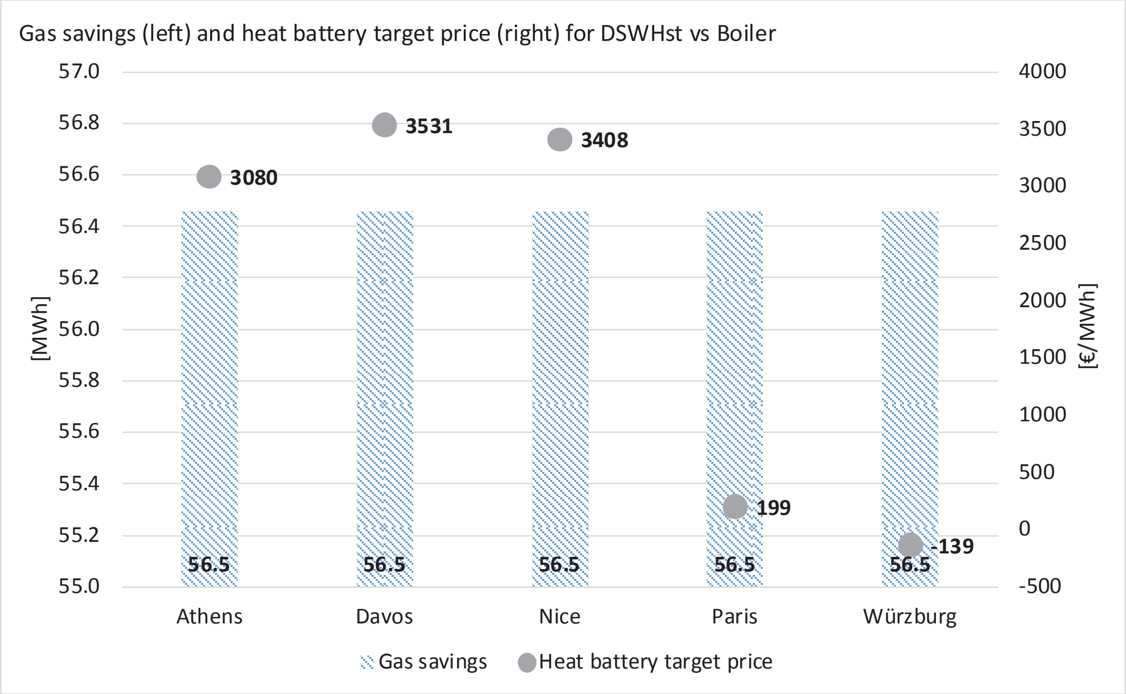

Figure 14 : Gas savings and heat battery target prices for DSWHst vs Boiler in different European cities

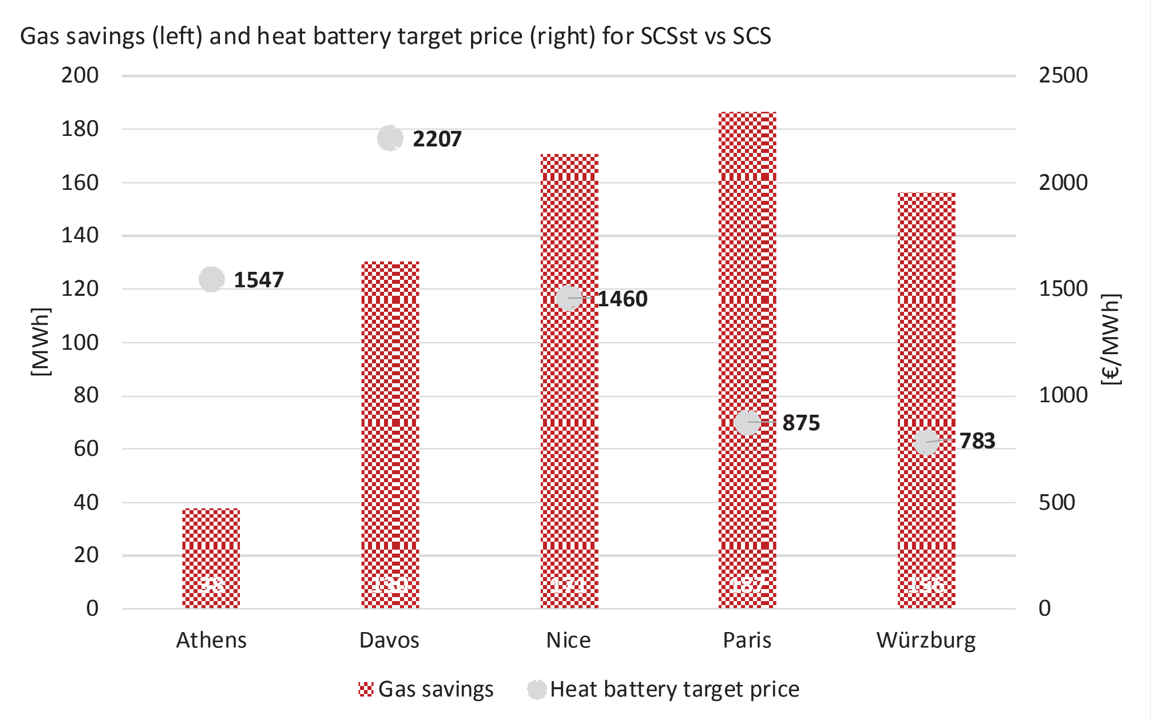

Figure 15 : Gas savings and heat battery target prices for SCSst vs SCS in different European cities – Dwelling type 100 kWh/(m².year)

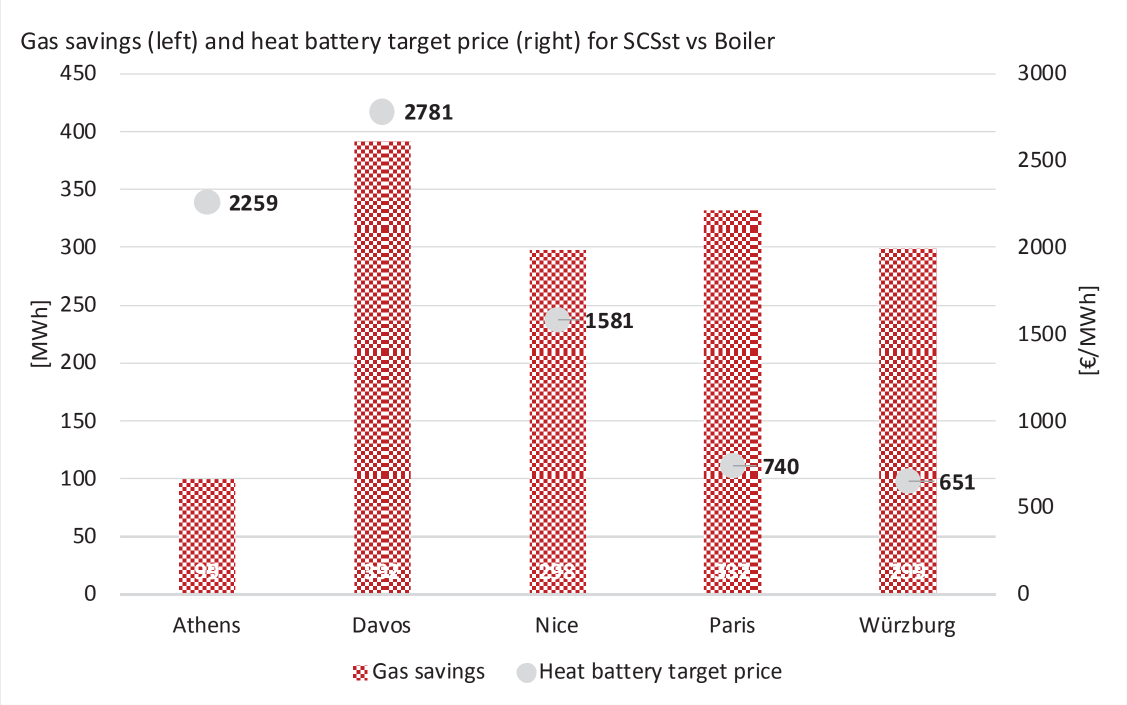

Figure 16 : Gas savings and heat battery target prices for SCSst vs Boiler in different European cities – Dwelling type 100 kWh/(m².year)

The previous four figures give a summary in terms of gas savings and heat battery target prices for the four comparison cases: DSWHst vs DSWH (Figure 13), DSWHst vs Boiler

(Figure 14), SCSst vs SCS (Figure 15) and SCSst vs Boiler (Figure 16). Apparently, there is no obvious relationship between the heat battery target price and the savings in gas consumption. In fact, the target price on top of including the savings in OPEX is a complex function of the heat demand, the solar irradiation, the gas price… Easy causal relationship is not obvious and local optima (see the case of Davos in Figure 10) may exist.

6. Preliminary lead geographical market analysis

In the following part of the paper the most potential geographical markets for thermal energy storage are analysed. The preliminary market survey conducted by FENIX assessed several countries to find the best market opportunity. The final lead countries were selected based on the level of solar thermal markets as the demand for CREATE heat battery is derived from this sector. The largest producer is Germany, followed by Greece, Austria, Italy, Spain, France and Poland. Selected markets were further analysed to determine the future market potential for the CREATE battery. For each country several aspects essential for assessing the heat battery demand were investigated:

- Basic country figures – including total square km area, population and changes in population, level of GDP, disposable income of households and gross energy consumption.
- Production of renewable energy – primary production, the share in gross energy consumption and 2020' targets and share of solar energy within renewable energy.
- Solar thermal market – current situation and future predictions.
- Irradiation and solar energy potential map – assessing the most potential regions within the country in terms of solar radiation.
- Construction sector – current situation, structure and future evolution particularly of the building sector as this sector is the main end-user for the application of the heat battery. The analysis covers various types of buildings and comprises of energy consumption of buildings, number of buildings, age of buildings, energy consumption by end-use and space heating and water heating consumption for each building sector in particular country.

Finally, potential thermal storage market for each country was deduced from investigations.

Methodology and approach used to analyse the lead geographical markets

Due to availability of information, calculations are based on 2012 data. Moreover, it is supposed that an average consumption per m² is not radically changing year to year. In case of missing building data for particular year, the data were adjusted (by statistics already provided) based on those latest available.

Information, data and figures used during the investigation for calculations are extracted from the following sources:

- Data about solar thermal market are from ESTIF: Solar Thermal Markets in Europe. 2012-2014;
- Data on energy consumption come from ODYSSEE database and EUROSTAT. 2012;
- Share of buildings in final energy consumption across the European member states are according to ODYSSEE and MURE Databases. 2012;
- Data about the structure of building stock goes from BPIE – Data Hub for the Energy Performance of Buildings. 2008-2014;

- The size of dwelling is based on data provided by ENTRANZE mapping.2008. Solar Radiation Maps are available at GeoModel Solar. 2015;

A reasonable annual storage potential of CREATE's heat battery was considered 7.5 GJ – 2,083 kWh (cf. AD-04 p. 20[18]). This number was taken as preliminary input and calculations can be adjusted in case of any changes during the further project investigations.

As the CREATE solution is intended for the future, evolution predictions of the market were necessary. Regarding the fact that the primary source of thermal energy for CREATE system is solar heat the size of potential thermal storage market was deduced from the totally installed and operating solar thermal capacity in particular country.

The estimations about future trends and market penetration was concluded based on development of solar thermal market, building sector, RES policy and targets and predictions presented by Full Research, Development and Policy' (RDP) scenario.

Through all the calculations conservative approach was applied.

6.1 Main results of the analysis

6.1.1 Identification of potential markets

The lead geographical markets were identified according to value of solar thermal market.

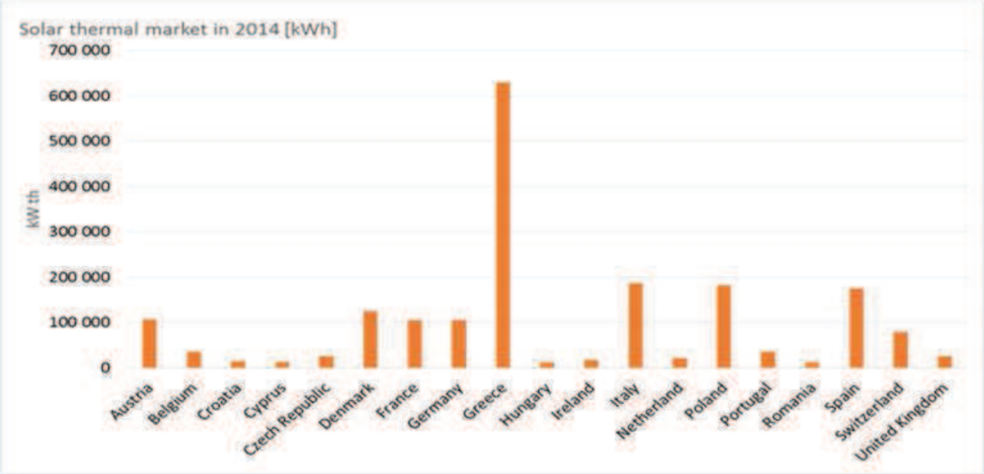

Figure 17: Market in 2014 (newly installed capacity), kW (th)

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[18] AD-024 p. 20 : "With a maximum of 2.5 m^3 stabilized thermochemical materials with an energy density of minimally 1.5 GJ/m^3 and a conservatively estimated two storage use-cycles per year, the total amount of thermal energy storage per year is 11.25 GJ (3125 kWh) per system".
This sentence may contain a mistake since the targeted storage density on a system level is 1.5GJ/m^3, the system volume is 2,5m^3 and the annual number of cycles is 2, this leads to a maximum stored energy of 2.5 m^3 × 1.5 GJ/m^3 × 2 cycles/year = 7.5GJ/year (what we indicated in this report) and not 11.25 GJ

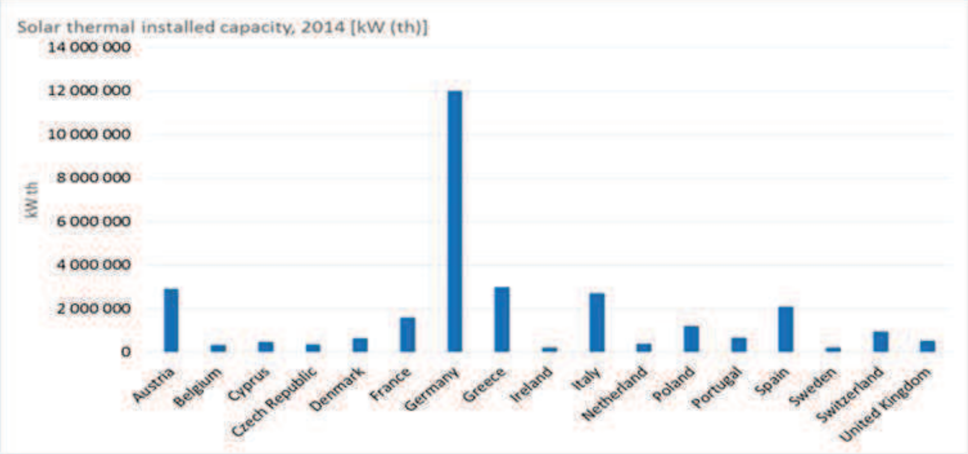

Figure 18 : Total installed capacity, kW (th), 2014

Germany has the biggest potential in terms of total solar thermal capacity installed. Despite the relatively small land area compare to other European countries, Greece takes the second place, followed by Italy, Austria, Spain, France and Poland. The emerging market is registered in Spain and Greece (see newly installed). Even though Poland shows slight decline in newly installed capacity, generally yearly increments are relatively high compare to others (see newly installed).

Background figures

Country	Population 2050 (*1000)	Change 2010-2050 (%)	Area sq km	Econom. Indicators				Energy consumption (mill. t of oil eq.)	Renewables			
				GDP growth rate	GDP (billion EUR)	GDP per capita in PPS (EU=100)	Disp. income of HH (per cap in PPS)		th. Toe	% of final en. consumption	2020' targets	% solar energy
Germany	74,491	-9.0%	357 021	1.6	2904	124	26,736	324.3	33,680	12.4%	18%	9.6%
Greece	11,445	1.0%	131 940	0.7	179	72	N/A	24.4	2,487	15.0%	18%	20.1%
Spain	53,229	14.0%	504 782	1.4	1058	93	18,340	118.8	17,377	15.4%	20%	15.4%
France	71,044	14.0%	547 030	0.2	2142	107	24,283	259.3	23,073	14.2%	23%	2.1%
Italy	61,240	2.0%	301 203	-0.4	1616	97	20,733	160	23,500	16.7%	17%	8.6%
Austria	9,127	9.0%	83 858	0.4	329	128	25,850	33.8	9,466	32.6%	34%	2.4%
Poland	33,275	-13.0%	312 685	3.3	413	68	N/A	98.2	8,512	11.3%	15%	0.2%

Table 10: Background figures for key potential markets

Despite the current struggling situation, renewables are expected to growth rapidly. Solar heat is a promising sector – it could provide up to **6.3%** of the 2020' target of renewable energy in EU and further growth is predicted – **by 2050 almost 20%.**

Solar thermal market

Generally, solar thermal market in the EU in not in good conditions. Literature describes the situation in the market as that the potential of the industry is not really fulfilled and expectations from previous years are not on the way to be realized. In particular, the EU is not on track towards 2020 as the current performance of the sector is not strong enough to achieve the indicative solar thermal targets proposed by the EU Member States in the National Renewable Energy Action Plans. The market results reported from 2014 reflects previous year decreasing trend. Even if some countries performed better than expected, the whole market continues to decline, mainly due to sharp slowdown in the construction sector in the main markets, particularly in Germany.

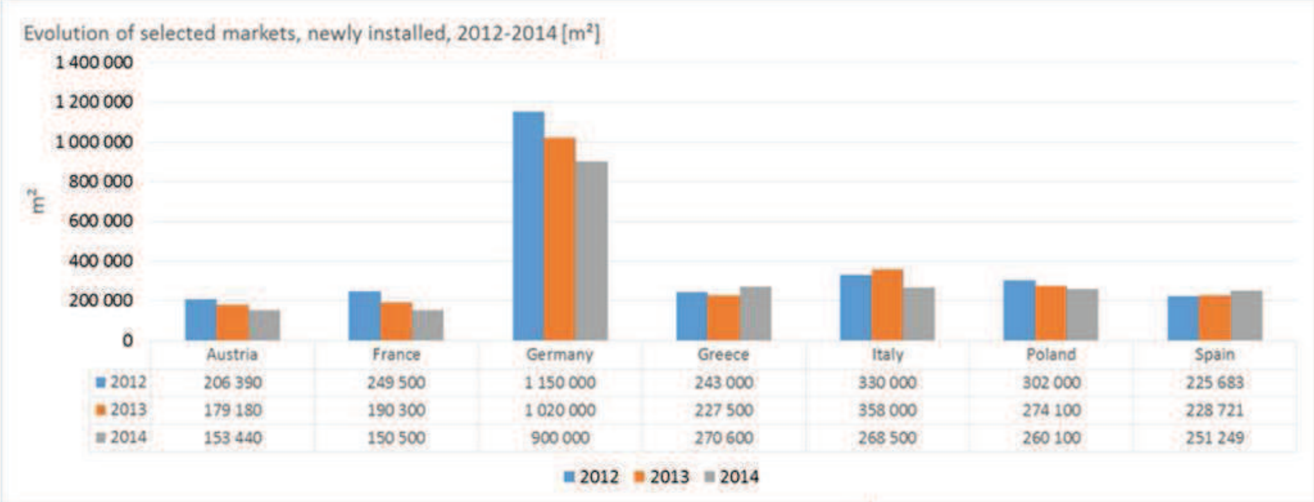

Figure 19 : Evolution of selected markets (newly installed), m^2, 2012-2014

Heat demand

As the CREATE solution is aimed on building sector where around 80% of consumed energy is within space heating and domestic hot water, the development of heat demand is a fundamental presumption for assessment of the thermal energy storage demand and generally production of renewable energy. At present, a substantial part (about 40%) of the total energy consumed in Europe is used for the generation of heat for either domestic or industrial purposes. The vast majority of this energy is produced through the combustion of fossil fuels such as oil, gas and coal – with a damaging environmental impact arising primarily from the associated greenhouse gas emissions and also from the resource extraction process. The large proportion of heat in total energy demand explains the substantial contribution that renewable heat – and thus solar heat – could make in meeting climate change and energy security objectives => the opportunity for CREATE project.
As the CREATE system will be capable of using and delivering heat as <100°C and because the prime source of thermal energy is considered solar thermal heat, the demand for high temperatures is not particularly relevant. The key sectors are low-industries, households and services with demand for low temperature heat. However, industries requiring heat above 500°C (such as cement and glass) pose a particular challenge to renewable energy technologies.
The overall future development of heat demand is under the influences of increasing energy efficiency. Therefore, the gradual decrease is expected from total of 550 to 325 Mtoe (23,000 – 13,600 PJ) in the EU. The figure below shows heat demand map across Europe.

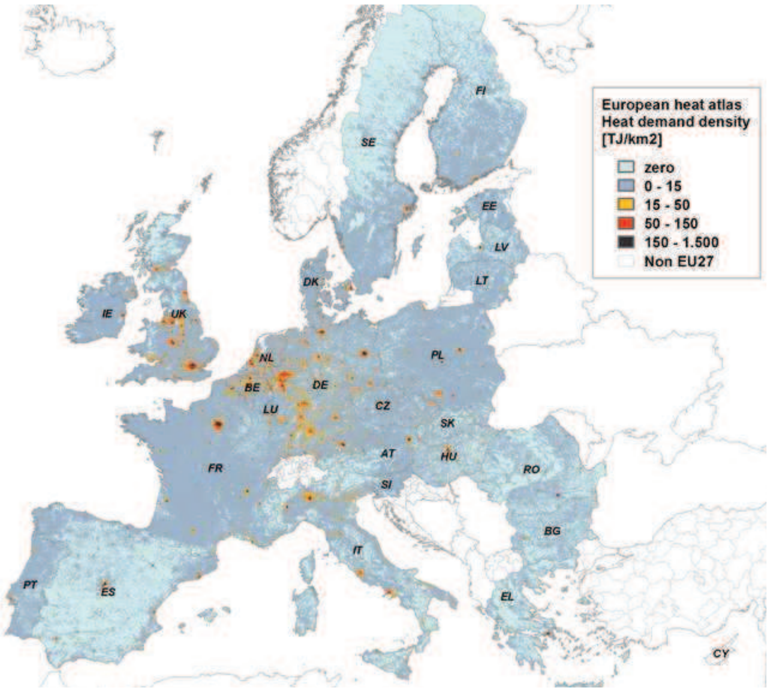

Figure 20: Heat demand density in European countries

Construction and building sector

After a long struggling period started in 2008, the construction sector is predicted to look positive. After the 2008 almost all member states experienced downturn, but from 2014 GDP for nearly all EU countries is growing. It is therefore unsurprising, that the future of the European construction market looks bright. Detailed description of future for different EU regions is a part of the analysis. As the most developing segment is supposed residential sector with dominance of nearly-zero and very-low energy buildings.

Country	Construction output prediction - % change in real time							
	Billion euro	2014	2015	2016	2017	2018	2019	2020
Germany	285	2.4	1.8	0.2	-0.4	0.3	0.39	0.48
France	200	-2.8	-0.4	1.8	1.6	1.66	2.13	2.47
Italy	163	-2.2	1.1	2.5	2.8	3.72	5.18	7.2
Spain	63	-2.4	1.8	3.6	5	6.5	7.93	9.04
Poland	44	4.9	7.1	6.2	6.7	7.5	8.78	10.45
Austria	32	1.7	1	1.3	1.5	1.91	2.63	3.52

Table 11: Construction output and 2020' prediction for selected countries

There are about 25 billion m^2 of useful floor space in European countries (in 2012). The residential sector is the biggest segment with an EU floor space of 75% of the building stock (25% is non-residential sector). The analysis indicates that 64% of the residential building floor area is associated with single family houses and 36% with apartments (multifamily). The split between the two main types of residential properties varies significantly from country to country (shown in the analysis).

Energy consumption of buildings

The European average consumption of energy in building is 40%. This number varies across the member states as is presented in the table:

Country	Consumption of buildings	Residential	Non-residential
Germany	43.0%	62.8%	37.2%
Greece	38.0%	64.5%	35.5%
Spain	31.0%	58.1%	41.9%
France	45.0%	63.3%	36.7%
Italy	42.5%	68.2%	31.8%
Austria	33.0%	71.2%	28.8%
Poland	45.0%	71.1%	28.9%

Table 12: Share of building in energy consumption, 2012, selected countries

Similarly, energy consumption by end use in residential and non-residential buildings differs in selected countries, to some extend influenced by different weather conditions.

Country	**Germany**				**Greece**				**Austria**			
Sector	Residen.		Non-resid.		Residen.		Non-resid.		Residen.		Non-resid.	
Total building floor m2	**4,689,375,000**		**2,268,940,000**		**456,000,000**		**213,470,000**		**362,000,000**		**154,000,000**	
Space heating kWh	142.3	67%	135.5	52%	43.5	25%	52.5	25%	165.1	65%	60.9	25%
Water heating kWh	36.6	17%	23.5	9%	43.5	25%	31.3	15%	31.8	12%	36.5	15%
Cooking kWh	10.8	5%	13	5%	33.1	19%	16.7	8%	7.6	3%	19.5	8%
Appliances kWh	20.3	10%	0	0%	29.6	17%	0	0%	39.4	15%	0	0%
Lighting kWh	2.7	1%	36.5	14%	15.7	9%	41.8	20%	10.2	4%	48.7	20%
Cooling kWh	0.0	0%	10.4	4%	8.7	5%	33.4	16%	0.0	0%	39	16%
Other kWh	0.0	0%	41.7	16%	0.0	0%	33.4	16%	0.0	0%	35	15%
Total kWh	**212.8**		**260.6**		**174.0**		**209.1**		**254.1**		**239.6**	
Country	**Italy**				**France**				**Spain**			
Sector	Residen.		Non-resid.		Residen.		Non-resid.		Residen.		Non-resid.	
Total building floor m2	**3,420,000,000**		**384,800,000**		**3,689,000,000**		**1,550,570,000**		**1,809,000,000**		**402,900,000**	
Space heating kWh	121.1	58%	120.8	42%	153.1	66%	144.8	48%	84.4	52%	106.4	41%
Water heating kWh	18.8	9%	34.5	12%	23.2	10%	33.2	11%	37.4	23%	34.5	13%
Cooking kWh	14.6	7%	23	8%	16.2	7%	24.1	8%	11.4	7%	20.1	8%
Appliances kWh	45.9	22%	0	0%	34.8	15%	0	0%	21.1	13%	0	0%
Lighting kWh	0.0	0%	43.1	15%	4.6	2%	57.3	19%	6.5	4%	60.4	23%
Cooling kWh	8.4	4%	31.6	11%	0.0	0%	15.1	5%	1.6	1%	34.5	13%
Other kWh		0%	34.5	12%		0%	27.1	9%		0%	31.6	12%
Total kWh	**208.8**		**287.5**		**232.0**		**301.6**		**162.4**		**287.5**	
Country	**Poland**											
Sector	Residen.		Non-resid.									
Total building floor m2	**1,392,400,000**		**508,344,000**									
Space heating kWh	168.4	66%	145	50%								
Water heating kWh	43.4	17%	31.9	11%								
Cooking kWh	12.8	5%	14.5	5%								
Appliances kWh	25.5	10%	0	0%								
Lighting kWh	5.1	2%	55.1	19%								
Cooling kWh	0.0	0%	5.8	2%								
Other kWh		0%	37.7	13%								
Total kWh	**255.2**		**290.0**									

Table 13: Energy consumption by end-use in buildings, selected countries, 2012

6.1.2 Thermal energy storage market potential in Europe

Total Europe

The overall European market is estimated to grow gradually. The grow is supported by developing solar thermal installations, inclination to renewable sources and increasing price of energy that stimulate owners of buildings to employ energy efficient solutions.

Total Europe	2014	2020	2030	2050
Market development	15%	15.0%	20.0%	40.0%
Installed capacity (kWth)	31,840,346	36,616,398	43,939,677	61,515,548
Potential thermal storage market (GWh)	24,000	27,600	33,120	46,368
Energy price development	0%	10%	25%	45%
Energy price (EUR/GJ)	18.0	19.8	22.5	26.1
Potential thermal storage market	€ 1,555,200,000	€ 1,967,328,000	€ 2,682,720,000	€ 4,356,737,280

Table 14: Total European thermal storage market projection

In the horizon of next 35 years the total estimated number of heat batteries demanded is 2,431,874.

		2020		2030		2050	
	Users preferences	Market penetration	Number of batteries	Market penetration	Number of batteries	Market penetration	Number of batteries
SFB	49%	8%	346,214	10%	519,322	15%	1,090,575
MFB	24%	2%	42,394	3%	76,308	4%	142,442
Non-Resid.	15%	3%	39,744	4%	63,590	5%	111,283
Industry	10%	0%	-	0%	-	0%	-
Plants	2%	0%	-	0%	-	0%	-
Total	100%		428,352		659,220		1,344,301

Table 15: Estimation of potential market size in the EU

Selected countries

Market 2012	**Germany**	**Greece**	**Austria**	**Italy**
Total thermal energy demand (GWh)	1,077,722	57,500	86,388	502,500
Storage potential (GWh)	240,678	24,715	15,819	117,313
Potential average savings	22%	43%	18%	23%
Potential thermal storage market (GWh)	8,319	1,999	2,054	1,760
Potential thermal storage market	€ 539,082,926	€ 129,520,767	€ 133,096,466	€ 114,064,717
Market 2012	**Spain**	**France**	**Poland**	
Total thermal energy demand (GWh)	276,944	926,389	384,722	
Storage potential (GWh)	75,063	188,408	78,731	
Potential average savings	27%	20%	20%	
Potential thermal storage market (GWh)	1,188	958	559	
Potential thermal storage market	€ 85,510,930	€ 68,954,808	€ 40,267,627	

Table 16: Thermal energy storage potentials in selected countries, current state

Storage potential means total energy that could be saved by storages (counting 2.083 kWh per battery). Potential thermal storage market is derived from capacity of solar thermal collectors installed in the particular country (in financial means current energy prices were used) and it refers to total market size. Predictions for the future are summary of detailed study that is part of the analysis. Estimation of market size expressed in number of batteries present expected market size of CREATE.

Germany	**2014**	**2020**	**2030**	**2050**
Total thermal energy demand (TWh)	970	873	786	707
Storage potential (TWh)	241	241	241	241
Potential average savings	24.8%	27.6%	30.6%	34.0%
Potential thermal storage market (GWh)	9,332	10,732	12,878	18,030
Potential thermal storage market	€ 604,728,846	€ 764,981,990	€ 1,084,883,549	€ 1,869,337,808
Estimation of market size (num.of batt.)	-	166,562	256,333	522,722
Greece	**2014**	**2020**	**2030**	**2050**
Total thermal energy demand (GWh)	51,750	46,575	41,918	37,726
Storage potential (GWh)	24,715	24,715	24,715	24,715
Potential average savings	47.8%	53.1%	59.0%	65.5%
Potential thermal storage market (GWh)	2,262	2,827	3,816	5,725
Potential thermal storage market	€ 146,551,097	€ 201,507,758	€ 309,131,220	€ 537,888,323
Estimation of market size (num.of batt.)	-	43,875	75,962	165,969
Austria	**2014**	**2020**	**2030**	**2050**
Total thermal energy demand (GWh)	77,749	69,974	62,977	56,679
Storage potential (GWh)	15,819	15,819	15,819	15,819
Potential average savings (%)	20%	23%	25%	28%
Potential thermal storage market (GWh)	2,229	2,564	3,077	4,000
Potential thermal storage market (EUR)	€ 144,468,939	€ 182,753,208	€ 249,208,920	€ 375,807,052
Estimation of market size (num.of batt.)	-	39,791	61,238	115,958
Spain	**2014**	**2020**	**2030**	**2050**
Total thermal energy demand (GWh)	249,250	224,325	201,892	181,703
Storage potential (GWh)	75,063	75,063	75,063	75,063
Potential average savings (%)	30%	33%	37%	41%
Potential thermal storage market (GWh)	1,409	1,832	2,473	3,463
Potential thermal storage market (EUR)	€ 101,465,542	€ 145,095,725	€ 222,590,032	€ 361,486,213
Estimation of market size (num.of batt.)	-	32,495	56,259	114,726
Italy	**2014**	**2020**	**2030**	**2050**
Total thermal energy demand (GWh)	452,250	407,025	366,323	329,690
Storage potential (GWh)	117,313	117,313	117,313	117,313
Potential average savings (%)	26%	29%	32%	36%
Potential thermal storage market (GWh)	2,091	2,718	3,669	5,137
Potential thermal storage market (EUR)	€ 114,064,717	€ 125,471,189	€ 156,838,986	€ 227,416,530
Estimation of market size (num.of batt.)	-	42,184	73,036	148,936
France	**2014**	**2020**	**2030**	**2050**
Total thermal energy demand (GWh)	833,750	750,375	675,338	607,804
Storage potential (GWh)	188,408	188,408	188,408	188,408
Potential average savings (%)	23%	25%	28%	31%
Potential thermal storage market (GWh)	1,115	1,394	1,603	1,923
Potential thermal storage market (EUR)	€ 80,283,288	€ 110,389,522	€ 144,259,034	€ 200,808,575
Estimation of market size (num.of batt.)	-	24,722	36,461	63,731
Poland	**2014**	**2020**	**2030**	**2050**
Total thermal energy demand (GWh)	346,250	311,625	280,462	252,416
Storage potential (GWh)	78,731	78,731	78,731	78,731
Potential average savings (%)	23%	25%	28%	31%
Potential thermal storage market (GWh)	806	1,209	1,813	2,720
Potential thermal storage market (EUR)	€ 58,024,886	€ 95,741,062	€ 163,194,993	€ 283,959,287
Estimation of market size (num.of batt.)	-	21,442	41,247	90,121

Table 17: Prediction of thermal energy storage market in selected countries

6.2 Summary of preliminary analysis

Undoubtedly, thermal energy storages have a huge potential across Europe, bringing many benefits such as reduction of CO_2 emissions and consumption of oil and gas (and other fossil fuels), reduction of energy imported, stability of electricity grid, creating new jobs and business opportunities and overall energy efficiency.

To conclude, the European Solar Thermal market despite the overall disappointing scenario of several last years is still promised to expand rapidly and be a crucial player in terms of renewable sources of energy and especially renewable heat.

Thermal energy storage based on thermochemical materials is being currently under the research and development, and is promising solution for the future compact storages.

European building sector appears to be in favourable shapes for heat battery applications thanks to regeneration patterns in new constructions and also a substantial share of the building stock is older than 50 years with many buildings in use that are hundreds of years old. More than 40% of the residential buildings have been constructed before the 1960s when energy building regulations were very limited and thus have a big potential to install energy storage or renewable technologies.

Naturally, there are differences between the countries:

Germany's solar thermal energy industry is among the world leaders. However, latest years revealed that solar thermal market potential have not been fully employed. Moreover, the volume of newly installed systems has been decreasing last years and does not reach previous prediction presenting the trend as increasing. Construction sector underperforms comparing to other European market and its development is not really promising with increase during last 5 years in average of 0.74%. However, to reach 2020 and 2050's target about share of renewable energy German's solar thermal market is highly possible to increase. To conclude, Germany is supposed to have a substantial potential for CREATE system, mainly due to large volume of buildings and strong and stable country's economy.

Even if the **Greek** economy and land area is incomparably smaller than Germany, solar thermal market here is highly established and present an important share in total EU's installed capacity. Moreover, the annual evolution of newly installed capacity is positive and one of the biggest in European countries. Large share of thermal energy savings (49,2% and 39%) means a considerable potential for thermal storage systems.

Austria presents the third biggest solar thermal market in Europe in terms of total installed capacity, but the evolution of newly installed capacity is not on a good track. With annual decrease of 14,4% and only 1% increase in total installed capacity, we suppose Austria to hardly follow future expectations about solar thermal market.

Italy is another struggling country already meeting 2020' renewable targets but with relatively positive construction outlook.

Spanish market is said to be finally stabilised, thus further growth can be expected, particularly in the area of Andalusia.

In spite of **French** importance in the EU, land area and economic results French market does not seem to have good potential. Solar thermal market is expected to suffer again in the next years until some thermal regulations or EnergyPlan are fulfilled.

On the other hand **Poland** is one of the most developing market with favourable potential in terms of solar thermal applications.

7. Conclusion and Perspectives

Evaluating the economic potential of a heat battery installed in a dwelling in Europe constituted the first operational part of the CREATE project. In order to carry out such a study, EDF created an excel tool able to technically represent the storage system with the solar panels and to financially analyse it (cost-benefit analysis) over its technical lifetime.

Assumptions and cases studies were defined by EDF and were reviewed and validated by the CREATE project's partners throughout the Task 2.1 timeline. Input data came from either the project's partners AEE and VAILLANT or by EDF. FENIX provided the preliminary market analysis. Results as conclusions and recommendations were discussed and validated during the project workshops and other exchanges.

This study proves that the heat battery has difficulties to find its profitability while only saving operating fuel expenditures because the calculated target prices are relatively low compared with the projections of the system costs. A single case leads to a target price greater than 5000 €/MWh.
In some cases, this price reaches negative value revealing the fact that the OPEX savings value is not sufficient to justify the installation of such a system in an individual dwelling.

These findings are directly dependent on the chosen assumptions. Further analyses could be carried out to test the sensitivity of the results to e. g. the targeted solar ratio (100% may not be the optimum), the discount rate or even the technical lifetime.

As previously said, results of T 2.1 will be directly used in T 2.3 ("Business case and exploitation models for heat storage systems"). So according to our results, we recommend the partners working on T 2.3 to develop and define extra values for the storage system so that it would become profitable according to the individual client point of view.

Appendix 1 (below attached) provides some indications of material costs that can be utilized in task 4.1 "Formulation and analysis of optimal material/stabilizer combination", connected to D 4.1 "Report on most promising TCM salt/stabilisers composite materials" due within M12 (30-09-2016)

8. List of figures

9. List of tables

10. APPENDIX 1

Aim of this appendix is to define a possible target price for the material (a salt) utilized as a core component in the heat battery developed within CREATE project.

According to the calculation developed within this document a target range of the whole unit could be 1500-3000 €/MWh, assuming a thermal battery ready to be sold in the market, hence with a TRL equal to 9.

The range 1500-3000 €/MWh has been derived from Figure 5 of the present deliverable and it is recalled here for convenience (Figure 21):

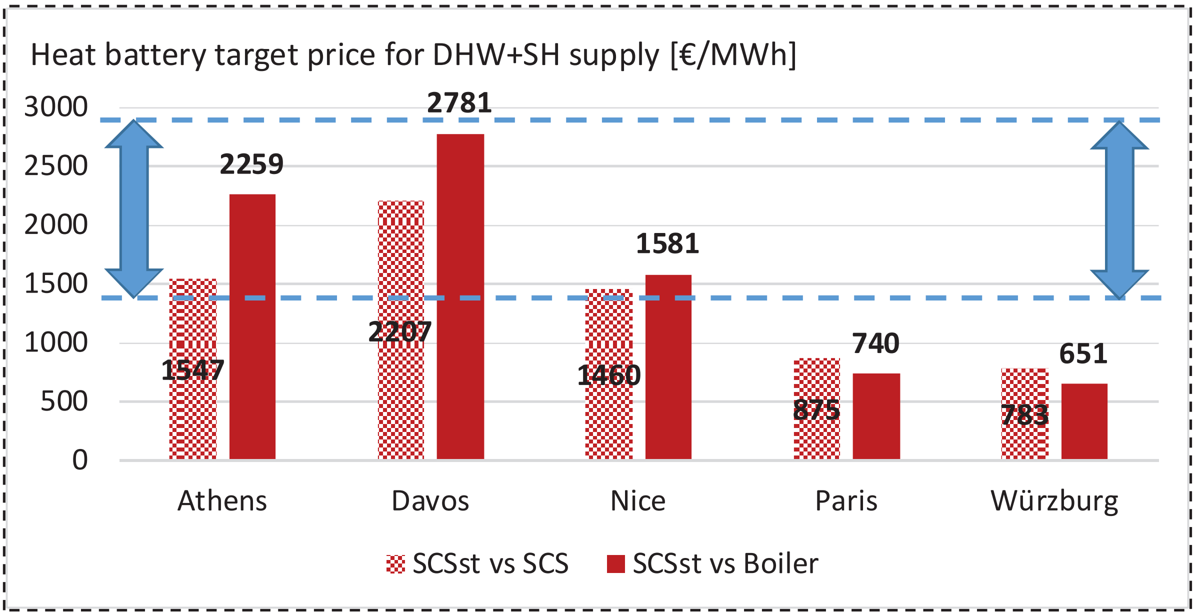

Figure 21 : Range of target prices for SCSst heat battery utilized in different European cities (dwelling type 100 kWh/(m².year)) – Optimistic sizing for SCSst and solar ratio related sizing for SCS (from Figure 5)

Two scenarios have been defined: scenario 1 (conservative) and scenario 2 (favourable). Scenario 1 foresees a conservative budget allocation to material, with a higher margin for the unit reseller and transport. Scenario 2 assumes a favourable budget allocation to material, with lower margin for transport and reseller, lower overall margins for the manufacturer. Each scenario assumes a range for the material cost per unit (between 20% and 30%).

The calculations in this appendix 1 have been performed assuming 1 MWh of heat stored and release per year (hence 1 cycle per year). In case 2 cycles are performed per year, the quantity of salts and the volumes of the system should be divided by two.

The following Table 18 presents the assumptions and the results.

			Scenario 1				Scenario 2			
1.1	**price to market (TRL 9)**	1500-3000	**1500**		**3000**		**1500**		**3000**	
1.2	reseller margin + transport	30%	30%				25%			
1.3	price EXW	[Euro]	**1050**		**2100**		**1125**		**2250**	
1.4	margin	20%-30%	20%	30%	20%	30%	15%	25%	15%	25%
1.5	overall unit costs	[Euro]	**840**	**735**	**1680**	**1470**	**956,3**	**843,8**	**1912,5**	**1687,5**
1.6	material cost (salt)	20%-30%	20%	30%	20%	30%	25%	35%	25%	35%
1.7	material cost per unit	[Euro]	**168**	**220,5**	**336**	**441**	**239,1**	**295,3**	**478,1**	**590,6**
1.8	other costs	80%70%	80%	70%	80%	70%	75%	65%	75%	65%
1.9	other costs	[Euro]	**672**	**514,5**	**1344**	**1029**	**717,2**	**548,4**	**1434,4**	**1096,9**
1.10	*depreciation*	*15%*	*15%*				*15%*			
1.11			**100,8**	**77,2**	**201,6**	**154,4**	**107,6**	**82,3**	**215,2**	**164,5**
1.12	*Labour*	*45%*	*45%*				*45%*			
1.13			**302,4**	**231,5**	**604,8**	**463,1**	**322,7**	**246,8**	**645,5**	**493,6**
1.14	*Energy*	*10%*	*10%*				*10%*			
1.15			**67,2**	**51,45**	**134,4**	**102,9**	**71,7**	**54,8**	**143,4**	**109,7**
1.16	*other (materials & costs) (steel, welding, plastics, etc.)*	*30%*	*30%*				*30%*			
1.17			**201,6**	**154,35**	**403,2**	**308,7**	**215,2**	**164,5**	**430,3**	**329,1**

Table 18: Scenario 1 and Scenario 2: assumptions and results

Price EXW (row 1.3) is the selling price of the manufacturer.
The two scenarios assume two different range of margin for the manufacturer (row 1.4) (20-30%) and (15-25%), hence enabling a lower or higher budget for the overall unit cost (row 1.5).
The two scenarios assume also two different range of material cost allocated, i. e. 20-30% and 25-35% (row 1.6), then allowing different range for "other costs" range for the unit, i. e. 80-70% and 65-75% (row 1.8).
The budget allocated for the material (the salt) is comprised between 168 and 590 € per unit (row 1.7).
Other cost to be considered includes depreciation (at 15%, row 1.10), labour costs (at 45%, row 1.12), energy (at 10%, row 1.14), other costs (at 30%, row 1.16), including steel, welding's wires, plastics, gaskets, harnessing, valves, etc.).
All the above parameters are kept constant (row 1.10, 1.12, 1.14, 1.16) and each cost in sub-scenario is calculated.

Table 19 presents the yearly production of heat battery units by the manufacturer (row 2.6), taking the depreciation figures from row 1.11 (row 2.1), assuming a 10-year depreciation of the assembly line of the unit (row 2.2), whose investment cost has been set at 1 000 000 euro (CAPEX) (row 2.5).
The units produced per year range from 465 to 1296. This number is influenced by the market price (row 1.1) and the costs allocate to depreciation (row 1.11), since lower depreciation costs allocated means higher number of units produced per year to cover yearly depreciation for manufacturing plant (row 2.4).

2.1	yearly depreciation per piece	101	77	202	154	108	82	215	165
2.2	10-year depreciation	10				10			
2.3	depreciation factor per unit	1008	772	2016	1544	1076	823	2152	1645
2.4	yearly depreciation for manufacturing plant	100000				100000			
2.5	**CAPEX (cost of manufacturing plant)**	1000000				1000000			
2.6	units production per year	992	1296	496	648	930	1216	465	608

Table 19: Yearly production of heat battery units (manufacturer's perspective)

Table 20 validates the labour parameter set at 45% (row 1.12).
Assuming a yearly workforce of 10 people (row 3.1), and 1760 hours worked per year, the yearly overall working hours are obtained (row 3.3).
Row 3.3 calculates the number of work hours allocated per unit across the 4 sub-scenarios, ranging from 14 to 38 hours (row 3.3).
Assuming a cost of 30000 € (salary, taxes, welfare) per worker a total cost per worker has been set at 17,05 €/h.
The labour cost per unit (row 3.6) is confirmed as in row 1.13.

3.1	workforce	10				10			
3.2	working hours (overall per year)	17600				17600			
3.3	work hours per unit	18	14	35	27	19	14	38	29
3.4	workforce overall cost per person	30000				30000			
3.5	cost per hour	17,05				17,05			
3.6	labour cost per unit	302,4	231,5	604,8	463,1	322,7	246,8	645,5	493,6

Table 20: Workforce and labour costs

Finally Table 21 below sets same parameters regarding:

- energy stored per m^3 (row 4.1) at 1.5 GJ/m^3;
- volume of material per unit (row 4.2) at 2.5 m^3 of salt per unit
- energy stored per unit (row 4.3 and 4.4) at 3.75 GJ or 1.04 MWh

It shall be considered that **1.5 GJ/m^3 (417 kWh/m^3) is a CREATE objective, very challenging, and it is worth to remind that all the above analysed scenarios assume a TRL 9 (market ready) level for the unit.**

4.1	energy stored per m3	[GJ/m3]	1,5				1,5			
4.2	volume per unit	[m3/unit]	2,5				2,5			
4.3	energy stored per unit	[GJ] (=277 kWh)	3,75				3,75			
4.4	energy stored per unit	[MWh]	1,04				1,04			
4.5	cost allocated to material per unit	[Euro/Unit]	168,0	220,5	336,0	441,0	239,1	295,3	478,1	590,6
4.6	cost allocated to material per MWh	[Euro/MWh]	161,7	212,3	323,5	424,5	230,1	284,3	460,3	568,6
4.7	cost allocated to material	[Euro/GJ/m3]	84,4	110,8	168,9	221,6	120,1	148,4	240,3	296,8
4.8	cost allocated to material per unit	[Euro/GJ]	44,8	58,8	89,6	117,6	63,8	78,8	127,5	157,5

Table 21: Material costs vs. different sub-scenarios

The range of material costs allocated to the material range from 84.4 €/(GJ.m^3) to 296,8 €/(GJ.m^3), as explained in row 4.7.
Row 4.8 presents the **range of material cost allocated per GJ per unit (with 2.5 m^3 of material) from 44.8 €/GJ to 157.5 €/GJ**.

As a further instrument an estimator-tool has been prepared, in order to observe the influence of the cost allocated to material.

The two scenarios have been modelled in the below Table 22:

	ESTIMATOR		Scenario 1				Scenario 2			
E.1	energy stored per unit	[GJ] (=277 kWh)	**3,75**				**3,75**			
E.2	energy stored per unit	[MWh]	1,04				1,04			
E.3	energy stored per m3	[GJ/m3]	**1,5**				**1,5**			
E.4	volume of material per unit	[m3/unit]	2,50				2,50			
E.5	cost allocated to material	[Euro/GJ/m3]	**84,4**	**110,8**	**168,9**	**221,6**	**120,1**	**148,4**	**240,3**	**296,8**
E.6	cost allocated to material	[Euro/GJ]	44,8	58,8	89,6	117,6	63,75	78,75	127,5	157,5
E.7	material cost per unit	[Euro]	168,0	220,5	336,0	441,0	239,1	295,3	478,1	590,6
E.8	material cost per m3	[Euro/m3]	67,2	88,2	134,4	176,4	95,6	118,1	191,3	236,3
E.9	material cost (%)	20%-30%	20%	30%	20%	30%	25%	35%	25%	35%
E.10	overall unit costs	[Euro]	840	735	1680	1470	956	844	1913	1688
E.11	margin	20%-30%	20%	30%	20%	30%	15%	25%	15%	25%
E.12	price EXW	[Euro]	1050	1050	2100	2100	1125	1125	2250	2250
E.13	reseller margin + transport	25%-30%	30%				25%			
E.14	**price to market (TRL 9)**		1500	1500	3000	3000	1500	1500	3000	3000

Table 22: Scenario estimation through KPI's

Figures that can be modified are shown in **blue bold**. They describe the overall KPI of the unit, i. e. energy stored (row E.1), energy stored per m^3 (row E.3).
Row E.5 allows inserting the cost allocated to material per m^3 per each sub-scenario and it copies the same amount of row 4.7, thus enabling the validation of the estimator-tool, utilizing the same parameters discussed in the above tables.

Row E.6 considers the cost of material considering the internal volume occupied by material, while row E.7 highlights the cost of material allocated per unit (i. e. the estimated cost that the manufacturer should allocate to purchase the material).
Row E.8 is the cost per m^3 of volume (2.5 m^3). Row E.9 (similar to row 1.6, Table 18) is in the range 20-30%, providing a price EXW (row E.10) between 840 and 1913 €/unit.
Row E.11 (similar to row 1.3) considers the margin for the manufacturer. Row E.12 is the EXW price. Row E.13 considers the margin for the reseller and transport costs. Row E.14 is the price to market.

It is possible to "play with different energy stored per m^3 (for instance 0.6 GJ/m^3, in row E.3 in Table 23), and observe how the market price of the unit will increase.
Figures are obtained from TNO-CREATE-ECM-26-i1_Preliminary TCM requirements (AD-03).

Keeping the same price of E.5 of Table 22 and changing row E.1 (energy stored per unit) and row E.3 it is possible to obtain the price to market, in the range of 4700-9400 € per unit.

	ESTIMATOR		**Scenario 1**				**Scenario 2**			
E.1	energy stored per unit	[GJ] (=277 kWh)	**4,2**				**4,2**			
E.2	energy stored per unit	[MWh]	1,16				1,16			
E.3	energy stored per m3	[GJ/m3]	**0,6**				**0,6**			
E.4	volume of material per unit	[m3/unit]	7,00				7,00			
E.5	cost allocated to material	[Euro/GJ/m3]	**84,4**	**110,8**	**168,9**	**221,6**	**120,1**	**148,4**	**240,3**	**296,8**
E.6	cost allocated to material	[Euro/GJ]	125,44	164,64	250,88	329,28	178,5	220,5	357	441
E.7	material cost per unit	[Euro]	526,8	691,5	1053,7	1383,0	749,7	926,1	1499,4	1852,2
E.8	material cost per m3	[Euro/m3]	75,3	98,8	150,5	197,6	107,1	132,3	214,2	264,6
E.9	material cost (%)	20%-30%	20%	30%	20%	30%	25%	35%	25%	35%
E.10	overall unit costs	[Euro]	2634	2305	5268	4610	2999	2646	5998	5292
E.11	margin	20%-30%	20%	30%	20%	30%	15%	25%	15%	25%
E.12	price EXW	[Euro]	3293	3292,8	6585,6	6585,6	3528	3528	7056	7056
E.13	reseller margin + transport	25%-30%	30%				25%			
E.14	**price to market (TRL 9)**		4704	4704	9408	9408	4704	4704	9408	9408

Table 23: Prediction of thermal

In Table 23 row E.6 changes from the range 44.8 €/GJ up to 157.5 €/GJ (see Table 22) to **125.44 up to 441 €/GJ,** thus increasing the allowable material cost **from 526.8 up to 1852.2 €/unit** (row E.7).

Keeping constant the other percentages the overall price is in the range around 4700-9400 € per unit, considering one cycle charge/discharge per year.

If the heat battery (the unit) is able to perform 2 cycles per year, hence the storage capacity should be divided by two, hence the material quantity and the relevant overall costs, lowering the unit price down to around 2350-4700 € per unit.