Integration of renewable energies in NZEBs

Affordable Zero Energy Buildings

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1 | Introduction

1.1 | Summary

AZEB (Affordable Zero Energy Buildings) is a European funding project framed into H2020–Energy efficiency program. The AZEB project focuses on the lifecycle cost reductions of new nZEBs (Nearly Zero Energy Buildings) through integral process optimization in all construction phases. AZEB aims to deliver a general methodology and to provide supportive structures and material that will encourage the relevant stakeholders in the building sector to actually adopt available solutions and cultivate a cost-efficient and highly performing (in terms of energy need, comfort, environmental impact) nZEB-practice.
This deliverable summarizes the main solutions that are on the market for renewable energies at building and district level. State of the art solutions are analysed and information on each solution is presented regarding technology description, performance, scale of application, price (analysed for the different life cycle phases whenever possible), market share and trends, and related regulation.

1.2 | Objectives of the report

The information in this report is intended to serve as input for the development of the AZEB methodology during the AZEB project. Gained insights on the available solutions for renewable energy sources as well as the various criteria which are relevant when selecting these, will be combined with the other relevant solution sets within AZEB to create a common methodology. Also, the information gathered in this report will in time be transformed into (e-)learning material for the AZEB online learning environment and possibly for live trainings and workshops on the AZEB methodology.

The report can however already be used stand-alone. The basic information condensed in the report should help decision makers (in particular building developers, project managers and designers) at the initial stages of the project, both to help setting requirements for the building and to aid on the conception and selection of building alternatives.

This report describes existing technological solutions for renewable energies, including their current regulatory and market structure, in order to explore their potential and put in perspective the opportunities for further integration of cost-effective renewable energy technologies into nZEBs.

Life cycle costs evaluation of some of the solutions with data from the different countries are presented whenever possible, in order to facilitate initial comparisons of up-front financing efforts and conditions with exploitation and operation benefits. Regulatory and market conditions for the integration of renewables are also part of the analysis, where data was available, in order to give information regarding potential barriers and cost-effectiveness of the solutions for integration of renewables.

1.3 | Contributions of the partners

No	Short name	Work Planned	Effort
3	TECNALIA	• Define a reporting template for renewable technologies, and circulation of questionnaire to request contributions from the partners. • Integrate responses and discussion of potential technologies and their application depending national characteristics (climate, building codes, regulation, building typologies, technology market etc.), and national regulations and energy market. • Prepare input (information notes, presentation) for discussion in LEAN workshops. • Extract conclusions from LEAN workshops regarding renewable energy technologies • Prepare D1.4 Integration of renewable energies in nZEBs	
5	PHI	• Collect information and respond to questionnaire from TECNALIA regarding national characteristics for renewable energy, and regulatory and market characteristics.	
6	ARMINES	• Collect information and respond to questionnaire from TECNALIA regarding national characteristics for renewable energy, and regulatory and market characteristics.	0.5
8	EERG	• Collect information and respond to questionnaire from TECNALIA regarding national characteristics for renewable energy, and regulatory and market characteristics.	
7	OKB	• Collect information and respond to questionnaire from TECNALIA regarding national characteristics for renewable energy, and regulatory and market characteristics.	
1	DNA	• Collect information and respond to questionnaire from TECNALIA regarding national characteristics for renewable energy, and regulatory and market characteristics.	

2 | How renewable energy contributes to NZEBs?

The AZEB project has been developed under the framework of the Energy Performance Building Directive (EPBD) in order to promote the improvement of the energy performance of buildings within the EU through cost-effective measures.

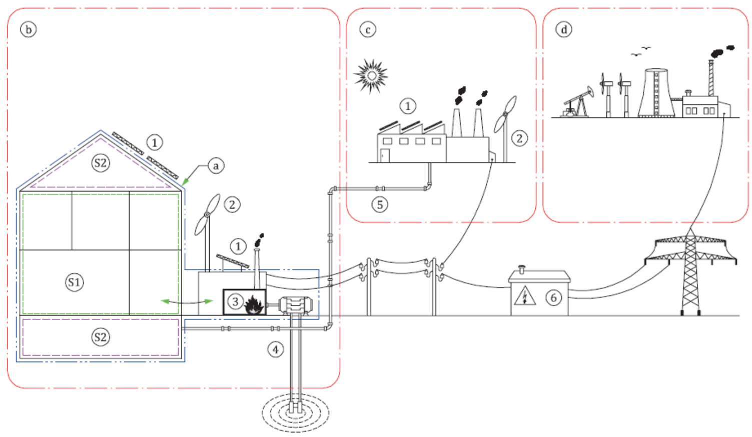
By the year 2021, all new buildings in the European Union shall be nearly Zero Energy Buildings (nZEB). Also globally, in North America and East Asian countries such as Japan, the objective of net Zero Energy Buildings shall be implemented within timeframes between 2020 and 2030. However, the definition of nZEB in the EU and other countries is still under development and existing definitions are not harmonised yet, but vary both in criteria and limits. According to article 2 of the EPBD, "'nearly zero-energy building' means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby"

While this definition is quite ambiguous, and is currently under discussion under the revision process of the EPBD, it already highlights a key issue when discussing renewable energy integration in new buildings, which is the balance between building and system efficiency on the one hand and renewable energy production on the other hand. The extent to which building energy needs through passive measures is reduced is a fundamental pre-requisite for nZEB, and systems efficiencies and the need for renewable energies should complement the required energy needs to achieve a near-zero energy balance.

Countries might have however different consideration of the various renewable energies in the total building energy balance. The assessment boundary and the accountancy methods for primary energy are of key importance on the analysis of how renewable energies can be used to satisfy thermal or electricity demands of buildings. Different renewable energy supply options exist, as described by Marszal et al [02] (Figure 1), which can be generated on-site and off-site.

Figure 1 Overview of possible renewable supply options which were found in descriptions for nearly zero energy buildings. [01]

In this report, the generation of renewable energy on the building footprint and on-site will be analysed, in line with the AZEB project of cost reduction through construction processes of new buildings.
District solutions are also analysed as grouping buildings offer new possibilities for renewable energy generation and optimization, and for interaction with the electricity grid. This approach is also in line with the standard *EN ISO 52000-1 Energy Performance Of Buildings - Overarching EPB Assessment - Part 1: General Framework And Procedures* , where district heating/cooling solutions are within boundaries for on-site assessment. (see figure 2).



Key

a	assessment boundary (use energy balance)	1	PV, solar
b	perimeter: on-site	2	wind
c	perimeter: nearby	3	boiler room
d	perimeter: distant	4	heat pump
S1	thermally conditioned space	5	district heating/cooling
S2	space outside thermal envelope	6	substation (low/medium voltage and possible storage)

Figure 2 Example of assessment boundaries from EN ISO 52000-1

While the calculation of primary energy factors of the different energy sources is not going to be discussed in this report, it has to be noted that it is a key point of discussion within the EPBD revision, and also on the energy efficiency and renewable energy directives.
As it is described in the EN ISO 52000-1 standard, "*energy weighting factors (e.g., primary energy, CO2) are defined for each energy flow delivered or exported through the assessment boundary, taking into account the origin for delivered and the destination of exported energy*".
The interaction with the electricity grid will also be discussed, particularly in relation of the regulatory situation for exchanging electricity from building integrated renewable energies. As it can be observed in Figure 2, depending on the time step for the electricity balance (and of course on the particular energy demand characteristics and renewable electricity produced), the load matching of demand and production can be reduced to 25% with hourly balance. How electricity markets are regulated to deal with this single issue is vital for the economic viability of building integrated renewable electricity generation,

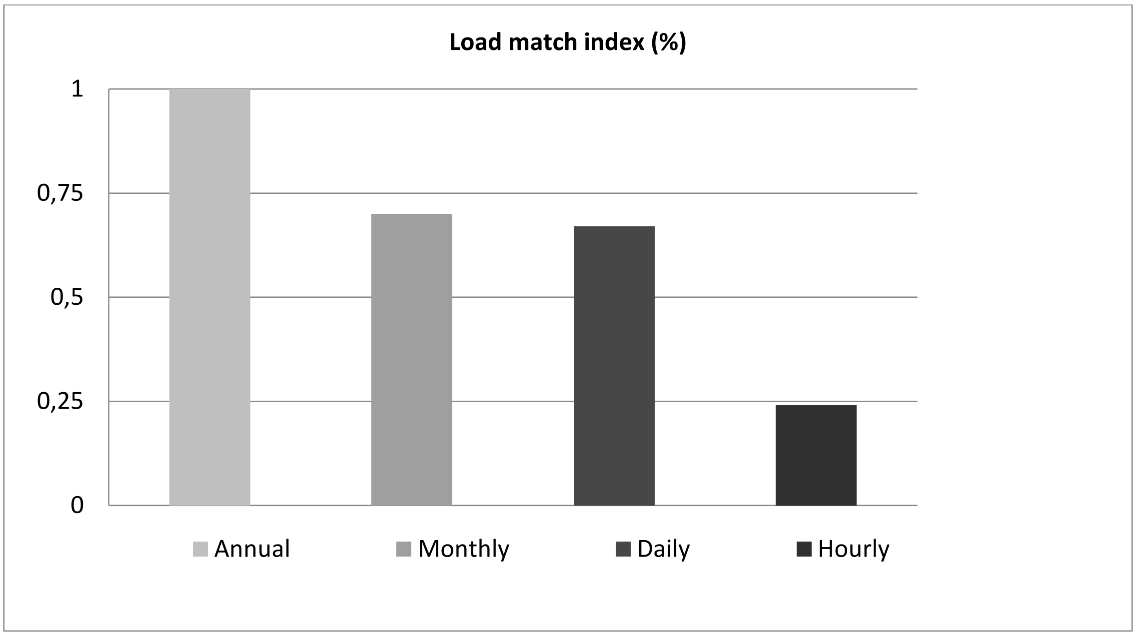


Figure 3 Load match index as a function of the time step for balancing [1]

3 | Building level renewable energies

This part included a description of renewable energy technologies at building level and seeks to compare the different aspects existing between different countries.

3.1 | Photovoltaic solar technology

The photovoltaic effect (the physical phenomenon responsible for converting light to electricity) is exploited by Photovoltaic solar technologies in order to generate electricity. Light shining on a semiconductor generates electron-hole pairs that are separated spatially by an internal electric field created by introducing special impurities into the semiconductor on either side of an interface known as a p-n junction.

A PV System consists in one or several PV modules, typically rate between 50W and 350W,connected to either an electricity network (grid-connected PV) or to a series of loads (off-grid). It comprises various electric devices aiming at adapting the electricity output of the module(s) to the standards of the network or the load: inverters, charge controllers or batteries. A wide range of mounting structures has been developed especially for BIPV; including PV facades, sloped and flat roof mountings, integrated (opaque or semi-transparent) glass-glass modules and “PV roof tiles”.. In general, cells can be classified as either wafer-based crystalline (single crystal and multicrystalline silicon), compound semiconductor (Thin-film), or organic.

Photovoltaic (PV) systems can be grouped into stand-alone systems and grid connected systems. In standalone systems the solar energy yield is matched to the energy demand. Since the solar energy yield often does not coincide in time with the energy demand from the connected loads, additional storage systems (batteries) are generally used. If the PV system is supported by an additional power source, this is known as a photovoltaic hybrid system.

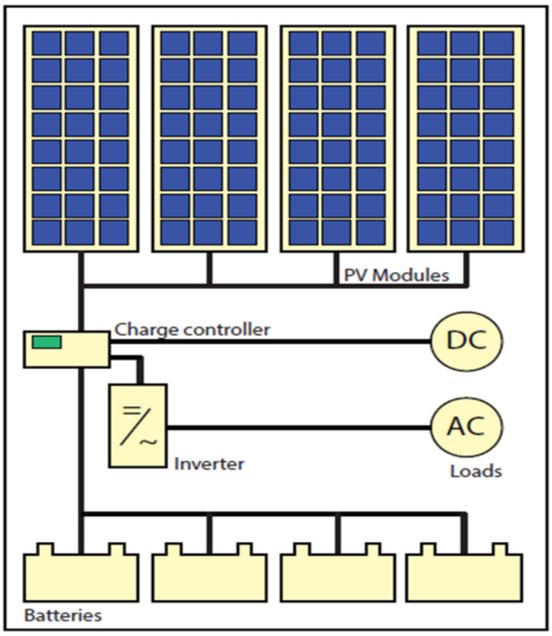


Figure 4 Common photovoltaic installation.

Figure 3 shows a PV installation using electric batteries to store electrical energy and this electrical energy can be converted to DC or AC using an inverter. In this example, photovoltaic systems are not connected to the electrical grid, which is not the most common solution. While the connection to the grid is technically very easy, nevertheless in some countries, the administrative barriers are more difficult to reach than the technical solutions.

3.1.1 | Scale of application

Photovoltaic technology based solutions are successful from very small scale applications (to supply batteries of all kind of electronic devices), to very large PV power stations of larger than 1GW. Modularity and scalability is one of its main advantages, and for buildings PV installations can be design and optimized to specific electrical loads.

3.1.2 | Main applications

In nZEBs, the main application of PV technology consists in the electrical generation for self-consumption and to export to the electricity grid. For self-consumption, generation could be used to many appliances and electrical devices, lighting, and in recent times, increasingly for building heating, cooling and DHW production when coupled to a heat pump.
The load matching between electricity demand and production is a key issue for the system design and for the economic viability of the system. While solving the time gaps between PV production and building electricity use could be done through on-site electrical storage, it is generally much more cost-efficient to use the electricity grid as regulation element. This way , the excess of the PV generation injected to the grid, and when PV generation is not enough to cover the building electricity demand, grid can supply to match building requirements.

3.1.3 | Limitations of its application

Three key limitations for photovoltaic technology can be highlighted.

First of all, the surface limitation. Surface availability is not always guaranteed and sometimes this limitation could affect the design of the system and the covered solar rate.
The efficiency of the photovoltaic units is the second limitation. Although new generations of photovoltaic cells are growing in their efficiencies, the values that can be reached are no very high, (theoretically 30% efficiency rates could be exceeded but only in multilayer cells)
The last limitation relates to regulatory and administrative uncertainties. In certain countries, PV installations , which is a handicap for the investors in this technology.

3.1.4 | Current technologies

Currently, crystalline silicon technologies account for more than 94% of the overall cell production in the IEA PVPS countries. Single crystal silicon (sc-Si) PV cells are formed with the wafers manufactured using a single crystal growth method and have commercial efficiencies between 16% and 25%. Multicrystalline silicon (mc-Si) cells, usually formed with multicrystalline wafers manufactured from a cast solidification process, have remained popular as they are less expensive to produce but are less efficient, with average conversion efficiency around 14-18%. III-V compound semiconductor PV cells are formed using materials such as GaAs on the Ge substrates and have high conversion efficiencies of 40% and more. Due to their high cost, they are typically used in concentrator PV (CPV) systems with tracking systems or for space applications. Thin film cells are formed by depositing extremely thin layers of photovoltaic semiconductor materials onto a backing material such as glass, stainless steel or plastic. Thin-film modules used to have lower conversion efficiencies than basic crystalline silicon technologies but this has changed in recent years. They are potentially less expensive to manufacture than crystalline cells. Thin-film materials commercially used are cadmium telluride (CdTe), and copper-indium-(gallium)- diselenide (CIGS and CIS). Amorphous and micro morph silicon (a-Si) used to have a significant market share but failed to follow both the price of crystalline silicon cells and the efficiency increase of other thin film technologies. In terms of efficiencies, in 2016, CdTe cells reached 22% in labs. Organic thin-film PV cells, using dye or organic semiconductors, have created interest and research, development and demonstration activities are underway. In recent years, perovskites solar cells have reached efficiencies higher than 20% in labs but have not yet resulted in stable market products.

3.1.5 | Main advantages

The main advantages of this technology have been summarized below:

- Solar energy is energy supplied by nature – it is thus free and abundant and can be made available almost anywhere there is sunlight
- Solar Panels cost is currently on a fast reducing track and is expected to continue reducing for the next years – consequently solar PV panels has indeed a highly promising future both for economic viability and environmental sustainability.
- Operating and maintenance costs for PV panels are considered to be low, almost negligible, compared to costs of other renewable energy systems
- PV panels are totally silent, producing no noise at all; consequently, they are an adequate solutionfor urban areas and for residential applications.

- Because solar energy coincides with energy needs for cooling PV panels can provide an effective solution to energy demand peaks – especially in hot summer months where energy demand is high.

3.1.6 | Main disadvantages

Among the main disadvantages of this technology, the following have been highlighted:

- As in all renewable energy sources, solar energy has intermittency issues; not only being unavailable at night but also during daytime there may be cloudy or rainy weather.
- Consequently, intermittency and unpredictability of solar energy makes solar energy panels less reliable a solution to match specific building load.
- Solar panels efficiency levels are relatively low (between 14%-25%) , compared to the efficiency levels of other renewable energy systems, so the required area is considerable.
- Though PV panels have no considerable maintenance or operating costs, they are fragile and can be damaged relatively easily; additional insurance costs are therefore of ultimate importance to safeguard a PV investment.

3.1.7 | Economic information

The economic information has been collected from the different countries by the AZEB´s partners.

- **Bulgaria**

Table 1 Standard cost associated to PV technology in Bulgaria

Cost category	Value
Initial design cost	450 € installed (for up to 30kWinstalled)
Product cost	900 €/kW installed
Installation cost	200 €/kW installed
Operational energy use revenues (from electricity sold to the grid)	184 €/kW installed year (for up to 5 kWp)[1]

- **France**

Table 2 Standard cost associated to PV technology in France

Cost category[2]	Value
Installation cost	2.8 € (without VAT) / Wp
Grid connection cost	1200-3000 € HT
Operational energy use revenues (from electricity sold to the grid)	<3 kWp, 18.7 c€/kWh, plus 4 c€/kWh if the PV modules replace a building element (e.g. PV

[1] The produced electricity from 1 installation kWp is 1,30 MWh per year. Revenue of 184€/year assuming the current price for electricity produced from PV.

[2] 14.16 c€/kWh has been taken as the Standard electricity cost and 100 €/year fixed cost for 6 kW in order to costs calculation.

	modules used instead of roof tiles, cladding, solar protection...)

- **Germany**

Table 3 Standard cost associated to PV technology in Germany

Cost category	Value
Product cost	1270 €/kWp (typical 10 to 100 kWp PV rooftop-system) [3]
Power generation cost	50-60 cents/kWh [04]

- **Italy**

Table 4 Standard cost associated to PV technology in Italy

Cost category[4]	Value
Installation cost	1500€/kWp
Grid connection cost	P<50 kW 100€ 50<P<100 kW 200€ 100<P<500 kW 500€ 500<P<1000 kW 1500€ P>1000 kW 2500€
Operational energy use revenues (from electricity sold to the grid)	0.16€/kWh[5]

- **Spain**

The prices are in Euro per Watt peak (€/Wp) and they have been provided by suppliers companies (excluding transport to the site, VAT/TVA and sales commission).

In Spain, there are many kinds of buildign integrated PV installations, depending on the characteristics of the surface available (ground or rooftop), location and meteorological conditions of the project, and this has a large impact on the associated costs.

To understand the estimation provided regarding costs, it is necessary to describe the regulatory situation in Spain nowadays, which has a strong influence on life cycle costs.

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[3] This is a net-price regression of about 90% over a period of 25 years and is equivalent to an annual compound average price reduction rate of 9%. The Experience Curve – also called Learning Curve - shows that in the last 36 years the module price decreased by 24% with each doubling of the cumulated module production. Cost reductions result from economies of scale and technological improvements.[03]

[4] The following assumption have been take for costs calculation. Electricity prices:0.243 €/kWh for households annual consumptions: 2500 kWh < consumption < 5000 kWh, according to Electricity prices for the year 2015. Fixed: about 10 €/month 0.160 €/kWh for industry annual consumptions: 500 MWh < consumption < 2000 MWh excluding VAT, according to Electricity prices for the year 2015 [05].

[5] There are two mechanism by GSE: "dedicated withdrawal" and "on-site exchange". In the first, the withdrawal price of electricity fed into the grid is equal to the hourly price of the market area where the plant is located (0,16 €/kWh)."On-site exchange" is a particular form of on site self-consumption allowing the electricity produced and fed into the grid to be taken at a different time from the production.

Before the publication of Royal Decree 900/2015 which regulates the installation of on self-consumption systems, all installations in development during 2015 in Spain, were approved to be connected directly to the main switch board of the electrical installation in low voltage.
When the new regulation entered into force, all installations had to be modified to fulfil all the mandatory requirements established. Among others, each installation has to submit a new application to the Distributor System Operator (DSO) to be connected to the grid and to be granted with a point of connection. Plus, it is mandatory to install a new energy meter, to measure the power production, in a location accessible from a public way to warranty 24/7 access to the DSO.
Currently, the technical conditions to be connected to the grid have not been approved yet by the National Authorities and each DSO has developed different and particular rules to be connected to their networks. This situation means that there are different costs depending on the regional area in the country.

Table 5 Turnkey Prices of Typical Applications in Spain [06]

Category/Size	Typical application and brief details	Current prices (per W)
Off-grid up to 1kW	Streetlight, telecommunication system, taximeter, camping, shelter…	2.5-3 €/W (can be higher with batteries)
Off grid > 1 kW	Farming, irrigating system , pumping, agricultural sector, rural electrification	2-2.8 €/W (can be higher with batteries)
Grid connected rooftop up to 10kW (residential)	Service sector, PYMES, Domestic sector	1.4-1.5 €/W
Grid connected rooftop from 10kW to 250 kW (commercial)	Hotels, big industries, cinemas	0.8-1.2 €/W

Table 6 Cost of residential roof PV system < 10kW in Spain [06]

Cost category	Average (€/W)
Hardware	
Module	0.675
Inverter	0.2
Other (structure, racking, wiring…)	0.48
Soft costs	
Installation	0.11
Operation and Maintenance	0.02
Subtotal hardware	1.355
Subtotal soft costs	0.13
Total	1.5

3.1.8 | Regulatory framework and legislation applied

The Energy Performance in Buildings Directive (EPBD) wrequirements on nZEB by 2020 might become an important driver of PV development in the building sector,pushing PV as the main possibility to reduce the net energy consumption in buildings after energy efficiency. While the final effect will have to be scrutinized after 2020, it represents a major opportunity for the building sector and PV to work together.

- **Bulgaria**

In Bulgaria, is necessary distinguee between PV systems which are either autonomous and the systems connected to the grid. The autonomous PV system can be installed absolutely free and do not underline any regulations.
If the system has to be connected to the grid, the project for it has to be aligned with the municipality, which then leads to permit to install the system and connect it to the grid. In this case, the generated energy can be used for:

- Self needs: only the excess energy is sold.
- For selling: all the energy generated is sold. The prices at the moment are ~0, 14 €/kWh (up to 5 kWp) and 0, 12 €/kWh (up to 30 kWp).

- **France**

PV systems are accounted for in the energy regulation, allowing the plus energy level to be reached. The cost of grid connection billed by the electricity distribution company is very high. There are two feed in tariffs: one if the whole electricity production is sold, one if a part is self-consumed and the rest is sold.
Investment aid of 0.4 €/Wp in case of self-consumption

- **Germany**

Communities and cities can determine that you have to include renewable energies into your building concept.
The Erneuerbare-Energien-Wärmegesetz (EEWärmeG) a law on renewable energies requires a minimal level renewable energies for new buildings and retrofits with an increase of living are of more than 50m² [07] . The requirements do not include photovoltaics but solar thermal panels.
The German government pays a feed-in remuneration for electricity including photovoltaics of around 10 to 12 cents/kWh [08].

- **Italy**

The annex 3 of the current Italian legislation about the promotion of renewable energy (Dlgs 28/11), coherent with the Directive 2009/28/CE, describes the minimum mandatory amount of energy provided via the exploitation of renewable sources for new buildings or major renovations. In particular:
the electrical power [kW] of the plants powered by renewable sources, compulsorily installed on or within the building or its perimeter, is calculated according the following formula:
P=1/K*S
where S is the floor surface of the building at ground level, measured in m2, and K is a coefficient (m2/kW) which is equal to 50, from 1st January 2017.
For public buildings, the obligations are increased by 10%.

It is important to underline that these systems are low-density produced energy per unit of surface: this inevitably entails the need to identify criteria related to soil consumption and landscape protection.

- **Spain**

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Consecutive Spanish governments put in place a legal framework allowing that the revenues coming from the price of retail electricity were below total system costs, which created the tariff being paid by electricity consumers. The cumulated deficit amounts now to 15 BEUR and it is estimated that the cost of renewables paid by electricity consumers has contributed to around 20% of this amount. In order to

reduce this deficit, retroactive measures have been taken to reduce the FiTs already granted to renewable energy sources but no other significant measures have been taken to reduce the deficit.
In the summer of 2013, the Government announced a new reform of the electricity market. Under the 24/213 Power Sector Act, the FiT system was stopped in July 2013 and the new schemes are based on the remuneration of capacities rather than production.
The new system is based on estimated standard costs, with a legal possibility to change the amounts paid every four years. This has caused many projects to be in a state of default. The biggest projects have changed hands, since international investors found interests in the acquisition of these projects.
The 24/2013 Power Sector Act considers very restrictive forms of self-consumption. During 2015 the regulatory framework for self-consumption was developed under Royal Decree (RD) 900/2015.
This RD established that the maximum capacity of the self-consumption installation must be equal or below the contracted capacity. It also specifies two types of self-consumers:

- Type 1: maximum capacity installed of 100 kW – there is no compensation for the electricity surplus fed in the grid.
- Type 2: no limit to the allowed capacity – the surplus can be sold in the wholesale market directly or through an intermediary. A specific grid tax of 0.5 EUR/MWh has to be paid together with a 7% tax on the electricity produced.

Regulation indicates that self-generated power above 10 kW is charged with a fee per kWh consumed as a "grid backup toll", commonly known as the "sun tax". Adding battery storage to the installation also implies an additional tax. Geographical compensation is not allowed, and self-consumption for several end customers or a community is not allowed.
However, grid parity has been reached in Spain thanks to two factors: rich solar irradiation resource and good prices for components. Given the context of no feed-in-tariff, the future of the Spanish PV market lies in the deployment of big PV plants , and specifically for the building sector, on appropriate regulation and elimination of the self-consumption barrier.

3.1.9 | European and national Markets for PV systems

Europe led PV development for almost a decade and represented more than 70% of the global cumulative PV market until 2012. Since 2013, European PV installations went down while there has been rapid growth in the rest of the world, and particularly in China. Europe accounted for only 17% of the global PV market with 8.5 GW in 2015. European countries installed 98 GW of cumulative PV capacity by the end of 2015, still the largest capacity globally, for the last year. It is important to distinguish the European Union and its countries, which benefit from a common regulatory framework from part of the energy market, and other European countries which have their own energy regulations.

- **Bulgaria**

According to national statistics in September 2017 6, there are currently 819 MWp installed in Bulgaria, as follows:

- Installations up to 30 kWp – 3,69 MWp
- Installations up to 5 MWp - 682,72 MWp
- Installations over 5 MWp – 132,59 MWp

Concerning the data from the national electricity provider for all the domestic electricity, the electricity generated from PV installations accounts for ~ 8% of the total electricity consumption in 2016.

- **France**

The installed power in France is around 6.9 GW, and the annual production 8.5 TWh, around 1.7 % of the electricity consumption.
Half of building integrated systems are in the residential sector, and half in public buildings (large area of modules). Silicium modules represent 90% of the market, the rest being thin films.

- **Germany**

The figure below shows the number of PV systems annually installed in Germany (% of annual capacity) [01] .

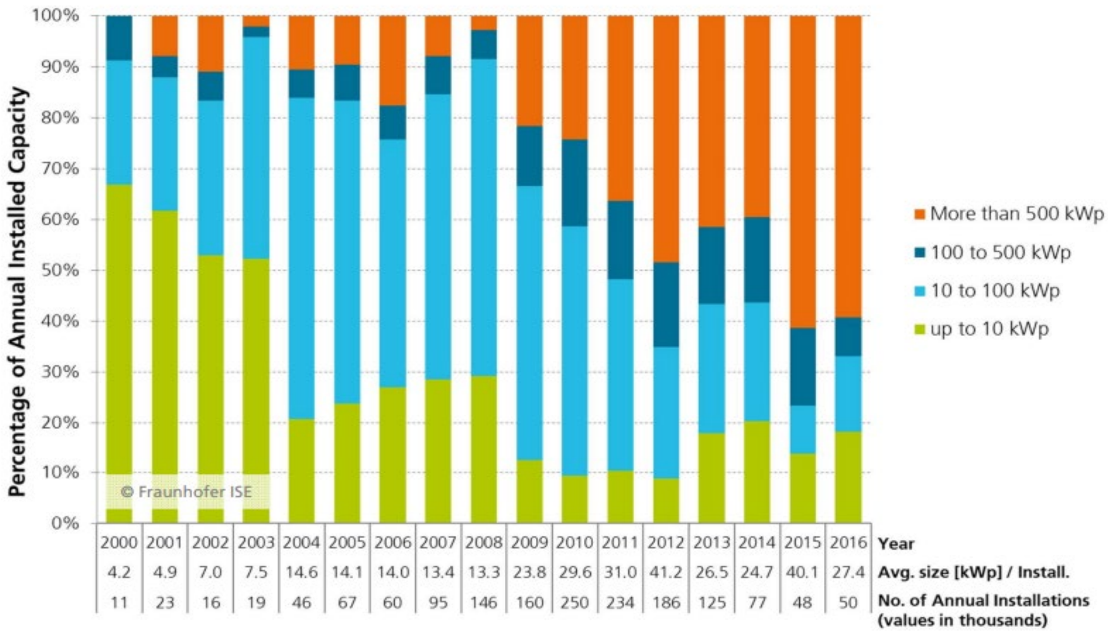

Figure 5 Percentage of annual installed capacity in Germany [7]

- **Italy**

The company GSE (Gestore Servizi energetici) reports in the year 2016 an overall value of energy produced by PV systems (732053 installed systems) equal to 22104 GWh, while the installed power is 19283 MW.

[6] http://vei-bg.org
[7] Data: up to 2008: extrapolation from utilities data; since 2009: Bundesnetzagentur. Graph : PSE AG 2017

79% of the installed systems belongs to household use while 51% of the power is in the industry sector.
At national level, 73% of the installed power is made of polycrystalline silicon, 21% monocrystalline silicon and 6% in thin film or in different materials.

- **Spain**

In 2007 and 2008, Spain's a feed-in-tariff (FiT) programme triggered a rapid expansion of the PV market. After a moratorium in October 2008 that made the market go down, in January 2012 a new moratorium was put in place for all the renewables projects with FiT. In 2015, only 49 MW were installed in Spain where a total installed capacity tops more than 4,8 GW which can be explained by the difficult economic environment and the constraining PV policies. In 2017, there was a turnaround of the situation for large PV installations, with increasing installations both at large scale (3,000 MW renewable energy auction launched with significant percentage of PV winners) and at building scale.

3.1.10 | Implementation trends

With the right regulatory and policy frameworks, solar technologies can still unlock significant additional cost reductions out to 2025 and beyond. There is significant potential for this technology to see continuous installed cost reductions and performance improvements, leading to lower life cycle costs of PV electricity.[09]

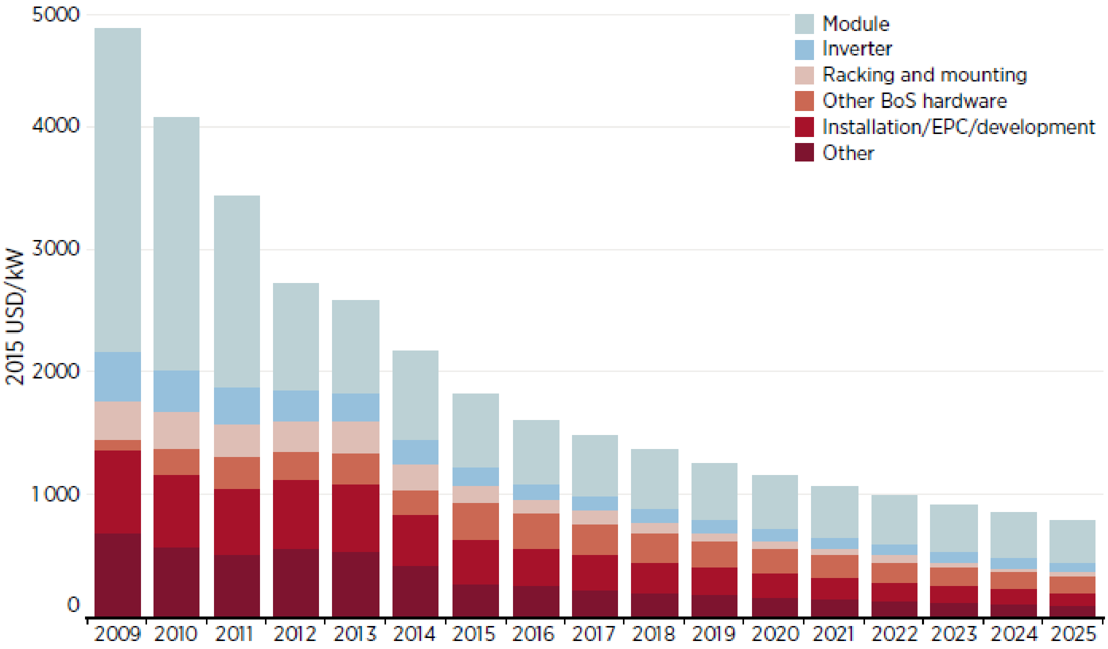

Figure 6[8] Global weighted average total system costs breakdown of utility-scale solar PV systems, 2009-2025 [09]

The steep decline in total installed costs of solar PV

[8] IRENA analysis and Photon Consulting, 2016

- **Bulgaria**

Steady development and increase in the number of installations. There is no indication that this will change soon.

- **France**

According to the French Energy and environment Agency (ADEME), 800 MWp will be installed yearly in the next years.

- **Italy**

EU countries have already agreed on a new renewable energy target of at least 27% of final energy consumption in the EU as a whole by 2030 as part of the EU's energy and climate goals for 2030. Within this renewables-target: electric (48-50%), thermal (28-30%), transportation (17-19%). To this end, the following instruments, operating at national level, is nowadays active for PV technology:

- 50% tax credit until 31/12/2017 during renovation works (Bonus ristrutturazioni). This is also applicable to the purchase and the installation of accumulation systems to be incorporated into existing photovoltaic plants;
- 10% VAT facilitation measure.

According to the GSE Report [2015], technological progress will further reduce PV costs by 40 to 70% per year. This costs reduction suggests an important development of this technology whose production should increase more than double within 2030.

- **Spain**

Since 2011the national PV market has been affected by non-favourable regulatory measures, which have resulted in very small installed capacity in 2016 and 2016. The publication of the Royal Decree 900/2015 on the 5th of October 2015, which regulates the installation of on self-consumption systems,further decreased sthe development and promotion of new projects , particularly in the building sector. However, interest on self-consumption in many economic sectors is still alive, and a timid recovery of the self-consumption sector has been seen in 2017, and is expected that the sector will steadily grow from 2018 onwards.

3.2 |Biomass

Biomass is a fuel developed from organic materials, a renewable and sustainable source of energy, and used to generate heat and/or electricity (industry).
A wide range of technologies have been developed to utilize the biomass resource. These vary from direct combustion in burner systems, to the production of more advanced biofuels, such as pyrolysis, through a variety of processing techniques (fermentation, gasification).
As with burning of fossil fuels, burning biomass releases carbon dioxide and other pollutants. Because the carbon in biomass has quite recently been absorbed from the atmosphere, if the biomass resource is managed sustainably there may be little net-emissions of carbon dioxide. This closed carbon cycle, however, does not necessarily include any energy needed to cultivate, harvest, and process the biomass.
Two categories of biomass fuels, woody fuels and animal wastes, comprise the vast majority of available biomass fuels. Most biomass used today is home grown energy. Wood-log, chips, bark, pellets and sawdust- accounts about 44% of biomass energy. Other biomass fuels include agricultural waste products. On the

other hand, there is the possibility of burning solid waste (one ton of garbage contains as much heat as 500 pounds of coal) and landfill gas and biogas, through which methane gas is generated as long as the waste decays.
Regarding AZEB, the biomass technology will be focused on the combustion of woody biomass (wood chips, pellet, etc.), which is the most extended and mature technique.
Biomass heating systems include different technologies and feeding structures regarding the installation size and number of end-users. Depend on the power rates, different alternatives exist:

- Heating generation through district heating
  District heating plants based on biomass boilers present an installed power > 500kW, being the normal values between 600-2.500 kW. These systems are used for heating and hot water generation for some apartment buildings, neighbourhoods or villages. The structure of this system is divided into 3 parts; Biomass supply, biomass power plant and distribution network and heating supply to the end-users.

Figure 7 850kW biomass boiler for district heating application [10]

- Medium size biomass systems (50-500 kW)
  Medium size boilers are designed to supply heating and hot water to a building (flats, offices, hotels). The type of boiler applied for this application is the fired-grate boiler (fixed/ cascade) or the bottom feeding system, which permit high efficiencies (>85%) and a low maintenance cost. The best benefit from this application is a lower price in the energy supply (between 50-100%), noise reduction and improvement of environmental conditions.

Figure 8 250kW medium size biomass boiler and storage bunker [10].

One of the main aspects of this application is the biomass storage. It mandatory having a storage and a biomass feeding system, located near the biomass boiler. The storage system which is usually used are silos,

which are normally located inside the building to be heated. The space required shall be enough to store the biomass needed for at least 1-2 weeks.
These systems also require a biomass feeding system, which has to feed the boiler periodically.

– Biomass boilers for single-family house (<40 kW)
To cover heating and hot water necessities of single- family houses, the suitable power if biomass boilers are near 40kW. In the market exist biomass boilers from 15 to 40kW, so they can be adapted to each end-user. This type of boilers can be used together to normal heating systems as radiators, radiant floor, hot air ventilation systems and to hot water production.

Figure 9 250kW biomass boiler for a single-family house and polypropylene silos for pellet (2-5t capacity) [10].

Moreover, 8-25 kW biomass stoves can be installed. The difference is that biomass stoves supply heat directly to the place/room installed. The installation costs are lower, mainly because they don't need a biomass warehouse, and biomass feeding to the stove is made manually.
The space required is smaller than the technologies above; due to the heating capacity supply is also lower.

– Pellet boiler (condensation technology - <30kW)
These boilers recover the condensation latent heat from the fuel by decreasing flue gas temperature until water steam condensates in the exchanger. This technology permits savings of about 15% on the pellet consumption and reaches efficiencies of about 103% with regard to the PCI.
The space requirements are in the same line than the technology above.

Generally speaking, when biomass boilers are used with automatic cleaning systems, it is required to plan ash removal from heat exchangers. Moreover, it is mandatory to control biomass level in the boiler and plan biomass availability in order to avoid the lack of supply.

Table 7 Biomass boiler efficiencies [10].

Biomass heating system	Installed power	Efficiency
Heating generation through district heating	>500kW	>95%
Medium size biomass systems	50-500 kW	~92%
Biomass boilers for single-family house	<40 kW	>90%
Pellet boiler (condensation technology)	<30 kW	~103%

3.2.1 | Scale of application

The small scale heating systems are usually installed in single private households. Heat appliances range from small scale stoves for room heating, to boiler of few kW to heat houses or buildings. Domestic batch-fed wood burning appliances include "high-efficiency" pellet stove and central heating boilers.
Wood biomass boilers (firewood, wood chips and wood pellets) up to 500 kW typically can both heat sanitary water and the whole house heating system.
Wood pellet stoves typically can be air appliance (single room heating) or water heating (heating system).
Biomass boilers can also supply mainly heat and sanitary heat water to flat buildings in terms of central boiler or in district heating scale. It shall depend on heat and water demand and district configuration.

3.2.2 | Main applications

As it has been explained before, in nZEB the main application of biomass boilers is to generate sanitary hot water and heat in single houses, flat buildings, tertiary buildings (offices, hotels, etc.) or district heating systems.

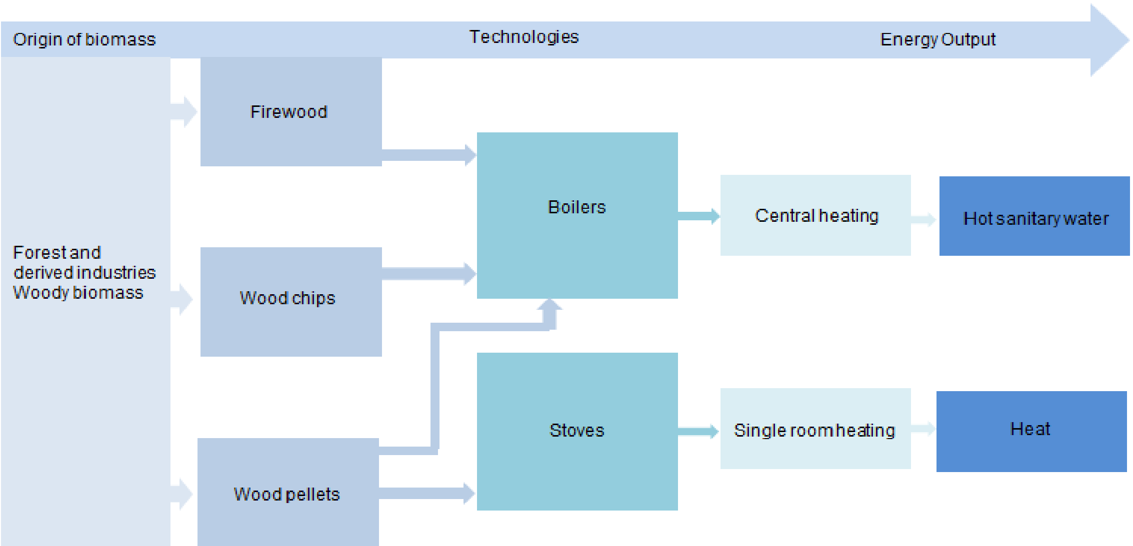

Figure 10 Application of woody biomass [11].

It has to be highlighted that heat /hot water production applications through combustion of pellets, are extended applications in Europe. In some of them as Sweden, Finland or Germany the installation of domestic biomass boilers has increased significantly since 2004. The main biomass consumer countries (per capita) are Nordic and Baltic countries, together with Austria and Finland.
In Austria, for example, the number of installations (<100kW) increased from 28.000 to 47.000 in 2006.

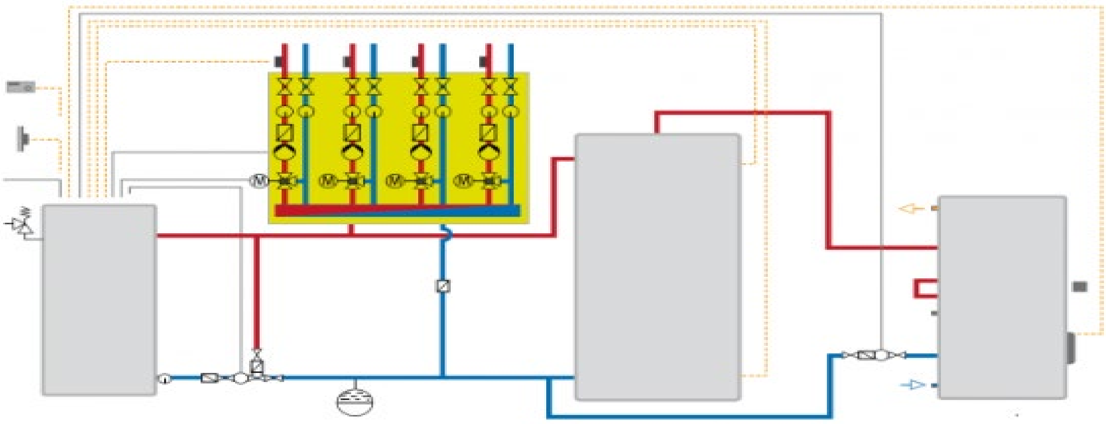

Figure 11 Biomass boiler application to cover all the demand [13].

If the intentions is covering 100% the demand of a new building or disable the old ones, the scheme to be followed is described in Figure 11. Depending on each installation, a buffer tank shall be needed depending biomass boiler efficiency at low modulations.

On the other hand, when the demand to be cover is high, it is recommended to install cascade systems, generally two. This brings many advantages as: the increased of the lifetime of the installation; having two boilers in order to operate both of them in parallel or having one operating and the other one stopped (maintenance operations).

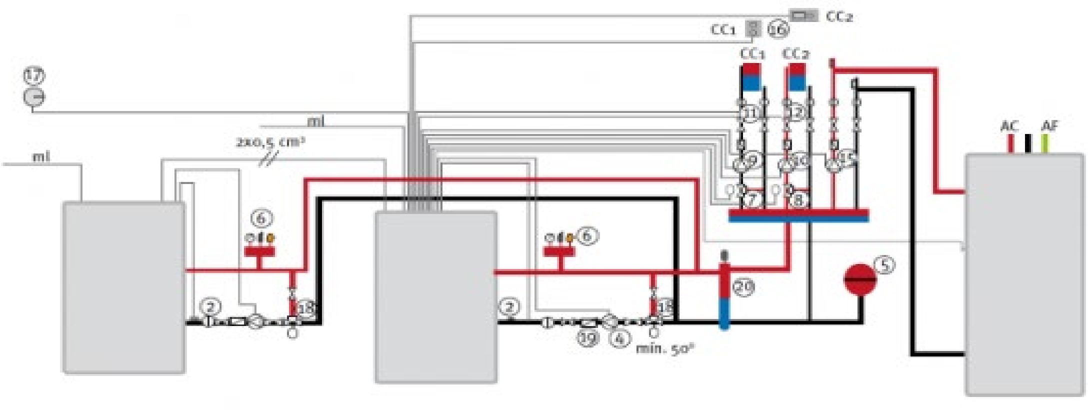

Figure 12 Cascade installation scheme for high demands [13].

This growth of biomass technology and the increase of pellet production has lead into a biomass European market, in which countries with biomass excess supply biomass consumer countries.

In case of Spain, the main biomass fuel comes from the forestry sector, which has been mainly used in the domestic sector to produce heat and hot water.

3.2.3 | Limitations of its application

The main barriers are described below:

- Lack of a developed biomass logistic market.
- Competition with other traditional fuels in terms of prices and service.
- Specialized staff to manage and store the biomass.

- Lack of specific regulation to use biomass for domestic issues.
- Requirement of space for the biomass installation and storage.
- In some cases, biomass fuel can be perishable.

3.2.4 | Current technologies

Biomass technologies are divided into:

- Adapted boilers to biomass: they used to be coal boilers adapted to be used with biomass or gasoil boilers with a biomass burner. Although they are cheap, their efficiency is low (75-85%). Normally, they are semi-automatic without clean and maintenance systems.
- Biomass boilers: specific designed boilers to a specific biomass fuel (pellets, wood chips, mainly). Their efficiency is higher near 92% with automatic biomass feeding system, heat exchanger clean system and ash extraction system.
- Pellet boiler power are normally <40kW, compact and high stable with the pellet supply. The investment cost is low and their efficiency high.
- Biomass boilers can vary from 25kW to hundreds of kW. They cannot operate with different biomass fuels at the same time, but it can be programmed considering the bunker emptying, refill and boiler reprogramming.

Figure 13 Pellet biomass boiler [14].

3.2.5 | Main advantages

- Biomass can contribute to the security of energy supply in two main ways. Firstly, because it can be stored easily in various forms (e.g. wood and its derivatives)), biomass is a stable renewable energy source that can balance the use of variable renewable sources such as wind and solar energy. Secondly, biomass can contribute to reducing reliance on specific energy sources in third countries, in so far as the majority of biomass demand is met from domestically produced raw material. Indeed, the EU forest area has grown by about 2% over the past decade.
- The main advantage is that the economic savings can reach to 40% with regard to gasoil fuel. Comparing with gas systems and electrical equipment, the savings can reach 10-15% and the payback can be

established between 2-3 years, depending on the equipment and the space to be heated.

- Pellet biomass can be easily stored.
- Biomass technology highly developed with high efficiencies and low emissions. These applications show more savings regarding GHE emissions compared with fossil fuels.
- Producing electricity from biomass is too expensive compared to PV and heat pumps. Since the market in Bulgaria is very price-sensitive, this automatically makes biomass electricity unattractive.

3.2.6 | Main disadvantages

- In 2010, a report drafted for the European Commission (known as the 'EU wood' study) estimated that although demand for wood for material and energy use could probably be met by 2020, supply would be insufficient to meet demand by 2030.
- Lack of subsidies in order to cover part of the initial investment and to assure the biomass supply.
- More technical and operating complexity on biomass management. Under-developing sector.
- Higher initial investment compared with fossil fuels installations.
- High space requirements to biomass storage and supply assurance.
- Higher maintenance costs.
- More difficulties on biomass storage and management.
- Seasonality and agro-climatology dependence to obtain certain biomass.

3.2.7 | Economic information

- **France**

Table 8 Cost associated to biomass in France

Cost category[9]	Value
Product cost	1,600 € VAT excluded for a 10 kW stove 1,680 for a 10 kW fireplace insert 4,620 € for a 20 kW wood boiler
Installation cost	440 € VAT excluded for a 10 kW stove 375 € for a 10 kW fireplace insert 1,270 € for a 20 kW wood boiler

[9] The following assumptions have been taken for costs calculation. Standard electricity cost: 14.16 c€/kWh and 100 €/year fixed cost for 6 kW. Standard gas cost : 7.05 c€ / kWh and 100 €/year fixed cost for 6,000 kWh

Operational energy costs	340 € per ton of pellets, delivered on site (i.e. 7 c€ / kWh) 115 € per m^3 wood logs (i.e. 3.3 c€ / kWh)

- **Italy**

Table 9 Cost associated to biomass technology in Italy [15]

Cost category[10]	Value
Product cost	500 €/kW P<35 kW 250 €/kW 35<P<100 kW 150 €/kW P>100 kW 2000 €/Stove (pellet stove 10kW)
Installation cost (biomass boiler)	200 €/kW P<35 kW 100 €/kW 35<P<100 kW 70 €/kW P>100 kW
Operational energy costs	Pellet: 4.5€ per 15kg, 230€ per ton, (0.07€/kWh)

- **Spain**

Prices (2016) of the biomass used in domestic applications are the following:

Table 10 Biomass prices in Spain [10].

Biomass fuel	PCI_{dry} (MJ/kg)	Moisture (%)	Price (€/t)
Pellet	18-19,5	<12	150-300
Olive pit	18	12-20	60
Fruit peel	16,7	8-15	60
Wood	14,4-16,2	20-60	90-120
Wood chip	14,4-16,2	20-60	36-80
Briquette	18-19,5	<12	150-300

– Pellet biomass boiler installation for a flat:

Table 11 Main economic parameters to value a biomass heating installation for a typical apartment in Spain [16]

Biomass pellet boiler (flat heating)	
PCI (pellet)	4306 kcal/kg

[10] The following assumptions have been taken for costs calculation. 0.243 €/kWh for households annual consumptions: 2500 kWh < consumption < 5000 kWh, according to Electricity prices for the year 2015.[05]
Fixed: about 10 €/month
0.160 €/kWh for industry annual consumptions: 500 MWh < consumption < 2000 MWh excluding VAT, according to Electricity prices for the year 2015. [05]

Pellet biomass price (+ VAT -21%)	3,50 €/15kg
Unit price	0,23
Price €/kWhth	0,046
Yearly consumption (100m^2)-heat	2.880kg; 14400kWh
Initial investment	**9.800**
Boiler+ feeding system	4.000
Installation	3.000
Heater	2.800
Costs (€/year)	**662**
Yearly increase (last 8 years)	6,07
Increase in 5 years	3.784
Increase in 10 years	9.018
Increase in 15 years	16.256
Cost in 5 years	13.584
Cost in 10 years	18.818
Cost in 15 years	26.056

– Biomass centralized heating network case:

Table 12 Main economic parameters to value a biomass centralized installation in Spain [17] .

Heating generation through district heating		
Gross thermal power	6.000 kW	
Thermal efficiency	85%	
Transport efficiency	90%	
Lifetime	20 years	
Operating hours	820 h/year	
Biomass consumption	1580 t/year (PCIh: 3500 kcal/kg)	
Biomass costs	224 €/tep	94.800 €/year
Operating costs	384 €/tep	162.450 €/year
Investment	2825 €/kW	1,69 M€
Energy production	423 tep/year	

– Another comparison that can be made, is between biomass boilers from 50-325 kW (data from 2005):

Table 13 Installation cost of biomass boilers [10]

	50kW	100kW	325kW
Biomass boiler	4.500	6.000	16.210
Automatisms (system for biomass supply to loading hopper; bank for combustion system, comburent supply system, automatic start-up system and automatic ash removal).	1.800	2.250	8.550
Connection to stack	758	947	3.600
Hydraulic system Piping; cold water, filling, emptying and expansion pipelines, expansion vessel; instrumentation.	696	870	3.305
Circulation pump to heating system	353	441	1.676
Electrical installation	1.000	1.251	4.752
Ventilations	394	492	1.871
Fire control system	151	188	715
Control system	722	903	3.431
Insulation	260	325	1.235
Total investment (no VAT included)	**10.634**	**13.667**	**45.345**
Total investment (VAT included)	**12.335**	**15.854**	**52.600**

3.2.8 | Regulatory framework and legislation applied

Technical specifications:

- CENT/TS 14588: Solid biofuels. Terminology, definitions and description.
- CENT/TS 14774: Solid biofuels. Methods to determine water content.
- CENT/TS 14775: Solid biofuels. Methods to determine ash content.
- CENT/TS 14778: Solid biofuels. Sampling methods
- CENT/TS 14780: Solid biofuels. Sample preparing methods.
- CENT/TS 14918: Solid biofuels. Methods to determine PCI.
- UNE-CENT/TS 14961: Solid biofuels. Specifications and types.
- CENT/TS 15103: Solid biofuels. Methods to determine bulk density.
- CENT/TS 15149: Solid biofuels. Methods to determine particle size distribution.
- CENT/TS 15149: Solid biofuels. Methods to determine pellet and briquette durability.

Regulation:

- The European Union's Eco design Directive (Directive 2009/125/EC)[1] establishes a framework to set mandatory ecological requirements for energy-using and energy-related products sold in all 28 Member States.
- Commission Regulation (EU) 2015/1189 of 28 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco design requirements for solid fuel boilers. This regulation includes efficiency requirements and limits of particle emissions to the atmosphere, CO, OCG and NOX from 1st January 2020 to the biomass boilers with a nominal power ≤ 500 kW.
- Commission Regulation (EU) 2015/1185 of 24 April 2015 implementing Directive 2009/125/EC of the European Parliament and of the Council with regard to eco design requirements for solid fuel local space heaters. This regulation includes efficiency requirements and limits of particle emissions to the atmosphere, CO, OCG and NOX from 1st January 2022 to the biomass boilers with a nominal power ≤ 50 kW.
- EN 303-5:2012: Heating boilers. Heating boilers for solid fuels, manually and automatically stoked nominal heat output of up to 500 kW. Terminology, requirements, testing and marking.

- **Bulgaria**

No regulation.

- **France**

Biomass is accounted for in the energy regulation, by calculating an energy consumption in terms of their efficiency. There is 30% subsidy for biomass systems if their efficiency is greater than 70%.

- **Germany**

Biomass facilities have to build a percentage of its power to be produced on demand so that fluctuations in the power grid can be balanced.

- **Italy**

The annex 3 of the current Italian legislation about the promotion of renewable energy (Dlgs 28/11), coherent with the Directive 2009/28/CE, describes the minimum mandatory amount of energy provided via the exploitation of renewable sources for new buildings or major renovations. In particular, the systems

producing thermal energy must be designed and realized to guarantee the contemporary respect to cover 50% of the expected consumption of domestic hot water (DHW) and 35% (50% from 2018 – Decreto Legge Milleproroghe) of the sum of the expected consumption of DHW, heating and cooling, using energy produced from Renewable Energy Sources (RES) plants. For public buildings, the obligations are increased by 10%.
Energy from biomass is counted as renewable energy. The current Italian legislation defines that biomass heat generators must have a minimum performance equal to 85% and respect specific technical requirements, according to DLgs. n°152 del 2006.

- **Spain**

Regulation:

- Real Decreto 314/2006,17th March, which approves the Technical Building Code. BOE n. 74 from 28th march 2006.
- Real Decreto 1027/2007, 20th July, which approves the Regulation of Thermal Installations in Buildings (RITE). BOE n. 207 from 29th August 2009.
- Real Decreto 1367/2007, 19th October, through which Noise regulation 37/2003 is developed.
- PAREER Program+ Crece: subsidies for energetic rehabilitation of buildings (IDAE): Between 20-30% of the investment in domestic biomass equipment is subsidized in order to attract the investment on this renewable technology.

Feed-in tariffs:

- Currently no support schemes in terms of feed-in tariffs for domestic renewable heating are developed in Spain.

3.2.9 | European and national Markets for the energy system

- **France**

250,000 wood stoves (100,000 using pellets), 80,000 fireplace inserts (5,000 using pellets) and 10,000 wood boilers (4,000 using pellets) are installed yearly, mainly in the residential sector.

- **Italy**

The company GSE (Gestore Servizi energetici) reports in the year 2015 an overall value of renewable thermal energy obtained through the exploitation of solid biomass for heating (firewood, pellets, and vegetable charcoal) equal to 304082 TJ. This value is distributed in direct consumptions (277342 TJ) and production of derived heat (26740 TJ).
Regarding the first group, the largest part of the solid biomass (about 97%) is used in the residential sector, where fireplaces, boilers, wood stoves, etc. are widely used (267682 TJ - residential sector, 6110 TJ - industry, 2119 TJ - trading and services, 1431 TJ - agriculture).

- **Spain**

The evolution of the installation of biomass boiler and stoves during the last 8 years can be shown in the graphs below:

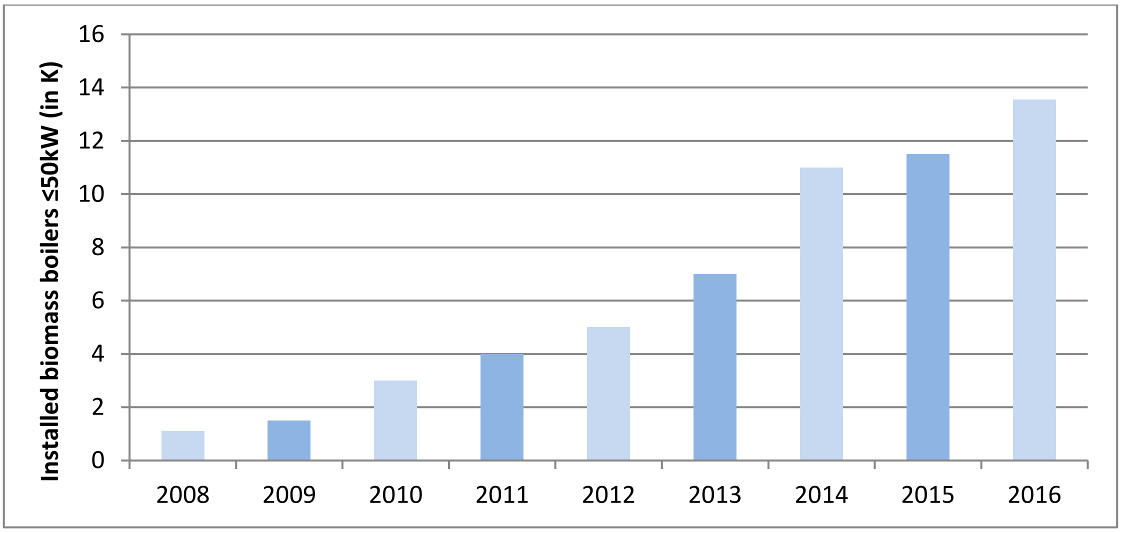

Figure 14 Evolution of the installed biomass boilers ≤ 50kW in Spain [12]

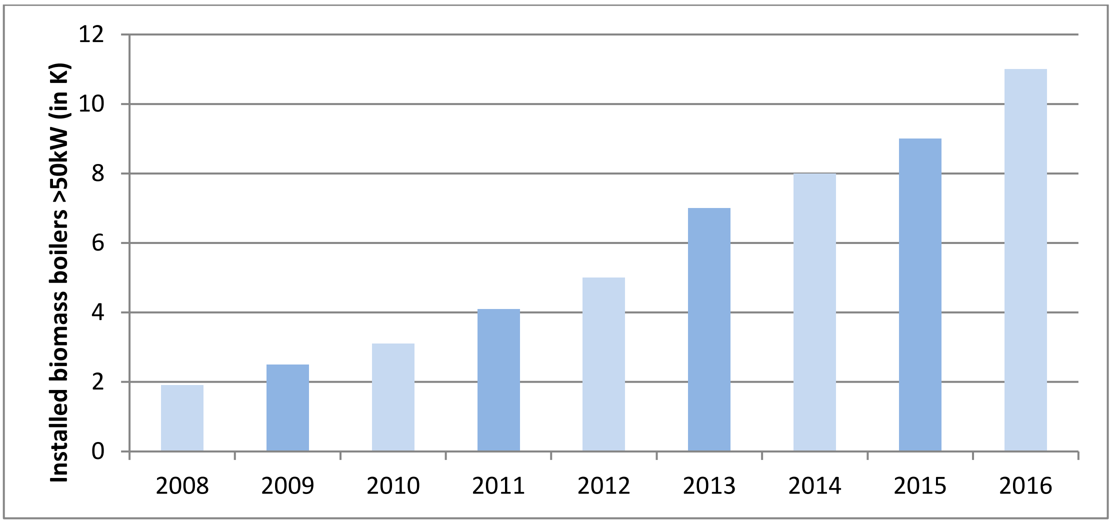

Figure 15 Evolution of the installed biomass boilers > 50kW in Spain[12].

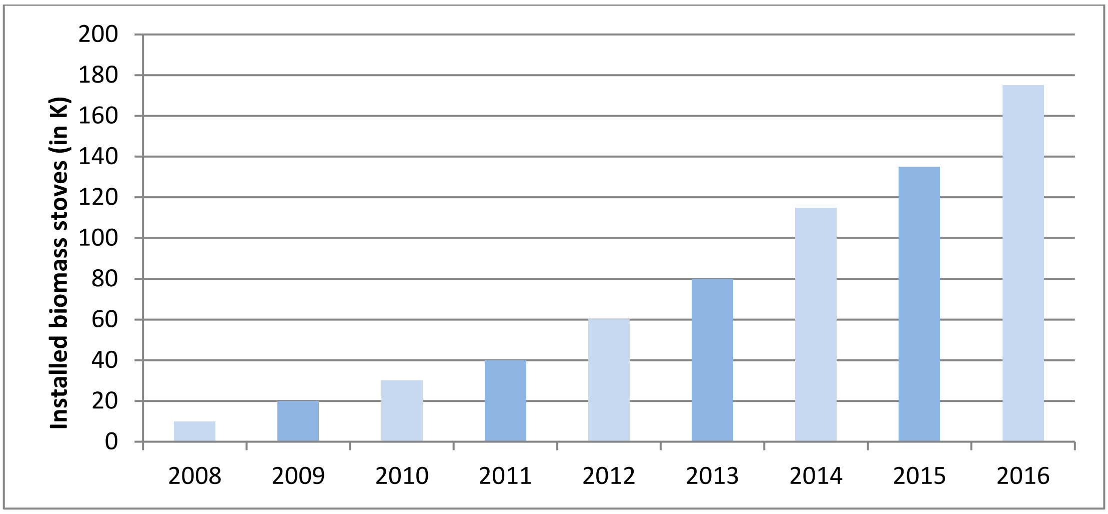

Figure 16 Evolution of the installed stoves in Spain [12]

3.3.10 | Implementation trends

- **France**

The objectives of the energy transition law are to increase the share of renewable energies in the French mix up to 32% in 2030. But there is no specific objective regarding biomass. Installing higher efficiency systems is encouraged through labelling (presently 85% with label).

- **Italy**

Biomass, historically highly developed in Italy, will have to be resized due to their negative impact on the emissivity levels (in particular thin powders): their development will address towards high quality environmental biomass generators.
About biomass generator, the following incentives are possible:

- The incentive mechanism "Conto Termico 2.0" max 65% in 1-2-5 years in relation to the amount of the incentive;
- 65% tax credit (on 10 years) for energy efficiency interventions until 31/12/2017 in terms of boiler replacement with high efficiency (>85%) biomass generators (eco bonus); from 1st January 2018 (from 1st January 2021 for the renovation of condominium) the incentive will be replaced with the tax cretit foreseen for building renovations (36%).
- 50% tax credit (on 10 years) during renovation works (Bonus ristrutturazioni); it is confirmed until 31st December 2017.

- **Spain**

The Administration is making efforts to promote the application of thermal biomass to use it as heat in heating, sanitary hot water generation and in industrial processes, according to "Plan Energético de Energías Renovables 2011-2020".
According to official data, the final energy consumption at the end of 2015 was 3.670.000 Tep and the final figure in 2020 was established in 4.850.000 Tep. The IDAE is promoting the market through the Energy Services Companies (ESE) and new financing lines through the Biomcasa program, the GIT Program (large thermal installations) and the Pareer-Crece Program (currently depleted).
As an example, Biomcasa program, was based in the BIOMCASA Program, worth 5.000.000 €, seeks to promote sector companies, previously authorized by the IDAE, acting as Energy Service Companies (ESCOs), performing projects for the sale of energy through the financing line that provides the program. The projects of thermal biomass installations in buildings developed by the companies of the program, may have financing from the IDAE with the following characteristics:

- T1: sanitary hot water and/or heating ≥50 kW (one building). Limit: 600 €/kW
- T2: sanitary hot water and/or heating > 50 kW (one building). Limit: 400 €/kW
- T3: sanitary hot water and/or heating and cooling ≤ 50 kW (one building). Limit: 800 €/kW
- T4: sanitary hot water and/or heating and cooling > 50 kW (one building). Limit: 700 €/kW
- T5: sanitary hot water and/or heating > 50 kW (two or more buildings). Limit: 500 €/kW

– T6: sanitary hot water and/or heating and cooling>50 kW (two or more buildings). Limit: 800 €/kW

Financing characteristics:

– Absolute limit of financing per project: 350.000 €.
– Maximum limit per company or business group:1.000.000 € included the financing of the previous program.
– Interest rate: EURIBOR + 4.5%.
– Maximum amortization period: 12 years.
– Standstill period (optional): 1 year.

3.3 | Heat Pumps

A heat pump is a thermal machine, subject to the thermodynamics laws, which transfers thermal energy from one source at a given temperature to another at a different temperature with high efficiency.
The advantage that heat pumps have over other systems lies in their ability to take advantage of the existing energy in the environment, either in the air, water or land.

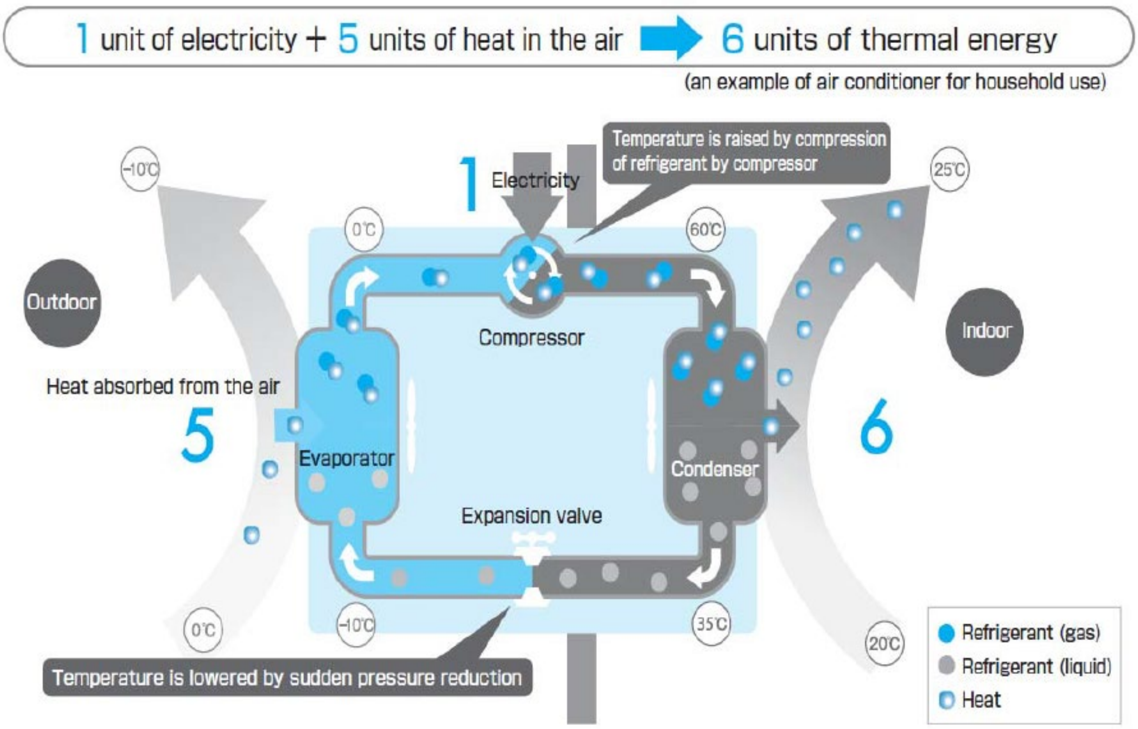

Figure 17 Mechanism of air source heat pump [19].

Heat pumps (HP) can be classified as follows:

– Air-air HP
– Air-water HP
– Water-air HP
– Water-water HP
– Ground-air HP
– Ground-water HP

Air source heat pumps use the ambient energy in outside-air or exhaust-air for heating, cooling and preparation of hot water. They can be installed as compact units entirely inside or outside the house (so called mono-bloc). Heat is commonly distributed inside the house by a hydronic distribution system or by air using fan coils or a ducted ventilation system.

Water source heat pumps use energy stored in ground, surface or sea water. Where ground water is easily available it is accessed by two drillings. One is used as a water source; the second is used to reinject the water into the ground. Heat is commonly distributed inside the house by a hydronic distribution system or by air using fan coils or a ducted ventilation system.

Ground source heat pumps use energy stored in the ground for heating, cooling and preparation of hot water. They extract heat from the ground either by a vertical or horizontal collector. Heat is commonly distributed by a hydronic distribution system or by air.

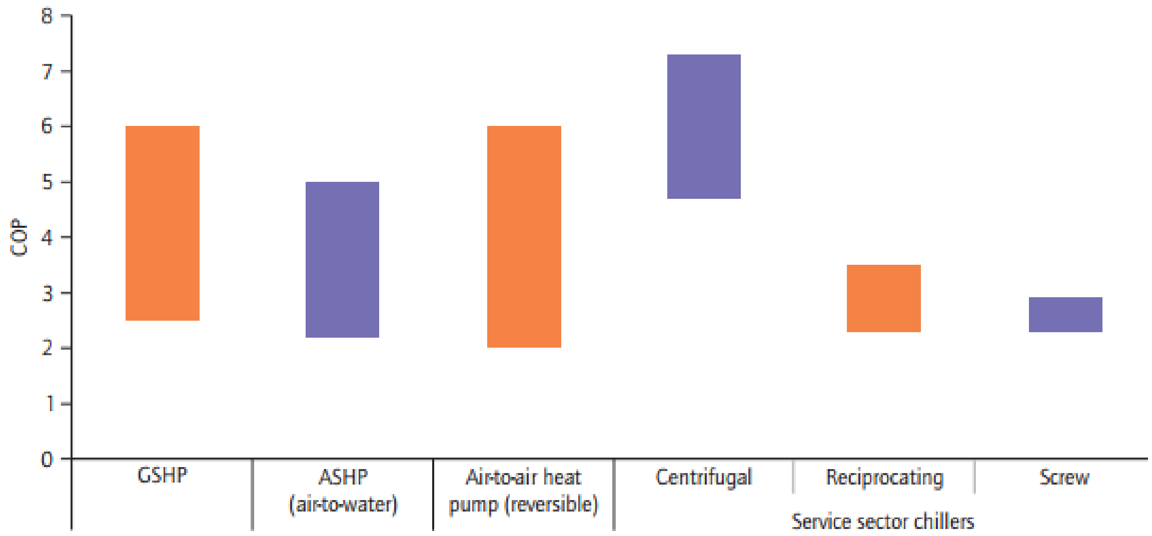

Figure 18 Typical current efficiency ranges[11] for heat pumps in heating and cooling modes by technology [26]

3.3.1 | Scale of application

Heat pumps are successfully applied in district heating systems or in combined district heating and cooling systems. Typical heat sources and heat sinks for the systems are sea water, ground water, rock or sewage, combined with other technologies (example: biomass and gas boilers, PV and solar thermal technologies with storage systems).

3.3.2 | Main applications

The heat pumps can be applied both for the air conditioning of dwelling and buildings (heating / cooling) and for the production of DHW (domestic hot water).

[11] Heat pumps have high end-use efficiencies that vary significantly depending on technology and climate.

It is a versatile and efficient system that, as well as taking part of its energy from renewable energy sources, reduces the number of emissions compared to other technologies such as condensing boilers, gas boilers, etc ...

In industry, heat pumps are used mainly in food processes, chemical processes, timber drying, pulp and paper processes and petrochemical and refining processes. Industrial heat pumps can provide a number of process-related benefits but despite these potential benefits, the number of industrial heat pumps installed to date is relatively low in comparison with the number of existing in the building sector.

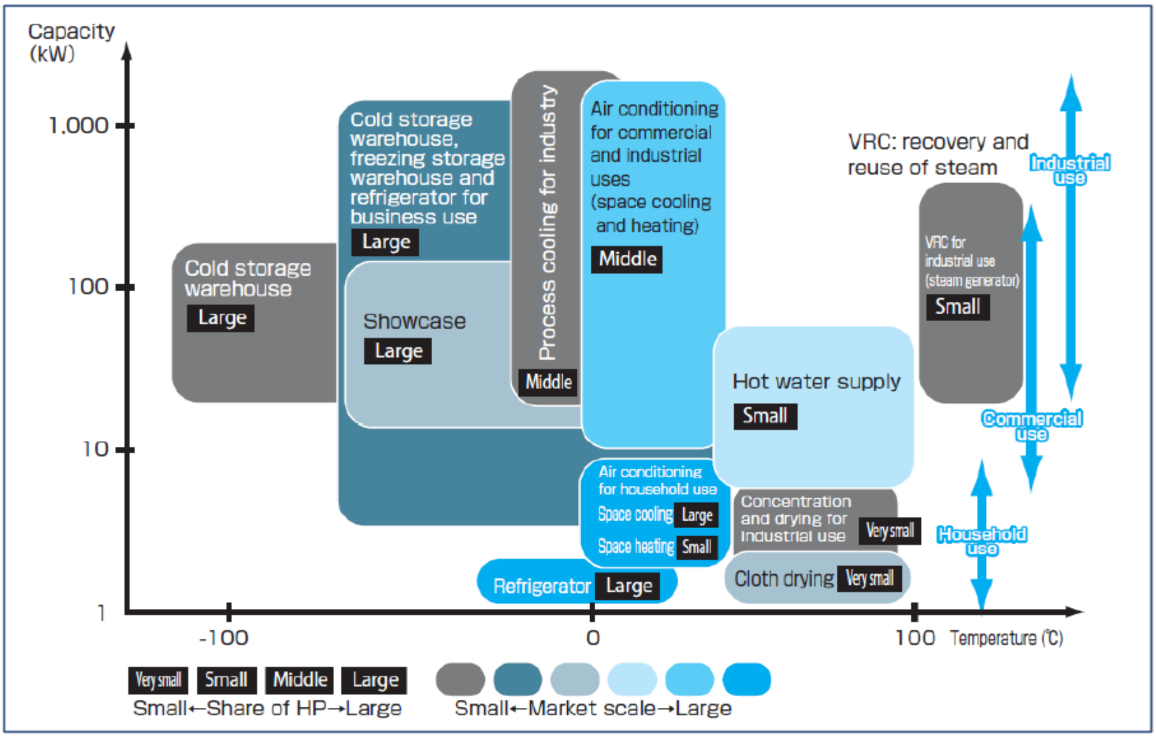

Figure 19 Heat pump application areas [21]

3.3.3 | Limitations of its application

Even though heat pump technology is mature and well established, there are still some challenges to be overcome in order to enhance overall performance and operation. Between the major limitations to heat pumps could be remark, the difference in temperature that the heat pump has to generate (lower the temperature difference the better the efficiency), the high initial cost and insufficient recognition of benefits are included.

3.3.4 | Current technologies

Heat pumps for heating and cooling were first commercialized in the second half of the 20th century, but applications in cold climates were limited to ground-source heat pumps because of the low temperatures of outdoor air.
Today's air-source heat pumps are able to supply heat even with outside air temperatures of -25°C. The market share of heat pumps for both heating and cooling applications is growing rapidly due to improved performance in terms of energy efficiency and CO_2 emissions.

The heat pump's efficiency has increased substantially over the past years as a result of technical improvements and the use of inverters and control systems. Recently, the seasonal performance factor or SPF (i.e. the ratio of heat delivered to the energy consumed over the season) of the most efficient, commercial heat pumps has reached the level of 6-7, although SPF varies considerably with the heat pump technology, heat source and operating conditions. Ground-source heat pumps (GSHPs) can serve as effective systems for space cooling (summer) and heating (winter), as in most regions the ground temperature remains stable throughout the year (i.e. .between 10-15°C). However, air-source heat pumps (ASHPs) are often the technology of choice for air-conditioning. The use of ASHPs is very cost-effective in regions where both space heating and cooling are required throughout the year.
Most advanced devices can reach co-efficient of performance or COP (i.e. the ratio of thermal energy provided to the energy consumed) of higher than six. Variable refrigerant flow (VRF) ASHPs for space heating and cooling of medium scale buildings can offer a COP above five in mild climates and above three with outside air temperatures of -10°C.
Large-scale ASHPs for large buildings or industrial processes can reach a COP above six. Among ASHPs for water heating, the so-called "Eco Cute", using CO2 as a refrigerant, can reach a COP of 5.1 (i.e. about four in terms of average annual performance factors). Large devices, such as centrifugal chillers, offer high performance for air-conditioning large buildings and industrial cooling (i.e. COP up to seven). Under certain operating conditions, centrifugal chillers with inverters, now being commercially sold, can reach a COP of up to 20. As far as cost is concerned, ASHPs are relatively inexpensive because neither underground nor water equipment is needed compared with GSHPs or water-source heat pumps. Especially room air-conditioners and VRF-ASHPs are becoming popular because of their low prices and easy installation. GSHPs are eco-friendly but expensive due to the need to bury heat exchangers underground and drill wells for heat sourcing. However, their running costs are lower.

3.3.5 | Main advantages

The main advantages of this technology are summarized below:

- Very efficient technology.
- Save energy to generate heating, cooling and hot water.
- The HP, nowadays, is the cheapest renewable technology for KW installed in the market to generate heating, cooling and hot water.
- HP has not flue gas in situ.

3.3.6 | Main disadvantages

The main advantages of this technology are summarized below :

- Space, always need an storage tank.
- HP has not instantaneous energy like an individual boiler.
- Always need a refrigerant that normally are dangerous for environment.
- Refrigerant circuit is a high pressure, so more dangerous than other technologies.
- More expensive fixed power contract with electrical companies than other technologies.

3.3.7 | Economic information

- **Bulgaria**

Table 14 Cost associated to HP technology in Bulgaria

Cost category	Value[12]
Initial design cost	500 €
Product cost	11.000 €
Installation cost	2.000 €
Maintenance cost (annual)	300€

- **France**

Table 15 Cost associated to HP technology in France

Cost category	Value
Product cost (7-8 kWth)	Geothermal ground-water: 11.250 € Geothermal water-water: 10.200€ Geothermal air-water:7400 € Geothermal air-air:5850 Hot water system, 300l (air-water):2.200€
Product cost (10-12 kWth)	Geothermal ground-water: 13.000€ Geothermal water-water: 12.800 € Geothermal air-water:10.100 € Geothermal air-air:6.790€
Installation cost (7-8 kWth)	Geothermal ground-water: 1.800€ Geothermal water-water: 2.000€ Geothermal air-water:1.300 € Geothermal air-air:1.500€ Hot water system, 300l (air-water):485€
Installation cost (10-12 kWth)	Geothermal ground-water: 2.000€ Geothermal water-water: 2.100€ Geothermal air-water:1.500 € Geothermal air-air:1.800€
Maintenance cost	150-200 €/year
Operational energy use cost:	14, 16 c€/kWh and 100 €/year fixed cost for 6 kW.[13]

- **Italy**

Table 16 Cost associated to HP technology in Italy

Cost category	Value[14]
Initial design cost	10% (on the whole plant system: generation, emission, distribution, controls).
Product cost	Air-air: 200 €/kW (up to 35 kW)

[12] Source: Opteemal project, https://www.opteemal-project.eu/

[13] Standard electricity cost: 14.16 c€/kWh and 100 €/year fixed cost for 6 kW. Standard gas cost : 7.05 c€ / kWh and 100 €/year fixed cost for 6,000 kWh Source: Iberdrola electric company

[14] ENTRANZE Project http://www.entranze.eu/

	150€/kW(35 Kw>P>100 Kw) 130 €/kW(P>100Kw) Air-water: 350 €/kW (up to 35 kW) 250 €/kW (35 kW<P<100 kW) 150 €/kW (P>100 kW) Water-water geothermal (ground): 700 €/kW (up to 35 kW) 600 €/kW (35kW<P<100 kW) 500 €/kW (P>100kW)
Installation cost	Air-air: 20 €/kW (up to 35 kW) 15 €/kW (35 kW<P<100 kW) 13 €/kW (P>100 kW) Air-water: 35 €/kW (up to 35 kW) 25 €/kW (35 kW<P<100 kW) 15 €/kW (P>100 kW) Water-water geothermal (ground): 70 €/kW (up to 35 kW) 60 €/kW (35 kW<P<100 kW) 50 €/kW (P>100 kW)
Operational energy use cost:	Electricity prices: 0,13 €/kWh + 10 €/month (VAT excluded)[15] Gas prices:0.091 €/kWh [16]

- **Spain**

Table 17 Cost associated to HP technology in Spain

Cost category	Value[17]
Product cost	GSHP : 826€/KW installed ERC18: 178€/KW installed WSAHP19: 592€/KW installed
Installation cost	GSHP: 700€ full installed ERC: 11€/KW installed WSAHP: 7,000 € full installed
Maintenance cost	GSHP: 800€/ kW installed year ERC: 17 €/KW installed, per year WSAHP: 14,5 €/KW installed, per year
Operational energy use cost:	0,117 €/KWh[20]

3.3.8 | Regulatory framework and legislation applied

[15] Source: Servizio elettrico Nazionale_Heat pump tariff
[16] Source: Eurostat
[17] Source: Opteemal project
[18] Electric Reciprocating Chiller
[19] Water Source to Air Heat Pump (WSAHP)
[20] Source: Iberdrola electric company

The European Commission published a methodology guide in March 2013 to help the countries measure the renewable energy output of their HP bases. It sets out guidelines for calculating the renewable energy share produced from heat pumps for the various technologies as stated in article 5 of the 2009/28/EC directive. The renewable energy taken into account differs with the technology and climate zone (cold, temperate and hot) of the heat pump installation site. The guide specifically cautions that heat pumps installed on air source hot water heaters only exceptionally achieve seasonal performance factors above the minimum threshold that make them eligible for inclusion as renewable energy producers.
Taking into account this methodology, from 2005-2012 heat pumps have saved up until 29.5 TWh of primary and 52 TWh of final energy. This corresponds with 0.17% and 0.41% to the overall EU energy savings.
The quantity of heat to be considered as energy from renewable sources for the purposes of the Directive shall be calculated according to the following indications:

- The minimum value of the Seasonal Performance Factor (SPF) of heat pumps that allows considering the quantity of energy produced as renewable energy (ERES according to Directive 2009/28/CE) must be:
  $SPF > 1.15 * 1/\eta$

  where η is the ratio between the total gross electricity production and the primary energy consumption for the energy production, calculate as average at EU level on Eurostat data.
- The use of reversible heat pumps for summer cooling is not recorded as renewable energy; therefore the heating mode alone can be considered (GSE 2015).

▪ Energy Efficiency Directive.
The role of heat-pump solutions in the Energy Efficiency Directive (EED), it is feasible to reach the targets of the proposed Directive if all efficient technologies are considered. The heat pumps can help reach the targets set out in the proposed Directive, such as in Article 6, which gives the Member States the option to take other national policy measures to achieve the 20% energy savings among final customers.

▪ Energy Performance of Buildings Directive (2010/31/EU).
The role of heat-pump solutions: They use 75% of renewable energy (air, water or ground) and only need 25% of electricity. The EPBD acknowledges heat pump applications in line with the RES Directive, and also explicitly mentions their reversible characteristic. Furthermore, heat pump applications fulfil the minimum energy requirements set for the building envelope. Ecofys mentions heat pumps as an important feature of the aforementioned nZEBs.

▪ Energy Labelling.
The role of heat-pump solutions: The energy label for heat pumps is based on the system's efficiency determined via ErP Lot 1, 2 and 10. With regards to the energy classes, it is as follows:

- A+++: heat pumps with an eta % primary energy > 150% for 55°C heat emitter systems and primary energy > 175% for 35°C heat emitter systems.
- G: heat pumps with an eta % primary energy < 40%.
  In fact, only heat pumps with an efficiency class of A+ and better will be allowed on the market.

- The Eco design Directive for Energy-related Products (ErP).
  Energy related products (the use of which has an impact on energy consumption) account for a large proportion of the energy consumption in the EU and include. ErP regulations exist for the following HVAC appliances:

- Space heaters up to 400 kW {gas and oil boilers, electric boilers, heat pumps (electrical and gas), cogeneration of heat and power appliances, integrated packages (space heater + supplementary space heater + solar thermal device + temperature control)}.

- Water heaters and hot water storage tanks up to 400 kW {gas or oil water heaters, electric water heaters, heat pump water heaters, solar thermal water heaters, storage tanks up to 2,000 litres, integrated packages (water heaters + solar thermal device)}.
- Air conditioners and air-to-air heat pumps up to 12 kW.

- Ecolabel.
  The EU Ecolabel is a voluntary environmental labelling scheme created in 1992. The role of heat-pump solutions: Heat pumping applications can collect heat from a range of renewable sources (air, ground, water). These applications contribute to improved energy efficiency, reduction or prevention of the risks for the environment and for human health related to the use of hazardous substances, lower global warming impact.

- **France**

Heat pumps are accounted for in the energy regulation, according to their coefficient of performance (for different hot and cold source temperatures) and using primary energy factors of electricity production according to their use (heating or hot water).

- **Italy**

The annex 3 of the current Italian legislation about the promotion of renewable energy (Dlgs 28/11), coherent with the Directive 2009/28/CE, describes the minimum mandatory amount of energy provided via the exploitation of renewable sources for new buildings or major renovations. In particular:
the systems producing thermal energy must be designed and realized to guarantee the contemporary respect to cover 50% of the expected consumption of domestic hot water (DHW) and 35% (50% from 2018 – Decreto Legge Milleproroghe) of the sum of the expected consumption of DHW, heating and cooling, using energy produced from Renewable Energy Sources (RES) plants. For public buildings, the obligations are increased by 10%.

- **Spain**

The amount of aerothermal, geothermal or hydrothermal energy captured by heat pumps to be considered energy from renewable source (ERES)s, according to the renewable energy directive, , iscalculated in accordance with the following formula:
ERES = Qusable * (1 – 1/SPF)
In Spain, the calculation of SPF must be covered by:

- EN 14825
- R.I.T.E regulation
- CE marking

3.3.9 | European and national Markets for the energy system

The heat pump market continues to be governed by three major trends:

- Air is and will remain the dominant energy source for heat pumps (note that cooling-only units are not counted in the report, see Annex II).
- Sanitary hot water heat pumps are the fastest growing heat pump segment across Europe. This category is the only one showing double-digit growth. Sanitary hot water units combine a heat pump and a hot water storage tank. They are either sold as stand-alone units with the heat pump and the tank in one casing or as systems combining a heat pump and a separate tank.
- Larger heat pumps for commercial, industrial and district heating applications are increasingly popular. They quite often use geothermal or hydrothermal energy. However also here, air is an energy source used by a number of installations. Air, water and ground can either carry renewable energy or waste heat from processes. In the latter case, this type of heat pump improves energy efficiency, but does not use a renewable source.

The figure below shows the European market evolution from 2004 to 2014.

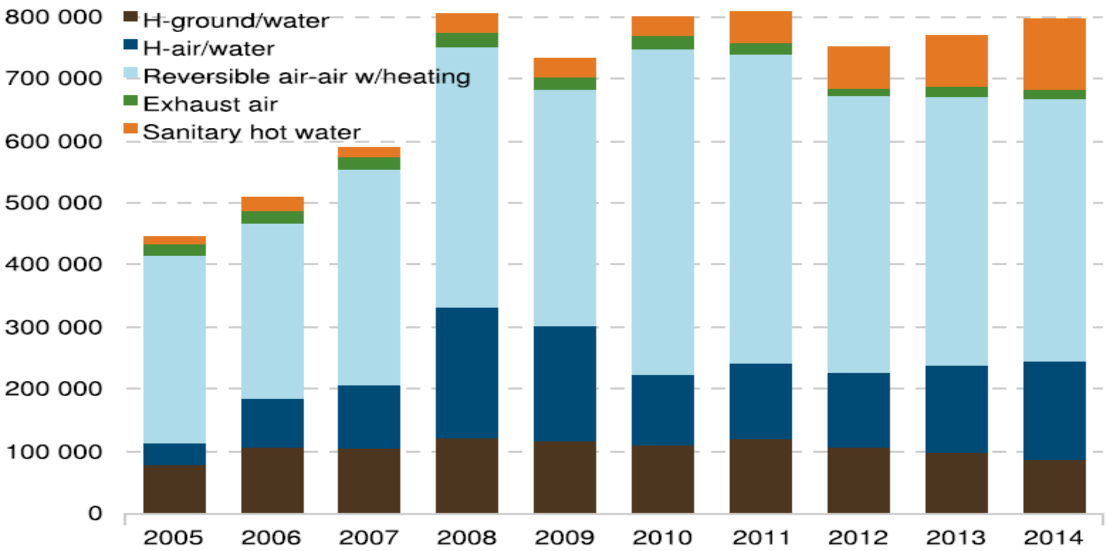

Figure 20 Market evolution during the last years, by technology (Unit/year) Development of heat pump sales in Europe 2005–2014, by category [21]

Overall, the industry is optimistic for a continued market growth and more markets returning to growth from 2015 to 2017due to a positive legal environment. For policy makers, this is good news as it provides a huge potential to reduce Europe's energy demand for heating, cooling and hot water production.
The figure below shows the split of renewable energy production from heat pumps on a country level.

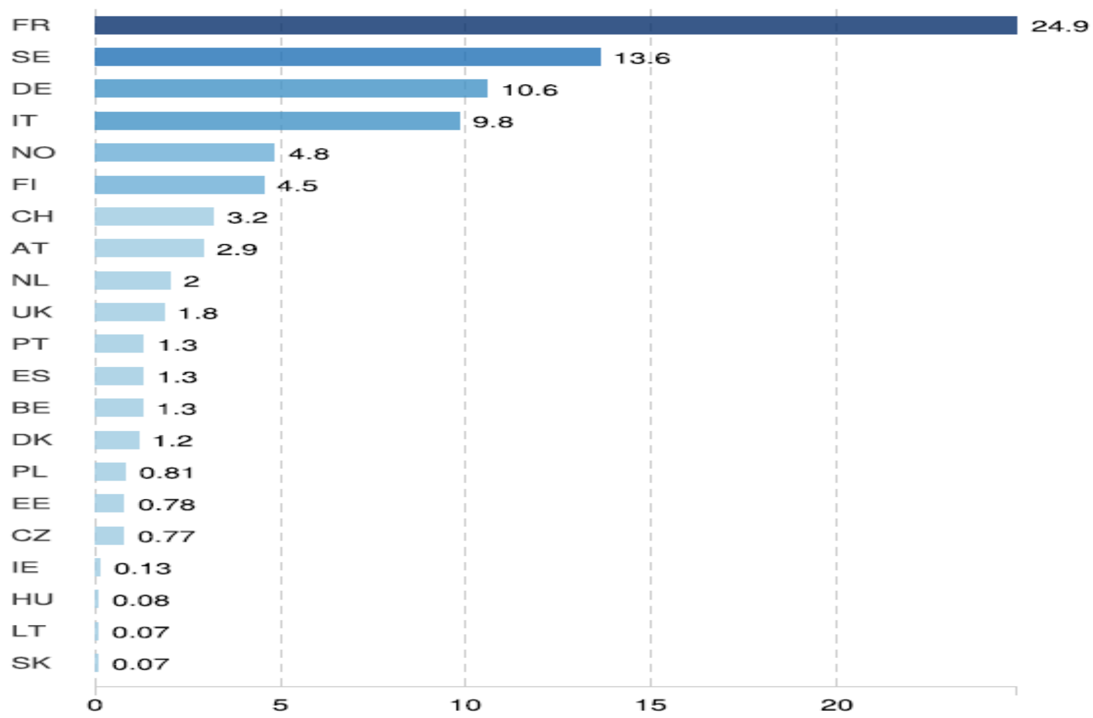

Figure 21 RES from 2014 heat pump stock, by country (in TWh) [21].

The heat pump stock in 2014 (heat pumps sold in the past twenty years) contributed to 22.1 Mt of greenhouse gas emission savings (see figure 1-4). The distribution of emission savings per country is very similar to that of renewable energy production, since both calculations are directly linked to the number of units installed.

In summary, heat pump markets are growing slightly. In light of the total heating market, this growth is insufficient to achieve the aim for decarbonisation of heating and cooling by 2050.

- **Bulgaria**

Relatively wide spread in single family houses, however no official statistics.

- **France**

The sales were the following in 2016: 372,200 air to air, 74,500 air to water, 3,100 geothermal heat pumps, and 76,500 thermodynamic hot water systems. 80% of this market is for residential buildings, 20% in the tertiary sector.

- **Germany**

37, 4% of new buildings 2016 have a heat pump heating system[21.]

[21] https://www.waermepumpe.de/fileadmin/_processed_/csm_WP-Anteile_Baugenehmigungen_2016_61f5e24fbb.jpg

The share in primary energy consumption 2016 is 0.3% [22]

- **Italy**

The company GSE (Gestore Servizi energetici) reports in the year 2015 an overall value of renewable thermal energy (Eres) provided by heat pumps (18.5 million of installed devices in Italy) in heating mode equal to 108208 TJ. This value is distributed in 104689 TJ (aerothermal), 352 TJ (hydrothermal),3167 TJ (geothermal).

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- **Spain**

According to the study carried out by the IDAE in 2014, on the National Park of Heat Pumps in Spain, heat pumps are present in 34% of all households and establishments in Spain.
Considering the 3 main climatic zones of:

- 50.2% of households and establishments in the Mediterranean area have a heat pump.
- 19.8% of households and establishments in the Continental zone have a heat pump
- 6.4% of households and establishments in the Atlantic-North zone have a heat pump

According to the annual study conducted by AFEC (Association of Air Conditioning Equipment Manufacturers of Spain) regarding the market of machines for the residential / domestic sector, the number of sales registered during the year 2016 (survey conducted among 40 national companies) reach to 662,702 Units sold, which meant 305.25 million euros invoiced.
Regarding the market of machines for the commercial sector, the turnover figure amounts to 328.09 million euros invoiced (in 2016).

3.3.10 | Implementation trends

The political and regulatory constraints should finally intensify in the renovation market. On 16 February 2015, the European Commission presented its Strategy for heating and cooling, in the form of a communication (COM 2016, 51 final), that aims to optimize heating and cooling production systems in two sectors, residential/tertiary and industry. This strategy is one of the flagship policies of the strategy framework for an Energy Union. It should contribute to improving the EU's energy security and the implementation of the post COP21 Climate Action programme.

To put an end to energy losses in buildings, maximize efficiency and increase the renewable energy share, the EU's strategy for heating and cooling primarily intends to implement a range of measures destined to simplify multi-occupancy

[22] http://www.bmwi.de/Redaktion/DE/Downloads/Energiedaten/energiedaten-gesamt-pdf-grafiken.pdf?__blob=publicationFile&v=24

building renovations, such as the installation of modern heating and cooling systems, with special emphasis on HPs. It also plans more even sharing of gains to enable tenant and owners alike to take advantage of the investments granted for renovating old buildings and apartments or for replacing their old heating installations by modern, high-performance systems that use renewable energy sources.
Heat pumps Scenario until 2020, if Europe doesn't meet its efficiency or its RES targets, heat pumps could bridge the gap (EHPA forecast based on 11,5 annual growth):

- Installed capacity: 35,6 GWth
- Energy provided: 191,62 TWhth
- RES integrated: 131,1 TWh
- GHG emission saved: 34,4 Mt (metric tonnes)
- Final energy saved: 165,2 Twh
- Primary energy save: 80,2 Twh
- Total number of units sold: 14,5 mio units

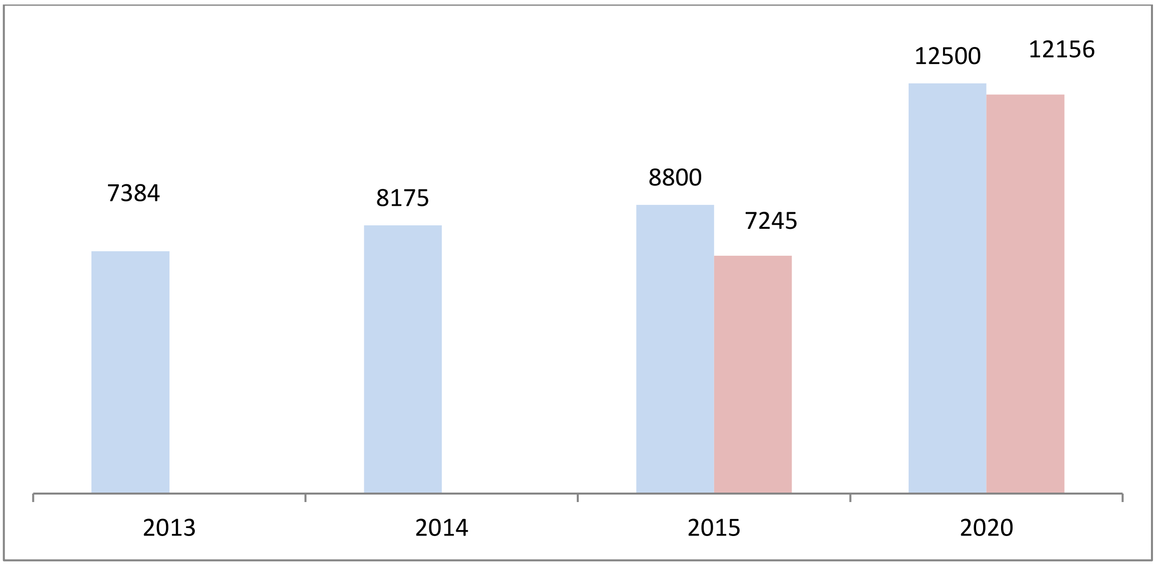

Figure 22 Actual trend of renewable Energy from heat pumps (in blue) compared with the National renewable Energy action plans NREAP (in Ktoe) [21].

EU countries have already agreed on a new renewable energy target of at least 27% of final energy consumption and a new energy efficiency target at least 40% in the EU as a whole by 2030, as part of the EU's energy and climate goals for 2030. Within this renewables-target: electric (48-50%), thermal (28-30%), transportation (17-19%).

- **Bulgaria**

Steady development and increase in the number of installations.

- **France**

The objectives of the energy transition law are to increase the share of renewable energies in the French mix up to 32% in 2030. But there is no specific objective regarding heat pumps. Choosing higher COPs is encouraged, e.g. the subsidies are provided for heat pumps except air to air (which have a lower COP).

- **Germany**

- **Holland**

- **Italy**

According to the National Energy strategy 2017 (SEN2017) Report, heat pumps will play a central role in achieving the target thanks to their high performance, while biomasses, historically highly developed in Italy, will have to be resized due to their negative impact on the emissivity levels (particularly fine particulate).
To this end, there are several alternative instruments, operating at national level for the promotion of heat pumps:

- The incentive mechanism “Conto Termico 2.0” (disbursed in 2-5 years in relation to the power of the heat pump) provides for incentives up to a maximum of 65% for heat pumps placed in substitution of the existing heating system;
- 65% tax credit (on 10 years) for energy efficiency interventions until 31/12/2017 in terms of boiler replacement with high efficiency heat pump (minimum value of COP according to DM 06.08.09) or condensing boiler (eco bonus); it is confirmed until 31st December 2017 (1st January 2021 for the renovation of residential complex). The essential condition to benefit from the tax credits is that the interventions are executed on existing buildings (or parts of buildings) with existing heating system.
- 50% tax credit (on 10 years) until 31/12/2017 during renovation works (Bonus ristrutturazioni); from 1st January 2018 (from 1st January 2021 for the renovation of residential complex) the incentive will be equal to 36%; the incentive is provided if the heat pump is used during winter heating, to integrate or substitute the existing heating plant;
- Savings in the bill thanks to the electricity tariffs reform (TD), in accordance to the EU Directive 2012/27/UE on Energy Efficiency, that shall enter into force from 2018; the elimination of the progressive feature of the electric tariff for the domestic sector implies, on the other side, a clear disincentives to energy savings and installation of energy efficient appliances.
- 10% VAT facilitation measure.

- **Spain**

In Spain, in order to meet the objectives set by the EU for 2030 (27% RES and 40% EE), the policies being implemented are focused on the implementation of renewable energies and energy efficiency improvements in general, nothing specific for the heat pumps, except for geothermal heat pumps, which have specific financial aid.
The National Building Regulation (Technical Building Code), that it is revised every 4 years, and in the coming months they are going to publish the new version that will force all new buildings to be at least classified A, according to the classification of efficiency energy consumption of buildings in Spain (i.e. almost zero energy consumption, nZEB), which will force them to be buildings with very low energy demand and a considerable renewable energy generation.

3.4 | Solar Thermal

Solar thermal energy is in many buildings , and particularly those with large hot water demand, a technically and economic viable heat energy source which is able to cover an important part of the thermal energy demand while seeking a transition into an environmentally friendlier energy generation model. Additionally, it represents the possibility of using local energy resources and reducing the dependence on fossil fuels, a scarce resource in Europe. Solar thermal systems differ from solar photovoltaic (PV) systems, which generate electricity instead of heat. The energy obtained from thermal solar collectors can be used to heat water or other fluids, and can also power solar cooling systems.

3.4.1 | Scale of application

The scale of application of solar thermal systems is very wide. From a small installation with a unique solar collector (2 square meter collector) to a big solar thermal collector fields (thousands of square meters) connected to a district heating system.

3.4.2 | Main applications

Depending on the temperature and the technology used, solar thermal energy can be divided in the following categories [23]:

- Low Temperature (< 95°C)
  - Swimming pool heating
  - Ventilation air preheating
  - Domestic water and space heating
  - Solar cooling

- Medium Temperature (95°C –250°C)
  - Industrial process heating
  - Water preheating
  - Sea water desalinization

- High Temperature (> 250°C)
  - Electricity generation
  - Testing new materials
  - Industrial process heating

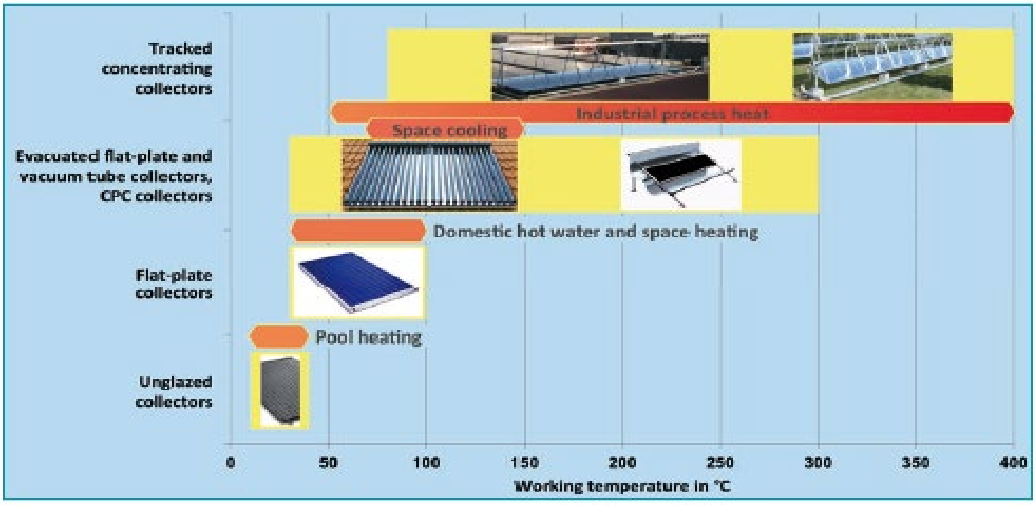

Figure 23 Temperature classification of solar thermal energy

3.4.3 | Limitations of its application

As every other emerging technology, there are several challenges and limitations solar thermal energy has to face. One of the main obstacles for solar thermal collectors is surface availability. In some cases, the surface needed is not available, affecting the production capacity of the facility and not covering the totality of the heat demand.
Other limitation is the disparity between production and consumption times. On the one hand, there is a higher heat demand in the winter months, when the weather is cold and the solar radiation is lower. On the other hand, there is a lower heating demand in the summer months when the production capacity reaches its peak. Therefore, heat storage acquires great importance in a solar thermal facility. This storage could either be seasonal, in the case of most district heating facilities (see section 4.6), or daily, in the case of domestic facilities. As heat storage represents an important economic cost, in the case of individual dwellings a lower number of modules is usually installed in order to reduce the size of the storage system and making the installation economically viable.
Finally, solar thermal production is typically installed in the same roof space as PV modules. As PV technology has dramatically reduced its price over the last decade while electricity price has risen, PV modules are progressively becoming a much more attractive investment than thermal collectors consequently reducing even more the roof surface available.

3.4.4 | Current technologies

Solar collectors could be classified in several different categories according to the characteristic being regarded.
According to the heat collection system:

- Non – concentrating.
- Concentrating.

According to the sun-tracking system:

- Stationary
- Single axis tracking
- Two-axes tracking

Despite sun tracking devices presenting better efficiencies, they require much higher investments and therefore are not commonly used in residential buildings. For this reason, this report will focus on stationary systems.
There are three main types of stationary collectors:

- Flat Plate Collectors (FPC)
- Stationary Compound Parabolic Collectors (CPC)
- Evacuated Tube Collectors (ETC)[24]

The most commonly used ones are the Flat Plate Collectors because of the reliability of the technology and their relatively low price. Evacuated Tube Collectors are mainly used with parabolic reflectors and a tubular absorber.
FPC presents the next main elements:

- The glazing. The ideal solar glass is transparent to short wave radiation but opaque to longer wave lengths. This way the greenhouse effect inside the module can be maximized. However FPC without glazing in the market can be found in the market and are a suitable solution to very low temperature applications.
- The absorber plate. It is the dark plate that absorbs the incoming radiation to heat up the fluid in pipes attached to the plate underneath.

– Insulation and fluid pipes. Good insulation has to be assured in order to achieve a high temperature inside the solar collector. Afterwards, the collected heat has to be transported to the building through metal pipes that should also be properly insulated to minimize transportation losses.

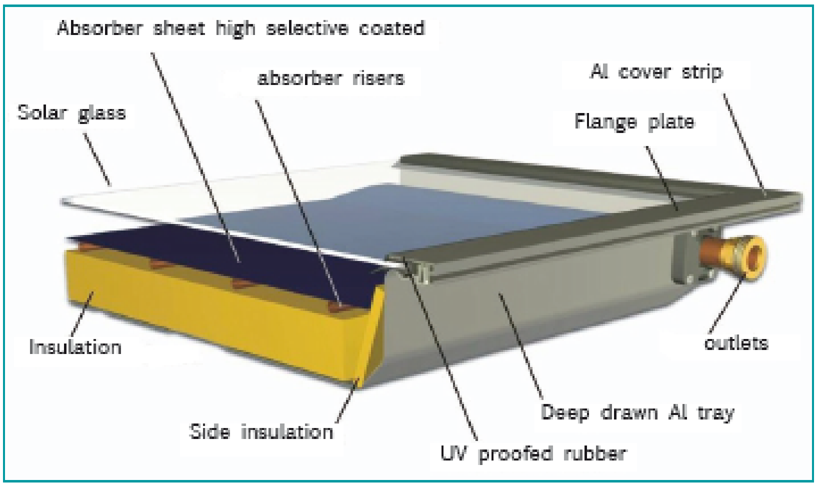

Figure 24 Components of a solar thermal panel.

3.4.5 | Main advantages

The main advantages are listed below:

- Climate protection, clean and renewable source of energy
- Stable price, while fossil fuel price is expected to rise
- Security of supply: reduce the dependency on fossil fuels
- Investment at national and local level
- Long-term local jobs

3.4.6 | Main disadvantages

The main disadvantages are:

- Not always competitive with fossil fuels or with other renewable energy technologies at current prices [23].
- Mismatch between the supply of solar irradiation and the demand for heat
  - Need for storage of the energy
  - No energy generation at night and less in the winter
  - Overheating in summer
- Roof surface is not always available or does not count with optimum orientation

3.4.7 | Economic information

The potential of cost reduction is still considerable,and since 1995, production costs have been cut by nearly 50%.
To calculate solar heat costs, the installed solar thermal system price is more relevant than the collector production costs. Dependent on the size of the system, costs for the collector area represent typically between 20% and 40% of the whole system. However, today's system prices cannot be compared with prices in the past, since in the meantime both the quality and the solar fraction

of systems have improved significantly by an increased efficiency and larger collector areas.

On the other hand, in recent years prices have rather stagnated, since lower components prices were often offset by increased distribution and installation costs.

In some countries, the installation costs of small domestic hot water systems may reach 50% of the investment.

In the future, it is expected that the price of components and systems, as well as installation, will continue to decrease.

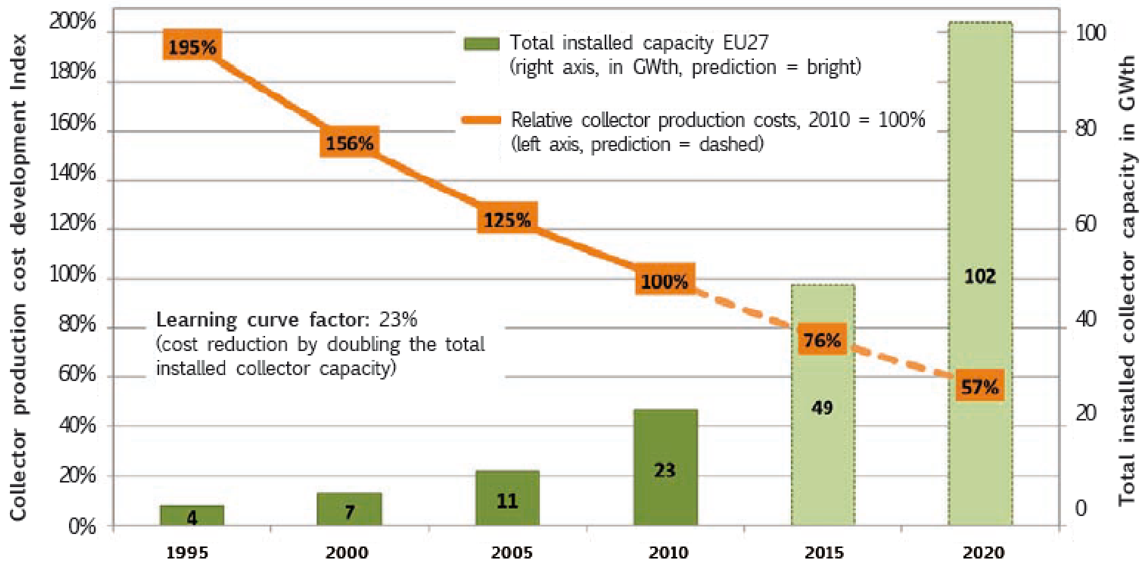

Figure 25 Collector production costs development for high – efficient flat plate collector panel of about 2.2 to 2.5 m2 gross collector area manufactured in Europe based on market expectations of the National Renewable Energy Action Plans (NREAPs).[23]

- **France**

Table 18 Cost associated to solar thermal in France.

Cost category	Value[23]
Installation cost	1200 €/m² collector for a complete solar hot water production system
Operational energy use (annual) cost	30-80 kWh $_{el}$ /m² collector (pump and control)

- **Italy**

Table 19 Cost associated to solar thermal in Italy.

Cost category	Value[24]

[23] Standard electricity cost : 14.16 c€/kWh and 100 €/year fixed cost for 6 kW. Standard gas cost : 7.05 c€ / kWh and 100 €/year fixed cost for 6,000 kW.

[24] Electricity prices: 0.243 €/kWh for households annual consumptions: 2500 kWh < consumption < 5000 kWh, according to Electricity prices for the year 2015 [ref. Eurostat] .Fixed: about 10 €/month

Initial design cost	5 €/m²
Product cost	600 €/m2 of panel if A<10 m² 550 €/m2 of panel if 10<A<40 m² 500 €/m2 of panel if A>40 m²
Installation cost	260 €/m2 of panel if A<10 m² 240 €/m2 of panel if 10<A<40 m² 210 €/m2 of panel if A>40 m²
Operational energy use (annual) cost	30-80 kWh $_{el}$ /m² collector (pump and control)

- **Spain**

Table 28 Cost associated to solar thermal in Southern Europe

		DHW (Southern Europe) thermosiphon Southern Europe		Industrial process heat low to high temperature Southern/Central Europe	
		low	high	low	high
Typical system price (installed)	€/system	750	3000	175000	400000
Collector area	m²	2,4	2,4	500	500
Avoided costs	€/system	150	150	0	0
Effective system price	€/m²	250	1188	350	800
Effective system price	€/KWth	357	1696	500	1143
System O&M costs annually	%/a	1%	1%	2%	2%
System O&M costs during lifetime	€/m²	38	238	140	320
Total costs - investment and O&M	€/m²	288	1425	490	1120
Total costs - investment and O&M	€/KWth	411	2036	700	1600
Expected lifetime of the system	a	15	20	20	20
Discount rate	%	3%	3%	3%	3%
Capital recovery factor	%	8,38%	6,72%	6,72%	6,72%
Annual horizontal radiation	kWh/m²	1585	1585	1585	1091
Solar yield factor for type		0,44	0,44	0,44	0,44
Annual solar energy yield	kWh/m²	697	697	697	480
Cost of solar heat supplied	€-cent/kWh	3	11	4	12

3.4.8 | Regulatory framework and legislation applied

- **France**

Solar thermal systems are accounted for in the energy regulation, allowing the plus energy level to be reached. Investment is subsidised by 15%.

0.160 €/kWh for industry annual consumptions: 500 MWh < consumption < 2000 MWh excluding VAT, according to Electricity prices for the year 2015 [ref. Eurostat].

- **Germany**

Communities and cities can determine that you have to include renewable energies into your building concept.
The Erneuerbare-Energien-Wärmegesetz (EEWärmeG) a law on renewable energies requires a minimal level renewable energies for new buildings and retrofits with an increase of living are of more than 50m² [26]. According to this law the solar energy share has to be at least 15%. For this you have to have 4% of the usable space filled with solar collectors [26]

- **Italy**

The annex 3 of the current Italian legislation about the promotion of renewable energy (Dlgs 28/11), coherent with the Directive 2009/28/CE, describes the minimum mandatory amount of energy provided via the exploitation of renewable sources for new buildings or major renovations. In particular:
the systems producing thermal energy must be designed and realized to guarantee the contemporary respect to cover the 50% of the expected consumption of domestic hot water (DHW) and the 35% (50% from 2018 – Decreto Legge Milleproroghe) of the sum of the expected consumption of DHW, heating and cooling, using energy produced from Renewable Energy Sources (RES) plants. For public buildings, the obligations are increased by 10%.

The obligation can be satisfied through a combination of energy sources and technological solutions that, summed up, are able to reach the minimum required percentages. For example, a solar thermal system could be coupled to a heat pump, a condensing boiler, or a biomass boiler.

- **Spain**

Current Spanish construction technical code (CTE) in its section DB-HE4 specifies the minimum contribution to the DHW demand that has to be supplied by solar thermal energy. This legislation applies to all new and rehabilitated buildings, and stablishes different contribution obligations according to the climatic zone of the building. However, this document also stablishes that it is not mandatory to install solar thermal modules if this minimum heat supply is provided by another renewable energy source or if irradiation conditions are too adverse.

3.4.9 | European and national Markets for the energy system

In 2015, the European market faced again a contraction of the newly installed capacity, which totalled 1.9 GWth (approximately 2.7 million m²). This represents a decrease of 6.6% in comparison with 2014. The total installed capacity augmented by 1.4 GWth, attaining 33.3 GWth (47.5 mio m²). It represents an increase of 4.4% on the total installed capacity by the end of the previous year.

- **France**

The production is 140 ktep yearly. 200,000 m2 collectors are installed yearly (50% for single family houses, 25% apartment buildings and 25% for both hot water and space heating). Flat plate collectors constitute nearly 100% of the market; there are a few unglazed collectors for swimming pools and very little vacuum collectors for refrigeration.

- **Germany**

In 2014, the leading European solar thermal market encountered further setbacks for the third consecutive year, following a trend initiated in 2008. With only 0.9 mio m², the market has slipped back to 2004 levels and more than halved since the record year of 2008. In 2014, the total cumulated area grew approximately to 12.9 GWth (18.4 mio m²). A decrease of 12 % from year to year reveals that both the technology and the market face major difficulties in Germany. The average size per installed system has continuously decreased to around 5 m² for hot water systems and 12.5 m² for combi systems for one and two family homes. The support for solar combi systems for hot water and space heating, which remained unchanged until March 2015, proved not to be sufficient to stimulate the market. [29]

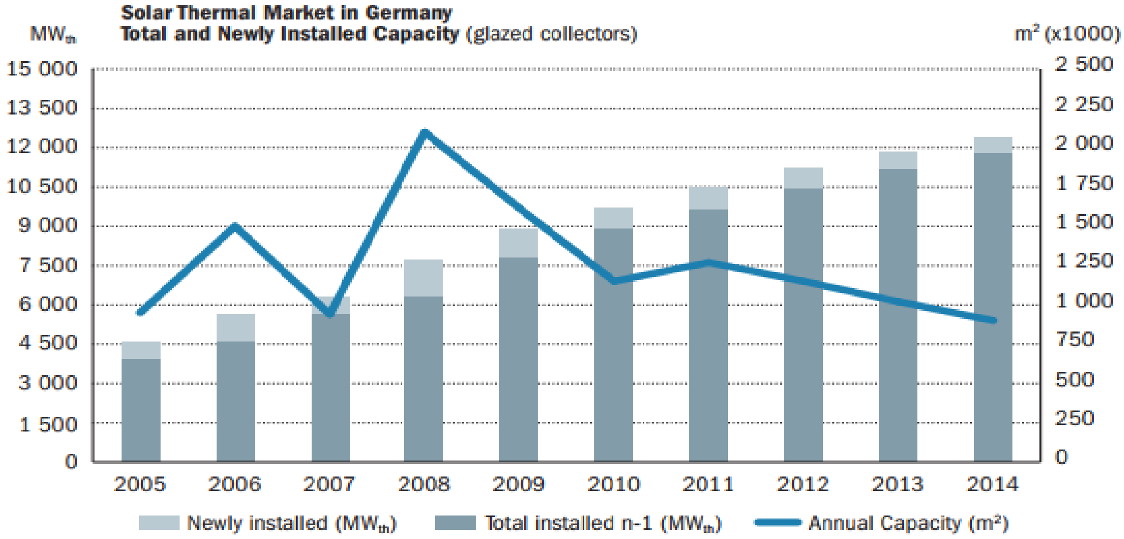

Figure 26 Solar thermal market in Germany from 2005 to 2014.[29]

- **Italy**

The company GSE (Gestore Servizi energetici) reports at the end of 2015, more than 3.7 million square meters of thermal solar collectors installed in Italy (in terms of opening area). It shows in the year 2015 an overall value of thermal energy by the exploitation of solar energy equal to 7953 TJ (up 5.8% over 2014 and 22% over 2012) distributed in 5884 TJ (74% residential sector-DHW), 398 TJ (5% industry), 1591 TJ (20% trading and services-sport facility), 80 TJ (1% agriculture).

- **Spain**

The Spanish market has finally stabilised after four consecutive years of decline, when the market almost halved (-47%). The newly installed capacity reached 178.5 MWth, with an increase of 9.8%. In spite of the building sector crisis, the new build is still expected to represent between 100 to 125 MWth (143000 to 178500 m²). The main reason behind the results achieved in the Spanish market in 2014 was the growth reported in Andalusia, the only region still actively supporting solar thermal. Aggressive marketing strategies applied by the region's major players have created a significant increase in demand, more than doubling the regional market (estimated to have represented 60 MWth in 2014). By the end of 2014, the installed capacity in Spain totalled 2.24 GWth, an increase of 9% over one year period. This installed capacity represents an estimated 2.24 TWth of heat generation, only 20% of the 2020 target for solar thermal set by the Spanish government.

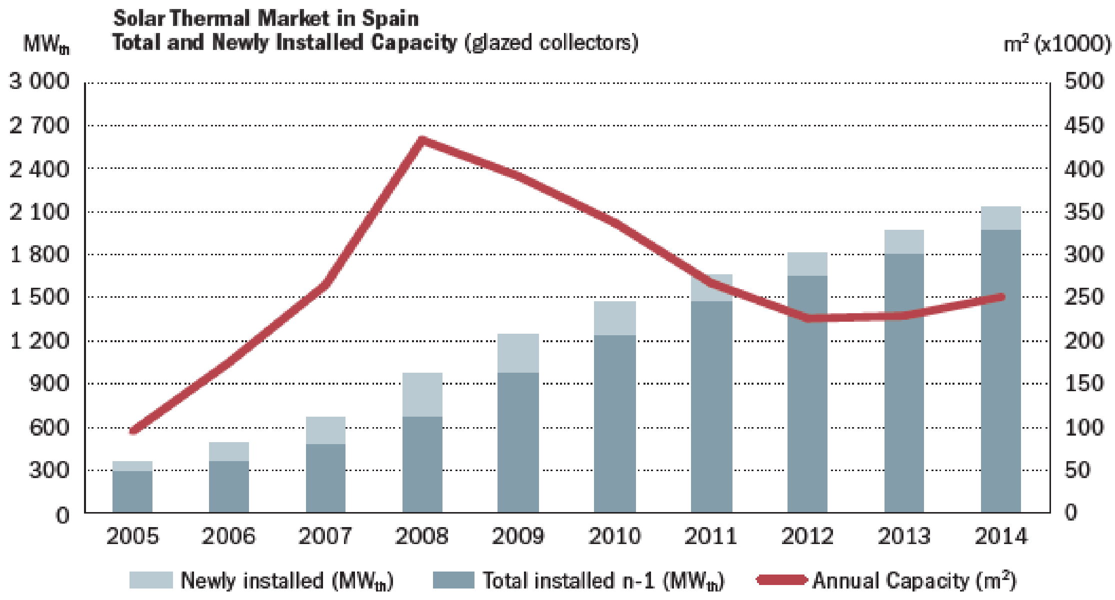

Figure 27 Solar thermal market in Spain from 2005 to 2014. [29]

3.4.10 | Implementation trends

In the next figure European solar thermal installation capacity goals for 2020 can be seen.

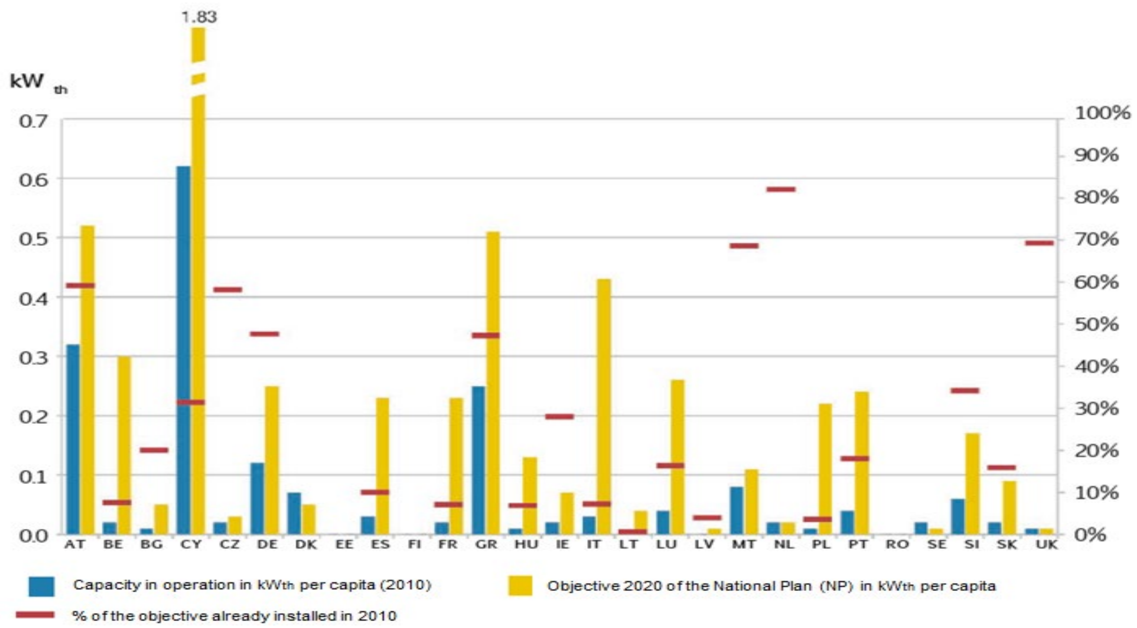

Figure 28 Analysis of 2020 targets for solar thermal energy [23] [23].

- **France**

The objectives of the energy transition law are to increase the share of renewable energies in the French mix up to 32% in 2030. But there is no specific objective regarding solar thermal systems and the evolution of this sector is uncertain.

- **Italy**

EU countries have already agreed on a new renewable energy target of at least 27% of final energy consumption in the EU as a whole by 2030 as part of the EU's energy and climate goals for 2030. Within this renewables-target: electric (48-50%), thermal (28-30%), transportation (17-19%).
According to the National Energy strategy 2017 (SEN2017) Report, solar thermal systems have shown insufficient cost reduction and technological innovation. It is therefore necessary an effort, even by producers and installers, to ensure this option has a non-marginal role, even in the light of opportunities offered by the legislation about the minimum share of renewable sources in new or deep retrofitted buildings.
To this end, there are several instruments, operating at national level for the promotion of renewable sources for thermal uses. The ones concerning solar systems are:

- The incentive mechanism "Conto Termico 2.0" provides for incentives calculated according to specific parameters whose value depends on the producibility of the solar panel;
- 65% tax credit (on 10 years) for energy efficiency interventions until 31/12/2017 if the solar panels are installed on existing buildings;
- 50% tax credit (on 10 years) until 31/12/2017 during renovation works (Bonus ristrutturazioni).

- **Spain**

European renewable energy targets for 2020 have strongly influenced Spanish energy strategy. In Figure 29 it can be seen how Spanish Solar thermal production has steeply grown over the last 8 years. Especially between 2011 and 2013 solar thermal production in Spain experienced its greatest rise, achieving 2.3 operating GW of thermal energy in 2017 [27].

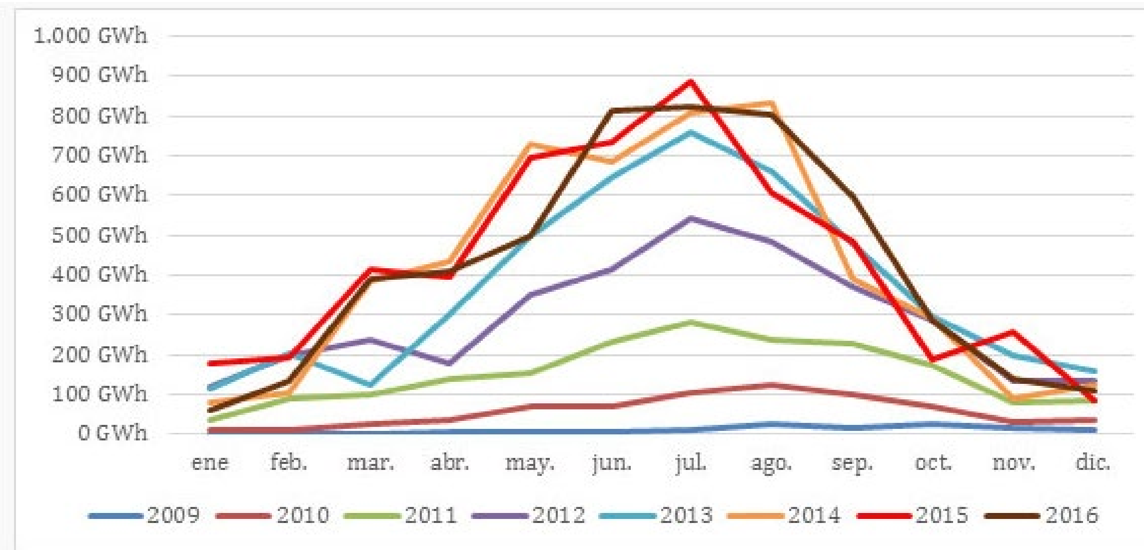

Figure 29 Solar thermal production in Spain from 2009 to 2016 [27].

Affordable Zero Energy Buildings

4 | Integration of renewable energy technologies into district energy systems.

4.1 | District heating and cooling system for integration of renewable energy sources

District energy, both heating and cooling, tie together the energy generating sources in a city with buildings and facilities having a need of heating and/or cooling. Instead of each building having its own heating or cooling system, the energy is delivered to several buildings in a larger area from a central plant. The water based distribution system guarantees that heat and cooling arrive safely to the end users. With district heating, energy is saved overall, as it takes advantage of resources that would otherwise not be have been used, making it an efficient and sustainable solution to satisfy the local heat and cooling demand in a city.

District heating is the most wide spread of the two types of district energy; heating and cooling. To transport heat efficiently, the district heating distribution infrastructure comprises a network of insulated pipes, delivering heat in the form of hot water, from the generation site to the end user. Networks can measure from a few hundred meters to covering entire large cities. End users range from residential buildings to offices and industrial facilities. The network's coverage can easily be extended by laying more pipes, often in combination of adding more points of generation.

The energy generated in the European district heating systems (Sweden, Finland, Germany) primarily comes from renewable or recycled fuels. The fuels mainly originate from residuals from the forest industry, household waste or residual heat and waste from industries. Other energy sources include: biomass and biogas, natural gas, fossil fuels, heat pumps or boilers and solar or geothermal sources.

Power and heat generation companies mix fuels and generation methods, depending on economic and environmental considerations. By not being dependent upon a specific fuel source, a reliable service is guaranteed and enables price competition in the supply chain.

After the heating process in the central plant, the hot water is transported through isolated pipes under high pressure and the water temperature remains between 70-120°C, depending on the season and weather. Upon arrival, the building heat exchanger uses the district heating system hot water to heat its own water system for tap water and radiators in the building. Smart metering and control systems give customers the opportunity to adjust their own heat consumption.

Figure 30 District cooling and heating of Stockholm with sustainable and locally recovered energy sources.[30]

The district cooling is based on the same distribution principle as district heating, and can be generated by different fuel sources and techniques. Free water cooling is a common technique, using sea or lake water in order to cool the water in the system. Heat pumps, generating both, heating and cooling, as well as cooling machines can also be used. Another way is to use the heat energy from the district heating in cooling sorption machines.

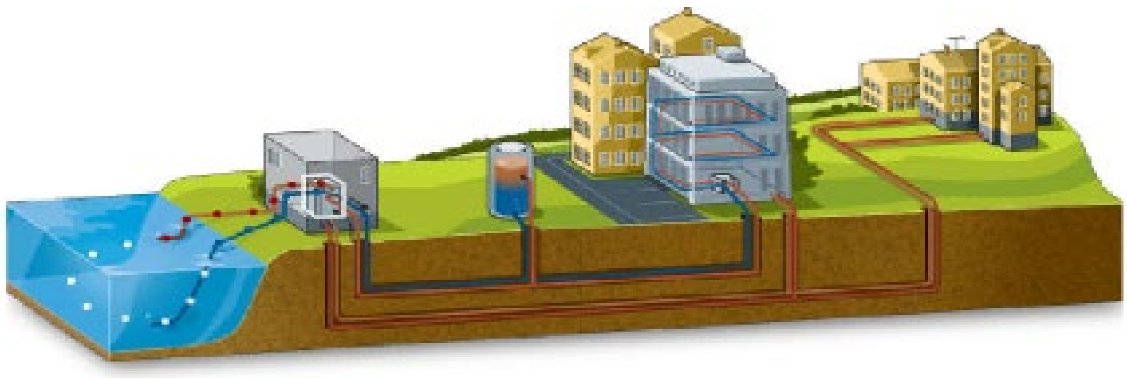

Figure 31 Layout of district cooling using free cooling with sea water.[30]

The common denominator for the different techniques to generate district cooling are the minimal levels of energy consumption and the low impact on the environment, compared to cooling through building specific facilities. A central district cooling generation plant is run more efficiently, mainly based on sustainable energy sources, such as free cooling.

4.2 | Waste heat recovery

Waste heat recovery is the transfer and use of residual heat from a thermodynamic cycle, industrial process or a different heat source such as the operation of computers in a data centre, which would otherwise be discharged into the environment. This residual heat with high operating temperatures can be used as useful heat at lower temperatures in the same system (preheating) or transferred to an adjacent system for further energy generation such as Rankine cycle for electricity generation and district heating network for space heating.

The more extended focus of waste heat recovery are the exhausted flue gases which are discharged to the atmosphere through the stack, at a temperature from 300-500°C, depending on the industrial process. Generating steam is a profitable way of reusing high-temperature waste heat. This can reduce the load on process steam boilers and allows you to save fuel or use the extra capacity for electricity generation. The most of the heat recovery installations include highly efficient waste heat recovery boilers that extract heat from hot flue gases and generate steam or hot water. A boiler is easily added to your flue gas stream and recovers heat that would normally be released into the air through a chimney. There are many possibilities to profit from recovered heat. It can be used for process heating, electricity generation or for district heating.

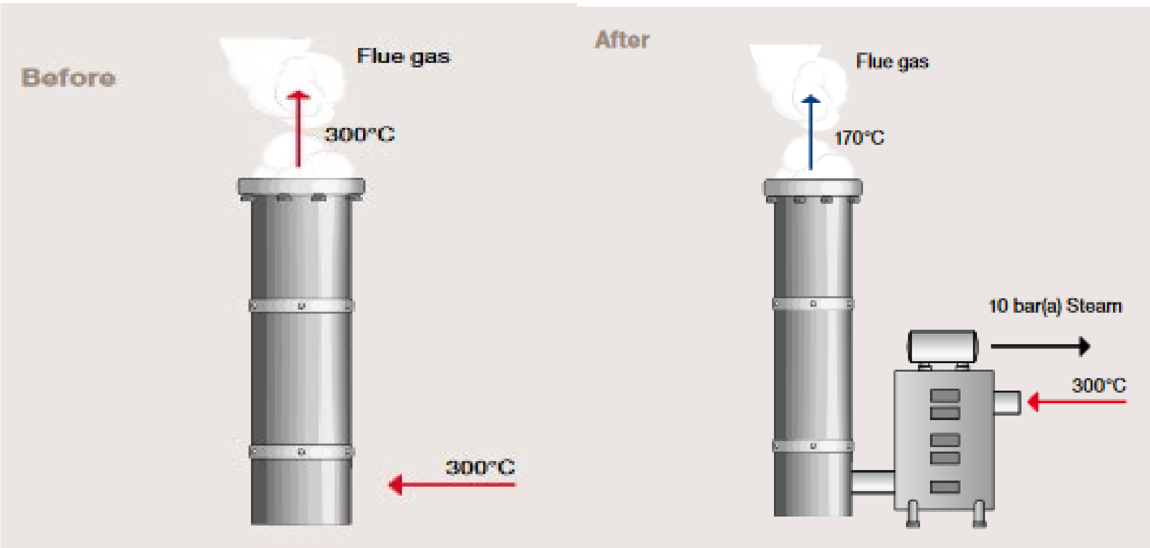

Figure 32 Layout of district cooling using free cooling with sea water.[31]

An example of this type of integration of waste heat recovery applied to district heating can be observed in a project framed on the 7th Programme FP7/2007-2013 in which Tecnalia participated and called PITAGORAS. The aim of this project was the installation of a real scale pilot plant for waste heat recovery from fumes of an Electric Arc Furnace (EAF) in a steel mill located in Italy. Waste heat is used to produce steam in a Waste Heat Recovery Unit, which is then used for two different purposes: the steam goes through heat exchangers to deliver heat to the city district heating network (winter time) or feeds the ORC unit to produce electricity (summer time). Figure 33 shows schematically the main idea of the developed system.

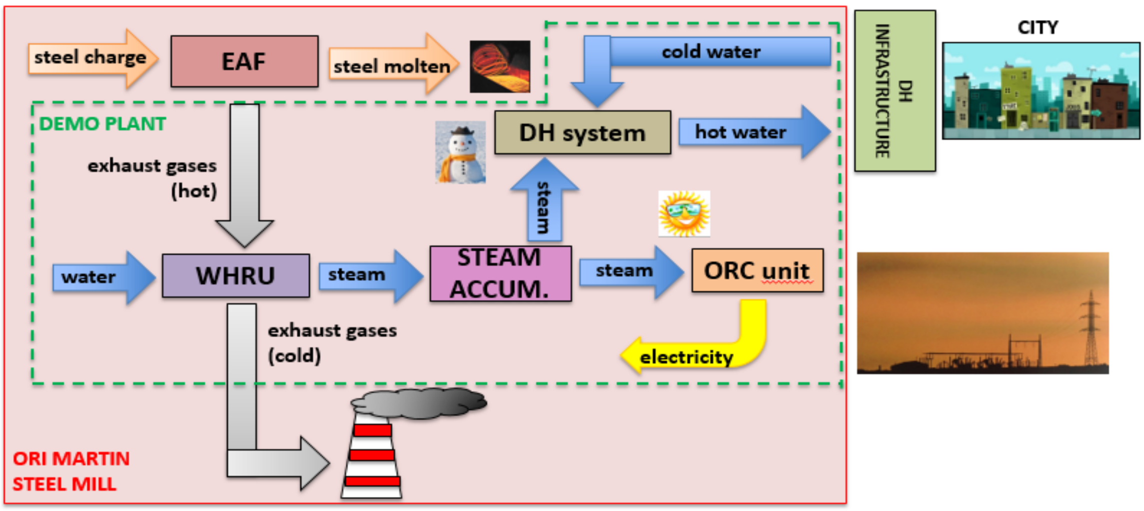

Figure 33 Conceptual scheme for waste heat recovery in an steel mill for electricity and district heat generation.[32]

During winter time, from October to April, the ORC is not working and the steam is used for district heat production. The heat supplied by this pilot plant is expected to represent around 3% of the total heat consumed within the DH network. Supply and return flow temperatures of the DH network vary during the year.

The saturated steam from the main distributor and stored in the Accumulator is directed to the DH system distributor, where the steam is divided into two flows and directed to two DH heat exchangers. Both units are equal and the design thermal capacity is 5 MWth each approximately. At these condensing heat exchangers, the steam exchanges its latent heat with the water flow circulating within the DH network. The outlet condensate from both heat exchangers is stored in a Flash tank. In the upper side of the Flash tank, there is a Condenser, where the condensate exchanged its remanent heat with the return cold water from the DH network, in order to be preheated before entering in the heat exchangers.
Supply and return flow temperatures of the DH network vary during the year. The average supply/return temperatures are around 95-120°C/60-85°C. The return flow enters first to a Condenser and to the two heat exchangers afterwards.

Table 20 DH system average production data. [32]

Thermal power heat exchangers	10 MW_{th}
Input operating pressure / temperature to heat exchangers	10barg / 185°C
Average flow rate to DH network	140 m^3/h
Hot water average supply temperature to DH network	95°C/120°C
Hot water average return temperature from DH network	60°C/85°C
DH system average availability (during 6 months)	95%
Expected annual thermal energy generation	26.500 MWh_{th}/year

4.3 | Biomass

District heating is often associated with biomass. High and consistent base loads are well suited to the operation of biomass boilers and the opportunity to spread capital costs over a number of properties can make economic returns more attractive. There are other benefits to having centralised plant and fuel storage which can be more efficient in space and in energy terms.
Heat networks can be implemented at different scales ranging from a handful of connected sites up to whole towns or cities properties. Urban areas are generally favoured due to the cost of pipe work and density of heat users.
Where there is sufficient demand, district cooling can also be provide through absorption cooling technologies.
Key parameters for judging and comparing the feasibility of a district heating system include the areal energy density and the line load.
Areal energy density is the ratio of the total energy demand (in MWh or GWh) and the geographical area (in km2) of the proposed system. The line load is the ratio between the total energy demand and the total length of pipes (in km)

in the network. Values will vary between regions, in Sweden for example, an annual areal density of 5 MWh/km2 (or 5 kWh/m2) and line loads of between 200-300 kWh/m would be would be considered acceptable. Areal energy densities can be increased by incorporating larger heat users which can provide a good base load for the system. Low line loads indicate relatively high system losses from pipework which may be remedied by relocating the plant room or re-routing the network.

District heating systems will contain three circuits (Figure 34), one for the boiler, one for the distribution network and one circuit for the consumer. Within the consumer circuit there is separate circuit for domestic hot water. The circuits are thermally connected by two plate heat exchangers, one on the biomass boiler side and one on the customer side.

The circuits are separated to prevent the boiler from being emptied of water in the event of a leak in the distribution system. The size of the distribution system in relation to the boiler means that even a small leak could empty the boiler of water quickly and cause a lot of damage.

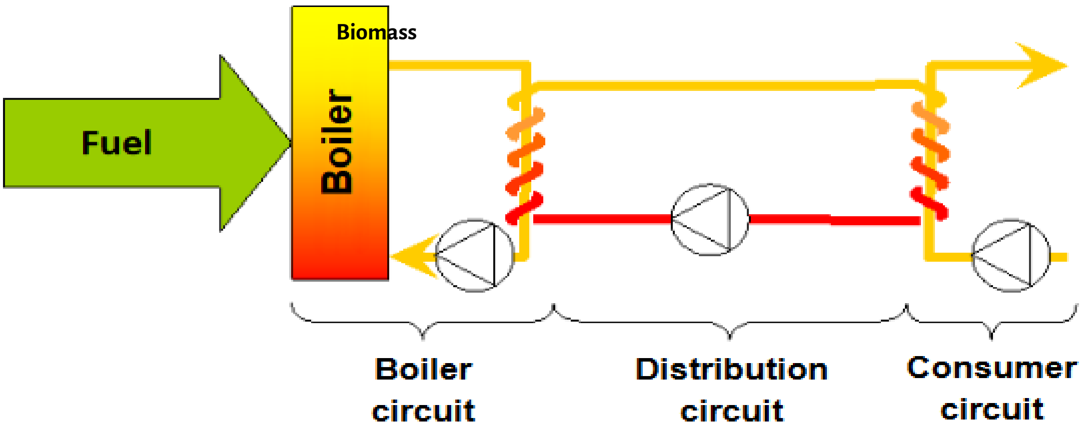

Figure 34 Circuits in a district heating system.FOREST. A guide specifying biomass heating systems. FOREST stands for "Fostering Efficient long term Supply partnerships". The project is funded by the European Commission through Intelligent Energy Europe (IEE). www.forestprogramme.com.[34]

– Biomass Boiler

Boilers designed for district heating up to about 10MWth are usually of the moving grate variety and will produce hot water and/or steam. These boilers are very robust and are often designed to take a range of biomass, especially the lower value, high moisture biomass. These boilers have substantial refractory linings and larger combustion chambers. This means that the boiler takes longer to get up to ignition temperatures but less sensitive to changes that might otherwise result from the introduction of wet biomass. As a result wet wood boilers are generally more expensive than those that are designed to take drier fuels. To have a high total efficiency it is important to maximise the difference between the flow and return temperature (referred to as a high Delta T or ΔT). With return temperatures, preferably below 50°C, this indicates that the largest amount of energy is being extracted from the heated water. At the same time keeping flow temperatures as low as possible (perhaps 65-70°C in the summer) will help to minimise losses in the network.

– The distribution network

The quality of the distribution network is of key importance to the economics of a district heating system. It is an important factor in reliability and also in managing system losses. In smaller systems network, losses can be in the range of 10-20%, while in larger systems it is possible to have losses as low as 5%, due to advanced combustion control and heat recovery.

To achieve these levels, pipes and connectors in the network are usually pre-insulated to a high standard and may take advantage of twin pipes where the flow and return pipes are enclosed by a common insulation with only one outer mantle.

Corrosion can become a major problem in distribution networks over time so pipes also need to be sealed against the diffusion of oxygen into the water. This is done by sealing tube walls or by chemically binding the oxygen with additives. Plastic pipes are not subject to corrosion, but metal joints and valves could still be, and while plastic remains inferior to metals with respect to oxygen diffusion, metal pipes and are often considered superior.

Figure 35 Twin pipes for a district heating network. [34]

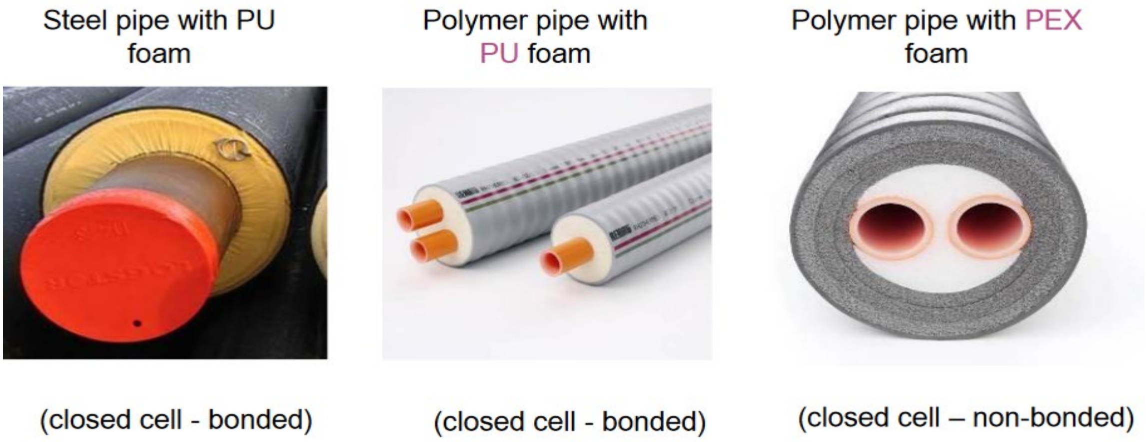

Figure 36 Options of pipe material for district heating networks.[35].

– The consumer circuit

Replacing individual boilers with compact heat exchangers has a number of advantages for consumers. The heat interface unit (HIU) is about the same size as a gas combination boiler and is silent in operation. It provides independent heating and hot water to each dwelling through the existing hydronic distribution system. Where fossil fuels are replaced, the system is cleaner, virtually maintenance free and reduces the risk of fires. Older individual appliances can also be very inefficient and therefore expensive to run and few will have the same benefit of sophisticated emissions controls as a large heating plant.

Figure 37 Domestic heat interface unit. Envinox. [34]

4.4 | Seasonal Thermal Energy Storage (STES)

The storage of heat over long periods this may be several weeks to months is known as seasonal thermal energy storage.
From May to September, the sun suppliers approximately 65% of the incoming solar energy to central Europe and this could cover 100% of the heat demand during this time. In contrast, 65% of the main heat consumption of residential buildings is from October to April, with the sun only covering 7% of this requirement.
The excess heat not utilized during the solar season must, therefore, be stored for the months with less solar radiation. To this end, seasonal thermal energy stores are used. They are charged, over the summer months, by solar heat from large solar collector fields in order to heat, in winter, the buildings connected to it via a heating network. The following figures explain the link between the solar heat supply in the summer and the heating demand in the winter.

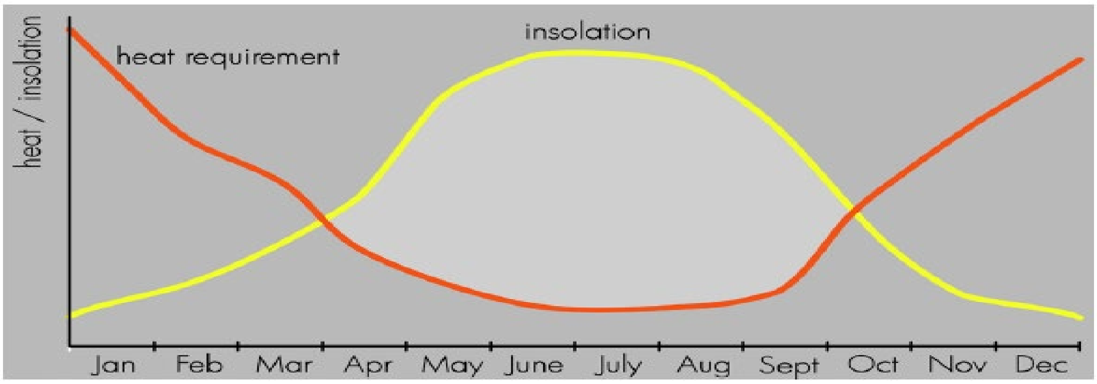

Figure 38 Solar heat supply in the summer[25] [36]

[25] Source: solites

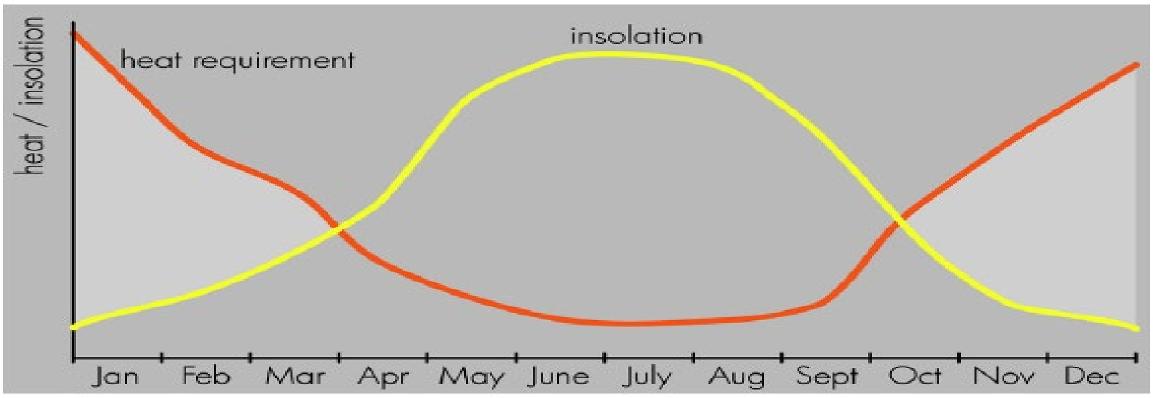

Figure 39 Heating demand in the winter[26] [36]

The seasonal thermal storage has been a field of research for nearly 40 years, provoked by the oil crisis in 1973 , most European governments enacted comprehensive energy saving programmes an initiated an intensive search for alternative sources of energy. It was quickly recognized that large thermal energy stores will play an important role in future energy supply concepts.

The development of storage technologies can be divided into four generations over time. The figure below shows the historical development of seasonal thermal energy storages from 1995 to 2020.

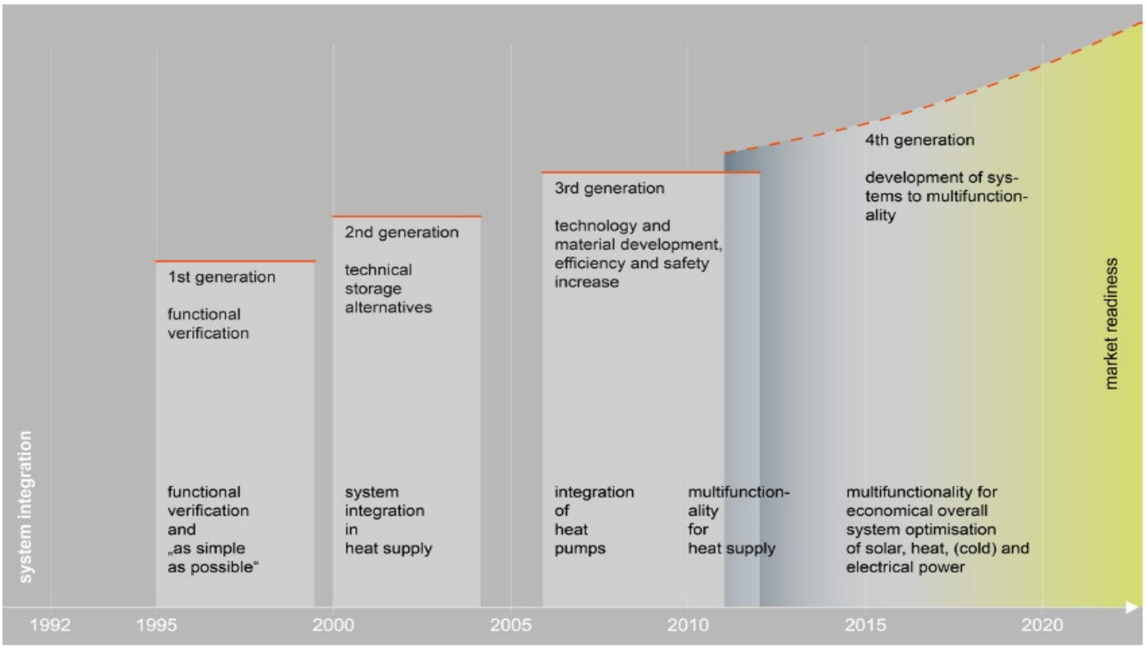

Figure 40 Historical development of STES [27] [36].

[26] Source: solites
[27] Source: solites

Depending on their design, seasonal thermal energy stores use either water or a gravel – water/ground –water mixture of the subsurface to store heat seasonally. The water heated by solar collectors, flow directly or through a heat exchanger into the storage medium and charges the thermal energy storage, provided that its temperatures are colder than the heated water. When heat is required, the storage medium , in turn , transfers the heat to colder water flowing through the storage until the storage is only 3° to 5°C warmer than the water to be heated. Further heat extraction from the storage is the possible with the use for example of heat pump.

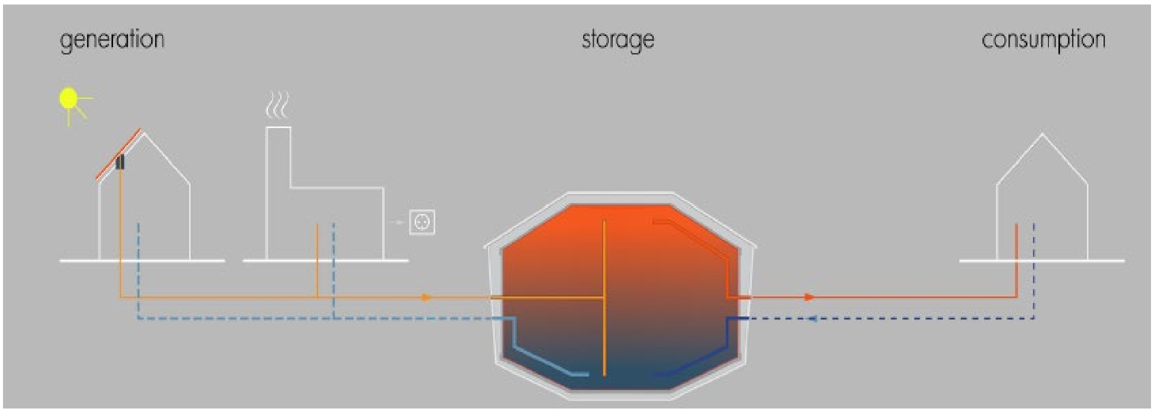

Figure 41 Schematic diagram of STES system [28][36]

The thermal energy stores usually require a large volume, since large amounts of heat have to be stored. They also need to operate reliably, be built at a reasonable price and to be usually (partly) integrated into the subsoil. Such thermal energy stores also have lower construction costs, because the sub-surface also helps to bear the static load of the water filling them, thus making construction of such stores more cost-effective.

There are also large aboveground thermal energy stores such as steel tanks more than 30 m high. However due to their height they can only be used in industrial zones, next to large power plants and the like.

Figure 42 Seasonal thermal energy storage in Hamburg (2010) [36]

[28] Source: solites

When this technology should be integrated in urban areas, important is that the STES can be integrated into the townscape by placing it underground or at least build it partly ground buried. Thus a STES can be placed under a car-park, in the garden, in the district green, combined with a children playground, in a schoolyard, in the city park etc.

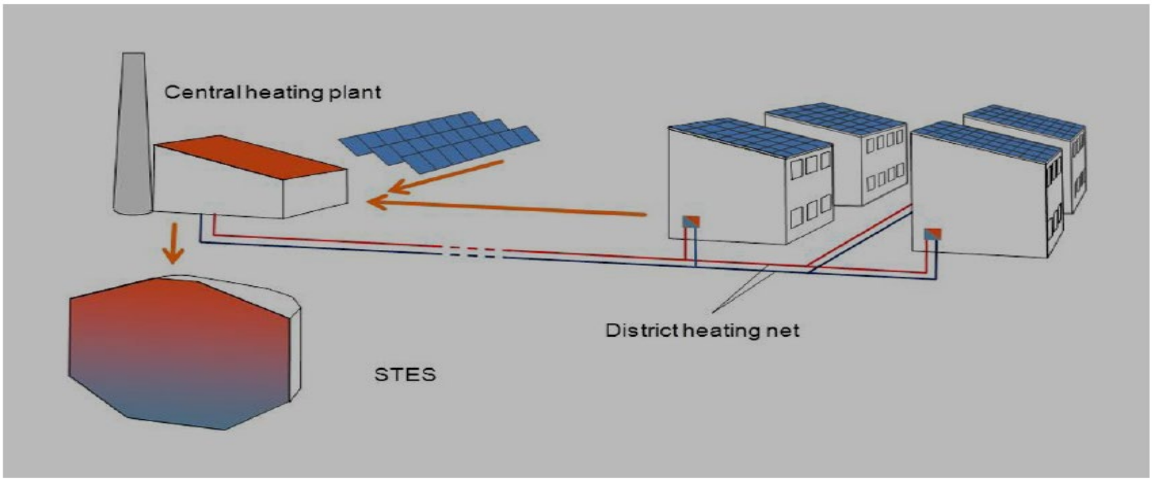

Figure 43 STES system integrated within a district heating [36].

Heat storage economy can be improved if the thermal energy storage is not only available to a solar energy plant as a source of heat for example, but if in parallel or at times when it is not used other sources of heat can be used for example, for peak load buffering (e.g. storage of CHP waste heat, operational optimisation of biomass boilers, etc.). However, it is important to ensure that the multiple uses of the heat store do not lead to unfair disadvantages for the main heat source (e.g. solar energy plant).

Depending on the heat source, different mass flows and temperature can occur when the store is charged and discharged. They can also be constant or fluctuating, depending on the generator. The type of heat store and the remaining plant technology must be modified to cope with this.

In contrast to, for example, solar thermal collectors, thermal energy stores are always a passive component: their mode of action is based on the charging and discharging by heat supplied or extracted via pipes and other technical components. The assessment of the functionality of a thermal store depends, therefore, on a very specific system configuration and system control.
For the other hand, the thermal capacity, it required by the system to charge and discharge the store must be reconciled with the constraints of the storage concepts that come into question. Some types, such as a borehole thermal energy storage system, can store large amounts of heat, but only transfer comparatively low heat power. Instead of increasing the transferable output of a storage concept by, for example increasing, in the case of geothermal probes, the entire geothermal probe length, the integration of an additional buffer store may be more economical.

Storage constructions are large, often underground and thus not easily accessible when carrying out modification work. They are designed for generally long (up to 40 years) lifetimes, which contrast with many other components: should the heat source, the heat demand of the consumers or something similar change, it must be possible to operate the system with the same storage device. That is why careful planning is necessary so that various use scenarios can be considered, resulting in a recommendation for the store that is optimally designed for the entire store life.

The table below summarizes the technical data of some thermal storage technologies.

Table 21 Technical data of different thermal storage technologies.[36]

Thermal store type	Capacity (kWh/t)	Efficiency (%)	Storage duration	Heat costs (€/MWh)
Hot water storage	20-80	50-90	Day-year	8-10
Cold water storage	10-20	70-90	Hour-week	8-10
Aquifer heat storage (ATES)	5-10	50-90	Months	5-60
Borehole heat storage	5-30	50-90	Months	10-140
Phase change materials	50-150	75-90	Hour-week	1000-5000
Ice storage	100	80-90	Hour-week	500-1500
Thermo-chemical heat storage	120-150	75-100	Hour-day	800-1400

4.5 | Large heat pumps

The Europe´s Strategic Framework for Low Carbon Heating in the European Union identifies heat networks as an important element of the decarbonisation of heat in buildings. However, to realise significant emissions reduction using district heating, the heat in the networks must be provided from low carbon sources. As the electricity grid also decarbonises, this presents a potential opportunity to use heat pumps to deliver heat from sources to networks and from networks to buildings.

The heat pumps are considered large if they exceed capacities of 100 kW. They can easily reach the one to several megawatt ranges with the largest units providing 35 MW in a single machine.

Currently available heat pump technology can provide heat up to 100°C with a spread between sources and sink temperature of approx. 50K per stage. Thus, the large heat pump can be applied to high temperature network (network suitable for conventional space heating emitters in existing buildings and domestic hot water (DHW), medium temperature (network suitable for providing underfloor heating but not necessarily DHW) and 'low temperature' (network unable to directly provide space heating and DHW without a further heat pump using it as a heat source).

- Application in high temperature network (>70ºC)

The application of heat pump in high temperature network, generally consist of a central heat pump retrofitted into an existing network. This often means that the heat pump delivers heat at high temperatures and consequently sub-optimal efficiencies or coefficients of performance (COPs); on the other hand the marginal cost and disruption of retrofitting a heat pump to an existing network are both low. The heat pumps are usually not the only, or even the greatest capacity, heat source within these networks. Where possible, they are connected to a CHP plant to carry out further heat recovery once conventional condensing and heat recovery processes have been undertaken. The heat pump then boosts heat from, for example, 50°C to 90°C. Alternatively, in several real district existent combine heat pumps with large scale solar thermal generation and STES. At the start of winter the heat from the store, at around 90°C, can directly be used in the heat network. As the store temperature decreases over the heating season, a HP is used to increase the temperature of the heat in the store before it is incorporated into the network. For any network which is a heat sink for a central heat pump, reducing the network temperature as far as possible not only results in lower thermal losses along the network but also means that heat pumps are more readily integrated. Where cooling networks are co-located with heating networks, heat pumps can provide an even greater benefit than when integrated into one or the other, by simultaneously providing cold and rejecting heat.

- Application in medium temperature network (40-70°C)

Several medium temperature networks are operational in Europe. These are normally smaller scale than the high temperature networks described above, due to the required presence of a group of relatively new, energy efficient buildings with underfloor heating or low temperature radiators. However, a minority of medium temperature networks are found in existing buildings which have been retrofitted with low temperature radiators.

Cooling is also a feature of medium temperature networks, especially if the heat is sourced from aquifers, in a configuration known as ATES – Aquifer Thermal Energy Storage. ATES systems are common in the Netherlands where aquifers are prevalent. The systems can yield high heat pump COPs: as heat is removed from the aquifer over the winter, it is pre-cooled ready for summer; and as heat is rejected into the aquifer over summer, it is preheated ready for the winter. This setup is effective where a cooling load exists, to minimise the net heat taken from the aquifer over a year. Where there is higher heating demand than cooling, the aquifer can be regenerated using dry air chillers which reject heat to the ground, but this has an energy and environmental cost.
A further benefit of ATES systems located in areas of particularly high cooling demand is reduction of the Urban Heat Island effect, through rejecting heat deep into the ground instead of the air.

- Low temperature networks (10-30°C)

The final type of district network considered here is low temperature networks, with distributed heat pumps in buildings using the network as their heat source. This type of network minimises heat losses from the network, which is at or slightly above ground temperature. That is, carrying out the majority of the heating as close as possible to the point of demand results in less opportunity for heat loss. Another advantage of this type of scheme is the potential to provide heating and cooling from the same low temperature network.
Examples of low temperature networks with building integrated heat pumps are limited. One technical consideration is the close control of the network temperature to avoid the return side freezing.

The table below shows COP values for typical source and sink temperatures.

Table 22 Typical Heat pump´s cost and COP data for different ranges of temperature network [37]

Category	Unit	Low temperature	Medium temperature	High termperature
Cost- central HP (incl.installation)	€/kW	500	1500	2500

Cost-water-to- water building-integrated HP (excl.installation)	€/kW	303	606	909
COP-central HP	COP (10°C source, 70°C sink)	1.5	2.21	3.6
COP- water –to-water building-integrated HP	COP (10°C source, 45 °C sink)	3.86 (from increasing sink T by 5°C)	4.53	5.31 (from decreasing sink T by 5°C)

4.6 | Solar thermal

The integration of solar thermal energy to District Heating Networks has begun to gain importance since the 1980s [38] in order to contribute to the production of heat, especially during the summer months. The main downside of solar thermal technology, production and demand seasonal mismatch, does not represent a problem any longer, thanks to the presence of big scale thermal storages.
There are two major large-scale solar heating applications: systems with short-term (diurnal) storage (CSHPDS = Central Solar Heating Plants with Diurnal Storage), see Figure 44, designed to supply 10-20 % of the total annual heating load or approximately 50% of the domestic hot water (DHW) heating requirements, and systems with long-term storage (CSHPSS = Central Solar Heating Plants with Seasonal Storage), see Figure 45, capable of supplying 50-70% of the overall heating demand for space heating and DHW in residential buildings.

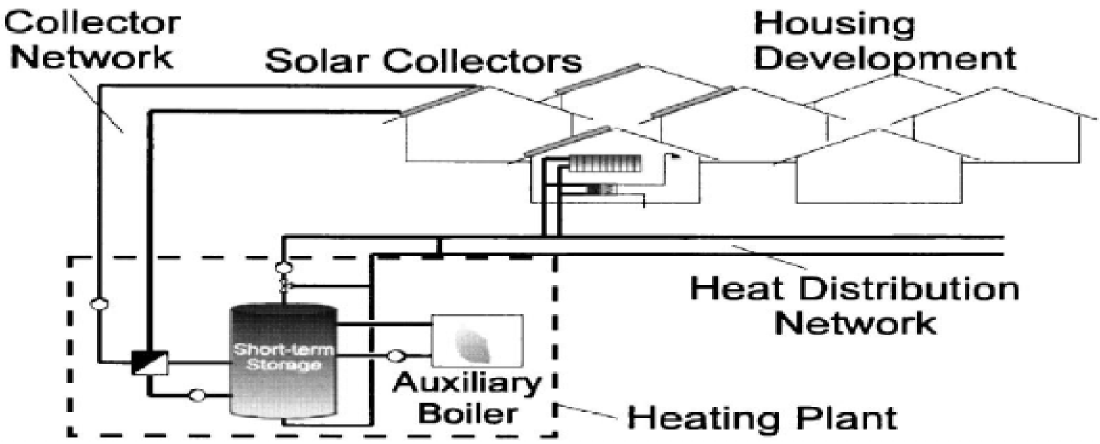

Figure 44 Central Solar Heating Plant with Diurnal Storage (CSHPDS) [40]

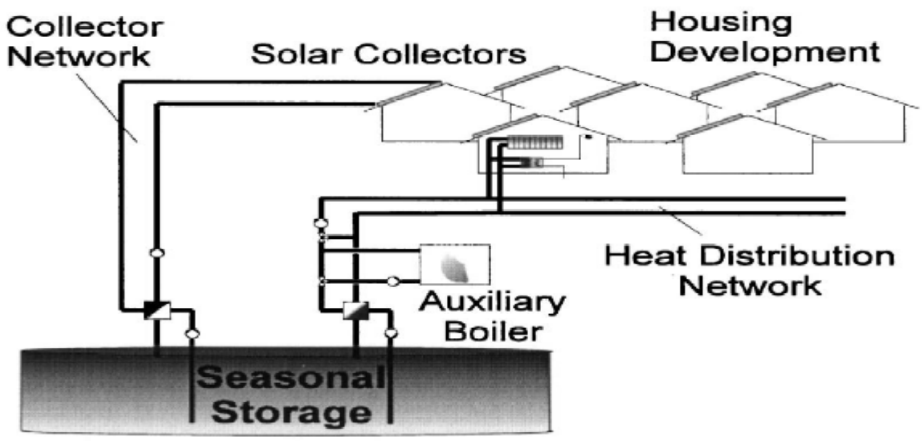

Figure 45 Central Solar Heating Plant with Seasonal Storage (CSHPSS) [40]

When integrating solar thermal technology into a District Heating Network with other technologies, both the collector and the network's operating temperature have to be carefully evaluated. Therefore, it has to be taken into account that the heating fluid coming out from the solar facility has to match the network's operating temperature before injecting it to the system or otherwise it will provoke temperature losses. A feasible way to overcome this setback is to use the solar modules to preheat the fluid and install an auxiliary system that will assure that the working fluid reaches the desired temperature.

The large-scale solar heating system market (above 700 kW) is in rise. This has resulted in a great growth in solar district heating systems, especially in Denmark, where over 75 systems had been installed in the country by the end of 2015. Currently, other countries are following the Danish lead and new installations recently started in Austria, Germany, Italy and France. In fact, since 2008 the average size of a new system has increased from 2.3 MW to over 6.5 MW. In Europe, 19 new large solar district systems came into operation in 2015, representing over 120 MW of newly installed capacity.

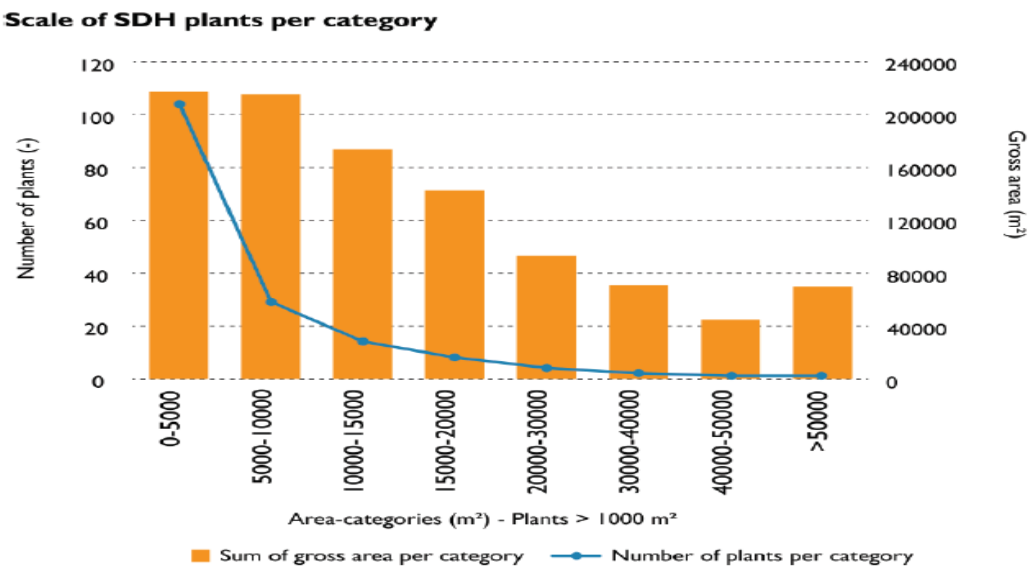

Figure 46 Installed solar thermal energy plants in Europe [39].

It is possible to find an example of a running district heating network combining seasonal storage and solar thermal energy in, Okotoks, Alberta, Canada. This project has demonstrated the feasibility of this kind of facilities and has been successfully operating since 2007 [39]. In Figure 47 the monthly performance of the facility can be seen.

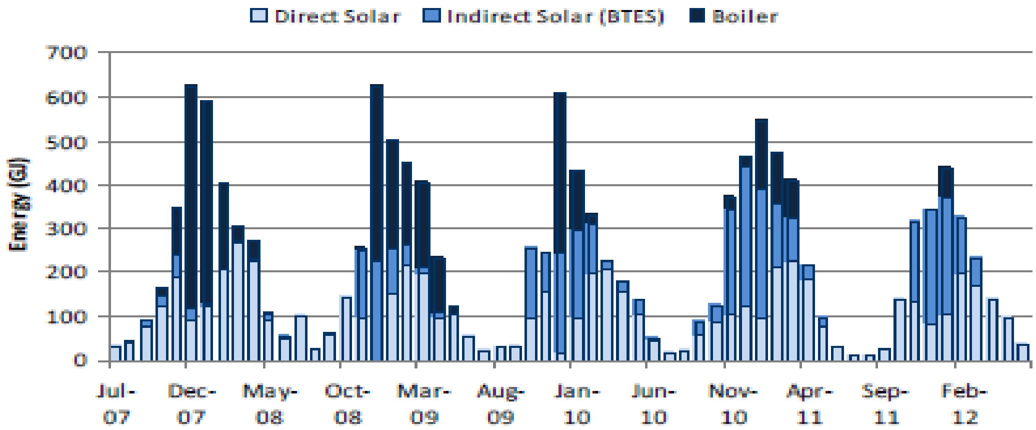

Figure 47 Okotoks' facility's monthly performance [39]

5 | Discussion of integration of renewable energies in nZEBs in stakeholder workshops

During the stakeholder workshops held in Spain and Netherlands, different points were raised regarding integration of renewable energies in nearly zero energy buildings, and about the different technologies described in this report.

In general terms, it was recognized that the transition from fossil to renewable energy sources is necessary to ensure the supply of energy at predictable and affordable prices in the future, and that costs should be properly assessed not only in terms of initial investment, but also through the whole life cycle of the building, and having a clear understanding of the energy cost savings and other operation and maintenance costs. Stakeholders agree that completely sustainable energy supply based on existing energy production technologies (Hydro, wind energy, PV, solar boilers, biomass, geothermal, ...) in combination with energy savings and system changes (eg. application of heat pumps in combination with heat storage, heat recovery ...) are required for the transition. .

While initial investment necessary for this transition is generally higher than for conventional buildings, the attractiveness could lie in the fact that renewable energy can ultimately offer the cheapest solution from a life cycle perspective, and that the market of sustainable energy technologies offers tremendous growth opportunities for the manufacturing industry, the construction and installation sector and (new) energy/ services companies with a significant chance to contribute to economic growth, employment and prosperity.

Complexities associated with the multidisciplinary nature (including technical, economic, sociological, regulatory and political aspects) constitute significant barriers, as well as the level and lifetime of the necessary initial investments, which require a clear long-term approach.

Local energy initiatives from companies and citizens can make an important contribution to the energy transition, because decentralized energy production can increasingly compete with centralized energy production by reducing costs and increasing the efficiency of small-scale generation.

District heating and cooling solutions could also play an important part on stimulating system changes in the consumption and production of energy. However, taking into account that building will have a very low energy demand due to passive measures, district and cooling solutions would only be economically and environmentally feasible if they rely on very low-cost renewable energy or waste resources, as maintaining a distribution grid and its associated losses would not make sense to supply building with low demands, unless a new type of heating and cooling networks are developed. For example, the maintenance of low temperature network, together with electrification of the heat supply by using electric heat pumps in combination with heat or cold storage, could give room to many new solutions to integrate renewable energies and help matching energy supply and demand.

6 | Consideration of RES within the AZEB methodology

The presented overview of RES, their associated costs for installation and operation phases, their environmental performance and potential barriers and risks for implementation, serve as a first step for the evaluation of RES options to be applied to achieve affordable NZEBs. Key of the AZEB methodology is to adopt an integrated perspective when making design decisions, balancing a variety of criteria: optimizing between lifecycle costs, energy performance, other environmental criteria and user criteria such as comfort and health. Clear knowledge of the various characteristics of a specific RE option, including relevant interfaces with other subsystems, is necessary to properly include the options in the decision making process.

Particularly at the initiation phase, the presented information together with an overview of contextual aspects can be used for a preliminary analysis of potential alternatives for NZEBs.

As an example, table 23 shows simple evaluation of relative costs of the different renewable energy technologies, based on the performance and cost data collected in this report, and on the discussion with the different stakeholders for the development of new housing projects in a maritime climate (north Spain)

Table 23 Approximation of the economic performance, GHG emissions and regulatory barriers and risks of renewable energy technologies

	Initial investment	Operational energy cost	Life Cycle Cost	Life Cycle GHG emission	Regulatory barriers and risks
Solar PV	Very high	Very Low	Medium	Very Low	Medium-high
Biomass	Medium	Medium	Medium	Very Low	Low-medium
Heat pump	High	Medium	High	Medium	Low-Medium
Solar thermal	Very high	Low	Medium-high	Very Low	Low
District Solutions	Very high	Depends on the energy source	Depends on the energy source	Depends on the energy source	Depends on the energy source

The table includes an indication of environmental performance (GHG emmissions) and regulatory barriers and risks, as other variables that can influence decision making on the preliminary stages of the project. For example, the regulatory differences between different locations and countries, which have been described for the different technologies, can affect the economic viability of projects. At the time of the stakeholder consultation for this project (December 2017), the large uncertainty regarding connection of solar PV installations to the grid, made stakeholders very cautious of selecting this alternative, despite the positive evaluation in terms of economic and environmental performance.

This type of initial considerations of the different technologies could be made taking this matrix as a starting point, together with the local climate, urban morphology, potential building geometry, space available and needed for the different technologies, resource and logistical factors, etc.

A key issue in relation to this is the interaction of building integrated renewable electricity production systems with the electricity grid. Long-term and clear regulatory and market conditions for self-consumption and grid injection of electricity would reduce the uncertainty and risks associated with investments in renewable energies.

A preliminary analysis of the RES can be a useful tool at the initiative phases of a project, e.g. when setting project requirements, or when conceiving and selecting different projects alternatives. At design stage, selected alternatives could be more thoroughly analysed using specific energy simulation tools and life cycle costing tools, in order to design an optimized building.

The information presented in this report is a starting point for information about each renewable energy solution, which should be complemented with contextual aspects and site and building particular characteristics to conceive and select a number of potential alternatives of RES utilization.

Simple factsheets for each of the technologies described in this report have been prepared as supporting information for users of AZEB methodology in these initial phases of the project. These are available at www.azeb.eu.

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