Revision of Cyprus Energy and Climate Plan

D4.4 – Evaluation of the efficiency and cost-effectiveness of RES technologies

Trinomics

The Cyprus Institute
RESEARCH·TECHNOLOGY·INNOVATION

EMERCON
EUROPEAN MANAGEMENT, ENGINEERING & CONSULTING

ECCO INTERNATIONAL INC.
Energy Consulting

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Contact person

Mr. Koen Rademaekers
T: +31(0)6 22725505
E: Koen.Rademaekers@trinomics.eu

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Acronyms

CA	Comprehensive Assessment
Capex	Capital Expenditure
CHP	Combined Heat and Power
DH	District Heating
FC	Fuel Cell
H&C	Heating and Cooling
HP	Heat Pump
Opex	Operational Expenditure
RHC	Renewable Heating and Cooling
SHW	Sanitary Hot Water

CONTENTS

1 List of Renewable Heating and Cooling technologies

1.1 Preliminary list

During the inception phase, as confirmed within the inception report, we established a preliminary list of Renewable Heating and Cooling (RHC) technologies, possibly applicable / usable in Cyprus.
This list can be found in Annex 1.

When conducting the work regarding the evaluation of the efficiency and cost-effectiveness of these technologies, we disregarded or combined some of them, while splitting others, for various reasons:

- Lack of specific data, due to their combination with other technologies or appliances
- Low relevance in the Cypriot H&C context

Table 1-1 starts from the preliminary list, and describes for each technology the underlying reason, or provides the code we use in the XLS.

Table 1-1 Screening of the preliminary list of RHC technologies

Heat and cooling generation technology	Application	Code / reason for disregarding
Solar water heater - small scale (<50kW)	Residential & small collective	Combined with space heater
Solar space heater - small scale (<50kW)	Residential & small collective	101 - solar heating small
Solar district heating - large scale	Collective DH	Not directly relevant, close to commercial applications
Solar heating - large scale	Commercial applications	102 - solar heating large
Solar cooling -small scale	Residential & small collective	111 - solar cooling small
Solar cooling-large scale	Commercial applications	112 - solar cooling large
Solar Process Heat Systems	Industrial application	Highly relevant in Cyprus, but limited data so far (cf. section 1.2.1)
Geothermal (deep and shallow) heat pumps - small scale (for H&C) (<50kW)	Residential & small collective	211 - geothermal HP small
Geothermal (deep and shallow) heat pumps - large scale (for H&C) (>50kW)	DH and Commercial applications	212 - geothermal HP large

Geothermal (deep and shallow) heat pumps - large scale (for H&C) (>50kW)	Industrial applications	close to commercial applications
Air heat pumps for heating & cooling - small scale (<50kW)	Residential & small collective	221 - air HP small
Air heat pumps for heating & cooling - large scale (>50kW)	DH and Commercial applications	222 - air HP large
Air heat pumps - for heating & cooling large scale (>50kW)	Industrial applications	Close to commercial applications
Heat pumps (air to water)	Residential	231 - air-to-water HP small
	Commercial applications	232 - air-to-water HP large
Heat pumps (water to water)	Commercial applications	Included in geothermal, large scale
Deep geothermal heater (direct)	Collective DH, commercial and industrial applications	Not relevant in Cyprus
Pellets boilers - small scale (<50kW)	Residential & small collective	311 - pellets boiler small
Pellets boilers - large scale (>50kW)	Collective DH, commercial and industrial applications	312 - pellets boiler large
Wood chips boilers - small scale (<50kW)	Residential	Replaced by 321 - wood chips boiler small
Wood log & pellets stoves - small scale (<50kW)	Residential & small collective	331 - wood log stove small
Pellets CHP - large scale (>50kW)	Collective DH, commercial and industrial applications	342 - Pellets CHP large
Wood chips CHP - large scale (>50kW)	Collective DH, commercial and industrial applications	352 - Wood chips CHP large
Liquid fuel boilers (e.g. biofuels) - small scale (<50kW)	Residential	431 - Liquid fuel boiler small
	Small & large collective	432 - Liquid fuel boiler large
Propane boilers (e.g. biopropane) - small scale (<50kW)	Residential & small collective	441 - Propane boiler small
Conventional gas boilers (e.g. biogas) - small scale (<50kW)	Residential & small collective	531 - Gas boiler small

Conventional gas boilers (e.g. biogas) - large scale (>50kW)	Collective DH, commercial and industrial applications	532 - Gas boiler large
H2 boilers - small scale (<50kW)	Residential & small collective	631 - H2 boiler small
H2 boilers - large scale (>50kW)	Collective DH, commercial and industrial applications	632 - H2 boiler large
H2 CHP FC - small scale (<50kW)	Residential	621 - H2 CHP FC small
H2 CHP FC - large scale (>50kW)	Collective DH, commercial and industrial applications	622 - H2 CHP FC large
Hybrid heat pump and (bio) gas boiler - small scale (<50kW)	Residential & small collective	831 - Hybrid HP & gas small
Hybrid heat pump and (bio) gas boiler - large scale (>50kW)	Collective DH, commercial and industrial applications	832 - Hybrid HP & gas large

Table 1-2 Screening of the preliminary list of RHC infrastructure

Heat infrastructure	Application	
New DHC - 5th Generation (low temperature)	Collective DH	This is addressed in section 1.2.1
Heat storage - large scale (CSP Technologies)	Collective DH	This is addressed in section 1.2.1
Heat storage - small scale (Various CSP technologies)	Residential & small collective	This is addressed in section 1.2.1
Geothermal Energy (Geothermal Maps available),	Industrial, Hotel, District Heating and Cooling	This is considered with Heat storage - large scale

1.2 Final list of technologies - data sources

This section examines the data source and application-specific assumptions. As there is not a single source providing all the required data, we had to use several sources, to provide a set large enough. All data sources were confronted to each other, and most were finally validated by representatives of the Cyprus Employers and Industrialists Federation[1] (OEB).

H&C system	Sources of data used	Explanation of final value
101 - solar heating small	DK Heating Technology List (2020) (1) ADEME (2017) (2) Cyprus Comprehensive Assessment (CA)	Capex from the OEB; Opex from ADEME (2% of capex); Validated by OEB

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[1] https://www.oeb.org.cy/en/

	OEB	
102 - solar heating large	DK Heating Technology List (2020) (1) ADEME (2017) Cyprus Comprehensive Assessment (CA) Keep warm Europe OEB	Capex from CA; Opex average ADEME values Validated by OEB
111 - solar cooling small	DK Heating Technology List (2020) Green Chiller Association Renewable Institute Cyprus Comprehensive Assessment (CA)	Capex from Renewable Energy Institute; Opex from CA
112 - solar cooling large	DK Heating Technology List (2020) Green Chiller Association The Renewable Energy Institute (REI[2]) Cyprus Comprehensive Assessment (CA)	Capex from REI; Opex from CA
211 - geothermal HP small	DK Heating Technology List (2020) EHPA (2021) (3) OEB	Capex from OEB; Opex from OEB & DK List; Validated by OEB
212 - geothermal HP large	DK Heating Technology List (2020) ADEME (2017) 2 actors in Cyprus[3]	Capex from OEB; Opex as average ADEME & OEB; Validated by OEB
221 - air HP small	DK Heating Technology List (2020) ADEME (2017) Assoclima Italy (2022) Cyprus Comprehensive Assessment (CA) 2 actors in Cyprus	Capex from CA; Opex from OEB; Validated by OEB
222 - air HP large	DK Heating Technology List (2020) ADEME (2017) Assoclima Italy (2022) Cyprus Comprehensive Assessment (CA) 2 actors in Cyprus	Capex from CA; Opex from OEB & CA; Validated by OEB
231 - air-to-water HP small	DK Heating Technology List (2020) ADEME (2017) Assoclima Italy (2022)	Capex from DK list; Opex from DK list & ADEME; Validated by OEB
232 - air-to-water HP large	DK Heating Technology List (2020) Assoclima Italy (2022) OEB	Capex from OEB; Opex – doubling the air HP O&M (4); Validated by OEB
311 - pellets boiler small	DK Heating Technology List (2020) ADEME (2017) OEB Cyprus Comprehensive Assessment (CA)	Capex from CA; Opex from CA; Validated by OEB
312 - pellets boiler large	DK Heating Technology List (2020) ADEME (2017)	Capex from CA; Opex from CA;

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[2] Solar Cooling With Small Size Chiller: State of the art - The Renewable Energy Institute (renewableinstitute.org)

[3] The two actors in Cyprus are Costas Moeses LLC (Consultants for building Services, Energy Audits and Energy Performance Certificates) and Patis & Hadjigregoriou LLC (Mechanical Consultants Building Energy performance certificates and energy auditing

	Keep warm Europe Cyprus Comprehensive Assessment (CA)	Validated by OEB
321 - wood chips boiler small	DK Heating Technology List (2020) ADEME (2017) Cyprus Comprehensive Assessment (CA)	Capex from CA; Opex from CA;
331 - wood log stove small	DK Heating Technology List (2020) OEB	Capex from OEB; Opex from OEB;
342 - Pellets CHP large	ADEME (2016)	Capex from ADEME; Opex from ADEME
352 - Wood chips CHP large	ADEME (2016) Cyprus Comprehensive Assessment (CA)	Capex from ADEME; Opex from ADEME
431 - Liquid fuel boiler small	DK Heating Technology List (2020) ADEME (2017) Cyprus Comprehensive Assessment (CA)	Capex from CA; Opex from CA; Validated by OEB
432 - Liquid fuel boiler large	DK Heating Technology List (2020) Cyprus Comprehensive Assessment (CA) OEB	Capex from OEB; Opex from CA; Validated by OEB
441 - Propane boiler small	Cyprus Comprehensive Assessment (CA)	Capex from CA; Opex from CA; Validated by OEB
531 - Gas boiler small	DK Heating Technology List (2020) ADEME (2017)	Capex from DK list & ADEME; Opex from ADEME; Validated by OEB
532 - Gas boiler large	DK Heating Technology List (2020) ADEME (2017)	Capex from ADEME; Opex from ADEME; Validated by OEB
631 - H2 boiler small	DK Heating Technology List (2020) Similar to gas capex	Capex from gas boiler; Opex from DK list; Validated by OEB
632 - H2 boiler large	DK Heating Technology List (2020) Similar to gas capex	Capex from gas boiler; Opex from DK list; Validated by OEB
621 - H2 CHP FC small	Cache climatization (5)	Capex from cache clim; Opex from cache clim;
622 - H2 CHP FC large	Hydrogen.Energy (6)	Capex from DOE; Opex from DOE

(1) This list was used as reference, providing break down of data, with a recent set (2020). These data are mainly used to confirm the magnitude of the proposed value.

(2) ADEME data are providing interesting break down, that could be used for further, deeper analysis. These data are mainly used to confirm the magnitude of the proposed value.

(3) EHPA, the HP EU association, provides EU average investment cost, but these are not including installation, to be added

(4) This is an assumption we had to take, in proportion to the investment cost

(5) https://www.cacheclimatisation.com (2019) provides figures for the first small scale FC CHP in France

(6) https://www.hydrogen.energy.gov/ (2011) DOE Hydrogen and Fuel Cell Programme Record provides figures for large scale CHP.

1.2.1 Remaining technologies

Some technologies were not addressed the same way, as it was not possible to find detailed data (e.g. data are not available in databases, or the literature only presents final LCOE, with very limited or no information regarding the underlying assumptions/data), or these technologies are combined with others and cannot be dissociated.

Hybrid systems (e.g. HP & Gas boiler)

Determining the LCOE of hybrid systems depends on many parameters which can be complex to model, and would require additional research:

- Offering a wide range of solutions for existing buildings
- Allowing to manage electricity grid impacts
- The consumer's energy bill can be reduced significantly with smart management, thanks to the high efficiency of the heat pump and the ability to switch to the lowest cost energy vector (time of use)
- Tackling all other end-user challenges, regarding temperature level, comfort, etc.
- Keeping multiple decarbonisation options, and design on an optimal balance between heat pump and conventional heating, depending also on the energy performance of the concerned building.

Hybrid heating system investment can be relatively modest[4], consisting of an electric heat pump sized to cover the frequently occurring heat demand (limited capacity) combined with a gas-fired boiler to cover high peak demand. Adding a small heat pump and a control system, to an existing high-performance boiler is also a viable option.

A heat pump's efficiency can reduce a building's energy bill once a hybrid heating system is installed, thanks to the higher efficiency of heat pumps (assuming a high COP). The energy bill is also reduced by the heat pump's high operating time and the possibility to make smart use of price signals. According to a study conducted by Ricardo (2020[5]), for the UK, savings of up to 50% were found, but with significant variations among countries and houses depending on local energy prices (e.g. electricity tariffs), regulations, the presence of additional incentives, the cost of installation. For the Netherlands, as example, recent analysis shows a potential yearly energy bill savings of up €600[6] (e.g. investment ~€6.900, minus €2.700 subsidy, giving a payback time around 7 years).

In the **special case of solar heat** used to produce space heating, there are a couple of aspects to consider:

- The heating appliance complementing the solar heat system (e.g. a heat pump or gas/wood boiler), will be the main heating system and should be able to provide the required heat at any time. Hence, it's nominal capacity should be determined independently of the solar system (there is no guarantee it will produce the required heat during peak demand, which is used to dimension the capacity of the system). It means that the capital expenditure of the main heating appliance will not be reduced thanks to the installation of a solar heat system (e.g. by installing a smaller system, less expensive);

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[4] https://hybridheatingeurope.eu/wp-content/uploads/2021/03/hhe_vision-paper_final.pdf

[5] Ibid.

[6] https://www.consumentenbond.nl/warmtepomp/beste-warmtepomp

- The same logic applies to operational expenditure, as the size of the heating system will not depend on the existence of a solar heating system;
- Solar heating systems should be considered as providing fuel savings to the main heating appliance;
- The cost of solar heat produced for space heating should not be compared to the LCOE of the technology it replaces as LCOE comprises capex, opex and fuel cost. It should rather be compared to fuel cost only.

This is important to have in mind when comparing the different technologies, as solar heat systems (STH) are installed to complement and not to replace the main heating system. Hence, LCOE could possibly be used according to the following

  - If STH has lower LCOE than the fuel cost of other technologies, it could be promoted to cover heat demand as much as possible (maybe 70-80% for SHW, but only 20-30% for space heating), as a complement to other Renewable H&C technologies;
  - If STH has higher LCOE than other Renewable H&C technologies, then support will probably be required to make it an attractive way to reduce fuel consumption as complement to another renewable technology (e.g. reducing biomass use is crucial given the scarcity of the resource, by bringing "sun savings");

DHC

The Technical Assistance Report "Development of a Heating and Cooling Strategy at a Local Level" (Ricardo Energy and Environment, 2018[7]) identifies the potential for high efficiency heating and cooling solutions in agreed areas of Cyprus, with high efficiency solutions like District Heating and Cooling (DHC) or local Combined Heat and Power (CHP), heat pumps and solar thermal solutions.

The economic potential of several combinations of DHC solution using Discounted Cash Flow (DCF) is analysed relatively to a baseline technology mix for each geographical area. E.g., the baseline technology mix in the touristic areas was set as oil boilers for SH and SHW and non-reversible heat pumps for cooling.

Providing data regarding the cost of DHC would require studying precise cases, as there are many parameters to consider. Therefore, the aim of this section is not to summarise or update the study and the underlying model, but rather to comment it, and provide some additional analysis, possibly to run the model with updated values, based on some key findings:

  - District Heating and Cooling (DHC) solutions based upon the CHP technologies fired by Refuse Derived Fuel (RDF) and oil-fired CHP are the most competitive compared to other energy sources (biomass CHP, LPG CHP, and water sourced heat pump). Solar thermal was not considered (due to limited available land in touristic areas), while it should be considered as a good option for projects with a high load factor. Both fuels, RDF and oil, were at very low cost, driving their competitive advantage. Updating the cost of these fuels in the current situation would be required;
  - A DHC based upon oil-fired CHP is more competitive than the baseline, which is made of oil boilers. This means that there is a case for a DHC using the same energy source as individual units, at least in touristic areas (the results relating to cost effectiveness of the individual building level CHP solutions evaluated broadly mirror those for the same CHP solutions supplying a DHC network);

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[7] https://energy.gov.cy/assets/entipo-iliko/RDF-District%20H-C.pdf

- Touristic areas, with hotels having a consumption over the entire year (high consumption hours, increasing the load factor), and a high density (reducing the cost of infrastructure, or length of the network), are among the most profitable for DHC;
- DHC solutions based on the other technologies evaluated (biomass CHP, LPG CHP and Water Source Heat Pumps) are not cost effective relative to the baseline. However, it should be recalled that the heating baseline is mainly fossil based (oil boilers);
- The existence of cost effective DHC potential is very sensitive to the load factor of the plant serving the modelled DHC scheme during the cooling season, with higher load factors favouring cost effectiveness;
- The investment cost used in the model for infrastructure (i.e. H&C network and possibly storage) should remain of the same order. Capex, opex and fuel costs of the H&C production units could be updated based on the data provided in the LCOE sheet;
- Sensitivity analysis indicates that the cost effectiveness of the DHC solutions is mainly driven by five key parameters: (1) capex of the H&C production plant (2) electricity price (3) thermal factor load (4) price of fossil fuels, and (5) capex of individual H&C appliances, whose heat/cooling is displaced by the outputs of the DHC. The order of importance of these parameters to the cost effectiveness of the DHC solutions depends on the main heat generating technology for the DHC solution.

Storage

Energy storage systems are used to reduce the use of heating appliances and improve the performance of the installation. E.g it allows a heat pump to operate at the highest efficiency points, when the outside temperature is higher, and possibly electricity PV generation is the highest, to store the heat produced for using it during the cooler periods of the day. Hence, the integration of a thermal storage system in a heat pump improves energy efficiency and contributes to reducing the energy bill of homes and industry.

Energy storage systems are either thermal or chemical[8]. Thermal storage materials are classified into sensible and latent materials. Sensible materials, including water (e.g. SDHW), stores heat by increase in its temperature.

Having a high-capacity, small and low-cost thermal storage system will improve the operating efficiency of heat pumps, and thus facilitating their implementation as an air-conditioning system. Phase Change Materials (PCM) can store large amount of thermal energy as latent heat thanks to their phase changes (solid-solid, solid-liquid) while maintaining a constant temperature, helping to improve the performance of the system while reducing the size and cost of heat pumps.
PCM offer much higher storage density with a narrower temperature range between heat storage and heat release than those based on sensible heat (i.e. water tanks). PCMs can be used as thermoregulating materials or as heat storages for narrow temperature ranges.
There are different PCMs technologies, allowing to store large amounts of heat in the phase transformation process, which is particularly attractive where the temperature range of operation is narrow.
The property of PCMs can be used as thermal energy storage whereby heat or coolness can be stored from one process or period in time, and used at a later date or different location.

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[8] Comprehensive review of the application of phase change materials in residential heating applications, Alexandria Engineering Journal, 2021

According to a Renewable and Sustainable Energy Review study (Elsevier, 2015[9]), a heat pump can be combined with seasonal thermal energy storage as an efficient heating system, to support increasing the stored energy temperature to the appropriate level.
Each storage technology has its advantages and disadvantages. E.g, a water tank is easy to install and operate, and does not require special geological condition, but it remains expensive. An aquifer thermal energy storage can be cheaper, but requires extensive geological investigation. Nevertheless, the appropriate system can be chosen, with due consideration for the system requirements, the specific heating or cooling profile, and the technology characteristics. In large and small buildings with only heating demand, a heat pump with hot water tank storage seems to be appropriate. For large buildings with only cooling demand, heat pump with aquifer thermal energy storage can be an option. For small scale cooling demand, heat pump with duct thermal energy storage[10]. The two main factors influencing the efficiency of seasonal thermal energy storage with a heat pump are the COP of the heat pump, and the solar fraction[11]. According to the same study, seasonal storage is a promising technology for energy saving, but is probably not cost effective for all applications.

According to the IEA study on "Thermal Energy Storage, Technology Brief" (IEA, 2013[12]), the cost of a sensible heat storage system ranges between €0.1-10/kWh, depending on the size, application and thermal insulation technology. Costs for PCMs range between €10-50/kWh while Thermo-Chemical Storage (TCS) costs are estimated to range between €8-100/kWh. In TCS and PCM, major costs are associated with the heat (and mass) transfer technology, to achieve a sufficient charging/discharging power. The economic viability of a Thermal Energy Storage (TES) depends heavily on application and operation needs, including the number and frequency of the storage cycles.

As emphasised by the "Evidence Gathering: Thermal Energy Storage (TES) Technologies" study (BEIS, 2016[13]), upfront cost may remain a major barrier to the wider deployment of Thermal Energy Storage, depending on the application and size.
Hot water cylinders for residential applications will remain a cost competitive investment, while it is a key barrier to the uptake of large-scale heat storage for commercial, industrial and district heating users, despite potential long term efficiency improvements. For the commercialisation of PCM and thermochemical TES costs remain also a crucial barrier. Most PCM products could be too expensive for replacing hot water tank-based systems, even though there may be some potential of PCM to replace tank systems. There are high chances that PCM products will complement the tank market, through hybrid applications or by using PCM based to address specific constraints or for different applications (e.g. space constraints or short-duration smoothing of heat pump production).

Solar Process Heat Systems A solar steam boiler system has been developed and built for Kean Soft Drinks Ltd. in Limassol, Cyprus. Its aim is to carry out industrial research demonstrating and verifying the dispatchability and performance of a high temperature

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[9] https://www.diva-portal.org/smash/get/diva2:797588/FULLTEXT01.pdf

[10] In this storage method, vertical or horizontal ducts are inserted under the ground to store heat. The optimum depth of the DTES depends on the heat load, ground thermal conductivity, the natural temperature in the ground, the ground water level, and the distance to other similar storage systems

[11] https://www.diva-portal.org/smash/get/diva2:797588/FULLTEXT01.pdf

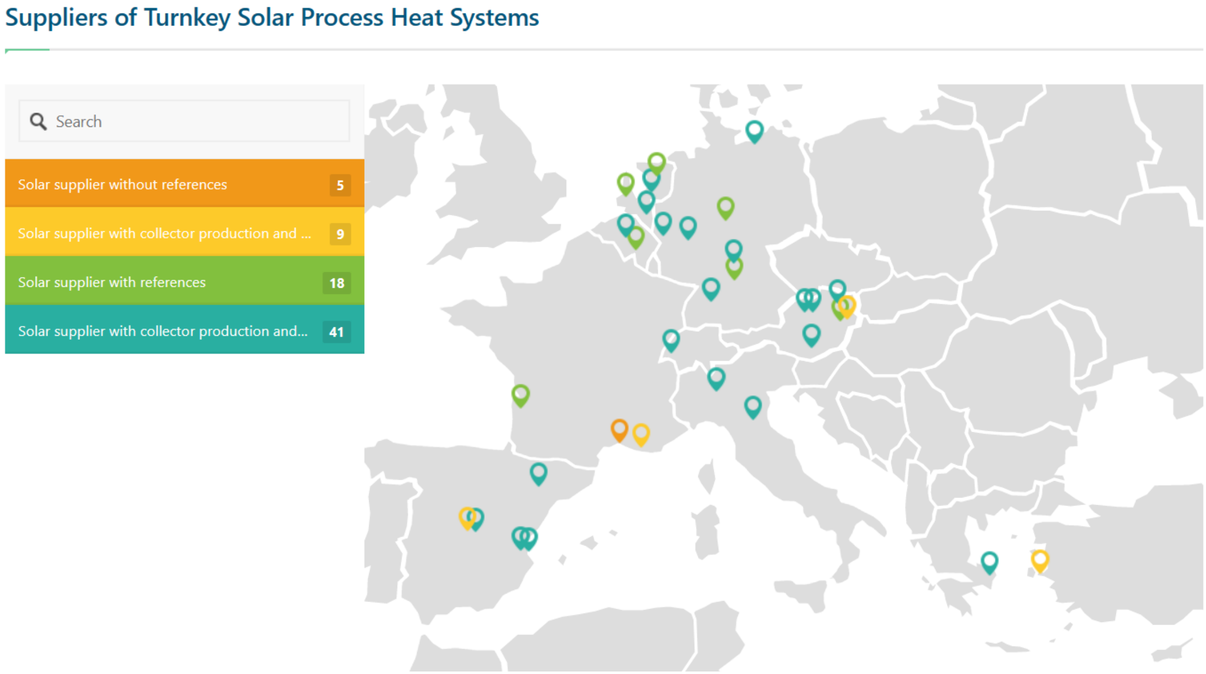
[12] https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2013/IRENA-ETSAP-Tech-Brief-E17-Thermal-Energy-Storage.pdf ; Innovation outlook: Thermal energy storage (irena.org, 2020)

[13] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/545249/DELTA_EE_DECC_TES_Final__1_.pdf

solar thermal system designed for continuous operation. The project is called EDITOR for "Evaluation of the Dispatchability of a Parabolic Trough Collector System with Concrete Storage".[14]

A recent thesis on the "Techno-economic Analysis and Market Potential Study of Solar Heat in Industrial Processes"[15] carried out a techno-economic analysis of several case studies (in Spain). On that basis, the study concludes that parameters such as solar radiation, and conventional fuel prices have a major impact on the economic results. A sensitivity analysis shows that locations with radiation levels above 1750 kWh/m2 have positive values for NPV, and above 2250 kWh/m2 the cost of generating solar heating (LCOH) is under European natural gas prices (2021 reference). Fuel prices above 50 €/MWh, which are common for SMEs, results in payback periods under 10 years. It also concludes that overall solar heat in industrial processes can be a feasible and strong alternative to conventional, fossil-based systems. It could also be seen as an appropriate complement to conventional systems. Solar Heat in Industrial Processes deployment will require supportive policies (driven by decarbonisation purposes), in addition to high radiation levels, and costly fuels prices (such as for SMEs).

The Solar Payback website provides a useful Supplier Map of Turnkey Solar Process Heat Systems, worldwide. The next figure maps these suppliers across Europe, also including references.



Source: solar-payback.com

There is a first prototype in Cyprus of a Linear Fresnel Collector (LFC) at the Cyprus Institute[16], which is expected to provide a strong basis and evidence regarding the economic interest of using solar heat in the built environment (supplies H&C to the Novel Technology Laboratory) using low to medium temperature levels. The prototype is integrated in the built environment and has been in operation since its completion in July 2016 under STS-MED project. It utilises tracking mirrors reflecting direct

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[14] Solar steam boiler for orange juice production in Cyprus - Protarget AG (protarget-ag.com)
[15] Master of Science Thesis Department of Energy Technology KTH 2020, Sweden, Guillermo de Santos López, 2021
[16] Linear Fresnel Collector (LFC) - Energy Department of the Cyprus Institute (cyi.ac.cy)

solar radiation on a 32m long absorber using mineral oil as Heat Transfer Fluid (HTF). The HTF is heated up to 180°C and stored in a thermal storage unit of pressurised water in temperatures up to 145°C that ensures 2 hours of continuous operation for cooling in the summer or 4 hours of operation to compensate solar resource decline in winter.

2 LCOE calculation method

2.1 LCOE Calculation

The levelized cost of energy (LCOE) or levelized cost of heat (LCOH) or cold (LCOC), is a measurement used to assess and compare alternative methods of energy production. The LCOE of an energy-generating appliance can be thought as the average total cost of constructing and operating the asset per unit of total energy generated over an assumed lifetime.

LCOE can also be thought as the average minimum price at which the energy generated by the asset is required to be sold in order to offset the total costs of production over its lifetime. It relates to calculating the Net Present Value of the H&C system.

LCOE reflects a per-unit cost of energy produced, and the risk occurred by a generating appliance is an integrated in the specific discount rate.

The LCOE can be calculated by first dividing the net present value of the total cost of installing and operating the H&C appliance by the net present value of the total energy produced over the lifetime of the appliance. LCOE will include the following expenditures

- The initial investment cost (I)
- Maintenance and operations (M)
- Fuel (where applicable) (F)

The total output of the H&C-producing asset will include:

- The sum of all energy produced (E)

The LCOE calculation has also to consider the two following factors:

- The discount rate of the project (r)
- The life of the system (n)

$$LCOE = \frac{\sum \frac{(I_t + M_t + F_t)}{(1 + r)^t}}{\sum \frac{E_t}{(1 + r)^t}}$$

Inflation (rate i) also applies to both Operation and Maintenance annual costs (M), and to annual Fuel costs (F), according to

$$M_t = M * (1+i)^t$$

$$F_t = F * (1+i)^t$$

For small scale solar heating systems, it looks like

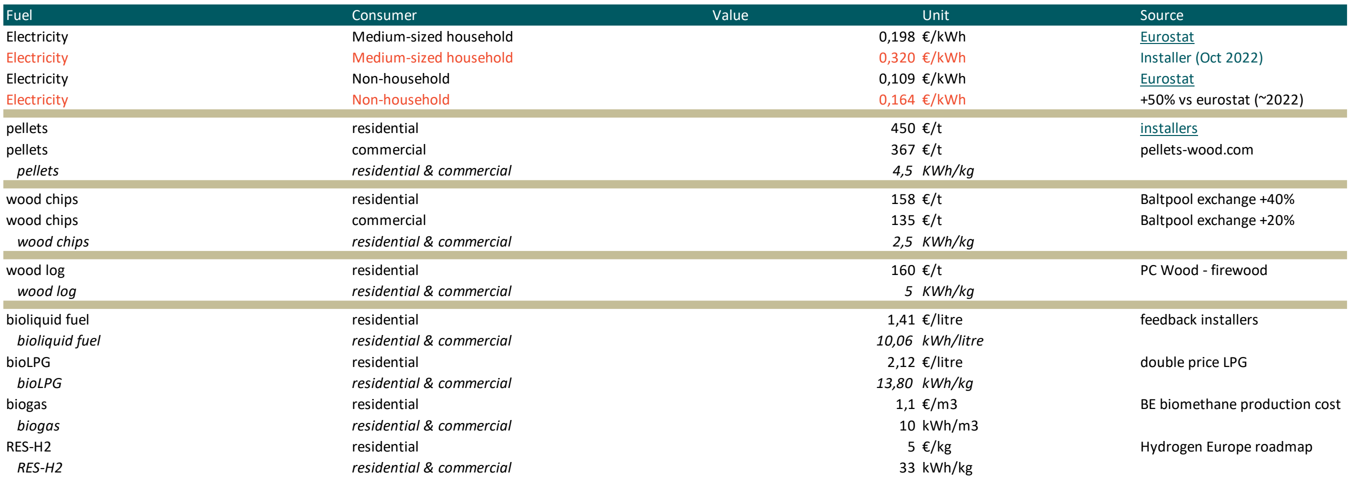
Total Costs	Entry	1	2	3	4	5	6	7
Initial Investment	3.102							
O&M Costs		62,66	63,29	63,92	64,56	65,21	65,86	66,52
Fuel Costs		0,00	0,00	0,00	0,00	0,00	0,00	0,00
Discount Factor		97,1%	94,3%	91,5%	88,8%	86,3%	83,7%	81,3%
Present Value of Costs		60,84	59,66	58,50	57,36	56,25	55,16	54,08
NPV of Total Costs	4.119							
Total Energy Output	Entry							
Yearly Output {kWh}		4.380	4.380	4.380	4.380	4.380	4.380	4.380
Discount Factor		97,1%	94,3%	91,5%	88,8%	86,3%	83,7%	81,3%
Present Value of Output		4.252	4.129	4.008	3.892	3.778	3.668	3.561
NPV of Total Output {kWh}	65.163							

2.2 Technology specific parameters

Energy/technical data		**Comments**
	Heat production capacity for one unit [kW_h]	This is a crucial information
	Expected share of space heating demand covered by unit [p.u.]	Nice to have, but not strictly needed (it is expected that all systems covers 100% of the needs, except Solar systems)
	Expected share of hot tap water demand covered by unit [p.u.]	Idem
	Heat efficiency (annual average, net) [p.u.]	This is a crucial information, to link the fuel (or final energy) consumption to the usable heating or cooling and the RES production
	Auxiliary Electricity consumption [kWh_e/y]	
	Technical economic lifetime [years]	This is a crucial information
Financial data		
	Nominal investment (*total) [k€/unit, 2020]	This is crucial information
	Nominal investment (equipment) [k€/unit, 2020]	The breakdown is interesting but not strictly needed
	Nominal investment (installation) [k€/unit, 2020]	“
	Nominal investment (additional) [k€/unit, 2020]	“
	Variable O&M (*total) [€/kWh, 2020]	The breakdown is interesting but not strictly needed (this is usually expressed in % of the initial capex and can vary between 2% for technologies requiring very limited maintenance, and 10% for complex installation requiring a lot of operational interventions)
	Fixed O&M (*total) [€/unit/y, 2020]	This is crucial information, and easiest to use
	Fixed O&M (electricity cost) [€/unit/y, 2020]	The breakdown is interesting but not strictly needed
	Fixed O&M (other) [€/unit/y, 2020]	“
	Annual O&M (time spent on manual maintenance) [hours/unit/y]	This is not used in the XLS sheet, but could be used as good proxy to reflect general O&M
Technology specific data		
	Solar collector area [m2]	This is a crucial information
	Performance (output per collector area) [kWh/m2/y]	This is a crucial information
Operational data		
	Heat energy production / y [MWh]	This is a crucial information, see common assumptions below
	Fuel cost [€/kWh, 2020]	This is a crucial information, see common assumptions below
	Discount rate [%]	This is a crucial information, see common assumptions below
	Inflation rate [%]	This is a crucial information, see common assumptions below

2.3 Common assumptions

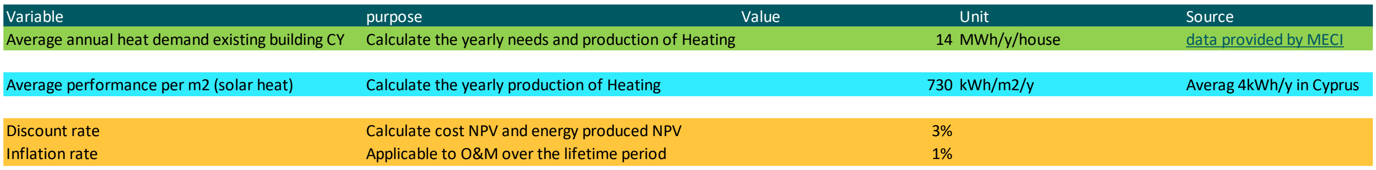
2.3.1 Fuels



Fuel	Consumer	Value	Unit	Source
Electricity	Medium-sized household	0,198	€/kWh	Eurostat
Electricity	Medium-sized household	0,320	€/kWh	Installer (Oct 2022)
Electricity	Non-household	0,109	€/kWh	Eurostat
Electricity	Non-household	0,164	€/kWh	+50% vs eurostat (~2022)
pellets	residential	450	€/t	installers
pellets	commercial	367	€/t	pellets-wood.com
pellets	*residential & commercial*	*4,5*	*KWh/kg*	
wood chips	residential	158	€/t	Baltpool exchange +40%
wood chips	commercial	135	€/t	Baltpool exchange +20%
wood chips	*residential & commercial*	*2,5*	*KWh/kg*	
wood log	residential	160	€/t	PC Wood - firewood
wood log	*residential & commercial*	*5*	*KWh/kg*	
bioliquid fuel	residential	1,41	€/litre	feedback installers
bioliquid fuel	*residential & commercial*	*10,06*	*kWh/litre*	
bioLPG	residential	2,12	€/litre	double price LPG
bioLPG	*residential & commercial*	*13,80*	*kWh/kg*	
biogas	residential	1,1	€/m3	BE biomethane production cost
biogas	*residential & commercial*	10	kWh/m3	
RES-H2	residential	5	€/kg	Hydrogen Europe roadmap
RES-H2	*residential & commercial*	33	kWh/kg	

Links are provided in the XLS

2.3.2 *Various assumptions*



Variable	purpose	Value	Unit	Source
Average annual heat demand existing building CY	Calculate the yearly needs and production of Heating	14	MWh/y/house	data provided by MECI
Average performance per m2 (solar heat)	Calculate the yearly production of Heating	730	kWh/m2/y	Averag 4kWh/y in Cyprus
Discount rate	Calculate cost NPV and energy produced NPV	3%		
Inflation rate	Applicable to O&M over the lifetime period	1%		

The importance of the discount rate in cost-benefit analysis of long term issues, such as climate change, has been widely acknowledged. However, the choice of the discount rate is still hardly discussed.[17]

To ensure inter-generational equity and be coherent with cost-benefit analysis normative choices, it is suggested to use low discount rates. Such low discount rates remain “theoretical”, as it is not assumed investors would take their decision with these levels. Also, the effective discount rate used by investors depends on the profile of the investor self, e.g. a household would not have the same expectations, nor the same risk practices as an industry.

Using a 3% discount rate seems to be an average of the current practice for investment dealing with topics like the energy or climate transition. In the recent “Energy costs, taxes and the impact of government interventions on investments” report (Trinomics, 2020), LCOE & LCOH are calculated using a discount rate of 3% (between 2% and 4%) for domestic systems and of 7% (between 6% and 8%) for all other technologies (renewables, nuclear and thermal). The IEA, in its “Renewables 2021, Analysis and Forecast to 2026” report (IEA, 2021), uses a 2% discount rate.

- The XLS tool provided allows to run different variations of the rate. The following results (chapter 3) runs a sensitivity analysis with the following discount rates5% for the residential sector
- 8% for non-residential sectors

The sensitivity shows clearly the higher impact on capex-driven technologies, compared to fuel or opex driven technologies.

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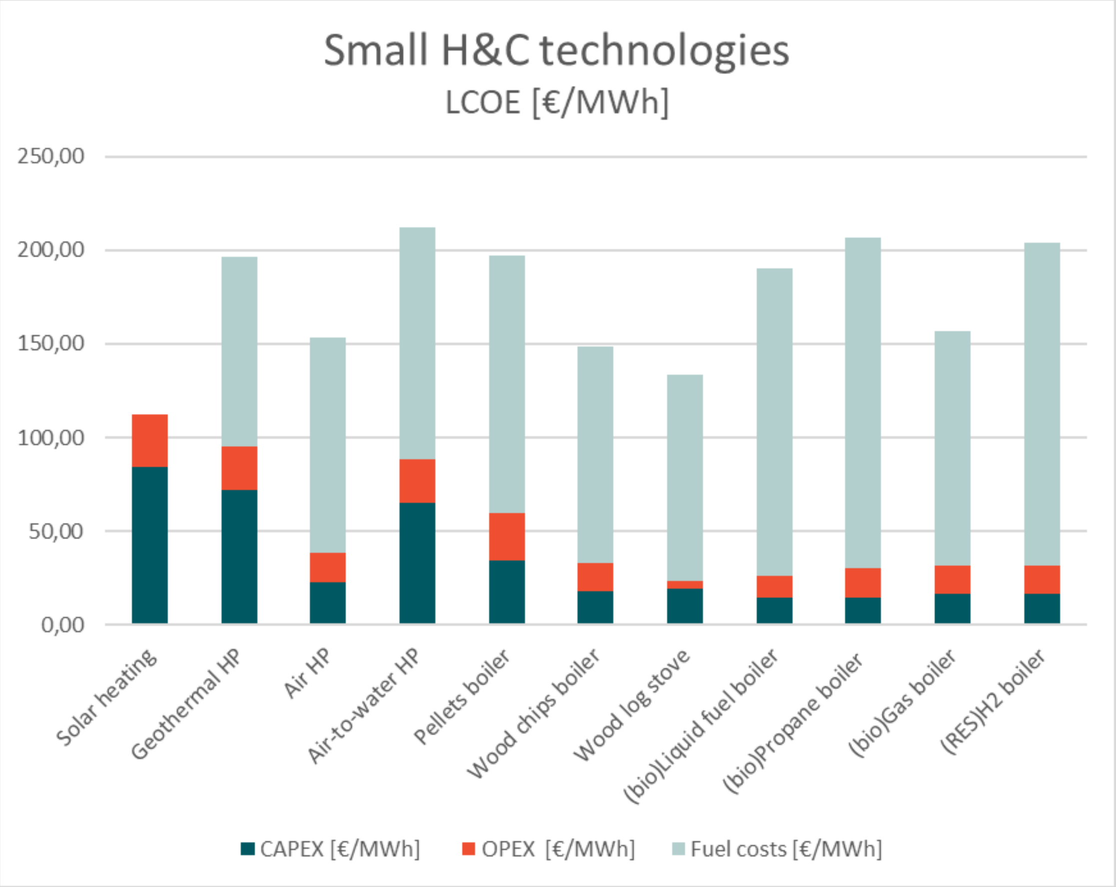
[17] https://iopscience.iop.org/article/10.1088/1748-9326/ab3cc9

3 Results

The XLS tool contains all data, and the possibility to extract the values, to develop such graph allowing to compare all technologies for small heating appliances.
Except for wood log stoves and solar heat (*), which cost highly depends on the local market of wood, all renewable heating technologies for small scale system have a LCOE above 130eur/MWh (all included).
(*) solar heat cannot be compared to the other technologies and fuels, considering that it is not a stand-alone technology for space heating.

3.1 Small scale systems



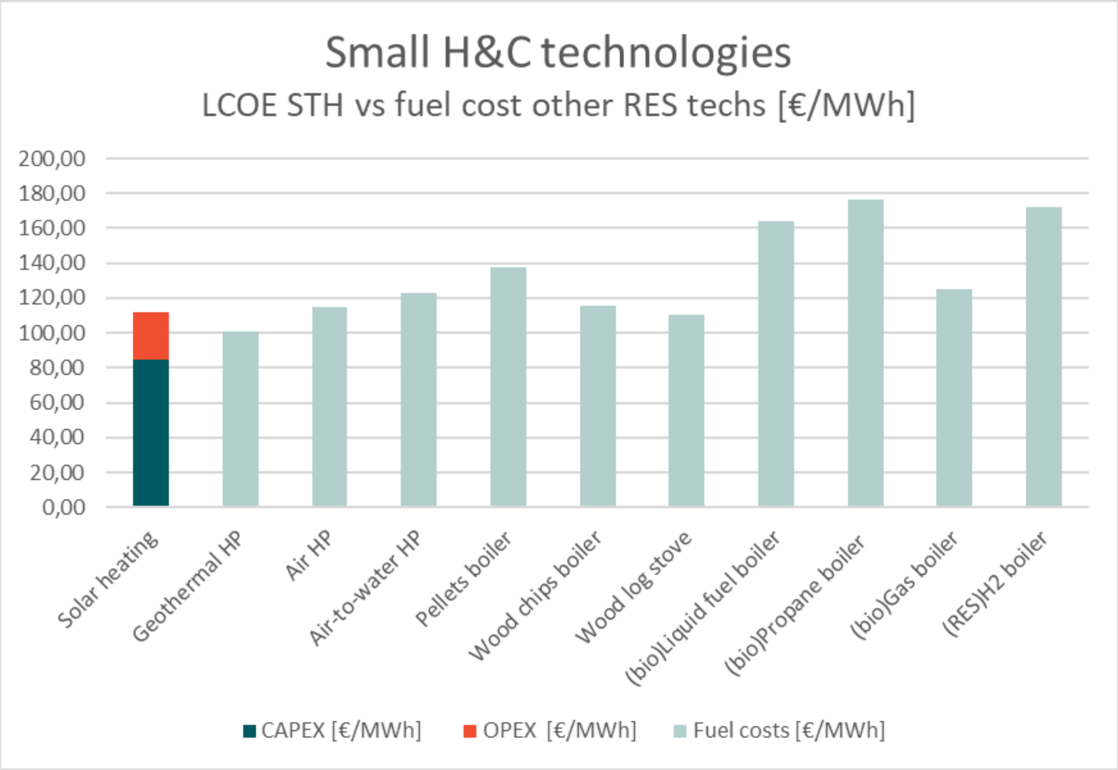
Note:

- *Wood chips boilers and wood log stoves are apparently attractive options. However, it should also consider that the cost of biomass was particularly low, and possibly not reflecting the current energy prices evolution. Also the efficiency of the system could be challenged, as these are currently set at the average between new and existing installations (the latter having lower efficiency)*

H&C technology	Size	CAPEX [€/MW	OPEX [€/MWh]	Fuel costs [€/MWh	LCOE [€/MWh]
Solar heating	Small	84,40	27,66	0,00	112,06
Geothermal HP	Small	72,02	23,60	100,68	196,29
Air HP	Small	22,95	15,40	114,98	153,32
Air-to-water HP	Small	65,52	23,10	123,19	211,81
Pellets boiler	Small	34,23	25,36	137,65	197,24
Wood chips boiler	Small	18,00	14,78	115,62	148,41
Wood log stove	Small	19,68	3,93	110,12	133,74
(bio)Liquid fuel boiler	Small	14,51	11,89	164,19	190,59
(bio)Propane boiler	Small	14,60	15,81	176,21	206,63
(bio)Gas boiler	Small	16,80	14,87	124,88	156,55
(RES)H2 boiler	Small	16,80	15,11	172,01	203,92

3.1.1 Comparison solar heat LCOE vs fuel cost for all other technologies

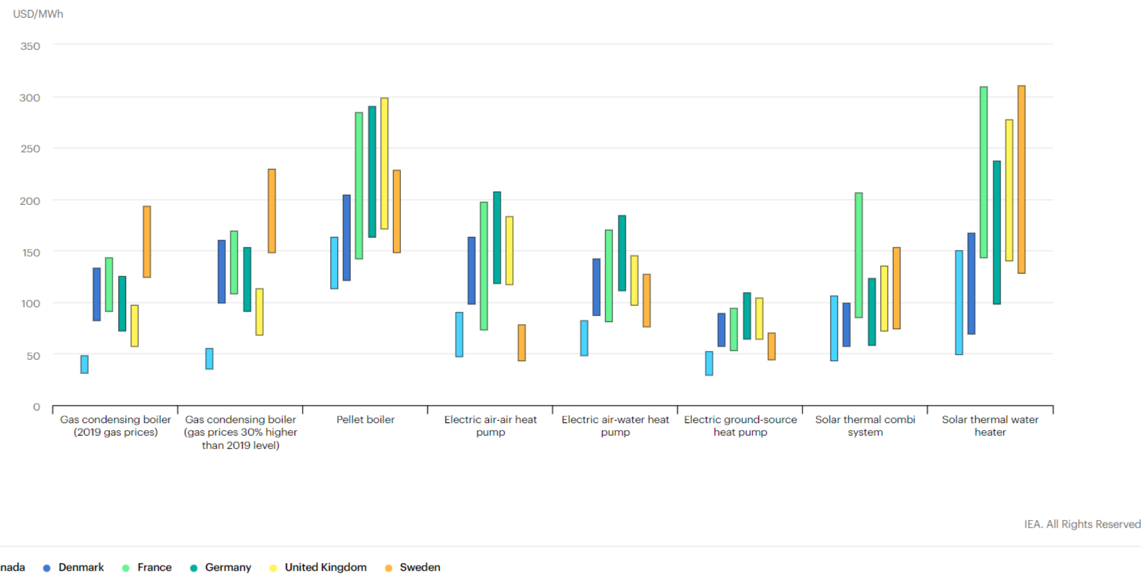
Solar heat (for sanitary hot water or space heating) is a technology that can be used as a complement to another heat production system, as it will never be self-sufficient and produce entirely the needed heat. Therefore, it can be considered as a technology to reduce the fuel use (generate fuel savings) of the main technology (the fuel can be either fossil-based or renewable). Consequently, the LCOE of solar heat should be compared to the fuel cost of other technologies.



The figure illustrates that solar heating is competitive already in the case of fuel-intensive technologies (such as air-to-water HP, pellet boilers, and bioliquid/biopropane/biogas/RES-H2 boilers), while it is of the same order as of more capex-driven technologies (such geothermal or air heat pumps).

3.1.2 Comparison with other sources

These LCOE can be compared to those established by the IEA in a recent work, for 5 countries (IEA, 2021).



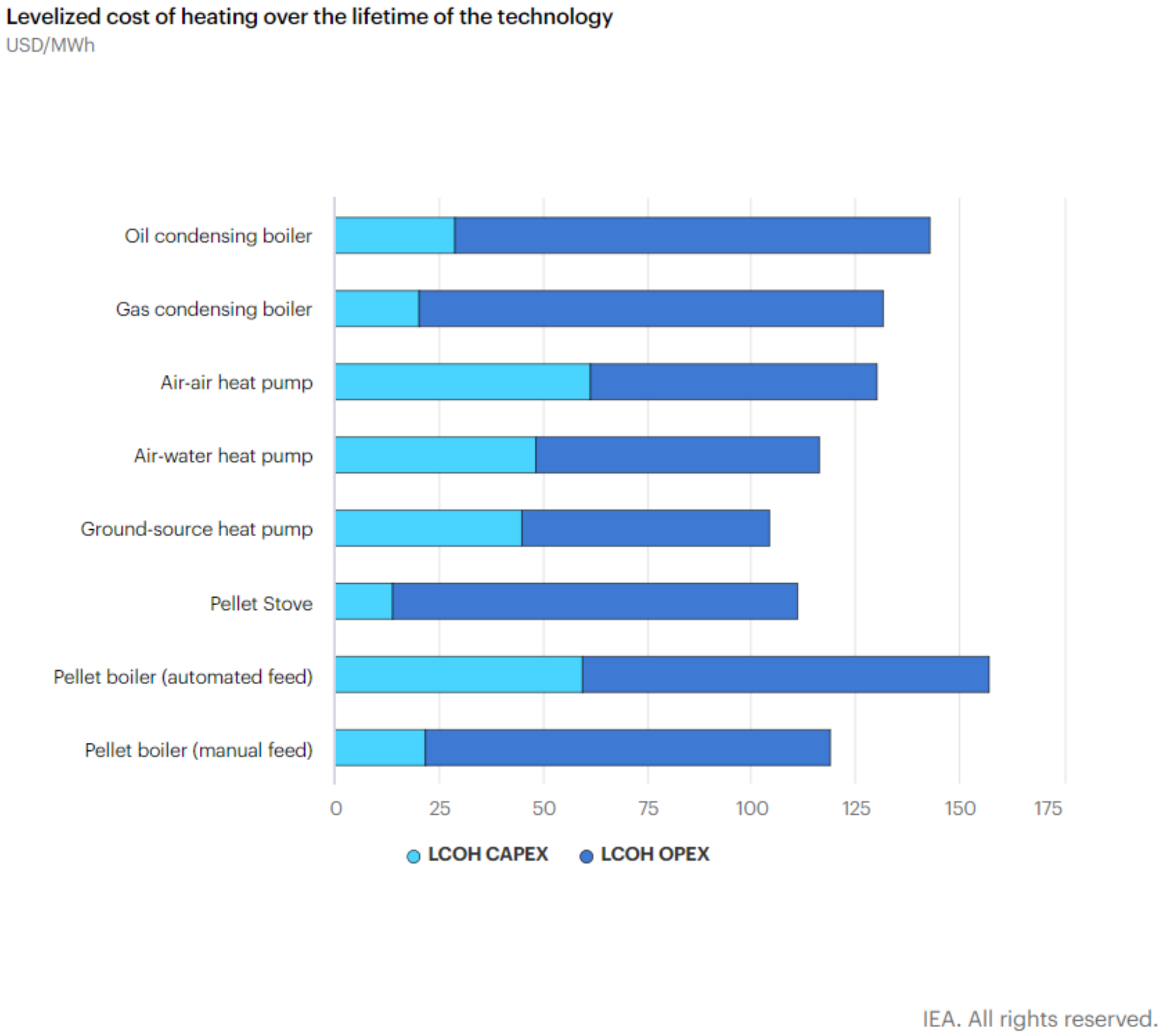
Source: [*https://www.iea.org/articles/are-renewable-heating-options-cost-competitive-with-fossil-fuels-in-the-residential-sector*](https://www.iea.org/articles/are-renewable-heating-options-cost-competitive-with-fossil-fuels-in-the-residential-sector)

It appears clearly on the graph that fossil-based systems are still among the cheapest options (natural gas-based), even though electric ground-source HPs look globally competitive (the important difference with Cyprus is certainly due to the still important installation cost, and to high electricity prices).

The LCOE range of solar thermal water seems very large, certainly due to the large variety of installation costs and solar irradiation. The fact that solar thermal combi systems seem to be less expensive than solar thermal water heaters (up to 4 times) is counterintuitive as sanitary hot water is used during the whole year (leading to high load hours), while space heating via combi systems should produce useful heat only during the cold season (leading to lower load hours). Consequently, the LCOE of SHW should probably be lower than combi systems (space heating). Hence, these figures cannot be used to assess the LCOE in Cyprus, without analysing deeply the assumptions behind.

It is also interesting to highlight the high cost of pellet boiler systems.

The details of France (IEA, 2021)

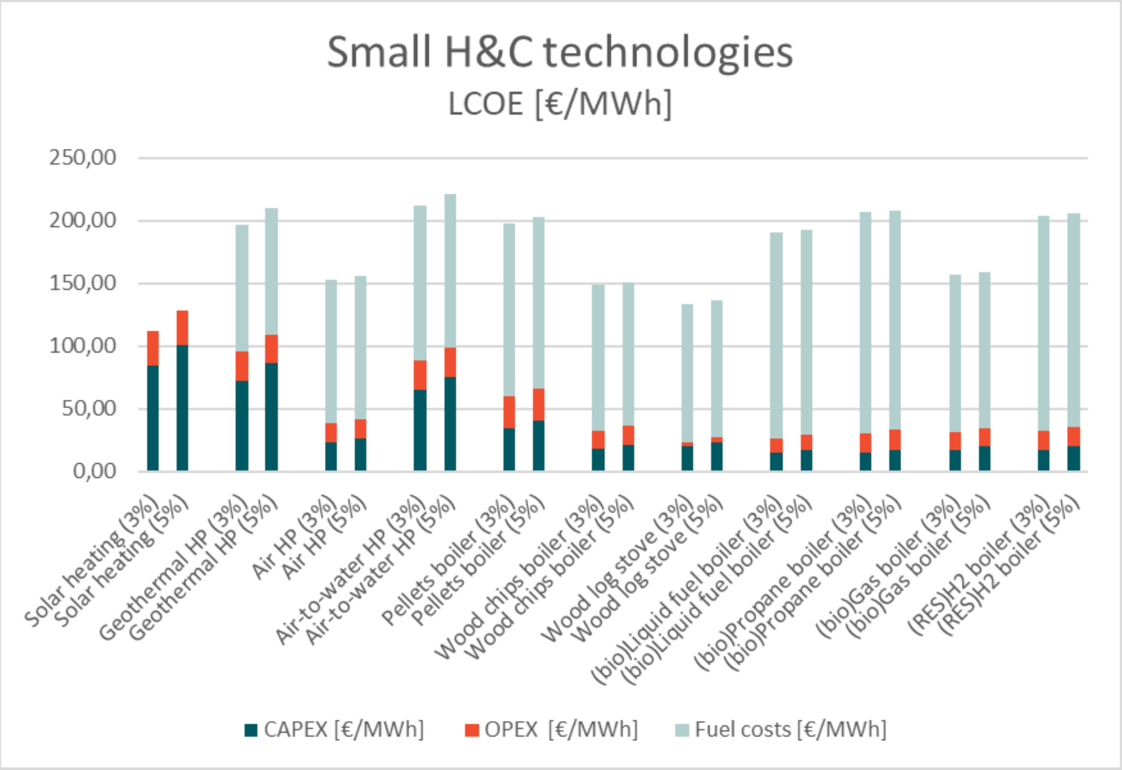


Source: ***https://www.iea.org/data-and-statistics/data-tools/residential-heat-economics-calculator***

This graph illustrates the differences between pellet systems, being automated or manual (this was not directly captured in the frame of this study). It also shows that renewable based systems become more competitive than formal fossil-based systems (on natural gas or oil). It is also interesting to see that installation costs of ground-source heat pumps may be cheaper than air HP (air-air or air-water), which is not yet the case in Cyprus (but may be a possible evolution when the technology deploys across the country).

3.1.3 Sensitivity analysis towards discount rate

A sensitivity analysis has been conducted to evaluate the impact of varying discount rates. The following graph compares small scale systems with 3% and 5% discount rates.



3.1.4 Takeaways for policies and measures for small scale systems

Globally, there is no clear-cut technology that appears to be the most cost effective for all applications across the country. To decarbonise the H&C, almost all technologies and options should be part of the future portfolio and contribute to the supply, but with varying intensities, depending on local parameters and constraints. Policies to deploy renewable energy in the H&C sector should consider the different technologies according to

- Solar heating systems should be seen as a way to save other non-renewable and renewable energy sources such as wood-based fuels, renewable electricity or bio-based fuels (liquids or gaseous). It should be considered as a key complementary energy source to supply heating in Cyprus. Hence, it should be slightly incentivised to deploy, especially in deep renovations and new buildings;
- Geothermal HP will benefit from a market development leading to a decrease in installation costs. Where feasible and cost-effective this technology should be promoted as it offers the highest efficiency, and consequently less use of electricity/fuels for the same amount of heat/cold produced. Combining HP and PV net-metering is a good option to benefit from cheaper electricity (the lowest capex, i.e. air HP systems, being the most profitable).
- Pellet boilers /heaters could be an affordable option in rural areas where air pollution is less critical (than in urban areas), and the resource is locally available (it means the local production should be encouraged to valorise by-products of the wood industry);
- Other wood-based fuels (logs or chips) are based on local resources, and should also be encouraged but with great care given the limitations of the resource;
- Bio-propane and bio-liquids should be promoted carefully, as their import would keep the current dependency and would rely on costly transport, unless produced on the national territory;

- Biogas for H&C can be an interesting and attractive solution only for local uses (near the place of production), as it would require transport, storage and distribution infrastructure (i.e. local network, or via trucks), that are not comprise in the LCOE;
- H2 in the built environment is usually not considered as the best option, as it would also require deploying the infrastructure to transport, store and distribute the fuel, and would therefore not be cost effective. The other technologies need to be promoted before hydrogen.

The deployment of renewables in H&C should always be combined (or even preceded) by the increase of the energy performance of buildings, in order to allow operation at lower temperature levels for heating (for HP it increases their efficiency) or to use fewer renewable resources. This is in line with the ‘Energy Efficiency First’ principle, which EU Member States must comply with in their design of decarbonisation policies and measures.

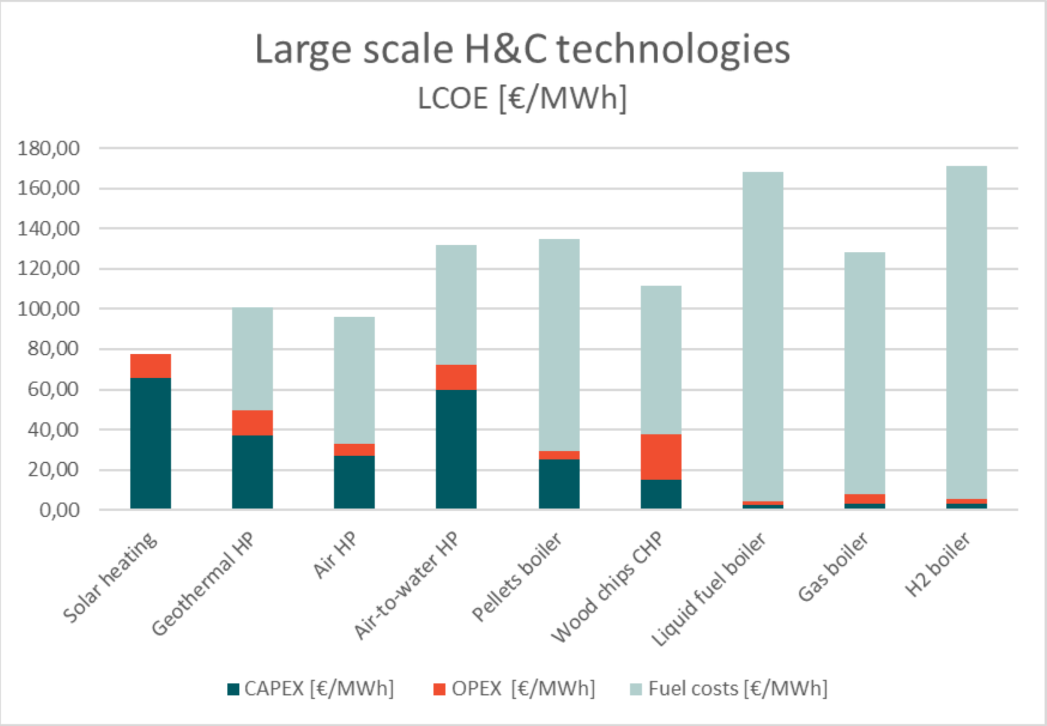
Globally, policies and measures to stimulate the deployment of renewable H&C technologies and fuels should ideally tackle various potential barriers such as policy barriers (e.g. lack of vision), market barriers (e.g. lack of competitiveness), financial barriers (e.g. lack of access to finance), capacity barriers (e.g. lack of acknowledgeable professionals), or technical barriers (e.g. lack of infrastructure). The analysis of LCOE is a crucial component to determine a H&C decarbonisation vision, as it would support identify the most cost effective pathway(s) towards a long term carbon neutral goal.

Designing and developing policies and measures to deploy renewable energy in H&C require to integrate many aspects in addition to LCOE, such as resource & fuel availability & sustainability, existing infrastructure, generation and grid capacity, building performance, etc. Also, learning curves and price evolution (capex and fuel) should be considered when designing policies. Hence, we recommend using these LCOE in combination with all these other factors to determine the most appropriate set of policies and measures for the deployment of renewable in the H&C sector. All these factors can be taken into account at the scenario simulations of the Cypriot energy system as part of DLV5.

To support the establishment of policies and measures, we recommend to use the Policy Support for Heating and Cooling Decarbonisation Roadmap (EC, June 2022), which provides key policy approaches for the integrated decarbonisation of heating and cooling (cf. chapter 4).

3.2 Large scale systems

The following graph illustrates the LCOE of large-scale systems



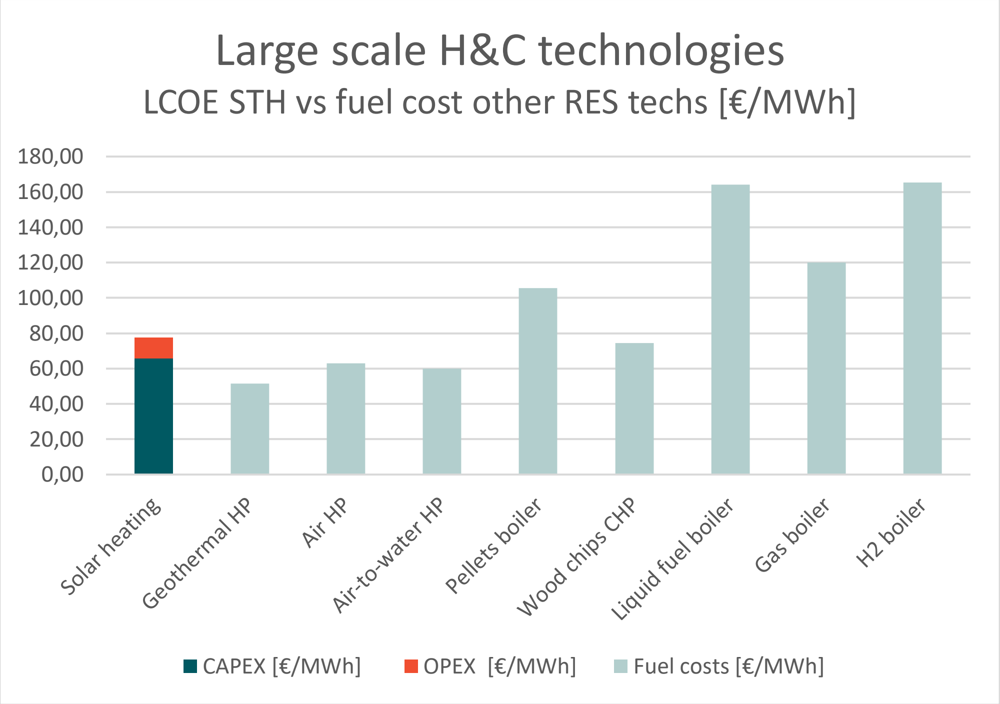
There are several differences between the small scale and large scale systems, which are most of the time explained by economies of scale. The main trend is that capex-driven technologies are more cost-effective for large scale than for small scale systems (e.g. heat pumps score better than the other technologies for large scale). The fuel price difference does not lead to important economies of scale (e.g. the difference between small and large scale biogas boiler LCOEs is not as high as the difference for geothermal heat pumps).

Fuel price in the LCOEs of fuel-driven technologies such liquid, biogas or H2 boilers is the predominant factor, meaning that the sensitivity is very high and dependent on fuel prices. This is crucial to notice as fuel prices are subject to evolve rapidly, due to international market fluctuations. Also evaluating the fuel price is a more delicate exercise than evaluating investment or operation and maintenance costs.

For large scale applications, we can globally observe that capex-driven technologies look more cost competitive than fuel-driven technologies.

H&C technology	Size	CAPEX [€/MWh]	OPEX [€/MWh]	Fuel costs [€/MWh]	LCOE [€/MWh]
Solar heating	Large	65,78	11,81	0,00	77,59
Geothermal HP	Large	37,34	12,24	51,49	101,07
Air HP	Large	26,83	5,99	63,00	95,82
Air-to-water HP	Large	59,75	12,24	60,07	132,05
Pellets boiler	Large	24,88	4,60	105,56	135,04
Wood chips CHP	Large	15,12	22,30	74,33	111,75
Liquid fuel boiler	Large	2,24	1,84	164,19	168,27
Gas boiler	Large	3,14	4,85	119,93	127,91
H2 boiler	Large	3,14	2,59	165,19	170,92

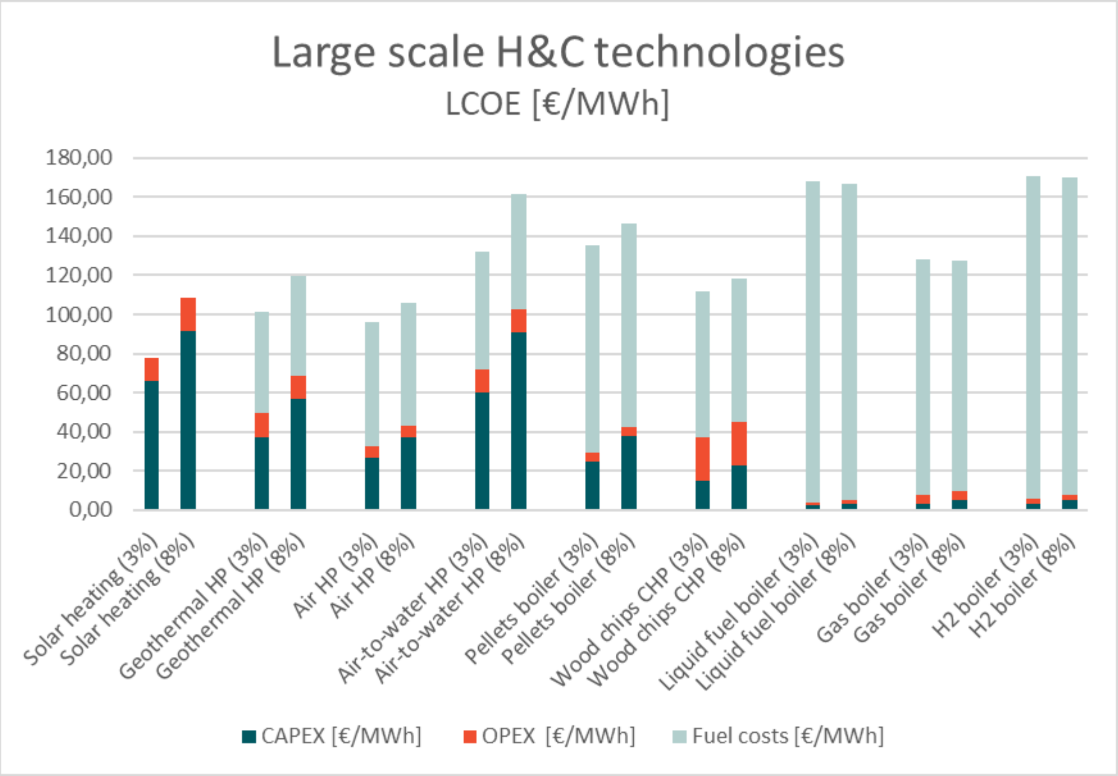
3.2.1 Comparison solar heat LCOE vs fuel cost for all other technologies



The figure illustrates that large solar heating is a needed and cost effective complementary technology to fuel-driven technologies (bio and hydrogen based), except for wood chips which remains more cost effective (than solar heat). Combining large solar heat to heat pumps (geothermal, air or air-to-water) would probably require to incentivise solar heat, as heat from the sun remains more expensive, due to the efficiency of large scale heat pumps. Such combination makes a lot of sense, for other reasons than only cost (e.g. providing more flexibility to the electricity system, saving electricity consumption, etc), and should be considered seriously, behind the LCOE.

3.2.1 Sensitivity analysis towards discount rate

A sensitivity analysis has been conducted to evaluate the impact of varying discount rates. The following graph compares large scale systems with 3% and 8% discount rates.



3.2.2 *Takeaways for policies and measures for large scale systems*

Although there is no clear-cut technology that appears to be the most cost effective for all applications across the country, capex-driven technologies seem to be the most promising for large scale systems, i.e. heat pumps and solar heating systems. However, this can be nuanced by the impact discount rate may have on these capex-driven technologies. Depending on the return expected by the investor, such conclusion may be jeopardised by an important rate (e.g. air-to-water HP becomes as expensive as liquid fuel boilers and even more expensive than pellet boilers with 8% discount rate, while it was less expensive than these two technologies with a 3% discount rate). Bio-based CHP (wood-chips in the LCOE analysis) are also an attractive option, and could be linked to the production of local feedstock. Of course, the availability of sustainable resources should be considered when designing policy measures.

Based on LCOE analysis only, to deploy renewable in the H&C sector for large scale applications (commercial and industry), it is recommended to focus first on heat pumps and solar heat, and CHP. Bio and hydrogen based options should no be discarded, but rather seen as a complement to these technologies, mainly for applications requiring high temperature levels (i.e. industry).
Policies to deploy renewable energy in the H&C should consider the different technologies according to

- Solar heating systems should be seen as a way to save other renewable energy sources such as renewable electricity, bio-based fuels (liquids or gaseous) or hydrogen based fuels. It should be considered as a key complementary energy source to supply heating in Cyprus in large buildings but also in the industry, and possibly in district heating. Hence, it should be incentivised to deploy, especially in deep renovations and new buildings. New technologies that operate at mid temperature levels should be demonstrated at scale, to cover industrial use with solar heat;
- Geothermal HP will benefit from a market development leading to a decrease in installation costs. This technology should be promoted as it offers the highest efficiency, and consequently

less use of electricity/fuels for the same amount of heat/cold produced. Sea-water based systems should also be promoted for large scale users (possibly by supplying DHC in touristic areas);

- Other heat pumps systems (air and air-to-water) should be considered when geothermal is not technically feasible.
- Wood chips CHP is an attractive option mainly for the industry but also for large service building needs (large building, such as a touristic compound), also possibly providing flexibility to the electricity system (e.g. when combined with heat storage, or flexible heat uses, especially in district heating). CHP could even be used in Trigeneration mode, supplying cold during the warm season. Large scale solid biomass systems should use the last performant technologies to reduce as much as possible air pollutions.
- Large scale pellet and other wood-based fuel boilers seem less attractive, and should be promoted with care given the higher LCOE, but also the fact that sustainable biomass may remain limited. However, large scale installations based on local supplies may be good options (e.g. encouraging to valorise by-products of the wood industry), from an economic and resilience point of view.
- Biogas for heating can be an interesting and attractive solution for local uses close to the place of production, to limit the need for distribution infrastructure (e.g. length of network) or transport (e.g. tank trucks with compressed gas, or even liquified gas), which are not comprised in the LCOE. Storage would be needed and added on top of the LCOE;
- Bio-propane and bio-liquids should be promoted carefully, as their import would keep the current dependency and would rely on costly transport, unless produced on the national territory. These would also be sensitive to international price fluctuations. Hence, they are not among the cost-effective options;
- H2 in the built environment is usually not considered as the best option, as it would also require deploying the infrastructure to transport, store and distribute the fuel, and would therefore not be cost effective. The other technologies need to be promoted before hydrogen in the tertiary sector. For the industry, H2 is more appropriate, depending on the processes, and need for high temperature (it could possibly become the complement of solar heat). However, this cannot be analysed without considering the entire hydrogen economy in Cyprus into account.

The deployment or renewable in H&C should always be combined (or even preceded) by the increase of the energy performance of buildings and industrial processes, in order to allow operation at lower temperature levels (for HP it increases their efficiency) or to use fewer renewable resources. As mentioned above, priority to energy efficiency improvements is also included in the ‘Energy Efficiency First’ principle, which EU Member States must comply with in their design of decarbonisation policies and measures.

See end of section 3.1.4 regarding the way to design policy options for large scale systems, using the Policy Support for Heating and Cooling Decarbonisation Roadmap (EC, June 2022), which provides key policy approaches for the integrated decarbonisation of heating and cooling (cf. chapter 4).

Annex 1: Preliminary list of RES technologies

Table 0-1 Preliminary list of heating and cooling technologies

Heat and cooling generation technology	Application
Solar water heater – small scale (<50kW)	Residential & small collective
Solar space heater – small scale (<50kW)	Residential & small collective
Solar district heating – large scale	Collective DH
Solar heating – large scale	Commercial applications
Solar cooling -small scale	Residential & small collective
Solar cooling-large scale	Commercial applications
Solar water heater high temperature – large scale (>50kW)	Industrial application
Concentrated solar systems	Industrial application
Geothermal (deep and shallow) heat pumps – small scale (for H&C) (<50kW)	Residential & small collective
Geothermal (deep and shallow) heat pumps – large scale (for H&C) (>50kW)	DH and Commercial applications
Geothermal (deep and shallow) heat pumps – large scale (for H&C) (>50kW)	Industrial applications
Air heat pumps for heating & cooling – small scale (<50kW)	Residential & small collective
Air heat pumps for heating & cooling – large scale (>50kW)	DH and Commercial applications
Air heat pumps – for heating & cooling large scale (>50kW)	Industrial applications
Heat pumps (air to water)	Residential and Commercial applications
Heat pumps (water to water)	Commercial applications
Deep geothermal heater (direct)	Collective DH, commercial and industrial applications
Pellets boilers – small scale (<50kW)	Residential & small collective
Pellets boilers – large scale (>50kW)	Collective DH, commercial and industrial applications
Wood chip boilers - large scale (>50kW)	Collective DH, commercial and industrial applications
Pellets stoves - small scale (<50kW)	Residential & small collective
Wood log stoves - small scale (<50kW)	Residential & small collective
Pellets CHP – large scale (>50kW)	Collective DH, commercial and industrial applications
Wood chips CHP – large scale (>50kW)	Collective DH, commercial and industrial applications
Liquid fuel boilers (e.g. biofuels) – small scale (<50kW)	Residential & small collective
Propane boilers (e.g. biopropane) – small scale (<50kW)	Residential & small collective
Conventional gas boilers (e.g. biogas) - small scale (<50kW)	Residential & small collective
Conventional gas boilers (e.g. biogas) - large scale (>50kW)	Collective DH, commercial and industrial applications
H2 boilers - small scale (<50kW)	Residential & small collective
H2 boilers - large scale (>50kW)	Collective DH, commercial and industrial applications
H2 CHP FC - large scale (>50kW)	Collective DH, commercial and industrial applications

Hybrid heat pump and gas boiler – small scale (<50kW)	Residential & small collective
Hybrid heat pump and gas boiler – large scale (>50kW)	Collective DH, commercial and industrial applications

Table 0-2 Preliminary list of heat infrastructure

Heat infrastructure	Application
New DHC – 5th Generation (low temperature)	Collective DH
Heat storage – large scale (CSP Technologies)	Collective DH
Heat storage – small scale (Various CSP technologies)	Residential & small collective
Geothermal Energy (Geothermal Maps available),	Industrial, Hotel, District Heating and Cooling

Annex 2: References

Danish Energy Agency (2020)	Technology Data - Individual heating technologies	https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-individual-heating-plants
ADEME (2020)	Coûts des énergies renouvelables et de récupération en France	https://www.geothermies.fr/sites/default/files/inline-files/ADEME_couts-energies-renouvelables-et-recuperation-donnees-2019-010895.pdf
Keep Warm Europe (2020)	Cool ideas for hot solutions to keeping our cities sustainably warm	https://keepwarmeurope.eu/fileadmin/user_upload/Resources/Promotional_materials/KeepWarm-marketing-brochure-A5-www.pdf
STRATEGO (2016)	Quantifying the Potential for DHC in EU Member States	https://heatroadmap.eu/wp-content/uploads/2018/09/STRATEGO-WP2-Background-Report-6-Mapping-Potenital-for-DHC.pdf
Assoclima (2022)	*See emails*	*Excel file*
Danish Energy Agency (2020)	Technology Data - District heating technologies	https://ens.dk/en/our-services/projections-and-models/technology-data/technology-data-generation-electricity-and

Trinomics B.V.
Westersingel 34
3014 GS Rotterdam
The Netherlands

T +31 (0) 10 3414 592
www.trinomics.eu

KvK n°: 56028016
VAT n°: NL8519.48.662.B01

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