Creating a world
fit for the future

Comprehensive Assessment of the Potential for Efficient Heating and Cooling

Report for Point F - Analysis of the Economic Potential of Different High Efficiency Technologies for Heating and Cooling

Report for Ministry of Energy, Commerce and Industry (MECI) of the Republic of Cyprus

Report for Ministry of Energy, Commerce and Industry (MECI), Cyprus – YEEB/YE/01/2020

ED 14106 | Issue number 1 | Date 27th July 2021

Ricardo Confidential

Customer:

Ministry of Energy, Commerce and Industry (MECI), Cyprus

Customer reference:

[customer reference]

Confidentiality, copyright and reproduction:

Contact:

Mahmoud Abu Ebid, Gemini Building, Fermi Avenue, Harwell, Didcot, OX11 0QR, UK

T: +44 (0) 1235 753 193

E: mahmoud.abu-ebid@ricardo.com

Author:

Richard Hodges

Approved by:

Mahmoud Abu Ebid

Signed

Date:

27th July 2021]

Ref: ED14106

Ricardo is certified to ISO9001, ISO14001, ISO27001 and ISO45001

Table of Contents

Table of Figures

Table of Tables

1 Introduction

Annex VIII of the Energy Efficiency Directive 2012/27/EU requires that the comprehensive assessment of national heating and cooling potentials includes an analysis of the economic potential for efficiency in heating and cooling. This Point F report satisfies this requirement by setting out the methodological approach to carrying out this assessment for the Republic of Cyprus, the results thereby returned and the conclusions arising from the analysis.

Specifically, this report is structured as follows:

Section 2 explains how the baseline technologies, against which high efficiency heating and cooling options are evaluated, are established. This is explained separately for the four distinct sectors of the economy analysed: Residential, Service, Industry and Agriculture. This section also explains how the baseline consumption for heating and cooling is established[1] and how this is adjusted to reflect already projected changes in heating and cooling demand out to 2030.

Section 3 sets out some of the detail of how the national demand for heating and cooling is represented in the modelling. It explains that, in order to manage the scope and complexity of the modelling, the heating and cooling demand is resolved into demand by a number of "architypes", which are defined to represent the diversity of demand across and within the different economic sectors.

Section 4 details the nature and characteristics of the high efficiency solutions evaluated. It splits these solutions into type generic types: District Heating and Cooling (DHC) solutions and individual building/site level solutions. Within each generic type of solution are a range of specific technologies. The operational nature of these are explained.

Section 5 explains the approach taken to the Cost Benefit Analysis (CBA) modelling, including the approach to establishing which technologies are applicable for satisfying demand in the different sectors, the costs and benefits captured in the analysis and the approach to capturing externalities (both costs and benefits) in the CBA. The main variables affecting the results are also listed in this section, and the effect of these is discussed in Sections 7 and 8.

Section 6 lists the variables used in the CBA which have the greatest potential to influence the results and points to where in the Appendices the values of these variables can be found.

Section 7 presents the results of the analysis, split by sector and technology. The sensitivity of the results for the cost effectiveness of DHC to key variables is discussed.

Section 8 discusses and caveats what the results presented in Section 7 mean, including uncertainties and areas where further work is need to be more definitive about what the analysis indicates at this stage.

Section 9 sets out the salient conclusions that can be drawn from the CBA.

2 Establishing the Baseline

2.1 Baseline Energy Consumption

The economic potential for efficient heating and cooling technologies has been evaluated for four sectors, as follows:

- Residential
- Service
- Industry
- Agriculture

Baseline consumption of heat and cooling in these sectors has been determined for 2018. The methodology used to do this is set out in the Point A section of the Point A&B report. The geographic

[1] See Point A report for how this is done.

distribution of these demands has been established as presented in the Point C report. The resulting distribution of demand for space heating (Residential and Service), process heating (Industry and Agriculture), space cooling (Residential and Service), process cooling (Industry) and sanitary hot water (Residential and Service) are shown in the heat map for the Republic of Cyprus. This heat map and the underlying data layers are now hosted on MECI's ArcGIS Online account.

2.2 Baseline Technologies for the Provision of Heating and Cooling

Baseline technologies for the provision of heating and cooling across the four sectors have been defined. The economic and financial case for supplanting these with a range of high efficiency solutions, both District Heating and Cooling (DHC) and individual building level solutions, has been evaluated by a Cost Benefit Analysis (CBA) Excel spreadsheet model developed for this work. The high efficiency solutions evaluated are presented in Table 4-1 and Table 4-2.

2.2.1 Residential

For the Residential sector, the model assumes a probability that the Space Heating (SH), Space Cooling (SC) and Sanitary Hot Water (SHW) demand is met by a combination of technologies. The probabilities of these combinations depends on the Residential architype under consideration. The technologies considered to be capable of providing SH, SC and SHW in the Residential sector are presented in Table 2-1, together with the probabilities considered to apply in 2018 for the three Residential architypes[2]. All architypes are listed in Section 3.

The mix of technologies for the Residential sector was constructed from the previous NCA for Cyprus 2015, as per Fig 1.1 (a)-(c), where the proportions of space heating, SHW and space cooling delivered by different technologies in the residential sector are presented [3].

Table 2-1 Technologies considered to be providing baseline SH, SC and SHW in the Residential sector

Space Heating (SH) Technology	Space Cooling (SC) Technology	Sanitary Hot Water (SHW) Technology	Apartment	Row House and Single House
Heat Pumps (split units)	Heat Pumps (split units)	Solar Panels	51%	23%
Electric Resistive Heating	Heat Pumps (split units)	Solar Panels	40%	18%
LPG Boiler	Heat Pumps (split units)	Solar Panels	1%	-
LPG Stoves	Heat Pumps (split units)	Solar Panels	7%	-
Oil Boiler	Heat Pumps (split units)	Solar Panels	0.3%	7%
Oil Stove	Heat Pumps (split units)	Solar Panels	-	46%
Solar Panels	Heat Pumps (split units)	Solar Panels	-	6%

[2] The three Residential architypes are: Apartments, Row Houses and Single Houses
[3] See tables A4.1-4.3 of Cost Benefit Analysis for the Potential of High-Efficiency Cogeneration in Cyprus
https://ec.europa.eu/energy/sites/default/files/documents/D%20I.4.1%20%20ReportCyprusen.pdf

2.2.2 Service

For the Service sector, with the exception of the Hotel architype, the same probability approach is taken to estimating the technology mix providing SH, SC and SHW in the baseline in 2018. The same technology mix is considered to apply across these seven Service sector architypes. The applicable technologies and their probabilities are presented in Table 2-2. The mix of technologies for the Service sector was taken from the previous NCA for Cyprus 2015, as per Fig 1.2 (a)-(c), where the proportions of space heating, SHW and space cooling delivered by different technologies in the service sector are presented [4].

In the case of the Hotel architype, it is assumed that the baseline in 2018 is comprised of oil boilers for SH and SHW demand and heat pumps (split units) for SC.

Table 2-2 Technologies considered to be providing baseline SH, SC and SHW in the Service sector (all architypes except Hotels)

Space Heating (SH) Technology	Space Cooling (SC) Technology	Sanitary Hot Water (SHW) Technology	All Nine Service Architypes
Heat Pumps (split units)	Heat Pumps (split units)	Solar Panels	77%
Heat Pumps and wet systems	Heat Pumps and wet systems	Solar Panels	7%
Solar panels	Heat Pumps (split units)	Solar Panels	1%
Oil Stoves	Heat Pumps (split units)	Solar Panels	13%
Oil Boiler	Heat Pumps (split units)	Solar Panels	1%

2.2.3 Industry (Non-EU ETS)

In the absence of disaggregated fuel consumption data for industrial sites not covered by EU ETS, the mix of technologies and fuels used for the Industrial sector was taken from the previous NCA for Cyprus 2015, as per Fig 1.3 (a)-(c), where the proportions of low, medium and high temperature heat delivered by different technologies in the industry sector are presented [5]. The applicable technologies and their probabilities for 2018 are presented in Table 2-3.

[4] See tables A4.4-4.6 of Cost Benefit Analysis for the Potential of High-Efficiency Cogeneration in Cyprus
https://ec.europa.eu/energy/sites/default/files/documents/D%20I.4.1%20%20ReportCyprusen.pdf

[5] See tables A4.7-4.9 of Cost Benefit Analysis for the Potential of High-Efficiency Cogeneration in Cyprus
https://ec.europa.eu/energy/sites/default/files/documents/D%20I.4.1%20%20ReportCyprusen.pdf

Table 2-3 Technologies considered to be providing baseline PH, PC and SHW in the Industrial sector (all non-EU ETS architypes)

Process Heating (PH) Technology	Process Cooling (PC) Technology	Sanitary Hot Water (SHW) Technology	All Non-EU ETS Industrial Architypes
Oil boiler	Electric chiller and wet system	Oil boiler	66%
Electric resistance heating	Electric chiller and wet system	Electric resistance heating	16%
LPG boiler	Electric chiller and wet system	LPG boiler	16%
Solar panels	Electric chiller and wet system	Solar Panels	2%
Biomass boiler	Electric chiller and wet system	Biomass boiler	<1%

2.2.4 Industry (EU ETS)

There are seven EU ETS industrial installations, 1 x cement and 6 x ceramics sites. The fuel consumption data for these were available and so the baseline technologies reflect the fuel types consumed by these sites.

2.2.5 Agriculture

The mix of technologies and fuels used for the Agriculture sector was taken from the previous NCA for Cyprus 2015, as per Fig 1.4, where the proportions of heating delivered by different technologies in the agriculture sector are presented [6]. The applicable technologies and their probabilities for 2018 are presented in Table 2-4.

Table 2-4 Technologies considered to be providing baseline PH, PC and SHW in the Agricultural sector (all architypes)

Process Heating (PH) Technology	Process Cooling (PC) Technology	Sanitary Hot Water (SHW) Technology	All Agricultural Architypes
Oil boiler	Electric chiller and wet system	Oil boiler	96%
Biomass boiler	Electric chiller and wet system	Biomass boiler	3%
LPG boiler	Electric chiller and wet system	LPG boiler	1%

[6] See tables A4.10 of Cost Benefit Analysis for the Potential of High-Efficiency Cogeneration in Cyprus https://ec.europa.eu/energy/sites/default/files/documents/D%20I.4.1%20%20ReportCyprusen.pdf

2.3 Baseline Adjustments for Existing Policies Related to Heating and Cooling

For the purposes of the Cost Benefit Analysis (CBA) of efficient heating and cooling, two versions of the baseline can be used. CBA results using these two baselines are presented in Section 7.

The rationale for using two baselines to see if there is a material impact on the potential for efficient heating and cooling as a result of projected evolutions in demand to 2030 driven by Government policy in Cyprus.

2.3.1 Heating and Cooling Demand in 2018

This is the 2018 demand for heating and cooling in 2018, as set out in the Point A section of the Point A&B report, and uses the technology mix set out in Sections 2.2.1 - 2.2.5. This demand is assumed to pertain in each year for which the CBA is carried out. The CBA is carried out over a period of 28 years (2022-2050) via a Discounted Cash Flow (DCF), for the balance of costs and benefits listed in Section 5.1[7].. Economic Net Present Value (ENPV) and Financial Net Present Value (FNPV) are calculated for each technology solution in terms of €2020.

2.3.2 Heating and Cooling Demand in 2030

In order to capture the impact of existing policies in Cyprus relating to heating and cooling, the 2018 heating and cooling demand is adjusted. The existing definitive analysis of the effect of existing policies on demand for heating and cooling is the analysis presented in Table 5.4 of the National Energy and Climate Plan (NECP)[8]. This shows an absolute increase in final energy consumption associated with the provision of heating and cooling in Cyprus of 12.55% between 2018 and 2030. During this time, according to the NECP, the population of Cyprus is projected to increase by 8.1% and the real GDP is projected to increase by 34%.

This absolute increase in final energy demand is considered to have the following components:

1. New demand at new sites, due to population increase, and
2. New demand at existing sites because of greater comfort expectations, especially in regard to cooling, as a result of higher incomes. It should be noted that projected increases in temperature due to climate change have not been taken into account explicitly in this analysis. However, over the period 1979-2020 the cooling degree days in Cyprus have increased on average by 12.5 CDDs per year while over the same period Heating Degree Days (HDDs) have decreased by 6.0 HDDs per year. Should this trend continue, it is reasonable to expect an increase in the demand for cooling that goes beyond that explained by greater comfort expectations.

In respect of 1, the effect of population growth is considered to increase the heating and cooling demand in the residential, service, industrial and agricultural sectors. Consequently, for the purposes of the CBA, the heating and cooling demand in all four sectors are projected to increase by 8.1% between 2018 and 2030. In the residential and service sectors this is executed in the model by increasing the points of demand for heating and cooling by 8.1%, while in the industrial and agricultural sectors, the demand at existing sites in modelled to increase by 8.1%.

In respect of 2, the balance of the increase in demand between 2018 and 2030 (12.55%-8.1% = 4.45%) is assumed to be attributable to an absolute increase in the demand for cooling in the residential and service sectors such that there is an overall increase in the demand for heating and cooling for Cyprus of 12.55% between 2018 and 2030, as set out in the NECP.

For this expanded demand, the CBA is carried out over a period of 28 years (2030-2058), using 2030 energy prices, CO_2 costs and other costs which change over time (see Appendices) and a NET Present Value (NPV) is calculated in terms of €2020. Both Economic Net Present Value (ENPV) and Financial Net Present Value (FNPV) are evaluated.

[7] Full cost assumptions are detailed in Appendices 2-9.
[8] https://ec.europa.eu/energy/sites/ener/files/documents/cy_final_necp_main_en.pdf

3 The Use of Architypes

There are approximately 567 thousand buildings in Cyprus. In order for the CBA to be computed without undue complexity and with optimal speed, architypes have been established to reflect the range of diversity of heating and cooling demand seen across Cyprus. Each defined architype has a specific demand for heating and cooling. The heating or cooling demand within a particular geographical boundary (i.e. Post Code) is then the number of each architype in the Post Code of interest multiplied by the heating or cooling demand of that architype, summed across all architypes found in the Post Code.

The development of architypes for the residential, service, industrial and agricultural sectors is explained in the Point C report in Section 1.2.2. Table 3-1 shows the number and description of the different architypes defined for each sector. For the avoidance of doubt, large industrial sites participating in EU ETS are reflected in the heat map and modelling as individual entities with their own specific heat demand, as determined from the available site level data.

Table 3-1 Architypes observed in the analysis

Sector	Architypes Observed
Residential	Apartment Row house Single house
Service	Airports Restaurant Health Hotels Offices Schools Shopping Other Services
Industrial (not EU ETS)	1 x Cement (EU ETS)[9] 6 x Ceramics (EU ETS) Chemicals (Non-EU ETS) Food and Drink (Non-EU ETS) Other Minerals (Non-EU ETS) Other industry (Non-EU ETS)
Agricultural	Greenhouses Other Agriculture

The heating and cooling consumption for each of the above listed architypes is produced in Appendix 1.

In the CBA modelling, the most economic individual building level solution is evaluated for each architype and this solution is assumed to apply for each incidence of that architype across Cyprus, irrespective of where it is located (i.e. irrespective of Post Code).

[9] Note; A cement non-EU ETS sector is also defined, but not used as all cement plant in Cyprus is covered by EU ETS.

4 Solutions Evaluated

Efficient heating and cooling solutions have been evaluated for District Heating and Cooling (DHC) and for individual building level heating and cooling solutions. The results of the economic modelling are presented in this report after being aggregated up to the Post Code level[10].

When evaluating a particular DHC solution in a Post Code, the solution under evaluation is modelled to serve all susceptible heating and cooling demand in that Post Code.

When evaluating building level solutions, the solution under evaluation is modelled to serve all of the susceptible heating and cooling demand in each building architype under consideration.

The susceptibility of heating and cooling demand to technology is discussed in Section 5.2.

The NPV for building level solutions in a Post Code is given by:

Equation 1

$$\begin{aligned} &NPV\ for\ Post\ Code\ A \\ &= \sum_{Architype\ 1}^{Architype\ N} NPV\ for\ Best\ Individual\ Solution\ for\ Architype\ 1 \\ &\times Number\ of\ Incidences\ of\ Architype\ 1\ in\ Post\ Post\ Code\ A \end{aligned}$$

The DHC solutions are evaluated at the Post Code level and are modelled to supply all susceptible heating and cooling for all architypes in the Post Code in question.

The CBA model presents results which may be expressed according to two preferences, as follows:

1. The most economical solution (greatest NPV) is counted as the best solution. Under this preference even if a DHC solution is found to be economic, if an individual building level solution is found to be more economic (i.e. have a higher NPV), the latter solution is counted as the best solution for the Post Code. This is the basis for the results presented and discussed.
2. Where DHC is found to be the most economical solution for a particular Post Code, this is counted as the best solution for that Post Code, regardless of the how economic individual level building solutions are

For either of these preferences, the model developed for carrying out the CBA for the Comprehensive Assessment allows for ranking of solutions according to best Economic NPV (ENPV), Financial NPV (FNPV), CO_2 savings or Primary Energy Savings (PES).

4.1 District Heating and Cooling Solutions (DHC) Evaluated

The cost effectiveness, primary energy and CO_2 savings of a number of "Types" of DHC solutions are evaluated in the model. Each type was modelled to supply all of the domestic and service sector buildings in each Post Code. In the case of industrial and agricultural architypes (both EU ETS and non-EU ETS) the heat demand of these sites is excluded from the DHC solution evaluated on the grounds that the grade of heat needed by such sites is incompatible with that which can be supplied by DHC.

Each DHC solution is evaluated to supply demands of Space Cooling (SC), Space Heating (SH) and Sanitary Hot Water (SHW), where the last is not currently supplied using solar thermal. Where SHW is assumed to be currently supplied using solar thermal, it is assumed that this arrangement will continue, even though SH and SC are supplied via the DHS scheme.

[10] There are also two sub-post code areas for which solutions have been evaluated, in order to gauge the impact of evaluating DHC solutions at a more detailed level. These two sub-post code areas are tourist areas known to have concentrated heating and cooling demand.

There are three basic “Types” of DHC solution evaluated, defined according to the approach taken to meeting the demands for cooling and heat in the buildings served by the solution. These are summarised below:

Type 1 – This is a 2-pipe solution, whereby the same flow and return pipes are used to supply hot water (for SH and SHW) and chilled water (for SC). This means that, at any one time, only heating or cooling can be supplied via the DHC network. Therefore, only hot water will flow in the DHC pipework in the winter/heating season (assumed to be November to April) and only chilled water will flow in the DHC pipework during the summer/cooling season (assumed to be May to October). A consequence of this supply arrangement is that the demand for SHW, which occurs throughout the year, cannot be met by the DHC network in the summer months when the network is dedicated to supplying chilled water for cooling. At these times, heat customers on the network will have to use their own local plant to meet all of their SHW demand. It is assumed that the existing technology for supplying SHW locally is retained and used for this purpose.

Type 2 – This is a 4-pipe solution, whereby there are separate flow and return pipes for hot water and chilled water. This means that at any one time both heating and cooling can be supplied by the DHC network, as required by the customers on the network. In contrast to the situation for Type 1, there is no need for local SHW heating plant (unless the end user is modelled to be currently using solar thermal for SHW, in which case the modelling assumes that particular arrangement continues).

Type 3 – This is a 2-pipe solution whereby the flow and return pipes are used only to supply hot water. No chilled water is carried by the DHC network. Instead, cooling is achieved locally using localised absorption chillers, but only where the building requiring cooling is a service sector building. Where the building in question is residential, it is assumed that the installation of localised absorption chillers to meet residential cooling demand would be prohibitively expensive, and in these cases the cooling demand is met by local heat pumps.

There are variations of each of the three Types of DHC solution mentioned above, with each variation relying on different primary, central heat generating plant. There are six types of primary, central heat generating plant. These are: Biomass CHP, Oil CHP, LPG CHP, RDF CHP, Water Source Heat Pumps (WSHP) and waste heat recovered from power stations or industrial plant with a thermal input capacity >20 MWth. WSHPs are only applicable for coastal post codes. As discussed in the Point A & B report, only waste heat from two sources (one power station and one cement works) are considered suitable for modelling.

Taking the three different types of DHC solutions and the six primary, central heat generation technologies means that we have investigated eighteen combinations of DHC solution type and primary, central heat generating technology. Depending upon the type of solution, heat and cooling top-up plant, used to supplement the primary plant heat and cooling outputs, may or may not be necessary. Table 4-1 sets out in detail the primary plant, top-up plant and DHC pipework arrangements associated with each of the eighteen combinations (also known as “solutions”).

The solutions evaluated are summarised in Table 4-1.

Table 4-1 Detailed characteristics of 18 combinations of DHC evaluated in this study

Combination No.	DHC Solution Type	No. Pipes (2 or 4)	Primary, Central Heating Plant	Top-up Central Heating Plant	Primary Central Cooling Plant	Top-up Central Cooling Plant	Localised Top-up SHW	Localised Top-up Cooling Plant
1	Type 1	2 pipe	Biomass CHP	Biomass boiler	Absorption chiller	Electric chiller	As per baseline	Not required
2	Type 2	4 pipe	Biomass CHP	Biomass boiler	Absorption chiller	Electric chiller	As per baseline	Not required
3	Type 3	2 pipe	Biomass CHP	Biomass boiler	N/A (Cooling generated locally)	N/A	As per baseline	Local Absorption chiller + Reversible heat pump (for residential buildings)
4	Type 1	2 pipe	Oil CHP	Oil boiler	Absorption chiller	Electric chiller	As per baseline	Not required
5	Type 2	4 pipe	Oil CHP	Oil boiler	Absorption chiller	Electric chiller	As per baseline	Not required
6	Type 3	2 pipe	Oil CHP	Oil boiler	N/A (Cooling generated locally)	N/A	As per baseline	Local Absorption chiller + Reversible heat pump (for residential buildings)
7	Type 1	2 pipe	LPG CHP	LPG boiler	Absorption chiller	Electric chiller	As per baseline	Not required
8	Type 2	4 pipe	LPG CHP	LPG boiler	Absorption chiller	Electric chiller	As per baseline	Not required
9	Type 3	2 pipe	LPG CHP	LPG boiler	N/A (Cooling generated locally)	N/A	As per baseline	Local Absorption chiller + Reversible heat pump (for residential buildings)
10	Type 1	2 pipe	WSHP	Not required	WSHP	Not required	As per baseline	Not required
11	Type 2	4 pipe	WSHP	Not required	WSHP	Not required	As per baseline	Not required
12	Type 3	2 pipe	WSHP	Not required	WSHP	Not required	As per baseline	Not required
13	Type 1	2 pipe	RDF CHP	RDF boiler	Absorption chiller	Electric chiller	As per baseline	Not required
14	Type 2	4 pipe	RDF CHP	RDF boiler	Absorption chiller	Electric chiller	As per baseline	Not required

15	Type 3	2 pipe	RDF CHP	RDF boiler	N/A (Cooling generated locally)	N/A	As per baseline	Local Absorption chiller + Reversible heat pump (for residential buildings)
16	Type 1	2 pipe	Industrial/Power Station Waste Heat	Not required	Absorption chiller	Electric chiller	As per baseline	Not required
17	Type 2	4 pipe	Industrial/Power Station Waste Heat	Not required	Absorption chiller	Electric chiller	As per baseline	Not required
18	Type 3	2 pipe	Industrial/Power Station Waste Heat	Not required	N/A (Cooling generated locally)	N/A	As per baseline	Local Absorption chiller + Reversible heat pump (for residential buildings)

4.2 Individual Site/Building Level Solutions Evaluated

For each Post Code the potential for Space Heating (SH), Process Heating (PH), Space Cooling (SC), Process Cooling (PC)and Sanitary Hot Water (SHW) to be satisfied using individual, site/building level high efficiency solutions was evaluated. These high efficiency solutions are:

1-3 CHP (biomass, oil and LPG fired), with individual building level absorption chillers and appropriate top up for heating and cooling. (Note: CHP solutions are only modelled for industrial and agricultural sites and non-residential buildings[11].

4. Individual heat pumps for SH and SC, with solar for SHW generation. (Note: This solution is not evaluated for industrial sites, as it is assumed that the grade of heat required by these sites cannot be supplied by heat pumps).
5. Solar SH, SC (using absorption chillers) and SWH. (Note: This solution is only evaluated for the residential and service sectors, only where the information available indicates that they are not currently used (i.e. it is not in the baseline) and where there is deemed to be enough roof space for its installation.
6. Heat Pump plus PV for SH, SC and SHW generation. (Consistent with the approach taken for other technologies, this solution is modelled to deliver SHW only where the baseline SHW is assumed not to be provided by solar thermal. Where the baseline SHW is supplied by solar thermal, this assumed to continue in the solution). Under this solution, the PV system is sized such that all of the electricity consumed by the heat pump in a year to meet heating and cooling demand can be generated by the PV system. Also, it is assumed that each system uses net metering, that excess generation is exported and that this offsets imports at times where electricity demand from the heating and cooling system exceeds generation by the PV system. In other words, there is no net import of electricity to supply the heating and cooling system. Additional Capex for a net meter is included in the Capex for this solution to reflect this way of operating.

Table 4-2 Detailed characteristics of the individual building level solutions evaluated

Combination No.	Primary Heating Plant	Top-up Space Heating Plant	Primary Cooling Plant	Top-up Cooling Plant	Primary SHW Plant	Top-up SHW Plant
1	Biomass CHP	Biomass boiler	Absorption chiller	Electric chiller	Where not solar thermal, Biomass CHP/biomass boiler	Where not solar thermal, Biomass CHP/biomass boiler
2	Oil CHP	Oil boiler	Absorption chiller	Electric chiller	Where not solar thermal, Oil CHP/Oil boiler	Where not solar thermal, Oil CHP/Oil boiler
3	LPG CHP	LPG boiler	Absorption chiller	Electric chiller	Where not solar thermal, LPG CHP/LPG boiler	Where not solar thermal, LPG CHP/LPG boiler
4	Heat pump	None	Heat pump	None	Solar thermal	Oil boilers (for hotels and hospitals) Electric resistance (for other non-domestic buildings)

[11] Also, RDF fired CHP is not considered an appropriate solution at the individual building level and so is not modelled here

						Baseline (for domestic buildings)
5	Solar thermal	Oil boiler (for hotels) Baseline (for other non-domestic and domestic buildings)	Absorption chillers	Electric chillers (for hotels) Baseline (for other non-domestic and domestic buildings	Solar thermal	Oil boiler (for hotels) Baseline (for other non-domestic and domestic buildings)
6	PV + Heat pump	None	PV + Heat pump	None	Solar thermal	Oil boilers (for hotels and hospitals) Electric resistance (for other non-domestic buildings) Baseline (for domestic buildings)

5 Approach to CBA

5.1 General Points

The cost effective economic and financial potential of the DHC and individual site/building level solutions set out in Sections 4.1 and 4.2 were evaluated for all Post Codes in the Republic of Cyprus. Economic potential represents the economic potential from the point of view of the public investor. The financial potential represents the potential from the point of view of the private investor. Cost effective economic potential is deemed to exist if the Economic Net Present Value (ENVP) is positive[12]. Cost effective financial potential is deemed to exist if the Financial Net Present Value (FNVP)[13] is positive.

In addition to this analysis at the Post Code level, more localised analysis was carried out for two areas where the demand for heating and cooling is known to be dense. These areas are:

- Poseidonos Avenue, Paphos, incorporating parts of three Post Codes (PC_{8041}, PC_{8042} and PC_{8204}). This area captures 25 hotels dispersed across this avenue Kryo Avenue.
- Kryo Avenue, Ayia Napa - This area captures 20 hotels dispersed across this avenue and is contained within one Post Code (PC_{5330}).

The rationale behind evaluating for these localised areas is to assess the impact on the relative cost effectiveness of DHC and individual level solutions of selecting areas where consumption of cooling and heating are known to be dense.

Cost effective potential was evaluated using Discounted Cash Flow (DCF) analysis of the costs and benefits relative to the baseline technology mix for each architype, as set out in Section 2.2.

The DCF analysis has included the following costs:

- Capital costs of plant and equipment
- Capital costs of the associated energy networks, i.e. the pipework for DHC networks and the heat network interface costs to allow buildings to take heating and cooling from the network
- Operating costs of the plant, equipment and energy networks (both fixed and variable)

[12] Using a Discount Rate of 4%.
[13] Using a Discount Rate of 12%.

- Energy costs
- Costs associated with the emission of CO_2 at installations covered by the EU ETS – considered only in the evaluation of financial potential.
- Societal costs associated with the emission of CO_2 considered only in the evaluation of economic potential.
- Environmental costs associated with the emission of pollutants arising from the combustion of fuels (specifically NOx, PM10 and SOx) - – considered only in the evaluation of economic potential.
- Energy security costs incurred/avoided as a result of the implementation of the high efficiency solutions. Specifically, the electricity price has been inflated to reflect the costs of system upgrade that would be necessitated by an increased implementation of heat pumps. Solution technologies that provide distributed generation of electricity (e.g. CHP) avoid this additional cost and are appropriately credited via the inflated price of electricity avoided, represented by their generation. For solutions involving the use of PV for the generation of electricity for consumption by heat pumps, since the PV is sized to meet the increased demand for electricity over the year (see Section 4.2), there is no net requirement for imported electricity and consequently no additional cost associated with system upgrade.

The **economic potential** is evaluated using a Discount Rate (DR) of 4% and the financial potential was evaluated using a DR of 12%. The economic potential is evaluated including an external cost associated with the deployment of the different technologies, in order to reflect the cost to wider society of fuel use. The external costs included here are two-fold:

(1) The costs of CO_2 arising from the combustion of fuel. The CO_2 costs are those used by the European Investment Bank in their guidelines for the appraisal of investment projects[14]. These costs are set at € (2006) 25/tCO_2e for emissions made in 2010, with the cost increasing by €1/tCO_2/year for each year after 2010. These costs have been inflated to 2020 prices using the inflation rate for the EU28 given by Eurostat.

(2) The costs associated with emissions from NOx, PM10 and SO2. The extent of such emissions depends upon whether the fuel is fossil fuel solid, fossil fuel liquid, fossil fuel gaseous or biomass. These differences are observed in the analysis. The quantity of emissions (g/kWh) for the different fuel types are taken from the European Environment Agency Air Pollutant and Emission Inventory Guidebook[15], The marginal costs of damage per tonne of each of the three pollutants is taken from the Cyprus NECP, 2020[16]. This results in a marginal pollution cost per kWh, as per Appendix 4. The damage costs associated with the consumption of generated electricity changes for each year of the analysis in response to the changing fuel mix for generation projected in the NECP. The damage costs for fuels consumed on site are assumed to remain constant.

The **financial potential** is evaluated excluding the above mentioned external costs but including the cost of CO_2 where the combustion capacity of the plant would mean that it was covered under EU ETS. This cost only becomes relevant for the larger DHC solutions and larger industrial and agricultural sites. The assumed prices of ETS emission allowances are taken from Figure 2 of the report: EU Reference Scenario 2016 Energy, transport and GHG emissions Trends to 2050[17]. These

[14] 'The Economic Appraisal of Investment Projects at the EIB' by the European Investment Bank http://www.eib.org/attachments/thematic/economic_appraisal_of_investment_projects_en.pdf?f=search&media=search
[15] European Environment Agency Air Pollutant and Emission Inventory Guidebook, Combustion in Manufacturing Industry, Tables 3.2-3.5 https://www.eea.europa.eu/publications/emep-eea-guidebook-2019
[16] See footnote 109, p. 230 of: https://ec.europa.eu/energy/sites/ener/files/documents/cy_final_necp_main_en.pdf
[17] https://ec.europa.eu/energy/sites/ener/files/documents/20160713%20draft_publication_REF2016_v13.pdf

prices are set out in Appendix 3. The cost of taxes levied on fuel is excluded from both the economic and financial analyses[18].

The installation of local electricity generation plant (as would be the case with DHC or individual site level solutions based upon CHP) has potential benefits for the whole electricity generation, transmission and distribution system. As the demand for electricity in Cyprus increases and a greater proportion of it is supplied from intermittent renewable sources, upgrades to the transmission and distribution infrastructure would be required. However, the generation of more electricity locally, which need not use this infrastructure, has the potential to avoid the costs associated with these upgrades. In order to reflect these potential cost savings, we have used electricity prices from the report by the Royal Institute of Technology, Sweden: Cost optimal scenario analysis for the Cypriot energy system (known as the "Cypriot Energy System Report") and, with agreement with MECI added an additional cost of €38/MWh plus 4% profit to reflect the infrastructure cost associated with the cost optimal scenario investigated in that report. The resulting unit price of electricity was then used in the analysis. By using this unit price in the analysis, any solution involving the generation of electricity (i.e. the CHP solutions) or a reduction in electricity taken from the grid, would displace electricity with this unit cost. Since the unit cost includes the infrastructure cost, the value of this cost avoided is credited to the solution. In this way the analysis implicitly includes the cost savings associated with the infrastructure where the solution saves electricity which would otherwise have to be generated centrally and supplied via the grid. As discussed above, solutions involving the generation of electricity via PV for supplying heat pump driven heating and cooling solutions are sized such that there is no net increase in the demand of electricity from the grid, do not incur an electricity cost and, therefore, are assumed not to incur this system upgrade cost.

The cost benefit analysis carried out here is consistent with the requirements of Article 15, para 7 of Directive (EU) 2018/2001 (Renewable Energy Directive II). The renewable heating and cooling technologies evaluated (see Section 4) are either inherently low ecological risk (e.g. heat pumps and solar thermal) or, where not, the analysis includes appropriate external costs to reflect any ecological risk (e.g. biomass CHP). The water source heat pumps evaluated here do not use land based water bodies as the heat source/sink, but instead use the sea and, as such, do not entail ecological risks that cannot be appropriately mitigated. In so far as the potential for renewable heating and cooling technologies have been evaluated for three distinct residential architypes, including a separate architype for detached houses, the potential for small-scale household projects has been evaluated. As discussed above this analysis has been spatial in nature.

5.2 Applicability of Solutions Across Sectors and Sites

As discussed above, the technology solutions evaluated in the CBA are presented in Table 4-1 and Table 4-2. For technical reasons not all of the heat demand is susceptible to all these solutions. The following principles have been adopted in the analysis to reflect this reality and should be kept in mind when interpreting the CBA results:

- A quantity of heat consumed at industrial EU ETS sites is high grade heat (i.e. heat with a temperature >400°C). This is the case at the cement and ceramics sites. None of the high efficiency solutions evaluated is capable of generating heat of this grade. To reflect this reality, this high grade heat demand is not addressed in the CBA.
- It is assumed that all heat required by industry is of a grade that cannot be supplied by DHC solutions. Consequently, only individual site level solutions are evaluated for industry. Of the individual site level solutions, only CHP solutions are considered applicable, since the grade of heat demanded by industry is predominantly steam and the other individual site solutions cannot generate steam.
- In the Residential sector, it is assumed that CHP is only a solution in the context of DHC, i.e. that individual, building level CHP solutions are not applicable in the Residential sector.

[18] Except in the case of domestic supplies where VAT of 5% in the financial analysis.

5.3 Sensitivity

There are a number of factors which, to a greater or lesser degree, have an impact upon the economic and financial potential of the solution being considered, relative to the baseline. The inherent uncertainties associated with the assumptions mean that it is important to understand which assumptions have the greatest impact on the result. As such, the modelling allows for an examination of the sensitivity of the economic and financial potential of a solution to a range of factors. The factors which can be explored in this way are:

- Electricity price
- Fossil fuel prices
- Renewable fuel prices (this applies to biomass and RDF)
- Environmental (external) and CO_2 costs (note this sensitivity is applied to both the external CO_2 cost (relevant to the Economic analysis) and the EU ETS CO_2 cost (relevant to the financial analysis)
- Primary Capex of DHC network
- Capex of connection to the DHC network and (where applicable) installation of a wet system[19]
- Capex and Opex of individual thermal plant
- Opex expressed as a % of Capex
- Thermal energy demand

Unless otherwise stated, the results presented in and discussed in Section 7.4 below are for these factors set at 100% of the applicable value set out in the Appendices.

6 Key Assumptions

The results of the CBA are determined to a large extent by technical and economic assumptions made. The main assumptions are provided in the Appendices, as follows:

Appendix 1 Heating, cooling and SHW demand for modelled architypes

Appendix 2 External Costs of CO_2 (Economic Analysis only)

Appendix 3 Assumed CO_2 Prices for EU ETS (Financial analysis only and solutions projected to exceed input threshold for EU ETS combustion)

Appendix 4 Marginal Damage Costs for NOx, PM10 and SOx per MWh of solid, liquid, gaseous and biomass fuels

Appendix 5 Assumed Hours of Occupancy of Different Building Types

Appendix 6 Energy Prices (Set 1 only – see model for Sets 2 and 3)

Appendix 7 CO_2 emissions associated with delivered grid electricity and primary energy input to delivered electricity output, over time

Appendix 8 Heating and Cooling Technology Assumptions

Appendix 9 District Heating and Cooling Pipework Assumptions

---

[19] To receive heating and cooling from DHC, a building will have to have a hydronic system. Some buildings are modelled as not having such a system in the baseline. Where this is the case, a cost to install a hydronic system is incurred.

7 Results

7.1 Best High Efficiency Heating and Cooling Solutions for Modelled Architypes

For the avoidance of doubt, unless explicitly stated otherwise, the results presented in Section 7 and discussed in Section 8 relate to the cost effective potential as measured against the demand for heating and cooling in 2018. Cost effective potential measured against 2030 demand is only discussed to make the point that the merit order of high efficiency technologies is unchanged when evaluating against the two baselines, which is an important finding in itself.

As detailed in Section 3, architypes are used to reflect the range of diversity of heating and cooling demand seen across Cyprus. Architypes are used for all points of heating and cooling demand except for sites that are covered by EU ETS. For these sites the actual fuel consumption is known, allowing heating demand to be deduced.

The best high efficiency solutions evaluated for these architypes have haven evaluated and the detailed results are presented in Appendix 10. For the avoidance of doubt, these results are for demand in 2018[20]. As can be seen in Appendix 10, the PV + Heat Pump individual building solutions is ubiquitous in the Residential and Service sectors. This has a profound effect on the results presented below.

The NPV of the best solution for each architype is used to calculate the NPV for all individual building level solutions in each Post Code and detailed area evaluated. The NPV for a post code or detailed area, associated with these individual building level solutions, is calculated as set out in Equation 1.

7.2 Best High Efficiency Heating and Cooling Solutions at Post Code Level for 2022 and 2030

Table 7-1 and Table 7-2 show the high efficiency heating and cooling solutions with the greatest Economic Net Present Value (ENVP) relative to the baselines presented in Section 2.2 at the Post Code level. Table 7-1 shows this relative to the 2018 baseline and Table 7-2 relative to the 2030 baseline. These tables summarise the results for all four sectors evaluated. The salient points to take from these tables are:

- There is only one Post Code for which District Heating and Cooling (DHC) is the best solution. This is Solution 16, which is waste heat recovery from the reciprocating engines at Dhekelia power station. This solution involves the centralised generation of cooling via absorption chillers and the supply of heating and cooling, via a DHC network, to satisfy the demand for heating and cooling in the same Post Code as the power station (7502). However, there are caveats associated with this finding which are discussed further in Section 8.4.
- For 2022 demand, overall, individual heat pumps powered by PV is the option with the best ENVP in the large majority of cases, accounting for 99% of space cooling and 76% of space heating demand.
- The second most prevalent “best” solution for the provision of heat is individual LPG CHP with absorption chillers for cooling.
- There are only very subtle differences between the analyses for heat demand in 2018 and 2030 in terms of the proportion of overall demand for which the different solutions are the best. For both analyses, the ranking of best solution is the same.

[20] When using demand forecast for 2030, there are only very subtle differences in the best solutions within the industry sector and no change to the best solutions in the residential, service and agriculture sectors.

- The increase in heating and cooling demand projected between 2018 and 2030 within Post Code 7502 has improved the ENVP from +€75m to +€92m. However, for all post codes, the increase in heating and cooling demand by 2030 has not resulted in the promotion any other DHC scheme above any other individual building solution in terms of ENVP.

Table 7-1 Best high efficiency heating and cooling solutions (all Post Codes and sectors) – Baseline 2018

Solution	DHC / individual solution number	Total ENPV relative to baseline where best solution (€m)	Total FNPV relative to baseline where best solution (€m)	Total lifetime CO2 savings relative to baseline where best solution (kTCO2)	Total lifetime PES relative to baseline where best solution (GWh)	Total lifetime electricity consumption reduction relative to baseline where best solution (GWh)	Total lifetime electricity generation relative to baseline where best solution (GWh)	Annual space cooling delivered (GWh/Yr)	Annual space heating delivered (GWh/Yr)	Annual water heating delivered (GWh/Yr)
DHC Solutions*		76.5	16.4	48.4	363.2	208.3	0.0	15.3	5.3	0.0
Individual solutions*										
Individual biomass CHP	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Individual oil CHP	2	11.2	20.6	-218.8	329.6	309.3	855.9	4.4	39.8	0.0
Individual LPG CHP	3	250.0	79.3	-333.8	3,806.6	2,822.8	7,592.5	11.7	409.8	0.0
Individual heat pumps and solar thermal hot water	4	161.1	-49.7	1,516.4	4,540.7	-1,935.7	0.0	0.0	230.9	0.0
Solar thermal space, heating, cooling and hot water (hotels only)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PV+individual heat pumps and solar hot water	6	6,580.0	1,602.2	21,741.3	68,811.5	75,816.3	0.0	4,639.5	2,153.1	88.2
Baseline*	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	922.6
TOTAL	-	**7,078.9**	**1,668.8**	**22,753.6**	**77,851.6**	**77,220.9**	**8,448.4**	**4,670.9**	**2,838.9**	**1,010.9**

Table 7-2 Best high efficiency heating and cooling solutions (all Post Codes and sectors) – Baseline 2030

Solution	DHC / individual solution number	Total ENPV relative to baseline where best solution (€m)	Total FNPV relative to baseline where best solution (€m)	Total lifetime CO2 savings relative to baseline where best solution (kTCO2)	Total lifetime PES relative to baseline where best solution (GWh)	Total lifetime electricity consumption reduction relative to baseline where best solution (GWh)	Total lifetime electricity generation relative to baseline where best solution (GWh)	Annual space cooling delivered (GWh/Yr)	Annual space heating delivered (GWh/Yr)	Annual water heating delivered (GWh/Yr)
DHC Solutions*		93.6	24.1	39.2	463.3	242.5	0.0	18.0	5.8	0.0
Individual solutions*										
Individual biomass CHP	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Individual oil CHP	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Individual LPG CHP	3	256.0	93.2	-1,647.7	2,435.4	3,831.0	11,467.7	39.8	563.4	6.0
Individual heat pumps and solar thermal hot water	4	113.3	-62.5	1,273.8	337.2	-1,527.2	0.0	0.0	184.7	0.0
Solar thermal space, heating, cooling and hot water (hotels only)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PV+individual heat pumps and solar hot water	6	7,222.9	1,875.3	17,900.4	42,058.2	86,834.0	0.0	5,427.9	2,304.6	89.4
Baseline*	-	0.0	0.0	0.0	0.0	0.0	0.0	1.7	10.5	997.4
TOTAL	-	**7,685.8**	**1,930.2**	**17,565.7**	**45,294.2**	**89,380.2**	**11,467.7**	**5,487.4**	**3,068.8**	**1,092.7**

7.2.1 Share of Renewables in Heating and Cooling Resulting from Best High Efficiency Heating and Cooling Solutions

It is possible to estimate the proportion of energy associated with heating and cooling that would be renewable in 2030 if the best solutions identified in Table 7-2 were implemented.

In arriving at this estimate it is necessary to take into account the fact that a proportion of the Final Energy Demand (FED) and Primary Energy Supply (PES) is associated with the supply of heating and cooling that is not susceptible to the high efficiency solutions that have been evaluated here. This is mainly due to the fact that the high efficiency solutions evaluated cannot meet very high grades of heat in industry.

Moreover, in arriving at the overall proportion of renewable energy for **all** heating and cooling **after** implementation of the best high efficiency measures, it is necessary to estimate the proportion of this non-susceptible heat that is supplied by renewable energy. For the purposes of simplicity, the proportion of renewable energy used in the supply of all heating and cooling in the "With Existing Measures (WEM)" projection presented in Point D (i.e. before the implementation of the best high efficiency technologies evaluated here) is assumed to apply to this non-susceptible heating and cooling.

Taking the results from Table 7-2 and the WEM projection presented in Point D, Table XX summaries the key inputs to the calculation of the proportion of all energy associated with the provision of heating and cooling in 2030 that would be renewable, if the best cost effective solutions are implemented. The Key inputs are as follows:

Col A – This is the FED and PES associated with the provision of heating and cooling in the WEM projection for 2030.

Col B – This is the % of FED and PES in Col A that is renewable.

Col C – This is the FED and PES associated with heating and cooling that is susceptible to the high efficiency solutions evaluated here.

Col D – This is the non-susceptible energy. By definition it is Col A – Col C.

Col E – This is the % of FED and PES associated with non-susceptible energy that is projected to be renewable in 2030.

Col F – This the renewable non-susceptible energy. By definition it is Col D X Col E.

Col G – This is the quantity of energy associated with the best high efficiency solutions that is renewable.

Col H – This is the total energy associated with heating and cooling that is renewable, assuming that the best solutions are implemented. By definition it is Col F + Col G.

Col I – This is the overall proportion of energy associated with heating and cooling that is renewable if the best high efficiency solutions are implemented. By definition it is Col H/Col A.

As can be seen from the table, if the best high efficiency solutions were implemented by 2030, the proportion of FED associated with heating and cooling that is renewable would increase from 35% to 77% and for PES this would increase from 29% to 69%.

Table 7-3 Increase in renewable share of Final Energy Demand (FED) and Primary Energy Supply (PES) for Heating and Cooling that is renewable, if cost effective potential for high efficiency solutions is implemented

	Col A WEM Energy	Col B WEM % Renewable	Col C Susceptible Energy (GWh)	Col D Non-Susceptible Energy	COL E % Renewable Non-Susceptible Energy	Col F Renewable Non-Susceptible Energy	Col G Renewable Cost Effective Potential for Susceptible Energy	Col H Total Renewable (Non-susceptible + CEP Susceptible Energy)	Col I % Renewable
Final Energy Demand	7,988 GWh	35%	7,206 GWh	782 GWh	34.7%	271 GWh	5,905 GWh	6,176 GWh	**77%**
Primary Energy Supply	10,359 GWh	29%	6,494 GWh	3,865 GWh	28.9%	1,117 GWh	5,909 GWh	17,026 GWh	**69%**

Table 7-4 and Table 7-5 show the high efficiency heating and cooling solutions with the greatest Economic Net Present Value (ENVP) relative to the baselines for the Residential and Service sectors for 2018 and 2030 demand. The salient points to take form these tables are as follows:

- There is only one Post Code for which District Heating and Cooling (DHC) is the best solution. This is the aforementioned Solution 16, recovering waste heat from the Dhekelia power station. Since DHC is modelled to only serve residential and service sector buildings, this solution shows up as the best solution for one Post Code for the residential and service sectors.
- Individual heat pumps powered by PV is the best solution for all of the heating and cooling demand in the residential and service sectors.
- There is very little difference indeed between the analyses for demand in 2018 and 2030 in terms of which solution has the best ENVP for the residential and service sectors. In both scenarios individual heat pumps powered by PV capture all of the demand in these two sectors.

•

Table 7-4 Best high efficiency heating and cooling solutions (all Post Codes, Residential and Service Sectors, only) – Baseline 2018

Solution	DHC / individual solution number	Total ENPV relative to baseline where best solution (€m)	Total FNPV relative to baseline where best solution (€m)	Total lifetime CO2 savings relative to baseline where best solution (kTCO2)	Total lifetime PES relative to baseline where best solution (GWh)	Total lifetime electricity consumption reduction relative to baseline where best solution (GWh)	Total lifetime electricity generation relative to baseline where best solution (GWh)	Annual space cooling delivered (GWh/Yr)	Annual space heating delivered (GWh/Yr)	Annual water heating delivered (GWh/Yr)
DHC Solutions*		76.5	16.4	48.4	363.2	208.3	0.0	15.3	5.3	0.0
Individual solutions*										
Individual biomass CHP	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Individual oil CHP	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Individual LPG CHP	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Individual heat pumps and solar thermal hot water	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar thermal space, heating, cooling and hot water (hotels only)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PV+individual heat pumps and solar hot water	6	6,580.0	1,602.2	21,741.3	68,811.5	75,816.3	0.0	4,639.5	2,153.1	88.2
Baseline*	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	922.6
TOTAL	-	**6,656.6**	**1,618.6**	**21,789.8**	**69,174.7**	**76,024.6**	**0.0**	**4,654.8**	**2,158.4**	**1,010.9**

Table 7-5 Best high efficiency heating and cooling solutions (all Post Codes, Residential and Service Sectors, only) – Baseline 2030

Solution	DHC / individual solution number	Total ENPV relative to baseline where best solution (€m)	Total FNPV relative to baseline where best solution (€m)	Total lifetime CO2 savings relative to baseline where best solution (kTCO2)	Total lifetime PES relative to baseline where best solution (GWh)	Total lifetime electricity consumption reduction relative to baseline where best solution (GWh)	Total lifetime electricity generation relative to baseline where best solution (GWh)	Annual space cooling delivered (GWh/Yr)	Annual space heating delivered (GWh/Yr)	Annual water heating delivered (GWh/Yr)
DHC Solutions*		93.6	24.1	39.2	463.3	242.5	0.0	18.0	5.8	0.0
Individual solutions*										
Individual biomass CHP	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Individual oil CHP	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Individual LPG CHP	3	16.9	16.3	-345.0	-469.3	297.0	1,477.0	25.5	22.9	6.0
Individual heat pumps and solar thermal hot water	4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Solar thermal space, heating, cooling and hot water (hotels only)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PV+individual heat pumps and solar hot water	6	7,222.9	1,875.3	17,900.4	42,058.2	86,834.0	0.0	5,427.9	2,304.6	89.4
Baseline*	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	997.4
TOTAL	-	**7,333.3**	**1,915.7**	**17,594.6**	**42,052.2**	**87,373.4**	**1,477.0**	**5,471.3**	**2,333.2**	**1,092.7**

Table 7-6 and Table 7-7 show the high efficiency heating and cooling solutions with the greatest Economic Net Present Value (ENVP) relative to the baselines for the Industrial and Agricultural sectors. Again, note that high grade industrial heat (>400°C) is omitted from this analysis, on account of the fact that it cannot be satisfied by any of the high efficiency solutions evaluated.

The salient points to take away from these tables are as follows:

- DHC is not modelled as being able to serve industrial and agricultural sites, so cannot appear as the best solution here.
- For 2018 demand, CHP (mainly LPG but some oil fired) is the best solution for about 66% of the heat demand, followed by individual heat pumps powered by the grid, accounting for the balance of demand in these two sectors.
- The best solution within the agricultural sector is always individual heat pumps and solar hot water, i.e. CHP is never the best individual solution for any of the agricultural architypes.
- LPG and oil fired CHP Oil CHP are the two best solutions in industry, i.e. none of the other technologies are found to be the best solution for any of the industry architypes.
- For 2030 demand, oil fired CHP ceases to be the best solution for any of the industry architypes, with the best solutions being LPG fired CHP (overwhelmingly) and some baseline technologies.

Table 7-6 Best high efficiency heating and cooling solutions (all Post Codes, Industry[21] and Agricultural Sectors, only) – Baseline 2018

Solution	DHC / individual solution number	Total ENPV relative to baseline where best solution (€m)	Total FNPV relative to baseline where best solution (€m)	Total lifetime CO2 savings relative to baseline where best solution (kTCO2)	Total lifetime PES relative to baseline where best solution (GWh)	Total lifetime electricity consumption reduction relative to baseline where best solution (GWh)	Total lifetime electricity generation relative to baseline where best solution (GWh)	Annual space cooling delivered (GWh/Yr)	Annual space heating delivered (GWh/Yr)	Annual water heating delivered (GWh/Yr)
Individual solutions*										
Individual biomass CHP	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Individual oil CHP	2	11.2	20.6	-218.8	329.6	309.3	855.9	4.4	39.8	0.0
Individual LPG CHP	3	250.0	79.3	-333.8	3,806.6	2,822.8	7,592.5	11.7	409.8	0.0
Individual heat pumps and solar thermal hot water	4	161.1	-49.7	1,516.4	4,540.7	-1,935.7	0.0	0.0	230.9	0.0
Solar thermal space, heating, cooling and hot water (hotels only)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PV+individual heat pumps and solar hot water	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Baseline*	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TOTAL	-	**422.3**	**50.2**	**963.8**	**8,676.9**	**1,196.4**	**8,448.4**	**16.1**	**680.5**	**0.0**

Table 7-7 Best high efficiency heating and cooling solutions (all Post Codes, Industry[22] and Agricultural Sectors, only) – Baseline 2030

Solution	DHC / individual solution number	Total ENPV relative to baseline where best solution (€m)	Total FNPV relative to baseline where best solution (€m)	Total lifetime CO2 savings relative to baseline where best solution (kTCO2)	Total lifetime PES relative to baseline where best solution (GWh)	Total lifetime electricity consumption reduction relative to baseline where best solution (GWh)	Total lifetime electricity generation relative to baseline where best solution (GWh)	Annual space cooling delivered (GWh/Yr)	Annual space heating delivered (GWh/Yr)	Annual water heating delivered (GWh/Yr)
Individual solutions*										
Individual biomass CHP	1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Individual oil CHP	2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Individual LPG CHP	3	239.1	77.0	-1,302.7	2,904.7	3,533.9	9,990.8	14.4	540.4	0.0
Individual heat pumps and solar thermal hot water	4	113.3	-62.5	1,273.8	337.2	-1,527.2	0.0	0.0	184.7	0.0
Solar thermal space, heating, cooling and hot water (hotels only)	5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
PV+individual heat pumps and solar hot water	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Baseline*	-	0.0	0.0	0.0	0.0	0.0	0.0	1.7	10.5	0.0
TOTAL	-	**352.4**	**14.5**	**-28.8**	**3,242.0**	**2,006.7**	**9,990.8**	**16.1**	**735.6**	**0.0**

21 Excluding high grade (>400°C) heat.
22 Excluding high grade (>400°C) heat.

7.3 Best District Heating and Cooling Solutions

As discussed in Section 7.1, individual building/site level solutions are the most economically cost effective solutions for the overwhelming majority of Post Codes. In spite of this, it is nevertheless instructive to explore the lack of cost effectiveness of DHC and the reasons behind it.

When considering the economic potential, DHC is not economic (i.e. produces a positive ENPV) value for any of the other Post Codes or detailed geographical areas evaluated, including the two detailed tourist areas.

When evaluated from a financial point of view (i.e. considering the Financial Net Present Value, FNPV), the two detailed tourist areas register a positive FNPV for Oil fired CHP, 2-pipe solution with individual absorption chillers distributed at the cooling consuming buildings. The FNPV for the waste heat recovery solution at the Dhekelia power station post code is also positive, indicating that the annual operating savings generated, when discounted at the higher rate (DR=12%), still more than offsets the Capex outlay.

Regarding the finding that the FNPV is higher than the ENVP for the two detailed tourist areas, this can only be explained by the inclusion in the cash flow in the ENVP analysis (and exclusion from the FNPV analysis) of the environmental (pollution) costs associated with fuel consumption, as set out in Appendix 4. The additional environmental costs included under the ENVP analysis is sufficiently large to have a material impact upon the cost effectiveness. When the analysis is rerun to exclude the environmental (pollution) costs from the evaluation of ENPV, a total of 22 Post Codes and detailed areas are found to have a positive ENPV for a DHC solution, including the two detailed tourist areas evaluated. With the exception of the one waste heat recovery solution already mentioned, all of the other Post Code and detailed areas register RDF fired CHP solutions as the best DHC solution. Nevertheless, for all of these 22 Post Code and detailed areas, DHC is only a better solution than individual building level solutions for the heat recovery options.

Although all but three of the Post Codes and detailed areas evaluated are found not to be cost effective (from an economic or financial point of view), when environmental (pollution) costs are included in the analysis, it is nevertheless instructive to consider which DHC solutions are closest to being cost effective (i.e. have the least negative ENVP) and for how many Post Codes is this the case. Table 7-8 sets this out for the Post Codes evaluated, by climatic area and DHC solution type.

The salient points to take from these results are as follows:

- Three out of 18 DHC solution Types evaluated are found to be the best DNC solution (highest ENVP) in over three-quarters of all Post Codes and detailed tourist areas evaluated.
- In three-quarters of coastal Post Codes, Type 12 (Reversible Water Source Heat Pump, 2-pipe and individual absorption chillers for cooling) is the best DHC solution.
- In the remaining non-coastal Post Codes, Type 7 (LPG CHP 2-pipe, DC only in summer and DH only in winter) is the best solution in 45% of these Post Codes, followed by Type 15 (RDF CHP, 2-pipe and individual absorption chillers for cooling (26% of Post Codes).

Table 7-8 Summary count of best DHC solution type across climatic regions

Climatic Region	Count. of Post Codes and Detailed Areas	Type 1 (Biomass CHP)	Type 2 (Biomass CHP)	Type 3 (Biomass CHP)	Type 4 (Oil CHP)	Type 5 (Oil CHP)	Type 6 (Oil CHP)	Type 7 (LPG CHP)	Type 8 (LPG CHP)	Type 9 (LPG CHP)	Type 10 (Heat Pump)	Type 11 (Heat Pump)	Type 12 (Heat Pump)	Type 13 (RDF CHP	Type 14 (RDF CHP	Type 15 (RDF CHP	Type 16 (Waste Heat)	Type 17 (Waste Heat)	Type 18 (Waste Heat)
Coastal	340	6	-	-		-	-	33	-	32	16	-	251	-	-		1	-	1
Low Land	177	12	-	-	8	-	-	137	-	17	-	-	-	3	-		-	-	-
Mountainous	119	1	-	-		-	-	-	-	-	-	-	-		-	118	-	-	-
Semi-Mountainous	243	15	-	-	72	-	-	108	-	10	-	-	-	15	-	23	-	-	-
Total	**879**	**34**	**0**	**0**	**80**	**0**	**0**	**278**	**0**	**59**	**16**	**0**	**251**	**18**	**0**	**141**	**1**	**0**	**1**

7.4 Sensitivity of Results

Given the finding that, when evaluated at the Post Code level, DHC is only cost effective (positive ENPV and FNPV) for one generic solution type in one post code (waste heat recovery in Post Code 7502) it is instructive to investigate the sensitivity of the results to certain key input parameters. This is useful analysis as there is an inherent uncertainty associated with the input values for these key inputs and, should relatively small changes in the value of inputs produce material impacts on the cost effectiveness of DHC solutions, the economic case is worth investigating further.

We have investigated the sensitivity of the results to 10 parameters, by varying their values by +- 20% about the central value. The central value is the value assumed in the results presented in Sections 7.3. The parameters investigated are:

1. Electricity price
2. Fossil fuel prices
3. Renewable fuel prices
4. Environmental and CO_2 costs
5. DHC primary network capex
6. DHC connection and wet system capex
7. Individual thermal plant capex and opex
8. DHC central thermal plant capex and opex
9. Opex as a percentage of Capex per year
10. Thermal energy demand

As discussed previously, solution Types 7 and 12, although never producing a positive ENPV, produce the best ENVP (i.e. least negative ENPV) for about 60% of Post Codes. As such it is instructive to test the sensitivity of results for these solutions to the above listed input parameters, to see whether any changes are material to the solution cost effectiveness. DHC is more likely to be cost effective when serving large demands for heating and cooling, as the savings relative to the baseline tend to be maximised for a given level of Capex. As such, Post Codes with the 10 highest levels of heating and cooling demand, for which Type 7 and 12 are the best DHC solutions, have been reviewed. For each of these the ratio of ENPV to heating and cooling demand have been calculated and the Post Code with the highest value has been selected for sensitivity analysis. The rational for this approach is that the higher the ENVP to heating and cooling demand ratio, the closer is the solution to becoming cost effective in response to changes in the input parameters. From this analysis, sensitivity analysis has been carried out for the following Post Code/Solution combinations:

Post Code = 4046, DHC Solution 12

Post Code = 5330, DHC Solution 7

The results of this sensitivity analysis are summarised in Table 7-9 and presented graphically in Figure 1 and Figure 2.

Table 7-9 Characteristics of DHC solution/Post Code combinations chosen for sensitivity analysis

Post Code	Solution	ENPV/Total Heating and Cooling Demand (€/MWh)	ENPV (€m) (No Sensitivity)	ENPV (€m) (Max Value)	ENPV (€m) (Min Value)	FNPV (€m) No Sensitivity)	FNPV (€m) (Max Value)	FNPV (€m) (Min Value)
4046	12	-2,543	-97	-59	-136	-97	-68	-125
5330	7	-1,847	-594	-322	-866	-449	-324	-574

Figure 1 Sensitivity of ENVP and FNVP to changes in key input parameters to the CBA (Post Code 4046, Solution 12)

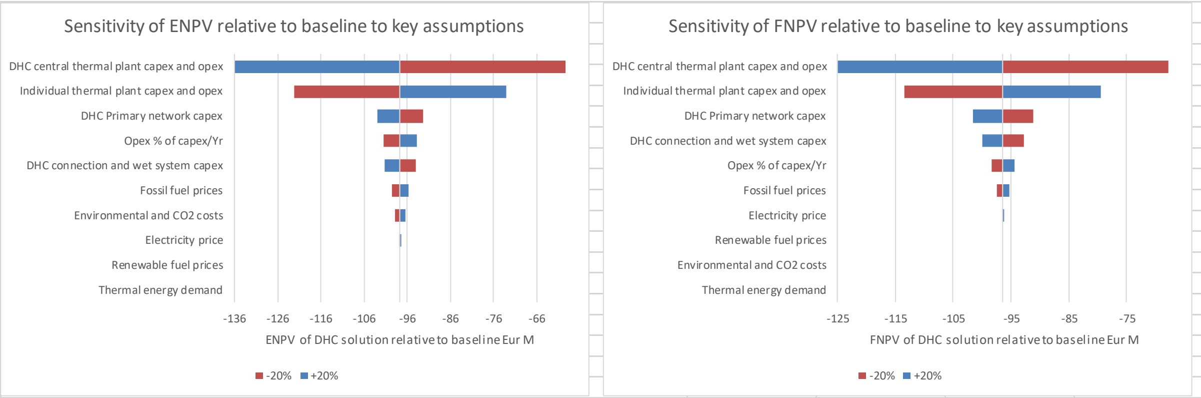
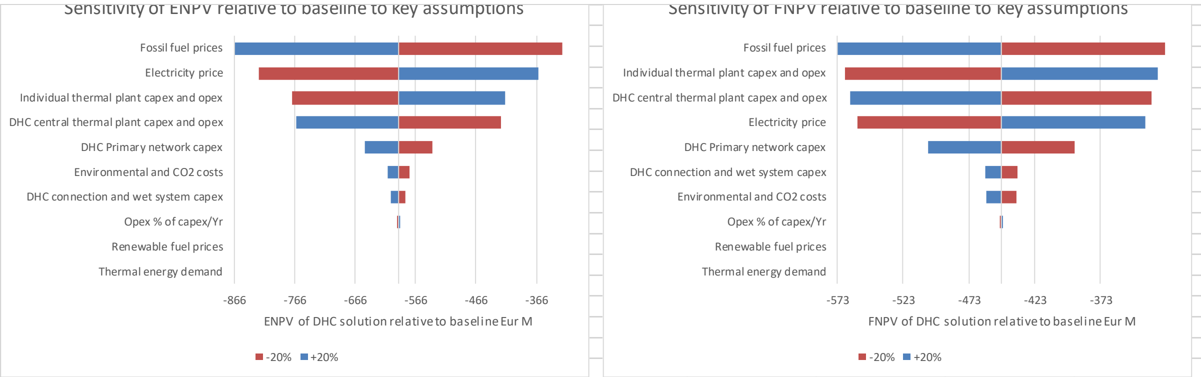


Figure 2 Sensitivity of ENVP and FNVP to changes in key input parameters to the CBA (Post Code 5330, Solution 7)



The input parameters with the greatest influence on the value of the ENPV are different for Solutions 7 and 12 and this reflects the different types of technology used (LPG CHP and Water Source Heat pumps, respectively). In the case of Solution 7, the cost of fossil fuels and the electricity price are the two largest determining factors for the ENPV value, which is to be expected given that the economics of any CHP based solution is driven by the price that must be paid for the fuel and the value of the electricity displaced by CHP generation. For Solution 12, the capex of the plant has greater influence, since there no fossil fuel consumed and electricity is not generated but consumed efficiently for the generation of heating and cooling.

However, in the case of Post Code = 4046, even with the relatively high heating and cooling demand and the relatively high value of ENVP per unit of energy demand, adjusting the input parameter with the greatest influence on cost effectiveness (DHC central thermal plant capex) fails to produce a positive ENPV.

Moreover, in the case of Post Code = 5330, for which Solution 7 was the best DHC solution, it is also the case that adjusting the input parameter with the greatest influence on cost effectiveness (fossil fuel prices) fails to produce a positive ENPV.

From this sensitivity analysis is can be said that adjustment of the values of the above parameters can be expected, in the main, not to have a significant improving impact on the cost effectiveness of the DHC solutions evaluated.

8 Discussion

8.1 Relative Economic, CO_2 and Energy Performance of District Heating and Cooling (DHC) and Individual Building Solutions

As seen above, when modelling at the Post Code level, with the DHC solution modelled to supply all of the susceptible heating and cooling demand in the Post Code, with the exception of one DHC solution in one post code, DHC is not cost effective relative to the existing baseline from a social point of view. High efficiency individual building level solutions are found to be cost effective, relative to the baseline, for the large majority of the heating and cooling demand modelled here.

For all building architypes modelled (i.e. all residential and service sector buildings), the most cost effective solution is heat pumps driven by PV supplying heating, cooling and sanitary hot water, where the last is not already modelled as being satisfied by solar thermal. Compared against the baseline technologies, deployment of this PV driven heat pumps will save both CO_2 and primary energy.

For the industry architypes, the most cost effective solutions are one of LPG CHP or oil CHP. The grade of heat demand modelled for industry is such that DHC and heat pump heating driven solutions are naturally discounted[23]. However, neither of these CHP solutions is found to save CO_2 relative to the baseline for the time period of the analysis, although they do save primary energy. Biomass CHP would save both CO_2 and primary energy relative to the baseline, but is not economically cost effective for any of the industry architypes evaluated, i.e. the ENPV is negative for all industrial architypes). However, biomass CHP is financially cost effective for most of the industry architypes (i.e. positive FNPV), again owning to the effect of the inclusion of pollution costs in the economic cost effectiveness evaluation. However, in all cases biomass CHP is not the best financial solution, with one of the other CHP technologies always having a higher FNPV value. When all damage costs associated with the combustion of fuel are removed from the analysis, biomass CHP is the most cost effective (highest ENPV) technology for most of the industry architypes.

For agriculture architypes, which are modelled as not requiring high grade heat, heat pumps are the most cost effective solution for providing heating – there is no cooling demand assumed for agriculture. This produces both CO_2 and primary energy savings relative to the baseline.

8.2 The Effect of Increasing Heating and Cooling Demand

As explained in Section 2.3.2, the heating and cooling demand projected to 2030 in the NECP has been applied in the modelling to see if absolute changes in demand and changes to demand density have any material impact on the ranking of DHC and individual building level solutions. This was found to have no impact, with still only one Post Code registering DHC as the best solution. In other words, increases in demand density modelled here have not tipped the balance in favour of DHC for <u>any</u> Post Code or detailed area analysed.

8.3 What is Hampering DHC Solutions?

DHC solutions, in the vast majority of cases, fail to register positive NPV values because the net cash flows, relative to the baseline, are insufficient to balance the additional investment costs that have to be made. This is likely the case because of the necessary approach taken to model DHC schemes, whereby each DHC scheme is modelled to supply all post code heating and cooling demand and not specifically selected sub-sets of this. Under this approach, the size of the central DHC thermal plant

---

[23] Heat pumps can be deployed at industrial sites to supply high grade heat at acceptable levels of efficiency if high grade waste heat is available for recovery and upgrading via a heat pump. However, the availability of high grade waste heat presupposes the existing of combustion on the site and there is insufficient information available about the availability and grade of waste heat to model this possibility. Consequently, all heat demand is modelled as requiring fuel combustion.

and pipe network will not be optimised for the quantity of heat and cooling demand and so operational savings per unit Capex will tend to be lower than they could be if specific heating and cooling demand areas were selected to be served by the DHC scheme.

This point is illustrated well by the findings that the two sub post code tourist areas are the only evaluated areas to produce positive FNPV. These areas were defined so as to capture specific zones known to be heating and cooling dense, thereby improving the optimisation of the scale of DHC plant and network for the demand. It is also likely that the economic case is improved in these areas because they have no residential demand in them. In the residential sector in Cyprus the heating and cooling demand is essentially zero for up to four months of the year and so there is a significant proportion of the year when savings are not generated to offset the Capex of the DHC serving residential properties.

The two areas that register positive FNPV happen to register negative ENVP, owing to the inclusion in the ENVP analysis environmental (pollution costs), as required for the economic analysis. When these pollution costs are removed from the ENPV analysis, the two areas register positive ENPV values, implying the DHC is cost effective in these areas from an economic and financial perspective, if pollution costs are not monetised. Removing pollution costs produces positive ENVP in another nineteen Post Codes, however none of these nineteen have a positive FNPV, indicating that these Post Codes continue to be hampered by the issues diffuse approach to defining the extent of DHC solutions and the presence of residential properties which have suppressed demand for a significant proportion of the year.

From this finding it can be concluded that there will be cost effective potential for DHC if the analysis boundary is drawn around smaller areas of heating and cooling demand where the heating and cooling demand is concentrated and extended throughout the year.

8.4 The Cost Effective Waste Heat DHC Solution

This solution is found in Post Code 7502 and relates to the recovery of waste heat from the ICEs operating at Dhekelia power station. The power generated by these ICEs is known and from this the quantity of waste heat has been calculated[24]. While this calculated heat is sufficient to meet the heating and cooling demand of Post Code = 7502, it is unclear from the data available whether the availability of this waste heat coincides with heating and cooling demand. Since this is unlikely to be the case, thermal storage has been modelled. This thermal store has been sized to be as large as it can be whilst still being the best solution of this Post Code. The size of this “cost effective” thermal store is sufficient to meet a heat demand for cooling (via an absorption chiller) of 103 MW for 4 hours.

Whether this thermal store is large enough to cover the deficit of supply would have to be examined further by analysing data on the coincidence of waste heat from the ICEs and demand for heating and cooling.

9 Conclusions

The CBA for efficient heating and cooling for the Republic of Cyprus has shown that there is very little to no economic potential for District Heating and Cooling (DHC), when evaluated at the Post Code level, which is necessary to obtain an estimate of potential at the national level.

The CBA has also evaluated the economic potential for DHC at a more detailed scale than the Post Code level for two specifically defined tourist areas known to have high density of demand. These two areas are found to be cost effective from a financial point of view, but not from an economic point of view. This is explained by the inclusion, in the economic analysis, of external costs associated with the emission of NOx, PM10 and SOx from the combustion of fuels. These particular costs are not included in the financial analysis. When these costs are left out of the economic potential analysis, the

[24] The heat that can be recovered from ICEs is genuine waste heat, because if not recovered would just be released to the atmosphere. This can be contrasted with the heat that “might” be extracted for a steam turbine. In the case of the latter a price is paid in terms of power generation being given up in exchange for the extracted heat and so, in that respect, the heat in question is not waste heat.

two detailed tourist areas in question are found to be economically cost effective. When doing the same for other Post Codes' economic potential analysis, nineteen other Post Codes are found to have economic potential. However, even when omitting these pollution costs, DHC is found not to be the best solution in any of these nineteen Post Codes, i.e. the economic Net Present Value for DHC is higher in these Post Codes for building level high efficient solutions. This finding indicates that it is likely that there is further economic potential for DHC in Cyprus, provided the analysis is carried out at a sufficiently detailed level, selecting smaller areas known to have high density of demand, which can be served by optimally sized DHC networks.

Overwhelmingly, heat pumps powered by PV is found to be the high efficiency solution with the highest economic potential in the Residential and Service sectors. This result would have to be refined with more local data about the suitability of Residential and Service buildings for the installation of PV. However, for cases where PV was found not to be practical, the most economical solution would revert to heat pumps powered by grid electricity for the overwhelming majority of buildings.

Within the Agriculture sector, heat pumps powered by the grid is found to be the solution with the highest economic potential.

Within the Industry sector, leaving out from the analysis high grade heat (>400°C) which cannot be served by any of the efficient technologies examined in this work, mainly LPG fired CHP, but some oil fired CHP, with absorption chillers for providing process cooling, where required, have the highest economic potential against the baseline. However, these solutions, which provide primary energy savings relative to the baseline, do not provide CO_2 savings.

Biomass CHP would offer both CO_2 and primary energy savings. However, when analysed according to the methodology described above, biomass CHP is not economically cost effective for any of the susceptible industrial heating and cooling demand. Biomass CHP is financially cost effective for most of the demand, but is not the best solution (i.e. solution with the highest FNPV). This is due to the pollution costs from the combustion of fuel attached to the economic analysis. If these pollutions costs were omitted, biomass CHP would be the most economically cost effective technology for most of the industry architypes and would, of course save CO_2 as well as primary energy.

Appendices

A1 Heating and Cooling Consumption for the Modelled Architypes

Table 9-1 Heating and Cooling Consumption for Modelled Architypes (Coastal Areas)

Sector	Architype	Space/Process Heating Demand (MWh)	Cooling Demand (MWh)	SHW Demand (MWh)
Residential	Apartment	1,800	5,294	1,491
	Row house	2,735	3,700	1,791
	Single house	3,118	5,352	2,187
Service	Airports	4,026,040	12,381,824	536
	Restaurant	38,901	100,430	16,936
	Hospitals	409,006	1,234,242	565,103
	Hotels	264,626	1,428,646	138,851
	Offices	27,248	61,167	0
	Schools	56,525	140,486	11,998
	Shopping	5,545	28,613	21
	Other Services	67,162	215,355	25,104
Industrial (Non-EU ETS)	Chemicals	276,838	48,985	0
	Food and Drink	266,627	14,037	0
	Other Minerals	41,877	0	0
	Other Industry	33,618	0	0
Agriculture	Greenhouses	3,027	0	0
	Other Agriculture	3,027	0	0

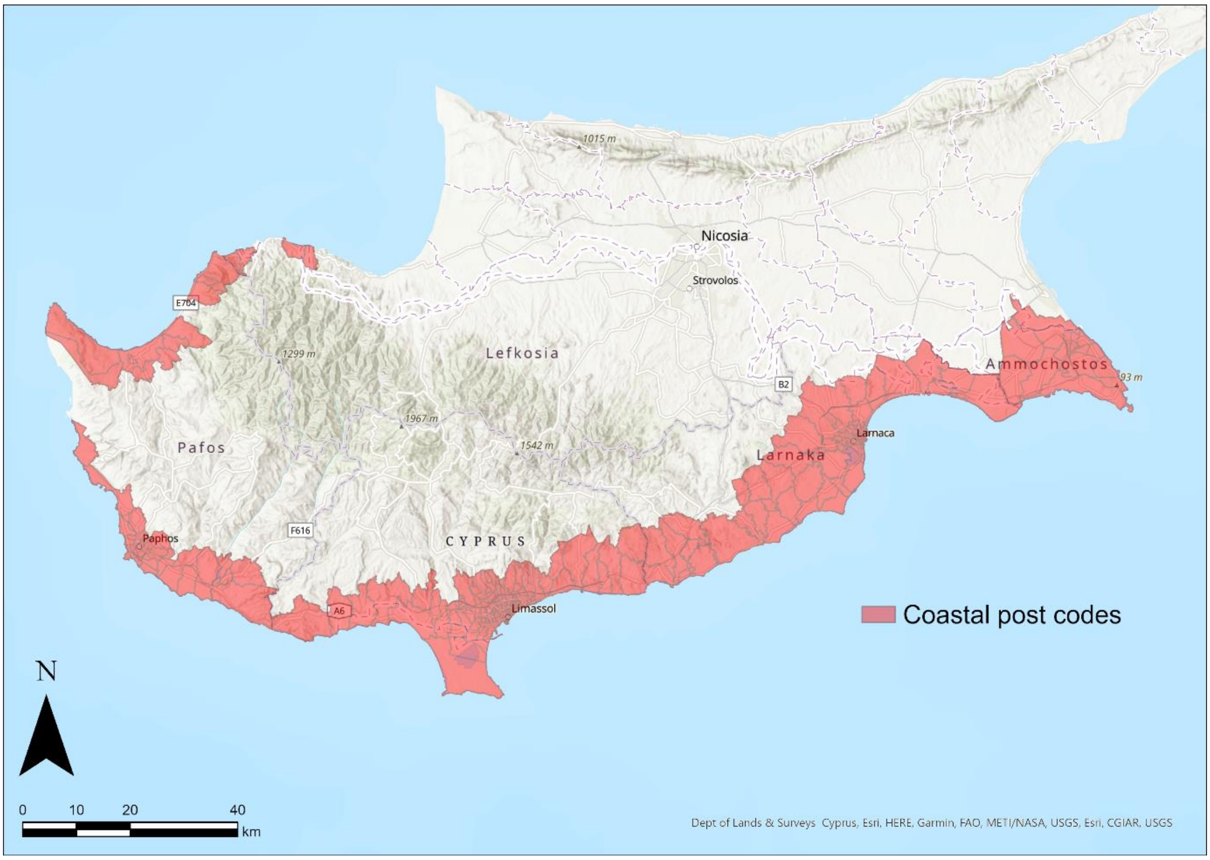

Nicosia
Strovolos
Lefkosia
Ammochostos
Pafos
Larnaka
Larnaca
Paphos
CYPRUS
Limassol
Coastal post codes
N
0 10 20 40
km
Dept of Lands & Surveys Cyprus, Esri, HERE, Garmin, FAO, METI/NASA, USGS, Esri, CGIAR, USGS

Table 9-2 Heating and Cooling Consumption for Modelled Architypes (Low Land Areas)

Sector	Architype	Space/Process Heating Demand (MWh)	Cooling Demand (MWh)	SHW Demand (MWh)
Residential	Apartment	1,807	5,314	1,497
	Row house	2,782	3,762	1,821
	Single house	3,118	5,352	2,187
Service	Airports	0	0	0
	Restaurant	38,901	100,430	16,936
	Hospitals	880,833	2,658,054	1,217,002
	Hotels	247,434	1,335,830	129,830
	Offices	27,248	61,167	0
	Schools	64,390	160,033	13,667
	Shopping	4,912	25,348	18
	Other Services	67,355	215,974	25,176
Industrial (Non-EU ETS)	Chemicals	386,661	68,418	
	Food and Drink	164,847	8,679	
	Other Minerals	19,009	0	
	Other Industry	27,648		0
Agriculture	Greenhouses	2,285	0	0
	Other Agriculture	2,285	0	0

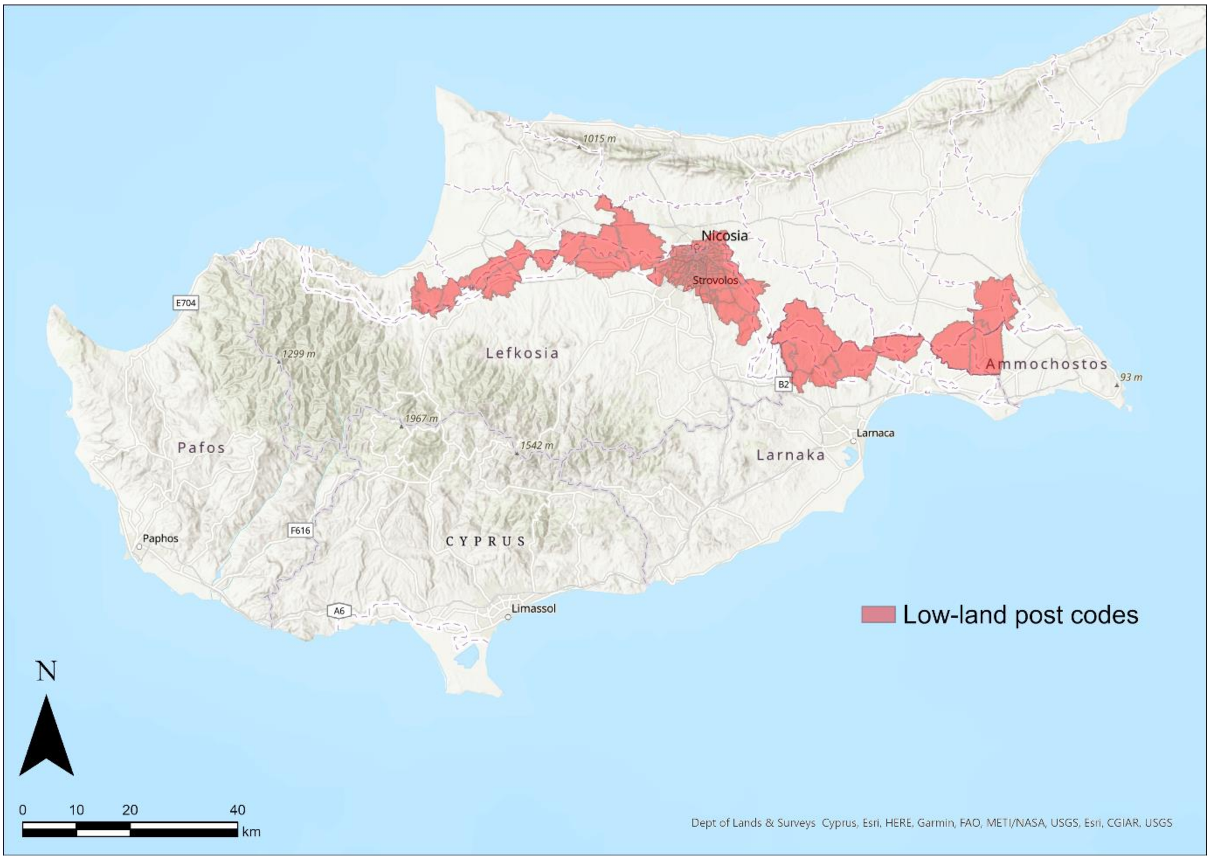

Nicosia
Strovolos
Lefkosia
Ammochostos
Pafos
Larnaka
Larnaca
Paphos
CYPRUS
Limassol
Low-land post codes
N
0 10 20 40
km
Dept of Lands & Surveys Cyprus, Esri, HERE, Garmin, FAO, METI/NASA, USGS, Esri, CGIAR, USGS

Table 9-3 Heating and Cooling Consumption for Modelled Architypes (Mountainous Areas)

Sector	Architype	Space/Process Heating Demand (MWh)	Cooling Demand (MWh)	SHW Demand (MWh)
Residential	Apartment	5,408	0	1,493
	Row house	7,789	0	1,699
	Single house	9,355	0	2,187
Service	Airports	0	0	0
	Restaurant	116,702	0	16,936
	Hospitals	2,063,030	0	950,128
	Hotels	162,844	0	28,482
	Offices	81,744	0	0
	Schools	74,154	0	5,246
	Shopping	16,050	0	20
	Other Services	198,020	0	24,672
Industrial (Non-EU ETS)	Chemicals	0	0	
	Food and Drink	99,377	0	
	Other Minerals	10,067	0	
	Other Industry	20,286		0
Agriculture	Greenhouses	2,438	0	0
	Other Agriculture	2,438	0	0

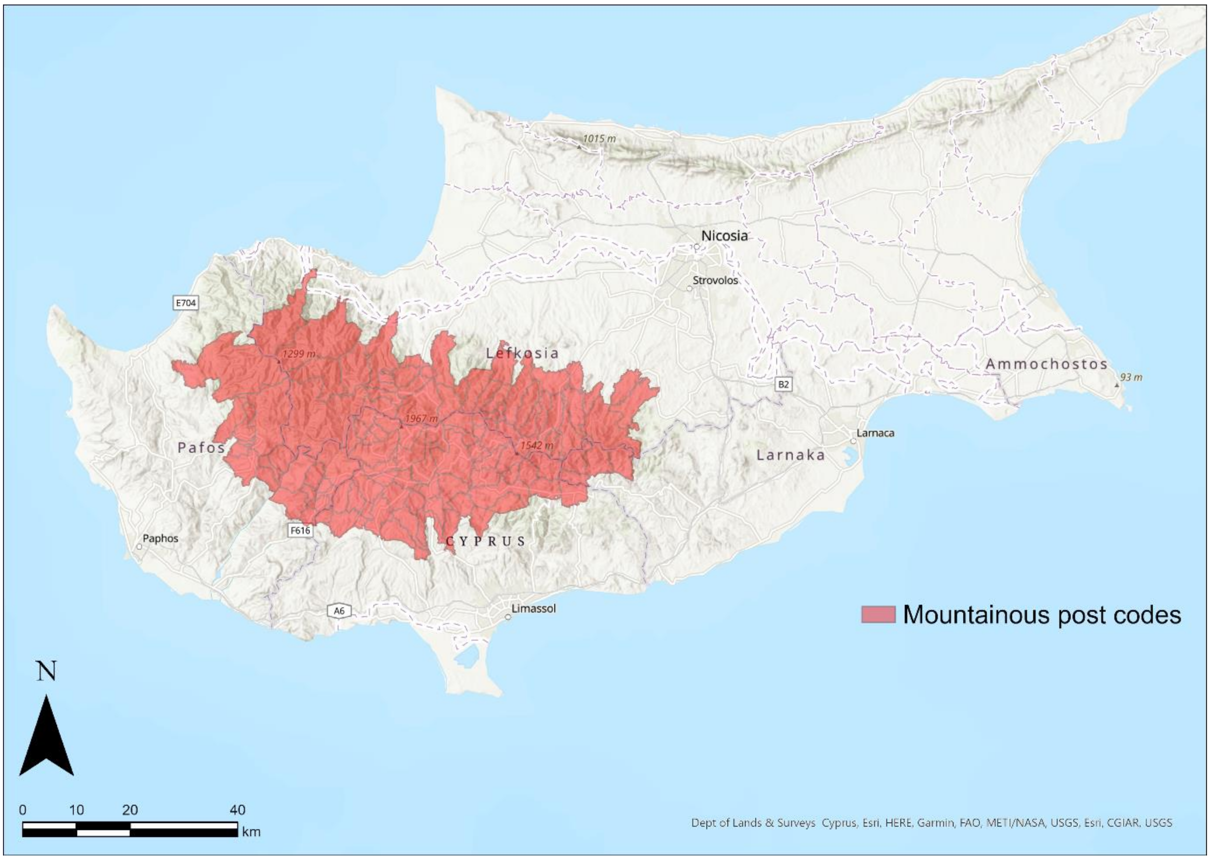
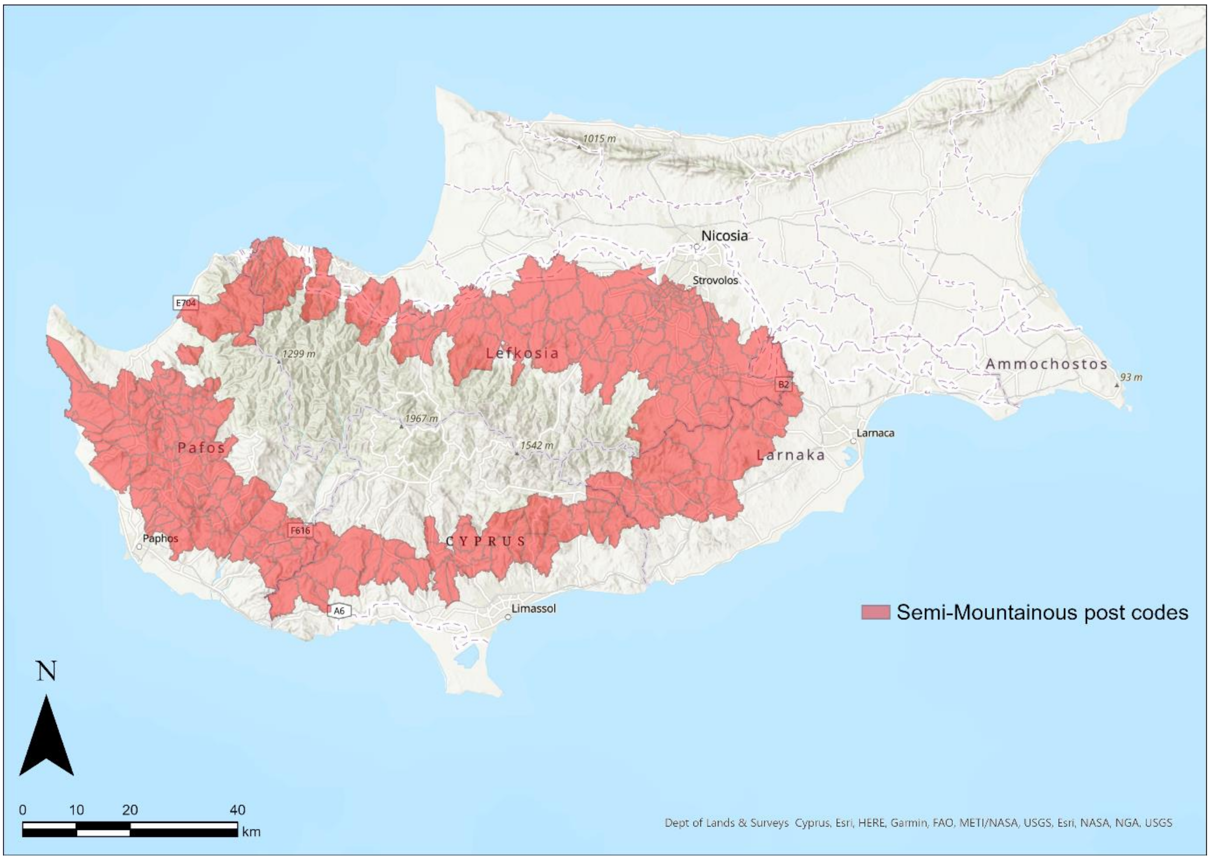

Nicosia
Strovolos
Lefkosia
Ammochostos
Larnaca
Larnaka
Pafos
Paphos
CYPRUS
Limassol
Mountainous post codes
N
0 10 20 40 km
Dept of Lands & Surveys Cyprus, Esri, HERE, Garmin, FAO, METI/NASA, USGS, Esri, CGIAR, USGS

Table 9-4 Heating and Cooling Consumption for Modelled Architypes (Semi--Mountainous Areas)

Sector	Architype	Space/Process Heating Demand (MWh)	Cooling Demand (MWh)	SHW Demand (MWh)
Residential	Apartment	2,149	3,688	1,484
	Row house	3,211	2,533	1,752
	Single house	3,742	3,746	2,187
Service	Airports	0	0	0
	Restaurant	46,681	70,301	16,936
	Hospitals	1,139,155	2,005,255	1,311,593
	Hotels	62,523	196,902	27,339
	Offices	32,698	42,817	0
	Schools	51,245	74,295	9,064
	Shopping	5,454	16,416	17
	Other Services	79,184	148,110	24,664
Industrial (Non-EU ETS)	Chemicals	323,432	40,061	
	Food and Drink	293,583	10,819	
	Other Minerals	24,369	0	
	Other Industry	46,462		0
Agriculture	Greenhouses	1,777	0	0
	Other Agriculture	1,777	0	0


Nicosia
Strovolos
Lefkosia
Ammochostos
Larnaca
Larnaka
Pafos
Paphos
CYPRUS
Limassol
1015 m
1299 m
1967 m
1542 m
93 m
E704
B2
F616
A6
Semi-Mountainous post codes
N
0 10 20 40 km
Dept of Lands & Surveys Cyprus, Esri, HERE, Garmin, FAO, METI/NASA, USGS, Esri, NASA, NGA, USGS

A2 External Costs of CO_2 (Economic Analysis only)

Table 9-5 External costs of CO_2 (€2020). Non-traded costs used only in economic analysis. Central projection used.

	Environmental cost £/tCO2		
	Low	Central	High
2016	€ 15.75	€ 37.56	€ 63.01
2017	€ 16.36	€ 38.77	€ 65.43
2018	€ 16.96	€ 39.99	€ 67.86
2019	€ 17.57	€ 41.20	€ 70.28
2020	€ 18.18	€ 42.41	€ 72.70
2021	€ 18.78	€ 43.62	€ 75.13
2022	€ 19.39	€ 44.83	€ 77.55
2023	€ 19.99	€ 46.04	€ 79.97
2024	€ 20.60	€ 47.26	€ 82.40
2025	€ 21.20	€ 48.47	€ 84.82
2026	€ 21.81	€ 49.68	€ 87.24
2027	€ 22.42	€ 50.89	€ 89.67
2028	€ 23.02	€ 52.10	€ 92.09
2029	€ 23.63	€ 53.32	€ 94.51
2030	€ 24.23	€ 54.53	€ 96.94
2031	€ 24.84	€ 55.74	€ 99.36
2032	€ 25.45	€ 56.95	€ 101.78
2033	€ 26.05	€ 58.16	€ 104.21
2034	€ 26.66	€ 59.37	€ 106.63
2035	€ 27.26	€ 60.59	€ 109.05
2036	€ 27.87	€ 61.80	€ 111.48
2037	€ 28.48	€ 63.01	€ 113.90
2038	€ 29.08	€ 64.22	€ 116.32
2039	€ 29.69	€ 65.43	€ 118.75
2040	€ 30.29	€ 66.64	€ 121.17
2041	€ 30.90	€ 67.86	€ 123.59
2042	€ 31.50	€ 69.07	€ 126.02
2043	€ 32.11	€ 70.28	€ 128.44
2044	€ 32.72	€ 71.49	€ 130.86
2045	€ 33.32	€ 72.70	€ 133.29
2046	€ 33.93	€ 73.91	€ 135.71
2047	€ 34.53	€ 75.13	€ 138.13
2048	€ 35.14	€ 76.34	€ 140.56
2049	€ 35.75	€ 77.55	€ 142.98
2050	€ 36.35	€ 78.76	€ 145.40
2051	€ 36.35	€ 78.76	€ 145.40
2052	€ 36.35	€ 78.76	€ 145.40
2053	€ 36.35	€ 78.76	€ 145.40
2054	€ 36.35	€ 78.76	€ 145.40
2055	€ 36.35	€ 78.76	€ 145.40
2056	€ 36.35	€ 78.76	€ 145.40
2057	€ 36.35	€ 78.76	€ 145.40
2058	€ 36.35	€ 78.76	€ 145.40

A3 CO_2 Traded Prices for EU ETS Installations (Financial Analysis Only)

Table 9-6 Traded costs of CO_2 (€2020). Traded costs used only in financial analysis. Central projection used.

	Traded (EU-ETS) £/tCO2		
	Low	Central	High
2016	€ 7.69	€ 7.69	€ 7.69
2017	€ 9.31	€ 9.31	€ 9.31
2018	€ 10.92	€ 10.92	€ 10.92
2019	€ 12.54	€ 12.54	€ 12.54
2020	€ 14.16	€ 14.16	€ 14.16
2021	€ 15.78	€ 17.76	€ 15.78
2022	€ 17.40	€ 18.77	€ 17.40
2023	€ 19.02	€ 20.89	€ 19.02
2024	€ 20.64	€ 21.90	€ 20.64
2025	€ 22.25	€ 23.51	€ 22.25
2026	€ 24.07	€ 26.13	€ 24.07
2027	€ 25.90	€ 28.15	€ 25.90
2028	€ 27.72	€ 30.27	€ 27.72
2029	€ 29.54	€ 32.39	€ 29.54
2030	€ 31.36	€ 35.01	€ 31.36
2031	€ 33.18	€ 36.79	€ 33.18
2032	€ 35.00	€ 38.56	€ 35.00
2033	€ 36.82	€ 40.34	€ 36.82
2034	€ 38.64	€ 42.12	€ 38.64
2035	€ 40.46	€ 43.89	€ 40.46
2036	€ 42.28	€ 45.55	€ 42.28
2037	€ 44.10	€ 47.20	€ 44.10
2038	€ 45.92	€ 48.86	€ 45.92
2039	€ 47.74	€ 50.51	€ 47.74
2040	€ 49.57	€ 52.17	€ 49.57
2041	€ 53.51	€ 53.51	€ 53.51
2042	€ 57.46	€ 57.46	€ 57.46
2043	€ 61.40	€ 61.40	€ 61.40
2044	€ 65.34	€ 65.34	€ 65.34
2045	€ 69.29	€ 69.29	€ 69.29
2046	€ 73.23	€ 73.23	€ 73.23
2047	€ 77.18	€ 77.18	€ 77.18
2048	€ 81.12	€ 81.12	€ 81.12
2049	€ 85.07	€ 85.07	€ 85.07
2050	€ 89.01	€ 89.01	€ 89.01
2051	€ 89.52	€ 89.52	€ 89.52
2052	€ 90.03	€ 90.03	€ 90.03
2053	€ 90.53	€ 90.53	€ 90.53
2054	€ 91.04	€ 91.04	€ 91.04
2055	€ 91.54	€ 91.54	€ 91.54
2056	€ 92.05	€ 92.05	€ 92.05
2057	€ 92.05	€ 92.05	€ 92.05
2058	€ 92.05	€ 92.05	€ 92.05

A4 Marginal Damage Costs for NOx, PM10 and SOx Associated with Fuel Combustion

Appendix_4_MDC_Electricity.xlsx

Fuel Type	NOx €2020/MWh	PM10 €2020/MWh	SOx €2020/MWh	Total Cost €2020/MWh	Comments
Electricity	**Varies each year is response to changing electricity generation mix. See attached spreadsheet for in year values.**				
Solid	5.66	59.50	55.98	**121.13**	**Applies all years**
Liquid	16.78	10.17	2.92	**29.88**	**Applies all years**
Gaseous	2.42	0.40	0.04	**2.86**	**Applies all years**
Biomass	2.98	72.72	0.68	**76.38**	**Applies all years**

A5 Assumed Hours of Occupancy of Different Building Types

Table 9-7 Hours of occupancy assumed for heating, cooling and SHW for a range of different building and end user types

Sub_Sector_no	Sub_Sector_list	Average weekly cooling hours in summer e.g. 8-5PM x 5 days per week = 45	Average weekly heating hours in winter e.g. 8-5PM x 5 days per week = 45	Average weekly water heating hours e.g. 8-5PM x 5 days per week = 45	Heating and cooling affected by degree days 1/0	Occupancy factor space cooling	Occupancy factor space heating	Occupancy factor water heating
1	Hotel_3star+	168.00	168.00	168.00	1	100.0%	100.0%	100.0%
2	Hotel_Other	168.00	168.00	168.00	1	100.0%	100.0%	100.0%
3	Education_1-2_Public	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
4	Education_1-2_Private	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
5	Education_Tertiary	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
6	Public_Electric_Heating	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
7	Public_Oil_Heating	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
8	Supermarket	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
9	Shopping_Malls	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
10	Hospital_Public	168.00	168.00	168.00	1	100.0%	100.0%	100.0%
11	Health_Private	168.00	168.00	168.00	1	100.0%	100.0%	100.0%
12	Restaurant	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
13	Office__Electric_Heating	45.00	45.00	168.00	1	26.8%	26.8%	100.0%
14	Office_Oil_Heating	45.00	45.00	168.00	1	26.8%	26.8%	100.0%
15	Retail	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
16	House	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
17	Apartment	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
18	Airport	168.00	168.00	168.00	1	100.0%	100.0%	100.0%
19	Other_Services	168.00	168.00	168.00	1	100.0%	100.0%	100.0%
20	Cement	117.60	117.60	117.60	0	70.0%	70.0%	70.0%
21	Chemicals	117.60	117.60	117.60	0	70.0%	70.0%	70.0%
22	Food, tobacco and bewerage	117.60	117.60	117.60	0	70.0%	70.0%	70.0%
23	Other minerals	117.60	117.60	117.60	0	70.0%	70.0%	70.0%
24	Other industry	117.60	117.60	117.60	0	70.0%	70.0%	70.0%
25	Greenhouses	10.50	10.50	10.50	0	6.3%	6.3%	6.3%
26	Other agriculture	90.00	90.00	168.00	1	53.6%	53.6%	100.0%
27	All	168.00	168.00	168.00	1	100.0%	100.0%	100.0%
28	Derelict/outbuilding	168.00	168.00	168.00	1	100.0%	100.0%	100.0%

A6 Energy Prices Set 1

Table 9-8 Fuel Prices – Economic analysis (EURO2020/MWh) (For prices beyond 2035 see model)

Sector	Subsector	Fuel	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Service	All	Electricity	142.57	146.18	150.06	154.05	131.23	133.85	136.19	136.67	137.14	137.68	138.31	140.22	143.09	149.61	149.77	149.64
Service	All	Diesel fuel oil	34.77	36.52	38.40	40.35	42.37	44.58	45.04	45.54	46.00	46.50	46.96	48.91	50.89	52.84	54.75	56.73
Service	All	Gas oil_CHP	72.83	72.94	73.06	73.17	73.29	73.40	74.05	74.69	75.33	75.97	76.61	77.07	77.53	78.00	78.46	78.92
Service	All	Gas oil_non_CHP	72.83	72.94	73.06	73.17	73.29	73.40	74.05	74.69	75.33	75.97	76.61	77.07	77.53	78.00	78.46	78.92
Service	All	Light fuel oil	68.92	69.02	69.13	69.24	69.35	69.46	70.07	70.68	71.28	71.89	72.50	72.93	73.37	73.81	74.24	74.68
Service	All	Kerosene	81.43	81.56	81.69	81.82	81.95	82.08	82.80	83.51	84.23	84.95	85.67	86.18	86.70	87.21	87.73	88.24
Service	All	LPG	80.36	80.49	80.62	80.74	80.87	81.00	81.71	82.42	83.12	83.83	84.54	85.05	85.56	86.07	86.57	87.08
Service	All	Solar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Service	All	Wood Chip (20%)	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41
Service	All	RDF	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
Service	All	Natural gas	59.76	59.25	58.75	58.24	57.74	57.23	58.32	59.41	60.50	61.58	62.67	62.90	63.14	63.37	63.60	63.84
Industry	All	Electricity	142.57	146.18	150.06	154.05	131.23	133.85	136.19	136.67	137.14	137.68	138.31	140.22	143.09	149.61	149.77	149.64
Industry	All	Diesel fuel oil	34.77	36.52	38.40	40.35	42.37	44.58	45.04	45.54	46.00	46.50	46.96	48.91	50.89	52.84	54.75	56.73
Industry	All	Gas oil_CHP	72.83	72.94	73.06	73.17	73.29	73.40	74.05	74.69	75.33	75.97	76.61	77.07	77.53	78.00	78.46	78.92
Industry	All	Gas oil_non_CHP	72.83	72.94	73.06	73.17	73.29	73.40	74.05	74.69	75.33	75.97	76.61	77.07	77.53	78.00	78.46	78.92
Industry	All	Light fuel oil	68.92	69.02	69.13	69.24	69.35	69.46	70.07	70.68	71.28	71.89	72.50	72.93	73.37	73.81	74.24	74.68
Industry	All	Kerosene	81.43	81.56	81.69	81.82	81.95	82.08	82.80	83.51	84.23	84.95	85.67	86.18	86.70	87.21	87.73	88.24
Industry	All	LPG	80.36	80.49	80.62	80.74	80.87	81.00	81.71	82.42	83.12	83.83	84.54	85.05	85.56	86.07	86.57	87.08
Industry	All	Solar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Industry	All	Wood Chip (20%)	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41
Industry	All	RDF	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
Industry	All	Natural gas	38.71	38.39	38.06	37.73	37.40	37.08	37.78	38.49	39.19	39.90	40.60	40.75	40.90	41.06	41.21	41.36
Agriculture	All	Electricity	142.57	146.18	150.06	154.05	131.23	133.85	136.19	136.67	137.14	137.68	138.31	140.22	143.09	149.61	149.77	149.64
Agriculture	All	Diesel fuel oil	34.77	36.52	38.40	40.35	42.37	44.58	45.04	45.54	46.00	46.50	46.96	48.91	50.89	52.84	54.75	56.73
Agriculture	All	Gas oil_CHP	72.83	72.94	73.06	73.17	73.29	73.40	74.05	74.69	75.33	75.97	76.61	77.07	77.53	78.00	78.46	78.92
Agriculture	All	Gas oil_non_CHP	72.83	72.94	73.06	73.17	73.29	73.40	74.05	74.69	75.33	75.97	76.61	77.07	77.53	78.00	78.46	78.92
Agriculture	All	Light fuel oil	68.92	69.02	69.13	69.24	69.35	69.46	70.07	70.68	71.28	71.89	72.50	72.93	73.37	73.81	74.24	74.68
Agriculture	All	Kerosene	81.43	81.56	81.69	81.82	81.95	82.08	82.80	83.51	84.23	84.95	85.67	86.18	86.70	87.21	87.73	88.24
Agriculture	All	LPG	80.36	80.49	80.62	80.74	80.87	81.00	81.71	82.42	83.12	83.83	84.54	85.05	85.56	86.07	86.57	87.08
Agriculture	All	Solar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Agriculture	All	Wood Chip (20%)	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41
Agriculture	All	RDF	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
Agriculture	All	Natural gas	38.71	38.39	38.06	37.73	37.40	37.08	37.78	38.49	39.19	39.90	40.60	40.75	40.90	41.06	41.21	41.36
Residential	All	Electricity	142.57	146.18	150.06	154.05	131.23	133.85	136.19	136.67	137.14	137.68	138.31	140.22	143.09	149.61	149.77	149.64
Residential	All	Gas oil_non_CHP	72.83	72.94	73.06	73.17	73.29	73.40	74.05	74.69	75.33	75.97	76.61	77.07	77.53	78.00	78.46	78.92
Residential	All	Light fuel oil	68.92	69.02	69.13	69.24	69.35	69.46	70.07	70.68	71.28	71.89	72.50	72.93	73.37	73.81	74.24	74.68
Residential	All	Kerosene	81.43	81.56	81.69	81.82	81.95	82.08	82.80	83.51	84.23	84.95	85.67	86.18	86.70	87.21	87.73	88.24
Residential	All	LPG	80.36	80.49	80.62	80.74	80.87	81.00	81.71	82.42	83.12	83.83	84.54	85.05	85.56	86.07	86.57	87.08
Residential	All	Solar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Residential	All	Wood Chip (20%)	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41
Residential	All	Natural gas	38.71	38.39	38.06	37.73	37.40	37.08	37.78	38.49	39.19	39.90	40.60	40.75	40.90	41.06	41.21	41.36

Table 9-9 Fuel Prices - Economic analysis (EURO2020/MWh) (For prices beyond 2035 see model)

Fuel	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Electricity	142.57	146.18	150.06	154.05	131.23	133.85	136.19	136.67	137.14	137.68	138.31	140.22	143.09	149.61	149.77	149.64
Diesel fuel oil	34.77	36.52	38.40	40.35	42.37	44.58	45.04	45.54	46.00	46.50	46.96	48.91	50.89	52.84	54.75	56.73
Gas oil_CHP	84.35	84.48	84.61	84.75	84.88	85.01	85.76	86.50	87.24	87.99	88.73	89.26	89.80	90.33	90.86	91.40
Gas oil_non_CHP	84.35	84.48	84.61	84.75	84.88	85.01	85.76	86.50	87.24	87.99	88.73	89.26	89.80	90.33	90.86	91.40
Light fuel oil	70.32	70.43	70.54	70.66	70.77	70.88	71.50	72.12	72.74	73.36	73.98	74.42	74.87	75.31	75.76	76.20
Kerosene	92.16	92.30	92.45	92.59	92.74	92.88	93.70	94.51	95.32	96.13	96.95	97.53	98.11	98.69	99.28	99.86
LPG	80.36	80.49	80.62	80.74	80.87	81.00	81.71	82.42	83.12	83.83	84.54	85.05	85.56	86.07	86.57	87.08
Solar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wood Chip (20%)	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41
RDF	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
Natural gas	77.20	76.54	75.89	75.24	74.58	73.93	75.34	76.74	78.15	79.56	80.96	81.26	81.56	81.86	82.17	82.47
Electricity	142.57	146.18	150.06	154.05	131.23	133.85	136.19	136.67	137.14	137.68	138.31	140.22	143.09	149.61	149.77	149.64
Diesel fuel oil	34.77	36.52	38.40	40.35	42.37	44.58	45.04	45.54	46.00	46.50	46.96	48.91	50.89	52.84	54.75	56.73
Gas oil_CHP	84.35	84.48	84.61	84.75	84.88	85.01	85.76	86.50	87.24	87.99	88.73	89.26	89.80	90.33	90.86	91.40
Gas oil_non_CHP	84.35	84.48	84.61	84.75	84.88	85.01	85.76	86.50	87.24	87.99	88.73	89.26	89.80	90.33	90.86	91.40
Light fuel oil	83.68	83.82	83.95	84.08	84.21	84.35	85.08	85.82	86.56	87.30	88.03	88.56	89.09	89.62	90.15	90.68
Kerosene	92.16	92.30	92.45	92.59	92.74	92.88	93.70	94.51	95.32	96.13	96.95	97.53	98.11	98.69	99.28	99.86
LPG	80.36	80.49	80.62	80.74	80.87	81.00	81.71	82.42	83.12	83.83	84.54	85.05	85.56	86.07	86.57	87.08
Solar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wood Chip (20%)	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41
RDF	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
Natural gas	43.02	42.65	42.29	41.92	41.56	41.20	41.98	42.76	43.55	44.33	45.11	45.28	45.45	45.62	45.79	45.95
Electricity	142.57	146.18	150.06	154.05	131.23	133.85	136.19	136.67	137.14	137.68	138.31	140.22	143.09	149.61	149.77	149.64
Diesel fuel oil	34.77	36.52	38.40	40.35	42.37	44.58	45.04	45.54	46.00	46.50	46.96	48.91	50.89	52.84	54.75	56.73
Gas oil_CHP	84.35	84.48	84.61	84.75	84.88	85.01	85.76	86.50	87.24	87.99	88.73	89.26	89.80	90.33	90.86	91.40
Gas oil_non_CHP	84.35	84.48	84.61	84.75	84.88	85.01	85.76	86.50	87.24	87.99	88.73	89.26	89.80	90.33	90.86	91.40
Light fuel oil	70.32	70.43	70.54	70.66	70.77	70.88	71.50	72.12	72.74	73.36	73.98	74.42	74.87	75.31	75.76	76.20
Kerosene	92.16	92.30	92.45	92.59	92.74	92.88	93.70	94.51	95.32	96.13	96.95	97.53	98.11	98.69	99.28	99.86
LPG	80.36	80.49	80.62	80.74	80.87	81.00	81.71	82.42	83.12	83.83	84.54	85.05	85.56	86.07	86.57	87.08
Solar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wood Chip (20%)	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41
RDF	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02	2.02
Natural gas	77.20	76.54	75.89	75.24	74.58	73.93	75.34	76.74	78.15	79.56	80.96	81.26	81.56	81.86	82.17	82.47
Electricity	142.57	146.18	150.06	154.05	131.23	133.85	136.19	136.67	137.14	137.68	138.31	140.22	143.09	149.61	149.77	149.64
Gas oil_non_CHP	100.37	100.53	100.69	100.85	101.01	101.16	102.05	102.93	103.82	104.70	105.59	106.22	106.86	107.49	108.13	108.76
Light fuel oil	83.68	83.82	83.95	84.08	84.21	84.35	85.08	85.82	86.56	87.30	88.03	88.56	89.09	89.62	90.15	90.68
Kerosene	109.66	109.84	110.01	110.19	110.36	110.53	111.50	112.47	113.43	114.40	115.36	116.06	116.75	117.45	118.14	118.83
LPG	80.36	80.49	80.62	80.74	80.87	81.00	81.71	82.42	83.12	83.83	84.54	85.05	85.56	86.07	86.57	87.08
Solar	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wood Chip (20%)	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41	44.41
Natural gas	77.20	76.54	75.89	75.24	74.58	73.93	75.34	76.74	78.15	79.56	80.96	81.26	81.56	81.86	82.17	82.47

A7 CO_2 Emissions Associated with Grid Electricity Over Time and Overall Efficiency of Generation

Table 9-10 Ratio of primary energy input to delivered electricity output and CO_2 intensity of delivered electricity

Year	Delivered Electricity/Primary Energy Ratio	Delivered electricity CO_2 intensity
2020	41.12%	0.629
2021	43.34%	0.574
2022	48.60%	0.379
2023	48.58%	0.376
2024	52.40%	0.332
2025	52.46%	0.330
2026	53.53%	0.310
2027	53.81%	0.307
2028	53.57%	0.310
2029	53.50%	0.313
2030	53.41%	0.314
2031	55.15%	0.290
2032	57.01%	0.266
2033	58.99%	0.242
2034	61.12%	0.218
2035	63.41%	0.194
2036	64.69%	0.182
2037	66.02%	0.169
2038	67.41%	0.157
2039	68.86%	0.144
2040	70.37%	0.132
2041	71.15%	0.125
2042	71.95%	0.119
2043	72.77%	0.113
2044	73.60%	0.107
2045	74.46%	0.100
2046	75.16%	0.095
2047	75.87%	0.090
2048	76.60%	0.085
2049	77.34%	0.080
2050	78.10%	0.075
2051	78.10%	0.075
2052	78.10%	0.075
2053	78.10%	0.075
2054	78.10%	0.075
2055	78.10%	0.075
2056	78.10%	0.075
2057	78.10%	0.075
2058	78.10%	0.075

A8 Energy Technology Assumptions

Technology_Assumptions.xlsx

A9 District Heating and Cooling Pipework Assumptions

DHC_Pipe_Assumptions.xlsx

A10 Best Individual Solutions for Evaluated Architypes

Sector	Subsector	Climatic Regions	Best Individual Solution	ENPV (€) Relative to Baseline (Range due to climatic region)	FNPV (€) Relative to Baseline (Range due to climatic region)	Saves CO_2 Relative to Baseline Over 2022 to 2050	Saves Primary Relative to Baseline Over 2022 to 2050
Residential	**Apartment**	**All**	**PV + Heat Pump + Solar Hot Water**	**3,300-4,500**	**-100 - 300**	**Y**	**Y**
Residential	**Row House**	**All**	**PV + Heat Pump + Solar Hot Water**	**6,500- 7,100**	**1,200 – 1,700**	**Y**	**Y**
Residential	**Single House**	**All**	**PV + Heat Pump + Solar Hot Water**	**7,400 – 10,100**	**1,700 – 2,300**	**Y**	**Y**

Sector	Subsector	Climatic Regions	Best Individual Solution	ENPV (€) Relative to Baseline (Range due to climatic region)	FNPV (€) Relative to Baseline (Range due to climatic region)	Saves CO_2 Relative to Baseline Over 2022 to 2050	Saves Primary Relative to Baseline Over 2022 to 2050
Service	Airports	Only one climatic region has airports.	PV + Heat Pump + Solar Hot Water	17,400,000	6,300,000	Y	Y
Service	Restaurant	All	PV + Heat Pump + Solar Hot Water	92,000 to 123,000	23,000 to 37,000	Y	Y
Service	Health (public)	All	PV + Heat Pump + Solar Hot Water	1,999,000 to 3,600,000	563,300 to 1,268,000	Y	Y
Service	Hotels	All	PV + Heat Pump + Solar Hot Water	375,000 to 2,300,000	88,000 to 620,000	Y	Y
Service	Offices	All	PV + Heat Pump + Solar Hot Water	60,000 to 81,000	11,000 to 24,000	Y	Y
Service	Schools	All	PV + Heat Pump + Solar Hot Water	60,000 to 81,000	11,000 – 24,000	Y	Y
Service	Shopping	All	PV + Heat Pump + Solar Hot Water	9,000 – 24,000	500 to 5,000	Y	Y
Service	Other	All	PV + Heat Pump + Solar Hot Water	168,000 to 256,000	47,000 to 79,000	Y	Y

Sector	Subsector	Climatic Regions	Best Individual Solution	ENPV (€) Relative to Baseline (Range due to climatic region)	FNPV (€) Relative to Baseline (Range due to climatic region)	Saves CO_2 Relative to Baseline Over 2022 to 2050	Saves Primary Relative to Baseline Over 2022 to 2050
Industry	Chemicals (Non-EU ETS)	All	Oil CHP + Absorption Chiller	300 to 263,000	123,000 to 289,000	N	Y
Industry	Food and Drink (Non-EU ETS)	All	LPG CHP + Absorption Chiller	49,000 to 213,000	10,000 to 81,000	N	Y
Industry	Other Industry (Non-EU ETS)	All	LPG CHP + Absorption Chiller	9,000 to 22,000	2,000 to 4,000	N	Y

Sector	Subsector	Climatic Regions	Best Individual Solution	ENPV (€) Relative to Baseline (Range due to climatic region)	FNPV (€) Relative to Baseline (Range due to climatic region)	Saves CO_2 Relative to Baseline Over 2022 to 2050	Saves Primary Relative to Baseline Over 2022 to 2050
Agriculture	Greenhouses	All	Heat Pumps + Solar Hot Water	700 to 1,400	-1,200 to -800	Y	Y
Agriculture	Other agriculture	All	Heat Pumps + Solar Hot Water	2,500 to 4,200	500 to 900	Y	Y

T: +44 (0) 1235 753000
E: enquiry@ricardo.com
W: ee.ricardo.com