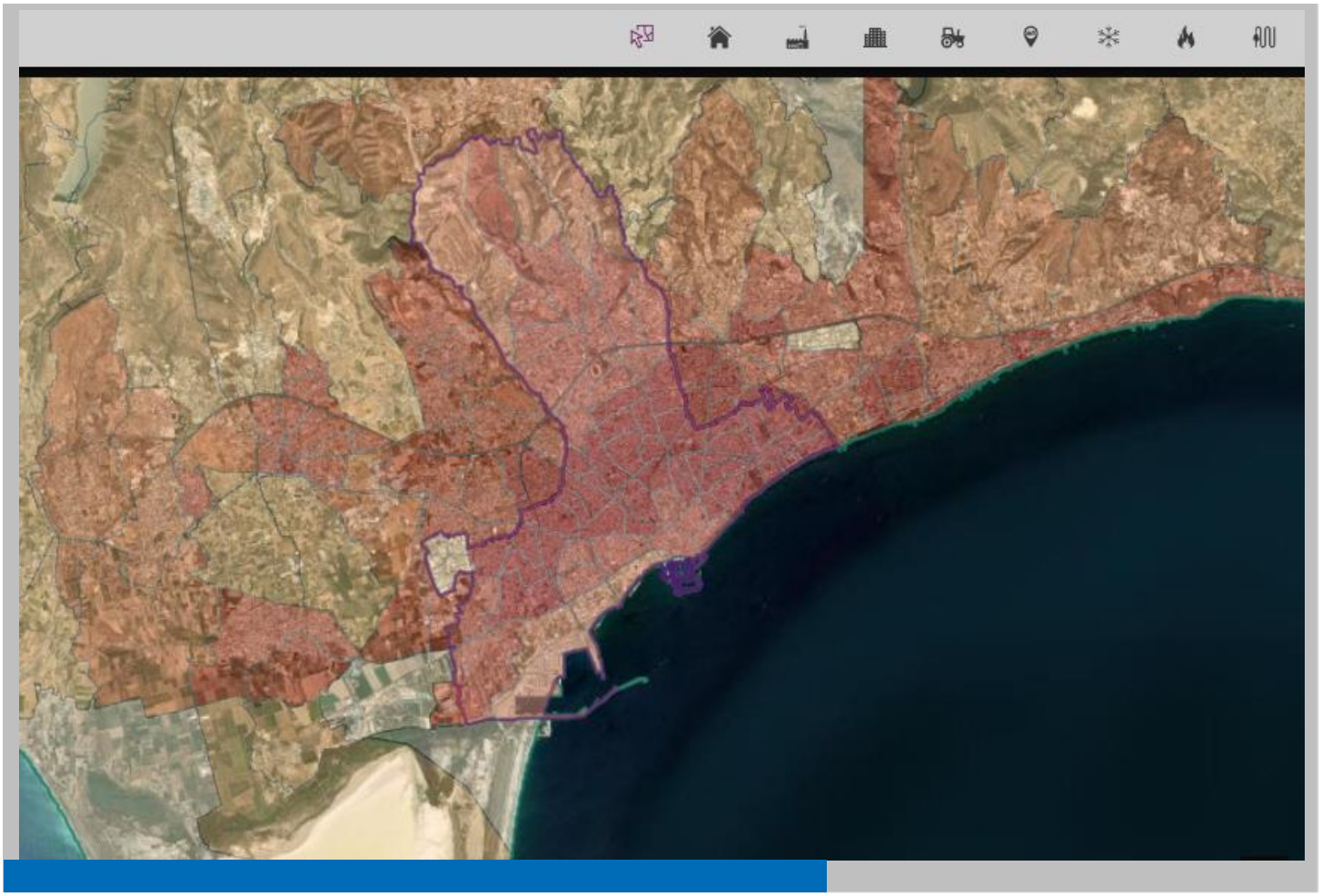
Creating a world
fit for the future

RICARDO



Comprehensive Assessment of the Potential for Efficient Heating and Cooling

Report for Limassol - 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/04/2023

ED 18485 | Issue number 1 | Date 19th July 2024

Ricardo Confidential

Customer:

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

Customer reference:

YEEB/YE/04/2023

Contact:

Aisling Crowley
Ricardo Plc
Gemini Building, Fermi Avenue, Harwell, Didcot, OX11 0QR, UK

T: +44(0)7968707754

E: aisling.crowley@ricardo.com

Confidentiality, copyright and reproduction:

This report is the Copyright of the Ministry of Energy, Commerce and Industry, Cyprus and has been prepared by Ricardo Energy & Environment, a trading name of Ricardo-AEA Ltd under contract Comprehensive Assessment of the Potential for Efficient Heating and Cooling dated 10th Jan 2024. The contents of this report may not be reproduced, in whole or in part, nor passed to any organisation or person without the specific prior written permission of the Ministry of Energy, Commerce and Industry, Cyprus. Ricardo Energy & Environment accepts no liability whatsoever to any third party for any loss or damage arising from any interpretation or use of the information contained in this report, or reliance on any views expressed therein, other than the liability that is agreed in the said contract.

Author:

Jeremy Stambaugh & Aisling Crowley

Approved by:

Mahmoud Abu Ebid

Signed



Date:

19th July 2024

Ref: ED18485

Ricardo is certified to ISO9001, ISO14001, ISO27001 and ISO45001

Table of Contents

Table of Contents iii
Table of Tables iv
1 Introduction 1
2 Establishing the Baseline 1
2.1 Baseline Energy Consumption 1
2.2 Baseline Technologies for the Provision of Heating and Cooling 2
2.2.1 Residential 2
2.2.2 Service 3
2.2.3 Industry (Non-EU ETS) 3
2.2.4 Industry (EU ETS) 4
There are no EU ETS industrial installations located in Limassol. 4
2.2.5 Agriculture 4
2.3 Baseline Adjustments for Existing Policies Related to Heating and Cooling 5
2.3.1 Heating and Cooling Demand in 2022 5
2.3.2 Heating and Cooling Demand in 2030 5
3 The Use of Architypes 6
4 Solutions Evaluated 6
4.1 District Heating and Cooling Solutions (DHC) Evaluated 7
4.2 Individual Site/Building Level Solutions Evaluated 11
5 Approach to CBA 13
5.1 General Points 13
5.2 Applicability of Solutions Across Sectors and Sites 14
5.3 Sensitivity 15
6 Key Assumptions 16
7 Results 17
7.1 Best High Efficiency Heating and Cooling Solutions for Modelled Architypes 17
7.2 Best High Efficiency Heating and Cooling Solutions at Post Code Level for 2022 and 2030 17
7.3 Best District Heating and Cooling Solutions 24
8 Discussion 25
8.1 Relative Economic, CO_2 and Energy Performance of District Heating and Cooling (DHC) and Individual Building Solutions 25
8.2 The Effect of future changes in energy demands and costs 25
8.3 What is Hampering DHC Solutions? 25
9 Conclusions 26
Appendices 26
A1 Heating and Cooling Consumption for the Modelled Architypes 27

Table of Tables

Table 2-1 Technologies considered to be providing baseline SH, SC and SHW in the Residential sector 2
Table 2-2 Technologies considered to be providing baseline SH, SC and SHW in the Service sector (all architypes except Hotels) 3
Table 2-3 Technologies considered to be providing baseline PH, PC and SHW in the Industrial sector (all non-EU ETS architypes) 4
Table 2-4 Technologies considered to be providing baseline PH, PC and SHW in the Agricultural sector (all architypes) 4
Table 3-1 Architypes observed in the analysis 6
Table 4-1 Detailed characteristics of 18 combinations of DHC evaluated in this study 9
Table 4-2 Detailed characteristics of the individual building level solutions evaluated 11
Table 7-1 Best high efficiency heating and cooling solutions (all Post Codes and sectors) – Baseline 2022 19
Table 7-2 Best high efficiency heating and cooling solutions (all Post Codes and sectors) – Baseline 2030 19
Table 7-3 Best high efficiency heating and cooling solutions (all Post Codes, Residential and Service Sectors, only) – Baseline 2022 21
Table 7-4 Best high efficiency heating and cooling solutions (all Post Codes, Residential and Service Sectors, only) – Baseline 2030 21
Table 7-5 Best high efficiency heating and cooling solutions (all Post Codes, Industry and Agricultural Sectors, only) – Baseline 2022 23
Table 7-6 Best high efficiency heating and cooling solutions (all Post Codes, Industry and Agricultural Sectors, only) – Baseline 2030 23
Table 7-7 Summary count of best DHC solution (highest ENPV even if negative) type across climatic regions 24
Table 9-1 Heating and Cooling Consumption for Modelled Architypes (Coastal Areas) 27
Table 9-2 Heating and Cooling Consumption for Modelled Architypes (Semi--Mountainous Areas) 29

1 Introduction

Article 25 (6) of the Energy Efficiency Directive (EU) 2023/1791 requires local authorities to prepare local heating and cooling plans at least in municipalities having a total population higher than 45 000. Within Cyprus this requirement applies to Nicosia, Strovolos, Limassol and Larnaca municipalities. Annex X of the directive 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 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 0 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 0 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 0 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 0 mean, including uncertainties and areas where further work is needed 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

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

- Agriculture

Baseline consumption of heat and cooling in these sectors has been determined for 2022. This is a national projection based on 2015[2] projections for all postcodes for each of the respective subsectors. The methodology used to do this is set out in the Point A section of the whole country Point A&B report. The geographic 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 using proven technologies, 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 depend 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 2022 for the three Residential architypes[3]. All architypes are listed in Section 3.

The mix of technologies for the Residential sector was constructed from the previous NCA for Cyprus completed in 2021, as per Fig 1.1 (a)-(c), where the projected proportions of space heating, SHW and space cooling delivered by different technologies in the residential sector are calculated for various years. The proportions in 2022 for the whole country only are shown.[4]

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	%of Apartment	Row House and Single House
Heat Pumps (split units)	Heat Pumps (split units)	Solar Panels	53%	24%
Electric Resistive Heating	Heat Pumps (split units)	Solar Panels	39%	17%
LPG Boiler	Heat Pumps (split units)	Solar Panels	2%	-

[2] See Annex 4 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
[3] The three Residential architypes are: Apartments, Row Houses and Single Houses
[4] 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

LPG Stoves	Heat Pumps (split units)	Solar Panels	6%	-
Oil Boiler	Heat Pumps (split units)	Solar Panels	0.5%	11%
Oil Stove	Heat Pumps (split units)	Solar Panels	-	39%
Solar Panels	Heat Pumps (split units)	Solar Panels	-	8%

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 2021. 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 completed in 2021, 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.[5]

In the case of the Hotel architype, it is assumed that the baseline in 2022 is comprised of oil boilers for SH and SHW demand and heat pumps (split units) for SC. The proportions in 2022 for the whole country are shown.

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	73%
Heat Pumps and wet systems	Heat Pumps and wet systems	Solar Panels	6%
Solar panels	Heat Pumps (split units)	Solar Panels	4%
Oil Stoves	Heat Pumps (split units)	Solar Panels	13%
Oil Boiler	Heat Pumps (split units)	Solar Panels	3%

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 completed in 2021, as per Fig 1.3 (a)-(c), where the proportions of low, medium and high temperature

[5] 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

heat delivered by different technologies in the industry sector are presented.[6] The applicable technologies and their probabilities for 2022 across the whole country are presented in Table 2-3.

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	65%
Electric resistance heating	Electric chiller and wet system	Electric resistance heating	17%
LPG boiler	Electric chiller and wet system	LPG boiler	15%
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)

2.2.5 There are no EU ETS industrial installations located in Limassol.Agriculture

The mix of technologies and fuels used for the agriculture sector was taken from the previous NCA for Cyprus completed in 2021, as per Fig 1.4, where the proportions of heating delivered by different technologies in the agriculture sector are presented.[7] The applicable technologies and their probabilities for 2022 across the whole country 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	95%
Biomass boiler	Electric chiller and wet system	Biomass boiler	4%
LPG boiler	Electric chiller and wet system	LPG boiler	1%

[6] 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

[7] 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 0.

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 2022

This is the demand for heating and cooling in 2022, as set out in the Point A section of the Point A&B report. 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 (2025-2053) via a Discounted Cash Flow (DCF), for the balance of costs and benefits listed in Section 5.1[8]. Economic Net Present Value (ENPV) and Financial Net Present Value (FNPV) are calculated for each technology solution in terms of €2023.

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 2022 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)[9]. This shows an absolute increase in final energy consumption associated with the provision of heating and cooling in Cyprus of 12.1% between 2022 and 2030. During this time, according to the NECP, the population of Cyprus is projected to increase by 6.4% and the real GDP is projected to increase by 21.4%.

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 and service sectors, but the increase in industrial and agricultural sectors is assumed to be at site level only. Consequently, for the purposes of the CBA, between 2022 and 2030, the useful heating and cooling demand in residential and service sector are both projected to increase by 21.7% in the residential sector and 20.4% in the service sector, and their building stocks are projected to increase at the same rate. But in the industry and agriculture sectors, the stock is assumed to remain constant with a decrease in heating and cooling demand of 5.2% for industry and an increase of 8.9% for agriculture at site level.

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 2023 money. Both Economic Net Present Value (ENPV) and Financial Net Present Value (FNPV) are evaluated.

[8] Full cost assumptions are detailed in Appendices 2-9.
[9] Preliminary Draft Update: Cyprus NECP report 2023

3 The Use of Architypes

There are approximately 617 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.

Table 3-1 shows the number and description of the different architypes defined for each sector.

Table 3-1 Architypes observed in the analysis

Sector	Architypes Observed
Residential	Apartment Row house Single house
Service	Restaurant Health Hotels Offices Schools Shopping Other Services
Industrial (not 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).

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.

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.

For each high efficiency solution, the Economic Net Present Value (ENPV), Financial NPV (FNPV), CO2 savings, and Primary Energy Savings (PES) are all calculated relative to the baseline and summed for each postcode in the same way. The model then allows any of these 4 parameters to be selected as the measure of the merit of each solution. Unless otherwise stated, ENPV is the selected measure.

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

Equation 1

$$ENPV\ for\ Post\ Code\ A = \sum_{Architype\ 1}^{Architype\ N} ENPV\ for\ Best\ Individual\ Solution\ for\ Architype\ 1 \times Number\ of\ Incidences\ of\ Architype\ 1\ in\ Post\ Post\ Code\ A$$

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. Where any of the DHC solutions is found to be beneficial (i.e. has a positive EPNV), the most economical (most positive) DHC solution for a particular Post Code, is counted as the best solution for that Post Code, regardless of the how economic individual level building solutions are. If no DHC solution is proved to be positive, then the most economic individual solutions for each archetype are selected (where positive). If no DHC or high efficiency individual solutions are economic (i.e., have a positive NPV), then the baseline is reported as being best.
2. 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 the total NPV of the most economic individual building level solutions in the postcode are found to be more economic (i.e. have a higher total NPV), the latter solution is counted as the best solution for the Post Code. This is the basis for the results presented and discussed.

4.1 District Heating and Cooling Solutions (DHC) Evaluated

The cost effectiveness, primary energy and CO_2 savings of several “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 (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 industrial sites is incompatible with that which can be supplied by DHC, and the spatial density of agricultural sites is likely to be too low for DHC to be suitable.

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 DHC scheme.

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 and Water Source Heat Pumps (WSHP). 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)

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.[10]

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)

[10] 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 (ENPV) is positive.[11] Cost effective financial potential is deemed to exist if the Financial Net Present Value (FNPV)[12] 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 not within the Limassol municipality, though the findings are still relevant. 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)
- 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%, these were used in the last NCA completed in 2021. The economic potential is evaluated including an external cost associated with the deployment of the

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

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 projected CO_2 costs were equated with the traded ETS price projection in the NECP report July 2023 update[13] and inflated to 2023 real terms. These are much higher for most years than those assumed in the 2021 central forecast which was based on the European Investment Bank guidelines.

(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[14], The marginal costs of damage per tonne of each of the three pollutants is taken from the Cyprus NECP, 2023[15]. 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 potentia**l is evaluated excluding the above-mentioned external costs, but including the traded ETS 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. As stated above, the assumed prices of EU ETS emission allowances are taken from the traded ETS price projection in the NECP report July 2023 update[16] and inflated to 2023 real terms. These prices are set out in Appendix 3. The cost of taxes levied on fuel is excluded from the economic analysis but included in the financial analyses.

The projected electricity generating cost calculated in the NECP for the WEM scenario including distributed generation was inflated to 2023 real terms and used in the ENPV analysis. Meanwhile the ratio of the domestic and non-domestic electricity retail prices including taxes in 2023 to the cost prices calculated in the NECP was multiplied by the NECP cost price forecast to estimate the projected retail prices used in the FNPV analysis. 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 or a 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

[13] See Cyprus Draft Updated NECP 2021 2030, July 2023, Table 4.1. Projections for fossil fuel prices, ETS prices.
[14] 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
[15] See Cyprus Draft Updated NECP 2021 2030, July 2023, footnote 86, p. 180.
[16] See Cyprus Draft Updated NECP 2021 2030, July 2023, Table 4.1. Projections for fossil fuel prices, ETS prices.

following principles have been adopted in the analysis to reflect this reality and should be kept in mind when interpreting the CBA results:

- 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.

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[17]
- 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 **Error! Reference source not found.** below are for these factors set at 100% of the applicable value set out in the Appendices.

[17] 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.

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

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 0 and discussed in Section 8 relate to the cost effective potential as measured against the demand for heating and cooling in 2022 with the cash flows beginning in 2025. Cost effective potential measured against 2030 demand (with cash flows starting in 2030) 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.

All technically suitable high efficiency solutions evaluated for these architypes have been evaluated and the detailed results are presented in Appendix 10. For the avoidance of doubt, these results are assuming plant is installed in 2025, and begins operating in 2026, with an annual heating and cooling demand as in 2022.[18] As can be seen in Appendix 10, the best individual solution in the Residential, service and agriculture sectors includes heat pumps. For single houses, apartments in coastal areas and all service sectors, the best solution also includes PV but in row houses, apartments in semi mountainous, and agriculture, it is better to omit PV. For industry, heat pumps are not suitable, and CHP is not the best solution, so the best solution is to remain with baseline technology.

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

Error! Reference source not found. and **Error! Reference source not found.** show the high efficiency heating and cooling solutions with the greatest Economic Net Present Value (ENPV) relative to the baselines presented in Section 2.2 at the Post Code level. **Error! Reference source not found.** shows this relative to the 2022 baseline and **Error! Reference source not found.** 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 are no postcodes in Limassol for which DHC is the best solution.
- For 2022 demand, overall, individual heat pumps powered by PV is the option with the best ENPV in the large majority of cases, accounting for 91.6% of space cooling and 63.1% of space heating demand.
- The second most prevalent “best” solution for the provision of heating and cooling (in overall energy terms) is individual heat pumps without PV, accounting for 7.9% of space cooling and 11.1% of space heating demand.
- For the remaining cooling and heating, the baseline is the best solution accounting for 0.5% of cooling demand and 25.9% of space heating demand.
- We assume existing solar thermal will continue to provide the majority of SHW, accounting for 97.7% and the remaining 2.3% by PV+heat pumps + new solar thermal is the best solution.

[18] 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.

- Assuming the solutions are not installed until 2029 with 2030 useful heating and cooling demands makes no difference to the ranking of best solutions but the share with PV+heat pumps does reduce from 91.6% to 69.7% of cooling and from 63.1% to 50.5% of space heating with the decrease essentially being taken up by heat pumps without PV. This may be possibly due to the following:
    i. The projected reduction in electricity generating cost, falling from €124/MWh in 2026 to €105/MWh in 2040 (2023 real) making it cheaper to run heat pumps and reducing the savings from PV.
    ii. The predicted reduction in external carbon and environmental damage costs associated with electricity as generation moves away from polluting oil towards natural gas and renewables.

Table 7-1 Best high efficiency heating and cooling solutions (all Post Codes and sectors) – Baseline 2022

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*		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	69.8	31.2	120.1	502.2	-9.3	0.0	47.1	36.7	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	440.0	345.0	1,807.6	5,951.6	8,659.3	0.0	547.3	208.8	2.7
Baseline*		0.0	0.0	0.0	0.0	0.0	0.0	2.9	85.6	117.9
TOTAL		**509.8**	**376.2**	**1,927.8**	**6,453.8**	**8,650.0**	**0.0**	**597.3**	**331.1**	**120.6**

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*		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	119.4	65.9	189.0	950.1	160.4	0.0	216.2	106.1	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	462.4	345.2	1,363.9	4,655.4	7,613.1	0.0	502.7	191.0	3.3
Baseline*		0.0	0.0	0.0	0.0	0.0	0.0	2.8	81.2	143.2
TOTAL		**581.9**	**411.1**	**1,552.9**	**5,605.4**	**7,773.5**	**0.0**	**721.7**	**378.3**	**146.5**

Error! Reference source not found.3 and **Error! Reference source not found.**4 show the high efficiency heating and cooling solutions with the greatest Economic Net Present Value (ENPV) relative to the baselines for the Residential and Service sectors for 2022 and 2030 demand in Limassol. The salient points to take form these tables are as follows:

- Individual heat pump is the best solution for all of the heating and cooling demand in the residential and service sectors, accompanied by PV for most of the demand.
- This is the case for both 2022 and 2030 scenarios but in 2030 the proportion which benefits from PV decreases.

Table 7-3 Best high efficiency heating and cooling solutions (all Post Codes, Residential and Service Sectors, only) – Baseline 2022

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*		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	68.4	31.4	114.2	484.2	-1.9	0.0	47.1	35.8	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	440.0	345.0	1,807.6	5,951.6	8,659.3	0.0	547.3	208.8	2.7
Baseline*		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	117.9
TOTAL		**508.4**	**376.4**	**1,921.8**	**6,435.8**	**8,657.4**	**0.0**	**594.3**	**244.6**	**120.6**

Table 7-4 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*		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	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	117.8	66.0	182.3	929.8	168.3	0.0	216.2	105.2	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	462.4	345.2	1,363.9	4,655.4	7,613.1	0.0	502.7	191.0	3.3
Baseline*		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	143.2
TOTAL		**580.2**	**411.2**	**1,546.2**	**5,585.1**	**7,781.4**	**0.0**	**718.9**	**296.2**	**146.5**

Error! Reference source not found. 5 and **Error! Reference source not found.** 6 show the high efficiency heating and cooling solutions with the greatest Economic Net Present Value (ENPV) 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. Heat pumps are not modelled as being able to serve industry, so are only assumed to be suitable for agriculture.

  For both the 2022 baseline and 2030 baseline the following is observed:
- Heat pumps and solar thermal without PV are the best solution for most agricultural sites.
- CHP is never the most cost effective solution, so the best solution for industrial sites is to retain baseline technologies.

Table 7-5 Best high efficiency heating and cooling solutions (all Post Codes, Industry and Agricultural Sectors, only) – Baseline 2022

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)	Total CHP Capacity where best solution (MWe)	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	0.0
Individual oil CHP	2	0.0	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	0.0
Individual heat pumps and solar thermal hot water	4	1.4	-0.2	5.9	18.0	-7.4	0.0	0.0	0.0	0.9	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	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	0.0
Baseline*		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	85.6	0.0
TOTAL		**1.4**	**-0.2**	**5.9**	**18.0**	**-7.4**	**0.0**	**0.0**	**2.9**	**86.5**	**0.0**

Table 7-6 Best high efficiency heating and cooling solutions (all Post Codes, Industry 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)	Total CHP Capacity where best solution (MWe)	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	0.0
Individual oil CHP	2	0.0	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	0.0
Individual heat pumps and solar thermal hot water	4	1.7	-0.1	6.7	20.3	-8.0	0.0	0.0	0.0	1.0	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	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	0.0
Baseline*		0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	81.2	0.0
TOTAL		**1.7**	**-0.1**	**6.7**	**20.3**	**-8.0**	**0.0**	**0.0**	**2.8**	**82.2**	**0.0**

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 all but one of the 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 only economic (i.e. produces a positive ENPV relative to baseline) value in postcode 7502 (supplied by waste heat from the Dhekelia Power Station's ICEs) which is not located in Limassol, not for any of the other Post Codes or detailed geographical areas evaluated, including the two detailed tourist areas.

Although no postcode DHC solution is found to be to be cost effective (from an economic or financial point of view) in Limassol, it is nevertheless instructive to consider which DHC solutions are closest to being cost effective (i.e. have the least negative ENPV) and for how many Post Codes is this the case. **Error! Reference source not found.** 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:

- Four out of 18 DHC solution Types evaluated are found to be the best DHC solution (least negative ENPV) in all Limassol Post Codes evaluated.
- In 74% of Post Codes Type 12 (Reversible Water Source Heat Pump, 2-pipe and individual absorption chillers for cooling) is the best DHC solution and in 21%, Type 10 (Reversible Water Source Heat Pump, 2-pipe, DC only in summer and DH only in winter).

Table 7-7 Summary count of best DHC solution (highest ENPV even if negative) 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	77	3	0	0	0	0	0	0	0	0	16	0	58	0	0	0	0	0	0
Low Land	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Mountainous	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Semi-Mountainous	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Total	**78**	**3**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**16**	**0**	**58**	**1**	**0**	**0**	**0**	**0**	**0**

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, 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 solar thermal providing sanitary hot water, where the last is not already modelled as being satisfied by solar thermal. Compared against the baseline technologies, deployment of PV driven heat pumps will save both CO_2 and primary energy.

For the industry architypes, the only practical high efficiency solutions are CHP fuelled by biomass, oil, or LPG. The grade of heat demand modelled for industry is such that DHC and heat pump heating driven solutions are naturally discounted[19]. However, none of these options provide a positive ENPV or FNPV. Biomass CHP would save CO_2 but have high damage costs associated with emissions. Neither oil nor LPG CHP solutions is found to save CO_2 relative to the baseline for the time period of the analysis. We understand that natural gas will soon become available which will be less polluting than oil and is predicted to be cheaper than oil or LPG. But this is earmarked for use in power generation in the foreseeable future which is one reason the carbon intensity of electricity is predicted to fall, making heat pumps an increasingly attractive option. However in the longer term, natural gas fired CHP may be economic for industry if gas becomes available

For agriculture architypes, which are modelled as not requiring cooling or high grade heat, heat pumps without PV are the most cost-effective solution for providing heating. This produces both CO_2 and primary energy savings relative to the baseline.

8.2 The Effect of future changes in energy demands and costs.

The main impact of modelling the heating and cooling strategy with plant installed in 2030 rather than 2025 is that PV becomes less economically attractive, likely due to decreases in electricity and associated environmental costs. The impact of increased demand is likely to be less significant cause of this shift. However the modelling shows heat pumps providing heating and cooling and solar thermal providing hot water will still be the best solution in most cases aside from industry where not suitable.

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 may in part be 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 densely populated sub-sets of this. Under this approach, the size of the central DHC thermal plant and pipe network will not be optimised for the quantity of heat and cooling demand

[19] 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 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.

From this finding it can be concluded that there is likely to be little socially economic cost effective potential for DHC or financially cost effective potential when compared with individual high efficiency solutions. However, there may be a small amount of potential which is financially cost effective when compared with the baseline only. Further investigation would require that smaller areas of dense non-domestic heating and cooling demand be investigated on a case by case basis.

9 Conclusions

The CBA for efficient heating and cooling for Limassol has shown that there is no socially economic potential for District Heating and Cooling (DHC), when evaluated at the Post Code level.

Overwhelmingly, heat pumps with solar thermal is found to be the high efficiency solution with the highest economic potential in the residential, service and agricultural sectors. In all of the service sectors and for single houses and apartments in and coastal areas, incorporating solar PV will improve the economics. 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 Industry sector, the only suitable high efficiency solutions modelled are CHP fired by biomass, oil and LPG. Natural gas CHP may have economic potential if gas becomes available beyond power stations.

Appendices

Appendix 1 - Heating and Cooling Consumption for the Modelled Architypes

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	1,808	4,781	1,408
	Row house	2,538	3,341	1,682
	Single house	2,893	4,834	2,063
Service	Airports	-	-	-
	Restaurant	45,260	104,942	17,828
	Hospitals	695,206	1,525,936	667,115
	Hotels	301,785	1,683,353	159,905
	Offices	28,074	63,915	-
	Schools	52,274	146,797	11,847
	Shopping	5,768	29,899	21
	Other Services	70,431	225,457	24,326
Industrial (Non-EU ETS)	Chemicals	93,247	52,946	-
	Food and Drink	94,803	14,452	-
	Other Minerals	14,752	-	-
	Other Industry	14,527	-	-
Agriculture	Greenhouses	2,978	-	-
	Other Agriculture	2,978	-	-

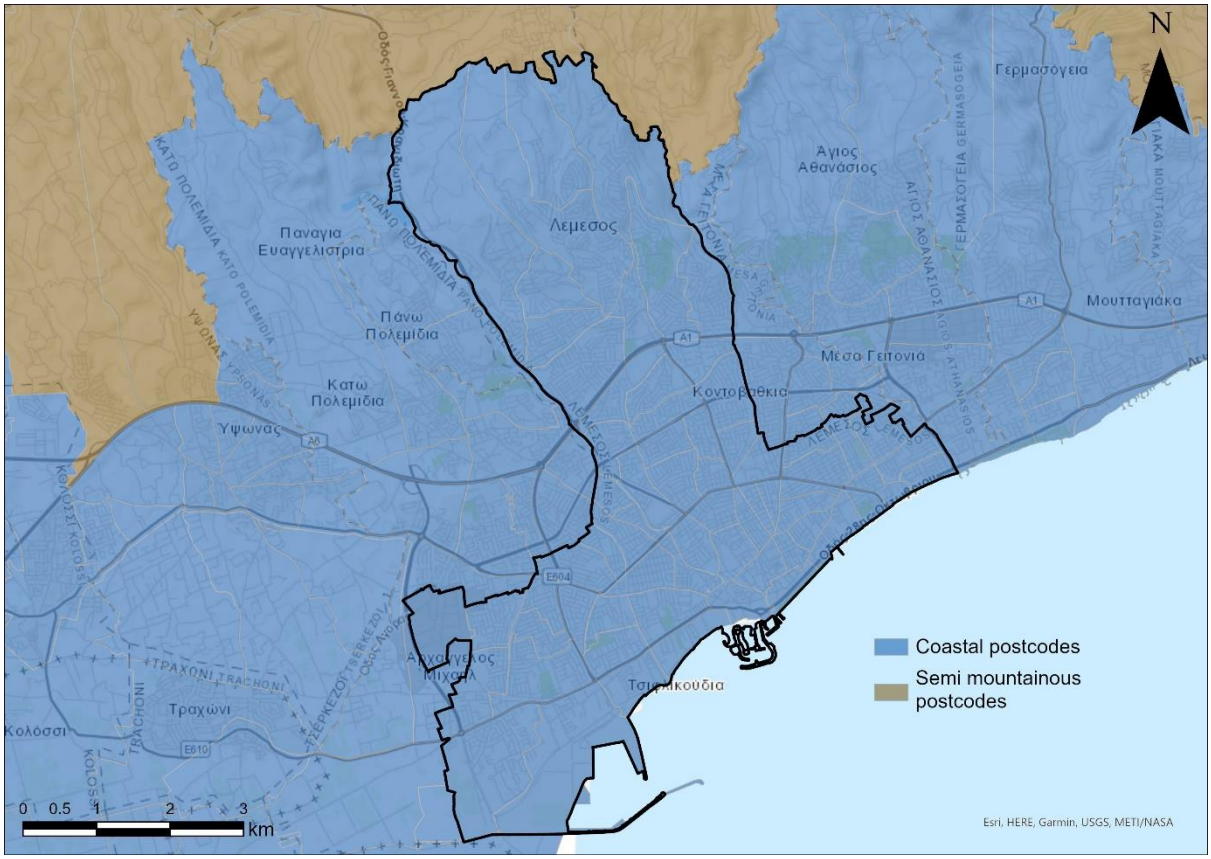
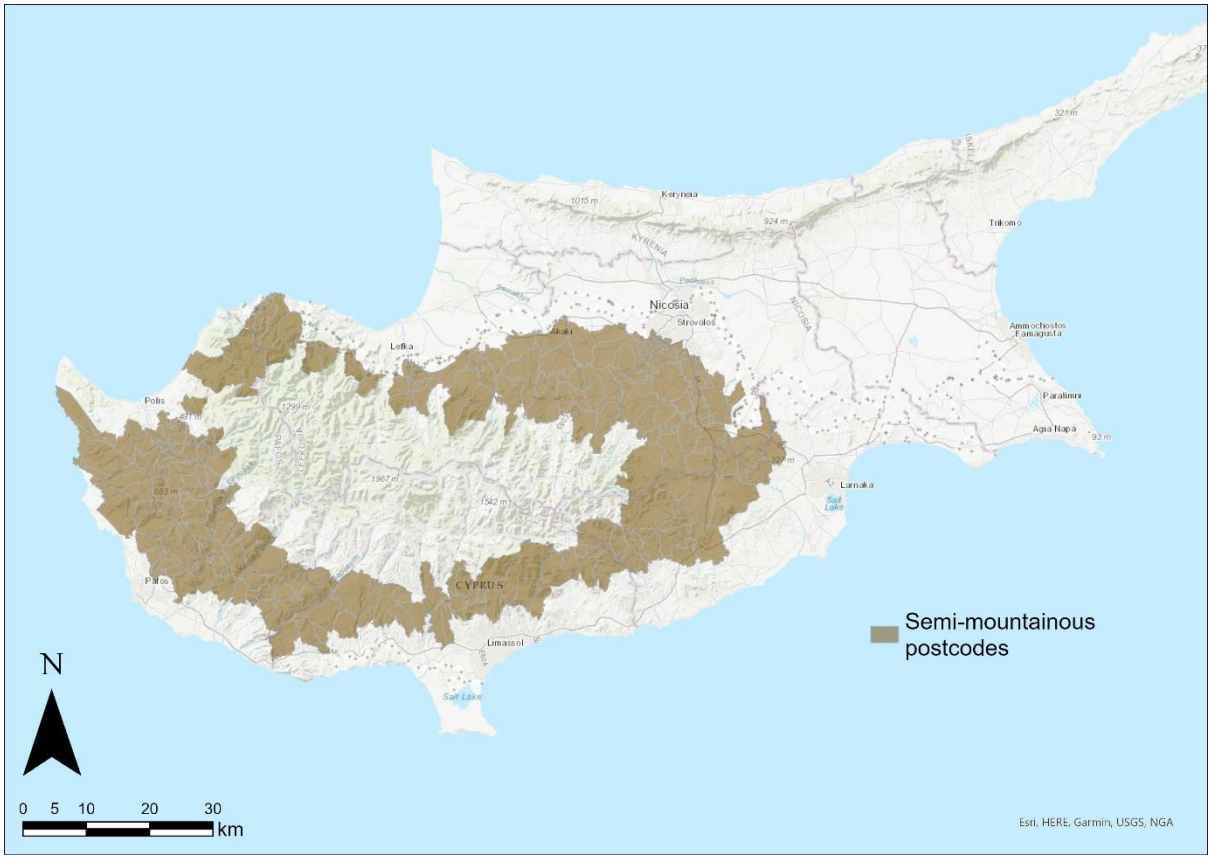

N
Λεμεσός
Παναγία Ευαγγελίστρια
Πάνω Πολεμίδια
Κατω Πολεμίδια
Υψώνας
Άγιος Αθανάσιος
Γερμασόγεια
Μουτταγιάκα
Μέσα Γειτονιά
Κοντοβάθεια
Αρχάγγελος Μιχαήλ
Τσερκέζοι
Τραχώνι
Κολόσσι
Coastal postcodes
Semi mountainous postcodes
0 0.5 1 2 3 km
Esri, HERE, Garmin, USGS, METI/NASA

Table 9-2 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	2,159	3,330	1,401
	Row house	2,979	2,288	1,645
	Single house	3,472	3,383	2,063
Service	Airports	-	-	-
	Restaurant	54,312	73,459	17,828
	Hospitals	1,393,115	1,783,720	1,114,020
	Hotels	-	-	-
	Offices	-	-	-
	Schools	47,391	77,632	8,950
	Shopping	-	-	-
	Other Services	82,948	154,890	23,874
Industrial (Non-EU ETS)	Chemicals	-	-	-
	Food and Drink	104,388	11,139	-
	Other Minerals	-	-	-
	Other Industry	20,077	-	-
Agriculture	Greenhouses	1,748	-	-
	Other Agriculture	1,748	-	-


Kerynia
Trikomo
Nicosia
Strovolos
Lefka
Ammochostos
Famagusta
Polis
Paralimni
Agia Napa
Larnaka
Salt Lake
CYPRUS
Pafos
Limassol
Salt Lake
Semi-mountainous postcodes
N
0 5 10 20 30
km
Esri, HERE, Garmin, USGS, NGA