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Comprehensive Assessment of the Potential for Efficient Heating and Cooling

Report for Points A and B

Report for MECI, Cyprus

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Glossary

Abbreviation	Definition
CCGT	Combined Cycle Gas Turbine
FEC	Final Energy Consumption
HHV	Higher Heating Value
ICE	Internal Combustion Engine
LHV	Lower Heating Value
OCGT	Open Cycle Gas Turbine
RE	Reciprocating Engine
ST	Steam Turbine
UE	Useful energy

1 Point A Determination of Annual Heating and Cooling Demand in Terms of Assessed Useful Energy and Quantified Final Energy Consumption

1.1 Introduction

Under Point A we determine the annual heating and cooling demand in terms of useful energy (UE) and quantified final energy consumption (FEC).

Consistent with the terms of the Technical Specifications set out by MECI, it is confirmed that useful energy means here the energy consumed by end users in the form of heat or cold after all steps have taken place to transform an input of electricity, fuel or primary heat, via a process of transformation taking place in heating or cooling equipment, into heat and cold.

The energy input to the transformation process is confirmed here as the quantified final energy consumption. This final energy consumption takes the form of input of electricity, fuels, ambient heat or geothermal heat to the heating or cooling equipment. As such it is the energy shown as “Final energy consumption” in the national energy balance for Cyprus by Eurostat.

In this work we refer to Eurostat Cyprus energy balance for 2018 and our analysis is conducted so that there is consistency between the final energy consumption in the energy balance and the total final energy consumption derived here for the purposes of heating and cooling. However, agreement between final energy consumption of a particular fuel in the energy balance and the final energy consumption of the same fuel associated with heating and cooling should not be automatically expected, since a proportion of the fuel shown in the energy balance may be consumed for purposes other than providing heating and cooling. This is especially the case, for example, for electricity where a large proportion of the final electricity consumed is for providing motive power or lighting.

The UE and FEC are broken down by the sector consuming the heat or cold. Here we observe the following sectors of consumption:

- Residential
- Services
- Industry, and
- Agriculture

We do not include any other distinct sectors in our analysis, since we do not believe that any other sector on its own accounts for more than 5% of total national useful heating or cooling demand.

Furthermore, we disaggregate demand according to the grade of heat and cooling demanded. This is a key step underpinning later tasks analysing the technical and economic potential for efficient heat and cooling, since the grade of heat demanded determines the technical viability of a range of potential heating technologies. Therefore, we observe the following grades of heating and cooling:

- High heat – Heat which is consumed in industry at >400°C
- Medium heat - Heat which is consumed in industry in the range 100°C - 400°C
- Low heat - Heat which is consumed in industry in the range <100°C
- Heating – Heat which is consumed for space heating in the Residential, Services or Agricultural sectors
- Sanitary Hot Water (SHW) – Heat for providing this service in the Residential and Service sectors
- Cooling – Cooling provided for the Residential and Service sectors, which can be provided by cooling fluids down to 4°C. Chilling below this temperature is excluded from this work on the grounds that it is difficult to achieve using absorption chilling – the efficient means of providing such cooling.

1.2 General Approach

Our general approach to establishing the UE and FEC associated with providing the above grades of heating and cooling across the relevant sectors can be summarised as follows:

- Build on the work done in 2015 in support of the NCA
- Make improvements to assumptions used in the previous work in response to new information received
- Update the work to reflect changes to the official energy balance for Cyprus and utilise other data sources which have become available in the meantime.

The specific approach followed for each of the four sectors is detailed in the sections below.

1.3 Residential Sector

1.3.1 Residential Sector Overview

According to Eurostat, in 2018 the residential sector in Cyprus had a final energy consumption 14,117 TJ (3,921,388 MWh)[1], of which 43% was in the form of electricity. Solar thermal accounted for the second largest proportion of final energy consumed (18%) followed by gas oil (16%), LPG (9.5%), primary biofuels (5.0%), charcoal (1.8%), ambient heat (3.0%) and geothermal (0.5%).

As shown below, the FEC associated with heating and cooling in the residential sector has been estimated to be 2,713,124 MWh.

An additional source of information relating to final energy consumption for the residential sector was provided by MECI[2], which gives the final energy consumed for a number of end uses, including space heating, space cooling and water heating, by fuel. Space heating, space cooling and water heating are assumed to directly map to Heating, SHW and Cooling grades of demand given in section 1.1. The FEC given in this source is 14,124 TJ, which is within 0.05% of the Eurostat figure. Consequently, we have decided to use the FEC in Eurostat 2018 and apportion the fuels across end uses in the same proportions as those in the MECI source.

1.3.2 Residential Data Sources Used

JRC split of UE by sector, subsector, fuel and technology from: <input data and assumptions for NECP.xlsx>, worksheet 'H&C - historic estimates'

Table 5 Energy Conversion Factors (Final to Useful) from: <Report Households.pdf>

National Energy Balance for Cyprus, Eurostat 2013

Heat Pump data for residential and service sector deployment: <E_PaMs_030719_1500_EC template.xls>

Final energy consumption by end use in residential sector from: <Households Sector by type of end use_2018.xls>

National Energy Balance for Cyprus, Eurostat 2018

[1] Note, this figure includes final energy consumed for all purposes, and so is larger than the final energy consumption figures derived for just heating and cooling.
[2] Households Sector by type of end use_2018

1.3.3 Residential Sector Methodology

The process for deriving the FEC and UE for heating, cooling and SHW for 2018 in the residential sector can be summarised as follows:

1. Take the UE split by subsector, end use, fuel and technology for 2013 which was an output of the 2015 NCA *(Use: JRC split of UE by sector, subsector, fuel and technology from: <input data and assumptions for NECP.xlsx>, worksheet 'H&C - historic estimates')*

2. Divide each element by the end use specific conversion factor turning UE into FE, thereby returning the FEC *(Use: Table 5 Energy Conversion Factors (Final to Useful) from: <Report Households.pdf>)*

3. Express each element as a percentage of the relevant FEC fuel consumed in the 2013 national balance

4. Calculate the quantity of each final FEC fuel consumed for H, C and SHW and express as a % of each FEC fuel *(Use: Final energy consumption by end use in residential sector from: <Households Sector by type of end use_2018.xls>)*

5. Adjust the element percentages in 3 to reflect the actual proportions calculated in 4.

6. Accept the adjusted percentages in 5 for all fuels other than electricity

7. For electricity, use the electricity consumption for heat pump operation in the residential sector given in MECI source "Heat Pumps" to deduce the quantity of electricity used for heating using heat pumps and heating using resistive heating *(Use <E_PaMs_030719_1500_EC template.xls>)*

8. Bring 6 and 7 together and use the resulting % of each FEC fuel for each subsector/technology/end use combination

9. Multiply the element percentages in 8 by the FEC for each fuel in the 2018 national balance to derive the quantity of each fuel used for each subsector/technology/end use combination.

10. Apply conversion factors to 9 to turn each FEC element into a corresponding UE value. The conversion factors used in this step have been updated from those presented in *Table 5 Energy Conversion Factors (Final to Useful) from: <Report Households.pdf>* to reflect improvements in efficiency deemed to have occurred since the 2015 NCA. Specifically, boiler efficiencies have been adjusted to those in the harmonised reference values for the separate production of heat[3]. In the case of heat pumps used for heating, the minimum space heating energy efficiency set out in Commission Regulation No 813/2013[4] has been used. In the case of heat pumps used for cooling, the minimum space cooling energy efficiency set out in Commission Regulation (EU) 2016/2281 has been used[5].

[3] See Annex II of Commission Delegated Regulation (EU) 2015/2402 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2402&from=DE

[4] See Annex II Ecodesign Requirements of Commission regulation (EU) No 813/2013 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0813&from=EN

[5] See Table 3 of Commission Regulation (EU) 2016/2281 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R2281&from=EN

1.3.4 Residential Sector Results

1.3.4.1 Useful Energy Consumption

Table 1-1 Residential UE by fuel

Fuel	Useful Energy Consumption (MWh/year)
Ambient heat (heat pumps)	Included in heat pump electric
Electricity (non-renewable)	1,997,091
Electricity (renewable)	207,934
Gas oil	553,719
Geothermal	18,032
Ambient heat (heat pumps)	117,007
Kerosene	98,430
LPG	161,293
Solar	580,511
Solid biomass	167,588
Total	**3,901,605**

Table 1-2 Residential UE by end use

End Use	Useful Energy Consumption (MWh/year)
Cooling	1,871,417
Heating	1,253,396
SHW	776,791
Total	**3,901,605**

Table 1-3 Residential UE by technology

Technology	Useful Energy Consumption (MWh/year)
Boilers	981,030
Heat pumps	2,083,622
Resistance heaters	256,442
Solar panels	580,511
Total	**3,901,605**

The full split of useful energy in the residential sector by subsector, end use, fuel and technology is given in the Excel file provided in Appendix 1.

1.3.4.2 Final Energy Consumption

Table 1-4 Residential FEC by fuel

Fuel	Final Energy Consumption (MWh/year)
Ambient heat (heat pumps)	117,007
Electricity (non-renewable)	677,856
Electricity (renewable)	70,577
Gas oil	636,459
Geothermal	18,032
Kerosene	113,138
LPG	177,245
Solar	707,940
Solid biomass	194,870
Total	**2,713,124**

Table 1-5 Residential FEC by end use

End Use	Final Energy Consumption (MWh/year)
Cooling	413,573
Heating	1,384,408
SHW	915,143
Total	**2,713,124**

Table 1-6 Residential FEC by technology

Technology	Final Energy Consumption (MWh/year)
Boilers	1,121,711
Heat pumps	625,778
Resistance heaters	257,695
Solar panels	707,940
Total	**2,713,124**

The full split of final energy consumption in the residential sector by subsector, end use, fuel and technology is given in the Excel file provided in Appendix 2.

1.4 Service Sector

1.4.1 Service Sector Overview

According to Eurostat, in 2018 the service sector in Cyprus had a final energy consumption of 11,575 TJ (3,215,178 MWh). Of this, 68% was electricity, followed by ambient heat (13%), gas oil (6.0%), LPG (5.6%) and solar thermal (3.9%).

As shown below, the FEC associated with heating and cooling in the service sector has been estimated to be 1,887,166 MWh.

1.4.2 Service Sector Data Sources Used

JRC split of UE by sector, subsector, fuel and technology from: <input data and assumptions for NECP.xlsx>, worksheet 'H&C - historic estimates'

Table 1 Energy conversion factors (from final to useful) Report-ServiceSector-Final02.17.doc

National Energy Balance for Cyprus, Eurostat 2013

Heat Pump data for residential and service sector deployment: <E_PaMs_030719_1500_EC template.xls>

National Energy Balance for Cyprus, Eurostat 2018

Data on fuel consumed, electricity and heat generated by 14 CHP plant operating in Cyprus <On site generation.xls>

1.4.3 Service Sector Methodology

1. Take the UE split by subsector, end use, fuel and technology for 2013 for Sector = Services *(Source: JRC split of UE by sector, subsector, fuel and technology from: <input data and assumptions for NECP.xlsx>, worksheet 'H&C - historic estimates')*

2. Divide each element by the end use specific conversion factor turning UE into FE, thereby deriving the FEC for each element *(Use: Table 1 Energy conversion factors (from final to useful) Report-ServiceSector-Final02.17.doc*

3. Express the FEC for each element as a percentage of the FEC of the relevant fuel in 2013 *(Use: National Energy Balance for Cyprus, Eurostat 2013)*

4. Calculate the quantity of each final FEC fuel consumed for H, C and SHW and express as a % of each FEC fuel

5. Calculate the proportion of total of each FEC fuel consumed for Heating, Cooling and SHW

6. Adjust the element percentages in 3 to reflect the actual proportions calculated in 5.

7. Accept the adjusted percentages in 6 for all fuels other than electricity

8. For electricity, use the electricity consumption for heat pump operation in the service sector given in MECI source "Heat Pumps" to deduce the quantity of electricity used for heating using heat pumps and heating using resistive heating *(Use: <E_PaMs_030719_1500_EC template.xls>)*

9. Bring 7 and 8 together and use the resulting % of each FEC fuel for each subsector/technology/end use combination

10. Multiply the element percentages in 9 by the FEC for each fuel in the 2018 national balance to derive the quantity of each fuel used for each subsector/technology/end use combination. *(Use: National Energy Balance for Cyprus, Eurostat 2018)*

11. Apply conversion factors to 10 to turn each FEC element into a corresponding UE value. The conversion factors used in this step have been updated from those presented in *Table 5 Energy Conversion Factors (Final to Useful) from: <Report Households.pdf>)* to reflect improvements in efficiency deemed to have occurred since the 2015 NCA. Specifically, boiler efficiencies have been adjusted to those in the harmonised reference values for the separate production of heat[6]. In the case of heat pumps used for heating, the minimum space heating energy efficiency set out in Commission Regulation No 813/2013[7] has been used. In the case of heat pumps used for cooling, the minimum space cooling energy efficiency set out in Commission Regulation (EU) 2016/2281 has been used[8].

1.4.4 Service Sector Results

1.4.4.1 Useful Energy Consumption

Table 1-7 Service sector UE by fuel

Fuel	Useful Energy Consumption (MWh/year)
Ambient heat (heat pumps)	419,053
Biogases	9,492
Electricity (non-renewable)	2,797,715
Electricity (renewable)	291,294
Gas oil	165,083
Kerosene	17,370
Light fuel oil	31,293

[6] See Annex II of Commission Delegated Regulation (EU) 2015/2402 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015R2402&from=DE

[7] See Annex II Ecodesign Requirements of Commission regulation (EU) No 813/2013 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32013R0813&from=EN

[8] See Table 3 of Commission Regulation (EU) 2016/2281 https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32016R2281&from=EN

LPG	97,734
Solar	89,647
Solid biomass	3,767
Total	**3,922,449**

Table 1-8 Service sector UE by end use

End Use	Useful Energy Consumption (MWh/year)
Cooling	2,783,370
Heating	905,005
SHW	234,073
Total	**3,922,449**

Table 1-9 Service sector UE by technology

Technology	Useful Energy Consumption (MWh/year)
Boilers	321,063
CHP[9]	3,677
Heat pumps	3,441,883
Resistance heaters	66,179
Solar panels	89,647
Total	**3,922,449**

The full split of useful energy in the service sector by subsector, end use, fuel and technology is given in the Excel file provided in Appendix 1.

1.4.4.2 Final Energy Consumption

Table 1-10 Service sector FEC by fuel

Fuel	Final Energy Consumption (MWh/year)
Ambient heat (heat pumps)	419,053
Biogases	12,093
Electricity (non-renewable)	903,732
Electricity (renewable)	94,095
Gas oil	189,751
Kerosene	19,966
Light fuel oil	35,969
LPG	107,400
Solar	100,726
Solid biomass	4,380
Total	**1,887,166**

Table 1-11 Service sector FEC by end use

End Use	Final Energy Consumption (MWh/year)
Cooling	691,521
Heating	934,293

[9] CHP in the Service sector is used exclusively in the waste management industry (STW and MSW processing sites).

SHW	261,353
Total	**1,887,166**

Table 1-12 Service sector FEC by technology

Technology	Final Energy Consumption (MWh/year)
Boilers	365,220
CHP	4,339
Heat pumps	1,350,033
Resistance heaters	66,848
Solar panels	100,726
Total	**1,887,166**

The full split of final energy consumption in the service sector by subsector, end use, fuel and technology is given in the Excel file provided in Appendix 2.

1.5 Industry Sector

1.5.1 Industry Sector Overview

According to Eurostat, in 2018 the industrial sector in Cyprus had a final energy consumption of 9,533 TJ (2,648,017 MWh). Of this, petroleum coke accounted for 25%, followed by electricity (20%), fuel oil (13%) renewable municipal waste (12%) and non-renewable municipal waste (8.4%) and gas oil (8.0%). The large consumption of petroleum coke and municipal waste is driven by the demand of the cement clinker producing process at Vasilikos. This plant and the ceramics producing installations are the most significant industrial undertakings in the Republic of Cyprus. Together, cement and ceramics production account for a little over two thirds of the final energy consumed in industry.

As shown below, the FEC associated with heating and cooling in the industry sector has been estimated to be 2,218,613 MWh.

1.5.2 Industry Sector Data Sources Used

JRC 2015 split of UE by sector, subsector, fuel, technology, and thermal end use from: <input data and assumptions for NECP.xlsx>, worksheet 'H&C - historic estimates'.

Proportion of final energy used for thermal end uses by industrial subsector and fuel from: <Copy of IndAnalysis_1015f-FINAL.xlsx>, worksheet ‘Final E by end-use’ table in cells C24:E34 but as overridden in various places in formulae embedded in application in cells X5:Z19.

Also indicated in energy rather than % terms in <CY Industry sector-FINAL-revised.doc>, Figure 3 but %s taken from above spreadsheet.

Energy conversion factors from final to useful (i.e. heating efficiencies) from: <Copy of IndAnalysis_1015f-FINAL.xlsx>, worksheet ‘Useful E by end-user’

Same also displayed in <CY Industry sector-FINAL-revised.doc>, Appendix Table 2.

2013 final energy per fuel type per industry subsector from National Energy Balance for Cyprus, Eurostat 2013 <Energy balance 2013_v4.xls>, Worksheet ‘eurostat’

2018 final energy per fuel type per industry subsector from National Energy Balance for Cyprus, Eurostat 2018 <CY-Energy-Balances-2018.xls>

1.5.3 Industry Sector Methodology

1. Split the 2018 national final energy consumption given for the non-metallic minerals subsector into that used by the cement and other non-metallic minerals subsectors using the same ratio as assumed in 2013 by the author of <Copy of IndAnalysis_1015f-FINAL.xlsx>, in worksheet 'Final E by end-use'.
2. Tabulate the final energy proportion consumed in 2013 for each fuel category in <Copy of IndAnalysis_1015f-FINAL.xlsx>, worksheet 'Final E by end-use' deduced from cells C24:E34 as overridden by the author in cells X5:Z19. In most cases this entailed substituting the proportions for fossil fuels in the 'other industry' subsector for sectors where the source table in cells C24:E34 had no data.

3. Manually map the subsector and fuel categories in the Eurostat national balance to those in the <Copy of IndAnalysis_1015f-FINAL.xlsx>, in worksheet 'Final E by end-use' cells C24:E34. Where fuels are not contained in <Copy of IndAnalysis_1015f-FINAL.xlsx>, they are still included as new fuel categories.

4. Use the above mapping to tabulate the fuel for heat proportions in line with Eurostat national balance (with non-metallic minerals split into cement and other as above) and revise where necessary. We have only made one revision. In the case of electricity in the chemicals sector which the author had assumed to be 0% which we believe is likely in error, so we have applied the 54% factor stated in the original source table. Proportions for new fossil fuels categories are similarly mapped to the fossil fuel proportion category, proportions for the new renewable solids category (only present in cement) to the biomass category, and we assumed 100% for the new solar thermal category (only present in chemicals).

5. Calculate the final energy consumed for heat in 2018 for each fuel in each Eurostat subsector (with non-metallic minerals split into cement and other as above) by combining the CY national energy balance for 2018 with the proportions of each fuel used to generate heat.

6. Manually map the subsector and fuel categories in the Eurostat national balance to those in the JRC split of UE <input data and assumptions for NECP.xlsx>, worksheet 'H&C - historic estimates')

7. Aggregate the final energy consumed for heat in 2018 for each fuel in each Eurostat subsector (with non-metallic minerals split into cement and other as above) JRC split of UE

8. Tabulate the heat efficiencies for each combination of industry subsector (as classified in JRC 2013 split of UE <input data and assumptions for NECP.xlsx>, worksheet 'H&C - historic estimates') and fuel as classified in the Eurostat 2018 national energy balance, based on the energy conversion factors from final to useful (i.e. heating efficiencies) from: <Copy of IndAnalysis_1015f-FINAL.xlsx>, worksheet 'Useful E by end-user' and assumed mapping to the JRC and Eurostat subsector and fuel classifications. We have assumed attributed the aggregate efficiency for fossil fuels in the 2015 data set to new fossil fuels, the efficiency for biomass to new renewable solid fuels and assumed 100% for solar thermal.

9. Estimate the final energy for heat in 2013 for each combination of industry subsector, fuel, technology and end use (high, med and low temperature) by dividing the same division of useful heat in <input data and assumptions for NECP.xlsx>, worksheet 'H&C - historic estimates' by the heat efficiencies for each subsector/fuel combination.

10. Aggregate the final energy consumed for heat in 2013 for each fuel in each Eurostat subsector (with non-metallic minerals split into cement and other as above) JRC split of UE

11. Calculate the proportion of final energy consumed for heat in 2013 by each technology for each end use within each subsector for each fuel type in 2013 by combining the output of steps 9 and 10.

12. Assume the same proportion of final energy was consumed for heat in 2018 by each technology for each end use within each subsector for each fuel type as for 2013. For new fossil fuels, assume the same proportion as the aggregate for all fossil fuels in 2013, for renewable solids (present in cement only), assume same proportions as for biomass and for solar thermal (present in chemicals only), assume 100% was consumed for low grade heat.

13. Apportion the final energy consumed for heat in 2018 calculated in step 7 above to each technology for each end use using the proportions calculated in step 12 above to result in the industry entries in the final energy table (Table A1 2020) i.e. industrial heating and cooling final energy split by industry subsector, fuel type, heating technology and end use (heat grade).

14. Multiply the final energy breakdown in step 13 above by the efficiencies derived in step 8 to result in the industry entries in the useful energy table (Table A2 2020) i.e. industrial heating and cooling useful energy split by industry subsector, fuel type, heating technology and end use (heat grade).

1.5.4 Industry Sector Results

1.5.4.1 Useful Energy Consumption

Table 1-13 Industry sector UE by fuel

Fuel	Useful Energy Consumption (MWh/year)
Biogases	12,869
Electricity (non-renewable)	53,467
Electricity (renewable)	5,567
Fuel oil	278,884
Gas oil	172,273
Industrial waste (non-renewable)	35,277
Kerosene	747
LPG	85,411
Non-renewable municipal waste	181,093
Other bituminous coal	131,413
Petroleum coke	537,994
Renewable municipal waste	260,266
Solar	4,667
Solid biomass	32,749
Total	**1,792,676**

Table 1-14 Industry sector UE by end use

End Use	Useful Energy Consumption (MWh/year)
High Heat	1,206,166
Low Heat	374,500
Medium Heat	195,910
Cooling	16,100
Total	**1,792,676**

Table 1-15 Industry sector UE by technology

Technology	Useful Energy Consumption (MWh/year)
Boilers	1,728,975
Chillers	16,100
Resistance heaters	42,934
Solar panels	4,667
Total	**1,792,676**

The full split of useful energy in the industry sector by subsector, end use, fuel and technology is given in the Excel file provided in Appendix 1.

1.5.4.2 Final Energy Consumption

Table 1-16 Industry sector FEC by fuel

Fuel	Final Energy Consumption (MWh/year)
Biogases	18,384
Electricity (non-renewable)	99,411
Electricity (renewable)	10,351
Fuel oil	340,102
Gas oil	210,089
Industrial waste (non-renewable)	43,552
Kerosene	911
LPG	99,315
Non-renewable municipal waste	223,572
Other bituminous coal	158,329
Petroleum coke	648,185
Renewable municipal waste	321,316
Solar	4,667
Solid biomass	40,430
Total	**2,218,613**

Table 1-17 Industry sector FEC by end use

End Use	Final Energy Consumption (MWh/year)
High Heat	1,476,308
Low Heat	474,214
Medium Heat	248,019
Cooling	20,072
Total	**2,218,613**

Table 1-18 Industry sector FEC by technology

Technology	Final Energy Consumption (MWh/year)
Boilers	2,104,185

Chillers	20,072
Resistance heaters	89,690
Solar panels	4,667
Total	**2,218,613**

The full split of final energy consumption in the industry sector by subsector, end use, fuel and technology is given in the Excel file provided in Appendix 2.

1.6 Agriculture Sector

1.6.1 Agriculture Sector Overview

According to Eurostat, in 2018 the agricultural sector in Cyprus had a final energy consumption of 1,776 TJ (493,307 MWh). Of this, gas oil accounted for 50%, followed by electricity (35%), LPG (6.7%), biogas (5.4%) and derived heat (3%).

As shown below, the FEC associated with heating and cooling in the agriculture sector has been estimated to be 277,894 MWh.

1.6.2 Agriculture Sector Data Sources Used

JRC split of UE by sector, subsector, fuel and technology from: <input data and assumptions for NECP.xlsx>, worksheet 'H&C - historic estimates'

<Report Agriculture.v3.doc> (specific assumption that efficiency of current heating equipment is 80%

National Energy Balance for Cyprus, Eurostat 2013

National Energy Balance for Cyprus, Eurostat 2018

Data on fuel consumed, electricity and heat generated by 14 CHP plant operating in Cyprus <On site generation.xls>

1.6.3 Agriculture Sector Methodology

1. Take the UE split by subsector, end use, fuel and technology for 2013 for Sector = Services *(Source: JRC split of UE by sector, subsector, fuel and technology from: <input data and assumptions for NECP.xlsx>, worksheet 'H&C - historic estimates')*
2. Divide each element by the end use specific conversion factor turning UE into FE, thereby deriving the FEC for each element *(Source: <Report Agriculture.v3.doc>, specifically assuming that current efficiency of heating equipment is 80%)*
3. Express the FEC for each element as a percentage of the FEC of the relevant fuel in 2013 *(Use: National Energy Balance for Cyprus, Eurostat 2013)*
4. Calculate the quantity of each final FEC fuel consumed for H, C and SHW and express as a % of each FEC fuel
5. Calculate the proportion of total of each FEC fuel consumed for Heating, Cooling and SHW
6. Multiply the element percentages in 5 by the FEC for each fuel in the 2018 national balance to derive the quantity of each fuel used for each subsector/technology/end use combination. *(Use: National Energy Balance for Cyprus, Eurostat 2018).*

1.6.4 Agriculture Sector Results

1.6.4.1 Useful Energy Consumption

Table 1-19 Agriculture sector UE by fuel

Fuel	Useful Energy Consumption (MWh/year)
Biogases	20,307
Gas oil	191,529
Heat	14,958
LPG	4,104
Total	**230,898**

Table 1-20 Agriculture sector UE by end use

End Use	Useful Energy Consumption (MWh/year)
Heating	230,898
Total	**230,898**

Table 1-21 Agriculture sector UE by technology

Technology	Useful Energy Consumption (MWh/year)
Boilers	199,947
CHP	30,951
Total	**230,898**

The full split of useful energy in the agriculture sector by subsector, end use, fuel and technology is given in the Excel file provided in Appendix 1.

1.6.4.2 Final Energy Consumption

Table 1-22 Agriculture sector FEC by fuel

Fuel	Final Energy Consumption (MWh/year)
Biogases	25,319
Gas oil	233,542
Heat	14,958
LPG	4,772
Total	**278,590**

Table 1-23 Agriculture sector FEC by end use

End Use	Useful Energy Consumption (MWh/year)
Heating	278,590
Total	**278,590**

Table 1-24 Agriculture sector FEC by technology

Technology	Useful Energy Consumption (MWh/year)
Boilers	244,692
CHP	33,899
Total	**278,590**

The full split of final energy consumption in the agriculture sector by subsector, end use, fuel and technology is given in the Excel file provided in Appendix 2.

2 Point B Identification/Estimation of Current Heating and Cooling Supply by Technology and Potential Supply from Waste Heat and Cold

2.1 Current Heating and Cooling Supply by Technology

2.1.1 The Analysis

The analysis underpinning the first Comprehensive Assessment (CA) and the Integrated National Energy and Climate Plan (NECP) for the Republic of Cyprus has been utilised to derive updated splits for the technologies providing heating and cooling supply.

The original analysis for the first CA and the NECP derived quantities of heating and cooling supplied across a comprehensive range of sectors and subsectors, split by technology and type of fuel. This analysis was anchored in the national energy balances for 2013. We have refreshed these splits to make consistent with the national energy balance for 2018. The methodology employed for doing that is explained above in Section 1, where the steps for deriving the splits for UE and FEC for each sector are set out in detail.

As previously stated, the results presented below carry forward the main assumptions used in 2015 for the split of heating and cooling technologies across sectors and subsectors, but reflect changes in share of final energy consumption taken by the sectors of interest, changes in the same for the different fuel types and assumed improvements in the efficiency of boilers and ehat pumps used for heating and cooling. It is also the case that additional fuel types are included in the 2018 national balance which were not included in the balance for 2015. This exercise has brought these additional fuel types in to the analysis.

The analysis discussed above distinguishes between the sectors and subsectors, heating and cooling end uses fuel type and technology type shown in Table 2-1.

Table 2-1 Summary of attributes used to characterise a unit of UE or FEC

Sector	Subsector	End Use	Fuel	Technology
Residential	Apartment buildings	Heating	Electricity (non-renewable)	Boilers
	Row	Cooling	Electricity (non-renewable)	Heat pumps
	Single houses	SHW	Gas Oil	Solar panels
Service	Airports	High temperature heat	Solar	Resistance heaters
	Shopping	Medium temperature heat	Petroleum Coke	CHP
	Schools	Low temperature heat	Ambient heat (heat pumos)	Chillers
	Hotels		LPG	
	Other		Fuel oil	
	Healthcare		Renewable municipal waste	
	Catering		Solid biomass	

Agriculture	Offices		Non-renewable municipal waste	
	Greenhouses		Renewable electricity	
	Other		Other bituminous coal	
Industry	Cement		Kerosene	
	Other Minerals		Biogases	
	Food, tobacco and beverages		Industrial waste (non-renewable)	
	Chemicals		Light fuel oil	
	Other industry		Geothermal	
			Heat	

2.1.2 Results

2.1.2.1 On-site Heating and Cooling Supply

Table 2-2 Technologies used to supply **heating (space heating and SHW) and cooling** at residential and service sites

Technology	End Use	Quantity Supplied (MWh)	Of which Renewable	Of which Non-renewable
Heat only boilers	Heating	1,302,093	177,170	1,124,923
CHP	Heating	3,677	3,677	-
Heat pumps	Heating	870,717	583,950	286,767
Resistance heaters	Heating	322,621	30,423	292,198
Solar panels	Heating	670,157	670,157	-
Heat pumps	Cooling	4,654,788	438,947	4,215,841
Total		**7,824,053**	**1,904,325**	**5,919,728**

For heating and cooling, where the input involves the consumption of electricity (i.e. heat pumps for heating, resistance heaters and heat pumps for cooling) a proportion of this electricity input is considered renewable. The underlying data used here relate to 2018 and in this year, according to Eurostat, 9.43% of the electricity generated was renewable[10], and this is the proportion of electricity consumption considered renewable.

All CHP heat shown in Table 2-2 is consumed at two sewage treatment works and one municipal solid waste processing facility. None of the CHP heat generated is supplied to a District Heating and Cooling (DHC) network.

[10] Out of a total gross electricity production of 435.1 ktoe, 41.1 ktoe came from renewable sources.

Table 2-3 Technologies used to supply **heating and cooling** at non-residential and non-service sites

Technology	End Use	Quantity Supplied (MWh)	Of which Renewable	Of which Non-renewable
Heat only boilers	Heating	1,928,922	311,079	1,617,843
CHP	Heating	30,951	29,243	1,707
Resistance heaters	Heating	42,934	4,049	38,886
Solar panels	Heating	4,667	4,667	-
Heat pumps	Cooling	16,100	1,518	14,582
Total		**2,023,574**	**350,556**	**1,673,018**

For heating and cooling, where the input involves the consumption of electricity (i.e. resistance heaters and heat pumps for cooling) a proportion of this electricity input is considered renewable. The underlying data used here relate to 2018 and in this year, according to Eurostat, 9.43% of the electricity generated was renewable[11], and this is the proportion of electricity consumption considered renewable.

All CHP heat shown in Table 2-3 is consumed at agricultural sites. None of the CHP heat generated is supplied to a District Heating and Cooling (DHC) network.

2.1.2.2 Off-site Heating and Cooling Supply

There are no District Heating and Cooling (DHC) networks presently operating in Cyprus.

2.2 Identification of Installations that Generate Waste Heat or Cold and their Potential for Heating and Cooling Supply, GWh per Year

2.2.1 Introduction

We have considered existing locations which could present themselves as sources of waste heat. Consistent with the requirements of the Technical Specification, we have considered the following types of installation:

- Thermal power generating installations with thermal input exceeding 50MW. There are three separate power station locations comprised of six distinct generating units, each of which have thermal input capacities exceeding 50MW. These are located at Vasilikos, Dhekelia and Moni.
- Heat and power cogeneration installations with total thermal input exceeding 20MW. There are no such installations in Cyprus.
- Waste incineration plants. There are no waste incineration plants in Cyprus. According to Eurostat, all in-country waste generated and consumed for energy purposes and waste imported for the same purpose is finally consumed within the non-metallic minerals sector as a fuel. This means the cement plant at Vasilikos, which is covered below.
- Renewable energy installations with a total thermal input exceed 20MW (if not already included in the categories above). There are no such installations in Cyprus.
- Industrial installations with a total thermal input exceeding 20MW. Such installations would be covered by EU ETS. Consulting data on EU ETS installations in Cyprus (excluding the power

[11] Out of a total gross electricity production of 435.1 ktoe, 41.1 ktoe came from renewable sources.

stations listed above) has revealed 1 x cement installation and 8 x ceramics installations. These are listed in the table in section 2.2.3 below.

- Large cooling systems may dump significant quantities of low grade heat which could conceivably feed a DHC scheme. In line with the Directive requirement for power stations of more than 20 GWh per year of electricity generation to be shown on the heat map as potential points of heat supply, we have adopted a similar philosophy for large cooling systems, i.e. we have considered whether there are any large cooling systems with the potential to dump more than 20 GWh of heat. For a cooling system with a COP of 3, this means a system serving a building or buildings with a cooling load of about 13 GWh. Such buildings or buildings are most likely to be located in tourist areas or central commercial areas in Nicosia. Therefore, we have carried out an assessment of building footprints in tourist areas and dense commercial areas in Nicosia and estimate that the largest cooling demand are in the region of 4-5 GWh per year at some hotel complexes in Paphos. Based on this, we conclude that there are no sufficiently large point sources of waste heat arising from cooling systems which could serve DHC.
- Large points of waste cold could also serve a potential point sources for cooling delivered via DHC. At present there are no large sources of waste cold in Cyprus. The Liquid Natural Gas (LNG) plant currently being constructed at Vassiliko will vaporise LNG delivered already in the liquid form. However, at present it is unclear whether the vaporisation process will be open loop or closed loop and, consequently, whether there will be any waste cold available.

2.2.2 The Analysis

As discussed above, there are three power generating installations and nine industrial installations falling within scope for the evaluation of waste heat potential. Below we explain the methodology used for estimating a quantity of waste heat potentially available for exploitation from these installations.

2.2.2.1 Power Stations

There are four power generating technologies employed at the six generating units at the three power station installations listed above in section 2.2.1: Steam Turbine (ST), Combined Cycle Gas Turbine, Open Cycle Gas Turbine (OCGT) and Reciprocating Engine (RE).

Waste heat can be extracted from all of these technologies, in effect turning each into CHP. When heat is extracted from ST and CCGT technologies, this is extracted as steam, which in effect deprives the ST of some of the steam energy which it would otherwise convert into power. Therefore, there is a power penalty associated with heat extraction from ST and CCGT technologies, which must be taken into consideration when evaluating the economics of heat recovery. In the case of RE and OCGT waste heat is available which, if extracted, has no effect on power generated.

For each technology we have assumed that it is possible to extract heat to convert the generating unit into a CHP with an efficiency of 80% (HHV). This allows the heat efficiency and, therefore, the quantity of heat that could be extracted to be quantified. The approaches to doing this are explained below. For the reasons given below, two different approaches are taken, depending on the power generating technology.

For RE and OCGT,

$$Heat\ Efficiency\ (\%) = 80\% - Power\ Efficiency\ (\%)$$

$$Power\ Efficiency\ (\%) = \frac{Annual\ Power\ Generation\ (MWh)}{Annual\ Fuel\ Input\ (MWh)}$$

$$Annual\ Heat\ Available\ for\ Recovery\ (MWh) = Heat\ Efficiency(\%) \times AnnualFuel\ Input\ (MWh)$$

For ST and CCGT,

$$Heat\ Efficiency\ (\%) = 80\% - Revised\ Power\ Efficiency\ (\%)$$

$$Revised\ Power\ Efficiency\ (\%) = \frac{Revised\ Power\ Output\ (MWh)}{Annual\ Fuel\ Input\ (MWh)}$$

$$Revised\ Power\ Output\ (MWh) = Original\ Power\ Output\ (MWh) - Power\ Loss\ via\ Heat\ Extraction\ (MWh)$$

$$Power\ Loss\ via\ Heat\ Extraction\ (MWh) = \frac{Annual\ Heat\ Available\ for\ Recovery\ (MWh)}{Z - Ratio}$$

$$Z - Ratio = \frac{Heat\ Gained\ from\ Steam\ Extraction\ (MWh)}{Power\ Lost\ (MWh)}$$

For the purposes of this analysis, we have assumed a Z-ratio of 8 which is consistent with previous analysis carried out for the UK NCA.

2.2.2.2 Cement Installation at Vasilikos

A bottom up assessment of heat available for recovery from cement clinker producing installations was carried out for UK installations[12].In all, primary data relating to waste heat available for district heating from this study was gathered for six different UK clinker producing installations.

For these installations, waste heat is assumed to be available from the separate streams of kiln preheater and precalciner. This available heat for each installation was plotted against the fuel input for each installation in order to obtain a characteristic of waste heat available per unit of fuel input. This plot produced a linear fit with a very good correlation ($R^2 = 0.92$) with a gradient of 0.113, implying that 11.3% of the energy content for the fuel inputs to the kiln is available as waste heat for district heating.

By default, we have assumed that the kiln technology used at Vasilikos uses multiple cyclone preheaters and a precalciner and, therefore, the characteristics of waste heat availability from the UK study is applicable in this case. Accordingly, we assume that 11.3% of the energy content of the fuel input to the kiln system at Vasilikos is available for recovery and reuse.

2.2.2.3 Ceramics Installations.

The same study of potential heat recovery from UK industrial installations mentioned above[2] quantified the waste heat available for district heating from three brickworks with continuous tunnel kilns. The fuel input for these kilns was obtained and plotted against the waste heat available for district heating. A good linear correlation was obtained with R2 = 0.99 with a gradient of 0.117, implying that 11.7% of the energy content of the fuel is available as waste heat for district heating.

We have made an assumption that the ceramics installations in EU ETS are similar to the UK installations (i.e. making bricks and using continuous tunnel kilns and have the same green product drying requirements). Accordingly, we assume that 11.7% of the fuel input at the ceramics installations is available as heat for district heating.

---

[12] The potential for recovering and using surplus heat from industry, Final Report for DECC by Element Energy (2014)

2.2.3 Results

Table 2-4 Summary of main attributes of thermal power generation installations and the potential for heat to be recovered from them

Sector	Site and Plant	Prime Mover	Electrical Capacity (MWe)	Annual Fuel Consumption (MWh HHV)	Power Efficiency (% HHV)	Annual Electricity Generation (MWh)	Full Load Hours (hrs)	Steam Extraction Potential (MWh/year)	Steam Extraction Potential (MWt)
Power (EAC)	Vasilikos ST	ST	390	4,031,869	37.6%	1,517,331	3,891	1,952,187	501.8
Power (EAC)	Vasilikos GT	OCGT	38.00	10,730	26.5%	2,838	75	5,745	76.9
Power (EAC)	Vasilikos CCGT 4	CCGT	220.00	1,728,095	45.3%	782,848	3,558	685,289	192.6
Power (EAC)	Vasilikos CCGT 5	CCGT	220.00	1,389,152	45.3%	629,302	2,860	550,879	192.6
Power (EAC)	Dhekeleia ST	ST	360.00	4,666,893	29.4%	1,371,257	3,809	2,699,723	708.8
Power (EAC)	Dhekeleia ICE 1	ICE	51.00	398,822	39.4%	157,133	3,081	161,925	52.6
Power (EAC)	Dhekeleia ICE 2	ICE	51.00	321,409	40.2%	129,174	2,533	127,953	50.5
Power (EAC)	Moni GT	OCGT	150.00	195,034	26.5%	51,594	344	104,433	303.6

A comprehensive worksheet setting out the calculations leading to the above values is provided in Appendix 6.

Note: As explained in the Point F report, opportunities to extract waste heat from the above power generating stations have only been pursued in respect of the ICEs at Dhekeleia. There are two reasons for this:

- The OCGT stations at Vasilikos and Moni are peaking plant (as evidenced by their very low full load hours) and consequently would not be a reliable source of waste heat for DHC

- The other generating stations use steam turbines (STs) which are assumed to be condensing. In order for heat extraction to be possible, the condensing ST would have to be replaced with a pass out condensing steam turbine. From our experience of evaluating the economics of this in the UK, this would not be economically viable. Instead, it is recommended that new power stations are required to be "CHP ready", i.e. have the necessary steam turbine configurations to allow heat to be extracted without expensive replacement of the existing ST.

Table 2-5 Summary of main attributes of industrial installations with thermal input >20MWth and the potential for heat to be recovered from them

Sector	Site and Plant	Annual Fuel Consumption (MWh LHV)	Full Load Hours (hrs)	Industrial Waste Heat Potential (MWh/MWh fuel input LHV)	Industrial Waste Heat Potential (MWht)
Cement	Vasiliko - non biomass	1,441,624	8,000	0.113	162,990
Cement	- biomass	401,778	8,000	0.113	45,425
Ceramics	United Brickworks	Not available	4,000	0.117	-
Ceramics	KAPA	9,537	4,000	0.117	1,111
Ceramics	Chrysafis	11,700	4,000	0.117	1,363
Ceramics	Kakogiannis	13,045	4,000	0.117	1,520
Ceramics	Melios & Pafitis	15,399	4,000	0.117	1,794
Ceramics	Gigas Tiles	Not available	4,000	0.117	-
Ceramics	Gigas Bricks	Not available	4,000	0.117	-
Ceramics	Ledra	13,934	4,000	0.117	1,623

Note: As explained in the Point F report, opportunities to extract waste heat have only been pursued in respect of the Vasilikos cement works. Feedback from the operators of the ceramics sites listed in Table 2-5 indicates that all surplus heat from the firing kiln is consumed for drying green product prior to the firing stage. Given this feedback, it is assumed that surplus heat is not available to supply DHC.

Appendices

Appendix 1 – Detailed split of Useful Energy (UE) by sector, subsector, fuel, end use and technology

Appendix 2 – Detailed split of Final Energy Consumption (FEC) by sector, subsector, fuel, end use and technology

Appendix 3 - Power generation installations and the potential for heat to be recovered from them

Appendix 4 -Industrial installations with thermal input >20MWth and the potential for heat to be recovered from them

A1 Detailed split of Useful Energy (UE) by sector, subsector, fuel, end use and technology

Appendix
1_Useful_Energy_Co

A2 Detailed split of Final Energy Consumption (FEC) by sector, subsector, fuel, end use and technology

Appendix
2_Final_Energy_Con

A3 Power Station Waste Heat Potential

Appendix 3
Power_Station_Was

A4 Industrial Installation Waste Heat Potential

Appendix 4
Industrial_Installatic

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Comprehensive Assessment of the Potential for Efficient Heating and Cooling

Report for Point C - Map of National Territory of Republic of Cyprus Showing Existing Heating and Cooling Demand Areas and Location of Existing and Planned Installations Generating Waste Heat and Cold

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

Report for MECI, Cyprus

ED 14106 | Issue number 1 | Date 28th July 2021

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28th July 2021

Ref: ED14106

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Table of Contents

1.1 Introduction

Annex VIII of the Energy Efficiency Directive 2012/27/EU (EED) requires that the comprehensive assessment of national heating and cooling potentials includes a map covering the entire national territory of the Republic of Cyprus. According to the revised Annex VIII of the EED, set out in Commission Delegated Regulation (EU) 2019/826, this map is to present the following information:

1. Heating and cooling demand areas following from the analysis of point 1, while using consistent criteria for focussing on energy dense areas in municipalities and conurbations
2. Existing heating and cooling supply points identified under point 2(b) and district heating transmission installations
3. Planned heating and cooling supply points of the type described under point 2(b) and district heating transmission installations.

In Sections 1.2 to 1.4, we set out our approach to satisfying these requirements. The results of our approach are presented in Sections AA-BB in the form of extracts of the Heat Map.

The Heat Map developed is an interactive heat map and is available at the GIS Online account for MECI:

https://meci.maps.arcgis.com/apps/webappviewer/index.html?id=abe1fecb3c7b4ecc8fe451f8be14a001

1.2 Heating and Cooling Demand Areas

1.2.1 Introduction

As indicated in the EED, heating and cooling demand areas are established following the "analysis of point 1". Point 1 in the context of this work are the results from Point A. In Point A, the demand for heating and cooling has been established for 2018, following the methodologies set out in the Point A report. In the Point A report, demand for heating and cooling was resolved into economic sectors (residential, service, industrial and agricultural) and end use (space heating, heating of sanitary hot water, space cooling and process cooling).

In order to meet the Directive's requirement to "focus on energy dense areas in municipalities and conurbations", it is necessary to present the heating and cooling demand from Point A in terms of density of demand (kWh/km^2), according to geographical location. In the heat map we present the Useful Energy (UE) demand, disaggregated according to sector and end use, expressed per km^2, as separate layers. Below we describe the method followed for determining the UE density across the different layers presented on the heat map.

1.2.2 Methodology

1.2.2.1 Residential Space Heating, Cooling and SHW

The demand for UE across these three end uses is taken from the results in Point A, where UE is evaluated for three residential architypes (Apartments, Row houses and Single houses).

The area for each of the three residential architypes across the whole of Cyprus is evaluated from a combination of census data (2011) and assumptions about the average floor area for the types of residential building observed in the 2011 census.

To calculate the space heating UE for each residential architype, the total space heating UE of this architype (from Point A) is divided by the total floor area for the architype across Cyprus. The same approach is taken for space cooling and SHW.

The derived UE for space heating and cooling per residential architype is further adjusted to account for climatic region. This analysis observes four climatic regions: Semi mountainous, Mountainous, Low land and Coastal. There is assumed to be no demand for space cooling in residential buildings located in mountainous regions and only 70% of the space cooling demand in semi-mountainous region compared to coastal regions. A further adjustment is that the demand for space heating in mountainous regions is assumed to be 3 times that in the coastal and in semi-mountainous region 1.2

times that in the coastal region. There are no other adjustments in respect of climatic region, i.e. the demand for SWH is assumed not to vary with climatic region.

The UE for each end use for each architype in each post code is then calculated by multiplying the floor area for the architype in that post code by the UE/m^2 for the end use, to derive the UE for that end use in that post code. This UE is then divided by the total area in the post code to derive and end use UE density for the architype under consideration.

These UE densities are plotted on the heat map.

A full list of the residential architypes and their heating, cooling and sanitary hot water consumptions is provided in Appendix 11.

1.2.2.2 Service Space Heating, Cooling and SHW

There are 8 architypes established for the service sector, one for each of the service subsectors presented in Point A. This means that service architypes are established as follows: Airports, Catering, Healthcare, Hotels, Offices, Schools, Shopping and Other.

The total floor area for each of these subsectors in each post code is evaluated. There are a range of ways of doing this, depending on the primary data available. The derivation of floor area for these service architypes is set out in detail below:

Airports – Only 2 airports: Larnaka (Area = 100,000m^2) and Pafos (Area: 29,000 m^2)

Catering – Area in PC = No. catering sites in PC x Floor Area/Catering site (80 m^2)

Health care (Private) – Area in PC = No beds in PC x 130 m^2/bed

Health care (Public) – Area in PC for 8 public hospitals was supplied to Ricardo by MECI

Hotels - Area in PC = No Hotel Rooms in PC x 50.5 m^2/Hotel Room

Offices – Area in PC No. sites in PC x 150 m^2/site

Schools – Area in PC supplied by MECI and covers private and public nursery, primary and secondary schools and tertiary education sites

Shopping - Area in PC supplied by MECI and covers malls, shopping centres and other retail

Other - - Area in PC supplied by MECI and covers sports buildings and other buildings

The total UE for each architype for end use (from Point A) is divided by the sum of floor area for each architype for each end use across all PC in Cyprus, to provide a UE/ m^2.

The UE for each end use for each architype in each post code is then calculated by multiplying the floor area for the architype in that post code by the UE/ m^2 for the end use, to derive the UE for that end use in that post code. This UE is then divided by the total area in the post code to derive and end use UE density for the architype under consideration.

These UE densities are plotted on the heat map.

A full list of the service sector architypes and their heating, cooling and sanitary hot water consumptions is provided in Appendix 11.

1.2.2.3 Industry

For Industry (ETS), only process heating demand is considered. The process heat demand is calculated separately for each of the 9 industrial sites covered by EU ETS. Since the locations of these sites are known, these a plotted as point sources of heat demand in the heat map.

For Industry (Non-ETS)- The Industry (Non-ETS) UE (heating and cooling) is determined by taking the UE for all industry, split by sub-sector, (Point A) and removing the ETS UE (see above), to derive the UE for non-ETS industry, split by subsector.

The non-ETS UE is then geographically distributed across the PCs by taking the proportion of total national industrial floor area in each PC and multiplying by the non-ETS UE.

A full list of the non-EU ETS architypes and their heating and cooling (where applicable) consumptions is provided in Appendix 11. The consumptions for the EU ETS sites in not provided, as the demands are specific to these sites and providing them could be disclose information deemed confidential.

1.2.2.4 Agriculture

For Agriculture only heating is considered. There is no SHW and cooling consumption. Total UE for Agriculture is taken from Point A. Distribution across Cyprus PC is calculated by taking the proportion of total national agricultural floor area in each PC and multiplying by the Agriculture UE.

A full list of the agriculture sector architypes and their heating consumptions is provided in Appendix 11.

1.3 Existing Heating and Cooling Supply Points

1.3.1 Introduction

As indicated in the EED, heating and cooling supply points are to be established as “identified under point 2(b)”. Point 2(b) in the context of this work are the results from Point B specifically relating to installations from which waste heat or cold could be recovered and act as potential supply points for meeting demand for heating and cooling elsewhere.

In Point B, and consistent with the EED, we have considered a range of installations from which waste heat and cold could be recovered, as follows:

Thermal power generating installations with thermal input exceeding 50 MWth. We find that there are three such installations in the Republic of Cyprus. The waste heat that could be available from these installations has been calculated according to methodology explained in the Point B report and the potential availability of this heat has been mapped.

Heat and power cogeneration installations with thermal input exceeding 20 MWth. As explained in the Point B report, there are no such installations in Cyprus.

Waste incineration plants. As discussed in the Point B report, there are no such plants and all in country waste generation and waste imports are consumed within the cement sector (see below).

Renewable energy installations with a total thermal energy input in excess of 20 MWth. As discussed in the Point B report, there are no such installations in Cyprus

Industrial installations with a total thermal input in excess of 20 MWth. As discussed in the Point B report, all such installations would be covered by EU ETS. EU ETS installations comprise the three thermal power generating installations (discussed above), 1 x cement installation and 8 x ceramics installations. The potential waste heat recoverable from the cement works was calculated according to the methodology described in the Point B report. Upon consultation with operators of large ceramics installations of the type covered by EU ETS, it was decided that all waste heat from the kiln is consumed for the drying of green product and that, therefore, there is no waste heat available form this source.

There are no existing district heating transmission installations in Cyprus to represent on the Heat Map.

Regarding the availability of waste heat from cooling installations, as discussed out in the Point B report, we conclude that there are no individual buildings with cooling demand large enough to produce waste heat on a scale that could make recovery and feeding into a DHC scheme feasible.

1.4 Planned Heating and Cooling Supply Points

Regarding potential supply points of waste cold, in the first instance the LNG plant under construction at Vasilikos Port could be viewed as a potential source, via recovery of coolth from the heat transfer medium used to vaporise the LNG. However, the Natural Gas Public Company is currently unable to confirm whether the regasification system will be open or closed loop. Consequently, the potential for this to act as a source of waste cold which could be tapped into cannot be evaluated at present.

There are no other planned potential heating and cooling supply point of the types detailed in Section 1.3.

Appendices

Appendix 1 - Total Cooling Density for Republic of Cyprus

Appendix 2 - Total Heating Density for Republic of Cyprus (excl. Sanitary Hot Water)

Appendix 3 - Total Residential Cooling Density for Republic of Cyprus

Appendix 4 - Total Residential Heating Density for Republic of Cyprus (excl. Sanitary Hot Water)

Appendix 5 - Total Service Cooling Density for Republic of Cyprus

Appendix 6 - Total Service Heating Density for Republic of Cyprus

Appendix 7 - Total Industry Process Cooling Density for Republic of Cyprus

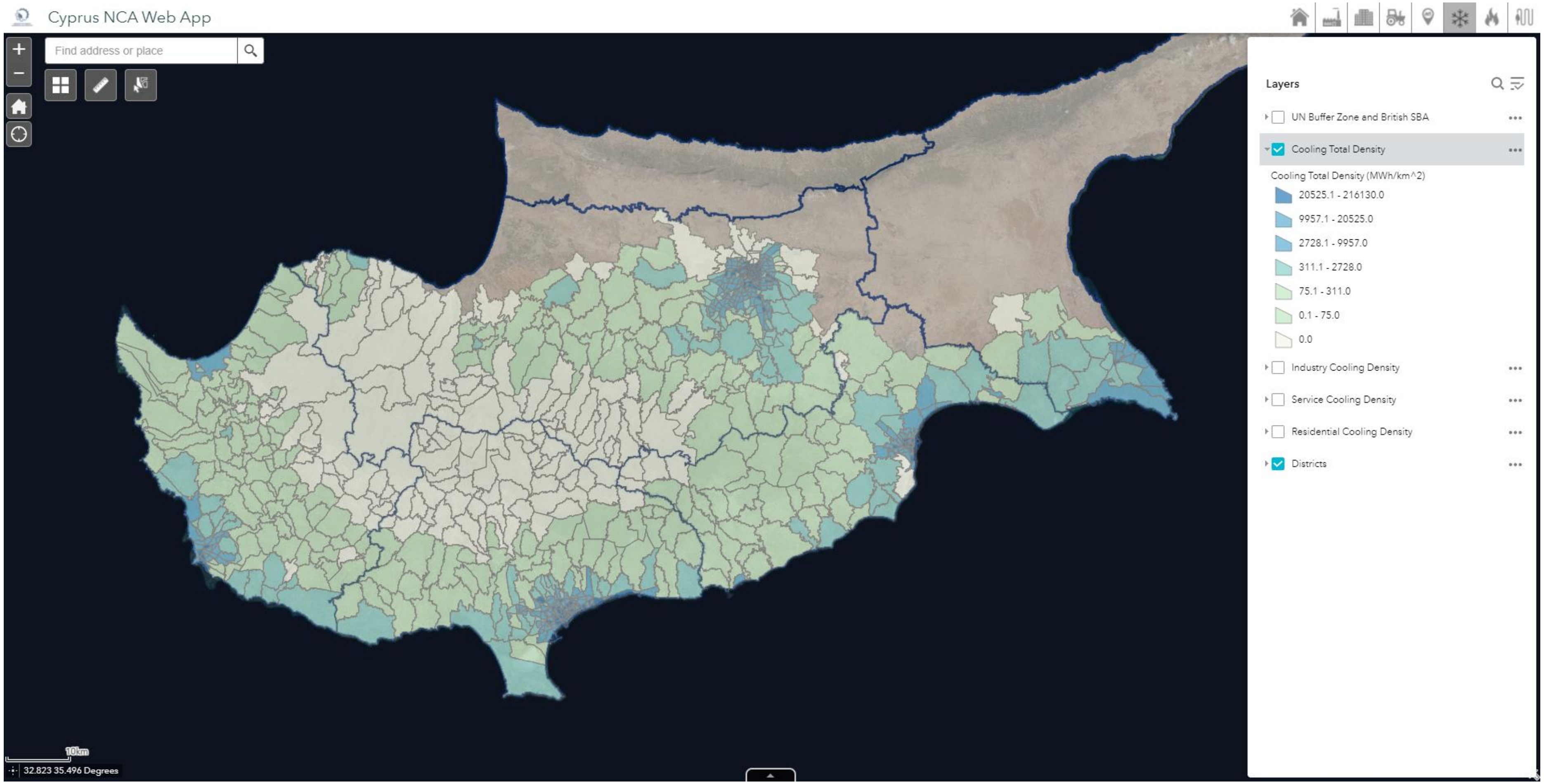
Appendix 8 - Total Industry (EU ETS) Heating Density for Republic of Cyprus

Appendix 9 - Total Industry (Non-EU ETS) Heating Density for Republic of Cyprus

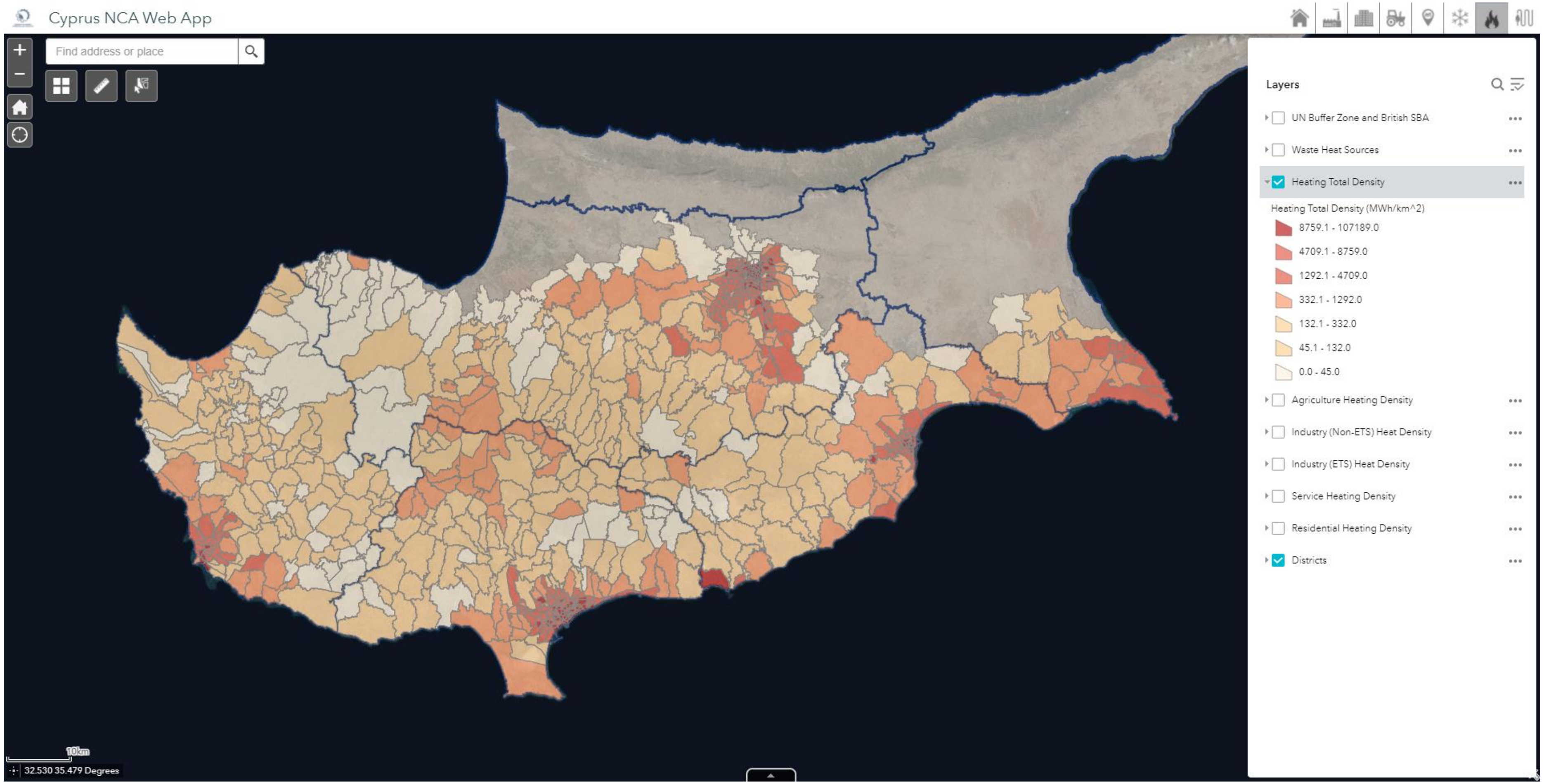
Appendix 10 - Location of Waste Heat Sources with Thermal Input >20MWth

Appendix 11 - Heating and Cooling Consumption for the Modelled Architypes

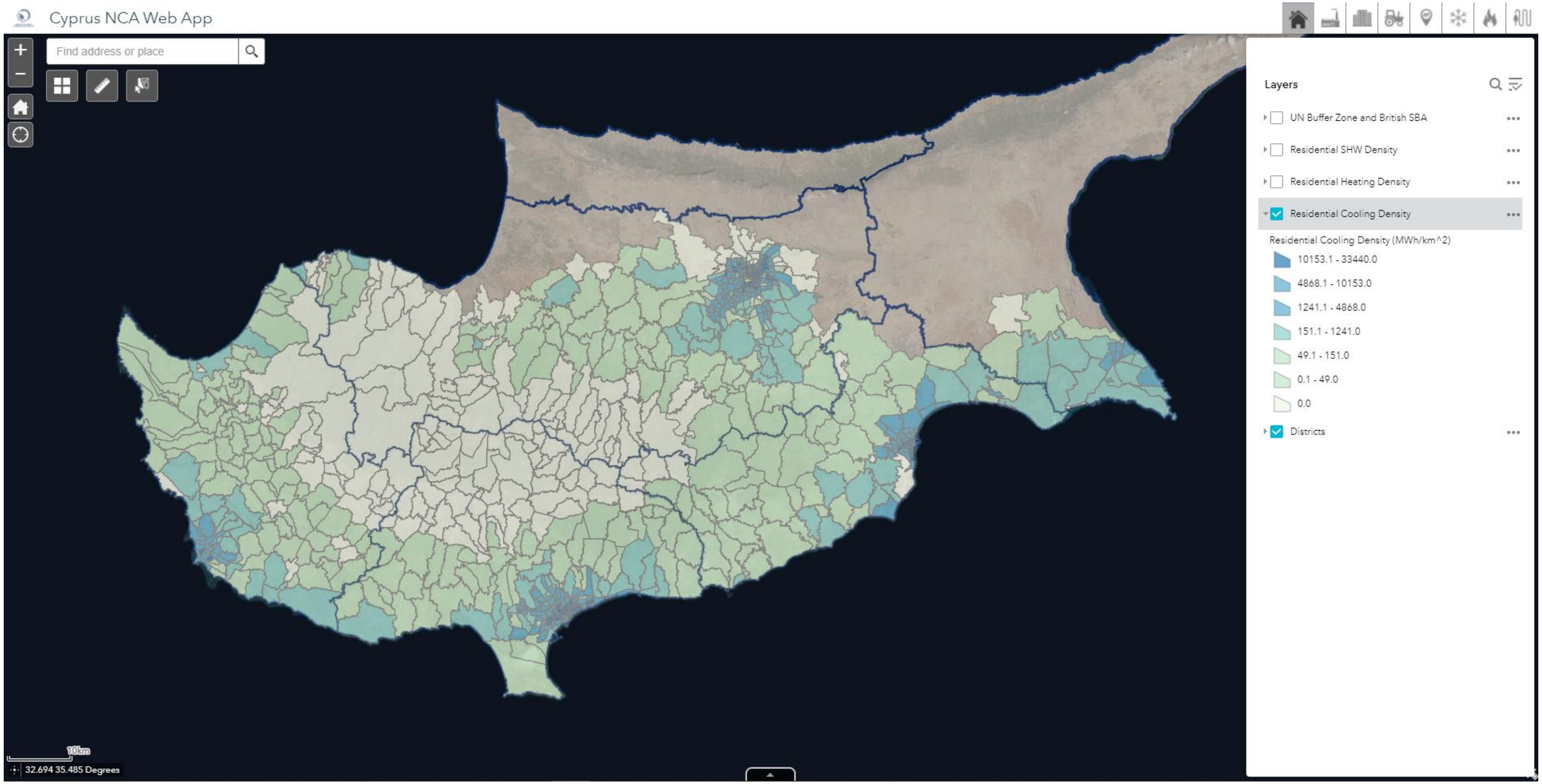
A1 Total Cooling Density for Republic of Cyprus



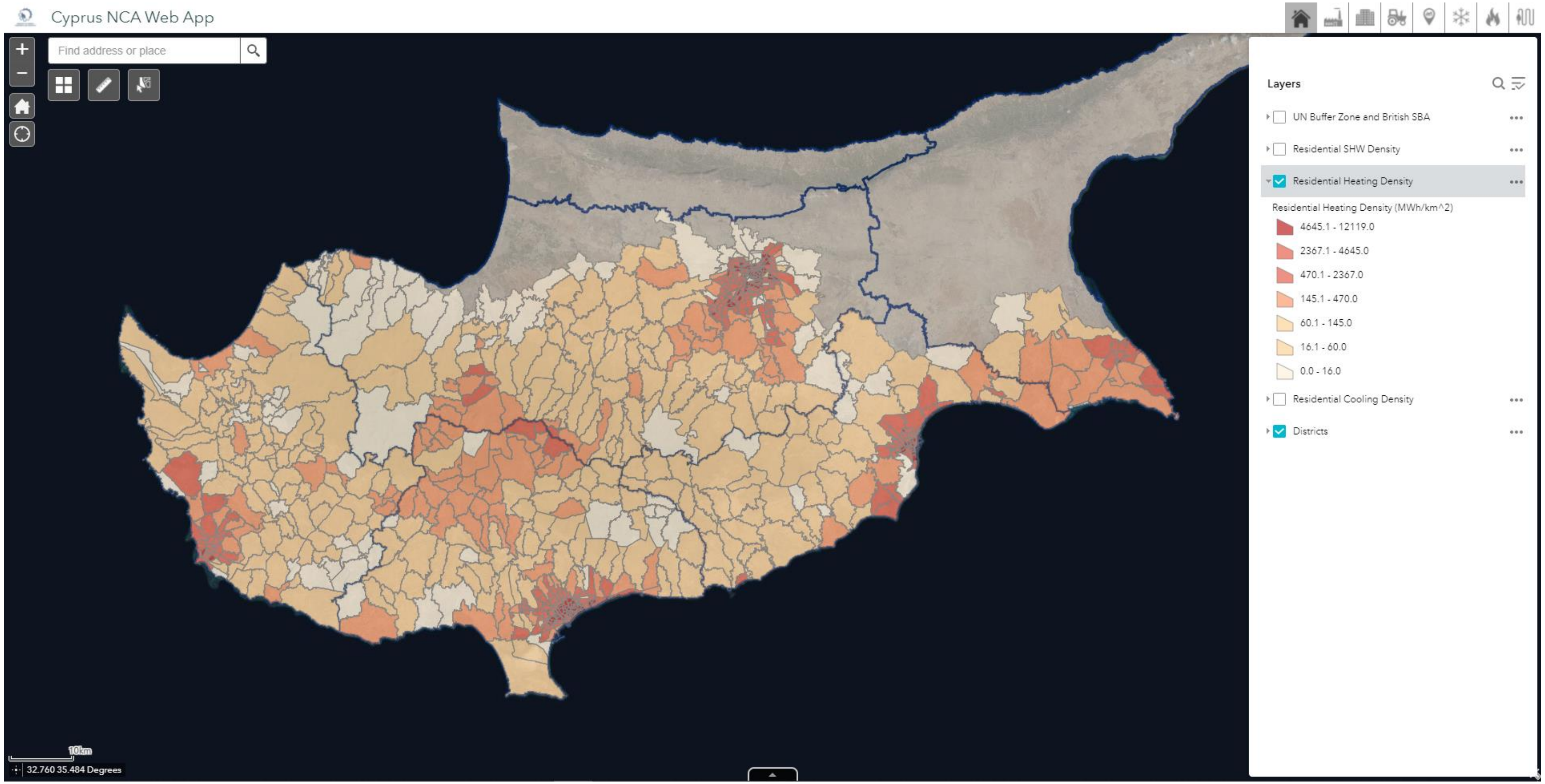
A2 Total Heating Density for Republic of Cyprus (excl. Sanitary Hot Water)



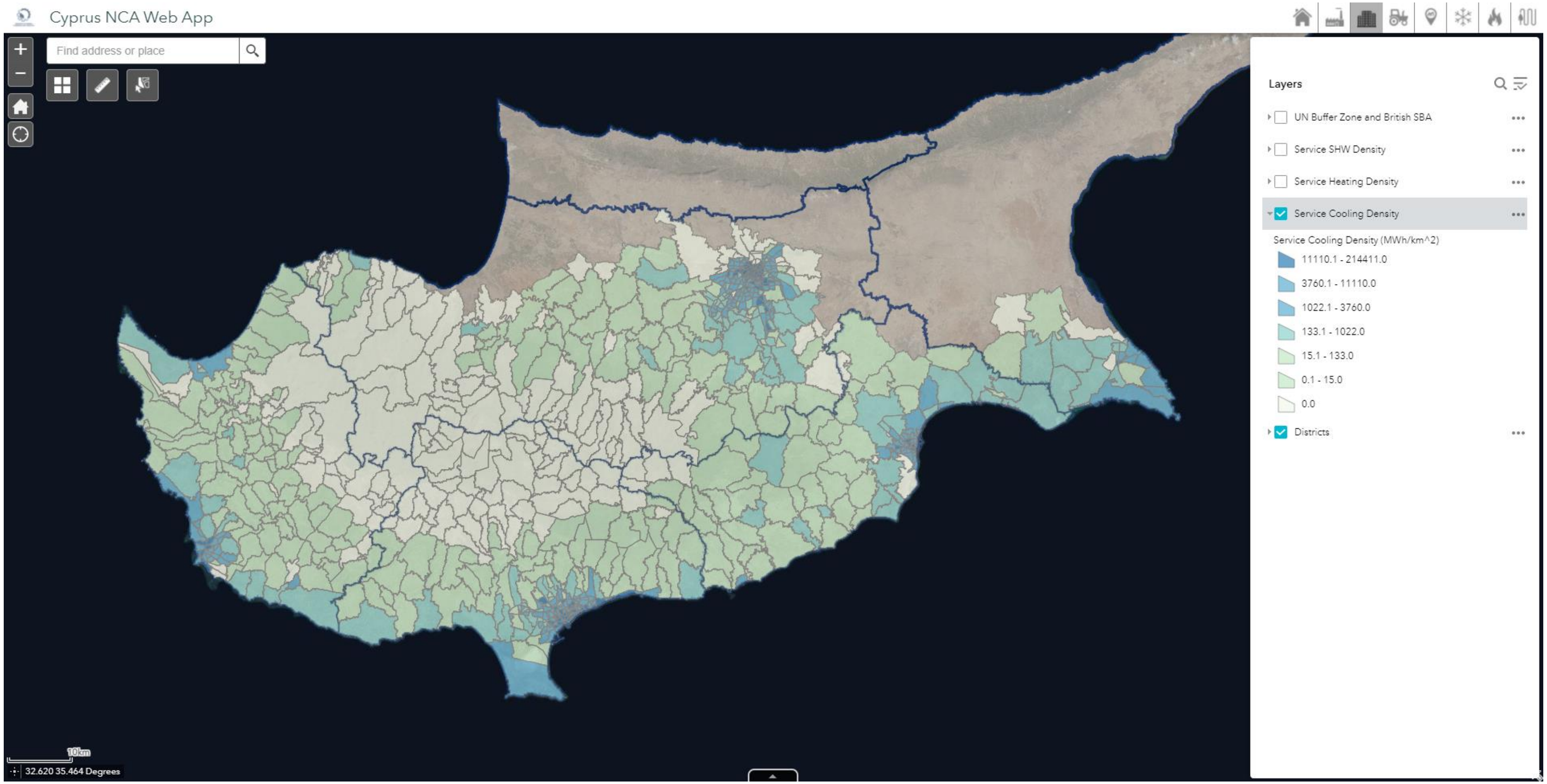
A3 Total Residential Cooling Density for Republic of Cyprus



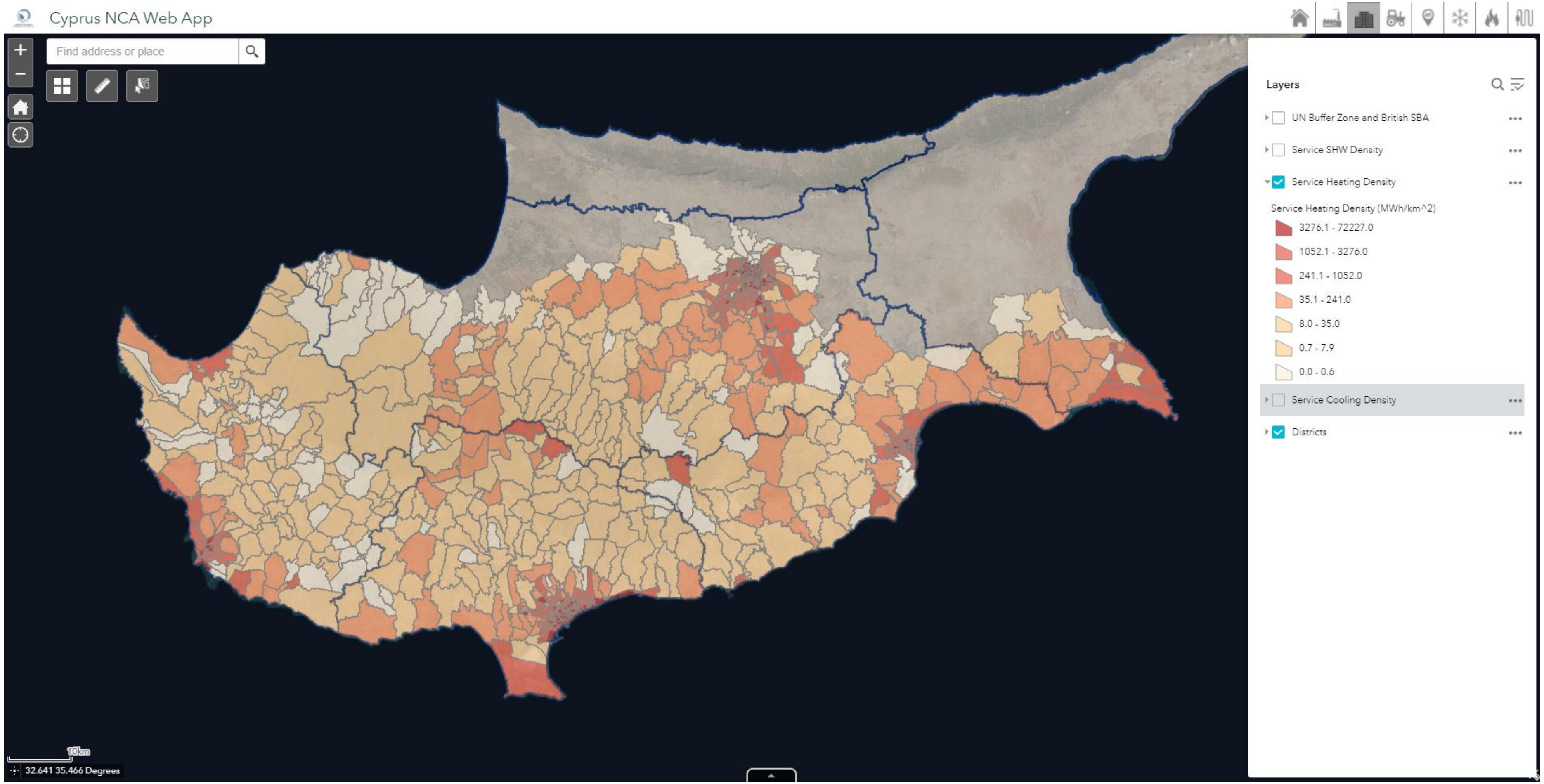
A4 Total Residential Heating Density for Republic of Cyprus (excl. Sanitary Hot Water)



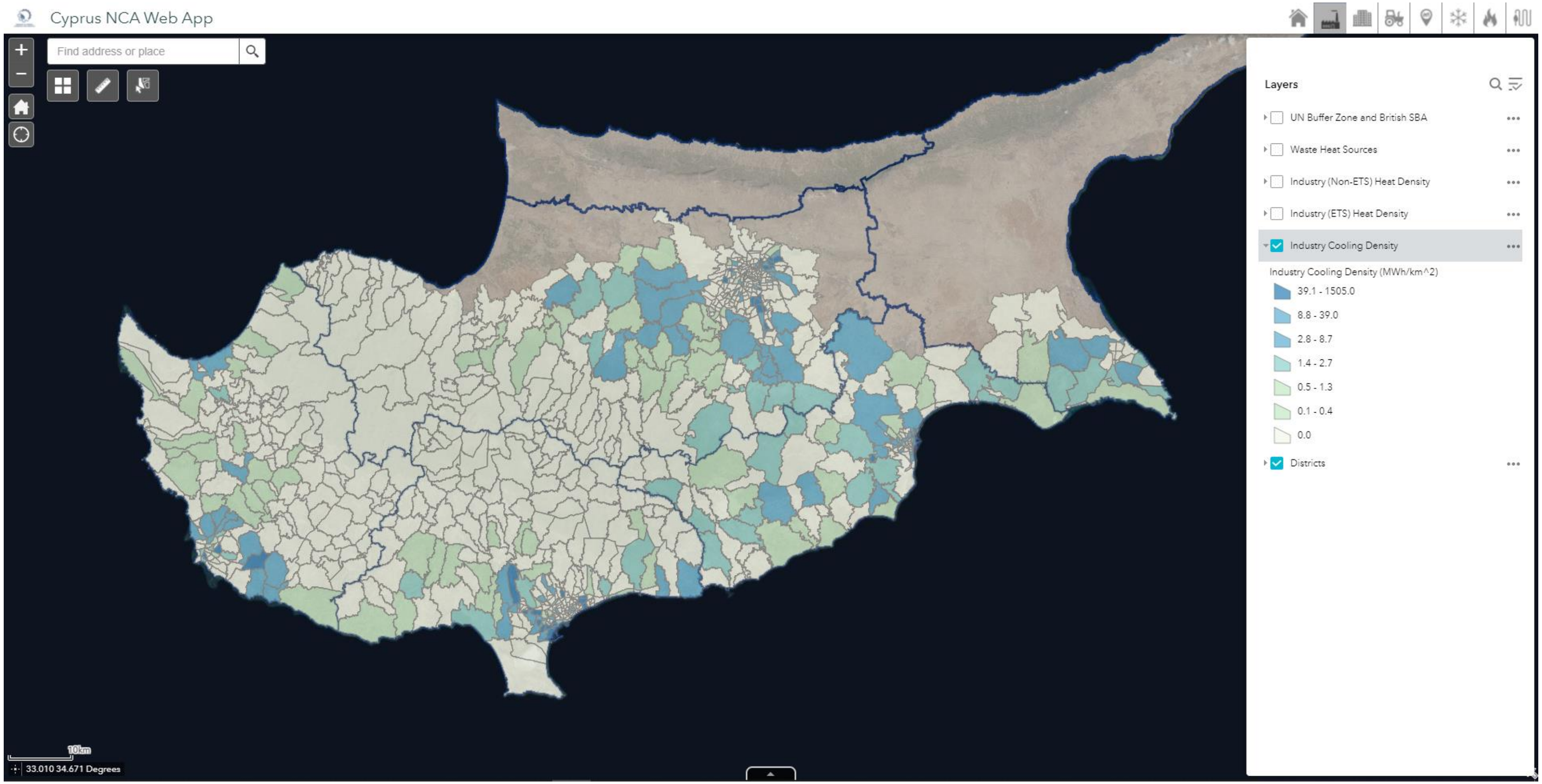
A5 Total Service Cooling Density for Republic of Cyprus



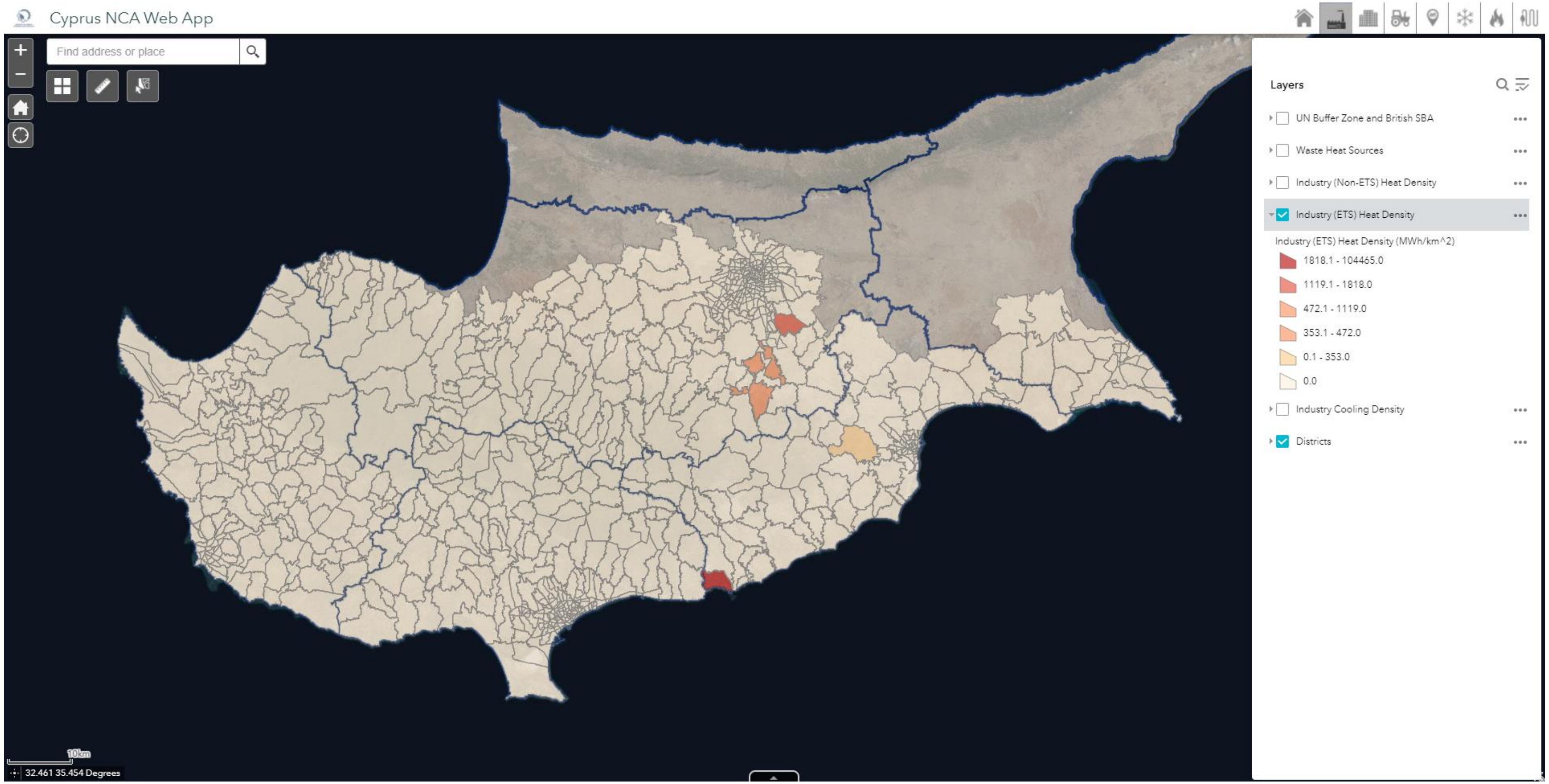
A6 Total Service Heating Density for Republic of Cyprus



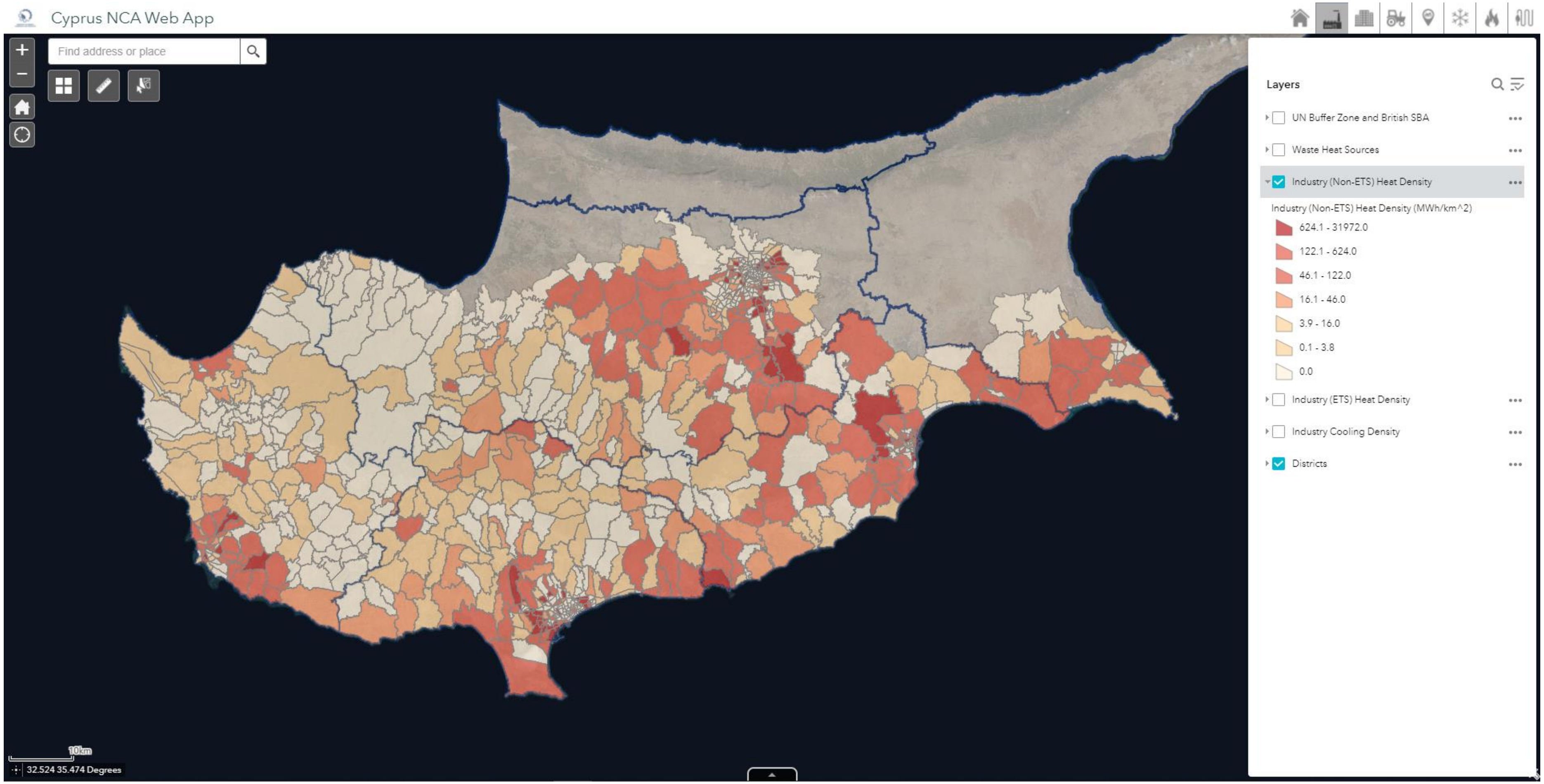
A7 Total Industry Process Cooling Density for Republic of Cyprus



A8 Total Industry (EU ETS) Heating Density for Republic of Cyprus



A9 Total Industry (Non-EU ETS) Heating Density for Republic of Cyprus



A10 Location of Waste Heat Sources with Thermal Input >20MWth

A11 Heating and Cooling Consumption for the Modelled Architypes

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

<u>Heating and Cooling Consumption for Modelled Architypes (Low Land Areas)</u>

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

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

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

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Comprehensive Assessment of the Potential for Efficient Heating and Cooling

Report for Point D Forecast of Demand Trends for Heating and Cooling Over the Next 30 Years

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

Report for MECI, Cyprus

ED 14106 | Issue number 1 | Date 22nd July 2021

Ricardo Confidential

Customer:

Ministry of Energy, Commerce and Industry, Cyprus

Customer reference: YEEB/YE/01/2020

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1 Introduction

Annex VIII of the Energy Efficiency Directive 2012/27/EU requires that the comprehensive assessment of national heating and cooling potentials includes a forecast of trends in the demand for heating and cooling to maintain a perspective for the next 30 years. It goes on to say that the projections should particularly take into account projections for the next 10 years, the change in demand in buildings and industry and the impact of policies and strategies related to heating and cooling.

Pursuant to this requirement, we have used the "With Existing Measures" (WEM) projection of Final Energy Demand (FED) for heating and cooling set out in the 2020 National Energy and Carbon Plan (NECP) and the NECP Impact Assessment. Projections are made each year to 2030 and then every 5 years to 2050. As required by Annex VIII, these projections have factored in the anticipated impact of policies, measures and strategies on the demand for heating and cooling out to 2050.

We have further made projections of the effect of this FED on Primary Energy Supply (PES) for heating and cooling using projections of fuel splits, including projections for primary energy supply to electricity generation for the same period. This has allowed us to associate primary energy with the final electricity used for the generation of heating and cooling. This gives a full picture of the primary energy inputs to meet heating and cooling demand and helps inform any security of supply issues which might arise in the future.

Finally, using the aforementioned FED fuel split and projections of the fuel split into electricity generation, including the considerable near term shift from oil to natural gas for electricity generation and the near and long term shift to renewable electricity, we have been able to project the CO_{2e} emissions associated with the heating and cooling demand out to 2050.

In the sections below we present these projections, first for the whole economy and then by sector.

2 Final Energy Demand, Primary Energy Supply and Carbon Emissions

Table 1 and Figure 1 below shows the WEM scenario projected final energy demands by energy type from 2021 to 2050 based on data in the NCEP Impact Assessment, Deliverable 5, plus the situation in 2018 as determined under Point A of the current work. This is the projection for heating and cooling across the whole economy.

In developing these projections, it should be noted that the Impact Assessment (IA) and the NCEP itself do not provide values for the ambient heat captured by heat pumps. However, consistent with the fuel split given in the National Energy Balance, this has been included in the breakdown given in Point A. To make the projections presented here consistent with Point A, it has been necessary to calculate the quantity of ambient heat from the tables given in the NECP and IA. To do this we have used the observation that the calculation of the percentage RES in the NCEP tables (e.g. Table 5.4 in the NECP) includes ambient heat in the numerator and denominator, but electricity is excluded from the denominator; i.e.:

$$\text{RES share}_{\textit{(NCEP tables)}} = \frac{\text{(Biomass + Geothermal + Solar thermal + Ambient heat)}}{\text{(Total}_{\textit{(incl. Ambient heat)}} - \text{Electricity)}}$$

Using this relationship has allowed us to calculate the FED that is ambient heat captured by heat pumps for each year of the projection.

The equivalent data for primary energy supply are presented in Table 2 and Figure 2, and for carbon emissions in Table 3 and Figure 3 – again for the whole economy. These have also been determined from data in the NCEP Impact Assessment, Deliverable 5, plus the situation in 2018 as determined under Point A. The emissions factor for delivered electricity has been determined from the projected WEM fuel mix for each year and is also shown in Table 3.

Indices for the three parameters are shown together for comparison in Figure 4.

Figure 5 to Figure 7 give the projections for FED, PES and CO_{2e} emissions, respectively, associated with the residential, service, industry and agriculture sectors.

Table 2-1 Final energy demand (FED) of the heating and cooling sector (PJ) – WEM scenario

	2018	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045	2050
Electricity	6.68	7.83	8.12	8.30	8.51	8.69	8.91	9.14	9.38	9.64	9.79	10.42	10.87	11.31	11.71
Other oil products	7.99	6.88	6.83	6.70	6.67	6.69	6.70	6.69	6.68	6.65	6.62	6.06	5.74	4.99	4.24
Pet Coke	2.33	3.16	2.95	2.74	2.58	2.49	2.41	2.33	2.26	2.18	2.13	1.92	1.72	1.58	1.47
LPG	1.40	2.61	2.60	2.56	2.57	2.61	2.65	2.70	2.74	2.78	2.82	2.81	2.69	2.48	2.19
Biomass	2.22	1.04	1.02	0.99	1.04	1.10	1.16	1.21	1.25	1.29	1.33	1.44	1.63	1.65	1.63
Geothermal	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.07	0.09	0.14	0.21
Solar thermal	2.93	3.01	3.03	3.03	3.11	3.20	3.29	3.40	3.51	3.63	3.75	4.77	5.99	7.09	8.2
HP ambient heat	1.93	2.01	2.04	2.07	2.10	2.13	2.16	2.19	2.23	2.24	2.27	2.41	2.56	2.69	2.85
Total	**25.55**	**26.60**	**26.65**	**26.45**	**26.64**	**26.97**	**27.34**	**27.71**	**28.10**	**28.46**	**28.76**	**29.90**	**31.29**	**31.93**	**32.50**
RES share	**30.4%**	**32.6%**	**33.2%**	**33.9%**	**34.8%**	**35.5%**	**36.2%**	**36.9%**	**37.6%**	**38.3%**	**39.0%**	**44.6%**	**50.3%**	**56.1%**	**62.0%**
FED index (2018 = 100)	100.00	104.10	104.31	103.54	104.26	105.55	107.01	108.46	109.97	111.37	112.55	117.01	122.47	124.95	127.19

Derived from: Point A and Tables 14 and 54 of the NCEP Impact Assessment Deliverable 5

Figure 1 Final energy demand (FED) of the heating and cooling sector (PJ) – WEM scenario

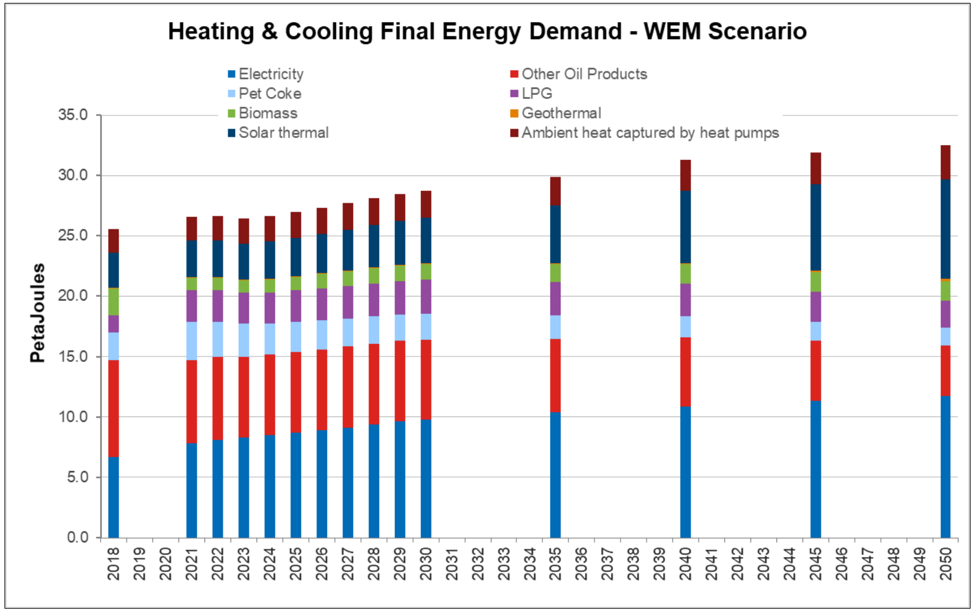


Table 2-2 Primary energy supply (PES) for the heating and cooling sector (PJ) – WEM scenario

	2018	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045	2050
Fuel for power generation	17.91	18.07	16.45	16.82	15.98	16.31	16.38	16.72	17.25	17.78	18.09	14.43	11.25	9.53	8.47
Other oil products	7.99	6.88	6.83	6.7	6.67	6.69	6.7	6.69	6.68	6.65	6.62	6.06	5.74	4.99	4.24
Pet Coke	2.33	3.16	2.95	2.74	2.58	2.49	2.41	2.33	2.26	2.18	2.13	1.92	1.72	1.58	1.47
LPG	1.40	2.61	2.6	2.56	2.57	2.61	2.65	2.7	2.74	2.78	2.82	2.81	2.69	2.48	2.19
Biomass	2.22	1.04	1.02	0.99	1.04	1.1	1.16	1.21	1.25	1.29	1.33	1.44	1.63	1.65	1.63
Geothermal	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.07	0.09	0.14	0.21
Solar thermal	2.93	3.01	3.03	3.03	3.11	3.2	3.29	3.4	3.51	3.63	3.75	4.77	5.99	7.09	8.2
HP ambient heat	1.93	2.01	2.04	2.07	2.10	2.13	2.16	2.19	2.23	2.24	2.27	2.41	2.56	2.69	2.85
Total	**36.78**	**36.84**	**34.98**	**34.98**	**34.11**	**34.59**	**34.82**	**35.30**	**35.97**	**36.60**	**37.06**	**33.91**	**31.67**	**30.15**	**29.26**
PES index (2018 = 100)	100.00	100.15	95.11	95.10	92.74	94.03	94.66	95.97	97.80	99.51	100.76	92.20	86.12	81.97	79.56

Derived from: Point A and Tables 15, 16, 55 and 56 of the NCEP Impact Assessment Deliverable 5

Figure 2 Primary energy supply (PES) for the heating and cooling sector (PJ) – WEM scenario

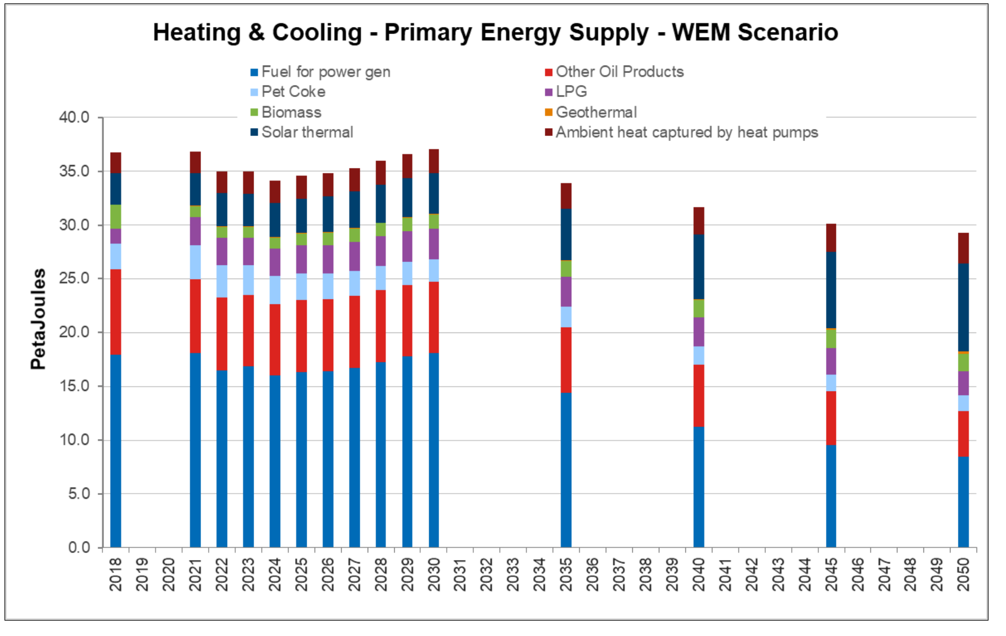


Table 2-3 Carbon dioxide equivalent emissions for the heating and cooling sector ($ktCO_{2e}$) – WEM scenario

	2018	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045	2050
All fuels	2,339	2,287	1,867	1,845	1,747	1,752	1,720	1,725	1,748	1,770	1,782	1,424	1,207	1,036	876
CO_{2e} emissions index (2018 = 100)	100.00	97.75	79.79	78.88	74.67	74.89	73.52	73.73	74.74	75.68	76.16	60.86	51.58	44.31	37.43

CO_{2e} emissions factor for delivered electricity (tCO_{2e}/PJ)	204,942	159,440	105,162	104,402	92,334	91,547	86,206	85,183	86,058	86,821	87,132	53,906	36,596	27,898	20,898

Figure 3 Carbon dioxide equivalent emissions for the heating and cooling sector ($ktCO_{2e}$) – WEM scenario

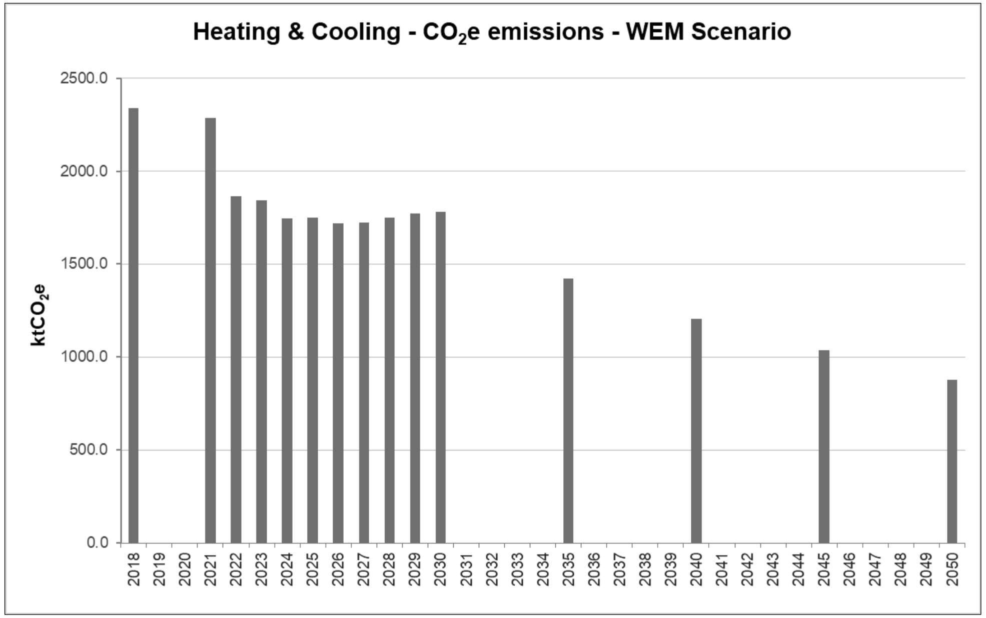


Figure 4 Carbon dioxide equivalent emissions for the heating and cooling sector ($ktCO_{2e}$) – WEM scenario

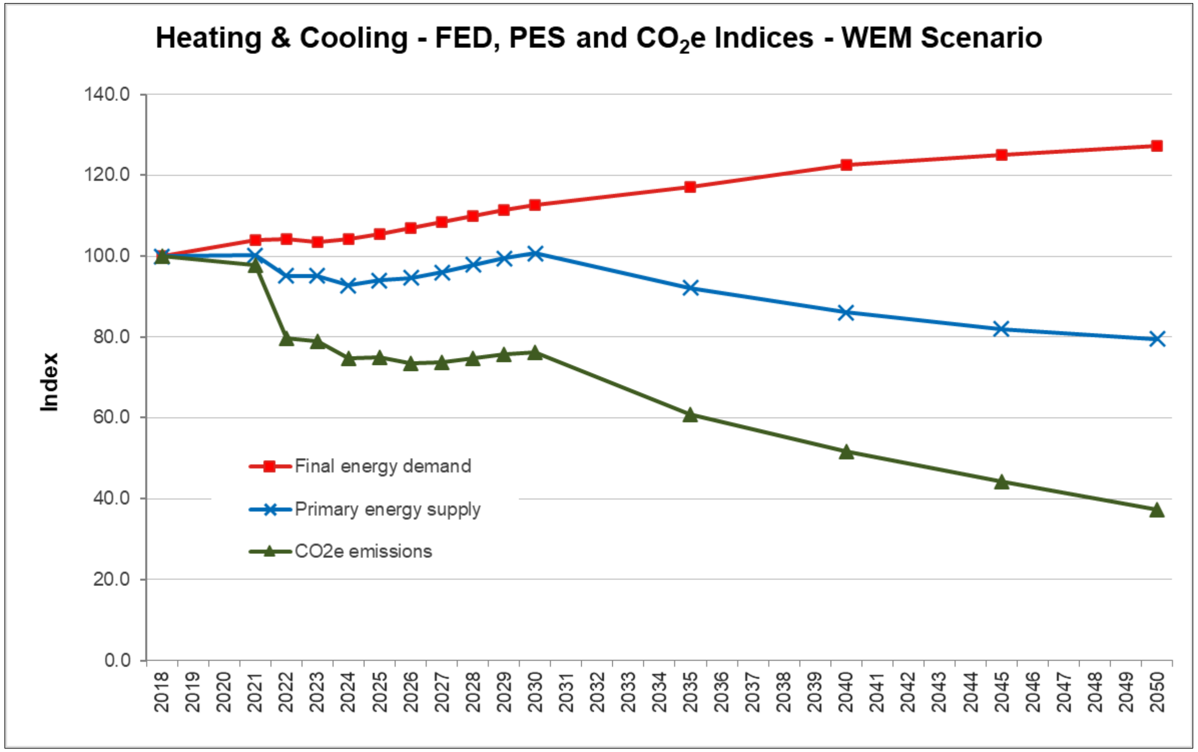


Figure 5 Sectoral (FED) of the heating and cooling sector (PJ) – WEM scenario

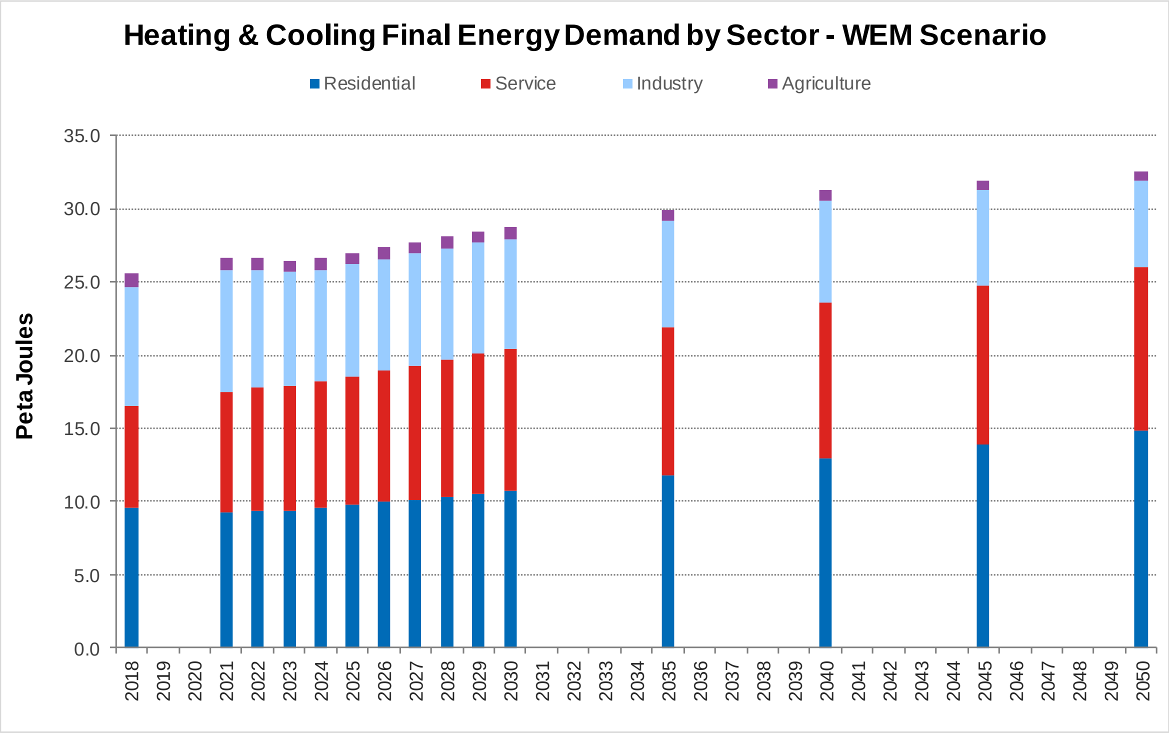


Figure 6 Sectoral (PES) for the heating and cooling sector (PJ) – WEM scenario

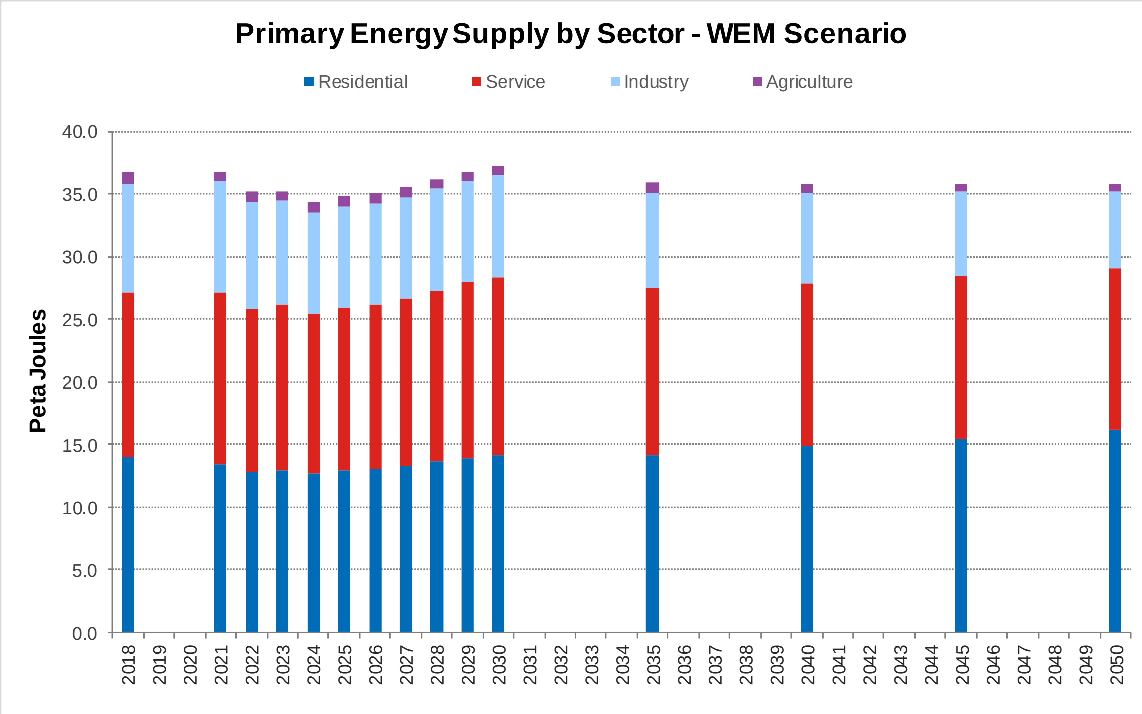
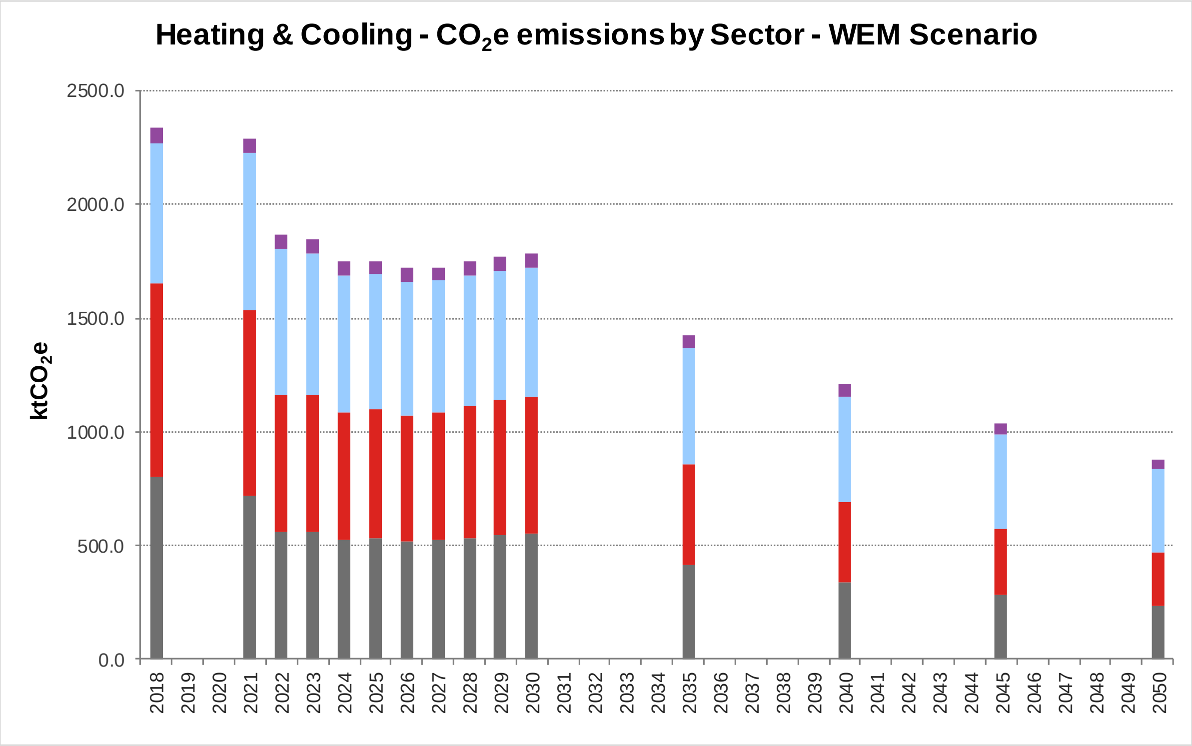


Figure 7 Sectoral carbon dioxide equivalent emissions for the heating and cooling sector (ktCO2e) – WEM scenario



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Comprehensive Assessment of the Potential for Efficient Heating and Cooling

Report for Point E Overview of Existing Policies Relevant for Efficient Heating and Cooling

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

Report for MECI, Cyprus

ED 14106 | Issue number 2 | Date 28th July 2021

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Customer:

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28th July 2021

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Ricardo is certified to ISO9001, ISO14001, ISO27001 and ISO45001

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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 overview of existing policies and measures (PaMs) relevant to heating and cooling:

i. as described in the Member State's most recent Integrated National Energy and Climate Plan (NECP); plus
ii. any further PaMs implemented to date and not identified in the NECP.

As required by Article 1(2) of the Governance Regulation (EU) 2018/1999, PaMs are categorised by the five energy union dimensions, which are:

1. Decarbonisation;
2. Energy efficiency;
3. Energy security;
4. Internal energy market; and
5. Research, innovation and competitiveness.

Cyprus's first NECP was finalised in January 2020. Sections 2.1 to 2.5 summarise, by the five energy union dimensions, those PaMs relevant to heating and cooling included under the NECP 'With Existing Measures' (WEM) scenario with the following exclusions since these cannot now be considered to be existing measures:

– various measures that were no longer operational at the time of NECP's development, having ceased or been succeeded by another measure on the WEM list of measures (the latest having ceased in 2018);
– one that ceased in 2019 – i.e. at about the time the NCEP was finalised; and
– one that was planned to commence in 2018 but was abandoned.

The information has been adapted from the report *Impact Assessment of the Cyprus Integrated National Energy and Climate Plan, Deliverable 3: Policies and measures (and relevant data) to be taken into consideration in the Impact Assessment,* September 2019.

2 Summary of Existing Policies and Measures Relevant to Heating and Cooling

2.1 Dimension Decarbonisation

This dimension is split into two sub-groups: the first being measures related to the management of direct GHG emissions; and the second relating to expansion in the use of Renewable Energy Sources (RES).

2.1.1 Greenhouse Gas Emissions and Removals

Name of policy or measure	Short description	Relevance to heating and cooling	Status
Preparation of the proper recovery system for F-gases in equipment	Preparation of the proper recovery system for F-gases in equipment; This is an obligation according to EU and national legislation. It is however still not properly implemented. WEM considers that the necessary implementing measures will be taken so that in 2020 proper recovery of F-gases in old equipment is performed. Commencement has been delayed to 2021 with a budget of €1 million.	All applications with older cooling or heat pump equipment, though assumed not to affect energy demand.	Expected to commence in 2021

Name of policy or measure	Short description	Relevance to heating and cooling	Status
Promotion of anaerobic digestion for the treatment of animal waste.	Further promotion of anaerobic digestion for the treatment and management of animal waste; promotion of anaerobic digestion in existing biogas plants; encouragement of new biogas plants to exploit organic waste from livestock breeding.	As well as reducing CH_4 emissions, biogas from AD is typically used to generate renewable electricity. Also, if there are suitable heat loads in the vicinity, useful renewable heat can be generated via CHP.	Implemented Ongoing

2.1.2 Renewable Energy Sources

Name of policy or measure	Short description	Relevance to heating and cooling	Status
Support scheme for the production of electricity from renewable energy sources for own use. Category A: Net-metering	The implementation of the measure started in 2013 as national policy to promote RES electricity. Currently Net-metering category is available for small scale photovoltaic systems with capacity up to 10kW, for all consumers (residential and non-residential). The scope of the net-metering is to provide the option to residential and small commercial consumers to cover all or part of their electricity consumption from PV. The generated RES electricity is subtracted from building's electricity consumption. Consumers pay only for the difference between the energy consumed and energy produced (net electricity used) plus a cost that reflects the cost of the electricity grid to support continuous supply and taxes (VAT, RES levy). Scheme capped at 20MW total capacity; 5MW residential, 15MW non-residential.	Where electricity is used for heating and/or cooling, particularly heat pumps and cooling plant, and Joule effect heating.	Adopted 2013 Ongoing
Support scheme for the production of electricity from renewable energy sources for own use. Category B: Net-billing	The implementation of the measure started in 2018 as national policy to promote RES electricity and reduce the cost of electricity to commercial and industrial consumers. Currently net-billing is available for RES installations (PV, biomass/biogas systems, etc.) between 10kW and 10MW at commercial and industrial premises and public buildings. The scope of the measure is to provide an option to medium and large-scale electricity consumers to cover all or part of their electricity consumption from RES. The generated RES electricity that is not self-consumed is credited to the consumer at the respective wholesale price of electricity from RES and that amount is subtracted from the cost of the electricity bought from the grid. Fees that reflects the cost of the grid to support continuous supply and taxes (VAT, RES levy) are applied. Scheme capped at 20MW total capacity.	Where electricity is used for heating and/or cooling, particularly heat pumps and cooling plant, and Joule effect heating.	Adopted 2018 It is planned that after 2025 or the cap is reached, the net-billing scheme will cease, and only self-consumption will apply.

Name of policy or measure	Short description	Relevance to heating and cooling	Status
Self-consumption of electricity from renewable energy sources	Self-consumption of RES electricity was introduced in 2013 in the Support scheme for the production of electricity from renewable energy sources for own use. In 2018 the net-billing category was introduced as an alternative option to self-consumption. Self-consumption is applied to all commercial and industrial consumers. It covers the installation of RES systems with power 10kW to 10MW. The scope of the measure is to provide an option to medium and large-scale electricity consumers to cover all or part of their electricity consumption from RES. In this case, unlike net-billing the consumer receives no credit for the generated RES electricity that is not self-consumed. Fees that reflects the cost of the grid to support continuous supply and taxes (VAT, RES levy) are applied. Based on Governmental Regulation and the amendments of RED II Directive after 2020, no fees may be applied to the self-consumed electricity.	Where electricity is used for heating and/or cooling, particularly heat pumps and cooling plant, and Joule effect heating.	Adopted 2013. Ongoing
Installation of net metering PV systems in houses of vulnerable consumers	Financial support of €900 per installed kW, with maximum grand amount of €2,700, is given for the installation of net-metering PV systems in houses of vulnerable consumers (families with low income, disabled persons, etc.).	Where electricity is used for heating and/or cooling, particularly heat pumps and cooling plant, and Joule effect heating.	Adopted 2013 Ongoing
Support scheme for the installation of net-metering photovoltaic systems with capacity up to 20kW, in public school buildings.	The measure provides the regulatory framework for the installation of 4.2 MW of photovoltaic systems in 428 public schools. The PV system will operate under the net-metering scheme. Each PV system will have a power up to 20kW. The roof tops were PV will be installed will also be thermally insulated.	Where electricity is used for heating and/or cooling, particularly heat pumps and cooling plant, and Joule effect heating.	Ongoing Planned to be completed by April 2022
Renewable Energy Communities	Installation of PV Systems in Governmental buildings with the net-billing scheme.	Where electricity is used for heating and/or cooling, particularly heat pumps and cooling plant, and Joule effect heating.	Ongoing Planned for 2019-2030
Support scheme for the installation or replacement of solar water heaters in households	The measure provides a grant of €350 for the installation of a solar water heater and a grant of €175 for the installation/replacement of solar panels.	Hot water production	Adopted 2004 Ongoing - the scheme is repeated annually

Name of policy or measure	Short description	Relevance to heating and cooling	Status
Incentives for encouraging the use of RES in different types of developments.	On 17 November 2014, the Minister for the Interior issued an order under Article 6 of the Town and Country Planning Act setting out incentives and/or requirements for encouraging the use of RES in different types of developments. The order aims to create the conditions for encouraging natural and legal persons to produce energy from RES and concerns different types of developments. The incentive comprises an increase of the building permit ratio, or in some cases the use of RES is a requirement for applicability of other incentives under the development plans.	RES in such developments is likely to provide heating and/or cooling	Adopted 2014. Ongoing.
Certification of small-scale RES system installers	From 2015 a certification scheme is available for installers of small scale (up to 30kW) biomass boilers and stoves, photovoltaic systems, solar thermal system, shallow geothermal systems and heat pumps. The candidates after the completion of their training and a success in a theoretical and practical examination can be registered in a registry of certified installers of RES systems of the Ministry of Energy, Commerce and Industry.	Important for ensuring that such RES systems for heating and/or cooling perform successfully, which gives confidence to potential adopters.	Implemented 2015. Ongoing.
Installation of PV systems for auto-production	This measure aims at installing photovoltaic systems in the holdings of commercial and industrial consumers, for own use. Following a relevant decision of the Cyprus Energy Regulatory Authority (CERA), commercial and industrial consumers will be able to install PV systems on the roofs of their holdings, to generate electricity for own use. No grant will be given under this measure for purchasing and installing the systems. By the end of 2017 94 PV Systems of total capacity 4.276 kW were installed.	Where electricity is used for heating and/or cooling, particularly heat pumps and cooling plant, and Joule effect heating.	Implemented 2013 Ongoing

2.2 Dimension Energy Efficiency

Name of policy or measure	Short description (precise scope and modalities of operation)	Relevance to heating and cooling	Status
Support Scheme for promoting energy audits and energy management schemes in SMEs	The scope it to encourage SMEs to perform energy audits and was launched in 2019. It provides financial support to cover part of the cost of the energy audit. Financial Support for energy management systems to be considered after 2019. The scheme is implemented by the National Government using national funds	Audits will identify energy saving measures likely to mainly address heating and/or cooling.	Adopted 2019-2030 Ongoing
Financing tool providing soft loans for energy efficiency investments	The scope is to provide soft loan to cover the capital cost for implementing energy efficiency investments. Launch year is 2021 (estimated). Target group is households, SMEs and public sector. It will provide low interest loans. The PAM will be implemented by the National Government and local banks. Source of financing: European and Structural funds	Energy saving measures likely to mainly address heating and/or cooling.	Adopted Expected to commence 2021

Name of policy or measure	Short description (precise scope and modalities of operation)	Relevance to heating and cooling	Status
Support Scheme for promoting roof thermal insulation	The scope is to encourage households to implement the measure. It will provide financial support to cover part of the cost of the investment (possibility to combine with installation of net metering photovoltaics). The scheme was implemented by the National Government. Source of financing: National funds	Roof insulation will reduce demands of heat and/or cooling.	Adopted 2018-2020 Ongoing
Energy efficiency network with voluntary agreements of businesses to reduce their energy consumption	Voluntary commitment from businesses to reduce their emissions by more than 8% by 2030. It includes specific commitment for improving their energy efficiency. The voluntary agreements are implemented by Cyprus Employers & Industrialists Federation, Cyprus Energy Agency and the National Government.	Heating and cooling will be significant energy uses in many of the participating businesses from the agriculture, industry and service sectors.	Adopted 2018-2030 Ongoing
Applying a lower VAT rate for the renovation and repair of private dwellings.	Has been in force since December 2015 and relates to applying a lower VAT rate (5%), instead of 19%, for renovation and repair works carried out in existing private dwellings, for works consisting in applying thermal insulation on the external envelope and replacing external door and window frames.	The eligible works reduce the demands for heating and/or cooling.	Adopted 2015-2030 Ongoing
Net billing scheme for high efficiency cogeneration (HECHP)	The net-billing scheme applies to commercial/industrial and public administration consumer categories for the installation of HECHP systems with the prime goal of covering their own consumption. The installed capacity of each net-billing system can be up to 5 MW. Launching year 2018	Supports viability of HECHP and thus the efficient generation of heat for space and water heating.	Adopted 2018 onwards Ongoing
Minimum energy performance requirements for new buildings (Law 142/2006)	All new tertiary sector buildings and all new dwellings, except those described in the Annex to the Regulation on the Energy Performance of Buildings Law (Law 142(I)/2006) must satisfy the minimum energy performance requirements established by a relevant decree adopted by the Minister for Commerce, Industry and Tourism. This measure arises from Cyprus' obligation to implement the Buildings Directive concerning the energy performance of buildings.	Heating and cooling would make up most of the energy consumption addressed.	Implemented 2009 Ongoing
National green public procurement action plan.	'Green public procurement' (GPP) means that environmental factors are taken into account in entering into (public) contracts for buying products, services or works falling within the scope of the two Coordination of Public Procurement Procedures Laws, with a view to ensuring continued progress in environmental performance, by reducing environmental impacts and maintaining economic sustainability.	Energy saving measures likely to mainly address heating and/or cooling.	Implemented 2007 Ongoing

Name of policy or measure	Short description (precise scope and modalities of operation)	Relevance to heating and cooling	Status
Horizontal measures (information campaigns, training eco-driving, organisation of workshops, etc.) to attain the target referred to in Article 7 of the Directive.	This consists in implementing energy savings information campaigns, carrying out advertising actions, organising workshops, conducting pupils' competitions, etc. All these are organised by MECI on an annual basis. An annual budget of €167,000 available for the period 2021-2030	Broad activities that will include energy efficiency in heating and cooling.	Implemented 2014 ongoing
Implementation of measures aimed at attaining the target referred to in Article 5 EED	This measure consists in implementing major renovation and individual energy savings measures in public sector buildings, as well as measures intended to improve user behaviour with a view to a more rational use of energy in public buildings	Energy saving measures likely to mainly address heating and/or cooling.	Implemented 2014 Ongoing
Increase in the RES fee applied on electricity.	This measure consists in increasing the RES and ES fee applied on electricity, which has been in force since 1 January 2017. From 01/01/2017 until 31/12/2019 the tax levy for RES and Energy Conservation in the electricity bill is increased from 0.5 euro cent per KWh to 1 euro cent per KWh. The measure applies to all electricity consumers excluding only the vulnerable consumers.	Agriculture, Industry, Service, Transport, Households	Implemented 2017-2019 Ongoing
Incentives for new buildings with higher energy efficiency than EPBD requirements	New buildings and buildings renovated can receive a 5% extra building factor if they achieve higher energy efficiency than the minimum mandatory levels provided by the legislation. Ongoing with different minimum requirements for the period 2021-2030	Energy saving measures likely to mainly address heating and/or cooling.	Implemented 2016-2020 2021-2030
Energy efficiency in existing hotels	Financial support, in the form of grants, for individual energy efficiency interventions. Implemented by the National Government	Energy saving measures likely to mainly address heating and/or cooling.	Implemented 2017 Ongoing

2.3 Dimension Energy Security

There are no specific policies and measures relevant to heating and cooling that affect energy security. In general terms, reductions through energy efficiency in end use demand improves energy security. However, a shift over time from fossil fuel heating systems to heat pumps risks increasing the stress on centralised electricity supply infrastructure. This can be ameliorated through increased local renewable power generation, particularly solar photovoltaics, and through greater energy efficiency of non-heating and cooling uses of electricity such as lighting, motive power, and appliances.

2.4 Dimension Internal Energy Market

Name of policy or measure	Short description (precise scope and modalities of operation)	Relevance to heating and cooling	Status
Ministerial Order (no. K.D.P. 289/2015) regarding energy poverty, the categories of vulnerable customers of electricity and the measures to be taken to protect such customers.	Based on the provisions of Directive 2009/72/EC the Order determines the categories of vulnerable consumers of electricity. Additionally, the Order defines the measures to protect vulnerable categories of electricity customers as follows: (a) reduced prices on electricity tariffs (special electricity tariff 08) which is based on a Ministerial Decision (no. K.D.P. 286/2016) (b) financial incentives (depending on the available budget) for installing a net-metering photovoltaic system (c) financial incentives (depending on the available budget) for upgrading the energy efficiency of their houses (d) safeguarding the continuous supply of electricity, during critical periods, to those vulnerable consumers that uninterrupted power supply is essential for reasons related to their health.	Vulnerable electricity consumers, particularly where electricity use is high due to it providing heating and/or cooling.	Implemented (a) since 2006 (b) since 2013 (c) since 2014 (d) since 2015

2.5 Dimension Research, Innovation and Competitiveness

There are no specific measures relevant to heating and cooling.

3 NECP Heating and Cooling With Existing Measures (WEM) Scenario

The report *Comprehensive Impact Assessment of the Planned Policies and Measures of the National Energy and Climate Plan of Cyprus, Deliverable 5*, December 2019 presents the projected impacts of the existing policies and measures, referred to as the With Existing Measures (WEM) scenario on the energy mix and emissions until 2030. The results are broken down by sector, i.e. electricity, transport, and heating and cooling. The heating and cooling results are presented and considered here. Whilst some of the measures originally included in the WEM Scenario were already historic, have since ceased or have been abandoned, their individual contributions to the projected final energy demands (if any) are not provided in the NCEP or the Impact Assessment reports. We assume that the measures that were already historic at the time of developing the NCEP will have not affected the projected final energy demands. Given this, we have used the NCEP WEM Scenario projections as the basis of the following analysis.

3.1 Final Energy Demand, Primary Energy Supply and Carbon Emissions

Table 1 and Figure 1 below shows the WEM scenario projected final energy demands by energy type from 2021 to 2050 based on data in the NCEP Impact Assessment, Deliverable 5, plus the situation in 2018 as determined under Point A of the current work. The Impact Assessment and the NCEP itself do not provide values for the ambient heat captured by heat pumps, but this has been calculated and included in Table 1 here. It is understood however, that the calculation of the percentage RES in the NCEP tables includes ambient heat in the numerator and denominator, but electricity is excluded from the denominator; i.e.:

$$\text{RES share}_{\textit{(NCEP tables)}} = \frac{\text{(Biomass + Geothermal + Solar thermal + Ambient heat)}}{\text{(Total}_{\textit{(incl. Ambient heat)}} \text{ - Electricity)}}$$

The equivalent data for primary energy supply are presented in Table 2 and Figure 2, and for carbon emissions in Table 3 and Figure 3. These have also been determined from data in the NCEP Impact Assessment, Deliverable 5, plus the situation in 2018 as determined under Point A. The emissions factor for delivered electricity has been determined from the projected WEM fuel mix for each year and is also shown in Table 3.

Indices for the three parameters are shown together for comparison in Figure 4.

Table 1: Final energy demand (FED) of the heating and cooling sector (PJ) – WEM scenario

	2018	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045	2050
Electricity	6.68	7.83	8.12	8.30	8.51	8.69	8.91	9.14	9.38	9.64	9.79	10.42	10.87	11.31	11.71
Other oil products	7.99	6.88	6.83	6.70	6.67	6.69	6.70	6.69	6.68	6.65	6.62	6.06	5.74	4.99	4.24
Pet Coke	2.33	3.16	2.95	2.74	2.58	2.49	2.41	2.33	2.26	2.18	2.13	1.92	1.72	1.58	1.47
LPG	1.40	2.61	2.60	2.56	2.57	2.61	2.65	2.70	2.74	2.78	2.82	2.81	2.69	2.48	2.19
Biomass	2.22	1.04	1.02	0.99	1.04	1.10	1.16	1.21	1.25	1.29	1.33	1.44	1.63	1.65	1.63
Geothermal	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.07	0.09	0.14	0.21
Solar thermal	2.93	3.01	3.03	3.03	3.11	3.20	3.29	3.40	3.51	3.63	3.75	4.77	5.99	7.09	8.2
HP ambient heat	1.93	2.01	2.04	2.07	2.10	2.13	2.16	2.19	2.23	2.24	2.27	2.41	2.56	2.69	2.85
Total	**25.55**	**26.60**	**26.65**	**26.45**	**26.64**	**26.97**	**27.34**	**27.71**	**28.10**	**28.46**	**28.76**	**29.90**	**31.29**	**31.93**	**32.50**
RES share	**30.4%**	**32.6%**	**33.2%**	**33.9%**	**34.8%**	**35.5%**	**36.2%**	**36.9%**	**37.6%**	**38.3%**	**39.0%**	**44.6%**	**50.3%**	**56.1%**	**62.0%**
FED index (2018 = 100)	100.00	104.10	104.31	103.54	104.26	105.55	107.01	108.46	109.97	111.37	112.55	117.01	122.47	124.95	127.19

Derived from: Point A and Tables 14 and 54 of the NCEP Impact Assessment Deliverable 5

Figure 1: Final energy demand (FED) of the heating and cooling sector (PJ) – WEM scenario

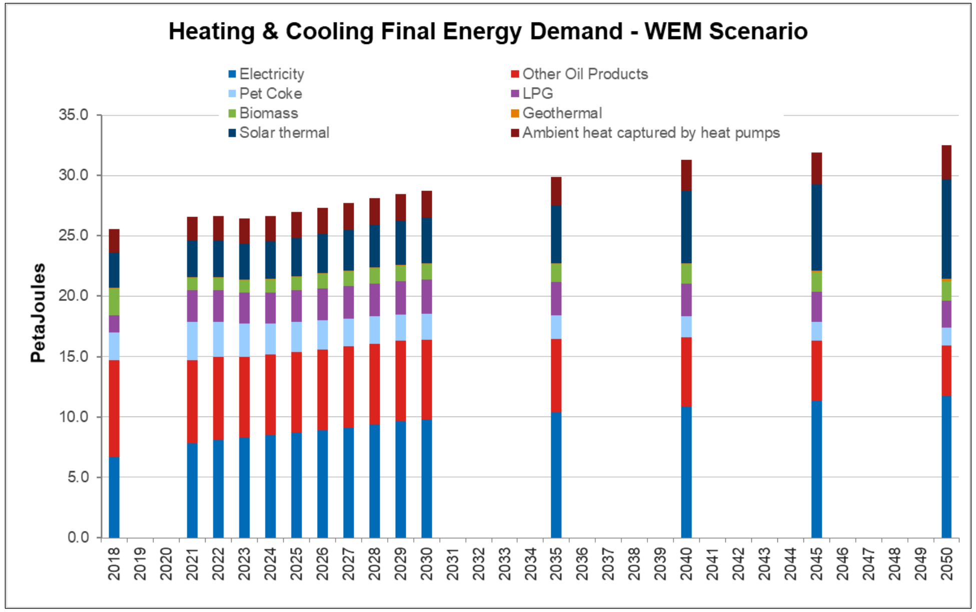


Table 2: Primary energy supply (PES) for the heating and cooling sector (PJ) – WEM scenario

	2018	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045	2050
Fuel for power generation	17.91	18.07	16.45	16.82	15.98	16.31	16.38	16.72	17.25	17.78	18.09	14.43	11.25	9.53	8.47
Other oil products	7.99	6.88	6.83	6.7	6.67	6.69	6.7	6.69	6.68	6.65	6.62	6.06	5.74	4.99	4.24
Pet Coke	2.33	3.16	2.95	2.74	2.58	2.49	2.41	2.33	2.26	2.18	2.13	1.92	1.72	1.58	1.47
LPG	1.40	2.61	2.6	2.56	2.57	2.61	2.65	2.7	2.74	2.78	2.82	2.81	2.69	2.48	2.19
Biomass	2.22	1.04	1.02	0.99	1.04	1.1	1.16	1.21	1.25	1.29	1.33	1.44	1.63	1.65	1.63
Geothermal	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.07	0.09	0.14	0.21
Solar thermal	2.93	3.01	3.03	3.03	3.11	3.2	3.29	3.4	3.51	3.63	3.75	4.77	5.99	7.09	8.2
HP ambient heat	1.93	2.01	2.04	2.07	2.10	2.13	2.16	2.19	2.23	2.24	2.27	2.41	2.56	2.69	2.85
Total	**36.78**	**36.84**	**34.98**	**34.98**	**34.11**	**34.59**	**34.82**	**35.30**	**35.97**	**36.60**	**37.06**	**33.91**	**31.67**	**30.15**	**29.26**
PES index (2018 = 100)	100.00	100.15	95.11	95.10	92.74	94.03	94.66	95.97	97.80	99.51	100.76	92.20	86.12	81.97	79.56

Derived from: Point A and Tables 15, 16, 55 and 56 of the NCEP Impact Assessment Deliverable 5

Figure 2: Primary energy supply (PES) for the heating and cooling sector (PJ) – WEM scenario

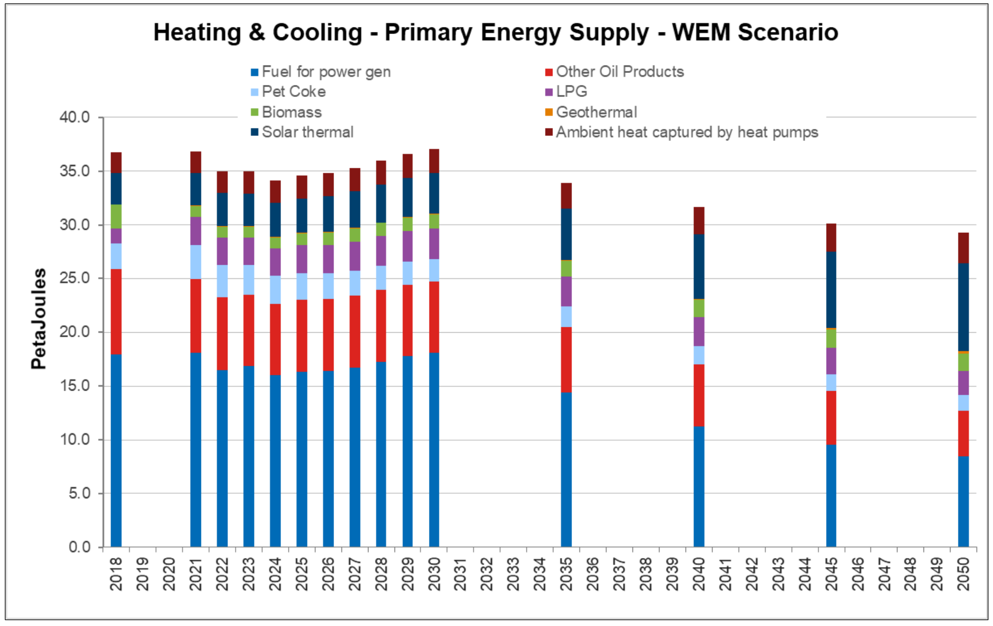


Table 3: Carbon dioxide equivalent emissions for the heating and cooling sector ($ktCO_2e$) – WEM scenario

	2018	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2035	2040	2045	2050
All fuels	2,339	2,287	1,867	1,845	1,747	1,752	1,720	1,725	1,748	1,770	1,782	1,424	1,207	1,036	876
CO_2e emissions index (2018 = 100)	100.00	97.75	79.79	78.88	74.67	74.89	73.52	73.73	74.74	75.68	76.16	60.86	51.58	44.31	37.43

CO_2e emissions factor for delivered electricity (tCO_2e/PJ)	204,942	159,440	105,162	104,402	92,334	91,547	86,206	85,183	86,058	86,821	87,132	53,906	36,596	27,898	20,898

Figure 3: Carbon dioxide equivalent emissions for the heating and cooling sector ($ktCO_2e$) – WEM scenario

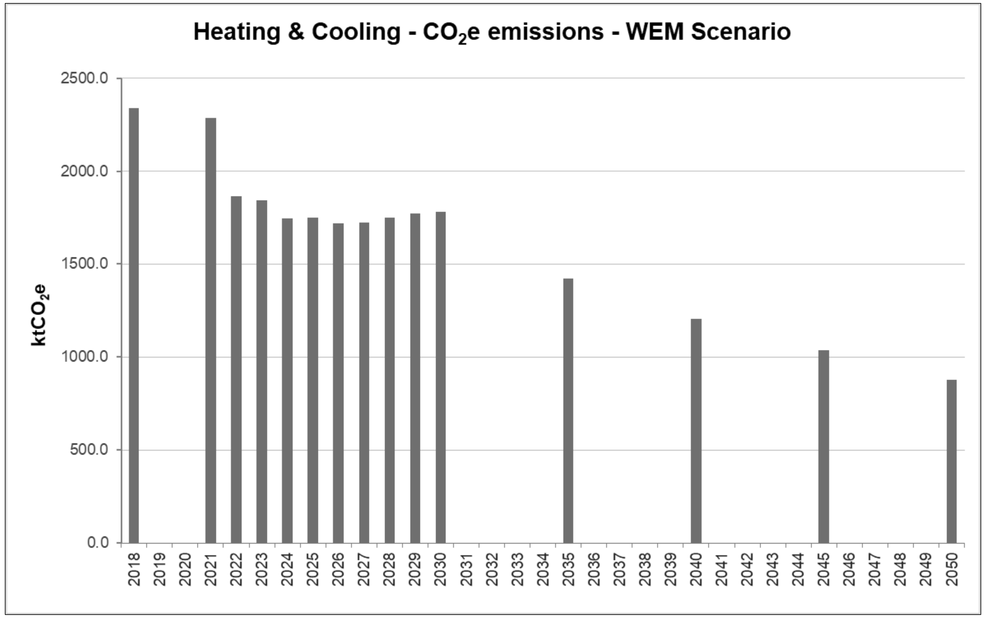
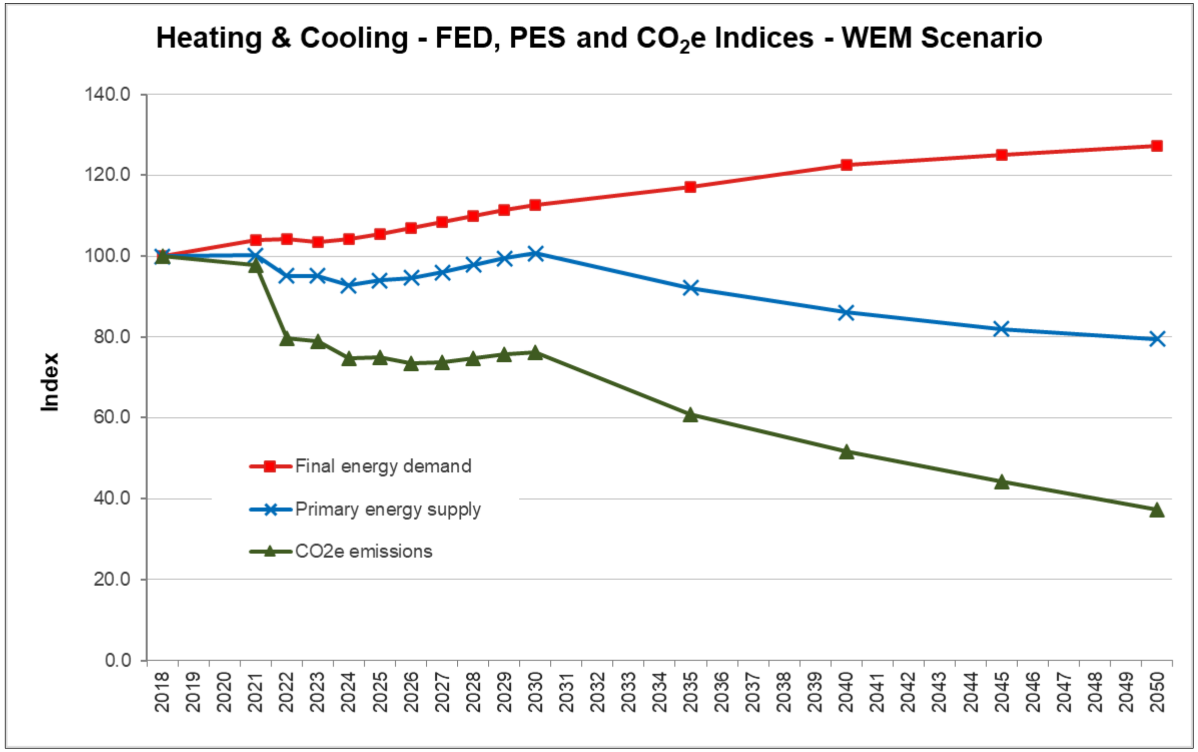


Figure 4: Carbon dioxide equivalent emissions for the heating and cooling sector ($ktCO_2e$) – WEM scenario



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Creating a world
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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

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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

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

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)

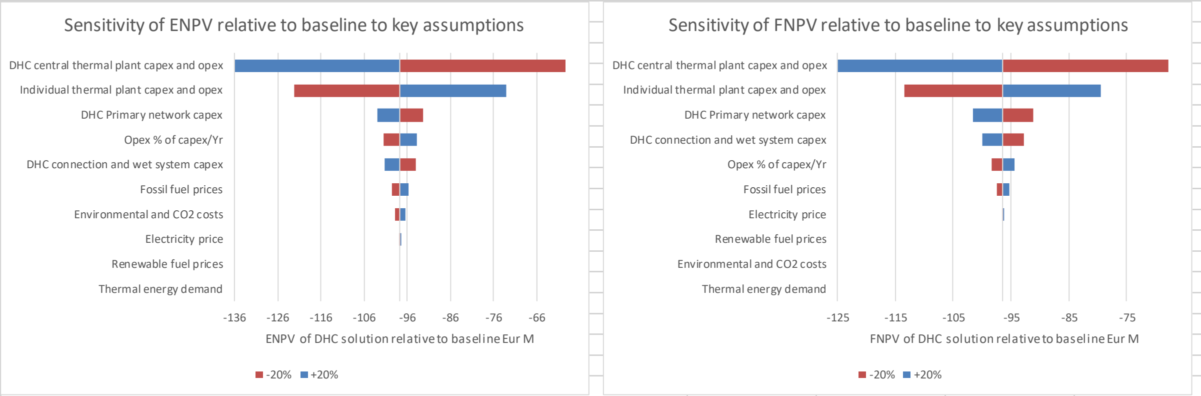
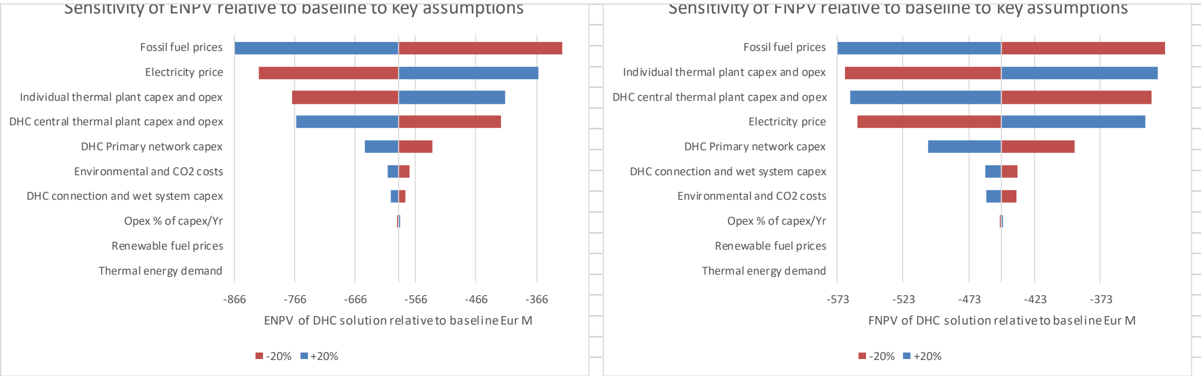


Figure 2 Sensitivity of ENVP and FNVP to changes in key input parameters to the CBA (Post Code 5330, Solution 7)



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 any 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

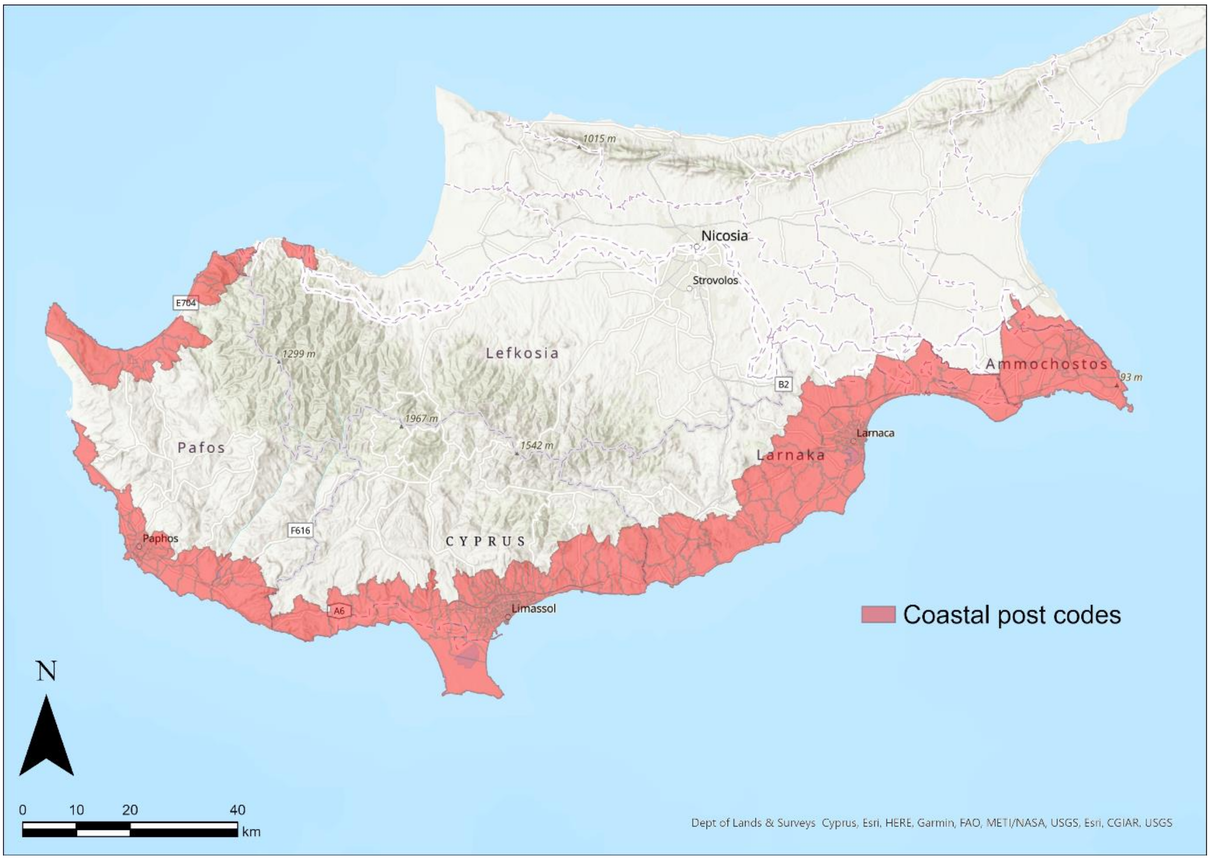

Nicosia
Strovolos
Lefkosia
Pafos
Paphos
CYPRUS
Larnaka
Larnaca
Ammochostos
Limassol
Coastal post codes
N
0 10 20 40
km
Dept of Lands & Surveys Cyprus, Esri, HERE, Garmin, FAO, METI/NASA, USGS, Esri, CGIAR, USGS

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

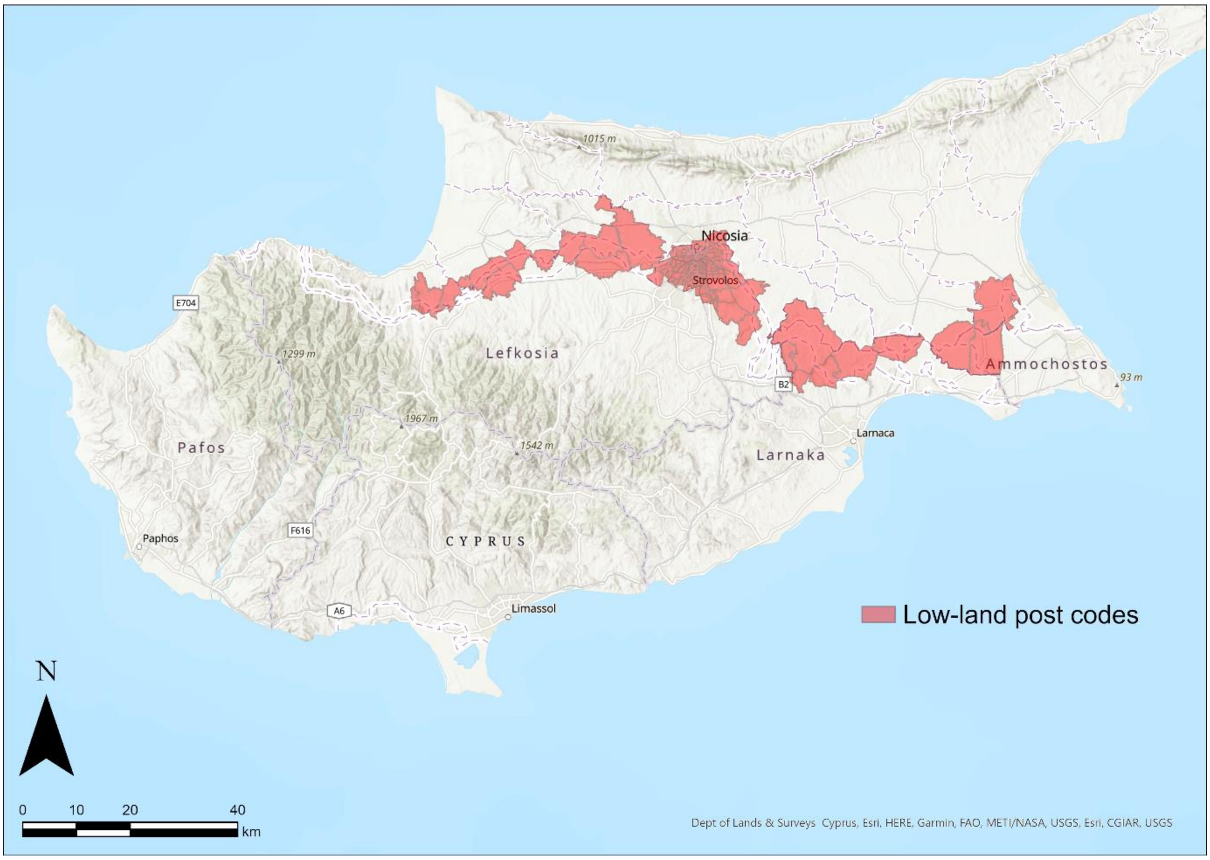

Nicosia
Strovolos
Lefkosia
Ammochostos
Pafos
Larnaka
Larnaca
Paphos
CYPRUS
Limassol
Low-land post codes
N
0 10 20 40 km
Dept of Lands & Surveys Cyprus, Esri, HERE, Garmin, FAO, METI/NASA, USGS, Esri, CGIAR, USGS

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

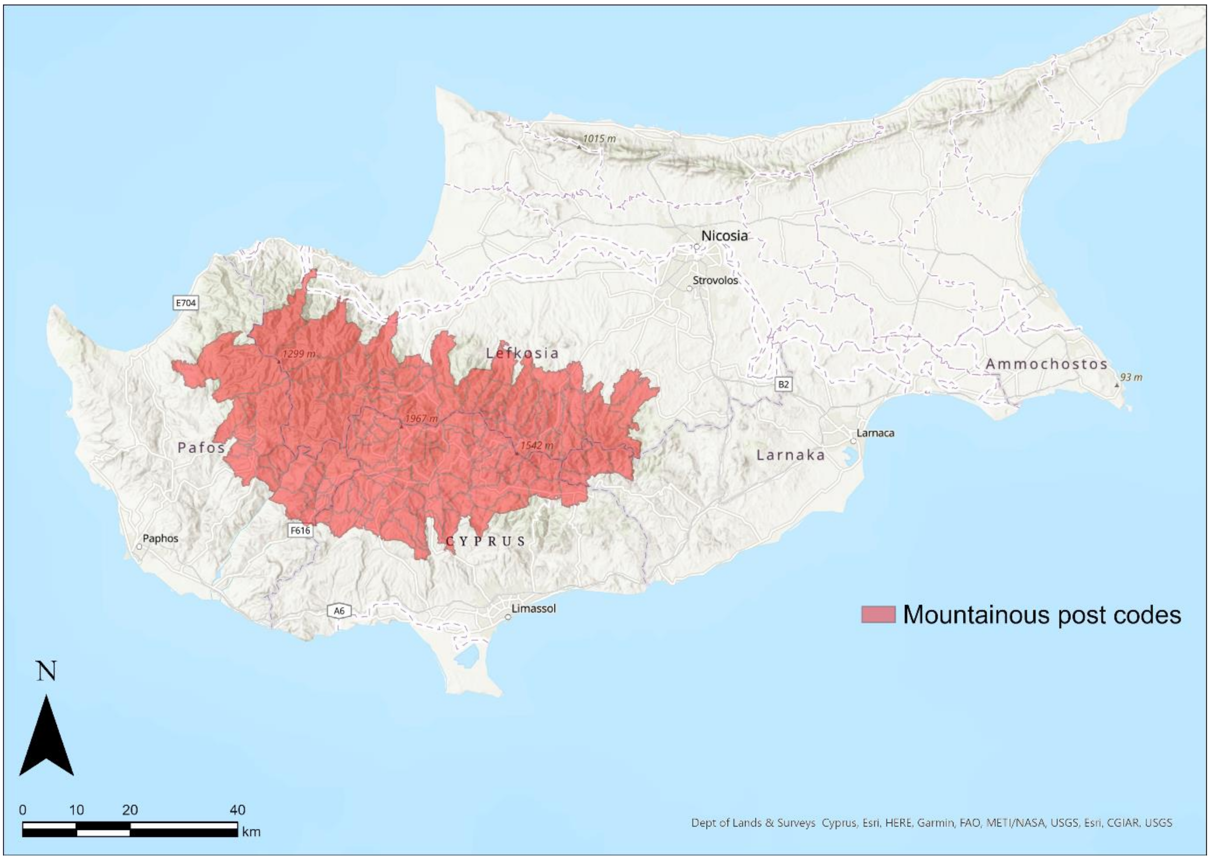
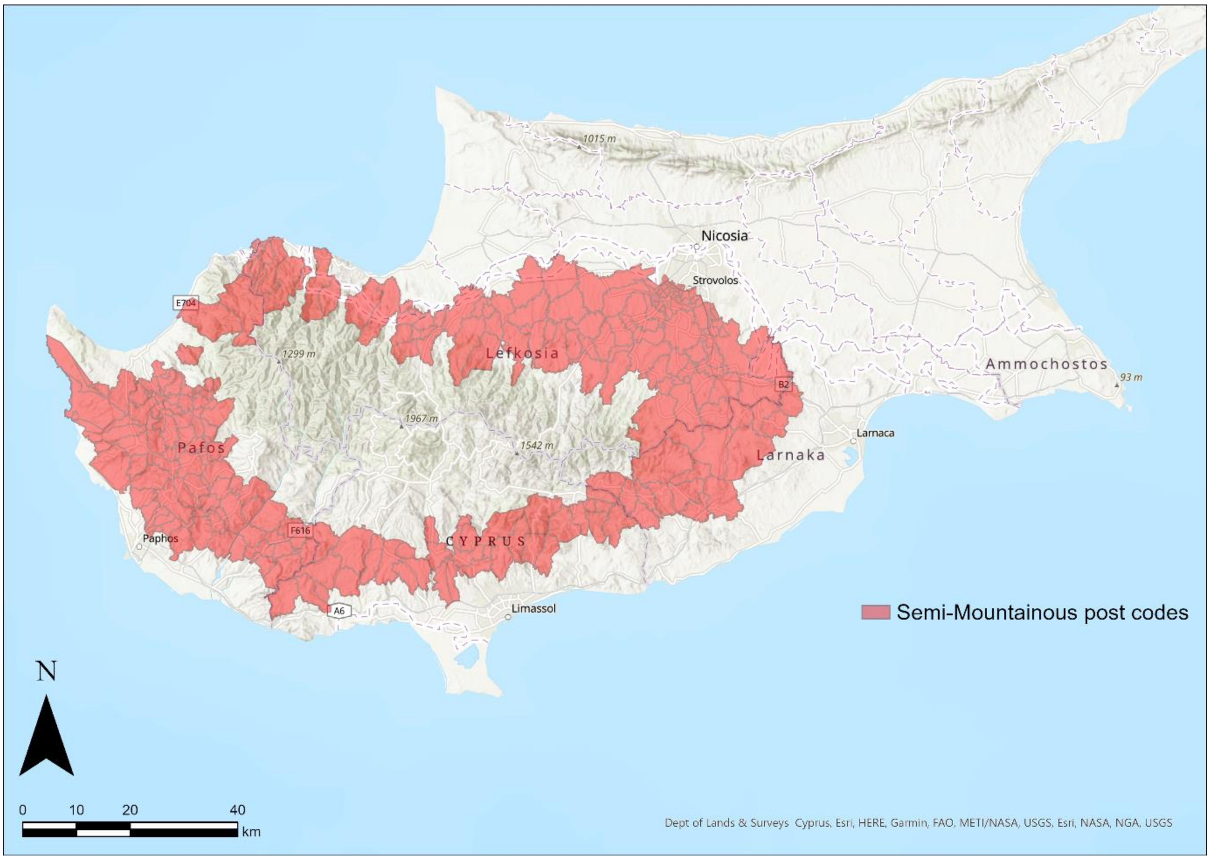

1015 m
Nicosia
Strovolos
E704
1299 m
Lefkosia
Ammochostos
93 m
B2
Pafos
1967 m
1542 m
Larnaca
Larnaka
Paphos
F616
CYPRUS
A6
Limassol
Mountainous post codes
N
0 10 20 40
km
Dept of Lands & Surveys Cyprus, Esri, HERE, Garmin, FAO, METI/NASA, USGS, Esri, CGIAR, USGS

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
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**

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Comprehensive Assessment of the Potential for Efficient Heating and Cooling Report for Point G

Report for Point G - An Overview of the Legislative and Non-Legislative Measures to Realise the Economic Potential

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

ED 14106 | Issue Number 1 | Date 27/07/2021

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1 Introduction

In the Point F report, the economic potential for efficient heating and cooling for the Republic Cyprus is set out. This potential was evaluated via a Cost Benefit Analysis (CBA) involving a Discounted Cash Flow (DCF) for a range of efficient heating and cooling technologies.

The CBA describes the economic potential as those technical solutions that have a positive Net Present Value (NPV), using a DCF and a Discount Rate (DR) of 4%, when evaluated against an established baseline technology or technologies. The baseline technology varies by sector and building type. The range of high efficiency technologies evaluated and the established baselines are set out in detail in the Point F report.

The high efficiency technology solutions under consideration here fall into two broad categories:

(1) District Heating and Cooling (DHC) solutions using, as the centralised source of heat, high efficiency cogeneration (both renewable and non-renewable), non-combustion high efficiency renewable heating technologies (heat pumps) and the recovery of waste heat from large combustion sites, and

(2) Individual site or building level high efficiency technologies

These two broad solution types compete against each other to cost effectively supply the heating and cooling demand in 877 Post Codes and 2 sub post code tourist areas[1]. Where a DHC solution is found to provide the heating and cooling demand at a lower cost than a suite of individual site/building level solutions, DHC is declared the cost effective technology, and vice versa. As discussed in the Point F report, in the vast majority of cases, individual site/building level solutions outcompete DHC.

The existing policy measures applying in the Republic of Cyprus, which have an effect on heating and cooling, are discussed in the Point E report. In the sections below we discuss the results of the CBA in the context of existing policies affecting heating and cooling, specifically from the point of view of whether these existing policies are able to support the realisation of the identified cost effective potential. Where it appears that the existing policies are not sufficient to support realisation of the potential, policy suggestions are made.

2 Existing Policy Measures and District Heating and Cooling (DHC) Solutions

Issue - In the modelling, out of 877 post code areas and 2 detailed sub post code areas, there is only one example of a DHC solution that is cost effective (i.e. positive ENPV). This involves the recovery of waste heat from one power station. Policy suggestions to increase the number of cases where this could become cost effective are discussed later.

With the exception of two sub post code detailed tourist areas evaluated, for all other DHC solutions, both the ENVP and FNPV are negative. In the case of the two tourist areas, the FNPV is positive but ENPV is negative. When pollution costs are removed from the ENPV analysis, the ENPV for the two tourist areas turns positive, as it does for 19 other Post Codes. However, for these 19 post codes, the FNPV remains negative. From this finding two things can be proposed:

That, given the very low discount rate used in the ENPV analysis (4%) it is difficult to justify, on grounds of value for money, the formulation of policy interventions to bring forward the vast majority of DHC schemes defined in the modelling. This view is further reinforced by the other non-financial barriers to DHC deployment, such as resistance to the situation of energy centres near to residential areas and the uncertainty with DHC operators gaining the security represented by long term energy supply contracts, necessary to re-risk projects.

[1] Owing to considerations of grade of heat, not all technologies are capable of supplying all the heat demand. Susceptible heat demand here therefore means the demand for heat in a post code (or sub post code area) which is of a grade that can be satisfied by the technology under consideration.

However, the cost effectiveness of the two detailed tourist areas raises the distinct possibility that, if the DHC cost effective potential analysis is carried out at a more granular level than the Post Code level used in this Comprehensive Assessment, then more cost effective DHC potential is likely to be found.

Under Article 14 paragraph 5 of the Directive 2012/27/EU, the results of this Comprehensive Assessment should be taken into account when a new thermal electricity generation installation is planned. In so far as these are very likely to be located on the same site or very close to the existing power stations and this CBA has found cost effective potential for the recovery of heat from one existing power station and its supply to a DHC scheme serving the post code in which it is located, this supports the view that cost benefit analyses should continue to be carried out in respect of new thermal electricity generation installations.

Regarding the cost effectiveness of the one heat recovery DHC solution, this is aided by the absence of fuel and environmental costs and by the fact that the waste heat is generated in reciprocating engines.

However, as it stands, recovery of heat from other power stations is not viable. There are two reasons for this.

- Power stations using technologies from which waste heat is available without the need to alter the technology (i.e. open cycle gas turbines) have load factors which indicate that they are operating as peaking plant and, therefore, would not be reliable sources of heat for DHC.
- With the exception of the one cost effective example mentioned above, all other power stations that are not operating as peaking plant (and therefore could act as reliable sources of heat for DHC), are understood to be using condensing steam turbines. In order for heat to be extracted from these, the steam turbines would need to be pass-out condensing steam turbines. The cost of replacing existing condensing STs with POCO STs would be prohibitive.

However, the marginal additional cost associated with specifying a POCO ST as opposed to condensing ST when a power ststion is designed is far lower and, for that reason, much more likely to yield a DHC scheme that is cost effective.

Recommendation – In light of the issue highlighted above, we would recommend that consideration should be given for new thermal power stations undergoing planning to be made CHP ready, with the caveat that a cost benefit analysis is carried out in respect of each individual case before this is made a condition of permitting. Recent studies carried out in Cyprus have shown that even for large planned power stations, the supply of heat extracted from the steam turbine of a CCGT would have to be delivered to a heat network no further than 4 km away for this to be cost effective. Similar distance constraints on heat linking can be anticipated for other planned power stations. There are other constraints that could have a deleterious effect on the cost effectiveness of making a power ststion CHP, which would only come to light via a proper study. Examples of such constraints are the possible need for the power station to provide frequency response to the network, which could adversely affect the economics of heat supply, and the ability of the installation to meet the primary energy saving requirements. Space constraints for auxiliary equipment, such as district heating heaters and hot water storage may also materially impact the proposition.

As explained in the Point F report, by far the most cost effective high efficiency heating and cooling technologies, as applicable to the residential and Service sectors, is the generation of electricity using PV and the use of this electricity as an input to heat pumps to provide space heating and cooling and, where not currently provided by solar, sanitary hot water.

There are two existing policy instruments which should be reviewed in order for this potential to be realised. These are the “proper recovery systems for F-gases equipment” and the “support scheme for the production of electricity from renewable sources for own use”. These are discussed in Sections 2.1 and 2.2.

2.1 Preparation of a Proper Recovery System for F-Gases in Equipment

Issue - This is an obligation according to EU and national legislation but, as explained in the Point E report, is still not properly implemented. Implementation of this becomes especially important if the number of heat pumps in deployment increases, as the number reaching the end of their lives will also increase going forward. It is understood that preparation of a proper recovery system has been delayed, but is due to commence this year (2021), and that a budget of €1 million has been set aside.

Recommendation - Review the work to date on the F-gas recovery system in the context of the large cost effective potential for heat pump deployment in the residential and service sectors. Ensure that delivery timelines and budget set aside for the preparation of this system are commensurate with the opportunity presented by significant deployment of heat pumps.

2.2 Support Scheme for the Production of Electricity from Renewable Energy Sources for Own Use

Issue - The large potential for PV + heat pumps in the residential and service sectors is partly underpinned by assumptions relating to the sizing of the PV panels and specifics of their operation. As explained in the Point F report, PV panels are modelled such that the capacity is sufficient to generate, over the year, all heat pump electricity demand to deliver space heating and space cooling. Since PV generation will not always be in phase heat pump electricity demand, as driven by the demand for heating and cooling, either electricity storage or net metering is required. In the modelling net metering is assumed. This avoids the need for battery storage and therefore has the advantage of keeping the Capex of the solution down and obviating any issues with the availability of space for battery storage.

As explained in the Point E report, the support scheme for the production of electricity is capped at 5 MW for residential and at 15 MW for non-residential per annum and is renewed each year. The total PV capacity needed to realise the cost effective potential where PV + heat pump is the best solution is 1,928 MWe, with approximately 50% of this is each of the residential and service sectors. Clearly, for the current net metering provision to support more than a modest proportion of this capacity the capacity caps would have to be raised significantly.

Recommendation – Consider raising the capacity cap for PV with net metering. Further work should be undertaken to understand how far the capacity cap could be raised in a way that is sustainable for the stakeholders involved. In respect of a revised cap, the modelling could be refined to identify the tranche of potential where savings are maximised for this cap. Policy could be formulated to facilitate the realisation of this specific tranche of potential. In respect of the currently identified potential which would exceed any new cap, the modelling would have to be refined to assess the relative cost effectiveness of the following options (1) importing electricity at times when PV generation is insufficient to meet heat pump demand, and (2) installing storage batteries of the required capacity and whether this can be done at the individual building level or at the system level, whereby central battery storage is employed. When that work is complete, it should be possible to assess whether new fiscal measures and policies are required to realise potential available which would not fall within the cap.

In further assessing options it should be kept in mind that, in the vast majority of cases, Point F has shown that heat pumps powered by grid electricity also serves as a cost effective option relative to the baseline.

3 Existing Policy Measures and Individual Site Level Industrial Heating and Cooling Demand

Within the industry sector, the most cost effective heating and cooling solutions are either oil or LPG fired CHP with absorption chillers, for architypes requiring process cooling[2]. These CHP solutions are cost effective from both the Economic (ENPV) and Financial (FNVP) perspectives. Therefore, when viewed through the architypes modelled in this work, oil and LPG CHP technologies are justified from a public and private investment perspective. In this regard, policy intervention should be unnecessary. However, this does raise the question of why CHP has only been deployed in the agriculture and waste management sectors, even though there is a net-billing scheme available for CHP deployed in the commercial/industrial and public administration sectors.

The deployment of CHP in agriculture and waste management is driven by the need to deal with waste arising in these sectors, where the waste can be used as a fuel. Oil and LPG fired CHP, if run efficiently can not only achieve the primary energy savings required under the definition of high efficiency cogeneration but can achieve CO_2 emissions per unit of electricity generated of less than the 0.55 $kgCO_2/kWh$ required by some investors. This is the case if the fuel for heat is stripped out of the calculation using the reference value for the separate generation of heat.

Given the cost effective potential of CHP, it is likely that a lack of experience with the implementation and maintenance of CHP is playing a role in the fact that it has not been implemented in industrial sectors like food and drink and some large commercial establishments. Given that natural gas is not available at the moment and will not be available for consumption in the future outside of the areas occupied by the power stations, the need to store LPG and oil on site to enable CHP deployment may also present as a physical obstacle for some industrial sites.

These cost effective CHP solutions (oil and LPG CHP), while they are found via the modelling to save primary energy relative to the baseline over the project lifetime, do not save CO_2. This is due to the significant decarbonisation of the electricity grid anticipated going forward. Biomass CHP, when applied to the industrial architypes, saves CO_2 and also produces a positive FNPV, but produces a negative ENPV. This is due to the pollution costs ascribed to the burning of biomass, specifically the cost attached to PM10 emissions. When these pollution costs are dis-applied (as is the case in the FNPV analysis) a positive ENPV is returned for biomass CHP against all industry architypes.

Recommendation – Regarding the near term implementation of oil or LPG fired CHP, which is efficient from an economic and primary energy point of view, but has not penetrated industry, consider measures that can address the current issues of lack of skills and experience with the implementation of CHP projects.

Further work is needed to assess what additional costs would have to be incurred to remove the PM10 issue from biomass CHP and what effect this would have on the cost effectiveness of the solution relative to the baseline and relative to the other CHP options that appear cost effective. In light of this work, assess whether there is any policy intervention needed to bring forward biomass CHP

4 Impacts of Realising the Economic Potential

Assuming policy measures are designed and put in place to realise the identified economic potential, the following benefits would result in 2030, 2035, 2040, 2045 and 2050, relative to the “With Existing Measures” (WEM) baseline.

[2] Process cooling is modelled as necessary in the Chemicals and Food and Drink sectors.

4.1 Greenhouse Gas Emissions Reductions

Table 4-1 In year CO_2 savings associated with the implementation of cost effective best high efficiency solutions, relative to the WEM projection

Year	Baseline CO_2 Associated with Heating and Cooling ($ktCO_2$)	Absolute Reductions w.r.t Baseline ($ktCO_2$)	% Reductions w.r.t Baseline
2030	1,782	1,340	75%
2035	1,424	880	62%
2040	1,207	630	52%
2045	1,036	484	47%
2050	876	363	41%

Since the WEM baseline has ever decreasing CO_2 emissions associated with it, the sooner the high efficiency cost effective potential is implemented, the greater will be the in-year reductions in heating and cooling CO_2 emissions.

4.2 Primary Energy Savings

Table 4-2 In year primary energy savings associated with the implementation of cost effective best high efficiency solutions, relative to the WEM projection

Year	Baseline Primary Energy Associated with Heating and Cooling (GWh)	Absolute Reductions w.r.t Baseline (GWh)	% Reductions w.r.t Baseline
2030	10,360	3,275	32%
2035	9,975	2,182	22%
2040	9,964	1,594	16%
2045	9,946	1,281	13%
2050	9,940	1,027	10%

Since the WEM baseline has an ever decreasing ratio of primary energy input to delivered energy output for electricity generation, as increasing proportions of primary renewables such as solar PV, solar thermal and wind are introduced, the in-year primary energy savings associated with implementation of cost effective high efficiency solutions decreases year on year. Therefore, the sooner the high efficiency solutions are implemented the greater will be the additional benefit to primary energy reduction.

4.3 Impact on Share of High Efficiency Cogeneration

Table 4-3 In year effect of implementation of best CHP high efficiency solutions on CHP electricity generation

Year	Current CHP Electricity Generation (GWh)	Additional CHP Generation Associated with Cost Effective Potential (GWh)	% Increase in CHP Generation w.r.t Baseline
2030	57.4	410	+714%
2035	57.4	410	+714%
2040	57.4	410	+714%
2045	57.4	410	+714%
2050	57.4	410	+714%

N.B For the purposes of this analysis, it is assumed that the CHP electricity generation in 2018 is maintained in the absence of the implementation of additional cost effective CHP potential.

4.4 Impact on Share of Renewables in National Energy Mix in Heating and Cooling Sector

Table 4-4 In-year share of renewable energy in primary energy supply associated with WEM projection and if the cost effective best high efficiency solutions are implemented

Year	Share of Renewables of Primary Energy Supply for Heating and Cooling Generation in Baseline	Share of Renewables of Primary Energy Supply for Heating and Cooling Generation if Economic Potential Realised	Additional Benefit Associated with Implementation of High Efficiency Solutions (
2030	29%	69%	+40%
2035	43%	73%	+30%
2040	52%	77%	+25%
2045	59%	79%	+20%
2050	66%	81%	+15%

The implementation of the best high efficiency always increases the share of renewable energy associated with the provision of heating and cooling, relative to the WEM baseline. However, as share of renewables in the baseline increases, the additional renewables contributed by the best cost effective solutions decreases.

4.5 Cost Savings for the Public Budget and Market Participants

The high efficiency solutions which are cost effective are so because they generate positive cash flow, relative to the baseline technologies, for years outside of capital expenditure. Below, expressed in €2020, are the total in-year savings to be enjoyed, relative to the baseline, if all of the cost effective high efficiency solutions identified in Point F are implemented. With a large proportion of the best solutions constituting PV + heat pumps, with significant free energy flows in the form of ambient heat and solar insulation, the in years are significant in absolute and relative terms.

Table 4-5 In-year economic and financial savings relative to the baseline

Year	In-year Positive Economic Cashflow Associated with Implementation of High Efficiency Solutions (€m)	% Economic Saving	In-year Positive Financial Cashflow Associated with Implementation of High Efficiency Solutions (€m)	% Financial Saving
2030	706	63%	577	59%
2035	709	63%	608	60%
2040	673	61%	590	59%
2045	651	60%	577	58%
2050	629	59%	565	57%

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