Annex 54

Heat Pump Systems with Low-GWP Refrigerants

Country Report Austria

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Preface

This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), which is a Technology Collaboration Programme within the International Energy Agency, IEA.

The IEA

The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of nearly 40 Technology Collaboration Programmes.

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the implementing agreement for a programme of research, development, demonstration and promotion of heat pumping technologies. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

Under the TCP, collaborative tasks, or "Annexes", in the field of heat pumps are undertaken. These tasks are conducted on a cost-sharing and/or task-sharing basis by the participating countries. An Annex is in general coordinated by one country which acts as the Operating Agent (manager). Annexes have specific topics and work plans and operate for a specified period, usually several years. The objectives vary from information exchange to the development and implementation of technology. This report presents the results of one Annex.

The Programme is governed by an Executive Committee, which monitors existing projects and identifies new areas where collaborative effort may be beneficial.

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The HPT TCP is part of a network of autonomous collaborative partnerships focused on a wide range of energy technologies known as Technology Collaboration Programmes or TCPs. The TCPs are organised under the auspices of the International Energy Agency (IEA), but the TCPs are functionally and legally autonomous. Views, findings and publications of the HPT TCP do not necessarily represent the views or policies of the IEA Secretariat or its individual member countries.

The Heat Pump Centre

A central role within the HPT TCP is played by the Heat Pump Centre (HPC).

Consistent with the overall objective of the HPT TCP, the HPC seeks to accelerate the implementation of heat pump technologies and thereby optimise the use of energy resources for the benefit of the environment. This is achieved by offering a worldwide information service to support all those who can play a part in the implementation of heat pumping technology including researchers, engineers, manufacturers, installers, equipment users, and energy policy makers in utilities, government offices and other organisations. Activities of the HPC include the production of a Magazine with an additional newsletter 3 times per year, the HPT TCP webpage, the organization of workshops, an inquiry service and a promotion programme. The HPC also publishes selected results from other Annexes, and this publication is one result of this activity.

For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
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8 Country Report: Austria

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8.1 Executive Summary

National and international regulations aim to reduce the greenhouse gas emissions caused by the release of refrigerants into the atmosphere by defining restrictions for refrigerants with high GWP values in certain applications and by limiting the total CO_2 equivalent of refrigerants on the market through a phase-down concept. However, currently, most used refrigerants have GWPs with a magnitude of 1000 or even more. While in other sectors like refrigerators or freezers, natural refrigerants like R290 and R600a can easily be used, the situation is different for heat pumps due to higher capacities and higher refrigerant charges. In IEA HPT Annex 54, the potential replacement of conventional (high GWP) refrigerants by so-called Low GWP refrigerants (e.g., R290) and its implications are investigated.

Task 3 is based on the investigations regarding the technical implications of changing a heat pump system from an R410A baseline system to a charge-optimized R290 system using Modelica simulations in Task 2. This third Task focuses on the impact of these system adaptations on the Life Cycle Climate Performance (LCCP) of a heat pump system.

To achieve comparability, unified calculations were performed to determine the LCCP of both the R410A baseline system and the charge-optimized R290 system. The LCCP was calculated using the software *Pack Calculation Pro*. As this calculation tool excludes indirect emissions from equipment manufacturing and equipment recycling as well as refrigerant manufacturing, this missing emission share was calculated with the Excel-based tool *IIR-LCCP-Calculation-Tool* (IIR 2018).

The investigations show that the charge-optimized R290 system does not only perform better regarding direct carbon dioxide equivalent (CO_{2e}) emissions (refrigerant leakages) due to its very Low GWP but also due to a better energy efficiency performance due to better thermodynamic properties:

Based on the leakage rates proposed by IIR (2016), the direct CO_{2e} emissions due to refrigerant leakage and end-of-life refrigerant losses of the R410A baseline system would account for approximately 38.3 tons CO_{2e}, those of the charge optimized R290 system to only 8 kg.

The (electrical) energy consumption of the R410A baseline system during its lifetime leads to indirect CO_{2e} emissions of approximately 20.3 tons CO_{2e}. Due to better thermodynamic properties, the respective value of the charge-optimized R290 system is significantly lower (16.6 tons CO_{2e}).

The direct CO_{2e} emissions from refrigerant leakage and the indirect CO_{2e} emissions due to the (electrical) energy consumption sum up to a Total Equivalent Warming Impact (TEWI) of approximately 58.5 tons CO_{2e} (R410A baseline system) resp. 16.6 tons CO_{2e} (charge optimized R290 system).

Adding indirect CO_{2e} emissions from manufacturing and recycling the LCCP of the R410A baseline system and the charge-optimized R290 system is calculated to approximately 59.6 tons resp. 17.4 tons CO_{2e}.

To better understand the significance of these values, the TEWI values were compared with the lifetime CO_{2e} emissions of a comparable natural gas-fired heating system: the latter would account for CO_{2e} emissions of approximately 128 tons CO_{2e}. In relation to this value, the TEWI values of the R410A baseline system and the charge-optimized R290 system are 46% resp. 13% of this value. The deviation in performance between the R410A baseline system and the charge-optimized R290 system supports the call for replacing conventional refrigerants with Low GWP refrigerants. Reducing the refrigerant charge and improving refrigerant leakage rates are further valid approaches for improving the LCCP of heat pump systems.

Furthermore, it should be mentioned that for Austria’s domestic heat pump market, the actual refrigerant leakage rate and end-of-life refrigerant leakage might be lower than assumed in this investigation. As in Austria, the exact situation regarding refrigerant leakages is not known; the assumptions in this investigation were made as recommended by the IIR. In the future, comprehensive investigations regarding the actual refrigerant leakage situation in Austria’s domestic heat pump market are highly recommended.

8.2 Introduction

Task 3 focuses on the impact of changing a heat pump system from an R410A baseline system to a charge-optimized R290 system on global warming. Unified calculations are performed with specialized tools to determine the life cycle climate performance (LCCP) of both systems.

The LCCP is expressed as the amount of carbon dioxide equivalent (CO2e) emissions that are emitted during the whole life cycle of a technical system. The latter is a metric measure used to compare the emissions from various greenhouse gases based on their global warming potential (GWP) by converting amounts of other gases to the equivalent amount of carbon dioxide with the same global warming potential (Eurostat, 2017).

Within this task, a concurrent bachelor thesis (Gattermeyer, 2022) was written by a student of the Renewable Energy Technologies Program at the University of Applied Sciences FH Technikum Wien. This thesis is the foundation of this chapter, the information was taken from IIR (2016).

8.2.1 Definition of “LCCP”

The LCCP analysis is a method to evaluate the amount of greenhouse gas that is generated and released over the lifetime of a system. It takes all emissions from manufacturing, operation, and final disposal into account. The occurring emissions are split into direct and indirect emissions. In

LCCP analyses, those emissions are both treated separately and linked together in the result. Besides the investigated system configuration, the outcome of an LCCP analysis depends on several parameters such as climate data, electricity mix, etc. The often-used calculation method "Total Equivalent Warming Impact" ("TEWI") also takes into consideration the above-mentioned direct and indirect CO2e emissions but, in contrast to the LCCP, does not include indirect CO_{2e} emissions from manufacturing and recycling.

8.2.1.1 Calculation of direct emissions

Direct emissions comprise the effects of refrigerant released into the atmosphere over the lifetime of the unit and at its disposal. This includes:

- Refrigerant loss from annual leakage (during the lifetime of the unit)
- Losses at the end-of-life disposal of the unit
- Atmospheric reaction products from the decomposition of the refrigerant in the atmosphere

Each group is calculated using the rate of refrigerant leakage multiplied by the refrigerant charge and the global warming potential (GWP) of the refrigerant.

8.2.1.2 Calculation of indirect emissions

Indirect emissions result from the use of the unit over its lifetime and include CO_{2e} emissions from:

- Electricity generation
- Manufacturing of materials
- Manufacturing of refrigerants
- Disposal of the unit (except for end-of-life refrigerant losses)

Each CO_{2e} emission share is calculated separately and then summed up. The main contributor to the indirect emissions is the CO_{2e} emissions from the (electrical) energy consumption of the unit.

8.2.2 Calculation Method

The calculation result is the amount of kg CO_{2e} or of kg CO_{2e}/kWh for the "specific" LCCP. To get comparable results, the assumption-based input values shall be the same for every simulated system. As stated previously, there are two general emission categories: direct (Formula 1) and indirect emissions (Formula 2). Those two are treated individually and then summed up together (Formula 3).

$$Direct\ Emissions = C * (L * ALR + EOL) * (GWP + Adp.GWP) \quad (1)$$

$$Indirect\ Emissions = L * AEC * EM + \sum(m * MM) + \sum(mr * RM) + C + (1 + L * ALR) * RFM + C * (1 - EOL) * RFD \quad (2)$$

$$LCCP = Direct\ Emissions + Indirect\ Emissions \quad (3)$$

The meaning of the abbreviations used in the formulas above is as follows (IIR, 2016):

- *"C = Refrigerant Charge (kg)*
- *L=Average Lifetime of Equipment (yr)*
- *ALR = Annual Leakage Rate (% of Refrigerant Charge)*
- *EOL = End of Life Refrigerant Leakage (% of Refrigerant Charge)*
- *GWP = Global Warming Potential (kg CO_{2e}/kg)*
- *Adp. GWP = GWP of Atmospheric Degradation Product of the Refrigerant (kg CO_{2e}/kg)*

- *AEC = Annual Energy Consumption (kWh)*
- *EM = CO_2 Produced/kWh (kg CO_{2e}/kWh)*
- *m = Mass of Unit (kg)*
- *MM = CO_{2e} Produced/Material (kg CO_{2e}/kg)*
- *mr = Mass of Recycled Material (kg)*
- *RM = CO_{2e} Produced/Recycled Material (kg CO_{2e}/kg)*
- *RFM = Refrigerant Manufacturing Emissions (kg CO_{2e}/kg)*
- *RFD = Refrigerant Disposal Emissions (kg CO_{2e}/kg)"*

8.2.3 Tools to perform LCCP-Analyses

Different tools and methods are available to perform LCCP analyses. In the following sections, the tools used in Task 3 are briefly discussed and explained.

8.2.3.1 Pack Calculation Pro

Pack Calculation Pro (IPU, 2022) is an application that compares the yearly energy consumption of refrigeration systems and heat pumps. The application compares different systems, taking into account their geographical location. *Pack Calculation Pro* provides a detailed simulation of the yearly energy consumption and a TEWI calculation. With *Pack Calculation Pro*, it is possible to simulate a real system in several different locations and at different loads. (IPU, 2021)

As the calculation of the indirect CO_{2e} emissions caused by manufacturing and recycling are not included in this tool, the calculation of these shares of CO_{2e} emissions is performed separately with the tool described in 8.2.3.2.

8.2.3.2 IIR-LCCP-Calculation-Tool

With the *LCCP-Calculation-Tool* (IIR, 2018) provided by the International Institute of Refrigeration (IIR), it is possible to run an LCCP analysis in an MS Excel environment. The needed inputs are described on the tool's main page and have to be entered there. The following inputs are necessary:

- Refrigerant (LCCP calculation available for HFC-32, HFO-1234yf, HFC-134a, R-290, HFC-404A, HFC-410A, L-41b and DR-5)
- Refrigerant charge in kg
- Unit weight in kg
- Annual refrigerant leakage rate in %/year
- End-of-life Leakage in %
- Lifetime in years
- Type of manufacturing emissions (virgin manufacturing or mixed manufacturing with shares of virgin materials and of recycled materials)
- AHRI Standard 210/240 test bench performance data at operating points A, B, H1, H2, H3
- Carbon intensity per Electricity Generation Region

The results are then presented in tables for the climates in Miami (Florida), Phoenix (Arizona), Atlanta (Georgia), Chicago (Illinois) and Seattle (Washington State). The climate data required for these calculations is included in the tool. The separate CO_{2e} emission shares and the total CO_{2e} emissions (LCCP) are listed individually. For visual illustration, graphs show the total CO_{2e} emissions and the percentage of the total CO_{2e} emissions (IIR, 2018).

In this report, the *IIR-LCCP-Calculation-Tool* is used to calculate some of the indirect CO_{2e} emissions (e.g. those emitted by the manufacturing of the equipment). Since the *IIR-LCCP-Calculation-Tool* includes climate data for regions in the USA only, the calculation of the main part of the CO_{2e} emissions was carried out using *Pack Calculation Pro*, which does include climate data for Austria (see 8.2.3.1).

8.2.4 Limitations of LCCP analyses

The calculations are impacted by several assumptions regarding the input parameters. The empirically determined values that are used to perform LCCP analyses are all subject to a certain amount of uncertainty. Therefore, the calculated results are not meant to be taken as an exact prediction of lifetime CO_{2e} emissions, but more as a comparable "value" between different settings and systems. Due to the uncertainty of the input values, small differences between systems may not be significant. Comparing different refrigerants regarding their LCCP only makes sense under certain circumstances. When comparing different systems, similar capacities are necessary for the results to be comparable.

8.3 LCCP Calculation – Comparison R290 vs. R410A

The approach of the Austrian IEA HPT Annex 54 Team focused on the present national situation regarding the refrigerants used in heat pumps installed in Austria: as in Tasks 1 and 2, R290 was identified as the sole refrigerant that corresponds to a low-GWP refrigerant in the narrower sense and has a broad potential area of application due to its thermodynamic properties, among other things, the LCCP analyses in Task 3 were only carried out for this refrigerant and for the synthetic refrigerant R410A, which is the most frequently used refrigerant in Austria's domestic heat pumps (KPC, 2021).

The heat pump system optimized to R290 (see Task 2) was compared with an R410A-baseline system using the LCCP analysis software *Pack Calculation Pro* (see 8.2.3.1) and for some parts the Excel-based tool *IIR-LCCP-Calculation-Tool* (see 8.2.3.2).

8.3.1 TEWI calculation

As explained in 8.2.3, with the calculation tool *Pack Calculation Pro*, the TEWI of the investigated system(s) can be calculated, but the tool does not provide the calculation of CO_{2e} emissions caused in the course of equipment manufacturing and recycling as well as refrigerant manufacturing. This section describes the TEWI calculation with *Pack Calculation Pro* only. The calculation of the CO_{2e} emissions caused by equipment manufacturing and recycling, as well as refrigerant manufacturing, is described in 0.

8.3.1.1 CO_{2e} emission intensity of electricity provision in Austria

The main share of indirect CO_{2e} emissions from heat pump systems is currently accounted for by electricity consumption during the system's lifetime. Since all electricity in Austria is to come from 100% renewable sources by 2030 (BMK, 2021), the CO_{2e} emission intensity of electricity provision in Austria decreases each year. Due to a lack of information on the exact annual development of the electricity CO_{2e} emission intensity of electricity provision, a linear reduction to the target value of 0 kg CO_{2e}/kWh in 2030 was assumed.

For the calculation a product lifetime of 15 years, from 2022 to 2036, was assumed. In 2022, the CO_{2e} emission intensity of electricity provision in Austria were approximately 0.2 kg CO_{2e}/kWh (Umweltbundesamt, 2022). This results in an annual reduction of this value by 0.025 kg CO_{2e}/kWh until 2030, when 0 kg CO_{2e}/kWh is assumed. This linear reduction is shown in Figure 8-1. The

CO_{2e} emission intensity values of the individual years and their average value are listed in Table 8-1. The average value that accounts to 0.06 kg CO_{2e}/kWh is used to calculate the indirect CO_{2e} emissions due to the systems' lifetime consumption of (electrical) energy using *Pack Calculation Pro*.

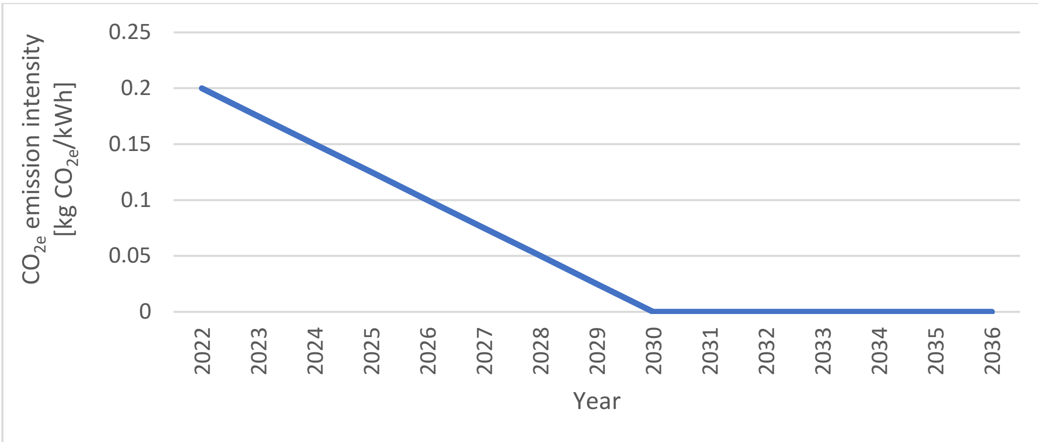

Figure 8-1: Assumed development of the CO_{2e} emission intensity of electricity provision in Austria in kg CO_{2e}/kWh

Table 8-1: CO_{2e} emission intensity of electricity provision in Austria

Year	**CO_{2e} emission intensity [kg CO_{2e}/kWh]**
2022	0.2
2023	0.175
2024	0.15
2025	0.125
2026	0.1
2027	0.075
2028	0.05
2029	0.025
2030 – 2036	0
2022 – 2036 average	**0.06**

8.3.1.2 Calculation with Pack Calculation Pro

The R410A baseline system and the charge-optimized R290 system were defined in *Pack Calculation Pro* in relation to the models used for the system simulations in Task 2. In the model library used for the system simulations in Task 2, a specific R290 compressor model comparable to the compressor model used for the R410A baseline system was not available. Therefore, a model of a compressor not yet certified for R290 was used. As *Pack Calculation Pro* does only allow the combination of refrigerants with compressors, that are certified for that certain refrigerant, a similar but slightly different compressor (Bitzer 4PESP-12P) to the one used for the system simulations in Task 2 was defined. The compressor defined in *Pack Calculation Pro* for the R410A baseline system is the same compressor as the one used in the system simulations in Task 2. Due to the simplicity of the modeling approach in *Pack Calculation Pro*, the refrigerant cycle adaptions defined in Task 2 are not represented accordingly. Besides the compressors, the R410A baseline system and the charge-optimized R290 system is modeled with the same components. The refrigerant cycle components of the *Pack Calculation Pro* models are default standard components; the tool's standard refrigerant cycle includes an internal heat exchanger, while the investigated refrigerant cycles in Task 2 were modeled without internal heat exchangers. Table 8-2 lists the main properties of both systems. Nevertheless, the resulting inaccuracy of the calculations was considered insignificant enough.

Table 8-2: Main properties of the R410A baseline system and the charge-optimized R290 system

Configuration	R410A baseline system	Charge-optimized R290 system
Heat pump type	Air source heat pump	Air source heat pump
Refrigerant	R410A	R290
Compressor	Bitzer GSD60154VA, 50Hz	Bitzer 4PESP-12P, 50Hz
Design capacity (A-15/W55)	30 kW	
Supply temperature	55°C	
Total superheat	5.0 K	
Non-useful superheat	0.0 K	

Annual (electrical) energy consumption

For the R410A baseline system and the charge-optimized R290 system, one year of operation was simulated, and the hourly load profile was calculated based on climate data for Vienna/Austria (weather station *Hohe Warte*). The simulations were performed on an hourly basis, using one steady-state simulation for each hour of the year.

The diagram in Figure 8-2 shows the (electrical) energy consumption per month of the simulated systems. Each bar equals the sum of the compressor energy consumption and the energy consumption of additional equipment (condenser and evaporator fans and pumps used in the system). The detailed results of this calculation are shown in Table 8-3. The charge-optimized R290 system achieves a 4% lower (electrical) energy consumption than the R410A baseline system.

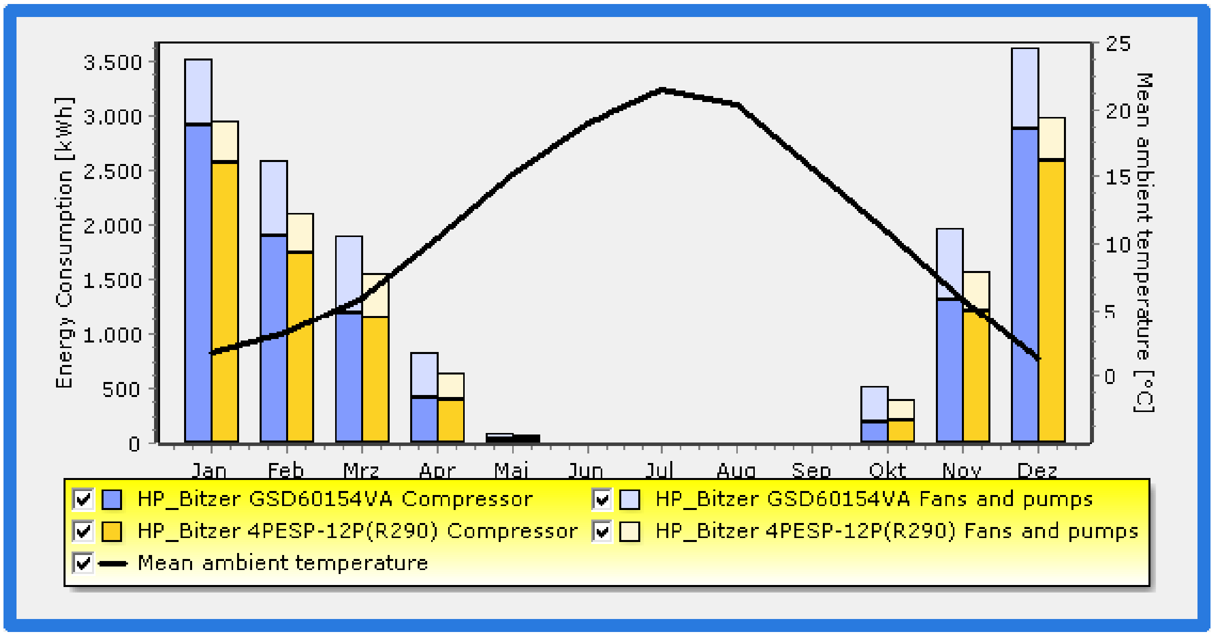

Figure 8-2: (Electrical) energy consumption of compressor as well as of fans and pumps - monthly values

Table 8-3: Results regarding the annual energy consumption of both investigated systems

	R410A baseline system	**Charge-optimized R290 system**
Refrigerant	R410A	R290
Average COP [-]	2.01	2.48
Energy consumption		
Pumps and fans [kWh]	4,173	2,401
Compressor [kWh]	10,851	9,875
Total [kWh]	**15,024**	**12,276**
Savings		
Yearly energy savings [kWh]	-	2,748
Yearly energy savings [%]	-	18.3%

TEWI

For the calculation of the TEWI in *Pack Calculation Pro*, essential input parameters must be assumed and entered into the program:

In Task 2, the refrigerant charge of the R410A baseline system and the charge-optimized R290 system were calculated for the components evaporator, condenser, and liquid line. The design capacity of both systems is 30 kW (A-15/W55). As the refrigerant charge in the compressor and the refrigerant mass dissolved in the lubricant were not included in this calculation, a different approach to estimate the total refrigerant charge was applied:

The refrigerant charge of the R410A baseline system was estimated based on empirical values; for the refrigerant charge value of the charge-optimized R290 system, the refrigerant charge of the GreenHP prototype (Zottl, 2016) was used. The empirical value regarding the refrigerant charge of the R410A baseline system was estimated as a mean specific refrigerant charge of 18 air/water heat pumps with the refrigerant R410A, of which the relevant manufacturers' data were available (from other projects). The estimated average value is 440 g R410A/kW design capacity, resulting in an absolute refrigerant charge for a 30 kW design capacity of 13.2 kg. The refrigerant charge of the GreenHP prototype (30 kW design capacity) is 1.9 kg resp. 63 g R290/kW design capacity.

The average lifetime of the two systems is assumed to be 15 years, the annual refrigerant leakage rate of 4% and the end-of-life refrigerant leakage rate of 15% (IIR, 2016). These values are common "standard values". As no exact data is available for Austria, these values were adopted, but it can be assumed that the refrigerant leakages, particularly the annual refrigerant leakage rate, would be lower. The above-mentioned assumptions are summarized in Table 8-4.

Table 8-4: Assumed input parameters for the TEWI calculations for the R410A baseline system and the charge optimized R290 system

	R410A baseline system	Charge optimized R290 system
System lifetime [years]	15	15
Estimated specific refrigerant charge [g/kW]	440	63
Design capacity (A-15/W55) [kW]	30	30
Refrigerant charge [kg]	13.2	1.9
End-of-life refrigerant leakage rate [%]	15.0	15.0
Annual refrigerant leakage rate [%/year]	4.0	4.0

The CO_{2e} emissions of the R410A baseline system due to refrigerant leakage amount to approximately 15.8 tons CO_{2e}, which is approximately 27% of the R410A baseline system's TEWI. The corresponding value of the charge-optimized R290 system is only about 3 kg CO_{2e}, which is a neglectable share of its TEWI.

While the end-of-life refrigerant losses of the R410A baseline system cause approximately 22.4 tons CO_{2e} emissions (corresponding to approximately 38.3% of the TEWI), the end-of-life refrigerant losses of the charge optimized R290 system led to CO_{2e} emissions of only about 5 kg CO_{2e}, also a neglectable share of the TEWI. The reason for the low values regarding the charge-optimized R290 system is clearly the very Low GWP of its refrigerant R290 (GWP = 3).

The CO_{2e} emissions of the R410A baseline system due to its (electrical) energy consumption during its lifetime account to approximately 20.3 tons CO_{2e}, which is approximately 34.7% of the R410A baseline system's TEWI. The corresponding value of the charge-optimized R290 system is approximately 16.6 tons CO_{2e}, which is almost 100% of its TEWI.

In total, the TEWI of the R410A baseline system accounts for approximately 58.6 tons CO_{2e}, compared to approximately 16.6 tons CO_{2e} of the charge optimized R290 system. This means a reduction in CO_{2e} emissions of approximately 72%. The values mentioned are summarized in Table 8-5.

Table 8-5: Direct CO_{2e} emissions caused by refrigerant leakage and end-of-life refrigerant losses as well as indirect CO_{2e} emissions from (electrical) energy consumption during the systems' lifespan and TEWI

	Refrigerant leakage [kg CO_{2e}]	End-of-life refrigerant losses [kg CO_{2e}]	Indirect CO_{2e} emissions (energy consumption) [kg CO_{2e}]	TEWI [kg CO_{2e}]
R410A baseline system	15,828 (27.0%)	22,423 (38.3%)	20,282 (34.7%)	58,533
Charge-optimized R290 system	3 (0.0%)	5 (0.0%)	16,572 (100.0%)	16,581

8.3.1.3 CO_{2e} emissions from manufacturing and recycling

As shown in 8.2.3, the share of indirect CO_{2e} emissions attributable to the manufacturing and recycling of the examined heat pump systems had to be determined separately, as these are not considered in the calculation tool used (*Pack Calculation Pro*).

For the calculation of this share, assumptions were made regarding the material composition of the two heat pump systems based on the data in the *IIR-LCP calculation tool* and the LCCP values were determined using known material-specific CO_{2e} emission intensity values for manufacturing and recycling of the used materials.

As the CO_{2e} emissions from manufacturing and recycling correspond to a small share of the LCCP, no detailed investigation on the exact mass and material distribution of the units was performed. Although there are differences in the system design defined in Task 2, for the R410A baseline system and the charge-optimized R290 system, the same unit mass and the same material distribution were assumed. Therefore, the results regarding the CO_{2e} emissions from manufacturing and recycling are the same for both systems. The results of the two systems thus only differ in the CO_{2e} emissions caused by the manufacturing of their refrigerants.

A mass of 230 kg was assumed for both heat pump systems. The assumed individual shares of the materials and their CO_{2e} emissions in the *IIR-LCP calculation tool* correspond to the information in the IIR's LCCP Guideline (IIR, 2016). In this, the share of steel is 46%, the share of aluminum is 12%, the share of copper is 19% and the share of plastics is 23%. Manufacturing emission values are calculated using 1.43 kg CO_{2e}/kg for steel, 4.5 kg CO_{2e}/kg for aluminum, 2.78 kg CO_{2e}/kg for copper, and 2.61 kg CO_{2e}/kg for plastics. The CO_{2e} emission values of the production of the materials refer to virgin material not mixed with any recycled material. For the recycling of metals, CO_{2e} emission values of 0.07 kg CO_{2e}/kg are used. Recycling emissions from plastics are 0.01 kg CO_{2e}/kg.

For the CO_{2e} emissions from the manufacturing of R410A, a value of 17.12 kg CO_{2e}/kg, for those from the manufacturing of the R290, a value of 0.08 kg CO_{2e}/kg was assumed. Due to a lack of data regarding indirect CO_{2e} emissions from refrigerant recycling, this share is neglected. The values just mentioned are summarized in Table 8-6.

Table 8-6: Materials, shares regarding material use in heat pump systems, CO_{2e} emission intensity values for manufacturing and recycling of units and their refrigerants

Material	Share	CO_{2e} emission value [kg CO_{2e}/ kg]
Manufacturing		
Steel	46%	1.43
Aluminum	12%	4.50
Copper	19%	2.78
Plastics	23%	2.61
Refrigerant manufacturing		
R410A	N/A	17.12
R290	N/A	0.08
Recycling		
Metals	N/A	0.07
Plastics	N/A	0.01

Compared to the systems' indirect CO_{2e} emissions caused by the (electrical) energy consumption during the heat pump systems' lifetime, the indirect CO_{2e} emissions from manufacturing and recycling are low: the CO_{2e} emissions of both systems due to equipment manufacturing account for approximately 817 kg CO_{2e}, the value regarding equipment recycling accounts for approximately 13 kg CO_{2e}.

While the manufacturing of the refrigerant for the R410A baseline system causes CO_{2e} emissions of approximately 86 kg CO_{2e}, the manufacturing of the refrigerant for the charge optimized R290 system causes CO_{2e} emissions of only 0.15 kg CO_{2e}. This very low value is plausible, as R290 (propane) is produced as a by-product of natural gas processing and petroleum refining.

In total, the CO_{2e} emissions from equipment manufacturing and recycling, as well as refrigerant manufacturing, the R410A baseline system accounts for approximately 1,056 kg CO_{2e}, compared to approximately 831 kg CO_{2e} of the charge-optimized R290 system, which is 21% less than the baseline value. The values just mentioned are summarized in Table 8-7.

Table 8-7: Indirect CO_{2e} emissions from equipment manufacturing, equipment recycling and refrigerant manufacturing

	Equipment manufacturing [kg CO_{2e}]	Equipment recycling [kg CO_{2e}]	Refrigerant manufacturing [kg CO_{2e}]	Indirect CO_{2e} emissions from manufacturing/recycling and ref. manuf. [kg CO_{2e}]
R410A baseline system	817.4	12.9	226.0	1056.4
Charge-optimized R290 system	817.4	12.9	0.15	830.5

8.3.2 LCCP

To calculate the LCCP, including both the TEWI and the indirect CO_{2e} emissions from manufacturing and recycling, the results of both separate calculations are summed up as follows:

The TEWI of the R410A baseline system of approximately 58.5 tons CO_{2e} (see 8.3.1.2) and the indirect CO_{2e} emissions regarding manufacturing and recycling of approximately 1.1 tons CO_{2e} (see 0) sum up to a LCCP of approximately 59.6 tons CO_{2e}.

The TEWI of the charge optimized R290 calculated with *Pack Calculation Pro* of approximately 16.6 tons CO_{2e} and the CO_{2e} emissions regarding manufacturing and recycling of approximately 0.8 tons CO_{2e} sum up to a LCCP of approximately 17.4 tons CO_{2e}. This value is approximately 42.2 tons CO_{2e} resp. 71% less than the baseline value. The direct and indirect CO_{2e} emissions, the TEWI, and the LCCP are summarized in Table 8-8.

Table 8-8: Direct and indirect CO_{2e} emissions, TEWI and LCCP

CO_{2e} emission source (calculation method)	Unit	R410A baseline system	Charge-optimized R290 system
Refrigerant leakage (*Pack Calculation Pro*)	[kg CO_{2e}]	15,828.0	3.0
End-of-life refrigerant losses (*Pack Calculation Pro*)	[kg CO_{2e}]	22,423.0	5.0
Indirect CO_{2e} emissions from (electrical) energy consumption (*Pack Calculation Pro*)	[kg CO_{2e}]	20,282.0	16,572.0
TEWI (*Pack Calculation Pro*)	**[kg CO_{2e}]**	**58,533.0**	**16,580.0**
Indirect CO_{2e} emissions from equipment manufacturing (*IIR-LCCP-Calculation-Tool*)	[kg CO_{2e}]	817.4	817.4
Indirect CO_{2e} emissions from equipment recycling (*IIR-LCCP-Calculation-Tool*)	[kg CO_{2e}]	12.9	12.9
Indirect CO_{2e} emissions from refrigerant manufacturing (*IIR-LCCP-Calculation-Tool*)	[kg CO_{2e}]	226.0	0.15
Indirect CO_{2e} emissions regarding manufacturing and recycling (*IIR-LCCP-Calculation-Tool*)	**[kg CO_{2e}]**	**1056.3**	**830.45**
LCCP	**[kg CO_{2e}]**	**59,589.3**	**17,410.5**

8.4 Conclusions

Due to the very Low GWP of R290 (GWP = 3), the direct CO2e emissions (refrigerant leakage and end-of-life refrigerant losses) of the charge-optimized R290 system are neglectable, while the direct CO_{2e} emissions of the R410A baseline system account for approximately 38 tons CO_{2e}. Furthermore, the charge-optimized R290 system achieves an approximately 18.3% lower (electrical) energy consumption than the R410A baseline system, which reduces the indirect CO_{2e} emissions by approximately 3.7 tons CO_{2e}.

The CO_{2e} emissions of the R410A baseline system sum up to an LCCP of approximately 59.6 tons $CO_{2e,}$ while those regarding the charge optimized R290 sum up to an LCCP of approximately 17.4 tons CO_{2e}, which is approximately 42.2 tons CO_{2e} resp. 71% less than the baseline value.

These values show that the charge-optimized R290 system does not only perform better regarding direct CO_{2e} emissions (refrigerant leakages) due to its very low GWP of 3 but also due to better energy efficiency and better thermodynamic properties.

To better understand the significance of the calculated LCCP, a comparison with a natural gas-fired heating system may be helpful. The CO_{2e} emissions of a comparable natural gas-fired heating system are roughly estimated as follows: the amount of thermal energy delivered in 15 years by the R410A baseline system resp. the charge-optimized R290 system is roughly 453 MWh_{th}. With an assumed energy efficiency of 95% for a modern natural gas heating system, natural gas consumption would be approximately 477 MWh. Applying the CO_{2e} emission intensity for natural gas of 0.268 kg CO_{2e}/kWh (Umweltbundesamt, 2022), the CO_{2e} emissions during a 15 years of lifetime would account for approximately 128 tons. As shown in Table 8-9, the TEWI of the R410A baseline system and the charge-optimized R290 system is 46% resp. 13% of the CO_{2e} emissions are emitted by the above-define natural gas heating system in 15 years.

Table 8-9: TEWI values of the R410A baseline system and the charge-optimized R290 system and CO_{2e} emissions in 15 years of a natural gas heating system.

System	TEWI (heat pump systems) resp. CO_{2e} emissions in 15 years (gas system) [tons CO_{2e}]	Relative values
R410A baseline system	58.5	46%
charge optimized R290 system	16.6	13%
LCCP reduction by R410A à R290	41.9	33%
natural gas heating system (simplified calculation)	127.8	100%

In other words, replacing a natural gas heating system with the R410A baseline system would lead to a reduction in CO2e emissions of 54%, while the replacement by a charge-optimized R290 system would achieve a reduction in CO_{2e} emissions of 87%. The deviation in performance between the R410A baseline system and the charge-optimized R290 system supports the call for replacing conventional refrigerants with Low GWP refrigerants. Reducing the refrigerant charge and improving refrigerant leakage rates are further valid approaches for improving the LCCP of heat pump systems.

Furthermore, it should be mentioned that for Austria's domestic heat pump market the actual refrigerant leakage rate and end-of-life refrigerant losses might be lower than assumed in this investigation. As in Austria, the exact situation regarding refrigerant leakages is not known; the assumptions were based on IIR recommendations (IIR, 2016). In the future, comprehensive investigations regarding the actual refrigerant leakage situation in Austria's domestic heat pump market are highly recommended.

8.5 References

Beshr, M., Aute, V. C., 2014, LCCP Desktop Application v1.0 Engineering Reference. Oak Ridge National Laboratoryhttps://info.ornl.gov/sites/publications/files/pub49128.pdf (Accessed 28.12.2021)

BMK (2021): Energiewende für Österreich eingeleitet: Bundesregierung präsentiert Erneuerbaren-Ausbau-Gesetz. https://www.bmk.gv.at/service/presse/gewessler/20210311_eag.html#:~:text=%C3%96sterreich%20wird%20im%20Jahr%202030,den%20Ausbau%20der%20Erneuerbaren%20investiert (Accessed 08.12.2022)

EPA, 2014a, Municipal Solid Waste Generation, Recycling, and Disposal in the United States, Tables and Figures for 2012. https://www.epa.gov/sites/default/files/201509/documents/2012_msw_dat_tbls.pdf (Accessed 28.12.2021)

EPA, 2014b, WARM Version 13. https://www.epa.gov/warm/versions-waste-reduction-modelwarm#13 (Accessed 17.12.2021)

European Copper Institute Copper Alliance, 2012, The Environmental Profile of Copper Products: A Cradle to Gate Life-Cycle Assessment for Copper Tube, Sheet and Wire Produced in Europe.

Eurostat, 2017, Glossary: Carbon dioxide equivalent. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Carbon_dioxide_equivalent#:~:text=A%20carbon%20dioxide%20equivalent%20or,with%20the%20same%20global%20warming (Accessed 10.12.2022)

Franklin Associates, 2014, Cradle-To-Gate Life Cycle Inventory of Nine Plastic Resins and Four Polyurethane Precursors. Fronius, 2021, FRONIUS Symo. https://www.fronius.com/~/downloads/Solar%20Energy/Datasheets/SE_DS_Symo_Advanced_EN.pdf (Accessed 17.12.2021)

Gattermeyer M., 2022, Einfluss einer Photovoltaikanlage auf die Ergebnisse einer LCCP Analyse einer Wärmepumpenanlage in einem Einfamilienhaus, Bachelorarbeit, Fachhochschule Technikum Wien

International Institute of Refrigeration (IIR), 2016, Guideline for life cycle climate performance. http://www.cold.org.gr/library/downloads/Docs/Guideline%20for%20life%20cycle%20climate%20performance.pdf (Accessed 15.11.2021)

International Institute of Refrigeration (IIR), 2018, IIR-LCCP-Calculation-Tool-V1.3-Feb2018.xls. (Software)

IPU, 2021, Pack Calculation Pro 5.0. User's guide.

IPU, 2022, Pack Calculation Pro Version 5.1.1.0 64-bit. https://www.ipu.dk/products/pack-calculation-pro/

KPC (2021): Auflistung der Wärmepumpen, die den Mindestanforderungen der EHPA-Gütesiegelkriterien Abschnitt 2.1 "Technical Conditions" der EHPA regulations for granting the international quality label for electrically driven heat pumps in der Version 1.7 vom 07.06.2018 entsprechen.
https://www.umweltfoerderung.at/fileadmin/user_upload/me-

dia/umweltfoerderung/Uebergeordnete_Dokumente/UEbersicht_Waermepumpen_EHPA.pdf (Accessed 22.12.2022)
Papasavva, S., Hill, W. R., Andersen, S. O., 2010, GREEN-MAC-LCCP: A Tool for Assessing the Life Cycle Climate Performance of MAC Systems. https://fdocuments.in/reader/full/green-mac-lccp-a-tool-for-assessing-the-life-cycle-climateperformance-of (Accessed 28.12.2021)
Umweltbundesamt, 2022, Berechnung von Treibhausgas (THG)-Emissionen verschiedener Energieträger. https://secure.umweltbundesamt.at/co2mon/co2mon.html (Accessed 13.12.2022)
Zhang, M., Muehlbauer, J., Aute, V., Radermacher, R., 2011, Life Cycle Climate Performance Model for residential heat pump systems. https://www.ahrinet.org/App_Content/ahri/files/RESEARCH/Technical%20Results/AHRTIRpt-09003-01.pdf (Accessed 28.12.2021)
Zottl, A. 2016. GreenHP Final report. https://www.ait.ac.at/fileadmin/mc/energy/downloads/TES/Final_report_GreenHP.pdf (Accessed 13.01.2023).

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