Technology Collaboration Programme
by iea

Technology Collaboration Programme on Heat Pumping Technologies (HPT)

Project 65

Heat Pumps in a Circular Economy

Task 1 Report

Operating Agent
Jakob Thomsen,
Danish Technological
Institute

March 2025
Report no. HPT-AN65-2

Published by Heat Pump Centre
c/o RISE – Research Institutes of Sweden
Box 857, SE-501 15 Borås
Sweden
Phone +46 10 16 53 42

Website https://heatpumpingtechnologies.org

Legal Notice Neither the Heat Pump Centre nor any person acting on its behalf:
(a) makes any warranty or representation, express or implied, with respect to the information contained in this report; or
(b) assumes liabilities with respect to the use of, or damages, resulting from, the use of this information.
Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement recommendation or favouring.
The views and opinions of authors expressed herein do not necessarily state or reflect those of the Heat Pump Centre, or any of its employees. The information herein is presented in the authors' own words.

Production Heat Pump Centre, Borås, Sweden

ISBN 978-91-90036-17-4
Report No. HPT-AN65-2

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.

Disclaimer

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.

This report has been produced within HPT Annex 65. Views and findings in this report do not necessarily represent the views or policies of the HPT TCP and 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:

Heat Pump Centre
c/o RISE - Research Institutes of Sweden
Box 857, SE-501 15 BORÅS, Sweden
Phone: +46 10 516 53 42
Website: https://heatpumpingtechnologies.org

Operating Agent

Jakob Thomsen
Business manager, Danish Technological Institute
jath@dti.dk
+45 72 20 15 63

Participating countries

Country	National contact	Date of joining the annex
Denmark	Jakob Thomsen	1/1-2024
Germany	Dr. Karl-Anders Weiß	1/1-2024
Italy	Marco Dall'Ombra	31/1-2024

Participants and contributors

Name	Role/Title	Country	Contact information
Jakob Thomsen	Danish Technological Institute, Business manager	Denmark	jath@dti.dk +45 72 20 15 63
Troels Stevns Pedersen	Danish Technological Institute, Consultant	Denmark	tsp@dti.dk
Dr. Karl-Anders Weiß	Fraunhofer ISE, Business Developer Service Life and Sustainability	Germany	Karl-Anders.Weiss@ise.fraunhofer.de
Marie Fischer	Fraunhofer ISE, Team for Usage Duration Analysis and Material Characterization	Germany	marie.fischer@ise.fraunhofer.de
Marco Dall'Ombra	Assoclima Assoclima representative	Italy	dallombra@assoclima.it +39 342 7790014
Christian Vering	RWTH Aachen University, Chief engineer, Team Leader Refrigerant cycles	Germany	cvering@eonerc.rwth-aachen.de
Dirk Müller	RWTH Aachen University, Professor	Germany	dmueller@eonerc.rwth-aachen.de
Gitte Tang Kristensen	Danfoss A/S	Denmark	gtang@danfoss.com
Yana Petkova-Olsson	NIBE	Sweden	Yana.Petkova-Olsson@nibe.se

Foreword

The shift towards a circular economy is influencing many sectors, including the heat pump industry. This Task 1 Report, developed as a part of the International Energy Agency's Technology Collaboration Programme on Heat Pumping Technologies (HPT), examines how circular economy principles affect domestic heat pumps.

The Task 1 Report aims to provide an overview and a common understanding among the participants in the project and stakeholders outside the project of various aspects related to the transition to a circular economy within the heat pump industry. By focusing on air-to-air, air-to-water, and ground source heat pumps, we explore ways to incorporate these principles into the lifecycle of heat pump systems.

I would like to thank all participants and contributors for their hard work and expertise. Your collaboration has been essential in advancing our understanding of sustainable practices in the heat pump sector.

We hope that this report will serve as a useful resource for policymakers, manufacturers, and stakeholders interested in promoting sustainability within the heat pump industry.

Jakob Thomsen - Project Leader of Project 65 of IEA Technology Collaboration Programme on Heat Pumping Technologies.

Abstract

This report, developed under the International Energy Agency's Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), examines the potential for integration of circular economy principles within the domestic heat pump sector. Focused on air-to-air, air-to-water, and ground source heat pumps below 30 kW for residential heating, the report explores the challenges and opportunities arising from the transition to a circular economy.

The study evaluates material efficiency standards, relevant regulations, lifecycle analyses, and case studies to identify strategies for reducing environmental impacts while maintaining product reliability and performance. Key findings highlight the importance of adapting international standards, such as the ISO 59000 series and EN 4555X standards, to specific product categories like heat pumps. The review also underscores the implications of regulations, including Ecodesign, WEEE, RoHS, and REACH, with a focus on material efficiency, recyclability, and the phase-out of substances like PFAS.

Case studies from Germany, Italy, and Denmark provide practical insights into innovative approaches to improving circularity in heat pump design, including the use of alternative refrigerants, material substitutions, and digital solutions for fault detection. Additionally, the report emphasizes the need for harmonized lifecycle data and the development of product-specific standards to enable meaningful comparisons and better decision-making.

Through national and international collaboration, this report aims to support policymakers, manufacturers, and stakeholders in advancing sustainability in the heat pump industry while aligning with circular economy principles. The findings serve as a foundation for future research and innovation in creating environmentally sustainable heating solutions.

Contents

1. Executive Summary

The transition to a circular economy is driving significant changes across industries, including the domestic heat pump sector. This report, developed under the International Energy Agency's Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), investigates the challenges and opportunities of integrating circular economy principles into the design, development, and lifecycle of domestic heat pumps. The focus is on air-to-air, air-to-water, and ground source heat pumps with a capacity below 30 kW for residential heating. The report is structured around four key tasks:

- **Task 1.1 Evaluating material efficiency standards**: The study reviews existing circular economy standards, such as the ISO 59000 series and the EN 4555X standards, and identifies gaps in their applicability to heat pumps.
- **Task 1.2 Reviewing relevant regulations**: The analysis highlights the impact of regulations such as Ecodesign, WEEE, RoHS, and REACH on the heat pump industry. This section provides an overview of the regulatory framework to navigate when developing circular economy strategies for heat pumps.
- **Task 1.3 Analyzing lifecycle impacts**: A review of lifecycle analyses (LCAs) underscores the environmental benefits of heat pumps in reducing greenhouse gas emissions compared to traditional heating systems. However, the findings also highlight the complexities of burden-shifting across environmental impact categories, emphasizing the need for holistic approaches.
- **Task 1.4 Presenting case studies on circular design measures**: Practical examples from Germany, Italy, and Denmark showcase innovative strategies to enhance circularity. These include the use of alternative refrigerants, material substitutions, and digital solutions such as machine learning for fault detection.

Key findings from the report include:

- The shift to a circular economy presents both challenges and opportunities for the heat pump sector. While circular principles can drive innovation and sustainability, they also require significant adaptation of existing standards, regulations, and design practices.
- Current circular economy standards, such as the ISO 59000 family and the EN 4555X series, need further adaptation to address the specific requirements of heat pumps. These standards, while generic, provide a foundation for developing product-specific guidelines to improve material efficiency and circularity. Developing product-specific standards is critical to enabling practical implementation.
- Regulatory frameworks like Ecodesign and REACH are increasingly pushing for sustainability through material efficiency, durability, and recyclability requirements. However, these regulations also create challenges, such as the potential impact of PFAS restrictions on material availability and product performance.
- A lifecycle analysis performed by RWTH Aachen confirms that air-to-water heat pumps in the German scenario reduce greenhouse gas emissions compared to conventional systems (gas boiler). However, the study also highlights the importance of also paying attention to the environmental impacts linked to the production and end-of-life phases in order to minimize the risk of burden-shifting.
- Collaboration within the industry is essential to harmonize lifecycle data, develop product-specific standards, and align with circular economy principles. For instance, the lack of harmonized Product Category Rules (PCRs) for heat pumps currently limits the comparability of Environmental Product Declarations (EPDs).

In conclusion, this report serves as a foundation for the heat pump sector to transition towards a circular economy. By fostering international collaboration, leveraging regulatory frameworks, and embracing innovative solutions, the industry can achieve sustainability goals while addressing resource efficiency, environmental impacts, and economic opportunities.

2. Background

The global push to tackle climate change and stick to the Paris Agreement is changing how we produce and use energy, and how we design products throughout their lifecycle. The Ellen MacArthur Foundation, widely recognized as a key reference in the promotion of a circular economy, offers a comprehensive definition and explanation of this concept. According to the foundation:

"The circular economy is a system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting. The circular economy tackles climate change and other global challenges, like biodiversity loss, waste, and pollution, by decoupling economic activity from the consumption of finite resources" .[1]

The linear "take-make-waste" model has been the dominant paradigm since the Industrial Revolution, but it is increasingly clear that this approach is unsustainable in a world of finite resources and growing environmental challenges. The circular economy concept proposes a radical rethinking of how we produce, consume, and dispose of goods. It emphasizes the importance of keeping materials in use for as long as possible, extracting the maximum value from them while in use, and then recovering and regenerating products and materials at the end of their service life. This approach not only reduces waste and pollution but also has the potential to drive innovation, create new economic opportunities, and contribute to addressing global challenges such as climate change and resource scarcity. The consumer and user perspectives of a circular economy are often illustrated in the butterfly diagram model created by the Ellen MacArthur Foundation in Figure 1.

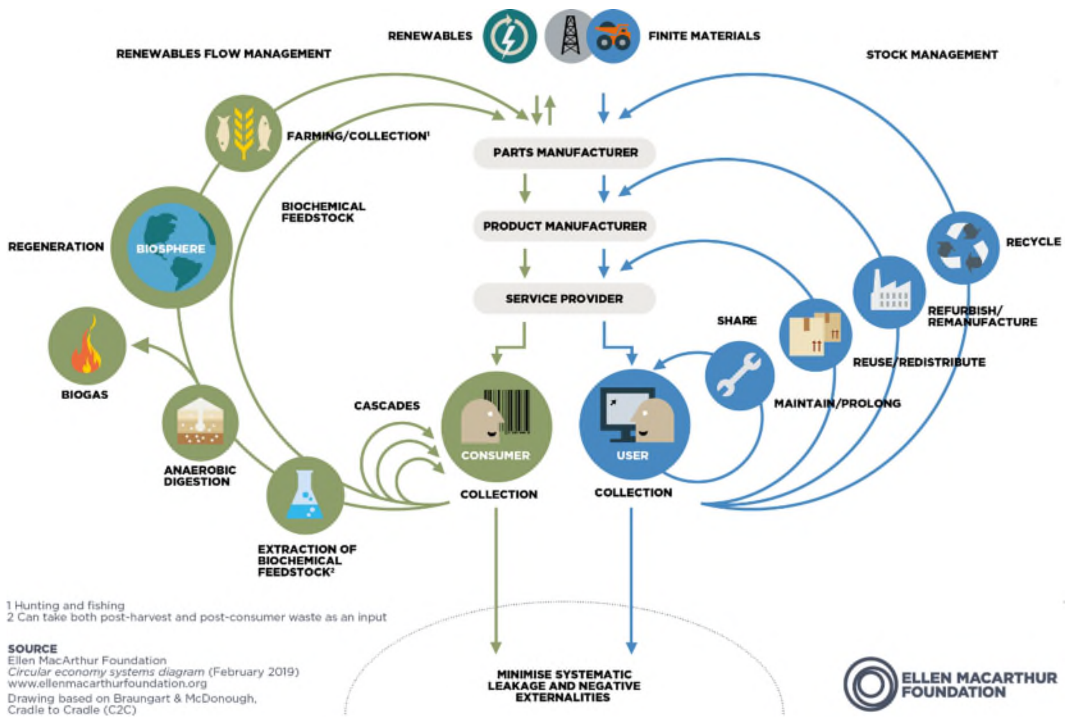


Figure 1: Butterfly diagram by the Ellen MacArthur Foundation [1].

This change from a linear to a circular economy is to a large extent characterized by being promoted by regulators to promote sustainability and efficient use of resources. The shift was initiated in the European Union by a Circular Economy Package which was released in 2015 [2]. This plan aimed to "close the loop" of product lifecycles through better recycling and re-use, benefiting both the environment and the economy. It highlighted key product areas and waste streams that could achieve circularity, paving the way for circular economy principles to be part of existing regulations, including the Ecodesign Directive.

In March 2020, the European Commission launched an updated Circular Economy Action Plan as a part of the European Green Deal [3]. This new plan aimed to make sustainable products the norm in the EU, focusing on designing durable and recyclable products, targeting key value chains such as electronics and textiles, reducing waste, and enhancing resource value. The strategy created circular economy opportunities for regions and cities while promoting circularity as a path to climate neutrality. Additionally, it positioned the EU to lead global efforts in circular economy transition. This comprehensive approach sought to accelerate the EU's shift towards a regenerative growth model that gave back to the planet more than it took, while boosting competitiveness and innovation across the Union. Concurrently similar initiatives were going on in other regions where for example the United States in 2021 launched a National Recycling Strategy showing a global trend towards circularity [4].

The latest development in this regulatory push is the Ecodesign for Sustainable Products Regulation (ESPR), introduced by the European Commission in 2024 [5]. This new regulation marks a significant expansion of product requirements beyond traditional areas like energy efficiency. The ESPR introduces comprehensive standards for material efficiency, durability, repairability, and recyclability. A key feature of the regulation is the mandate for digital product passports, which will facilitate repair, recycling, and product updates. By implementing these far-reaching standards, the ESPR aims to establish sustainable products as the norm in the EU market. This approach is designed to accelerate the transition towards a more circular economy while addressing critical global challenges, including resource scarcity and climate change. Switching to a circular economy can be tough for heat pump makers because of new rules, but it’s also a business chance. A 2018 study suggests that the circular economy in the EU could boost the GDP by 0.5% in 2030 and create 700,000 new jobs [6].

This IEA HPT project 65 aims to explore and promote circular economy ideas within the heat pump sector, focusing on air-to-air, air-to-water, and ground source heat pumps with a heating capacity below 30 kW for residential heating. While individual countries have made efforts to address material efficiency in heat pumps within a circular economy framework, there remains a lack of coordinated international collaboration in this specific area. This IEA HPT project 65 aims to bridge this gap by establishing a collaborative platform where national authorities and manufacturers can jointly develop and steer the transition towards circular economy practices in the heat pump sector. Through active engagement with manufacturers, policymakers, and stakeholders in the building industry, the project seeks to accelerate the adoption of circular economy principles within the heat pump industry. This collaborative approach is designed to ensure the development of sustainable and reliable energy solutions that will meet future needs while adhering to circular economy principles.

3. Structure of this document

The document is structured to align with the legal text for Project 65, focusing on heat pumps in a circular economy. It includes sections dedicated to each specific subtask described in the legal text, providing a comprehensive overview. The sub tasks are:

- Task 1.1 - Evaluation of standards for material efficiency in energy-related products
- Task 1.2 - Review of relevant regulations for heat pump materials
- Task 1.3 - Literature review on lifecycle analyses conducted on domestic heat pumps
- Task 1.4 - Case study descriptions of previous common measures in heat pump design for domestic applications to lower the impact of materials.

The report will include detailed findings from our research and incorporate perspectives from industry stakeholders to reflect the different perspectives in the project group.

4. Task 1.1 - Evaluation of standards for material efficiency in energy-related products

This section investigates the ISO standards on Circular economy, as well as the European material efficiency standards that are a part of the Ecodesign and energy labeling regulations. Even though the material efficiency standards are made for Europe, they are important worldwide. Many heat pump manufacturers are located outside Europe but still sell their products there. This global market presence means that European standards have far-reaching effects beyond the continent's borders. While these standards are developed and implemented within the European Union, their influence extends worldwide due to the interconnected nature of global trade and manufacturing. As a result, these European regulations can potentially shape manufacturing practices, product designs, and material choices across the global heat pump industry because manufacturers are interested in the benefits of economies of scale to be cost competitive with alternative heating sources.

4.1. The ISO 59000 family of standards

The International Organization for Standardization (ISO) has published a family of standards focusing on circular economy aspects. According to ISO, "This standard provides comprehensive guidance" and "contributes "to the United Nations Agenda 2030 for Sustainable Development by facilitating a transition to a circular use of resources" [7]. Currently, the family of standards consists of five distinct standards, focusing on different topics within the field of circular economy and laying the groundwork regarding principles and guidelines:

- ISO 59004: 'Circular economy: Vocabulary, principles and guidance for implementation'
- ISO 59010: 'Circular economy: Guidance on the transition of business models and value networks'
- ISO 59020: 'Circular economy: Measuring and assessing circularity performance'
- ISO 59040: 'Circular economy: Product circularity data sheet'
- ISO 59014: 'Environmental Management and circular economy: Sustainability and traceability of secondary materials recovery – Principles, requirements and guidance'.

Within their family of standards, ISO provides the following definition of Circular economy:

> *"Economic system that uses a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development. […] Resources can be considered concerning both stocks and flows. […] The inflow of virgin resources is kept as low as possible, and the circular flow of resources is kept as closed as possible to minimize waste, losses and release from the economic system"* [7].

This set of standards has only been published as of this year and is therefore quite new. However, providing this starting point on the international level is an important step in the transition to a circular economy on the global scale. These standards are intended to be applicable across all sectors and are therefore rather generic. Further technology-specific differentiation is required to allow for practical application to specific technologies. It seems relevant that the standardization committees responsible for heat pumps address this topic.

4.2. Background on material efficiency standards

The Ecodesign Directive was introduced by the European Commission as a key regulatory framework to improve how energy-related products perform environmentally throughout their lifecycle. Since it started, the directive has grown to cover a wider range of environmental impacts, focusing not only on the energy products in use but also on their overall material efficiency and the requirements during the product's lifetime.

As mentioned before, in 2015 the European Commission launched its first Circular Economy

Action Plan, marking a big step towards sustainable growth by using resources more efficiently. This led to a standardization mandate called M/543 from the European Commission targeting material efficiency aspects under the Ecodesign Directive [8]. This resulted in a series of horizontal standards to evaluate the material efficiency of products (EN 4555X) [9]. These standards have been developed to be implemented in the coming regulation of the product categories subject to Ecodesign and energy labelling regulation, and compliance with these standards may very well become a prerequisite to sell heat pumps in Europe and other countries adopting the Ecodesign legislation.

4.3. Material efficiency standards (EN 4555X standard series)

The standardization mandate called M/543 from the European Commission resulted in the standard series EN 4555X that are intended to be included in upcoming revisions of products subject to ecodesign regulation. The standards are:

- CLC/TR 45550:2020 'Definitions related to material efficiency';
- EN 45552:2020 'General method for the assessment of the durability of energy-related products';
- EN 45553:2020 'General method for the assessment of the ability to remanufacture energy-related products';
- EN 45554:2020 'General methods for the assessment of the ability to repair, reuse and upgrade energy-related products';
- EN 45555:2019 'General methods for assessing the recyclability and recoverability of energy-related products';
- EN 45556:2019 'General method for assessing the proportion of reused components in energy-related products';
- EN 45557:2020 'General method for assessing the proportion of recycled material content in energy-related products';
- EN 45558:2019 'General method to declare the use of critical raw materials in energy-related products';
- EN 45559:2019 'Methods for providing information relating to material efficiency aspects of energy-related products'.

Additionally, there is also a proposal out for a standard called EN 45560:2024 ‘Method to achieve circular designs of products’. This is, however, not confirmed yet.

The original horizontal material efficiency standards from the standardization mandate M/543 have been investigated by Bundgaard et al. to evaluate the applicability, gaps and potential for these standards in the Ecodesign directive for the products already [10]. The standards have been investigated based on the understanding of resource and material efficiency related to a circular economy as illustrated in Figure 2.

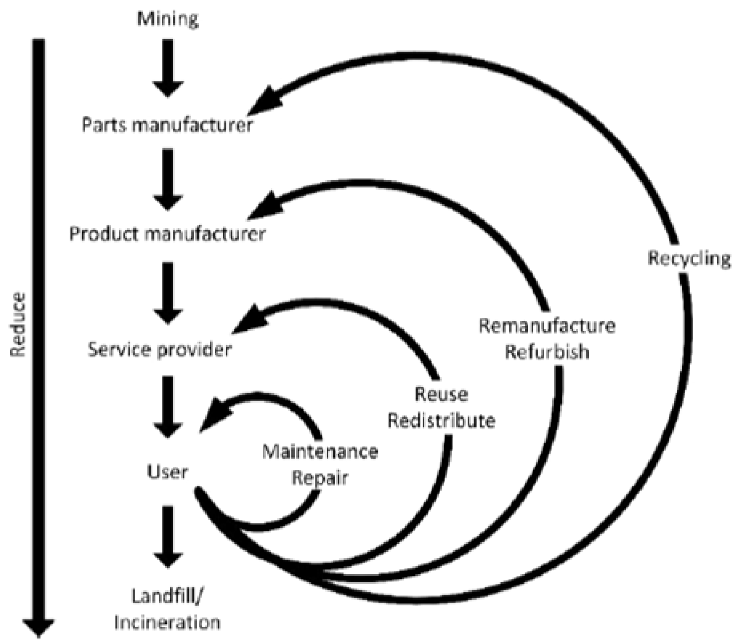


Figure 2: The applied understanding from Bundgaard et al. of resource and material efficiency related to a circular economy [10].

All standards created under standardization mandate M/543 are horizontal and not directly applicable to energy-related products or product groups. Instead, they serve as guidance for developing vertical, product-specific standards [10]. The exceptions are the standard on critical raw materials (EN 45558) and the standard on methods for providing information (EN 45559), which can be directly applied to product groups [10]. Bundgaard et al. have summarized the gaps in standards to make them applicable for a given product or product group.

Standards	**Gaps that need to be addressed by product-specific or product group-specific standards**
EN 45552 Durability	• Define product or product group priority functions or parts. • Define environmental or operating conditions. • Describe test methods to assess reliability of priority parts. • Define “limiting states” and potential “end-of-life” states.
EN 45553 Remanufacture	• Identify product-specific attributes for the product or product group. • Assess or score relevant parameters that need to be product specific.
EN 45554 Repair, reuse and upgrade	• The priority parts need to be identified for each product category. • Next, the criteria relevant for the specific product category need to be selected. The criteria cover aspects such as disassembly depth, fasteners and connectors, tools, working environment, skill level diagnostic support and interface, spare parts availability, availability of parts for upgrade, types and availability of information, return options, data management and password and factory reset for reuse. • Disassembly depth is the only criterion where a calculation can be used for the evaluation. The remaining criteria are evaluated according to classes ranging from A to E. Therefore, it is also necessary to decide whether each class is relevant for the different criteria for that specific product category.

EN 45555 Recyclability	• What does the end-of-life scenario look like (relevant design characteristics, qualitative or quantitative scenario)? • Product or product group standards need to be created.
EN 45556 Reused components	• Calculation methods need to be chosen. • Product or product group standards need to be created.
EN 45557 Recycled content	• Definition of “same process”. • Material clustering and unspecified material. • Traceability chain of custody.
EN 45558 Critical raw materials	• No gaps: considered to be directly applicable, but reporting thresholds for critical raw materials need to be defined by either product standard or legislation.
EN 45559 Information	• No gaps: considered directly applicable depending based on the EN 45552–45558 standards.

Table 1: Gaps that need to be addressed by product-specific or product group–specific [10].

Table 1 illustrates the gaps that need to be addressed by product-specific or product group-specific standards for various EN standards related to material efficiency. Upon analysis, it becomes evident that numerous choices and considerations are required to evaluate these gaps for a given product group, such as domestic heat pumps. This underscores the complexity of adapting these horizontal standards to specific product categories and highlights the need for collaborative efforts within the industry to effectively implement material efficiency measures.

As mentioned before, the EN 45560:2024 ‘Method to achieve circular designs of products’ is focused on how to design products for improved circularity. As is the case with the other standards, this is not a heat pump specific standard but a horizontal standard that can improve circularity in different products. This standard has also established a waste hierarchy in relation to the material efficiency standards that can be used for choosing which aspects to focus on. This waste hierarchy is shown in Figure 3 and can be used as a guideline for how to prioritize the efforts between focusing on reusability, remanufacturing, refurbishing etc.

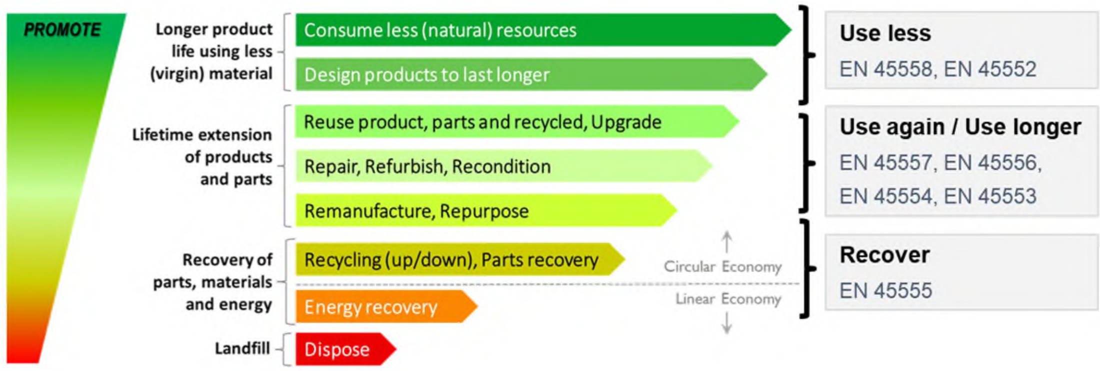


Figure 3:The use and waste hierarchy in material efficiency.

4.4. Company perspectives

Given the potential impact of material efficiency standards on heat pump manufacturers, it was deemed relevant to include company perspectives in this document. These insights provide valuable context on how industry leaders perceive and address these standards, helping to highlight practical challenges and opportunities within the sector. The following questions serve as a point of departure for companies to provide their insights on the impact and applicability of material efficiency standards within their operations. These questions aim to explore how these standards influence product design, drive innovation, and align with sustainability goals. By considering these aspects, companies can offer valuable perspectives on the role of material efficiency standards in fostering a transition to a circular economy.

- Have you considered applying these standards in your current processes, and if so, how have they been applicable?
- Have the material efficiency standards influenced your approach to product design?
- What opportunities have these standards created for innovation in your company?
- In what ways do these standards align with your company's sustainability goals?

4.4.1. Danfoss

At Danfoss, circularity is integral to product design and innovation processes, guided by a comprehensive sustainability framework. This framework emphasizes three key principles: Rethink, Reduce, and Recirculate, which drive the approach to creating sustainable and circular products.

- **Rethink:** This principle encourages a fundamental reassessment of product design and business models from the outset to design for both decarbonization and circularity. It includes strategies such as designing for disassembly, modularity, and durability, which enhances the longevity and usability of products and components.
- **Reduce:** This principle aims to lower overall impact throughout the product's life cycle by strategically selecting materials and packaging, selecting efficient production processes, and optimizing products for reduced energy consumption. Specific guidelines include focus on the use of sustainable, low-carbon, recycled, and recyclable materials, minimizing waste, and enhancing energy efficiency, all contributing to reduced carbon footprints and enabling circularity.
- **Recirculate:** This principle focuses on the end-of-life phase of products by promoting maintenance and upgrades, reuse, repair, remanufacturing, and recycling. Guidelines emphasize how to prolong the lifetime of products and ensure a second life, and how to loop products, components, and materials back into use to reduce the need for new resources, minimize waste and support a circular economy.

Danfoss has developed a Danfoss Circularity Index (DCI) tool to assess the circularity of products. It quantitatively measures circularity based on criteria such as longevity, repairability, and recyclability, providing insights that guide design decisions. The tool enables benchmarking against, e.g., industry standards, fostering continuous improvement in product design and ensuring alignment with sustainability frameworks.

Danfoss aligns its circularity practices with established standards and frameworks, such as those proposed by the Ellen MacArthur Foundation and the Cradle-to-Cradle design approach. These frameworks provide a foundation for circularity initiatives, ensuring that practices are consistent with global sustainability goals. The DCI, for instance, builds on existing circularity metrics and methodologies, enabling a standardized assessment of product circularity across a diverse portfolio.

Additionally, regulatory developments, such as the European Commission's Circularity Action Plan and Ecodesign for Sustainable Products Regulation, guide product design strategies by setting frameworks that prioritize resource efficiency and recyclability. This regulatory landscape is crucial for driving the transition to a circular economy and informs design decisions to enhance sustainability, and the Danfoss Sustainability Framework is aligned with these external developments.

In summary, Danfoss integrates circularity into product design through a structured approach based on established principles and standards to the extent possible, ensuring that innovations contribute to a more sustainable future while meeting regulatory and market demands.

4.4.2. Nibe

Material efficiency has always been seen as an extremely important aspect by us. There are two key areas in which a tremendous effort has been done over the years: heat pump energy efficiency and the expected lifetime for the products. By improving the energy efficiency of heat pumps, less energy is needed over the usage phase which is in direct correlation to the material efficiency of electricity production infrastructure. Naturally, by designing products to last longer than previous generations and being repairable, material efficiency has also been improved. But like other organizations, we also see a new dimension of material efficiency, i.e. circularity and circular economy business models.

Indeed, we have registered the existence of the horizontal standards in the series of EN 4555X related to material efficiency. It is positive to have them in place since they give us some basic guidelines on how durability, ability to repair, recyclability, etc. should be assessed. Nevertheless, we can conclude that until now they have had a quite low impact on our product design process. We also see that there are gaps which need to be closed.

We believe that more exact product-specific guidelines should be established. For example, if more components are refurbished, upgraded or reused in future heat pumps, then routes and product group standards need to be created. Is it possible to reuse some brass fittings from a 20-year-old heat pump in a future product? If yes, in what products (heat pump or other product), and what will be acceptable in terms of technical performance, quality, and substance content for a reused part.

Closing gaps and creating product specific standards might be a strong driver for enabling a higher degree of reused/refurbished parts in heat pumps which eventually will affect the material efficiency and the environmental impact of these products.

5. Task 1.2 - Review of relevant regulations for heat pump materials

In the transition to a circular economy, understanding the regulatory landscape is crucial. This subsection aims to evaluate the connections between existing regulations and circular economy principles as they apply to heat pumps. By thoroughly assessing the current regulatory framework, we can identify opportunities to enhance the circularity of heat pumps. This section has been written during 2024 and early 2025 where only European countries have joined the project, and this is the reason for the main focus on European legislation.

5.1. Ecodesign and material efficiency requirements

Material efficiency requirements have been introduced in the latest proposals for updated Ecodesign and Energy Labelling for space and water heaters (air-to-water, ground source and domestic hot water heat pumps), and air-conditioners (air-to-air heat pumps). Both proposals are dated to 2023 and elaborate on several key requirements aimed at enhancing the sustainability and circularity of these products. The highlights of the proposal include:

- Spare parts must be available on the market for professionals for at least 10 years for space heaters and 7 years for air-to-air heat pumps after the last unit of a specific model has been placed on the market. A list of the components subject to this requirement is included.
- Spare parts shall be possible to replace using common tools without damage to the heat pumps.
- Requirement on when spare parts need to be sent from the supplier or delivered to the person who placed the order.
- Information regarding repair and maintenance must be made available to professional operators, potentially through a registration process.
- Products must be designed to allow disassembly for material recycling and without contamination.
- Professional operators may be required to register to access repair and maintenance information. Manufacturers and importers may require these operators to document their competencies before registration.
- Requirements regarding what the repair and maintenance information should include.

These material efficiency requirements are anticipated to be part of an upcoming update of the Ecodesign requirements for space and water heaters. While the exact timing for the final negotiation of this regulation remains uncertain, it is expected that material efficiency requirements will be included. The regulation is, however, projected to be finalized before the end of December 2026.

5.1.1. Material efficiency requirements in other product categories

Material efficiency requirements are not specific to heat pumps; rather, they are part of a broader movement towards implementing these standards across all product categories. Historically, methodologies and standards initially developed for one product category have often been adapted and transferred to others once they become part of regulatory focus. By examining how material efficiency is being addressed in other product categories, stakeholders in the heat pump industry can gain insight into potential regulatory developments and prepare for upcoming changes. Observing these trends can help manufacturers and policymakers in the heat pump sector to anticipate regulatory shifts and proactively adopt sustainable practices. This is why we have included some examples of requirements in other product categories that might serve as a forecast for what can be expected for heat pumps.

One example of such regulations likely to be adopted from other product categories is the repairability index for tumble dryers. This initiative is motived by the observation that the average lifespan of tumble dryers has decreased from 14 to 12 years, and without any action it is likely to decrease further [11]. The regulation is not yet in force but has recently undergone a feedback procedure in late 2024.

The aim of the repairability index is to encourage consumers to prioritize repairable products and motivate manufacturers to design with sustainability in mind. The repairability index will be displayed as an icon in the supplementary information section of the EU energy label for household tumble dryers.

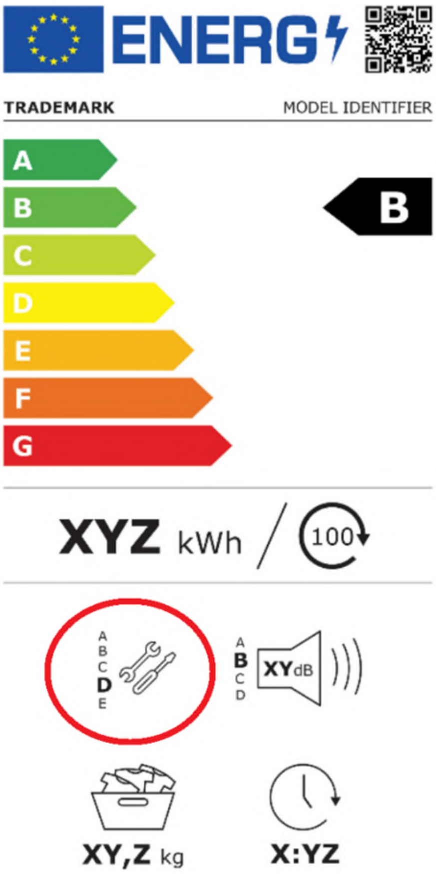


Figure 4 - Example of suggested repairability index identification (marked with red circle) to add on the energy label.

Annex 3 of this regulation focuses on the design and requirements for labels that provide repairability information for household tumble dryers in alignment with circular economy principles. It introduces a repairability index, which rates products into classes ranging from A (most repairable) to E (least repairable). The index is calculated based on factors such as disassembly depth, the type of fasteners used, tools required, and the availability of repair information. Labels are required to include the repairability class, energy efficiency rating, and additional product details. These labels are designed with standardized layouts, colors, and pictograms to ensure that they are clear, comparable, and easy for consumers to understand.

From the work with tumble dryers, it is likely that the repairability index could also be applied to heat pumps. The repairability index (R) would be calculated based on four parameters ($S_{\#\#}$) each with a corresponding weight factor (a, b, c & d):

$$R = 0{,}450_a * S_{DD} + 0{,}225_b * S_F + 0{,}225_c * S_T + 0{,}100_d * S_{RI}$$

- S_{DD} is the Disassembly Depth score, steps required to remove to part.
- S_F is the Fasteners (type) score, removability and reusability of the fasteners used.
- S_T is the Tools (type) score, complexity and availability of the tools needed.
- S_{RI} is the Repair Information score, basis of the repair and maintenance information.

The scores for these parameters would be based on key components specifically relevant to heat pumps, which should be adapted from those used for tumble dryers. Adjustments to the weight factors used for the tumble dryer example are also expected to reflect the unique characteristics of heat pumps. In Figure 5, the repairability classes according to the repairability index are shown.

Repairability class	Repairability index (R)
A (most repairable)	$R > 9,00$
B	$7,00 \leq R \leq 9,00$
C	$5,00 \leq R < 7,00$
D	$3,00 \leq R < 5,00$
E (least repairable)	$R < 3,00$

Figure 5 - Repairability classes according to repairability index (R).

The regulation also mandates that information about spare parts availability and repair instructions must be accessible, either through QR codes or through dedicated web links. This approach ensures transparency and supports both professional repairers and end users in maintaining the product throughout its lifecycle.

The repairability framework described in Annex 3 could also be applied to heat pumps by using similar methods to evaluate disassembly processes, tools required, and spare parts accessibility. This would support the development of heat pump designs that align with circular economy principles, promoting longer product lifetimes and improved resource efficiency.

5.2. The Waste Electrical and Electronic Equipment (WEEE)

The Waste Electrical and Electronic Equipment (WEEE) Directive (EU 2012/19) is a crucial regulatory framework within the European Union aimed at minimizing the environmental impact of electrical and electronic equipment (EEE) by promoting reuse, recycling, and recovery. Among the wide range of products covered by this directive are domestic heat pumps.

Domestic heat pumps are included under the categories of electrical and electronic equipment due to their reliance on electric currents for operation. As such, they must comply with a set of requirements designed to ensure proper handling at the end of their life cycle. The WEEE Directive mandates that producers of domestic heat pumps are responsible for the collection, treatment, and environmentally sound disposal of these units once they become waste, termed as Waste Electrical and Electronic Equipment (WEEE). This responsibility is often handled by admitting to a national or local scheme handling the producer’s responsibility.

Key requirements of the WEEE Directive applicable to domestic heat pumps include:

- **Producer responsibility:** Manufacturers and importers of heat pumps must finance and manage the collection and proper treatment of heat pump waste. This involves setting up systems to facilitate the return of WEEE from consumers.
- **Collection and recycling targets:** The directive sets specific targets for the collection and recycling of WEEE. Producers are expected to meet these targets to ensure that a significant proportion of waste is diverted from landfills and instead reused or recycled.
- **Information and marking:** Producers must provide clear information to users regarding the separate collection of heat pumps and the potential environmental impacts of improper disposal. Additionally, equipment must be marked with the crossed-out wheeled bin symbol to indicate that it should not be disposed of with general waste.
- **Reporting and compliance:** Producers are required to report the

quantities of heat pumps placed on the market and the amounts collected and treated as WEEE. This data helps ensure compliance with the directive's targets and facilitates monitoring by national authorities.

By adhering to these requirements, the WEEE Directive seeks to foster a circular economy approach, reducing the environmental impact and resource consumption associated with domestic heat pumps and other electrical equipment.

5.3. The Restriction of Hazardous Substances (RoHS) directive

The Restriction of Hazardous Substances (RoHS) directive is a regulatory framework established by the European Union to limit the use of specific hazardous materials in electrical and electronic equipment [12]. The primary goal of RoHS is to protect human health and the environment by reducing the risks associated with exposure to toxic substances.

RoHS restricts the use of several hazardous substances, including lead, mercury, cadmium, hexavalent chromium, and certain polybrominated flame retardants (PBDE and PBB). Compliance with RoHS requires manufacturers to ensure that these substances are not present above specified threshold levels in their products. To support compliance with the ROHS directive, the standard EN IEC 63000:2018 specifies the technical documentation that the manufacturer must compile in order to declare compliance with the applicable substance restrictions [13].

To achieve compliance with the RoHS, manufacturers must select materials and components that do not contain restricted substances above specific threshold values. In this context, it is important to note that there are, in some cases, time-limited exemptions to give the industry time to prepare. This process of selecting materials and components in compliance with the RoHS may require redesigning components and systems and collaborating with suppliers to source compliant materials. Extensive testing is necessary to ensure that products meet safety and performance standards without compromising quality or efficiency. It is, however, a possibility for heat pumps providers to request information from component suppliers to ensure that the components comply with the RoHS. An example of such a certificate can be found here from Danfoss link.

5.4. REACH

The REACH Regulation (Registration, Evaluation, Authorisation, and Restriction of Chemicals) is an EU framework designed to control the use of chemicals to protect human health and the environment. It requires companies to register and provide detailed information on the chemicals they manufacture or import. This includes evaluating and managing risks, ensuring safe usage, and potentially replacing hazardous substances with safer alternatives [14].

For the domestic heat pump industry, understanding REACH is essential to ensure compliance with regulations governing the materials, refrigerants, and substances used in production.

In January 2023, five European Member States (Germany, the Nederland's, Sweden, Norway and Denmark) submitted to the European Chemicals Agency (ECHA) a restriction proposal under the REACH Regulation covering per- and polyfluoroalkyl substances (PFAS)[1]. The proposed restriction would ban the

---

[1] PFAS in the proposal from the five European countries are defined as: Any substance that contains at least one fully fluorinated methyl (CF3-) or methylene (-CF2-) carbon atom (without any H/Cl/Br/I attached to it). A substance that only contains the following structural elements is

manufacturer, placing on the market, and the use of PFAS in non-essential applications. PFAS covers a broad range of substances, which includes HFCs and HFOs used as refrigerants. According to the proposal, there will be a transitional arrangement of up to 12 years for PFAS substances for specific purposes.

The proposed REACH restriction on PFAS may have significant implications for the refrigeration and heat pump industry. One aspect of the potential ban on PFAS substances is the availability of refrigerants where the current formulation of the proposal will restrict the use of HFOs due to the chemical composition. Depending on the implementation of the regulation, this could influence the service lifetime of products if the refrigerant charge cannot be refilled in case the heat pumps experience a loss of refrigerants charge.

Another aspect of the ban of PFAS substances is the restriction on certain materials used in components for heat pumps. This topic has been investigated in an impact assessment conducted by ASERCOM, the Association of European Refrigeration Component Manufacturers [15]. The impact assessment describes the impact for the entire HVACR industry, but the findings are also relevant for domestic heat pumps. According to ASERCOM's findings, PFAS substances, particularly fluoropolymers, are widely used in HVACR systems due to their properties that enable performance under challenging operating conditions [ASERCOM]. HVACR systems operate in environments with large temperature ranges from -50°C to 175°C and pressures up to 45 bar.

Fluoropolymers play a crucial role in ensuring the longevity of heat pumps, as highlighted in the ASERCOM impact assessment. These materials are known for their strong carbon-fluorine bonds and chemical inertness, which allow them to withstand the harsh environments within HVACR systems. By maintaining low friction and resisting degradation, fluoropolymers help extend the lifespan of heat pump components, reducing the frequency of replacements and minimizing waste. Another potential impact is that a ban on fluoropolymers could pose significant challenges for the availability of spare parts for existing products. Without suitable alternatives, maintaining the operational efficiency and longevity of current heat pump installations could become problematic, emphasizing the need for careful consideration of such regulatory actions.

The topic has also been investigated by Danfoss that also highlights the importance of fluoropolymers in components for vapor compression systems. Figure 6 shows a schematic of a solenoid valve and a compressor where critical elements including fluoropolymers are highlighted.

---

excluded from the scope of the proposed restriction: CF3-X or X-CF2-X’, where X = -OR or -NRR’ and X’ = methyl (-CH3), methylene (-CH2-), an aromatic group, a carbonyl group (-C(O)-), -OR’’, -SR’’ or –NR’’R’’’, and where R/R’/R’’/R’’’ is a hydrogen (-H), methyl (-CH3), methylene (-CH2-), an aromatic group or a carbonyl group (-C(O)-).

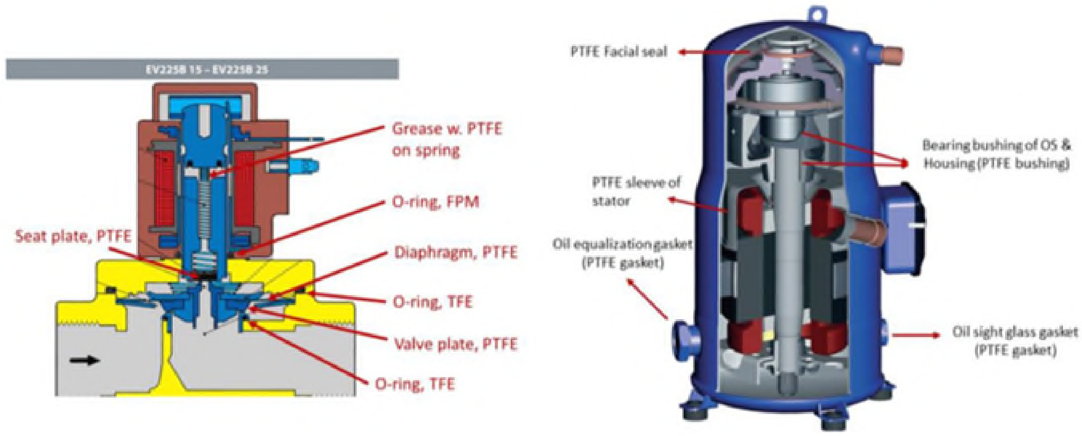


Figure 6: Flouropolymers in a solenoid valve and a compressor. Source: Danfoss.

Danfoss has also created a table that lists the key components, products, properties, and the relevant PFAS materials. This list is shown in Table 2.

Key components	Key products	Key properties/requirements in relation to the materials used	PFAS materials
Bearings, Gaskets, Seals, Seal rings, Coatings, Bushings	Compressors, Expansion valves, Heat exchangers, Solenoid valves, Ball valves, Service valves, Sight glasses, Pressure regulating valves, Non-return valves	Lifetime / reliability, High to low temperature performance, Lubricant resistance, Dimensional stability	PTFE, FEPM, PFA, FEP, FKM, PVDF, PFPE, FEPM

Table 2: List of fluoropolymers used in vapor compression components. Source: Danfoss.

Table 2 illustrates the extensive use of fluoropolymers across various components and products within vapor compression systems, including heat pumps. The highlighted properties, such as chemical resistance, low intrinsic friction, and high-temperature degradation resistance, are integral to maintaining the product lifetime and reliability of these systems. If alternative materials cannot match these properties, the overall product lifetime could be significantly impacted, potentially leading to increased wear, maintenance needs, and reduced operational efficiency.

5.5. EU Taxonomy for sustainable activities

The EU Taxonomy is a classification system established to provide clarity on which economic activities can be considered environmentally sustainable [16]. It is a cornerstone of the European Green Deal, aiming to redirect capital towards sustainable projects and activities.

According to the EU Taxonomy, two criteria must be met for an activity to be defined as a sustainable economic activity: 1) Contribute to at least one of six environmental objectives, and 2) Do no significant harm to any of the other objectives, while respecting basic human rights and labour standards. See Figure 7 below where these categories are illustrated:

Source: EU Taxonomy Technical Expert Group final report, March 2020.

Figure 7: EU Taxonomy alignment steps.

The six objectives are 1) climate change mitigation, 2) climate change adaptation, 3) sustainable use and protection of water and marine resources, 4) transition to a circular economy, 5) pollution prevention and control, and 6) protection and restoration of biodiversity and ecosystems. In delegated acts, technical screening criteria define specific requirements and thresholds for an activity to be considered as significantly contributing to a sustainability objective, while the "Do No Significant Harm" (DNSH) principle ensures that the activity does not cause significant harm to any of the other objectives.

Specific technical screening criteria that assess the potential negative impacts of an activity throughout its lifecycle must be met to comply with the DNSH requirements. For instance, an activity might be evaluated for its effects on water resources, pollution levels, or biodiversity to ensure alignment.
To demonstrate compliance, companies must conduct thorough assessments and provide evidence that their activities meet the DNSH technical screening criteria. This requires a detailed understanding of e.g., environmental impacts and product composition down to substance level and may involve sharing of detailed information in the value chain and collaboration across various sectors.

By adhering to the DNSH principle, businesses can support the EU's broader objectives of achieving climate neutrality and fostering sustainable growth, while also minimizing their ecological footprint.

According to the EHPA, heat pumps can in most cases be classified as sustainable [17]:

- For the manufacturing of heat pumps, they are considered sustainable if they are rated in the highest two energy efficiency classes under the EU Ecodesign Regulation, or if they comply with technical screening criteria, including a maximum Global Warming Potential (GWP) of 675, energy efficiency requirements, and circularity standards.
- For installation, maintenance, or repair, heat pumps are deemed sustainable if they contribute to the renewable energy targets under the EU Renewable Energy Directive (RED) or meet similar criteria as outlined above.

The rules ensure that the vast majority of modern heat pumps on the market are eligible for support from both private and public investments and thereby driving the green transition and reducing CO_2 emissions across Europe.

6. Task 1.3 - Literature review on lifecycle analyses conducted on domestic heat pumps

The task of conducting a literature review on lifecycle analysis (LCA) of domestic heat pumps aims to gather and synthesize existing studies to understand the environmental impacts and benefits associated with these systems. This will serve as a baseline for evaluations conducted in the other tasks of the project. The ambition extends beyond collecting and analyzing existing literature to also include the creation of a comprehensive database of EPDs for domestic heat pumps.

6.1. Existing literature on lifecycle analyses

To establish a comprehensive understanding of the environmental impacts associated with domestic heat pumps throughout their lifecycle, this section presents an evaluation of existing literature on lifecycle analyses (LCA). This review encompasses both previously published studies that are still deemed relevant and recent work conducted by members of the project group.

The analysis of existing literature serves multiple purposes:

1. It provides a foundation for understanding the current state of knowledge regarding the environmental performance of domestic heat pumps.
2. It helps identify trends, methodologies, and best practices in conducting LCAs for heat pump systems.
3. It highlights potential gaps in research that this project may address.

In the following subsections, we present a selection of key studies and their findings. For each study, we provide a brief description of the methods used and the main conclusions drawn. This approach allows for a comprehensive overview of the field while also facilitating comparisons between different studies and methodologies.

The studies included here represent a diverse range of approaches and focus areas within the broader context of heat pump lifecycle analysis. By examining this variety of perspectives, we aim to build a nuanced understanding of the environmental impacts associated with domestic heat pumps, from production and installation through to end-of-life considerations.

6.1.1. Findings from IEA SHC Task 71

IEA SHC Task 71 focuses on the development of a comprehensive methodology to enable and ensure fair comparisons of heating systems based on their economic and ecologic performance. For this, the definition of a common functional unit as well as comparable system boundaries is essential. The task aims to provide data sets for reference systems as well as scenarios.

A major need is to have Circular Economy related information provided for all products in a usable, validated, and complete state. It is seen as crucial to have terminology (recycled content, recyclability, circularity…) defined as well as data exchange formats.

The ecological assessment is conducted by applying and adapting life cycle assessment, while the economic assessment is done based on the levelized cost of heat approach. By choosing 1 kWh of heat supplied to the defined reference building, different technologies can be compared.

Relevant regulations on the national and international level have been collected and summarized in a report, The reference buildings as well as the assessed heating technologies have been documented and published in the form of technical data sheets. Details on the methodology can be found in the report “Guidelines for LCA and LCOH Assessment and Comparison of Heating Technologies” which is expected to be published in Q2/25.

6.1.2. Findings from RWTH Aachen study

In an in-depth LCA study of air-to-water heat pumps in Germany, Vering et al. investigated the environmental impacts of switching from a gas condensing heating system to an air-to-water heat pump, focusing on various impact categories beyond climate change influenced by different refrigerants and electricity mixes [18]. The results are summarized in Figure 8 (refrigerants) and Table 3 (electricity mixes).

In Figure 8, there is a comparison when switching from a gas condensing boiler to a heat pump with seven different refrigerants. All refrigerants are deployed in the basic refrigerant cycle. The differences occur due to a fluid-dependent compressor model which defines efficiency based on the refrigerant used. In addition, there are different production routes for heat pumps with HCs, HFC, and HFOs (using copper) and the heat pump with ammonia (avoiding copper). Each refrigerant has its own production route including relevant upstream processes. In this case study, seven refrigerants in heat pumps supply the heating demand of a residential building. The reference case is heating the building with a gas-condensing boiler. Thus, normalization to 100% represents the boiler case. At conditions with German electricity mix 2020, switching from boiler to heat pump reduces the GHG emissions (climate change) down by about 40% for the heat pump with worst efficiency (R410A) and highest global warming potential (GWP) and down by about 50% for the heat pump with best efficiency (R290 or R717) at low-GWP level. To look beyond the metric of climate change, the impact in 16 environmental metrics is calculated. Environmental metrics are depicted in a descending order of importance.

Main conclusions:

- Switching from high-GWP (R410A) refrigerants to low-GWP refrigerants (HCs) reduces direct GHG emissions.
- The production routes of R410A, R32, and R1234yf account for higher ozone depletion because of ODP substances in the production process that leak into the environment even before it comes to operation.
- Indirect emissions related to heat pump operation dominate all environmental impacts accounting for clean electricity mixes and high heat pump efficiencies.
- The impact of materials is mainly related to the use of copper which is underlined in categories 10-13. Avoiding copper in the R717 heat pump reduces environmental impacts due to production. Avoiding copper could be quasi-equivalent with implementing circular strategies to reduce the need for copper significantly.

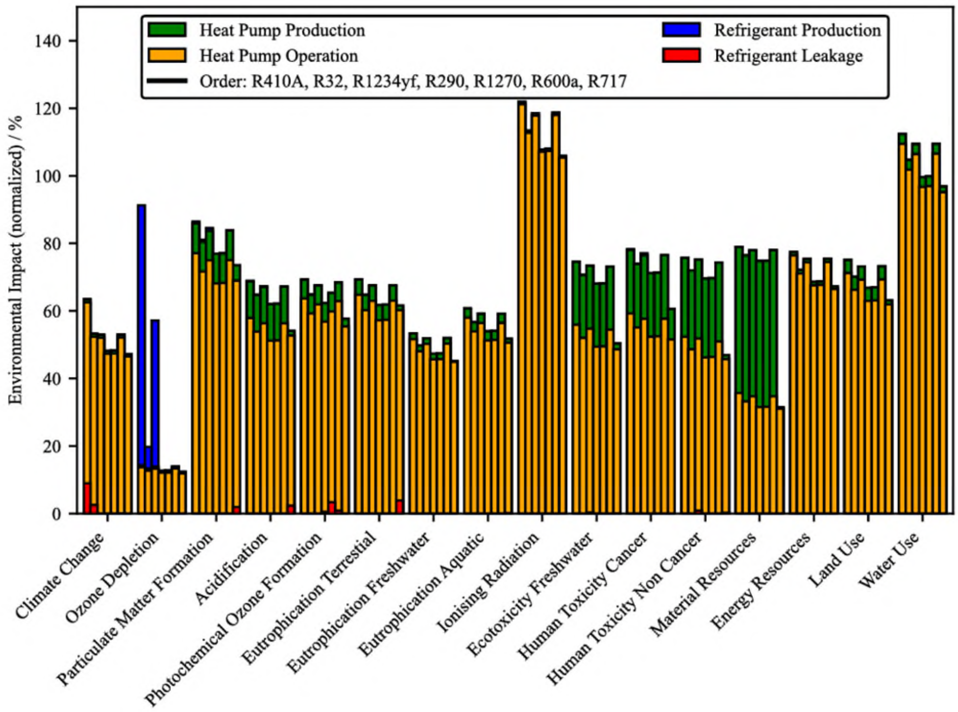


Figure 8: Comparison between a gas boiler and air-to-water heat pumps operating on different refrigerants. Source: Vering et al.

Since the grid mix has significant impact on heat pump operation, which has large impact on all environmental metrics, Table 3 shows the impact of the grid mix on environmental metrics when switching from gas boiler to heat pump with R410A as a refrigerant.

	GE (521 gCO_2/kWh)	GE-to-SDS (317 gCO_2/kWh)	SDS (114 gCO_2/kWh)	Wind Energy (32 gCO_2/kWh)	Photovoltaic (99 gCO_2/kWh)
Climate Change					
Ozone Depletion					
Particulate Matter Formation					
Acidification					
Photochemical Ozone Formation					
Eutrophication, terrestrial					
Eutrophication, freshwater					
Eutrophication, aquatic					
Ionizing Radiation					
Ecotoxicity, freshwater					
Human toxicity, cancer					

Human toxicity, non cancer					
Material Resources					
Energy Resources					
Land Use					
Water Use					

The main conclusions of the study were:

1. Environmental categories: Improvements are noted in climate change, ozone depletion (most important categories), and energy resource consumption, while other categories like eutrophication and freshwater toxicity are impacted negatively depending on the electricity mix. It is important to note that the impact visualized in Table 3 is not solely linked to the heat pump but also includes impacts coming from expansion of the electrical grid and integrating renewable electricity sources. Another important note is that linear changes in the electricity mix do not lead to linear progress in all environmental impacts which means that there are nonlinear interdependencies. This highlights the need for a detailed analysis to avoid misleading conclusions.
2. Burden shifting: Switching to heat pumps might lead to "burden shifting", where reductions in one environmental category result in increases in another. Since the importance of categories is not entirely understood, it is not possible to draw a general conclusion if we need to improve all categories simultaneously. The concept of planetary boundaries could help assess in which category burden-shifting should be avoided.

In summary, while heat pumps can significantly reduce GHG emissions in Germany, which is the main goal of exchanging boilers, they also lead to increased impacts in certain environmental categories, indicating the need for careful consideration of the overall ecological footprint in the long term. Circular strategies might help reduce the overall impact on the environmental categories when changing from gas boilers to heat pumps.

6.1.3. Heat pump supply chain environmental impact reduction to improve the UK energy sustainability, resiliency, and security

This study investigates the environmental impacts of heat pump technologies and their supply

Table 3: Results of LCA analysis of domestic air-to-water heat pump in different scenarios. Green indicate an improvement compared to the base scenario, white is neutral, and red indicates a negative impact. The impacts are based on a full scenario of the electricity mix in Germany with new infrastructure and power generation, and this means that the heat pump is not responsible for all the impacts. Source: Vering et al.

chains, aiming to align them with the UK's sustainability and net-zero emissions goals [19]. The findings highlight that reshoring production or expanding domestic manufacturing capacity can significantly reduce environmental impacts, particularly by lowering transportation emissions and enhancing supply chain resilience.

The research also emphasizes the importance of integrating renewable energy into the grid to reduce emissions during the operation and maintenance phases of heat pumps.

6.1.4. Evaluation of the link between material consumption in boilers and heat pumps (Assoclima)

At the macro scale, heat pumps are manufactured from similar raw materials to the boilers they replace. Some of the main materials used in a heat pump are various types of steel (reinforcing, low-alloyed, stainless), copper, and elastomers. Compared to a representative gas boiler, the heat pump uses a greater quantity of copper, some additional materials, and notably a refrigerant. Steel is used to make compressors, housing heat exchangers, and piping of a heat pump. Copper is used to produce heat exchangers, piping, electric cables, and expansion valves.

Large heat pumps (for industrial and DHC applications) are made from similar materials. However, materials may be used in different combinations and proportions depending on the temperature and refrigerant used [20].

Some of these materials, notably copper, are set to remain in high demand as clean energy transitions advance. Air-source heat pumps for residential applications contain around 15 to 20 kilograms of copper, predominantly in their pipes and valves, making up roughly 10% of the overall cost of the device [21]. The industry is exploring using aluminum alternatives to copper for key components to reduce costs [21].

Residential hydronic heat pumps typically contain more than twice as much aluminum and 15 times more copper and brass than their condensing gas boiler equivalents [21].
Table 4 below shows more details related to the share of metals present inside the above-mentioned products.

Type of product	**Capacity [kW]**	**Weight [kg]**	Steel Stainless Steel	Al	Cu&Brass	**METAL**	Plastic & Others	TOTAL	Ratio ATWHP vs Boiler
Gas condensing boiler *	22.0	28.65	62.8%	9.1%	3.8%	75.7%	24.3%	100%	
			17.99	2.61	1.09	**21.69**	6.96	28.65	
Air to Water heat pump monobloc * (ATWHP)	16.0	130.00	50.7%	6.9%	18.7%	76.3%	23.7%	100.0%	
			65.91	8.97	24.31	**99.19**	30.81	130.00	4.6
Air to Water heat pump monobloc ** (ATWHP)	5.5	89.00	50.7%	6.9%	18.7%	76.3%	23.7%	100.0%	
			45.1	**6.1**	**16.6**	**67.9**	21.1	89.00	3.1

Source : PEP EcoPassport *

Source : Assoclima assumption on PEP EcoPassport **

Table 4: Comparison of material composition between gas boiler and air-to-water heat pump.

Air-to-water heat pumps are expected to replace gas boilers in residential applications. Recovering and recycling the dismantled boilers is an opportunity that cannot be lost, considering that with 3 or 4 of them it will be possible to get back (secondary) the raw materials (steel, aluminum, and copper) needed to manufacture a brand-new heat pump.

From 2019 to 2023, in the top three EU gas boiler markets, 10.3 million equipments have been replaced containing enough steel and aluminum to produce 3.4 million of residential air-to-water heat pumps. In the same period in these markets, around 2.7 million heat pumps have been sold. About copper, it is another story, because only 0.5 million heat pumps could benefit from the raw material theoretically recovered.

Anyhow, improving the collection, treatment, and recycling of boilers at the end of their life can increase resource efficiency and support a faster shift to a consistent circular economy and contribute to the security of supply and a more stable price trend for these raw materials.

But the benefits are much greater. Materials recycling cuts CO2 emissions from the materials manufacturing process significantly [22]. Primary steel requires 1.9 tCO2/ton emissions while recycled only 0.4. About aluminum, primary 6.7 against 0.5 when recycled.

6.2. Data collection from EPD's and ecodesign

To expand on the existing knowledge that can be retrieved from previously published lifecycle analysis performed on domestic heat pumps, it was decided to also create a database that combines performance data from ecodesign and energy labelling with public available Environmental Product Declarations (EPDs). To facilitate this, a data collection format was developed and discussed among the project participants. This format includes a combination of energy efficiency and capacities from European standards like EN 14825 and data from other lifecycle stages from the EPDs. The template can be found in 13. Appendix 1.

When the annex was initiated in 2024, few EPDs for domestic heat pumps were public available on websites like Ecoplatform (https://www.eco-platform.org/epd-data.html), but as new EPDs become available, they will be added to this database on the website for the project (link). The compilation of this database will serve as a valuable resource for stakeholders, offering detailed insights into the environmental performance of various heat pump models. There is, however, a French initiative by the organization called P.E.P. Association [23] who has a mission to develop internationally the environmental declaration program PEP ecopassport® concerning electrical, electronic, and HVAC (heating, ventilation, air-conditioning, refrigeration) products.

One of the common topics when discussing EPDs is the harmonization of Product Category Rules (PCRs) across different markets. PCRs serve as the foundational guidelines for creating EPDs, dictating how life-cycle assessments should be conducted for specific product categories. The harmonization of these rules, or lack thereof, is crucial because it affects the consistency and comparability of EPDs globally. Differences in PCRs across markets can lead to discrepancies in how environmental impacts are reported, challenging the goal of achieving universal transparency and comparability. Consequently, discussions often focus on aligning PCRs internationally to facilitate smoother trade and competition, ensuring that products are assessed on a level playing field regardless of geographic location. EPD International features a comprehensive library of Product Category Rules (PCRs) covering a diverse range of products. However, a search specifically for PCRs related to heat pumps or air conditioners currently gives no results. There are however guidelines with Product Category Rules and Product Specific Rules linked to the French P.E.P. Association which can be found here [24], but these national rules can become an issue for manufacturers operating on many different markets. This is why there are two ongoing trends on this topic: 1) Program operators for EPDs are working on achieving mutual recognition of EPDs to achieve comparability across markets and 2) Business associations make their own PCR or “industry EPDs”. This enhances the industry's emphasis on lifecycle assessment of products. However, there is a potential risk that non-efficient products might go unnoticed within the broader context of “industry EPDs”. Both trends are ways to address market needs for EPD data in cases where alignment on PCR is lacking.

7. Task 1.4 Case study descriptions of previous common measures in heat pump design for domestic applications to lower the impact of materials

So far, when it comes to heat pumps, the main focus in product design has been on safety, energy efficiency, noise (primarily from air source heat pumps), and greenhouse gas emissions during the usage phase. In recent years, there has also been an increased focus on material efficiency, and this section investigates previous cases where material impact has been important. Each participating country has chosen topics that it would be interesting to share in relation to the challenges that the transition to a circular economy will pose for domestic heat pumps.

7.1. Germany

This section includes case study descriptions from Germany described by the German participant Fraunhofer ISE

7.1.1. LC150

In Germany, a recent research project called “LC150” (FKZ: 03EN4001A) focused on the development of a heat pump cooling circuit with a reduced refrigerant charge of 150 g of R290 (propane). As a natural refrigerant, propane has a significantly lower GWP than comparable synthetic refrigerants. The motivation for this research project was primarily based on safety aspects since propane is a flammable refrigerant. Circular economy of material efficiency has not been addressed in this project. However, due to the reduction of refrigerant charge, smaller components were used. Therefore, the development led to an overall reduced material consumption while maintaining sufficient heating capacity and efficiency.

Further investigations (outside this project) regarding the material requirements of heat pumps have shown that the reduction of material demand and the use of recycled materials will play a central role in the security of supply in both the short and long term. Investigated materials include copper, iron, and nickel, among others, and results show that the change in the design of the refrigerant cycle may lead to reductions in material consumption of up to 80% depending on the material.

7.2. Italy

The case description from Italy is described by the Italian trade organization for HVAC systems Assoclima.

7.2.1. Circular economy for refrigerants

In February 2024, the Regulation (EU) 2024/573, most commonly known as F-Gas Regulation, was published, and the content will enter into force in the first quarter of 2025. Heat pump manufacturers are mainly focused on the placing on the market prohibitions list, referred to in Article 11(1) and summarized in annex IV. This content will influence the next generation of heat pumps, but a much harder challenge has to be tackled for the stock of equipment already placed in the market.

Annex VIII of the regulation sets the maximum quantities and calculation of reference values and quota for placing hydrofluorocarbons on the market as referred to in Article 17. Starting from 42.8 million tons CO2e, this value will go down to zero in 2050, in coherence with the Green Deal target of net zero emission (Figure 9).

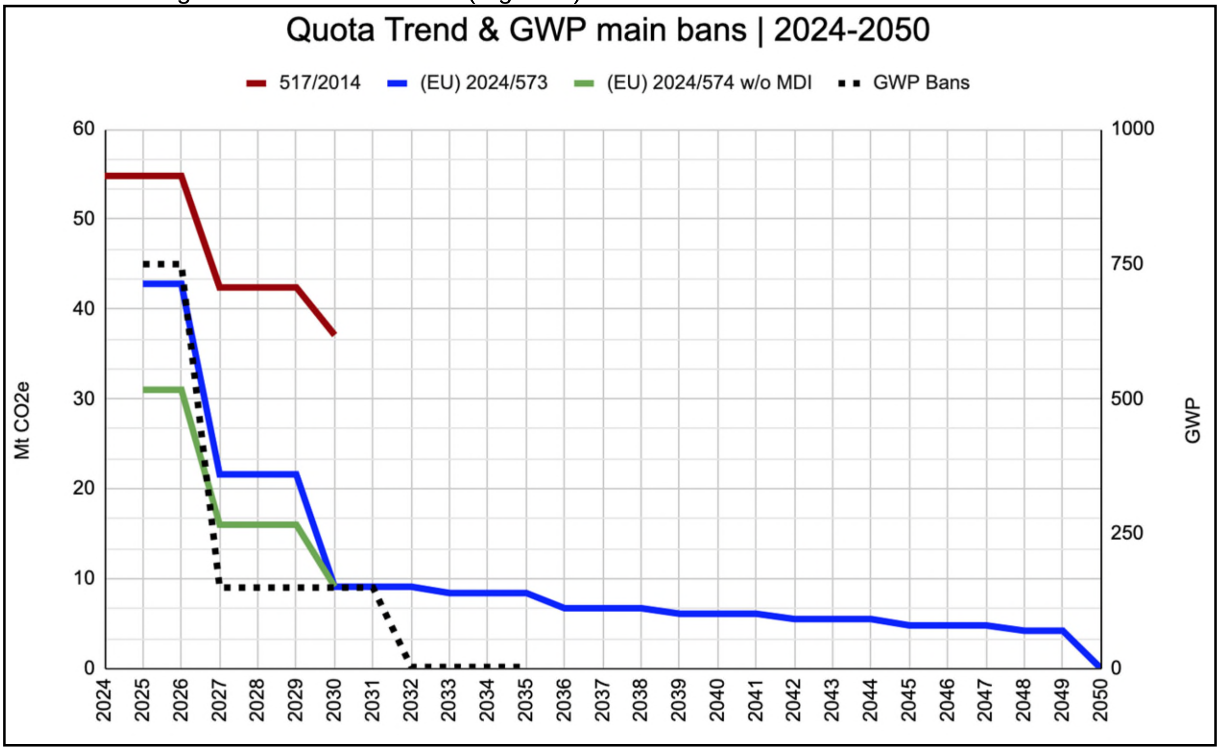


Figure 9: Green Deal Target; Quota Trend & GWP main bans (2024-2050)

The available quota must satisfy the needs of refrigerant for new equipment that will be placed in the market as well as the portion needed to maintain (refill leakages and reparations) the stock already installed. The decarbonization of the residential heating segment is expected to boost the air-to-water heat pump sales in the next decade coupled with the rising need of cooling in the central and northern part of the EU that will sustain the air-to-air heat pump sales.

What could happen by 2030 in a market with growing demand for refrigerants and a sharp decrease in available quotas?

For the purpose of this document, we will focus on the Italian market, sharing some data sourced from a study made by Assoclima, one of the biggest in the EU for heat pumps.

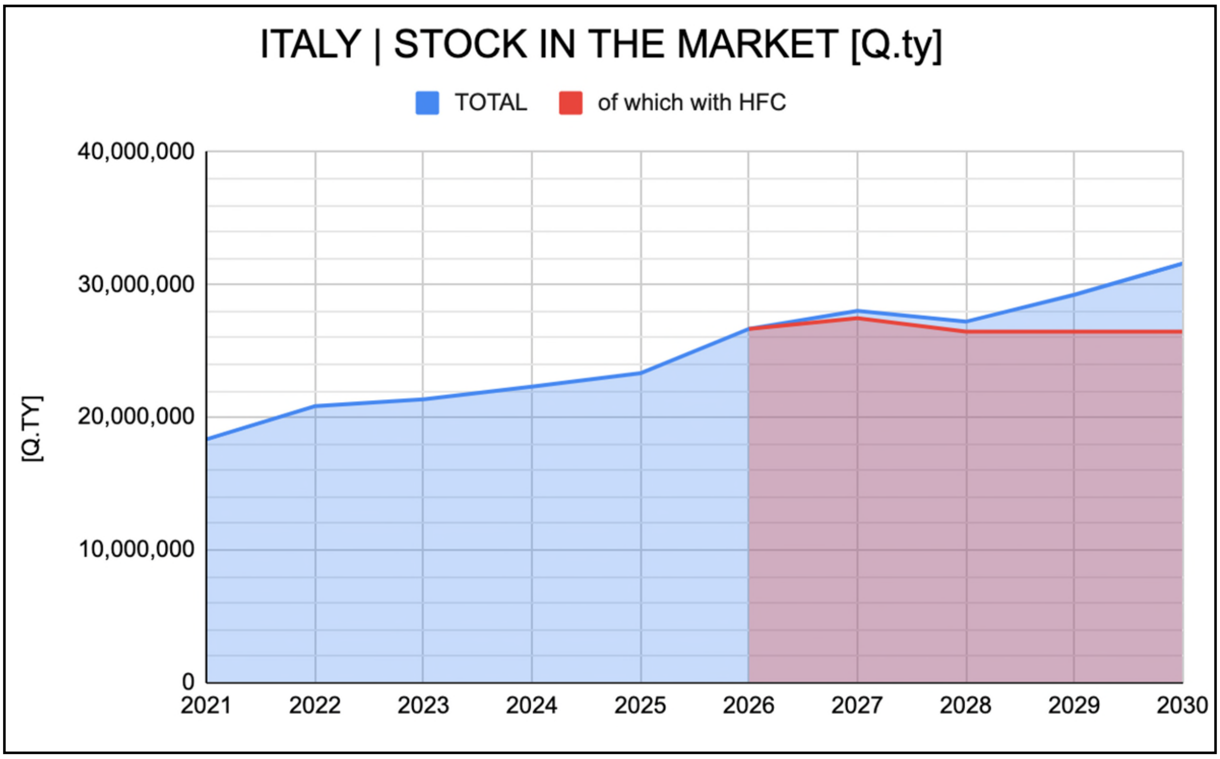


Figure 10: Stocks in the Italian market.

In 2023, the stock of reversible heating and air conditioning devices in use consisted of 21.3 million units and it is expected to grow to 31.6 million, of which 26.4 million are filled with HFC (Figure 10).

From 2026 new products filled with extremely low GWP refrigerants (hydrocarbons and HFO) will start to decouple the equipment's growth from the needed quota, due to the implementation of some of the bans listed in annex IV. This process will end in 2028 when the stock of units filled with HFC is expected to be fully stabilized.

As mentioned, the equipment in use must be refilled with refrigerant due to unavoidable leakages or after a repair intervention. Starting from 2018, F-Gas certified installers must upload into the Banca Dati F-Gas web portal all the requested data related to new equipment installed or the refilling activity of the ones already in use.

Every year ISPRA[2] publishes the Italian Greenhouse Gas National Inventory Report where they report the total leakage values for the heat pump and air conditioning equipment in use. These data, coupled with the available quota each year, will give the possibility to estimate the percentage of quota needed for refilling as a portion of the total available quota (Figure 11).

[2] ISPRA The Italian Institute for Environmental Protection and Research.

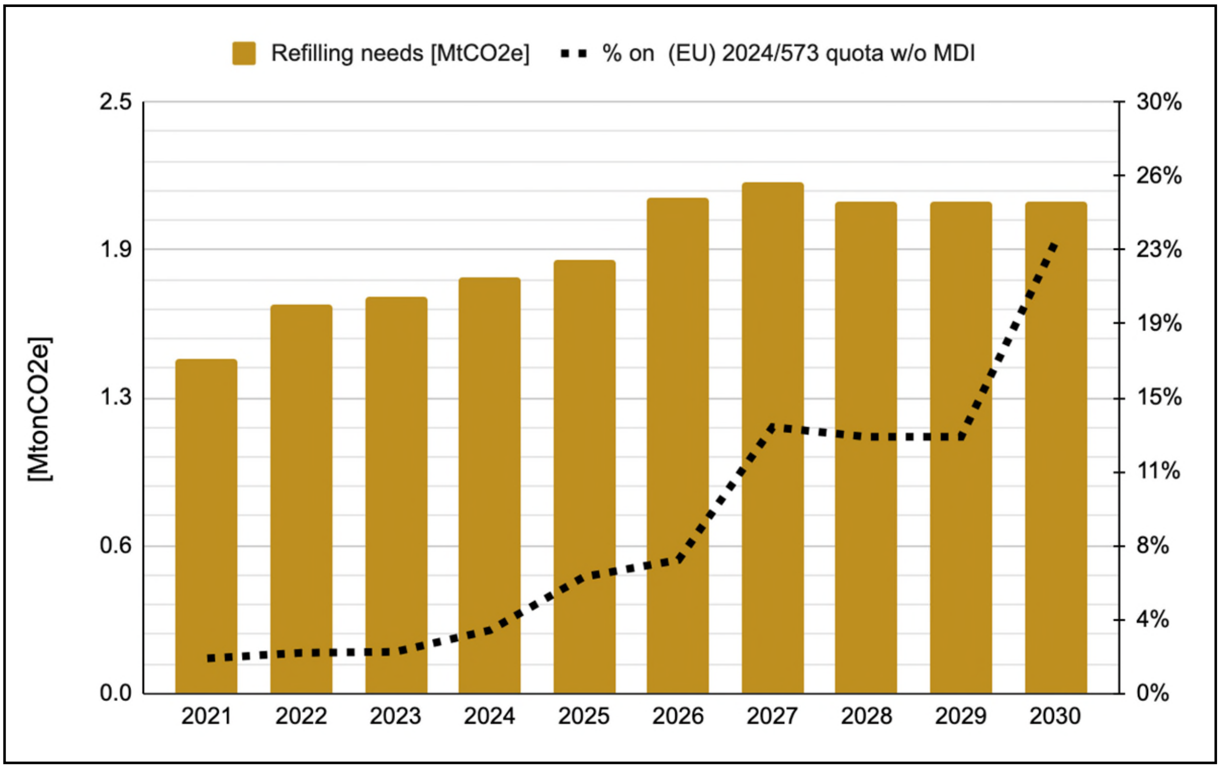


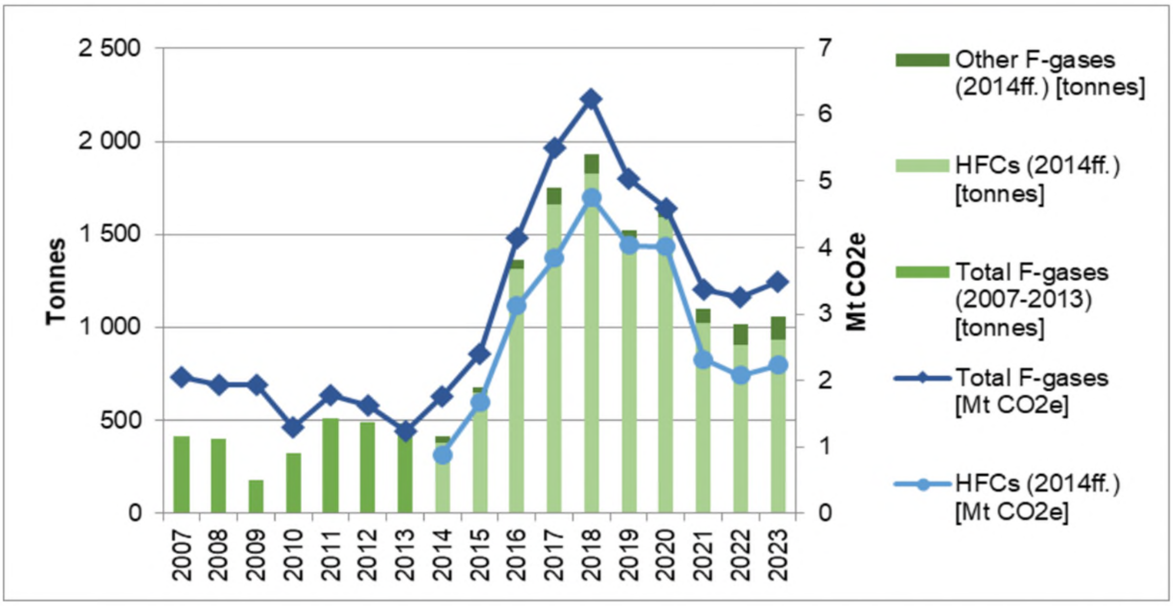
Figure 11: Projection of refilling needs and quotas in the Italian market until 2030.

In 2021, this value was 1.8%, rising to 3.2% in 2024, mainly led by the equipment stock increase. From 2025, due to the combination of the equipment's stock increase and the reduction of available quota, the share will more than double in 2025 (6.8%), doubling again in 2027 (13.5%). Eventually, it is expected to reach 23% in 2030.

It is important to note that quota values apply at the EU level, while refilling needs pertain exclusively to Italy. It is evident that, from 2025 onwards, the situation will become critical both at the Italian and EU levels. The market should be prepared to face a significant price increase for the most diffused HFC refrigerants (R410A, R134a, R32), but from 2026 onwards, an availability issue could also rise.

According to the latest European Environmental Agency report on F-gas, from 2021 to 2023 only about 2.0 MtonCO_2e have been reclaimed in the whole RACHP+R[3] industry at EU level (Figure 12), representing 70%-85% of the whole Italian refilling needs [25].

[3] Room Air Conditioning, Heat Pump + Refrigeration in 2023 represented 76% in weight and 57% in CO_2e of the total EU consumption of HFC. Among all the industries where HFC is in use, RACHP+R is the only one where reclamation can happen because the refrigerant is filled inside an equipment and not lost during the process.



Note: The geographical scope of presented data is the EU-28 except Croatia for 2007-2008, EU-28 for 2009-2019, EU-27+UK for 2020, and EU-27 for 2021 and subsequent years. The scope of F-Gases in the data presented is determined by Regulation (EU) 517/2014. Annex II F-gases (unsaturated HFCs and HCFCs, HFEs and alcohols, and NF_3 and other perfluorinated compounds) were not subject to reporting for the years 2007-2013.

Sources: EC, 2011 and 2014; EEA, 2023a and 2024b.

Figure 12: Share of F-gasses and Mt CO2 equivalents compared to amount of tonnes refrigerant.

This proves that today the overwhelming part of the refilling activities is performed with virgin refrigerant. Could the recovery and reclaim activity represent an opportunity to mitigate the expected price increase and the potential availability issue?

A potential source of refrigerant is the scrapped units, mainly at the end of their useful life. RACHP products are fully under the scope of the WEEE Directive that requires separate collection and proper treatment of waste electrical and electronic equipment. The regulations relating to the management of professional WEEE (Waste Electrical and Electronic Equipment) provide for the obligation of the Producers to guarantee the end user of the good the possibility of returning it when it becomes waste by financing the related costs. A Producer Responsibility Organisation, specialised in the collection and valorisation of professional WEEE, represents the safe and virtuous way for the producers to comply with EU and national regulations on WEEE, thus enhancing the commitment of its associates to social and environmental issues.

The newly approved Regulation (EU) 2024/573 has introduced the responsibility of the producer for the refrigerant management at the end of life of the equipment. This is an additional burden that in reality is already part of the collection and proper treatment of the equipment. The whole process is quite complicated with many subjects and with different levels of formal responsibility involved. This is the reason why the share of refrigerant collected from scrapped equipment today is quite low and the reclaimed portion neglectable.

But we have a very good reason not to give up. Type and quantity of refrigerant in the scrapped units could be able to solve the issue of the need for refilling the units already in operation.

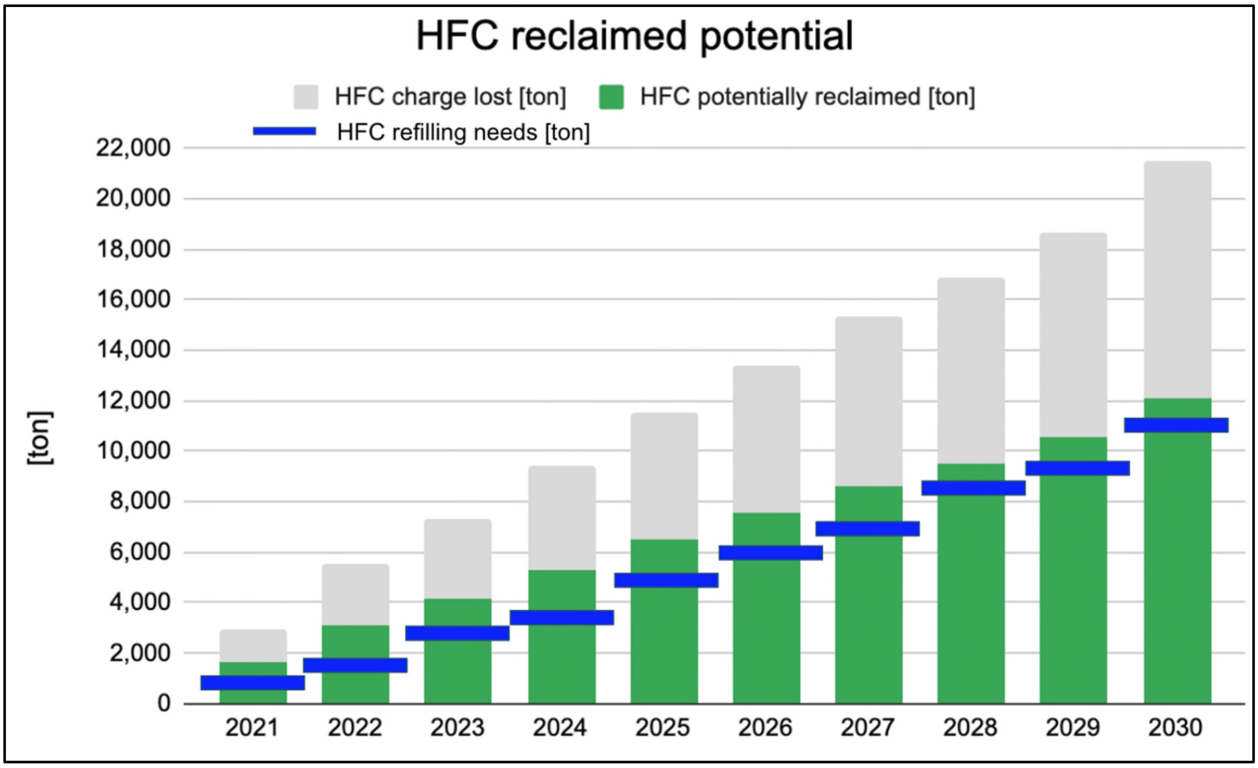


Figure 13: HFC reclaimed potential.

Assoclima estimates that the stock of refrigerant inside the units installed consists of 55% R32, 35% R125 (combining it with R32 will result as R410A), and 10% R134a.

The ISPRA's Italian Greenhouse Gas National Inventory Report states that the disposal emissions (end-of-life emissions) value of 43% has been calculated as the difference between the remaining HFC in products at decommissioning and the quantity of HFC recovered. This means that 57% of the refrigerant included in the stock of units could be theoretically eligible to be reclaimed.

Figure 13 shows that by recovering and reclaiming this amount of refrigerant, potentially 100% of the yearly refilling needs could be satisfied till 2030. However, from ideal to real world, many things must change quickly:

a) End of life products collection - in 2020 the share of collected R1[4] WEEE was 42% against a 65% EU target.
b) Refrigerant collection must be done during the decommissioning stage at the installation premises. This will avoid losing the refrigerant charge during the multiple transportation phases from the installation site to the scrapping site.
c) Installers must be properly incentivized to perform the refrigerant collection as described at point b) – also for small quantities. One of the best practices in promoting this behavior is ADC3R[5] in France. In recent years, some Italian refrigerant

---

[4] R1 WEEE category includes refrigerators, freezers, and air conditioning equipment.

[5] ADC3R is an association created in 2013. Members are companies that are active in France as distributors, fillers, recoverers, and reclaimers of refrigerants. It aims in particular to encourage the recovery, treatment, and regeneration of refrigerants as well as to promote any action relating to the limitation of CO2 emissions linked to the activities of our members. https://adc3r.com/en/qui-sommes-nous/

distributors, EU specialized companies, and multinational RACHP manufacturers started to propose dedicated service and incentives to Italian installers in order to stimulate their commitment in refrigerant recovery.

The issue is there and the potential to mitigate it too. What is still lacking is a strong coordinated commitment to tackle it quickly.

7.3. Denmark

The Danish group for the IEA HPT Project 65 has contributed with case descriptions which have been developed in collaboration with Danish Technological Institute who is the national representative for Denmark. The case descriptions can be found in the appendices.

7.3.1. Metro Therm – Machine learning fault detection on Metro Therm Delta heat pump

Metro Therm, a Danish heat pump manufacturer, integrated machine learning into their PVT heat pump systems to improve longevity and reduce maintenance costs. The project used algorithms like logistic regression and CUSUM to detect refrigerant leaks and clogged filters early, minimizing environmental impact. This initiative highlights the potential of machine learning to enhance heat pump efficiency and reliability.

7.3.2. Danfoss – Reduce material impact of ETS Colibri

Danfoss, a Danish company, introduced the ETS Colibri®, an innovative electric expansion device for advanced chillers and heat pumps, resulting in a reduced material impact and energy consumption. The initiative involved changing the valve body material from brass to stainless steel, significantly reducing the product's weight and emissions by 36%. Additionally, the design eliminated the need for holding current, drastically reducing cutting the use phase carbon footprint. Overall, this resulted in a total carbon footprint reduction from approximately 45 to 4.7 kg CO_2e, achieving a 90% decrease.

7.3.3. Danfoss – Material trade-offs in heat pump design and the case of silicon-based brass vs lead-based brass

Danfoss has provided a case description concerning the topic of brass used in some of the components produced by Danfoss for heat pumps. This case does not fit the description in the template for case descriptions decided by the project group, but it still offers some interesting insights which is why it is included here.

Danfoss provides an illustrative example of this challenge using silicon-based brass as a replacement for traditional lead-based brass. While this material shift offers significant advantages, it also introduces challenges that need to be carefully evaluated to ensure sustainable outcomes.

One of the primary benefits of using silicon-based brass is its ability to reduce exposure to lead, which is particularly crucial for applications involving the handling of drinking water. However, the adoption of silicon-based brass also poses challenges, particularly in terms of recycling. Unlike lead-based brass, which benefits from established recycling systems, silicon-based brass requires a separate waste stream to prevent contamination. As a result, the current recycling rate for silicon-based brass is very low. This low recycling share increases the reliance on virgin materials, which contributes to higher consumption of scarce resources and a larger carbon footprint. Over time, these challenges could be mitigated if recycling infrastructure for silicon-based brass is developed and implemented.

The ability - or lack thereof - to recycle a material also directly impacts its availability. Poor recycling systems can result in limited material availability, which diminishes the overall positive impact of transitioning to alternative materials. This issue underscores the need for a well-functioning recycling infrastructure to support sustainable material choices and the difficulties in being a frontrunner in adopting new materials. Depending on the specific application and the existing recycling systems, switching to a different material might be a better solution. Each choice must be carefully evaluated to ensure it aligns with the broader goals of sustainability and resource efficiency.

Another consideration is the impact of silicon-based brass on production processes. The material requires more powerful production equipment, leading to increased use of additional resources and materials. This added demand must be factored into the overall evaluation of its environmental impact. Danfoss emphasizes that material impact reductions should not be pursued in isolation but must be approached holistically, considering multiple indicators such as recyclability, resource consumption, production demands, and long-term sustainability.

In conclusion, the case of silicon-based brass illustrates the complexity of making material choices in heat pump components. While the shift away from lead-based brass offers clear health and environmental benefits, it also introduces challenges related to recycling, resource availability, and production. Danfoss stresses that these trade-offs must be assessed thoroughly, and multiple indicators should be applied to make informed, case-specific decisions. This integrated approach ensures that efforts to reduce material impact are both effective and aligned with the principles of sustainability.

11. Conclusion

This report has served as a foundational step towards fostering a common understanding of definitions, frameworks, and relevant information on the relationship between circular economy principles and domestic heat pumps. By addressing key topics such as material efficiency, lifecycle impacts, and regulatory frameworks, the report provides a comprehensive overview for stakeholders within the heat pump industry and beyond.

The findings demonstrate that the shift to a circular economy brings both challenges and opportunities for the heat pump sector, particularly in areas such as material efficiency, regulatory compliance, and lifecycle environmental impacts. The investigation into standards shows that while circular economy standards, such as the ISO 59000 family and the European EN 4555X series, have been established, these standards remain generic and require adaptation. Product-specific standards for heat pumps have not yet been developed, highlighting a critical gap that must be addressed to ensure practical implementation within the sector. It seems relevant that the standardization committees responsible for heat pumps address this topic.

Through a review of regulations such as Ecodesign, WEEE, RoHS, and REACH, the report underscores the growing regulatory push for sustainable practices. It also identifies the potential impacts of restrictions on materials like PFAS. Moreover, the case of fluoropolymers illustrates the trade-offs that arise when selecting alternative materials. While such choices can reduce environmental impact, they may simultaneously affect the product lifetime and performance of components, as well as create barriers for material and component circularity. Additionally, if substances like PFAS are banned from the market, the availability of key components could also be significantly impacted. Balancing these trade-offs requires careful evaluation to ensure that material choices align with both sustainability goals and the durability and availability of heat pump systems.

The literature review of lifecycle analyses confirms the environmental benefits of heat pumps in reducing greenhouse gas emissions compared to traditional heating systems. However, it also highlights the complexities of burden-shifting across environmental impact categories, underscoring the importance of adopting holistic lifecycle approaches. Complementing this, the project group has developed a template to facilitate the collection of Ecodesign-related data, combining energy efficiency data with publicly available Environmental Product Declarations (EPDs). Investigations have revealed that while the number of available EPDs for heat pumps is currently limited, this resource is growing. Discussions also emphasized the importance of Product Category Rules (PCRs) in shaping EPDs, revealing that no common PCRs for heat pumps exist at present. However, specific rules have been identified in France, linked to the PEP Association.

Case studies from Germany, Italy, and Denmark illuminate practical measures to enhance circularity in heat pump design and operations. These include innovations in refrigerant use, material substitutions, and digital solutions like machine learning for fault detection. Such examples demonstrate that the transition to a circular economy is not only achievable but can also drive innovation and competitiveness in the industry. Furthermore, the case study descriptions highlight the many interconnected topics at play in a transition to a circular economy, offering a glimpse into the complexities faced by manufacturers and component manufacturers as they navigate this shift. These complexities include adapting to new regulatory requirements, optimizing material efficiency, and managing supply chain challenges, all while ensuring product performance and sustainability.

In conclusion, this report serves as a point of departure for further analysis into the topic of domestic heat pumps and the circular economy. By fostering international collaboration, leveraging regulatory frameworks, and embracing innovative solutions, the industry can continue to make significant progress towards aligning with circular economy goals and achieving sustainability.

12. References

[1] Ellen MacArthur Foundation, “What is a circular economy?” Accessed: Nov. 05, 2024. [Online]. Available: https://www.ellenmacarthurfoundation.org/topics/circular-economy-introduction/overview

[2] European Commission, “Closing the loop: Commission adopts ambitious new Circular Economy Package to boost competitiveness, create jobs and generate sustainable growth,” 2015. Accessed: Mar. 21, 2022. [Online]. Available: https://ec.europa.eu/commission/presscorner/api/files/document/print/en/ip_15_6203/IP_15_6203_EN.pdf

[3] European Commission, “Circular economy action plan,” 2020, Accessed: Jan. 05, 2024. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/45cc30f6-cd57-11ea-adf7-01aa75ed71a1

[4] U.S. Environmental Protection Agency, “National Recycling Strategy: Part One of a Series on Building a Circular Economy for All,” 2021. Accessed: Dec. 08, 2022. [Online]. Available: https://www.epa.gov/system/files/documents/2021-11/final-national-recycling-strategy.pdf

[5] European Commission, “Ecodesign for Sustainable Products Regulation.”

[6] Cambridge Econometrics, Trinomics, and ICF, “Impacts of circular economy policies on the labour market,” 2018.

[7] “ISO 59004:2024 - Circular economy — Vocabulary, principles and guidance for implementation.” Accessed: Dec. 17, 2024. [Online]. Available: https://www.iso.org/standard/80648.html

[8] EUROPEAN COMMISSION, “COMMISSION IMPLEMENTING DECISION of 17.12.2015 on a standardisation request to the European standardisation Organisations as regards ecodesign requirements on material efficiency aspects for energy-related products in support of the implementation of Directive 2009/125/EC of the European Parliament and of the Council,” 2015. Accessed: Mar. 28, 2022. [Online]. Available: https://ec.europa.eu/growth/tools-databases/mandates/index.cfm?fuseaction=search.detail&id=564#

[9] CEN-CENELEC, “CEN/CLC/JTC 10 - Material efficiency aspects for products in scope of Ecodesign legislation.” Accessed: Mar. 28, 2022. [Online]. Available: https://standards.cencenelec.eu/dyn/www/f?p=205:32:0::::FSP_ORG_ID,FSP_LANG_ID:2240017,25&cs=10B7B067CC7107748A52C1C034BB4CFD3

[10] M. A. Bundgaard, R. D. Huulgaard, A. Remmen, and C. M. R. Gil, “Aalborg Universitet Requirements on material efficiency within the Ecodesign Directive,” 2021. Accessed: Mar. 25, 2022. [Online]. Available: https://vbn.aau.dk/ws/portalfiles/portal/415550738/Requirements_on_Material_efficiency_within_the_Ecodesign_Directive.pdf

[11] “Repairability score for tumble dryers (updated detailed rules).” Accessed: Jan. 15, 2025. [Online]. Available: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/14063-Repairability-score-for-tumble-dryers-updated-detailed-rules-_en

[12] European Commission, *DIRECTIVE 2011/65/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (recast) (Text with EEA relevance)*. European Directive, 2011.

[13] European Commission, “Summary of references of harmonised standards published in the Official Journal – Directive 2011/65/EU1 of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment.” Accessed: Dec. 17, 2024. [Online]. Available: https://ec.europa.eu/docsroom/documents/41284

[14] European Chemicals Agency, “Understanding REACH.”

[15] ASERCOM, “PFAS Ban Proposal Analysis: An ASERCOM Impact Assessment.” Accessed: Jan. 06, 2025. [Online]. Available: https://www.asercom.org/get-your-pfas-download-here/

[16] European Commission, “EU taxonomy for sustainable activities - European Commission.” Accessed: Jan. 06, 2025. [Online]. Available: https://finance.ec.europa.eu/sustainable-finance/tools-and-standards/eu-taxonomy-sustainable-activities_en

[17] European Heat Pump Association, “Note on heat pumps in the EU Taxonomy.” Accessed: Feb. 12, 2025. [Online]. Available: https://www.ehpa.org/wp-content/uploads/2022/12/20210510-Note-on-Taxonomy-and-heat-pumps.pdf

[18] C. Vering *et al.*, “Towards integral assessment of heat pumps and refrigerants using LCA: A case study for the German building stock,” 2023, Accessed: Dec. 19, 2024. [Online]. Available: https://www.hpc2023.org/wp-content/uploads/gravity_forms/3-7075ba8a16c5f78b321724d090fb2a34/2023/05/0311_HPC2023_Full_Paper_Vering_v03.pdf

[19] M. Shamoushaki and S. C. L. Koh, “Heat pump supply chain environmental impact reduction to improve the UK energy sustainability, resiliency and security,” *Sci Rep*, vol. 13, no. 1, p. 20633, 2023, doi: 10.1038/s41598-023-47850-x.

[20] A. Toleikyte *et al.*, “CLEAN ENERGY TECHNOLOGY OBSERVATORY 2024,” Joint Research Centre (European Commission). doi: 10.2760/7205477.

[21] International Energy Agency, “World Energy Outlook Special Report The Future of Heat Pumps,” 2022. [Online]. Available: www.iea.org

[22] Material Economics, “Preserving value in EU industrial materials A value perspective on the use of steel, plastics, and aluminium,” 2020. Accessed: Feb. 12, 2025. [Online]. Available: https://materialeconomics.com/node/15

[23] P.E.P. Association, “P.E.P. Association.” Accessed: Dec. 20, 2024. [Online]. Available: http://www.pep-ecopassport.org/pep-association/

[24] P.E.P. Association, “Produce a LCA.” Accessed: Dec. 20, 2024. [Online]. Available: http://www.pep-ecopassport.org/create-a-pep/produce-a-lca/

[25] S. Ludig, W. Jörß, and V. Liste, “Fluorinated greenhouse gases 2024 - ETC CM Report 2024/05,” 2024. Accessed: Feb. 12, 2025. [Online]. Available: https://www.eionet.europa.eu/etcs/etc-cm/products/etc-cm-report-2024-05

13. Appendix 1
Template for Heat Pump Lifecycle Data collection

<table>
<tr><td>Heat pump and supplier name</td><td>Model name: [Model name]
Manufacturer: [Company name]</td></tr>
<tr><td>EPD data</td><td>Type of EPD: [Type]
Declared unit: [value]
Reference service lifetime (link): [years]
EPD programme operator: [Name]
Publication date: [date]
Link to the published EPD: [URL]
Data set valid until: [year]</td></tr>
<tr><td>Technical heat pump data</td><td>Heat pump type: [Air-air, Air-water, liquid-water etc.]
Heat pump components included: [Outdoor unit + tower unit, Outdoor unit + buffer tank, tower unit + brine collector]
Application: [Space heating, combination heater, domestic hot water only]
Refrigerant: [R134a, R290, R407C, R32, …]
Dimensions [length, width, height]
Weight: [NUMBER] kg
Rated heating capacity low temperature: [P_rated] kW
Low temperature $SCOP_{Heating}$: [SCOP according to EN14825]
Rated heating capacity low temperature: [P_rated] kW
Medium temperature $SCOP_{Heating}$: [SCOP SCOP according to EN14825]</td></tr>
<tr><td>Flow diagram</td><td>[INSERT FLOW DIAGRAM if included in the EPD]</td></tr>
<tr><td>Product category rules</td><td>[Insert the product category rules applied]</td></tr>
<tr><td>Material distribution</td><td><table>
<tr><td>Material</td><td>Weight-% of declared product</td></tr>
<tr><td>[Steel]</td><td>[NUMBER]</td></tr>
<tr><td>[aluminum]</td><td>[NUMBER]</td></tr>
<tr><td>[Copper]</td><td>[NUMBER]</td></tr>
<tr><td>[Plastic]</td><td>[NUMBER]</td></tr>
<tr><td>[Other]</td><td>[NUMBER]</td></tr>
</table></td></tr>
<tr><td>Product packaging</td><td><table>
<tr><td>Material</td><td>Weight-% of declared product</td></tr>
<tr><td>[Wooden pallet]</td><td>[NUMBER]</td></tr>
<tr><td>[Plastic]</td><td>[NUMBER]</td></tr>
<tr><td>[Cardboard]</td><td>[NUMBER]</td></tr>
<tr><td>[Other]</td><td>[NUMBER]</td></tr>
</table></td></tr>
<tr><td>Hazardous substances</td><td>[Describe the list substances listed on 'Candidate List of Substances of Very High Concern for authorization (http://echa.europa.eu/candidate-list-table)']</td></tr>
<tr><td>System boundary</td><td>(X = included in LCA; MDN = module not declared)<table>
<tr><td></td><td colspan="10">Lifecycle indicators</td></tr>
<tr><td></td><td>A1-A3</td><td>A4</td><td>A5</td><td>B1</td><td>B2-B7</td><td>C1</td><td>C2</td><td>C3</td><td>C4</td><td>D</td></tr>
<tr><td>Lifecycle modules included</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table></td></tr>
</table>

Waste treatment rates (Module C4)	*Material* | *Recycling rate* | *Incineration rate* | *Landfilling Rate* *[Steel]* | *[NUMBER] %* | *[NUMBER] %* | *[NUMBER] %* *[aluminum]* | *[NUMBER] %* | *[NUMBER] %* | *[NUMBER] %* *[Copper]* | *[NUMBER] %* | *[NUMBER] %* | *[NUMBER] %* *[Plastic]* | *[NUMBER] %* | *[NUMBER] %* | *[NUMBER] %* *[Other]* | *[NUMBER] %* | *[NUMBER] %* | *[NUMBER] %*
Lifecycle data about this heat pump from environmental product declaration	(see table below)
Company contact information	*Name:* *Organization:* *Phone number:* *Email:* *Multiple contacts can be stated if necessary, e.g. if it is relevant to also mention end-user, supplier, etc.*
Appendix and additional information	*Optional. If relevant additional inputs/figures can be given here to elaborate on the case. However, this will not be included in two page description, but might be part useful later in the Annex work to elaborate further on the case.*
Date	*Please put in date for filling out this template*

Lifecycle data about this heat pump from environmental product declaration:

	Lifecycle indicators									
	A1-A3	A4	A5	B1	B2-B7	C1	C2	C3	C4	D
GWP [kg CO2 eq.]										
ODP [kg R11 eq.]										
Total use of non-renewable primary energy resource (PENRT)										
Total use of renewable primary energy resource (PERT)										
Use of net fresh water (FW)										
Water (user) deprivation potential (WDP)										
Hazardous waste disposed (HWD)										
Non hazardous waste dispose (NHWD)										
Components for re-use (CRU)										
Materials for recycling (MFR)										
Materials for energy recovery (MER)										

14. Appendix 2.1

Danish case descriptions – Danfoss ETS Colibri

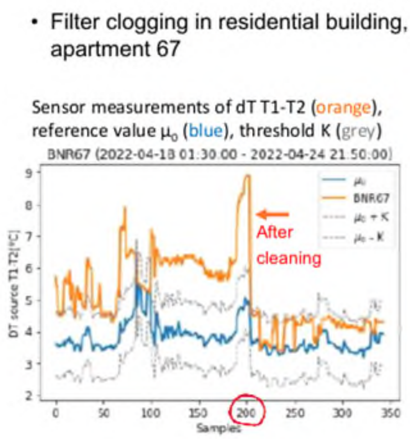
<table>
<tr><td>Heat pump manufacturer/ supplier name</td><td>Company: Danfoss
Country of origin: Denmark (but the product is not produced in DK)</td></tr>
<tr><td>Short description of the initiative</td><td>The ETS Colibri® is a new type of electric expansion device for advanced chillers and heat pumps. The material impact has been significantly reduced by more levers, including change of material and use phase energy consumption.</td></tr>
<tr><td>Picture of product/component</td><td></td></tr>
<tr><td>Motivation</td><td>Development of an electronic stepper motor valve with lower carbon footprint as well as better performance.</td></tr>
<tr><td>Category</td><td>Change of materials and production processes
Other: Use of sold products

Type of measures:
<table>
<tr><td>Take back</td><td>☐</td></tr>
<tr><td>Extend product life</td><td>X</td></tr>
<tr><td>Limit use of materials</td><td>☐</td></tr>
<tr><td>Production changes</td><td>X</td></tr>
<tr><td>Other (please describe):</td><td>X</td><td></td></tr>
</table></td></tr>
<tr><td>Key Learnings</td><td>Material choice and material reduction: Changing brass material with stainless steel for valve body led to a substantial weight reduction. Overall, the material change reduced emissions from materials and production by 36%.
Use of sold products: By design, the need for holding current in the application was eliminated, thereby reducing the use phase carbon footprint by more than 97%.
The case provides a good example illustrating how the use of LCA data can be used for making decisions already in the design phase considering both material use and energy consumption. In this case, the total carbon footprint was reduced from approx. 45 to 4.7 kg CO2e (GWPF), corresponding to a 90% reduction.</td></tr>
</table>

Changes in market position	Danfoss has now a much better understanding of the carbon footprint impact of our products during their lifetime - and we can provide the data to our customers in an EPD, Environmental Product Declaration. This is such a great step forward for us in our efforts to help our customers decarbonize. One pilot project was designed to explore how two similar products perform from an environmental perspective, in other words what their CO_2 footprint/emission would be, and that was a decisive factor for commercial HP customers that were looking for EPD declaration of products and embed as low as possible high carbon footprint products in its new range.

15. Appendix 2.2

Danish case descriptions – Metro Therm Delta –Fault detection of PVT-heat pump system using machine learning methods

<table>
<tr><td>Heat pump manufacturer/ supplier name</td><td>Company: Metro Therm
Country of origin: Denmark</td></tr>
<tr><td>Short description of the initiative</td><td>Metro Therm, a Danish heat pump manufacturer, initiated a project to incorporate machine learning algorithms for fault detection in PVT heat pump systems. The primary objective was to develop a model that enhances product lifetime, reduces maintenance costs, and improves heating system performance. By leveraging machine learning techniques, such as logistic regression and CUSUM algorithms, the initiative sought to detect faults like refrigerant leakage and clogged filters early, thus minimizing environmental impact and maintaining efficiency. The project demonstrated that despite significant refrigerant loss, the system maintained operational capacity, showcasing the robustness of Metro Therm's heat pumps</td></tr>
<tr><td>Picture of product/component</td><td>

</td></tr>
<tr><td>Motivation</td><td>Metro Therm initiated the machine learning project to improve fault detection in heat pump systems, aiming to reduce maintenance costs and extend product lifespan. The focus was on detecting refrigerant leakage and clogged filters early to maintain system efficiency and minimize environmental impact.</td></tr>
<tr><td>Category</td><td>Type of measures:
<table>
<tr><td>Take back</td><td>☐</td><td></td></tr>
<tr><td>Extend product life</td><td>☐</td><td></td></tr>
<tr><td>Limit use of materials</td><td>☐</td><td></td></tr>
<tr><td>Production changes</td><td>☐</td><td></td></tr>
<tr><td>Other (please describe):</td><td>☒</td><td>Fault detection through machine learning</td></tr>
</table></td></tr>
<tr><td>Key Learnings</td><td>Key learnings from Metro Therm's initiative:
Machine learning algorithms, such as logistic regression and CUSUM, effectively detect faults like refrigerant leaks and clogged filters.
Optimal feature selection is crucial for accurate model performance.</td></tr>
</table>

	• Heat pumps maintained functionality despite significant refrigerant loss. • Advanced algorithms can enhance product reliability and efficiency. • Identified the most sensitive parameters for effective fault detection.
Changes in market position	The initiative highlighted the need for advanced processors to handle the data-intensive nature of machine learning models, especially when deploying sophisticated algorithms like logistic regression and CUSUM. Additionally, Metro Therm identified the importance of strategically selecting sensors to capture critical data for accurate fault detection. These insights are crucial for balancing performance improvements with practical implementation constraints in heat pump systems.

www.heatpumpingtechnologies.org

Heat Pump Centre
c/o RISE - Research Institutes of Sweden PO Box 857
SE-501 15 BORÅS
Sweden
Tel: +46 10 516 53 42
E-mail: hpc@heatpumpcentre.org

www.heatpumpingtechnologies.org

Report no. HPT-AN65-2