# ORC Power Plants for Thermal Energy Harvesting

## Aspects related to Policy, Finance and the Job Market

CE Delft

Committed to the Environment

# ORC Power Plants for Thermal Energy Harvesting

## Aspects related to Policy, Finance and the Job Market

This report was prepared by: Ward van Santen and Martijn Blom

Delft, CE Delft, December 2023

Publication code: 23.230206.170

The work was performed under contract with the Knowledge Center on Organic Rankine Cycle technology (KCORC)

Publications of CE Delft are available from www.cedelft.eu

Further information on this study can be obtained from the contact person Ward van Santen (CE Delft)

**CE Delft**
Committed to the Environment

Through its independent research and consultancy work CE Delft is helping build a sustainable world. In the fields of energy, transport and resources our expertise is leading-edge. With our wealth of know-how on technologies, policies and economic issues we support government agencies, NGOs and industries in pursuit of structural change. For 45 years now, the skills and enthusiasm of CE Delft's staff have been devoted to achieving this mission.

# Content

# Executive summary

In the EU's endeavour to achieve its climate goals, a relevant improvement of the energy efficiency of industrial manufacturing processes could be achieved by making use of waste heat. One of the technologies that is suitable for the conversion of waste heat into electricity are Organic Rankine Cycle (ORC) power plants. This report covers three different topics. Firstly, a policy review of the current EU policies relevant to ORC technology is carried out, and policy recommendations are made to better address thermal energy harvesting. Secondly, the financial viability is studied by describing indicative ORC business cases for six relevant industries/sectors (glass, cement, steel, oil & gas, chemicals, and the maritime sector). Finally, a high-level estimation of the potential job creation perspective for ORC in the EU is provided.

## Policy review

Table 1 shows an overview of current policies relevant to thermal energy harvesting and ORC power plants. The most relevant developments are:

- Since ORC is explicitly mentioned as cogeneration technology in the third revision of the Energy Efficiency Directive (**EED III**), more awareness will be drawn to ORC technology when implementing the EED at national level. In this report, we discuss a few best practice cases of how ORC is already embedded in national energy saving policies in Germany (funding program), Italy (White Certificates), and The Netherlands (tax scheme).

**Table 1 - Overview policy review**

| Policy | Relevance for ORC | ORC explicitly mentioned | Adoption or last revision | Status |
|---|---|---|---|---|
| Energy Efficiency Directive (EED) | High | Yes | 2023 | In force |
| Renewable Energy Directive (RED) | Low | No | 2023 | In force |
| EU Emission Trading System (ETS) Directive | Medium | No | 2023 | In force |
| FuelEU Maritime Regulation | High | No | 2023 | In force |
| EU Taxonomy Regulation | Medium | No | 2020 | In force |
| – EU Taxonomy Climate Delegated Act | Medium | No | 2023 | In force |
| Industrial Emissions Directive (IED) | Medium | No | 2010 | Trilogue negotiations on revision |
| – BREFs: Iron and Steel (2012); Glass (2012); Ceramic (2007); Non-ferrous metals (2016); Chemicals[1] (2007-2017); Oil & gas (2014) | High | No | 2007-2017 | In force; Ceramic: formal draft of revision |
| – BREF Cement | High | Yes | 2013 | In force |
| – BREF Energy Efficiency | High | Yes | 2009 | In force |
| F-Gas Regulation | High | No | 2014 | In force |
| Net-Zero Industry Act (NZIA) | Medium | No | NA | Proposal; vote planned late 2023 |
| Strategic Energy Technology (SET) Plan | Medium | Yes | 2023 | In force |

---

[1] There are five BREFs related to chemicals.

- The Best Available Techniques (BAT) Reference Documents (**BREFs**) – falling under the (Industrial Emissions Directive (**IED)** – are the main reference documents used by authorities in EU countries when issuing operating permits for industrial installations that represent a significant pollution potential. They inform relevant decision makers about what may be technically and economically available to the industry in order to improve the industry's environmental performance. In some of the BREFs that we studied, ORC systems are already mentioned as potential cogeneration technology. Although IED prescribes that BREFs should be revised within eight years after being published, we found that most of the documents were outdated. In the horizontal BREF on Energy Efficiency, for example, information on the efficiency of the ORC systems is missing, potentially leading to misinterpretations around the Technology Readiness Level of this technology.

Concluding, we note that some EU instruments are designed or better suited to prescribe specific technologies (e.g., BREFs), whereas others (e.g., EED, EU ETS, and EU Taxonomy) have a more technology-neutral character. These technology-neutral policies can have a generic stimulating effect on energy-efficient technologies like ORC. Although these directives do not explicitly refer to ORC technology, they may form an important base for increasing the market of waste heat to power technologies in the upcoming decade. By design, these EU instruments call for concerted efforts by Member States to implement national legislation in line with the objectives of these EU instruments.

## Financial viability

Although there are many factors that determine the financial characteristics of the business case, average or typical investments in ORC power plants are shown in Table 2.
The information was collected through interviews with suppliers and (potential) users of ORC systems. Even though most figures have been provided by suppliers, we have received no signals from technology users that the underlying assumptions are too optimistic. We identified four parameters that are most relevant to the business case: the electricity price, additional costs (on top of the ORC system), the discount rate used, and the operating hours of the plant. The uncertainty around the energy prices (due to many possible factors) is identified as one of the major risks to the implementation of ORC. Besides that, the potential ban on PFAS (that is available in the working fluid of part of the ORC systems) could potentially lead to delays in the uptake of ORC and/or closure of existing plants.

**Table 2 - Overview of the key figures of indicative business cases* (prices in $€_{2023}$; discount rate 8%)**

| Figure | Unit | Glass | Cement | Steel | Oil & gas | Chemicals | Maritime |
|---|---|---|---|---|---|---|---|
| *Power capacity* | *$MW_{el}$* | *1.0-2.0* | *1.0-8.0* | *1.0-5.0* | *5.0* | *0.4* | *0.1-0.2* |
| *Electricity price, paid for* | *€/MWh* | *110* | *90* | *80* | *NA* | *120* | *NA* |
| *Operating hours* | *Hours/year* | *8,500* | *7,500* | *7,500* | *5,500* | *8,000* | *4,500* |
| Savings per year | Mln. € | 0.9-1.9 | 0.7-5.4 | 0.6-3.0 | NA | 0.3-0.4 | 0.08-0.13 |
| Payback period | Years | 3.0-4.8 | 2.8-6.7 | 4.7-7.5 | 7.0 | 5.0-7.0 | 2.1-3.8 |
| Net Present Value | Mln. € | 6-13 | 3-34 | 2-17 | NA | 2-4 | 0.4-0.5 |
| Internal Rate of Return | % | 20-33% | 14-35% | 12-21% | NA | 13-20% | 25%-47% |
| $CO_2$-eq. savings | Ton/year | 2,100-4,300 | 1,900-15,000 | 1,900-9,000 | 8,000 | 700 | NA |
| $CO_2$-eq. abatement costs | €/ton $CO_2$-eq | -95-128 | -52-104 | -34-71 | NA | -49-115 | NA |
| *Source* | | *Suppliers (3)* | *Suppliers (3)* | *Suppliers (3)* | *ORC user (1)* | *ORC user (1)* | *Supplier (1) & ORC user(1)* |

* The figures provided by suppliers are based on average or typical cases in the current industry (2023); figures for the oil & gas and chemicals industries are each provided by one (potential) user of ORC systems. The information cannot be generalized as it depends on many variables.

## Job creation perspective

We provided high-level estimates of the theoretical potential of direct labour opportunities created by ORC investments within the EU. For temporary labour opportunities, the potential is estimated between 4,000 and 41,000 (most likely, between 4,000 and 12,000) fte per year for a ten-year period. The permanent labour opportunities are estimated between 6,000 and 10,000 fte.

## Recommendations

Based on our findings, we have come to the following recommendations (that are discussed in more detail at the end of Chapter 5 and aimed at EU policy makers):

- spread best practices of national EED implementations amongst Member States;
- update the BREF documents and update them more frequently;
- classify ORC (besides cogeneration technology) also as waste heat to power technology in the EED and the BREFs for Cement and Energy Efficiency;
- research the feasibility to include waste heat to power technologies, most notably ORC systems, in the BREF documents for iron & steel, glass, ceramic, chemicals, and oil & gas;
- carry out a social cost benefit analysis on the application of ORC systems;
- consider including waste heat to power technologies in the Climate Delegated Act of the EU Taxonomy Regulation.

# Abbreviations

| Abbreviation | Description |
|---|---|
| BAT | Best Available Techniques |
| BAFA | Federal Office of Economics and Export Control of Germany |
| BREF | Best Available Techniques (BAT) Reference |
| CAPEX | Capital Expenditures |
| CCS | Carbon Capture and Storage |
| CHP | Combined Heat and Power |
| Commission | European Commission |
| Council | Council of the European Union |
| CO2 | Carbon dioxide |
| CO2-eq | Carbon dioxide equivalent |
| EED | Energy Efficiency Directive |
| EC | European Commission |
| ECHA | European Chemicals Agency |
| EIA | Energy Investment Allowance |
| EML | Recognised Energy Efficiency Measures List (or, ‘Erkende maatregelenlijst’) |
| EP | European Parliament |
| EPBD | Energy Performance of Buildings Directive |
| ETS | Emission Trading System |
| EU | European Union |
| F-Gas | Fluorinated greenhouse gas |
| GHG | Greenhouse Gas |
| HFC | Hydrofluorocarbon |
| INCITE | Innovation Centre for Industrial Transformation and Emissions |
| IRR | Internal Rate of Return |
| IED | Industrial Emissions Directive |
| IWG | Implementation Working Group |
| Fte | Full Time Equivalent |
| KCORC | Knowledge Center on Organic Rankine Cycle |
| kWh | Kilo Watt hour |
| LCOE | Levelized Cost of Electricity |
| MW | Mega Watt |
| $MW_{el}$ | Mega Watt eletric |
| MWh | Mega Watt hour |
| NECP | National Energy and Climate Plan |
| NPV | Net Present Value |
| NZIA | Net-Zero Industry Act |
| OPEX | Operational Expenditures |
| ORC | Organic Rankine Cycle |
| PET | Polyethylene terephthalate |
| PFAS | Per- and polyfluoroalkyl substances |
| PV | Photovoltaics |
| NA | Not Available |
| RED | Renewable Energy Directive |
| R&D | Research & Development |
| SET | Strategic Energy Technology |
| TRAN | Parliament’s Committee on transport and tourism |

# 1 Introduction

## Context

In the EU's endeavour to achieve its climate goals, a relevant improvement of the energy efficiency of industrial processes could be achieved by making use of the thermal energy that is generated by human activity and discarded to the atmosphere. One of the technologies that is suitable for the conversion of thermal power into electrical or useful mechanical power is the use of Organic Rankine Cycle (ORC) power plants. KCORC, the Knowledge Center on Organic Rankine Cycle technology, published a white paper in 2022 on the current situation and the potential of this technology to contribute to the EU climate goals. The paper contains a general description of the technology, the role of the technology in the EU energy transition, a techno-economic analysis of various applications of ORC systems, a chapter on policy and regulation, and a chapter on research and development in relation to this technology.

## Goal

The goal of this report is to contribute to the second version of KCORC's white paper by:

- improving the chapter on financial viability and providing an initial set of key figures related to actual business cases;
- improving the chapter on policy and regulation by providing a review on the latest relevant developments in the EU in relation to ORC technology;
- improving the section on the job creation perspective by providing a high-level estimation of the potential job creation perspective for the ORC industry in the EU.

## Scope

There is a wide range of industrial applications in which ORC technology for thermal energy harvesting can be used. The white paper published by KCORC distinguishes five different, exemplary types of sources of wasted thermal energy which are suitable to power ORC systems:

1. Manufacturing processes.
2. Natural gas supply infrastructure.
3. Propulsive engines.
4. Combustion of fuels and other energy carriers (including hydrogen).
5. Electrochemical reactions.

Thermal energy from manufacturing processes has a large potential for waste heat to power in the EU. This is, therefore, the focus of this report.

Useable thermal energy can be classified depending on the temperature level at which it is available. The white paper describes that in general terms, the higher the temperature of the energy source and the larger the amount of energy, the more economically attractive the conversion of otherwise wasted thermal energy into electricity by means of ORC technology. Based on this, it is identified that the following industrial sectors offer the highest potential for immediate and economically viable installation of ORC power plants: iron and steel, non-metallic minerals (e.g., cement, clinker, glass), non-ferrous metals, chemicals and petrochemicals.

As the range of areas suitable for ORC power plant installations is so wide, the scope of this project is limited to providing key figures for six indicative business cases. These will be business cases for thermal energy from manufacturing processes in the glass, cement, steel, chemicals and oil & gas industries, and one related to the maritime transport sector.
The policy review is focussed on EU policies that are relevant to achieving the objectives of the EU Green Deal (and, for some directives, the increased ambitions put forward by REPowerEU), assessing whether ORC technology has been considered. The directives, regulations, and plans that are covered are:

- Energy Efficiency Directive (EED);
- Renewable Energy Directive (RED);
- EU ETS;
- FuelEU Maritime Regulation;
- EU Taxonomy Regulation;
- Industrial Emissions Directive (IED);
- F-Gas Regulation;
- Net-Zero Industry Act (NZIA);
- Strategic Energy Technology (SET) Plan.

The policy review eventually results in policy recommendations regarding the coverage of ORC technology in these directives, regulations, and plans.

## Reading guide

The policy review is covered in Chapter 2. In order to make the reader familiar with the terminology and the process EU legislation undergoes, a short summary of the EU decision-making process is given at the beginning of this chapter. Afterwards, the policies above are discussed. In Chapter 3, the financial viability of ORC systems in various applications is discussed. It starts with the methodology, followed by the presentation and discussion of the business cases. After that we discuss risks and barriers and co-benefits related to the business cases. In Chapter 4, the job creation perspective is covered, containing a methodology section and a section that discusses the results. Chapter 5 summarizes the conclusions and presents the policy recommendations.

# 2 Policy review

## 2.1 Introduction

In order to make the reader familiar with the terminology and the process EU legislation undergoes, a short summary of EU decision-making is given at the beginning of this chapter. Afterwards, the relevant policies are discussed by giving a general description and information about recent developments, followed by an assessment whether ORC technology has been considered in these policies. The directives, regulations, and plans that we considered are:

- Energy Efficiency Directive (EED);
- Renewable Energy Directive (RED);
- EU ETS;
- FuelEU Maritime Regulation;
- EU Taxonomy Regulation;
- Industrial Emissions Directive (IED);
- F-Gas Regulation;
- Net-Zero Industry Act (NZIA);
- Strategic Energy Technology (SET) Plan.

As will be discussed in the following section, the EU Green Deal, Fit for 55 and - later on - REPowerEU have played a key role in relation to these directives, regulations, and plans with new legislative proposals and increased ambitions.

We conclude this chapter with an overview of our of the policy review. Policy recommendations are put forward in Chapter 5.

## 2.2 EU decision-making

The European Commission is the only EU institution that can propose new EU legislation. The most common types of EU legislative acts are Directives and Regulations. Directives stipulate the general objectives of the legislation but need to be implemented through national legislation adopted by the EU’s Member States. Regulations, in contrast, have direct legislative power in all Member States.

The most common decision-making procedure in the EU, which is in general also applicable in the fields of climate, energy, and industry, amounts to co-decision by both the Council of the European Union (containing 27 national ministers, representing the Member States) and the European Parliament (EP, containing 705 members, currently related to 8 political groups, and with a direct mandate from the EU’s electorate). After the Commission has published a new legislative proposal, it is scrutinised by both the Council and the EP, and both institutions prepare their positions towards the proposal, including possible amendments. During informal negotiations between the Council, the EP and the Commission, referred to as trilogues, it is attempted to bridge the differences between the various positions. When an agreement is reached in the trilogues, it needs to be adopted formally by both the Council and the EP before the legislative act enters into force. This entire process, from Commission proposal to entry into force, typically takes one or two years.

In special cases, related to technical or implementation details of the legislation but not to its essence, the EP and Council can authorise the Commission to adopt parts of the legislation itself through so-called Implementing Acts or Delegated Acts. These cannot be amended by the EP and the Council but can be rejected. Whereas Member States are primarily responsible for implementing EU law, Implementing Acts are typically concerned with areas where uniform conditions for implementation are needed (such as taxation, agriculture, the internal market, health, etc.). Delegated Acts are non-legislative acts that serve to amend or supplement elements of the legislation and are typically used to establish measures of a technical nature.

**Green Deal and Fit for 55**

In December 2019, the Commission presented the European Green Deal (EC, 2019). The Green Deal is a package of policy initiatives and was framed as EU's new growth strategy, aiming to transform the EU into a fair and prosperous society, with no net greenhouse gas (GHG) emissions by 2050 and an economic growth decoupled from the use of natural resources. While the main objective of the Green Deal is to achieve climate neutrality, it also includes ambitious objectives in the policy areas of environment, nature restoration and biodiversity. In 2021, the European Climate Law was adopted, enshrining in the EU's legislative framework the aim of a net reduction of 55% of GHG emissions by 2030 and of climate neutrality by 2050.

In order to implement the 55% reduction target, the Commission presented an extensive set of legislative proposals in July 2021, referred to as the Fit for 55 package. These proposals covered many different economic sectors and included the revision of the Renewable Energy Directive (RED), the Energy Efficiency Directive (EED) and the Emission Trading System (ETS), as well as a proposal to decrease the carbon intensity of fuels used in the maritime sector (FuelEU Maritime Regulation). Just over two years later, almost all Fit for 55 proposals have been negotiated and adopted by the Council and the EP.

**REPowerEU**

Following the invasion of Ukraine by the Russian Federation and the resulting energy market disruptions, the Commission initiated the so-called REPowerEU Plan, a comprehensive set of ambitions and proposals to increase energy savings, boost the EU's domestic renewable energy generation, and diversify (the origin of) its energy supplies. The REPowerEU Plan included amendments to the Commission's own revision proposals for the RED, the EED and the Energy Performance of Buildings Directive (EPBD), increasing some of the key targets set in de proposal. These amendments were, however, not always reflected in the final text of the legislative acts – see below.

## 2.3 Relevant EU policy developments

### Energy Efficiency Directive (EED)

The EU Energy Efficiency Directive (EED) was adopted in 2012 to deliver on a minimum of 20% energy efficiency improvements (compared to the projections for energy use in 2020 made in 2007) by 2020 (EC, 2012). The EED was revised in 2018 (from there on also referred to as EED II) setting the EU objective of reaching at least 32.5% energy efficiency improvements by 2030 (compared to the projections for 2030 made in 2007), with each Member State required to achieve higher annual energy savings obligations (0.8% annually between 2024 and 2030) (EC, 2018).

As part of the Fit for 55 package, in 2021 the Commission proposed another revision of the EED (or 'EED III'). The EP and Council negotiators reached a provisional agreement on 10 March 2023. This agreement sets a reduction of primary and final energy consumption by

11.7% at EU-level (compared to projections for energy use in 2030 made in 2020; the target for primary consumption is indicative); this corresponds to a reduction of 40.5% of primary energy consumption and 38% of final energy consumption if compared to the projections for energy use in 2030 made in 2007. The yearly energy savings targets for Member States are set at an average rate of 1.5% per year until 2030, starting at 1.3% per year until the end of 2025, increasing to 1.9% per year between 2026 and the end of 2030. The EP and the Council adopted the revised directive in July 2023. In September 2023, the EED III was officially published (EU, 2023a). Although there are no strict timelines on how often a directive is revised, it is not expected that there will be a revision of the EED any time soon.

### *Relevance and implications for ORC technology*

In the EED III, under part II of Annex II, ORC is explicitly mentioned as cogeneration technology that is covered by the Directive (EU, 2023a). It is important to stress that ORC is explicitly not mentioned as waste heat to power technology. Having ORC systems listed as cogeneration technology, could give the idea that the main purpose of using ORC systems is the combined production of power and heat and not the conversion of waste heat into electric power.

As the general objectives of the EED need to be implemented through national legislation, Member States are incentivised to adopt new policy instruments in order to meet their EED targets. One way to contribute to meeting these targets is through subsidies, tax schemes, or other supporting schemes. In KCORC's white paper several examples related to ORC are mentioned. In Italy, for example, energy efficiency measures are promoted through a White Certificates scheme (related to Article 9[2] of EED III), that obliges electricity and natural gas distributors to obtain a number of certificates corresponding to their annually increasing energy efficiency targets. One of the eligible energy efficiency measures is the installation of ORC systems, for which a specific incentive scheme with a 10-year benefit holds (KCORC, 2022). Use cases of how ORC technology is financially stimulated in Germany and the Netherlands are described in the textbox below. These lists of eligible technologies can be used as an important instrument to stimulate the adoption of ORC power plants for waste heat to power. Another example from the Netherlands, in which a list of energy efficiency measures is used, is described in the textbox below as well (Recognised Energy Efficiency Measures List).

**Germany**

***BAFA - Federal funding for energy and resource efficiency (Module 4)***

Under Module 4 (Energy and resource-related optimisation of systems and processes) of the funding program of the Federal Office of Economics and Export Control (BAFA), funding is provided for investments in carbon-saving, energy efficiency, and resource efficiency measures of industrial and commercial plants. In Module 4 ORC is explicitly mentioned as waste heat recovery technology. The maximum funding amounts to € 15 million per investment project, with a funding rate of up to 50% of the eligible investment costs. The maximum funding is limited to an amount of € 500 (€ 900 for medium-sized companies and € 1,200 for small and micro companies) per tonne of $CO_2$ saved per year (funding efficiency) (BAFA, 2023).

---

[2] This Article is a key pillar of the EED, which requires Member States to use Energy Efficiency Obligation Schemes (EEOSs). Under the EEOS, energy companies must save an annual percentage of their energy sales to final customers (0.8% in 2021 and 2023, 1.3% in 2024 and 2025, 1.5% in 2026 and 2027, and 1.9% in 2028, 2029, and 2030) with additional energy efficiency projects. This Article also offers Member States the option to introduce alternative policy measures to EEOSs, provided that these measures deliver equivalent energy savings. An example of this is the White Certificate scheme.

**The Netherlands**

***The Energy Investment Allowance (EIA)***

The EIA is a tax scheme for companies in the Netherlands that is aimed to promote investments that result in substantial energy savings. Companies deduct 45,5% of the investment costs from their taxable profit, leading to an average fiscal advantage of around 12%. Investments are eligible when they are included (or meet the requirements) in the so-called ‘Energy List’. This is a document that includes almost 200 codes, describing specific (clearly defined investments or technologies) and generic (tailor-made investments) ‘company resources’. The Energy List – that is renewed and published every year – has been shown to have an ‘attention effect’. This means that the fact that a company resource is included on the list, already creates a positive signal to companies making this resource better known (SEO & CE Delft, 2023). In the latest version of the Energy list, ORC technology is included, whereby the following components are eligible for the incentivised investment: condenser, evaporator, pump, turbine, separator, heat exchanger, generator, and connection to the electricity grid (RVO, 2023).

***Recognised Energy Efficiency Measures List (EML)***

Starting in 2023, (locations of) companies and institutions in the Netherlands that use more than 50,000 kWh of electricity or more than 25,000 $m^3$ of natural gas per year fall under the ‘Energy Efficiency Obligation’. Under this obligation, companies and institutions are required to take all energy efficiency measures with a payback period of less than five years. The Recognised Energy Efficiency Measures List - or ‘Erkende maatregelenlijst’ (EML) - is a list of energy efficiency measures (with a payback period of less than five years) that companies and institutions can use to comply with the Energy Efficiency Obligation (RVO, 2021). Although the list does not contain all measures with a payback period of less than five years, companies and institutions comply with the Energy Efficiency Obligation, as long as they take all measures from the list that they are technically able to take. The list contains three categories: buildings, facilities, and processes. Under ‘processes’ some measures are mentioned related to (the use of) process heat - for example, investing in a heat exchanger – but ORC is not explicitly mentioned as one of the technologies in this category (that has a payback period of less than five years).

## Renewable Energy Directive (RED)

The EU Renewable Energy Directive (RED) was adopted in 2009 to deliver a minimum 20% share of renewable energy in the EU’s gross final energy consumption by 2020 (EC, 2009a). The RED was revised in 2018 (also referred to as RED II) to deliver the EU’s objective of a minimum 32% share of renewable energy by 2030 (EU, 2018). As part of the European Green Deal, the Commission adopted the Fit for 55 package in 2021, including a significant revision of the RED (EC, 2021b), also referred to as RED III.

Initially, RED III would increase the binding EU minimum share of renewable energy to 40% by 2030. In the REPowerEU plan the Commission proposed 45%, which was also the position of the EP. The Council, however, aimed at a share of 40%. The trilogue negotiations between the Parliament, the Council and the Commission concluded with a provisional agreement on 30 March 2023 on a 42,5% share of renewables by 2030 (with an additional 2,5% indicative, non-binding top-up). The Council formally endorsed the final text on the 16th of June 2023 (Council of the European Union, 2023). After that, a plenary vote took place in September 2023 (European Parliament, 2023b).

### *Relevance and implications for ORC technology*

As was described in KCORC’s white paper (KCORC, 2022), the RED II did not consider waste heat and cold as a source of renewable energy. Waste heat and cold are only considered for direct use in the heating and cooling sectors. The definition of renewable energy under the RED II (Article 2, definition 1) is: “‘energy from renewable sources’ or ‘renewable energy’ means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas;” Therefore, waste heat is not considered renewable if it is originated from a process where fossil fuels are used, and thus, ORC-generated electricity in such cases does not comply with the definition of renewable energy under this directive. The RED III, published on 31 October 2023, refers to the same definition as in the RED II (EU, 2023b).

Although ORC is currently - in the context of waste heat recovery - primarily dependent on heat sources from processes where fossil fuels are used, this could change in the future. If the use of, for example, green hydrogen would become more common in industrial manufacturing processes or if heat were generated from electricity imported from a fully decarbonised grid, this means that electricity produced by ORC systems could be considered renewable.

## EU Emission Trading System (ETS)

The EU ETS is a ‘cap and trade’ system, setting an absolute cap on greenhouse gas emissions within the subjected sectors in the EU, covering all Member States. The cap decreases over time, setting a trajectory for emission reduction over time. The cap is expressed in emission allowances, where one allowance gives the right to emit one tonne of $CO_2$-eq. (carbon dioxide equivalent). Every year, companies must submit sufficient allowances to account for their emissions. Companies can buy these emission allowances on the EU carbon market and can trade these with other companies. The price of an allowance serves as a signal: the higher the price, the more incentive there is for companies to invest in innovative, low-carbon technologies. Allocation of allowances is organised through auctioning and free allocation. There are two methods for free allocation of allowances: grandparenting (entities receive emission allowances according to their historical emissions in a base year or base period) and benchmarking (allowances are allocated according to performance indicators). The most relevant developments around the allocation of allowances are described below.

**Phase 1** lasted from 2005-2007. In this period, only emissions from power generators and energy-intensive industries (such as oil, iron and steel, cement, glass, and ceramics) were considered in the ETS, and almost all allowances were allocated for free.

**Phase 2** ran from 2008-2012, where more sectors (including intra-European Economic Area[3] aviation) and countries were added to the system. The cap was decreased, and fewer free allowances were allocated (around 90%). The carbon prices were relatively low during this period, due to the economic crisis of 2008 leading to a decrease in emissions caused by the reduction in economic activity.

**Phase 3** lasted from 2013-2020. In this phase, an EU-wide cap was established rather than national caps on emissions. Moreover, 57% of the allowances were auctioned and the remainder allocated for free based on benchmarks. Free allocation for electricity was mostly phased out, and more sectors (such as petrochemicals and nonferrous metals) and gases (nitrous oxides and perfluorocarbons) were included in the system (EC, 2023d).

In **Phase 4** (2021-2030), the pace of emissions cuts was increased (the overall number of emission allowances will decline at a yearly rate of 2,2% raising to a linear reduction factor

---

[3] The European Economic Area (EEA) includes all 27 EU countries and Iceland, Liechtenstein, and Norway.

of 4,3% from 2024 to 2027 and 4,4% from 2028, compared to 1,74% before) and free allocation of allowances will be further phased out, although not completely[4]. As included in the ETS revision that was adopted in May 2023, from 2024 on, EU ETS will also cover emissions from maritime transport (all large ships - of 5,000 gross tonnage and above - entering EU ports, regardless of the flag they fly) (European Parliament, 2023d).

### *Relevance and implications for ORC technology*

The increasing pace of emission cuts set by EU ETS will increase the incentive for the energy sector, the industry, and the maritime sector to focus on increasing energy efficiency and decreasing emissions. As discussed in Chapter 3 in more detail, carbon pricing will increase the costs of fossil fuel and therefore has a positive impact on the ORC business case: on the one hand, by an increasing price for end-users, on the other hand, because operators of installations that fall under ETS directive are incentivised to increase energy efficiency. Additionally, in as much as, in the maritime transport sector, electricity is generated on board through - for example, a diesel generator (independent from the main engine and with the sole purpose of generating electricity)-, the costs of electricity used on board depend on the costs of the fuel used to generate it. As carbon pricing will eventually increase the costs of fossil fuels, it could improve the business case of ORC modules in the maritime sector.

## FuelEU Maritime Regulation

As part of the Fit for 55 package, in July 2021, the European Commission presented the FuelEU maritime initiative. The proposed regulation introduces limits on greenhouse gas intensities of fuels used by vessels from 2025, which obliges them to use alternative fuels. It applies to commercial vessels (inland and ocean but excluding fishing vessels) - of 5,000 gross tonnage and above - entering EU ports, regardless of the flag they fly. It covers all energy used on board when the ship is at an EU port and traveling between EU ports, and 50% of the energy used on voyages departing from or arriving to an EU port. As mentioned in Section 2.2, regulations – in contrast to directives, who stipulate general objectives of the legislation that need to be implemented through national legislation adopted by the Member States - have direct legislative power in all Member States.

After the trilogue, the Council and Parliament agreed on cuts on greenhouse gas intensity of energy used on board of large ships of 2% by 2025, 6% by 2030, 20% by 2035, 38% by 2040, 64% by 2045, and 80% by 2050. Additionally, a dedicated ‘Ocean Fund’ should be established to improve the energy efficiency of ships and support investment aimed at helping decarbonise maritime transport. The Parliament’s Committee on transport and tourism (TRAN) approved the provisional agreement in May 2023, followed by the Parliament and Council in July 2023. The final act was signed on 13 September 2023 and was published in the Official Journal of the EU on 22 September 2023 (European Parliament, 2023a).

### *Relevance and implications for ORC technology*

The main focus of the FuelEU Maritime Regulation is the reduction of greenhouse gas intensities of fuels used on board of large ships. In line with the EU ETS, this incentivises the improvement of the energy efficiency of ships. Although not mentioned in the regulation, one potential way to achieve this is by installing ORC modules that use the waste heat of exhaust gas, saturated steam, thermal oil, or cooling water to produce

---

[4] Furthermore, the reform includes two one-off ‘rebasings’ of the cap, reducing it by 90 million allowances in 2024 and an additional 27 million in 2026.

electricity when in operation. This reduces the need to generate electricity on board through traditional methods such as diesel generators. Annex III of the regulation sets general requirements for zero-emission technologies[5], including a 'non-exhaustive' list of technologies (on-board fuel cells, on-board electrical energy storage, and on-board power generation from wind and solar energy). Besides that, it is mentioned that power supplied by on-board technologies that are not identified in this list but achieve zero emissions, can be added to the list by means of delegated acts (EU, 2023c).

## EU Taxonomy[6] Regulation

In 2020, the EU Taxonomy Regulation entered into force (European Parliament & The Council of the European Union, 2020). Article 9 of the Taxonomy Regulation sets out six environmental objectives:

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.
6. Protection and restoration of biodiversity and ecosystems.

The regulation establishes the basis for the EU taxonomy by setting out the four overarching criteria – as described in Article 3 of the regulation - that an economic activity has to meet in order to qualify as environmentally sustainable:

1. Making a substantial contribution to at least one environmental objective.
2. Doing no significant harm to any of the environmental objectives.
3. Complying with minimum safeguards (related to business and human rights).
4. Complying with the technical screening criteria set out in the Taxonomy delegated acts (see below).

The EU Taxonomy is technology-neutral and is aimed at facilitating the transition of polluting sectors to sustainability. It can be seen as a classification system that establishes clear definitions of what an environmentally sustainable activity is. This can help companies and investors to make informed decisions on environmentally sustainable activities. The EU Taxonomy will be updated regularly.

The EU Taxonomy is explicitly **not**: a mandatory list of economic activities for investors to invest in; a mandatory requirement for public investment; or a mandatory requirement on environmental performance for companies or financial products. It is a voluntary instrument that helps actors to steer their financial decisions towards more sustainable investments and finance (EC, 2023e).

---

[5] According to Article 3, point (7), 'zero-emission technology' means a technology that, when used to provide energy, does not result in the release of the following greenhouse gases and air pollutants into the atmosphere by ships: carbon dioxide ($CO_2$), methane ($CH_4$), nitrous oxide ($N_2O$), sulphur oxides ($SO_x$), nitrogen oxides ($NO_x$) and particulate matter (PM).

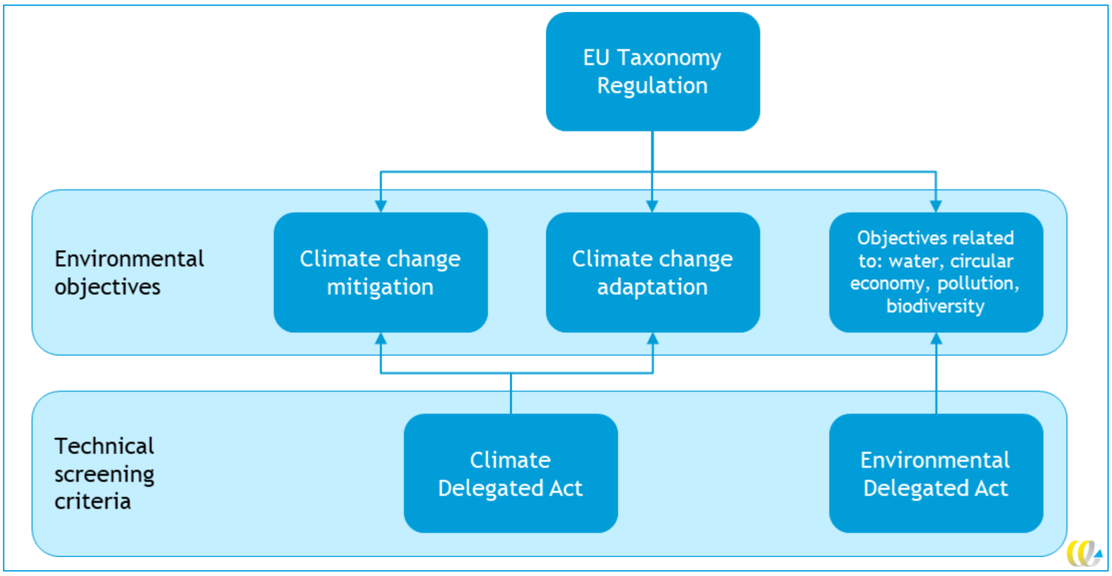
[6] A taxonomy is a scheme of classification.

Under the Taxonomy Regulation, the Commission was mandated to adopt a list of environmentally sustainable activities by defining technical screening criteria[7] - ensuring that an economic activity substantially contributes to one of the environmental objectives, while not doing significant harm to any of the other objectives - through two delegated acts[8]:

1. **The Environmental Delegated Act** (related to sustainable use and protection of water and marine resources, transition to a circular economy, pollution prevention and control and protection and restoration of biodiversity and ecosystems).
2. **The Climate Delegated Act** (related to climate change mitigation and adaptation).

In 2021, the EU Taxonomy Climate Delegated Act was published in the Official Journal and the Delegated Act became applicable from 1 January 2022 (EC, 2021a). Since then, the Commission has adopted two amendments. In July 2022, the Complementary Climate Delegated Act was published, including - under strict conditions - specific nuclear and gas energy activities in the list of economic activities and became applicable as of January 2023 (EC, 2022a). In 2023, the Delegated Act was amended once more, establishing additional technical screening criteria (EC, 2023a).

**Figure 1 – Graphical representation of how the EU taxonomy is related to environmental objectives and regulations to achieve them**



## *Relevance and implications for ORC technology*

In relation to ORC technology, the Climate Delegated Act is most relevant as it covers climate mitigation objectives for which increasing energy efficiency is an important measure. Besides that, like the Environmental Delegated Act, it covers - amongst other categories - economic activities of the heavy industry and water transport.

---

[7] The criteria are informed to a large extent by the recommendations of the Platform on Sustainable Finance, an advisory body of the Commission, containing a panel of experts from various backgrounds.

[8] As explained in Section 2.2, in special cases, the Commission can adopt parts of the legislation itself through so-called Delegated Acts. Delegated Acts are non-legislative acts that serve to amend or supplement elements of the legislation and are typically used to establish measures of a technical nature.

In KCORC's white paper, it is discussed that the utilisation of waste heat is considered, in the Climate Delegated Act, as one of the environmentally sustainable economic activities, but not for the production of electricity. In the two amendments mentioned in the previous paragraph, the scope of the use of waste heat has not changed. However, as the EU Taxonomy is aimed to be updated regularly, in order to keep up to date with technological and policy developments, the option remains to incorporate waste heat to power as a form of waste heat recovery in the future.

## Industrial Emissions Directive (IED)

In 2010, the EU adopted the Industrial Emissions Directive (IED) (European Parliament & The Council of the European Union, 2010). The Industrial Emissions Directive (IED) is the main EU instrument regulating pollutant emissions from industrial installations. All installations undertaking the industrial activities listed in Annex I of the Directive are required to operate in accordance with a permit (granted by the authorities in the Member States). This permit should contain conditions set in accordance with the principles and provisions of the Directive.

The permit conditions – including emission limit values – must be based on the Best Available Techniques (BAT). In order to define BAT and the BAT-associated environmental performance at EU-level, the Commission organises an exchange of information with experts from Member States, industry, research institutes, environmental NGOs and the European Commission. This process is coordinated by the European IPPC Bureau - who sets up technical working groups per sector or industry - and results in BAT Reference Documents (BREFs)[9].

**BAT Reference Documents (BREFs)**

BREFs are the main reference documents used by authorities in EU countries when issuing operating permits for industrial installations that represent a significant pollution potential. They inform relevant decision makers about what may be technically and economically available to the industry in order to improve their environmental performance. The conclusions from these documents ('BAT conclusions') are adopted by the Commission as Implementing Decisions. The IED requires that these BAT conclusions are the reference for setting permit conditions.

The majority of BREFs cover specific agro-industrial activities; such BREFs are referred to as 'sectoral BREFs'. However, there are also several 'horizontal BREFs' dealing with cross-cutting issues such as energy efficiency, industrial cooling systems or emissions from storage with relevance for industrial manufacturing in general (EIPPCB, 2023a). Producing a BREF is a two-to-three-year process, involving up to 100 experts, with the key support of the EIPPCB mediating the process. There is a rolling programme to revise BREFs periodically in order to account for developments in manufacturing techniques and in pollution control (EC, 2023). According to IED, the Commission should strive to revise BREFs within eight years after the publication of its previous version.

Once finalised, each BREF is formally presented by the European IPPC Bureau to the forum established under Article 13 (3) of the IED, which is an expert group comprising Member States' representatives, industries, and environmental NGOs. Subsequently, the BAT conclusions are endorsed by the IED Article 75 Committee and published as Implementing Decisions in the Official Journal of the European Union (EIPPCB, 2023b).

---

[9] An overview of the BREFs and their current status can be found on the website of the European IPPC Bureau: www.eippcb.jrc.ec.europa.eu/reference.

In 2022, the Commission adopted - in line with the European Green Deal - proposals to revise the IED (EC, 2022b). The proposal aims to improve the Directive by increasing the focus on energy efficiency (as well as water and material efficiency and reuse; and the use of safer, less toxic or non-toxic chemicals in industrial processes).

Other relevant changes in the Directive are:

- Ensuring full and consistent implementation of the IED across Member States, where Member State permitting authorities will be required to use tighter pollutant emission limit values when revising permits or setting new permit conditions.
- The EU framework for preventing and controlling industrial emissions will become more forward-looking and innovative. In order to facilitate this, an Innovation Centre for Industrial Transformation and Emissions (INCITE) should be established, that will identify and evaluate emerging techniques and - if they are ready for use at an industrial scale within a short timescale - incorporate them in the Best Available Techniques framework as candidate techniques.

The trilogue negotiations between the Parliament and the Council have started in 2023 (European Parliament, 2023c).

### *Relevance and implications for ORC technology*

As shown in Table 3, most of the BREF documents (related to the industries iron and steel, glass, ceramic, chemicals, and oil and gas) make references to cogeneration and/or combined heat and power (CHP). A quick scan of these references is presented in the table. In case of the Cement industry and Energy Efficiency, ORC is mentioned explicitly. However, similarly to the EED, ORC is categorized as cogeneration technology rather than waste heat to power technology, again potentially leading to the misconception that the main purpose of using ORC systems is the combined production of power and heat and not the conversion of waste heat into electric power.

In the BREF document involving the cement industry (Production of Cement, Lime and Magnesium Oxide) ORC systems are mentioned three times (JRC, 2013). In Section 1.2.5.8 (‘Cogeneration’), ORC systems are mentioned as a potential technology for cogeneration. The process of how ORC systems work is explained and it is illustrated by its first application in the cement industry in a German cement kiln. In Section 1.4.2.4 (‘Energy recovery from kilns and coolers/cogeneration’), the German case is compared to an application of a conventional steam cycle process for waste heat recovery at a Swedish cement plant. The conclusion drawn from comparing the economics of the two cases is that waste heat recovery from the kiln and clinker cooler for power generation may be assessed case by case as the economic viability may depend on factors such as the local electricity price and the size of the plant. The business case of the German ORC plant is described in the Annex (6.2.3.2). It describes its efficiency, yearly $CO_2$ savings, CAPEX, OPEX, and yearly generated electricity, which are in line with the business case figures we present in Section 3.3.1 of this report.

In the BREF Energy Efficiency document - under Section 3.4.1 (‘Different types of cogeneration’), Table 3.20 – ORC systems are mentioned as cogeneration technology[10] (EC, 2009b). Moreover, in contrast to some other technologies shown in the table, its efficiency - or power to heat ratio, representing the ratio between electricity from cogeneration and useful heat when operating in full cogeneration - is not given, what could be interpreted as the technology being still under development or not fully commercial. Any additional

---

[10] But is misspelled (‘Rankin’ instead of ‘Rankine’).

information on ORC (e.g., on how ORC systems work, or the economics of an ORC power plant) is not given. Although the IED prescribes that BREFs should be revised no later than eight years after them being published, Table 3 makes it clear that this has not happened for most of the documents. For example, the BREF on energy efficiency was published in 2009 and - although a corrected version of the document was published in 2021 - has never been revised.

**Table 3 - BREF documents review**

| BREF | Adopted/ published | ORC explicitly mentioned | References (relevant) to ORC |
|---|---|---|---|
| Iron and Steel | 2012* | No | Cogeneration/CHP mentioned in Section 2.2 (Power plants in iron and steel works): describes the use of CHP for electricity production and mentions that most steel works have a surplus of heat (and thus, no internal demand for heat). |
| Cement | 2013* | Yes | ORC mentioned (see analysis above):<br>– Section 1.2.5.8 (Cogeneration);<br>– Section 1.4.2.4 (Energy recovery from kilns and coolers/cogeneration);<br>– Section 6.2.3.2 (Cogeneration with the Organic Rankine Cycle (ORC) process-cement plant in Lengfurt in Germany). |
| Glass | 2012* | No | Waste heat recovery mentioned:<br>– Section 4.4.2.6.1 (3R technique): fuel efficiency can be improved using waste heat recovery;<br>– Section 4.4.3.3 (Dry or semi-dry scrubbing): waste heat recovery mentioned as one of the most important environmental targets related to $SO_2$ abatement. |
| Ceramic | 2007* | No | Cogeneration/CHP mentioned in revised BREF document (August 2023) in Section 4.3.11 (Cogeneration/combined heat and power plants): mentioned as technique to reduce the consumption of energy and for decarbonisation. The document describes that the heat produced by CHP can be used in the spray-drying process (especially for wall/floor tiles, household ceramics, and brickworks). |
| Non-ferrous metals | 2016 | No | No relevant references. |
| Large Volume Inorganic Chemicals | *NA* | No | No BREF yet. Drawing up started, publication planned in 2027. |
| Large Volume Inorganic Chemicals - Ammonia, Acids and Fertilisers | 2007* | No | No relevant references. |
| Large Volume Inorganic Chemicals - Solids and Others Industry | 2007* | No | Cogeneration/CHP mentioned many times throughout the document referring to different applications of CHP. |
| Production of Large Volume Organic Chemicals | 2017 | No | Cogeneration/CHP mentioned in Section 2 (Techniques to reduce energy consumption) as relevant technology to co-produce electricity and steam. Also, a reference to the Energy Efficiency BREF is made (which mentions ORC, see below). |
| Manufacture of Organic Fine Chemicals | 2006* | No | Cogeneration/CHP mentioned in Section 2.3.5 (Energy supply): mentioned that self-production of electricity is especially advantageous on large sites. |
| Oil and gas | 2014 | No | Cogeneration/CHP mentioned: many references to CHP throughout the document, referring to the need to produce on-site electricity and steam. |
| Horizontal BREF: Energy Efficiency | 2009* | Yes | ORC mentioned (see analysis above) in Section 3.4.1 (Different types of cogeneration), Table 3.20. |

Source: www.eippcb.jrc.ec.europa.eu/reference.

* Not revised in the last 8 years.

## F-Gas Regulation

Fluorinated greenhouse gases (F-gases) are fluorinated compounds which have a very low ozone-depletion potential but a very high greenhouse gas effect, that are widely used in, for example, the refrigeration industry. At EU-level, F-gases currently account for about 2.5 % of total GHG emissions (EC, 2023b). In order to control emissions from (F-gases) – including hydrofluorocarbons (HFCs), the most commonly used F-gas, representing around 90% of F-gas emissions – the EU has adopted the F-gas Regulation. The regulation was originally adopted in 2006 (EU, 2006) and updated in 2014 (EU, 2014). It limits the total amount of HFCs that can be sold in the EU from 2015 onwards and phasing them down in steps to one-fifth of 2014 sales in 2030. Besides that, it bans the use of F-gases in many new types of equipment where less harmful alternatives are widely available (such as fridges, air conditioning, foams, and asthma sprays) and prevents emissions of F-gases from existing equipment by requiring checks, proper servicing, and recovery of the gases at the end of the equipment's life. The regulation is currently being reviewed, resulting in increased ambitions levels and prevented GHG emissions.

### *Relevance and implications for ORC technology*

Part of the commercially available ORC systems make use of HFCs as working fluids and are therefore affected by the F-gas regulation. As all HFCs are indexed as per- and polyfluoroalkyl substances (PFAS) fluids and a recent initiative led by some Member States is pushing the European Chemicals Agency (ECHA) to ban PFAS (ECHA, 2023), this could affect the ORC industry.

In ORC systems, the working fluids are used in a closed loop, which is sealed from the environment (comparable to a refrigeration system). According to a recent position paper published by KCORC (KCORC, 2023), PFAS are emitted due to leakages or improper handling of the working fluid. Replacing PFAS fluids with a natural refrigerant (such as hydrocarbons or $CO_2$) is not only possible, but in some cases also economically interesting - due to the low cost of natural refrigerants - even if this might require significant development and adjustment time for the industry and certifying bodies, leading to potentially significant delays in the uptake of ORC technology and even (temporary) closure of existing ORC power plants.

## Net-Zero Industry Act (NZIA)

In January 2023, the Commission announced the Green Deal Industrial Plan, which proposes a set of initiatives that aims to enhance the competitiveness of Europe’s net-zero industry and to accelerate the transition to climate neutrality (EC, 2023f). One of these initiatives is the Net-Zero Industry Act (NZIA), which was proposed on 16 March 2023. The NZIA is aimed at strengthening the European manufacturing capacity of net-zero technologies and at overcoming barriers to scaling up the manufacturing capacity in Europe. The measures included in the act should increase the competitiveness of the net-zero technology industrial base and improve the EU’s energy resilience (EC, 2023g).

### *Relevance and implications for ORC technology*

The NZIA creates the necessary conditions to facilitate investments in net-zero manufacturing technologies and makes it easier for project promoters to build up net-zero industrial manufacturing. It does so by addressing the core drivers of net-zero technology manufacturing investments through measures such as lowering administrative burdens and ensuring access to information.

The list of technologies - which does not include ORC - is focussed on the following categories:

- solar pv and solar thermal technologies;
- onshore and offshore renewable technologies;
- battery/storage technologies;
- heat pumps and geothermal energy technologies;
- electrolysers and fuel cells;
- sustainable biogas/biomethane technologies;
- Carbon Capture and Storage (CCS) technologies;
- grid technologies.

As can be seen, the list covers renewable energy technologies to a large extent – but not exclusively.

## Strategic Energy Technology (SET) Plan

In 2007, the Commission launched SET Plan as a first step to establish an energy technology policy for Europe. The overall objective of the SET Plan is to provide a common vision, goals, and coordination in accelerating the development and deployment of efficient and cost-competitive clean technologies (EC, 2023h). By improving new technologies and bringing down their costs through coordinated national research efforts, the SET Plan helps promote cooperation among EU countries, companies and research institutions. It does so by helping to coordinate national research and innovation activities in developing low-carbon energy among EU countries and associated countries, as well as aligning national research and innovation programmes with its agenda.

The SET Plan was updated in 2015, where it defined 10 key action areas such as integrating renewable technologies in the energy systems, reducing costs of technologies, but also energy efficiency for the industry (EC, 2015). As part of the SET Plan (that is led by the SET Plan Steering Group and Bureau), 14 Implementation Working Groups (IWGs) - related to the key action (sub)areas - are set up that monitor and report progress on the SET Plan targets and research and innovation activities carried out at national and European levels.
The activities and targets, published in the working groups' implementation plans, are identified in cooperation with national governments and stakeholders (industry and research bodies). The implementation plans represent the reference document of the SET Plan in each field and ensure that it is aligned with the key industrial developments.

### *Relevance and implications for ORC technology*

In 2021, a revised implementation plan on energy efficiency in the industry - of which KCORC was one of the contributors - was published (SETIS, 2021). In this implementation plan, ORC technology is explicitly mentioned (in the annex, under 'Heating and Cooling Activity Fiches') as a suitable waste heat to power technology. The communication on the revision of the SET Plan, adopted on 20 October 2023, refers explicitly to this implementation plan (EC, 2023c). As Member States report on their activities within the SET Plan through National Energy and Climate Plans (NECPs) – which plays a key role in Member States' climate and energy policy – this increases the chance that ORC systems can be brought under the attention of national policy makers.

## 2.4 Recap

This chapter covered a policy review focussed on EU policies that are relevant to achieving the objectives of the EU Green Deal (and, for some directives, the increased ambitions put forward by REPowerEU), assessing whether ORC technology has been considered. Table 4 provides an overview of these policies. The main conclusions of this chapter are summarized in Chapter 5, where also the policy recommendations are presented. In the next chapter, we study the financial viability of ORC technology.

**Table 4 – Overview policy review**

| Policy | Relevance for ORC | ORC explicitly mentioned | Adoption or last revision | Status |
|---|---|---|---|---|
| Energy Efficiency Directive (EED) | High | Yes | 2023 | In force |
| Renewable Energy Directive (RED) | Low | No | 2023 | In force |
| EU Emission Trading System (ETS) Directive | Medium | No | 2023 | In force |
| FuelEU Maritime Regulation | High | No | 2023 | In force |
| EU Taxonomy Regulation | Medium | No | 2020 | In force |
| EU Taxonomy Climate Delegated Act | Medium | No | 2023 | In force |
| Industrial Emissions Directive | Medium | No | 2010 | Proposal adopted by EC in 2022; trilogue negotiations started on revision |
| BREF Iron and Steel | High | No | 2012 | In force |
| BREF Cement | High | Yes | 2013 | In force |
| BREF Glass | High | No | 2012 | In force |
| BREF Ceramic | High | No | 2007 | In force; Formal draft (2023), review started |
| BREF Non-ferrous metals | High | No | 2016 | In force |
| BREF Chemicals[11] | High | No | 2007-2017 | In force: 4; drawing up started: 1 |
| BREF Oil and gas | High | No | 2014 | In force |
| BREF Energy Efficiency | High | Yes | 2009 | In force |
| F-Gas Regulation | High | No | 2014 | In force |
| Net-Zero Industry Act (NZIA) | Medium | No | NA | Proposal; vote planned late 2023 |
| Strategic Energy Technology (SET) Plan | Medium | Yes | 2023 | In force |

---

[11] There are five BREFs related to chemicals: 'Large Volume Inorganic Chemicals', 'Large Volume Inorganic Chemicals – Ammonia, Acids and Fertilisers', 'Large Volume Inorganic Chemicals – Solids and Others Industry', 'Production of Large Volume Organic Chemicals', and 'Manufacture of Organic Fine Chemicals'. For more detail, see Table 3.

# 3 Financial viability

## 3.1 Introduction

This chapter covers business cases for ORC systems in waste heat recovery applications in the selected industries and the maritime transport sector. We start with the methodology (Section 3.2), followed by main results found for a set of (typical or average) business cases (Section 3.3.1). Subsequently, we discuss the most relevant parameters that have an effect on the financial characteristics of the business cases (Section 3.3.2). For some of these parameters, we carry out a sensitivity analysis in order to assess their impact on the business case (Section 3.3.3). This analysis includes costs and benefits within the industrial host where the ORC system is installed. We will discuss risks and barriers with regards to the implementation of ORC technology in the EU in Section 3.4 and potential co-benefits in Section 3.5. A short description of the ORC applications in the selected industries is given in Annex A.

## 3.2 Methodology

In order to gather insights in the business cases for the selected industries and the maritime transport sector we have conducted a set of interviews with both suppliers and users of ORC systems. We held interviews with five suppliers and four users of ORC systems (see Annex B). The interviews with suppliers were aimed at getting a broad perspective on the business cases in different sectors and at acquiring typical or average business case figures.
The interviews with users of ORC systems were set up to provide insight in the perspective of users of the technology and to validate figures provided by suppliers. These interviews gave insights on the technology implemented in the concerned industrial processes like implementation, installation, operation, and maintenance costs, and other factors such as the reliability and operating hours of the system. The interviews with users thus provided additional information on specific business cases based on practical feasibility. In both types of interviews, we identified the (financial) risks and barriers for the implementation of ORC technology.

The business cases for ORC technology can be approached in two ways: the operators can use the electricity generated by the ORC system for internal processes or they can also sell this electricity to a third party (e.g., the energy supplier or a company nearby). In the first case, the business case is estimated through avoided costs (the difference between the costs of the electricity generated by the ORC system and the same electricity imported from the grid). In the second case, the business case is estimated by the difference between the costs of electricity generated by the ORC system and the price at which this electricity can be sold to a third party. As the interviews made clear that most users consume the electricity generated by the ORC system for their own internal processes, this is the reference case that we will follow in our approach.

**Lease contracts**

In the last few years, ORC suppliers have started to provide lease contracts in which the supplier does the complete capital investment and operates the ORC system at the client's facility. The client pays a fixed fee per year, guaranteeing a fixed price for electricity (assuming the waste heat availability that is agreed upon is met; this is the responsibility of the client) and a payback from day one (assuming a client only engages in a lease contracts if the regular electricity price is higher than the implicit electricity price secured by the contract). Contracts are typically a minimum of five to seven years (depending on the complexity of the installation). Lease constructions are specifically suited for modular ORC systems as dismantling and transporting is much easier for these systems. Lease contracts are outside of the scope of this research and are therefore not further considered in the rest of this report, but are likely to provide reasonably comparable outcomes in terms of financial outcome.

## 3.3 Business cases

### 3.3.1 Results

In this section, we discuss the key figures for a set of indicative business cases of the different sectors. The key figures that we consider are: savings per year, the payback period, Net Present Value (NPV), Internal Rate of Return (IRR), $CO_2$ savings, and $CO_2$ abatement costs. These figures - that are presented in Table 5 - are based on typical or average cases provided by suppliers and specific cases of (potential) ORC users. In order to make the data provided by the different parties consistent in our model, we have fixed the underlying assumption (i.e. electricity price, operating hours, lifetime, discount rate, and carbon intensity of electricity) per sector and used the same definitions for all key figures presented in Table 5. The electricity price, operating hours and discount rate are presented in the table; the other underlying assumptions provided in the next section). As the table shows, the business cases for the glass, cement, and steel industries and maritime sector are provided by suppliers and therefore cover a wide set of use cases. The figures for the oil & gas and chemicals industry are based on one single use case: a compressor station and a PET manufacturer, respectively.

**Table 5 - Overview of the key figures of indicative business cases* (prices in €$_{2023}$; discount rate 8%)**

| Figure | Unit | Glass | Cement | Steel | Oil & gas | Chemicals | Maritime |
|---|---|---|---|---|---|---|---|
| *Power capacity* | *MW$_{el}$* | *1.0-2.0* | *1.0-8.0* | *1.0-5.0* | *5.0* | *0.4* | *0.1-0.2* |
| *Electricity price, paid for* | *€/MWh* | *110* | *90* | *80* | *NA* | *120* | *NA* |
| *Operating hours* | *Hours/year* | *8,500* | *7,500* | *7,500* | *5,500* | *8,000* | *4,500* |
| Savings per year | Mln. € | 0.9-1.9 | 0.7-5.4 | 0.6-3.0 | NA | 0.3-0.4 | 0.08-0.13 |
| Payback period | Years | 3.0-4.8 | 2.8-6.7 | 4.7-7.5 | 7.0 | 5.0-7.0 | 2.1 - 3.8 |
| NPV | Mln. € | 6-13 | 3-34 | 2-17 | NA | 2-4 | 0.4 - 0.5 |
| IRR | % | 20-33% | 14-35% | 12-21% | NA | 13-20% | 25% - 47% |
| $CO_2$-eq. savings | Ton/year | 2,100-4,300 | 1,900-15,000 | 1,900-9,000 | 8,000 | 700 | NA |
| $CO_2$-eq. abatement costs | €/ton $CO_2$-eq. | -95-128 | -52-104 | -34-71 | NA | -49-115 | NA |
| *Source* | | *Suppliers (3)* | *Suppliers (3)* | *Suppliers (3)* | *ORC user (1)* | *ORC user (1)* | *Supplier (1) & ORC user(1)* |

* The figures provided by suppliers are based on average or typical cases in the current industry (2023); figures for the oil & gas and chemicals industries are based on one use case each. The information cannot be generalized as it depends on many variables.

## Savings per year

The savings per year express the difference between the operating costs and the avoided costs of electricity. It is given by given the following formula:

$$Savings\ per\ year_{industry} = MW_{el} * (operating\ hours * Electricity\ price - OPEX)$$

$$Savings\ per\ year_{maritime} = Fuel\ savings\ per\ year - OPEX$$

As Table 5 shows, all business cases have positive savings per year, meaning there is a positive business case. Obviously, under equal conditions, the yearly savings in absolute terms are lower for smaller ORC power plants as their yearly produced electricity is lower. Besides that, the savings depend on the amount of operating hours, the electricity price from the grid[12], and the OPEX, which are discussed in following sections. For maritime transport, the yearly savings are calculated through the fuel savings, which depend on many factors such as the operating hours, type of engine, engine load, type of fuel used (e.g., marine gas oil or diesel), and the fuel price.

## Payback period

The payback period is an indicative method that defines the period in which the investment in an ORC power plant (or module) is paid back (not taking into account the time value of money). As discussed in the previous paragraph, there are different definitions that can be used for the payback period. The definition that we use, based on avoided costs, is

$$Payback\ period = \frac{CAPEX}{Savings\ per\ year}.$$

As we can see from Table 5, the payback period for this exemplary cases ranges from 2.8 to 7.5 years for industrial manufacturing processes. In general, the payback periods for the steel and cement industry can be expected to be relatively longer than for the glass industry, mostly due to the higher electricity price typically paid by companies of the glass industry and the lower expected yearly operating hours in the steel and cement industry. In the exemplary case related to the maritime transport sector, the payback period is significantly shorter: 2.1 to 3.8 years. There are several factors that play a role in this: on-board generated electricity is typically significantly more expensive than land-based electricity and the OPEX (as % of CAPEX) and CAPEX (€/$MW_{el}$) are relatively lower[13].

## Net Present Value (NPV)

In contrast to the payback period, the NPV and the IRR take into account the time value of money and are more commonly used for financial analyses of projects. The NPV is the difference between the present value of cash inflows and outflows over a period of time. In general, a positive NPV represents a profitable investment. As shown in Table 5, the NPV varies between € 2 and 34 million for the industries (the lower NPV's corresponding to smaller ORC systems), and between € 0.4 and 0.5 million for maritime transport. The discount rate used in NPV calculations can vary per company and/or type of activity.

---

[12] Electricity prices differ between different industries (as some industries have access to CHP generated electricity, resulting in lower kWh prices) and different countries.

[13] One of the reasons that the CAPEX are relatively lower for the maritime sector, might have to do with the fact that modules – that are easier to install - are typically applied in the maritime sector.

For the sake of comparability, we assume a discount rate of 8% for all cases. In a sensitivity analysis in Section 3.3.3 we will demonstrate the effect of different discount rates.

## Internal Rate of Return (IRR)

The IRR is a measure to estimate the profitability of potential investments. It is the discount rate that makes the NPV of all cash flows equal to zero in a discounted cash flow analysis. In general, the higher the IRR, the better the investment. The IRR varies between 12 and 35% for the industries, and between 25 and 47% for maritime transport. The IRR's presented in Table 5 are relatively good; the IRR for the maritime sector is even quite high. In line with the payback period, the IRR indicates relatively more profitable investments for the glass industry, compared to cement and steel.

## Carbon savings

The $CO_2$-eq. savings in Table 5, ranging from 700 to 15,000 ton $CO_2$-eq. per year, are based on the avoided electricity use from the grid, calculated through multiplying the electricity produced by the ORC system annually by the average GHG intensity of electricity generation in the EU in 2022 (0.251 ton $CO_2$-eq./MWh) (EEA, 2023). There are many ways to select a carbon intensity and, this choice highly impacts the outcome. Carbon intensities can vary between countries: France, for example, has a lot of electricity generated at nuclear power plants and therefore a relatively low-carbon intensity (0.068 ton $CO_2$-eq./MWh) and Sweden with a lot renewable energy has the lowest of the EU (0.007 ton $CO_2$-eq./MWh), whereas Poland has highest GHG intensity of the EU (0.666 ton $CO_2$-eq./MWh).

## Carbon abatement costs

Based on the $CO_2$-eq. savings and the NPV of the cases, we have calculated $CO_2$-eq. abatement costs. As all business cases have positive NPV's, from the perspective of the ORC user, the abatement costs are negative, and the investments are therefore, at the lower end of the merit order of the marginal abatement costs curve. We can also look at the $CO_2$-eq. abatement costs from a government perspective. This is illustrated in the following text box.

**$CO_2$-eq. abatement costs of a national subsidy**

In Section 2.3, we discussed how the Energy Investment Allowance (EIA), a tax scheme in the Netherlands, financially support investment in ORC technology. The fiscal advantage that companies can have when using the fiscal scheme is around 12%; this is lost income for the government. If we apply this, say in the glass industry, to an investment of € 6 million in an ORC power plant, this means that the 'costs' for the government are € 720,000. If we apply this to the carbon savings over the lifetime of the ORC system (e.g., 60,000 ton $CO_2$-eq.), this leads to abatement costs of € 12 per ton $CO_2$-eq. for the government. This is fairly low, compared to, for example, the current ETS price of around € 80 per ton. However, one has to keep in mind that there will also be companies that use the subsidy that would have made the same investment without the subsidy (so-called 'free riders'). Therefore, the carbon abatement costs have to be corrected by (an estimation of) this share of free riders, leading to the net carbon abatement costs (that are higher than the gross carbon abatement costs).

## 3.3.2 Parameters

**Table 6 - Overview of the main parameters considered in the assessment of business cases (prices in €$_{2023}$)**

| Figure | Unit | Glass | Cement | Steel | Oil & gas | Chemicals | Maritime |
|---|---|---|---|---|---|---|---|
| Power capacity | MW$_{el}$ | 1.0-2.0 | 1.0-8.0 | 1.0-5.0 | 5.0 | 0.4 | 0.1-0.2 |
| Temperature level | | Medium | Medium-high | Medium-high | NA | Low | Low-medium |
| CAPEX | Mln. €/MW$_{el}$ | 2.8-4.5 | 1.9-4.5 | 2.8-4.5 | NA | 6.0 | 1.6-2.3 |
| OPEX | % of CAPEX | 1.1-2.5% | 1.1-2.0% | 1.1-2.0% | NA | 2% | 0.25% |
| Electricity price, paid for | €/MWh | 110 | 90 | 80 | NA | 120 | NA |
| LCOE | €/MWh | 40-60 | 33-60 | 40-65 | NA | NA | NA |
| Operating hours | Hours/year | 8,500 | 7,500 | 7,500 | 5,500 | 8,000 | 4,500 |
| Lifetime | Years | 20-25 | 20-25 | 20-25 | NA | 20-25 | 14 |

In this section, we discuss the most relevant parameters that have an effect on the financial characteristics of the business cases:

- The **installed power capacities** shown in the table represent typical or average sizes of ORC installations. As can be seen in Table 6, ORC systems are currently (in 2023) typically applied at sizes ranging from 1 MW$_{el}$ up to 8 MW$_{el}$ (however, larger sizes are already realized). In general, ORC installations used for waste heat recovery in industrial manufacturing processes are larger than the modules that are applied in the maritime transport sector. However, also here, larger applications (than 100-200 27l ready already applied in the maritime sector, and there is potential to apply this more in the future, for example in large cargo ships.

- The **temperature levels** represent the range at which waste heat is typically recovered by ORC systems in these sectors. The higher the temperature of the heat source, the higher the specific thermal energy available[14], and the higher the fraction of this energy that could potentially be converted into electricity. This is, for example, clearly demonstrated in a set feasibility studies for ORC systems at dredging vessels (Westhoeve et al., 2023).

- The **Capital Expenditures (CAPEX)** range from € 2 to 6 million per MW$_{el}$ for applications in manufacturing processes, and from € 1.5 to € 2 million per MW$_{el}$ in maritime transport. For the cases presented, this means the total investments range from around € 3 to 36 million. In general, it holds that the larger the capacity of the ORC system is, the more scale effects there are and the lower the CAPEX per MW$_{el}$. However, economies of scales effects are not necessarily linear.
  The CAPEX figures that have been provided by the suppliers do not always include all investment costs that the client (the user of the ORC system) eventually has to incur. In the interviews with suppliers and (potential) users of ORC systems, we gathered information about these additional costs and incorporated them in the figures presented in Table 5.
  - **Additional costs** vary widely case by case and involve costs for components (such as additional heat exchangers, transformers, piping, etc.), installation costs, and/or other overhead costs such as insurance costs and taxes. In industrial

---

[14] Unused thermal energy is typically available from a stream of hot fluid (gas, liquid). Specific thermal energy refers to the thermal energy contained in a set mass of such hot fluid.

manufacturing processes, for example, ORC systems applied to liquid heat sources can be installed relatively easily, whereas for gaseous heat sources more expensive components are needed. Another example can be found in the maritime sector, in which the availability of a thermal oil system (often available in older ships running on heavy fuel oil that needs to be pre-heated), that is needed for the heat transport from the exhaust gas pipe to the ORC unit, reduces the additional costs significantly.

**Lang factor**

One way to estimate the total costs of an investment is by using the so-called Lang factor, typically applied in the petrochemical sector. This factor estimates the total costs of a project by multiplying the costs of all the purchased technical components with a certain factor that differs per type of process. However, this factor will significantly vary per industry sector resulting in different business cases per sector.

According to Lemmens (2016), this factor is also applied to ORC systems (in the chemical industry and geothermal applications) and varies from 6.32 for greenfield to 4.16 for brownfield solutions. This factors represents additional costs like installation, piping, controls, and basic engineering and is based on (Bejan et al., 1996). An example (not specifically for ORC) of how such a Lang factor is compiled, is shown in the following table. Based on which equipment or components are already in place or not, an investor can use this to determine the factor.

| **Item** | **Process type** | | |
|---|---|---|---|
| | **Fluids** | **Fluids-solids** | **Solids** |
| 1. Major equipment, total purchase costs | PCE | PCE | PCE |
| *f* 1 Equipment erection | 0.4 | 0.45 | 0.50 |
| *f* 2 Piping | 0.70 | 0.45 | 0.20 |
| *f* 3 Instrumentation | 0.20 | 0.15 | 0.10 |
| *f* 4 Electrical | 0.10 | 0.10 | 0.10 |
| *f* 5 Building, process | 0.15 | 0.10 | 0.05 |
| **f* 6 Utilities | 0.50 | 0.45 | 0.25 |
| **f* 7 Storages | 0.15 | 0.20 | 0.25 |
| **f* 8 Site development | 0.05 | 0.05 | 0.05 |
| **f* 9 Ancillary buildings | 0.15 | 0.20 | 0.30 |
| 2. Total physical plant costs (PPC)<br>*PPC = PCE (1 + f 1 + … + f 9) = PCE x* | 3.40 | 3.15 | 2.80 |
| *f* 10 Design and Engineering | 0.30 | 0.25 | 0.20 |
| *f* 11 Contractor's fee | 0.05 | 0.05 | 0.05 |
| *f* 12 Contingency | 0.10 | 0.10 | 0.10 |
| Fixed capital = *PPC (1 + f 10 + f 11 + f 12) = PPC x* | 1.45 | 1.40 | 1.35 |

* Omitted for minor extensions or additions to existing sites.

Source: www.chemicalprojects.wordpress.com/tag/lang-factor/.

- According to the suppliers we consulted, the **economic lifetime** of ORC systems applied in industrial manufacturing processes varies between 20 and 25 years, whereas the lifetime of ORC modules designed for maritime transport is around 14 years.
  The lifetime affects the depreciation of the CAPEX and the NPV, IRR, and $CO_2$-eq. abatement costs presented in Table 5.

- The **Operating Expenditures (OPEX)** per year vary between 1.1 and 2.5% of the CAPEX for ORC applications in industrial manufacturing processes. Typically, the OPEX of ORC modules are relatively lower than non-modular power plants. In the maritime sector, the OPEX are significantly lower: around 0.25% of the CAPEX per year. In general, for ORC systems the main driver of the OPEX are maintenance costs.

- The **electricity price** is the price per MWh that the user of the ORC system would have to pay if the electricity generated by the ORC unit had been purchased from the grid; these are the marginal costs, including taxes and grid costs. The higher these costs of electricity, the better the business case (and the other way around). Along with other energy prices, electricity prices have increased heavily in the last two years. Besides that, electricity prices can differ strongly between countries and - depending on the type of contract an industrial company - from month to month, day to day, or even hour to hour. In some cases, this highly complicates determining the business case.
  The electricity prices presented in Table 5 are therefore typical or average prices, are differentiated per industry, and are assumed to include grid costs and tax. In case of the maritime transport, electricity is typically produced on board - for example, using diesel generators - and can differ even more strongly between different cases.

- The **Levelized Cost of Electricity (LCOE)** expresses the overall cost of electricity per MWh produced by the ORC system over its lifetime. It is calculated as the costs over the lifetime of an ORC system divided by the energy produced over its lifetime.
  The electricity produced by an ORC system can be used on-site or it can be exported to the grid or another external consumer. As our study focusses on manufacturing processes of energy intensive industries, in most cases the produced electricity is used internally (on-site). However, in some cases - when electricity prices are high - it is lucrative for companies to sell electricity to the grid. The LCOE figures presented in Table 6 - provided by the ORC suppliers - are used to illustrate the order of magnitude of the LCOE and have not been used to calculate the key indicators presented in Table 5.

- The **operating hours** express the yearly amount of hours the ORC system is assumed to run. The figures presented in Table 5 are provided by suppliers. The operating hours in used for the glass industry are higher than those for the cement and steel industry, as the manufacturing process of glass is typically a process that operators avoid to stop (less cool down events because glass hardens out otherwise). The operating hours of an ORC system in the maritime sector is typically lower since ships are not in operation (in dock) more often than industrial manufacturing installations. Despite these lower operating hours, the business case still looks very good. The amount of operating hours strongly affects the business case of ORC systems. In order to gain more insight in the effect of potential overestimation, we carry out a sensitivity analysis for this parameter in Section 3.3.3.

### 3.3.3 Sensitivity analyses

#### Operating hours

This section presents some sensitivity analyses on parameters that have important effect on the business case. Table 7 presents the key figures for the glass industry under different numbers of operating hours. The results show that the savings per year decrease (and the payback period increases) as operating hours decrease, but still indicate a positive NPV when only half of the expected operating hours would be realised. This shows that the business case is relatively robust with respect to the operating hours.

**Table 7 - Key figures under different yearly operating hours (industry: glass)**

| Operating hours | Savings per year | Payback period | NPV | IRR | $CO_2$ savings | $CO_2$ abatement costs |
|---|---|---|---|---|---|---|
| **8,500*** | **0.9-1.9** | **3.0-4.8** | **6-13** | **20-33%** | **2,100-4,300** | **-95-128** |
| 7,500 | 0.8-1.6 | 3.4-5.5 | 5-11 | 18-29% | 1,900-3,900 | -84–18 |
| 6,500 | 0.7-1.4 | 3.9-6.3 | 3-9 | 15-25% | 1,600-3,400 | -70–109 |
| 5,500 | 0.6-1.2 | 4.6-7.4 | 2-7 | 12-21% | 1,400-2,900 | -46–97 |
| 4,500 | 0.5-1.0 | 5.7-9.1 | 0-5 | 9-17% | 1.100-2.400 | -11–79 |

* Reference case.

## Electricity prices

In Table 8, the key figures for the glass industry are presented under different electricity prices. The results demonstrate that the business case improves under higher electricity prices. Under lower electricity prices, the savings per year decrease and the payback period increases (while the NPV and the IRR decrease). The NPV is still positive down to electricity prices of around € 50 per MWh. This indicates that, under current circumstances, the business case is relatively robust with respect to the electricity prices. If electricity prices would drop in the future, however, this would clearly weaken the business case.

**Table 8 - Key figures under different electricity prices (industry: glass)**

| Electricity price | Savings per year | Payback period | NPV | IRR | $CO_2$ savings | $CO_2$ abatement costs |
|---|---|---|---|---|---|---|
| 130 | 1.1-2.2 | 2.5-4.1 | 8-17 | 24-39% | 2,100-4,300 | -134-173 |
| **110*** | **0.9-1.9** | **3.0-4.8** | **6-13** | **20-33%** | **2,100-4,300** | **-100-135** |
| 90 | 0.8-1.5 | 3.7-5.9 | 4-10 | 16-27% | 2,100-4,300 | -67-98 |
| 70 | 0.6-1.2 | 4.7-7.6 | 2-7 | 12-21% | 2,100-4,300 | -31-65 |
| 50 | 0.4-0.8 | 6.6-10.6 | 0-3 | 7-14% | 2,100-4,300 | -7-32 |
| 30 | 0.3-0.5 | 11.0-17.6 | -3-0 | 1-7% | 2,100-4,300 | -46–1 |

* Reference case.

## Additional costs

In Table 9, the key figures for the glass industry are presented under different additional costs. The results demonstrate that even when the CAPEX would double, the payback time doubles accordingly, but the NPV is still positive. This indicates that, despite it being a capital-intensive investment, the business case is relatively robust with respect to potential additional costs.

**Table 9 - Key figures under different levels of additional costs (industry: glass)**

| CAPEX | Savings per year | Payback period | NPV | IRR | $CO_2$ savings | $CO_2$ abatement costs |
|---|---|---|---|---|---|---|
| **CAPEX +0%*** | **0.9-1.9** | **3.0-4.8** | **6-13** | **20-33%** | **2,100-4,300** | **100-135** |
| CAPEX +25% | 0.9-1.9 | 3.7-6.0 | 5-12 | 16-27% | 2,100-4,300 | 80-119 |
| CAPEX +50% | 0.9-1.9 | 4.5-7.2 | 3-11 | 13-22% | 2,100-4,300 | 56-106 |
| CAPEX +75% | 0.9-1.9 | 5.2-8.4 | 2-9 | 10-19% | 2,100-4,300 | 30-93 |
| CAPEX +100% | 0.9-1.9 | 6.0-9.6 | 0-8 | 8-16% | 2,100-4,300 | 4-80 |

* Reference case.

### Discount rate

In our analysis, we used a discount rate of 8%. However, as mentioned before, the discount rate used in NPV calculations vary per company, industry and/or type of activity. Therefore, we have carried out these calculations for the glass industry for three different rates: 6%, 8%, and 10%. Under a discount rate of 6%, the NPV increases to € 8-17 million. Under a discount rate of 10%, the NPV decreases to € 4-13 million.

## 3.4 Risks & barriers

Based on the interviews with suppliers and users, we have identified the following risks and barriers with regards the implementation of ORC technology:

- **Low electricity prices**. As discussed in Section 3.3.1 and demonstrated in the sensitivity analysis in Section 3.3.3, lower electricity prices weaken the business case for ORC systems. Since large and/or energy-intensive industrial companies generally pay a lower price for energy – an example of the energy tax system in the Netherlands is given in the text box below – this is seen as one of the main barriers for ORC systems. In case of the maritime transport sector, there is even no tax charged on fuel sold.

**Energy tax system he Netherlands**

As shown in the following tables, in the Netherlands a degressive energy tax system is used: the more energy is being used, the less tax is being paid per unit of energy. This causes that end-user costs for energy for the industry are significantly lower compared to, for example, households or smaller businesses.

Table 10 - Energy tax natural gas, 2023

| | 0-170.000 $m^3$ | 170.001-1 mln. $m^3$ | 1-10 mln. $m^3$ | > 10 mln. $m^3$ |
|---|---|---|---|---|
| Tax tariff (€/$m^3$) | 0.48980 | 0.09621 | 0.05109 | 0.03919 |

Table 11 - Energy tax electricity, 2023

| | 0-10.000 kWh | 10.001-50.000 kWh | 50.001-10 mln. kWh | > 10 mln. kWh |
|---|---|---|---|---|
| Tax tariff (€/kWh) | 0.12599 | 0.10046 | 0.03942 | 0.00115 |

Source: (Belastingdienst, ongoing).

- **Uncertain energy prices**. The energy crisis in the EU of the last two years has shown energy prices can be very volatile. In societies that become more and more dependent on renewable energy sources such as solar and wind power, we see that prices can also highly fluctuate from day to day, or even hour to hour. This is because of the recent high prices of natural gas, that is still widely used for grid balancing. Especially companies with flexible energy contracts are affected by this. On the one hand, this leads to uncertainty around the business case of ORC systems. On the other hand, this could incentivise companies to use ORC technology, as this is a source that generates electricity at a stable price.

- **Potential ban on PFAS**. As discussed in Section 2.3, a recent initiative, led by some Member States, is pushing the European Chemicals Agency (ECHA) to ban PFAS. As part of the commercially available ORC systems make use of HFCs (which are indexed as PFAS fluids) as working fluids, this could potentially lead to delays in the uptake of ORC technology and/or closure of existing plants. Replacing PFAS fluids with a natural refrigerant where needed is possible, since these natural working fluids are already used in ORC systems today, but requires time for the industry and certifying bodies.

- **Low(er) internal payback times industry**. Earlier in this chapter, we saw that for industrial manufacturing processes most investments in ORC systems are paid back in 3 to 7.5 years. These are generally considered acceptable payback times for energy investments although, in practice, large industrial companies have traditionally been used to investments with payback times of less than three years. This image was confirmed in the interviews ORC suppliers. However, with the increased focus on sustainability and carbon abatement, suppliers also experience that this is shifting into a direction in which industrial companies are highly interested in investments with negative carbon abatement costs.

- **Technical constraints electricity grid**. As societies become more dependent on renewable energy sources such as solar and wind power, countries are confronted with the technical constraints of the electricity grids. In more and more countries, the electricity grid is heavily loaded and in several countries there is already grid congestion. With the expected electrification (such as electric cars) and increase in renewable generation (such as solar pv), this pressure on grids in the district will increase further. Especially in cases where an ORC unit is used to generate electricity to deliver to the grid, this could lead to barriers when the electricity grid is congested due to a temporary overshoot of solar and wind power, resulting in lower operating hours. On the other hand, as will be discussed in the next section, ORC systems can contribute to off-load the grid net by generating electricity locally.

- **Competition of other sustainable technologies**. According to some of the parties that we interviewed, there is competition between ORC systems and other energy-efficiency or renewable energy technologies that also have zero marginal costs. Additionally, these can be more subsidised, have lower investment costs and/or are easier to place (such as solar pv panels). On the other hand, under low grid electricity prices (when it is attractive to sell electricity to the grid) ORC has an advantage compared to CHP because it has zero marginal costs, whereas CHP does have marginal costs.

- **Low GHG-intensity of electricity**. In some countries, such as Sweden (with a lot of renewable energy) and France (with a large share of nuclear energy), the GHG-intensity of electricity is relatively low. This lowers the incentive to decrease GHG-emissions, and therefore to invest in ORC technology. As countries within the EU will continue to decarbonise their electricity supply over the coming years, this will play a role in more and more countries.

## 3.5 Co-benefits

Besides the financial benefits and abated GHG emissions described in this chapter, investments in ORC power plants can provide additional benefits that are not captured in the business case. They contribute to positive societal benefits and savings of investments on other domains. Based on the interviews with suppliers and users and on available literature, we have identified the following co-benefits with regards the implementation of ORC technology:

- **Secured electricity supply and price**. As discussed in the previous paragraph, there are several factors influencing the availability and the price of electricity. Having an ORC power plant available at industrial sites can help to secure electricity supply (that is increasingly at stake due to grid congestion and the volatility of the availability of renewable energy sources) and help to guarantee reasonable price of electricity (providing certainty in times with highly fluctuating electricity prices).

- **Peak-shaving**. The load on the electricity grid changes during the day. The base electricity demand is also called the *base load*. The *peak load* occurs at times of high demand. The peak load has the strongest impact on the grid as the capacity can come under pressure. In industrial processes, the emitted waste heat correlates in time with peak electric power use. Therefore, electricity generated by an ORC plant correlates with peak electric power use. Besides securing the electricity supply at peak times, this so-called ‘peak-shaving’ can help to balance the electricity grid. This could potentially contribute to avoiding investment costs in the (local) electricity grid. However, the current debate around this topic provides no clear answer to what extent investing in grid reinforcement or in decentralised energy generation systems (that can provide grid support) is the solution.

- **Labour opportunities**. The further uptake of ORC power plants can lead to be both temporary as well as permanent (direct) labour opportunities in different phases of the process (R&D, manufacturing, transport & installation, operation & maintenance). This is discussed in Chapter 4, in which some estimations of the potential for the EU will be provided.

- **Other financial benefits**. ORC users can experience other financial benefits such as a reduced need for process cooling redundancy equipment (as this service can be (partly) fulfilled by the ORC system) or less costs for a local switch board or grid net (when extra electricity is required and/or an extra connection to the electricity grid is needed). The extend to which these financial benefits apply is situation specific.

## 3.6 Recap

In this chapter, we presented a set of indicative business cases of ORC technology in different industries (glass, cement, steel, oil & gas, chemicals) and the maritime transport sector. The information on the business cases is gathered through interviews with ORC suppliers and (potential) users. By combining the information of the different parties, for each industry or sector, a range of values was presented in between which the key figures of the ORC business case typically fall. In all interviews with suppliers and users it was stressed that case by case there are many differences impacting the outcome of the business case. However, the key figures presented in Table 5 should give a good indication of the business case (potential) ORC users and policy makers can expect. Besides the financial key figures of the business cases, both risks and barriers and potential co-benefits were discussed. Chapter 5 summarizes the conclusions from this chapter. The next chapter covers the job creation perspective related to ORC technology.

# 4 Job creation perspective

## 4.1 Introduction

This chapter covers a high-level estimation of the potential job creation perspective for the ORC industry in the EU. We start with the methodology, in which we describe the two different methods that we use. After that, a short description of the results is given.

## 4.2 Methodology

The labour opportunities will be estimated using two different methods:

3. Method 1: Share of CAPEX and OPEX to labour costs.
4. Method 2: Direct Labor Employment model.

For both methods we will use the theoretical potential of waste heat that was estimated in KCORC's white paper and used for the job creation perspective. This amounts to 19 $GW_{el}$, which we will also assume to be realized in a ten-year period, which would correspond to a realized capacity of 1.9 $GW_{el}$ per year.

### Method 1: Share labour costs of CAPEX and OPEX

This method is based on the share of CAPEX and OPEX that goes to labour costs and combines input from the interviews with existing literature and expert opinion. In this method we make a distinction between temporary (CAPEX related) and permanent (OPEX related) labour opportunities. The temporary labour opportunities are estimated using the following formula:

$$Labour_{temp} = \frac{Capacity * CAPEX * \ Allocation_{CAPEX}}{Wage}$$

where Capacity is the assumed capacity installed per year (assumption: 1.9 $GW_{el}$), CAPEX the average investment costs per $MW_{el}$ (assumption: € 3.3 million), $Allocation_{CAPEX}$ the allocation of CAPEX to wages (assumption: 5 to 15%)[15], and Wage is the average costs of labour per year (assumption: € 75k).

The permanent labour opportunities are estimated using the following formula:

$$Labour_{perm} = \frac{Capacity * OPEX * \ Allocation_{OPEX}}{Wage}$$

where OPEX are the average operational costs (assumption: 2% of CAPEX), $Allocation_{OPEX}$ the allocation of OPEX to wages (assumption: 40 to 60%), and Wage is the average costs of labour per year (assumption: € 75k).

---

[15] Both the CAPEX and OPEX allocations are based on input from the interviews, estimations made in (ECN & EIB, 2016), and expert judgement.

## Method 2: Direct Labor Employment model

The second method is based on a model developed by CE Delft: the Direct Labour Employment model. This model has been developed on data for the Netherlands and makes estimations for the total direct labour demand for a set of different energy technologies: onshore wind power, offshore wind power, solar energy, biomass-based energy, electricity from fossil fuels, energy-saving techniques in the built environment (green gas, all-electric and collective heating), and distribution reinforcement in energy networks. None of these technologies are perfect reflection of ORC technology, but we chose electricity from fossil fuels as input.

The model can make estimations based on investments in 2020 and 2030. Since the investments are assumed to be realised over a ten-year period, we chose 2030 as output variable. For the investment we multiplied the average investment costs per $MW_{el}$, which is, again – based on the interviews – € 3.2 million per $MW_{el}$. Based on the 1.9 $GW_{el}$ realised capacity per year, this amounts to a yearly investment of € 6.1 billion.

The labour opportunities are calculated for four different phases (research & development, manufacturing, transport & installation, and operation & maintenance) and divided into permanent and temporary labour. We expect that the OPEX phase of an ORC power plant is less labour-intensive than a fossil fuel power plant. Therefore, we only use the output of this model for temporary labour opportunities, for which we think the output represents a good order of magnitude.

## Comparison of Method 1 and Method 2

Methods 1 and 2 split out the results in permanent and temporary labour opportunities. Furthermore, when carrying out the estimations presented in the next paragraph, both methods make use of the same underlying assumptions for the potential capacity of ORC in the EU and CAPEX figures (in million €/$MW_{el}$). The differences between the two methods are described in Table 12.

**Table 12 - Differences between methods to estimate labour opportunities of ORC technology**

| Method 1: Share labour costs of CAPEX and OPEX | Method 2: Direct Labor Employment model |
|---|---|
| Developed for the case of ORC (based on information from interviews with ORC suppliers and users) | Developed for the case of electricity production from fossil fuels (not on ORC) |
| CAPEX and OPEX figures used as input parameters | CAPEX used as input parameter |
| | Results split out in different labour phases: research & development, manufacturing, transport & installation, and operation & maintenance |
| | Proven, robust model in other applications |

## 4.3 Results

### Temporary labour opportunities

The theoretical potential of temporary labour opportunities created through large-scale implementation of ORC systems in the EU, is shown in Table 13. Based on the assumption that 1.9 $GW_{el}$ of ORC units are being realised per year, the overall potential is estimated to lay between 4,000 and 41,000 fte. These labour opportunities would be created for a ten-year period, assuming that the full potential of 19 $GW_{el}$ will be evenly realized in ten years. The estimation is lower than the estimate that was made in KCORC's white paper, where the potential was estimated to be 45,000 fte. Method 1, based on input from the interviews, estimates the potential to be lower than Method 2, using the Direct Labour Employment Model. Additionally, the Direct Labour Employment Model gives an indication of the type of labour that is needed: roughly 10% for research & development, 30% for manufacturing, and 60% for transport & installation.

**Table 13 - Temporary labour opportunities in the EU through ORC, in fte (yearly basis; theoretical potential)**

| | Lower bound | Upper bound |
|---|---|---|
| Method 1: Share of CAPEX and OPEX to labour costs | 4,000 | 12,000 |
| Method 2: Direct Labour Employment model | 38,000 | 41,000 |
| **Overall** | **4,000** | **41,000** |

### Permanent labour opportunities

The theoretical potential of permanent labour opportunities created through the large-scale implementation of ORC systems in the EU, is shown in Table 14. Based on the assumption that 1.9 $GW_{el}$ of ORC units are being realised per year, we estimated the cumulative potential of permanent labour opportunities to lay between 6,000 and 10,000 fte. This would be the theoretical potential after ten years, assuming that the full potential of 19 $GW_{el}$ is met. Based on the interviews the labour opportunities created would be mostly in maintenance.

**Table 14 - Permanent labour opportunities in the EU through ORC, in fte (cumulative after realising full potential of 19 $GW_{el}$; theoretical potential)**

| | Lower bound | Upper bound |
|---|---|---|
| Method 1: Share of CAPEX and OPEX to labour costs | 6,000 | 10,000 |
| Method 2: Direct Labour Employment model | NA | NA |
| **Overall** | **6,000** | **10,000** |

## 4.4 Recap

As this chapter covers some high-level estimations of the theoretical potential of direct labour opportunities created by ORC investments, the main goal is giving insight in the order of magnitude of the theoretical potential. The main conclusions of this chapter are summarized in the next chapter.

# 5 Conclusions

This chapter provides a summary of the conclusions drawn in the chapters on the policy review, financial viability, and job creations perspective. We conclude this chapter with the policy recommendations.

## 5.1 Policy review

Based on the policy review carried out in Chapter 2, we summarize the conclusions as follows:

- **Energy Efficiency Directive (EED).** In the EED III - adopted in September 2023 - for the first time, ORC is explicitly mentioned as cogeneration technology that is covered by the Directive. Because of this, more awareness will be drawn to ORC systems when implementing the EED at Member State-level. A few examples of how this is currently done already, were discussed:
    - In Germany, a funding program of the Federal Office of Economics and Export Control (BAFA) supports investments in ORC systems. The maximum funding amounts to € 15 million per investment project, with a funding rate of up to 50% of the eligible investment costs.
    - In Italy, energy efficiency measures are promoted through a White Certificates scheme (related to Article 9 of the EED). One of the eligible energy efficiency measures is ORC technology, for which a specific incentive scheme with a ten-year benefit holds.
    - In The Netherlands, for example, a tax scheme (the Energy Investment Allowance, or EIA) works with a list of eligible techniques and enables companies to gain more than 10% of fiscal advantage on investments in ORC technology.

  Having ORC systems listed as cogeneration technology, however, could give the idea that the main purpose of using ORC systems is the combined production of power and heat and not the conversion of waste heat into electric power.

- **Renewable Energy Directive (RED)**. Under the RED III, that was adopted in September 2023, ‘energy from renewable sources’ or ‘renewable energy’ means energy from renewable non-fossil sources. Therefore, waste heat is not considered renewable when it is originated from a process where fossil fuels are used. Although ORC systems primarily operate today on heat sources from processes where fossil fuels are used, this could (and will) change in the future. If the use of, for example, green hydrogen would become more common in industrial manufacturing processes or if heat were generated from electricity imported from a fully decarbonised grid, this means that electricity produced by ORC systems could be considered renewable.

- **EU Emission Trading System (ETS) Directive.** The revised version of the ETS directive, adopted in May 2023, contains adjustments that broadens of the scope to the build environment and transport (ETS2), involves a stricter cap in time (ETS1), and includes the maritime transport sector. This is a relevant development for ORC modules applicable on ships as carbon pricing improves the business case of ORC for the maritime sector. In general, an increasing carbon price incentivizes companies to take energy efficiency measures and thus will contribute to a significant increase of the ORC market.

- **FuelEU Maritime Regulation**. The regulation – that was adopted in September 2023 – is focussed on the reduction of greenhouse gas intensities of energy used on board of large ships. Although it does not describe the use of waste heat recovery technologies explicitly, it does incentivise to improve the energy efficiency of ships and thus, potentially the use of ORC systems. Besides that, Annex III of the regulation sets general requirements for zero emission technologies, including a 'non-exhaustive' list of technologies (on-board fuel cells, on-board electrical energy storage and on-board power generation from wind and solar energy). It is mentioned that power supplied by on-board technologies not identified in this list that achieve zero emissions, can be added to the list by means of delegated acts. This provides the opportunity for ORC to be included in the list.

- **EU Taxonomy Regulation.** In the Climate Delegated Act - containing a list of environmentally sustainable economic activities related to climate change mitigation and adaptation - the utilisation of waste heat is considered as one of the environmentally sustainable economic activities, but not for the production of electricity. The EU taxonomy was last amended in 2023 and is aimed to be updated regularly.

- **Industrial Emissions Directive (IED).** The Best Available Techniques (BAT) Reference Documents (BREFs) – falling under t-e IED - are the main reference documents used by authorities in EU countries when issuing operating permits for industrial installations that represent a significant pollution potential. In case of the cement industry and (the horizontal BREF) energy efficiency, ORC is mentioned explicitly as a potential technology for cogeneration. However, similarly to the EED, ORC is categorized as cogeneration technology rather than waste heat to power technology. Most of the BREFs (related to the industries that we study) make references to cogeneration and/or combined heat and power (CHP) and some to waste heat recovery (but only for direct use of thermal energy), but not to ORC. Although IED prescribes that BREFs should be revised no later than eight years after them being published, this has not happened for most of the documents that we studied.

- **F-Gas Regulation**. The F-Gas Regulation aims to control emissions from F-gases - including hydrofluorocarbons (HFCs), the most commonly used F-gas, representing around 90% of F-gas emissions. Part of the commercially available ORC systems make use of HFCs (which are indexed as PFAS fluids) as working fluids and are therefore affected by the F-gas regulation. A recent initiative, led by some Member States, is pushing the European Chemicals Agency (ECHA) to ban PFAS. Replacing PFAS fluids with a natural refrigerant is possible, but requires time for the industry and certifying bodies, potentially leading to significant delays in the uptake of ORC and/or the (temporary) closure of existing ORC power plants.

- **Net-zero industry act (NZIA).** The NZIA aims to strengthen the European manufacturing capacity of net-zero technologies and to overcome barriers to scaling up the manufacturing capacity in Europe. The measures included in the act should increase the competitiveness of the net-zero technology industrial base and improve the EU's energy resilience. The list of measures includes technologies such as solar pv and CCS, but does not contain ORC systems.

- **Strategic Energy Technology (SET) Plan.** The overall objective of the SET Plan (originally launched in 2007) is to provide a common vision, goals, and coordination (among Member States, companies and research institutions) in accelerating the development and deployment of efficient and cost-competitive clean technologies.

> The plan contains 10 key action areas, including energy efficiency for the industry. Implementation plans – written by Implementation Working Groups (IWGs) – are used as reference document when revising the SET plan. In the latest implementation plan on energy efficiency in the industry (2021), ORC technology is explicitly mentioned as a suitable waste heat to power technology. The revision of the SET Plan, adopted on 20 October 2023, refers explicitly to this implementation plan. As Member States report on their activities within the SET Plan through National Energy and Climate Plans (NCEPs) – which plays a key role in Member States' climate and energy policy – this increases the chance that ORC technology can be brought under the attention of national policy makers.

Concluding, we should note that some EU instruments are designed or better suited to prescribe specific technologies (such as the BREFs), whereas others (such as the EED, EU ETS, and the EU Taxonomy) have a more technology-neutral character. These technology-neutral policies can have a generic stimulating effect on energy efficient technologies like ORC. Although these directives do not explicitly refer to ORC technology, they form an important base for increasing the market of waste heat to power technologies in the upcoming decade. By design, these EU instruments call for concerted efforts by Member States to implement national legislation in line with the objectives of these EU instruments.

## 5.2 Financial viability

Overall, this report has shown that the ORC business case in different manufacturing industries (glass, cement, steel, oil & gas, chemicals) and the maritime sector look good. ORC power plants in the manufacturing industry are typically at sizes ranging from 1 $MW_{el}$ up to 8 $MW_{el}$; in the maritime sector ORC systems of 100 to 200 $kW_{el}$ are typically seen (however, larger applications on, for example, large cargo ships are possible). Although there are many factors that determine the financial characteristics of the business case, average or typical investments in ORC power plants show figures for the payback period (2.8 to 7.5 years), NPV (€ 2 to 34 million, for power capacities ranging from 0.4 $MW_{el}$ to 8 $MW_{el}$; the lower NPV's corresponding to smaller ORC systems), IRR (12 to 35%), carbon savings (700 to 15,000, again, highly dependent on the size of the plant), and negative carbon abatement costs. Within the manufacturing industries we found that there are some differences (glass comes out a bit better), but overall, the business cases for the industries look rather similar. The figures for the maritime sector look slightly better: a payback period of 2.1 to 3.8 years, an NPV of € 0.4 to 0.5 million (ORC-systems in the maritime sector are typically small and modular), and an IRR of 25 to 47%.

Despite the many factors that influence the financial characteristics of the business case, we have identified four parameters that have the strongest relation with it: the electricity price, additional costs (on top of the CAPEX), the discount rate used, and the operating hours of the plant. The sensitivity analyses that we carried out showed that the business cases are rather robust to changes in these parameters. The uncertainty around the price (due to many possible factors) and availability of electricity (due to grid congestion) is identified as one of the major risks to the implementation of ORC. Besides that, the potential ban on PFAS (that is available in the working fluid of most commercially available ORC systems) could potentially lead to delays in the uptake of ORC and/or closure of existing plants.

The main co-benefits that were identified are: secured electricity supply and price, peak-shaving, labour opportunities, and other financial benefits such as a reduced need for process cooling redundancy equipment or less costs for a local switch board or grid net. These co-benefits have not been quantified and the extent to which these financial benefits apply is situation-specific.

Although outside of the scope of our report, a comparison of the financial performance of ORC systems against alternative (waste heat recovery) technologies would be valuable. This way, it can be assessed what share of the existing market of waste heat recovery systems ORC units can potentially take. Besides that, it would be interesting to identify if there are niche markets were ORC systems would hardly have any competition, by raising the question whether there is an actual alternative to ORC systems for certain applications.

## 5.3 Job creation perspective

This report covered some high-level estimations of the theoretical potential of direct labour opportunities created by ORC investments. The main goal of this was giving insight in the order of magnitude of the theoretical potential. We used two methods to estimate the potential. Method 1 is better tailored to the specific case of ORC, we expect that these estimations (between 4,000 and 12,000 fte) are more accurate than the estimations based on Method 2, that uses the Direct Labor Employment model (between 38,000 and 41,000 fte).

The permanent labour opportunities are only estimated using Method 1. According to this method, the cumulative potential of permanent labour opportunities (mostly in maintenance) lays between 6,000 and 10,000 fte. This would be the theoretical potential after ten years, assuming that the full potential of 19 $GW_{el}$ is met.

## 5.4 Policy recommendations

Based on our findings, we have come to the following recommendations, aimed at EU policy makers:

**Spread best practices of national EED implementations amongst Member States**
As the general objectives of the EED need to be implemented through national legislation, Member States are held to adopt new policy instruments in order to meet their EED targets. One way to contribute to meeting these targets is through subsidies, or tax schemes, or other supporting schemes like energy obligation schemes (white certificates).
As part of these national implementations, we have shown how countries like Germany, Italy, and the Netherlands have put instruments in place that support ORC. This includes lists of measures with a payback time of less than five years that are obligatory to take, but also lists of technologies that are eligible for financial support. We have illustrated how such subsidies or tax schemes (supporting ORC) can provide opportunities for low-carbon abatement costs.

**Update the BREF documents, and update them more frequently**
Although the IED prescribes that BREFs should be revised no later than eight years after them being published, our analysis made clear that this has not happened for most of the documents we studied. The horizontal BREF on energy efficiency, for example, was published in 2009 and has never been revised since. Although the scope of our report was not to compare different technologies, BREFs that have not been revised such periods of

time could potentially mean that not all of the most efficient or cost-effective technologies are included in the list.

In relation to ORC, the horizontal BREF on Energy Efficiency and the BREFs on ‘Production of Cement, Lime and Magnesium Oxide’ make references to ORC, but some of the information is outdated. In the Energy Efficiency BREF, no power to heat ratio is provided for ORC. In the BREF related to cement, a business case of an ORC application at a cement plant is provided, but dates from the year 2007 (by then, the first ORC application in the cement industry). Improving these texts with up-to-date information, current use cases, and demonstration of the wide application of this technology could highly improve the credibility of ORC.

**Classify ORC (besides cogeneration technology) also as waste heat to power technology in the EED and the BREFs related to Cement and Energy Efficiency**
As our policy review has pointed out, in the EED and BREF documents related to Cement (more specifically, ‘Production of Cement, Lime and Magnesium Oxide’) and Energy Efficiency, ORC systems are currently considered as cogeneration technologies. This could, however, lead to the misconception that the main purpose of using ORC systems is the combined production of power and heat and not the conversion of waste heat into electric power. Therefore, we recommend to classify ORC (besides cogeneration technology) also as waste heat to power technology in future revisions of the EED and the BREF documents for Cement and Energy Efficiency.

**Research the feasibility to include waste heat to power technologies, most notably ORC systems, in the BREF documents for iron & steel, glass, ceramic, chemicals, and oil & gas**
Our review of the BREFs showed that cogeneration, Combined Heat and Power (CHP) and/or waste heat recovery were mentioned in the documents for iron & steel, glass, ceramic, chemicals, and oil & gas, but that ORC technology was not. Based on the findings in our report, we believe that ORC is a relevant technology for these industries. As these BREFs are expected to be updated within the next couple of years, we recommend researching the feasibility to include ORC as potential technology in these BREF documents.

**Carry out a social cost benefit analysis on the application of ORC systems**
In our report, we studied and provided key figures for business cases of several sectors. Besides these financial benefits, we also discussed several co-benefits related to the implementation of ORC systems that are typically difficult to quantify. These co-benefits (or, positive external effects), that are very site-dependent, could, however, have a significant impact on the business case. In order to be able to incorporate these co-benefits better in business cases, we recommend to further study these effects by carrying out a social cost benefit analysis on applications of ORC systems.

**Consider including waste heat to power technologies in the Climate Delegated Act of the EU Taxonomy Regulation**
Our report has illustrated how waste heat to power technologies - in this case, ORC technology - have the potential to increase the energy efficiency in different sectors. Besides the financial benefits that these technologies can provide and the potential to avoid GHG emissions, other (positive) external effects - that could potentially be quantified by a social cost benefit analysis - may apply. Therefore, we recommend to consider including waste heat to power technologies in the Climate Delegated Act of the EU Taxonomy Regulation.

# References

BAFA. (2023). *Modul 4 – Energie- und ressourcenbezogene Optimierung von Anlagen und Prozessen. Anlage zum Merkblatt Bundesförderung für Energie- und Ressourceneffizienz in der Wirtschaft – Zuschuss.*

Bejan, A., Tsatsaronis, G., & Moran, M. J. (1996). *Thermal Design and Optimization.*

Belastingdienst. (ongoing). *Tabellen tarieven milieubelastingen.* https://www.belastingdienst.nl/wps/wcm/connect/bldcontentnl/belastingdienst/zakelijk/overige_belastingen/belastingen_op_milieugrondslag/tarieven_milieubelastingen/tabellen_tarieven_milieubelastingen

Colonna, P., Casati, E., Trapp, C., Mathijssen, T., Larjola, J., Turunen-Saaresti, T., & Uusitalo, A. (2015). Organic Rankine Cycle Power Systems: From the Concept to Current Technology, Applications, and an Outlook to the Future. *Journal of Engineering for Gas Turbines and Power, Vol. 137*(Issue 10).

Council of the European Union. (2023). *Directive of the European Parliament and of the Council of amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive*

*98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652.*

EC. (2009a). Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC (Text with EEA relevance). *Official Journal of the European Union*, *L140*(5.6.2009), 16-62.

EC. (2009b). *Reference Document on Best Available Techniques for Energy Efficiency (corrected version as of 09/2021).*

EC. (2012). Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance. *Official Journal of the European Union*, *L 315*(14.11.2012), 1-56.

EC. (2015). *Communication from the Commission : Towards an Integrated Strategic Energy Technology (SET) Plan: Accelerating the European Energy System Transformation.*

EC. (2018). *Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 Amending Directive 2012/27/EU on energy efficiency ( Text with EEA relevance).*

EC. (2019). *Communication from the Commission : The European Green Deal, COM(2019) 640 final.*

EC. (2021a). *Commission Delegated Regulation (EU) 2021/2139 of 4 June 2021 supplementing Regulation (EU) 2020/852 of the European Parliament and of the Council by establishing the technical screening criteria for determining the conditions under which an economic activity qualifies as contributing substantially to climate change mitigation or climate change adaptation and for determining whether that economic activity causes no significant harm to any of the other environmental objectives (Text with EEA relevance).*

EC. (2021b). *Proposal for a Directive of the European Parliament and of the Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652, COM/2021/557 final.* European Commission (EC). https://eur-lex.europa.eu/resource.html?uri=cellar:dbb7eb9c-e575-11eb-a1a5-01aa75ed71a1.0001.02/DOC_1&format=PDF

EC. (2022a). *Commission Delegated Regulation (EU) 2022/1214 of 9 March 2022 amending Delegated Regulation (EU) 2021/2139 as regards economic activities in certain energy sectors and Delegated Regulation (EU) 2021/2178 as regards specific public disclosures for those economic activities (Text with EEA relevance)*.

EC. (2022b). *Proposal for a Directive of the European Parliament and of the Council amending amending Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) and Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste COM/2022/156 final*.

EC. (2023a). *Commission delegated regulation (EU) …/... of 27.6.2023 amending Delegated Regulation (EU) 2021/2139 establishing additional technical screening criteria for determining the conditions under which certain economic*
*activities qualify as contributing substantially to climate change mitigation or climate change adaptation and for determining whether those activities cause no significant harm to any of the other environmental objectives (Text with EEA relevance)*.

EC. (2023b). *Commission welcomes agreement on new legislation to prevent 500 million tonnes of emissions from fluorinated gases and ozone depleting substances*. European Commission. https://ec.europa.eu/commission/presscorner/detail/en/ip_23_4781

EC. (2023c). *Communication from the Commission to the European Parliament, the Council, the European economic and social committee and the committee of the regions on the revision of the Strategic Energy Technology (SET) Plan*.

EC. (2023d). *Development of EU ETS (2005-2020)*. European Commission. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/development-eu-ets-2005-2020_en

EC. (2023e). *EU Taxonomy Navigator*. European Commission. https://ec.europa.eu/sustainable-finance-taxonomy/

EC. (2023f, 17-02-2023). *The Green Deal Industrial Plan: putting Europe's net-zero industry in the lead*. European Commission (EC). https://ec.europa.eu/commission/presscorner/detail/en/ip_23_510

EC. (2023g). *Proposal for a Regulation of the European Parliament and of the Council on establishing a framework of measures for strengthening Europe’s net-zero technology products manufacturing ecosystem (Net Zero Industry Act)*.

EC. (2023h). *Strategic Energy Technology Plan*. European Commission. https://energy.ec.europa.eu/topics/research-and-technology/strategic-energy-technology-plan_en

ECHA. (2023). *Per- and polyfluoroalkyl substances (PFAS)*. European Chemicals Agency. https://echa.europa.eu/hot-topics/perfluoroalkyl-chemicals-pfas

ECN, & EIB. (2016). *Methodiek werkgelegenheid energie : Achtergrondrapport bij de Nationale energieverkenning 2015*.

EEA. (2023). Greenhouse gas emission intensity of electricity generation. In: European Environment Agency.

EU. (2006). *Regulation (EC) No 842/2006 of the European Parliament and of the Council of 17 May 2006 on certain fluorinated greenhouse gases (Text with EEA relevance)*.

EU. (2014). *Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases*.

EU. (2018). *Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (Text with EEA relevance.)*.

EU. (2023a). *Directive (EU) 2023/1791 of the European Parliament and of the Council of 13 September 2023 on energy efficiency and amending Regulation (EU) 2023/955 (recast) (Text with EEA relevance)*.

EU. (2023b). *Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources, and repealing Council Directive (EU) 2015/652*.

EU. (2023c). *Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC (Text with EEA relevance)*.

European Parliament. (2023a). Legislative Train Schedule - Fuel EU Maritime - Sustainable maritime fuels - In “A European Green Deal”. In: European Parliament.

European Parliament. (2023b, 23-11-2023). *Legislative Train Schedule - Revision of the Renewable Energy Directive - In “A European Green Deal”*. European Parliament (EP). https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-revision-of-the-renewable-energy-directive

European Parliament. (2023c). *Revision of Directive 2010/75/EU on industrial emissions (REFIT) - In “A European Green Deal”*. European Parliament. https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-revision-of-the-industrial-emissions-directive-(refit)

European Parliament. (2023d). *Revision of the EU emission trading system (ETS): In “A European Green Deal”*. European Parliament. https://www.europarl.europa.eu/legislative-train/theme-a-european-green-deal/file-revision-of-the-eu-emission-trading-system-(ets)

European Parliament, & The Council of the European Union. (2010). Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) Text with EEA relevance. *Official Journal of the European Union*, *L334*(17.12.2010), 17-119. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32010L0075&from=NL

European Parliament & The Council of the European Union. (2020). *Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088 (Text with EEA relevance)*.

JRC. (2013). *Best Available Techniques (BAT) Reference Document for the Production of Cement, Lime and Magnesium Oxide*.

KCORC. (2022). *Thermal Energy Harvesting - The Path to Tapping into a Large CO2-free European Power Source*.

KCORC. (2023). *Position paper on the upcoming PFAS regulation for Organic Rankine Cycle power systems*.

Lemmens, S. (2016). Cost Engineering Techniques and Their Applicability for Cost Estimation of Organic Rankine Cycle Systems. *Energies*, *June 2016*(vol. 9(7)), 1-18. https://ideas.repec.org/a/gam/jeners/v9y2016i7p485-d72615.html

RVO. (2021, 10-11-2023). *Erkende Maatregelenlijsten energiebesparing (EML)*. Rijksdienst voor Ondernemend Nederland (RVO). https://www.rvo.nl/onderwerpen/duurzaam-ondernemen/energie-besparen/informatieplicht-energiebesparing/bedrijven-en-instellingen/erkende-maatregelenlijsten

RVO. (2023). *Energieinvesteringsaftrek (EIA) - Energielijst 2023*. Rijksdienst voor Ondernemend Nederland (RVO).

SEO, & CE Delft. (2023). *Evaluatie energie-investeringsaftrek periode 2017-2021*.

SETIS. (2021). *SET Plan Action 6 on Energy Efficiency in Industry - Implementation Plan Revision 2021*.

Turboden. (2023). Solutions - Oil & Gas. In: Turboden. https://www.turboden.com/solutions/1054/oil-gas

Westhoeve, J., Mestemaker, B., & Biert, L. v. (2023). *Waste heat recovery on dredging vessels*.

# A Studied industries

## A.1 Cement

One of the first applications of industrial waste heat recovery ORC power plants can be found in the cement industry. Throughout the production of cement, about 40% of the process heat is wasted to the environment, mainly via the exhaust gases from the rotary kiln, coming from the limestone preheaters, and also from the ambient air used for clinker cooling. Depending on the cement plant configuration (e.g., number of preheating stages) and the process efficiency, waste heat streams are available at temperatures between approximately 200 and 400ºCelsius (Colonna et al., 2015).

## A.2 Steel

In comparison to the quite standardized cement production process, steel manufacturing requires quite diverse processes. Heat recovery from the exhaust gas of electric arc furnaces (EAF) and rolling mills can be used by ORC.

## A.3 Glass

The glass industry also offers opportunities for waste heat recovery by means of indirectly heated ORC power systems. An intermediate heat transfer loop can collect thermal energy from the hot gas exiting the oven that melts and refines the raw materials. The exhaust gas temperatures are relatively high (400–500°C) (Colonna et al., 2015).

## A.4 Chemicals

The chemical industry is a large industry, covering a wide range of different products (both organic and inorganic chemicals). Currently, not many ORC systems have been applied in the chemical industry. Waste heat is typically recovered from exhaust gasses related to the chemical processes.

## A.5 Oil & gas

Within the oil and gas industry, ORC systems typically recover excess waste heat from the exhausts of gas turbines or reciprocating engines, or from hot streams. The following three applications are often seen:

- Gas compressor stations: ORC systems can use the exhaust gas streams from gas turbines in gas compressor stations.
- Associated petroleum gas: Associated Petroleum Gas (APG) can often be found at oil and gas extraction sites. When the chemical composition of APG is poor and therefore its exploitation is problematic with traditional technologies, it is typically burned via torches. In such cases, the flare gas is undoubtedly wasted. ORC is a viable technology that can use the energy content of flare gas to produce electric power. The heat recovery configuration involves a boiler fuelled by flare gas that heats up a thermal vector fluid, typically thermal oil. The thermal oil feeds the ORC unit, which then

produces electricity and thermal power at low temperature (in case of a CHP unit) (Turboden, 2023).

- Process hot streams: both the upstream and the downstream sectors are characterised by the presence of heat sources at medium-to-low temperature. On the one hand, exhausted extraction wells are often full of hot water. On the other hand, oil refining processes take place at high temperatures and the products (diesel, kerosene, etc.) exit the process at temperatures between 150°C and 250°C and must be cooled down before storage. In both cases, an ORC with the proper working fluid can exploit these low enthalpy sources to produce useful power (Turboden, 2023).

## A.6 Maritime transport

Within the maritime transport sector ORC systems typically convert waste heat from exhaust gases (up to 600°C), cooling water (75-110°C), saturated steam (120-180°C) or thermal oil (120-180°C) into electricity. The ORC systems applied are often small modules (100 kW or 200 kW) and reduce the amount of fuel used as electricity is typically generated on board.

# B Interview list

During this project we interview the following parties:
- five suppliers of ORC technology;
- two (potential) users of ORC technology from the oil and gas industry;
- one (potential) user of ORC technology from the chemicals industry;
- one (potential) user of ORC technology from the maritime transport sector.