

MARKET REPORT ON ORGANIC RANKINE CYCLE POWER SYSTEMS: RECENT DEVELOPMENTS AND OUTLOOK

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ABSTRACT

The Organic Rankine Cycle (ORC) is a thermal driven power cycle operated with an organic working fluid. It is especially suitable to exploit low to medium temperature heat sources at small to medium size capacity ranges. For these conditions, it outperforms the standard Clausius Rankine Cycles. Suitable heat sources can be either renewable in nature (i.e. biomass, solar, geothermal) or waste heat (i.e. mobile, stationary). The size of these power units ranges from very few kW to several dozen MW. It is the intention of this report to present an up-to-date overview on the recent developments in the ORC industry. This publication provides insights on the number and capacity of most of the installed ORC plants worldwide as well as the current and future market expectations from ORC manufacturer's perspective.

Information from 30 manufacturers, representing a total of more than 2600 projects have been collected and analyzed providing information on trends in the past and the market evolution during the last four years in terms of installed capacity and installed plants divided by application, macro region and manufacturer. At the end of 2020, the cumulated ORC installed capacity was 4.07 GW. Since 2016, the overall ORC market increased by 40 % (+1.18 GW) in terms of installed capacity and by 46 % (+851) in terms of installed plants. Regarding the capacity increase between 2016 and 2020, the largest increase is due to geothermal application (+970 MW, +45 %), while waste heat systems have the largest growth concerning the number of installed systems (628 plants, + 207 %).

For the market survey, ten established ORC manufactures contributed their current and future perspective on the ORC market. The results highlight that, despite the impact of the COVID-19 situation, the current market situation is in good shape and that the majority of the manufacturers have positive expectations concerning the short-term development of both the ORC market and number of employment. Central and Eastern Europe as well as the ASEAN region are rated as the regions with the highest growth potential. Geothermal energy and small waste heat sources are seen as the most relevant heat sources for the coming years.

1 INTRODUCTION

1.1 Organic Rankine Cycle Technology

In order to limit global warming to a maximum of 1.5°C, even more rapid and holistic changes of the global energy system become inevitable. Besides the increase in PV and wind power generation systems, the use of reliable low and medium temperature heat sources is an important building block in the energy transition in order to meet current climate goals (Quoilin et al., 2013). There is a tremendous technical potential for the conversion of low and medium temperature heat, such as from geothermal reservoirs, solar systems, biomass combustion or waste heat sources. In this context, the Organic Rankine Cycle (ORC) is a key technology for increasing the share of these low to medium temperature renewable and sustainable energy sources. As discussed in detail by Macchi (2016), the ORC outperforms both gas cycles and water/steam cycles at rather low heat source temperatures and small to medium plant sizes. Colonna et al. (2015) highlight that the ORC technology is probably the most flexible applicable technical solution for the utilization of external thermal energy sources. In addition,

ORC systems are suitable for the combined generation of power, heating and/or cooling. A more detailed description of the history on ORC power systems and their technical options are presented by Bronicki (2016) and Astolfi (2016).

1.2 Purpose and Methodology

This section describes the purpose and the methodology of both the ORC database and the market survey.

1.2.1 Purpose

It is the aim of this report to present an up-to-date overview on the recent developments in the ORC industry in a quantitative as well as in a qualitative way from different perspectives. Therefore, this publication provides an overview on (1) the number and capacity of almost all installed ORC plants worldwide as well as (2) the current status and future market expectations from an ORC manufacturer's perspective. This report will be the starting point of bi-annual market report updates aligned with the International Seminar on ORC Power Systems. This work is a joint effort of the Technical University of Munich (market assessment) and the Politecnico di Milano (analysis of worldwide ORC installations database). The Knowledge Center on Organic Rankine Cycle ([KCORC](https://www.kcorc.org)) as the umbrella organization of the conference acts as the main contact point regarding the market report and will further exploit its results to the community.

1.2.2 Methodology

The market assessment is a compilation and evaluation of data from the ORC manufacturers. For this purpose, a survey has been developed, benchmarked and distributed to all relevant ORC manufacturers in order to obtain valuable insights on the current market situation. In addition to that, the expectations and prospects for the next two years were also part of the survey. In total ten manufacturers have completed the survey, representing small-, medium- and large-scale ORC manufacturers.

The first version of the world database of installed ORC power plants has been built by Thomas Tartiere and Marco Astolfi in 2016 counting more than 2.7 GW of installed capacity and more than 1700 ORC units from 27 different ORC manufacturers. A full analysis of this ORC market status database is reported by Tartiere and Astolfi (2017). The database has been updated in 2021 which consistently increased the number of records by adding new references from 12 ORC manufacturers (labelled with * in Table 1), while the others declined to take part to the survey because of confidentiality reasons or because they are not in the business anymore. The ORC database now includes almost all plants commissioned since 1975 and a map of all references is available at <https://orc-world-map.org>. Table 1 reports in alphabetical order the list of the 30 ORC manufacturers that are included in the database with the number of installed units as well as the total installed capacity until October 1, 2021. The analysis carried out in section 2 is considering plants installed until the end of 2020 and it is important to underline that this analysis always refers to installed plants and capacity since the precise information regarding the actual status of ORC projects and the actual running capacity is often not available.

Table 1: ORC manufactures included in the database. Manufacturers labelled with * updated their reference in the last four years.

Manufacturer	Capacity, kW	Plants	Manufacturer	Capacity, kW	Plants
ABB	3'800	2	GMK	5'399	21
Adoratec	18'434	24	gT - Energy Tech.	670	2
BEP - E-rational	3'732	21	Johnson Control	1'750	1
Calnetix	2'478	20	Kaishan	33'155	46
Calnetix/CETY	700	5	OPCON E.S. AB	1'995	3
Calnetix/Ingeco	3'125	25	Orcan Energy AG*	40'973	503
Dürr Systems AG*	5'920	53	ORMAT*	2'806'220	1'226
Electratherm	3'535	63	RANK*	1'558.5	26
Enerbasque*	253	11	TAS	143'000	17
ENERTIME*	27'500	14	TICA*	27'720	99
ENEX	9'300	1	TMEIC	1'000	1
ENOGIA*	3'400	94	TRIOGEN*	7'048	50
Enreco	180	3	Turboden*	771'934	408
EXERGY*	476'539	50	UTC Power	3'080	11
General Electric	101'000	6	Zuccato*	6'460	39

2 ORC MARKET ANALYSIS

2.1 Historical trends and current market status

Figure 1 depicts the historical trend of installed power (Figure 1.a) and installed plants (Figure 1.b) since 1975 divided by application. In particular, Figure 1.c and Figure 1.d report the relative share of each application in the last 45 years. It is worth to highlight that the installed capacity by year remains relatively low (below 100 MW) until 2008 when it started to rapidly increase by reaching a maximum value close to 400 MW in 2015 and then stabilizing around 300 MW. Main contribution to the soar of ORC installed capacity is due to geothermal application followed by biomass - especially between 2000 and 2012 - and by waste heat recovery (WHR) in more recent years. Current cumulative ORC capacity divided by application highlight the dominant position of geothermal field (77.4 %), an almost equivalent share for WHR (11.6 %) and biomass applications (10.1 %) and a minor contribution of the other applications: waste-to-energy (0.7 %), solar (0.2 %), remote applications (0.03 %).

Regarding installed plants the annual trend is less static and shows few peaks in the past represented by the installation of a large number of micro-scale (around 1kW) remote units while a rapid increase is achieved in last two years thanks to small-scale WHR installations. The yearly share of installed plants has been dominated by geothermal energy until 2000 (with occasional drops related to remote application), by biomass between 2000 and 2012 and by WHR nowadays. Current cumulative ORC installed plants is dominated by WHR (34.5 %) and remote (32.3 %) applications followed by biomass (16.2 %) and geothermal applications (15.3 %). Solar and waste to energy counts a small number of plants equal to 1 % and 0.7 % of the overall market, respectively.

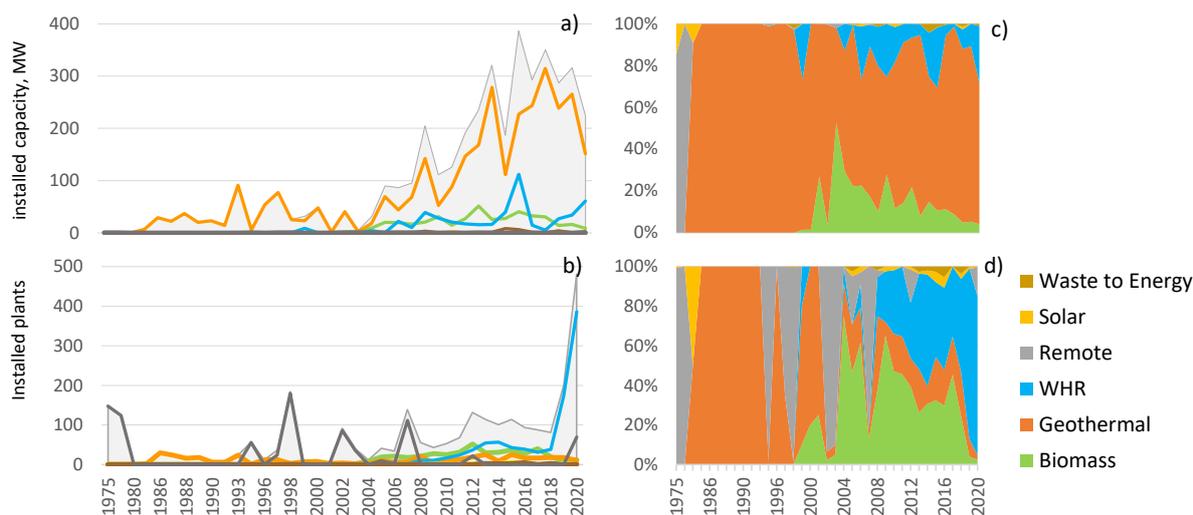


Figure 1: Historical trend of ORC installed capacity (a) and installed plants (b) divided by applications and relative share by year (c-d).

2.2 Market change in 2016-2020

Figure 2 depicts the cumulative installed power (Figure 2.a) and the cumulative installed plants (Figure 2.b) from 1975 to 2020. It is interesting to note that the trend is firmly increasing and that from the last analysis in 2016 the overall ORC market increased by 40 % (+1.18 GW) in terms of installed capacity and 46 % (+851) in terms of installed plants. Actual capacity installed is close to 4.1 GW with more than 2700 installed plants. Moreover, more than 430 MW and 160 plants have been either built in the first months of 2021 or are planned for the next years. Regarding the market increase between 2016 and 2020 (Figure 2.c) the largest increase in terms of capacity is due to geothermal application (+970 MW, +45 %) while a minor contribution in terms of capacity is due to WHR, biomass and Waste-to-Energy. The latter three fields of application also show good relative increases between 20 % and 36 %. Finally, solar capacity has doubled during the last four years but still has a nearly negligible contribution to the overall ORC world market. Regarding installed plants (Figure 2.d) in the last four years, the largest

share is due to WHR, which increases its installations by 628 plants (+207%), while the other applications increase their units by around 20 - 25%.

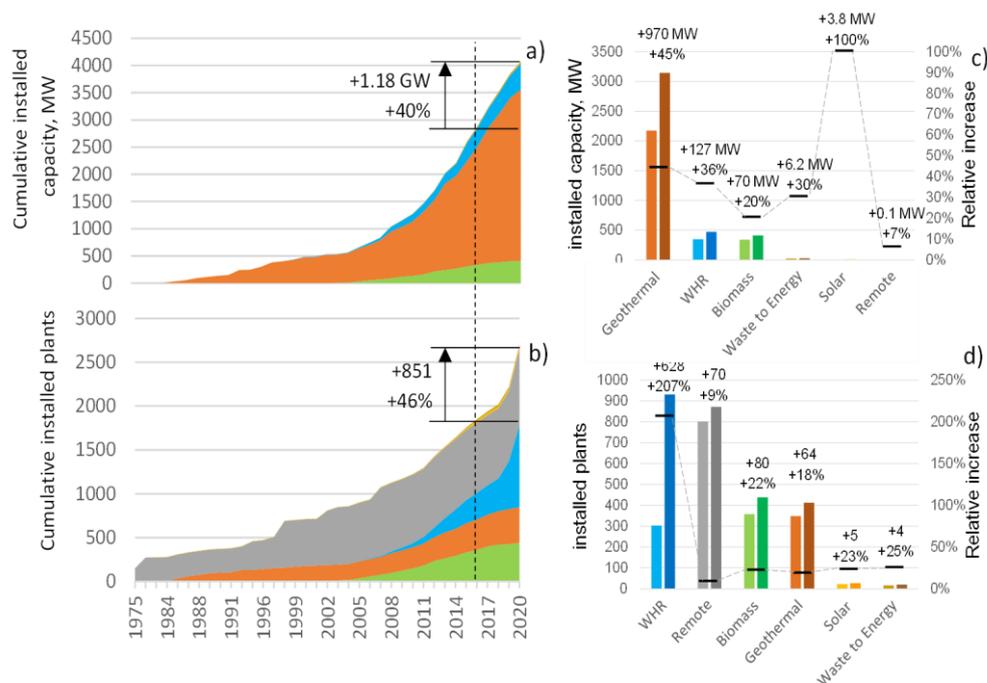


Figure 2: Historical trend of cumulated ORC installed capacity (a) and installed plants (b) divided by applications and increase between 2016 and 2020. Market increase in 2016-2020 divided by application in terms of installed capacity (c) and plants (d).

2.3 ORC market by region

Figure 3 reports some information regarding the geographical distribution of ORC plants. The prime two ORC macro regions in terms of installed capacity are the Middle East and North America thanks to the availability and the exploitation of geothermal energy followed by Europe where biomass energy is the most common technology. On the contrary, in terms of installed power plants Europe is leading since both biomass and WHR adopts relatively small power plants between 1 and 5 MW while Russia (in second position) counts for a very large number of very small remote ORC plants along gas pipelines but a very low overall installed capacity. Geothermal energy is mainly exploited in Turkey and the USA while biomass plants have been mostly installed in Europe (Germany and Italy) because of favorable incentives. WHR applications are more uniformly spread around the world because they are coupled with industrial processes and not to the availability of a specific natural energy source.

2.4 ORC market by manufacturer

Regarding the ORC market from an ORC manufacturer's point of view, it is interesting to underline that the three main companies, that were leading the market in 2016, were able to firmly hold their position in the last four years. They installed more than 78% of the new installed capacity between 2016-2020: Ormat (+775.6 MW), Turboden (+158.2 MW) and Exergy (+156.2 MW). Each one of them increased their corresponding installed capacity by around 40-50%. The remaining installed capacity in the last four years (87 MW) is shared between manufacturers of small ORC units that, on the contrary, largely increased their installed capacity: Orcan Energy AG (+3900%), Enogia (+595%), Rank (+192%), Dürr Systems AG (+111%), Enerbasque (+72%) and Zuccato Energia (+60%). Thus, demonstrating that also this type of business is sustainable and highlighting the large room for market growth and possibilities for new players. In this context, it is worth to highlight two cases: (1) Enertime, which commercializes plants between 2-3 MW, has been able to increase its capacity by 430%. (2) Tica, a Chinese company, which was not existed back in 2016 and has been able to install 23 MW during the last four years.

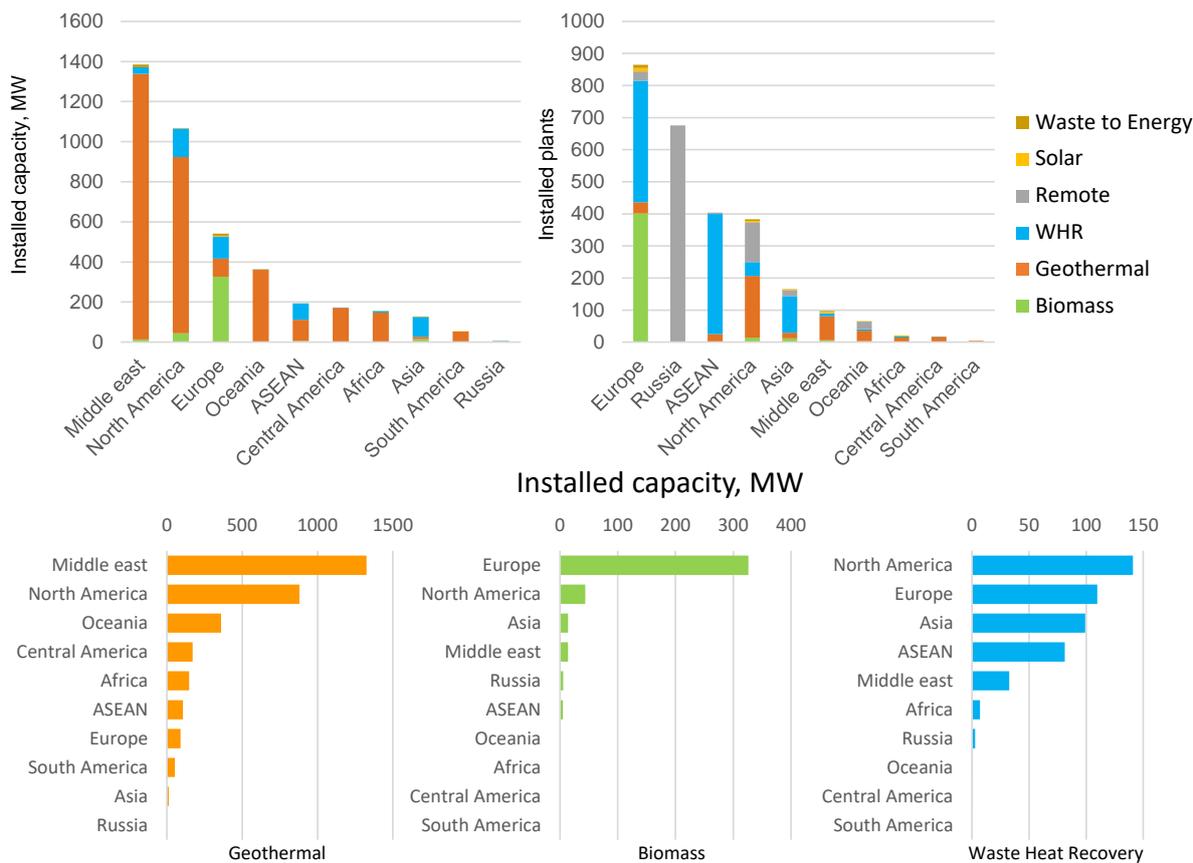


Figure 3: Installed capacity (top-left) and installed plants (top-right) divided by application in the different macro-region worldwide. Detailed of installed capacity for different applications (bottom).

3 OUTLOOK

3.1 Business Development

The business and market development is based on the feedback of the participating technology providers in the ORC2021 market survey. Considering the fact that the last two years have been strongly affected by the COVID-19 pandemic, it was important to measure the temperature of the technology providers. The results are shown in Figure 4.

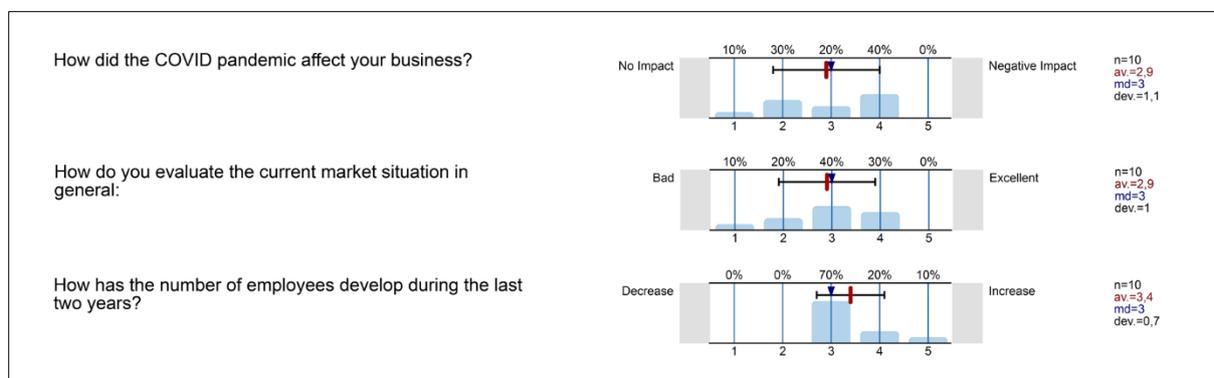


Figure 4: Survey result on current market situation.

The response to the question on “How did the COVID pandemic affected your ORC business?” was on average 2.9 on a scale ranging from 1 (No Impact) to 5 (Negative Impact), with a standard deviation of

1.1 and a median of 3. Showing that the ORC industry is quite robust, but was definitely suffering some impacts from the COVID pandemic.

The response to the question on “How do you evaluate the current market situation in general?” was on average 2.9 on a scale ranging from 1 (Bad) to 5 (Excellent), with a standard deviation of 1 and a median of 3. This satisfactory feedback from the community suggests that the ORC business might have experienced an even stronger growth during the last years, if COVID would not have affected the markets.

With respect to employability, the ORC market was quite robust with the numbers of employees being either increasing or at least remaining at a constant level. The result obtained is an average of 3.4 on a scale ranging from 1 (Decrease) to 5 (Increase), with a standard deviation of 0.7 and a median of 3.

With respect to the short-term development forecast of the ORC business the technology providers came up with the results as shown in Figure 5.

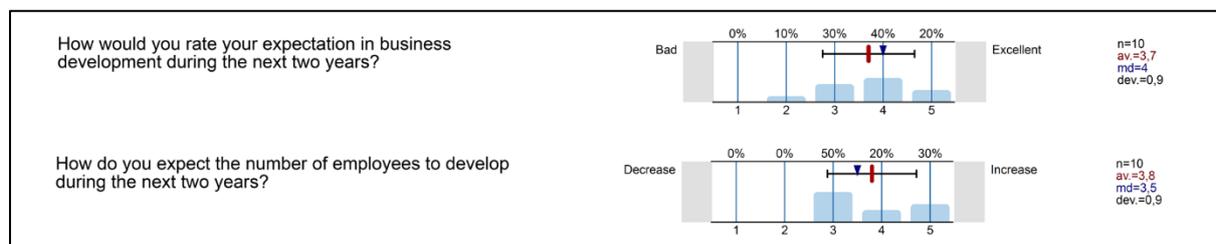


Figure 5: Survey result on short-term future market situation.

The response to the question on “How would you rate your expectation in business development during the next two years?” was quite a positive outlook with an average 3.7 on a scale ranging from 1 (Bad) to 5 (Excellent), with a standard deviation of 0.9 and a median of 4. This positive outlook of the community indicates that the ORC business is further emerging and will potentially recover quite fast from the latest COVID restrictions.

Also in terms of employability, the ORC manufacturers will build up capacity, as the ORC technology providers are expecting to recruit new employees in the near future. The result obtained is on average 3.8 on a scale ranging from 1 (Decrease) to 5 (Increase), with a standard deviation of 0.9 and a median of 3.5.

3.2 Market Development

In order to investigate the expected future market development and to identify emerging markets in specific macro regions, the participating technology providers have been asked for their input. The results are shown in Figure 6 and can be concluded as follows:

Manufacturing of components

- The manufacturing of components will mainly increase in China.
- Also India and the ASEAN region will experience a slight increase.
- Europe will maintain its role as a component manufacturer, experiencing slight regional shifts from Northern to Central and Eastern Europe.
- The role of America as a component manufacturer is expected to decrease slightly.

Manufacturing of ORC systems

- The manufacturing of ORC systems is expected to increase almost all over Europe, except Northern Europe.
- China and ASEAN region will also increase in importance.
- The role of Northern Europe, India and Africa is not subject to significant changes.

This general increase is in line with the positive outlook on business development in the previous section.

Employment perspective

- The ORC sector experiences a slightly positive employment perspective for Europe
- The main drivers in employment are most likely found in China and ASEAN region.

Market development

- A positive market development is expected on a global scale.
- Main increase in Europe might occur in Central and Eastern Europe.
- Outside Europe, ASEAN region will might a dominant role in market development.

Import of ORC systems

- Europe's import of ORC systems will further reduce. As Europe has quite a number of established ORC technology manufacturers, they are capable to serve their home market directly.
- Similarly, China's market will have less import of ORC systems, which is due to (i) joint-ventures with European manufacturers, (ii) own capacity built-up and (iii) existing market barriers for European manufacturers.
- As the demand is rising also in other regions, their imports will increase.

Export of ORC systems

- Central Europe and China are likely to become the leading exporting regions of ORC systems.
- In parallel to that, other regions will experience a slight increase, except for the African region.

	Central Europe	Eastern Europe	Northern Europe	Southern Europe	Americas	China	India	ASEAN	Africa
Manufacturing of components	Green	Green	Red	White	Red	Green	Green	Green	White
Manufacturing of ORC systems	Green	Green	White	Green	Green	Green	White	Green	White
Employment perspective in ORC	Green	Red	White	Green	Green	Green	Green	Green	White
Market for ORC Systems	Green	Green	White	Green	Green	Green	Green	Green	Green
Import of ORC Systems	Red	White	Red	White	Green	Red	Green	Green	Green
Export of ORC Systems	Green	Green	Green	Green	Green	Green	Green	Green	White

Figure 6: Region-specific industry development. (green: increase in importance, red: decrease in importance), light to dark represents an increasing degree of change

In order to identify the most important heat sources per region for ORC technology, the participating technology providers have provided their input. The color-coded summary is shown in Figure 7. While biomass and solar will only slightly increase during the next years, geothermal will increase especially in ASEAN region and the Americas. For waste heat recovery, significant growth rates, especially in Europe are projected mainly for small-scale units. Large-scale units in waste heat utilization will experience only slight increases with a focus on China and ASEAN. Other heat sources than the ones mentioned above have not been further specified, but play a negligible role anyways.

	Central Europe	Eastern Europe	Northern Europe	Southern Europe	Americas	China	India	ASEAN	Africa
Biomass									
Geothermal									
Solar									
Waste heat (small)									
Waste heat (large)									
Others									

Figure 7: Region-specific installations development. (green: increase in importance), light to dark represents and increasing degree of change

3.3 Research Demand from Manufacturers Perspective

Prime focus of ORC manufacturers is to bring their products into the field. However, innovations are necessary in order to optimize and further develop the products. Besides the more fundamental research demand, applied research close to manufacturer needs is of high interest to the ORC research community. Therefore, ORC2021 market survey asked ORC technology providers where they see the largest R&D needs. The following component- and concept-related areas have been identified:

1. High performance working fluids which are non-flammable, with low GWP and ideally suitable for high temperature-levels
2. Direct condensation with dry cooling towers
3. High performance heat exchangers for exhaust gases
4. CHP-concepts

Besides these specific research needs mentioned above, several manufacturers see a need for a general price reduction of the technology. This includes mechanical, but also electrical components. According to Lemmens (2015), for medium-scale ORC systems of 375 kW size, the main cost drivers by far are the rotational equipment with roughly 70 % of purchased equipment costs. Heat exchangers account for the remaining 30 % of the purchased equipment costs and overheads for installation and thermal oil circuit sum up to 20 % each. Therefore, research on technology leaps and significant cost reductions in rotational equipment and heat exchangers are always justified. Another option for cost reduction can be achieved by a “good enough” design strategy of ORCs instead of over-engineered designs reaching for highest efficiencies. This comprises also the modular approach with off-the-shelf-products, where the trade-off between costs and efficiency is optimized.

3.4 Effective Regulatory Measures to Increase ORC Technology Diffusion

In order to facilitate the transition of the current energy system, ORC technology is not only desperately needed for electricity production from geothermal or biomass, but also to harvest waste heat from industry as this potential is huge. This emerging ORC market can be accessed by appropriate regulatory measures:

1. Subsidies on capital expenditures (CapEx) have proven successful in Germany. This can act as a role model for other European countries, as the decision-making criteria for industry are short payback-periods of ≤ 3 years.
2. Market based approaches:
 - a. (Tradable) white certificates for implemented energy efficiency measures are considered to be effective, but have been implemented only in few countries over Europe (i.e. Great Britain, France, Italy and the Flemish Region).
 - b. Reduction of free certificates in the ETS (as for 2020 still 30% of total certificates)

Bottom line, the technology providers who participated in ORC2021 market survey identified a lack of effective national implementation of [Article 7 of European Energy Efficiency Directive](#) on energy savings obligation. A more harmonic implementation based on the suggestions/mechanisms above is desired.

Besides this, another complex regulatory barrier has been identified: Electricity grid codes – not only in Europe, but also elsewhere, e.g. in the ASEAN region. Two potential solutions for ORC technology have been identified:

- a. Standardization and unification
- b. Liberation for ORC units up to a certain MW-size-range

4 CONCLUSIONS

This work provides updated information on the development of the installed ORC systems and the ORC market worldwide. By representing the input of around 2700 projects, it provides crucial insights on the current market developments and trends. In combination with the market survey, more detailed insights on the current and future market situation can be presented. This report will be the starting point of regular market report updates aligned with the International Seminar on ORC Power Systems under the umbrella of the KCORC. Thus, the current developments within the ORC industry will be presented on a regular basis to the whole ORC community. The main conclusions of this report are:

- At the end of 2020, the cumulated ORC installed capacity was 4.1 GW. Since 2016, the overall ORC market increased by 40 % (+1.18 GW) in terms of installed capacity and by 46 % (+851) in terms of installed plants. A consistent increase of both capacity and installed plants is expected in the next two years from plant currently under construction.
- Regarding the capacity increase between 2016 and 2020, the largest increase is due to geothermal application (+970 MW, +45 %) mainly in Middle East and North America, while waste heat systems have the largest growth concerning the number of installed systems (628 plants, + 207 %) as demonstration of the large interest for energy efficiency and energy savings worldwide.
- The results of the market survey highlight that, despite the impact of the COVID-19 situation, the current market situation is considered as robust and that the majority of the manufactures have positive expectations concerning the development of both the ORC market as well as the employments during the next two years.
- Central and Eastern Europe as well as the ASEAN region are rated as the regions with the highest growth potential. The most relevant heat sources for the coming years are regarded as geothermal energy and small-scale waste heat.

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