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A World Overview of the Organic Rankine Cycle Market

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Abstract

The Organic Rankine Cycle (ORC) technology is a reliable way to convert heat into electricity, either for renewable energy applications (biomass, geothermal, solar), or industrial energy efficiency. ORC systems range from micro-scale (a few kW) for domestic cogeneration to large multi-megawatt geothermal power plants. After a slow initial start, the technology has experienced a much stronger development since the 1970s, mainly because of economic incentives and surging energy prices. However, the large range of applications, manufacturers, and countries make it hard to track the evolution of the technology over the world.

Information about more than 700 projects has been collected, cross-validating 27 manufacturers' data with publications and testimonies, allowing to build the first reliable and exhaustive database of ORC plants. As a result, this work analyses the evolution of the ORC market over the years, with today 2.7 GW of cumulated installed capacity. After introducing the ORC technology with a focus on its history, working principle and main applications, the current state and the new trends of the ORC market are presented with a detailed analysis of each application. The evolution of each market is discussed considering the present installed capacity, historical data and macro-economic trends. Finally, future perspectives and growth potential of the ORC market are evaluated, with a special focus on Waste Heat Recovery applications.

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1. Introduction

1.1. Organic Rankine Cycle technology and applications

The Organic Rankine Cycle (ORC) follows the same principles than the traditional steam Rankine cycle used in most thermal power plants to produce electricity, but uses an organic fluid instead of water. The possibility to select the best working fluid depending on the available heat source and the plant size results in multiple advantages: (i) more efficient turbomachinery, (ii) limited vacuum at condenser and (iii) higher performance compared to both steam Rankine cycles and gas cycles especially for heat sources lower than 400°C and power output lower than 20 MW [1, 2]. Working fluids can be selected from a long list of candidates including hydrocarbons, hydrofluorocarbons, siloxanes and mixtures of these components [3]. These distinctive characteristics make ORC the most reliable option for unconventional heat sources like hot geothermal brines, biomass combustion, waste heat recovery from industrial processes and thermal solar applications.

The principle of the ORC technology was established as early as 1826 by T. Howard [4] who first experimented the use of ether as working fluid in a power cycle. From this idea, several naphtha engines were built to power launches by Ofeldt and Esher Wyss AG. These engines remained confined to niche markets as they were involved in various accidents that hampered the growth of the ORC technology at that time. The first example of modern ORC was built by D'Amelio in 1936: this plant was based on a simple monochloroethane Rankine cycle heated by solar energy and powered by a single stage impulse turbine. In the following years, the same idea was applied to a couple of low-temperature geothermal plants with 2.6 kW and 11kW power output respectively. In the 1960's, following D'Amelio considerations, Tabor and Bronicki at the National Physic laboratory of Israel started an extensive screening of potential fluids that highlighted the advantages of using high complexity freons and defined the regenerative saturated cycle configuration still widely in used today. Similar scientific researches were carried out by Professors Angelino, Macchi and Gaia at Politecnico di Milano.

These experiences led to the design of several prototypes and to the founding of ORMAT (1964) and Turboden (1970), two companies that are still today the biggest players in the ORC market. Many other institutions contributed to the ORC technology like Laapeernanta University of Technology with the development of small sealed turboexpanders and City University of London with the study of volumetric expanders and the definition of innovative cycle configurations. In more recent years, many new companies have developed and implemented their own technology: Exergy (radial outflow turbine), Enertime and Enogia (medium to small axial turbines), TriOgen (direct evaporation units), Zuccato (radial inflow turbine), Electratherm, Opcon and E-Rational (screw expanders for small size applications). Multiple combinations of working fluid, expander or cycle configurations are possible, creating a dynamic industry with strong collaborations between industrial and academic partners.

1.2. Purpose and methodology

The ORC technology is not very well-known and the number of power plants that are based on that technology is often underestimated. This prevents local governments from tabling favorable motions that would foster the development of this market, as a solution for carbon-free electricity generation. The objective of this work is to provide an overview of the ORC market, at the industrial level. As a result, small ORC plants at the lab scale or that are not connected to the grid have been ignored. An exception has been made for demo plants that are not commercial but have a significant power output of several hundreds of kilowatts / several megawatts.

Manufacturer data from 27 companies, published articles and financial reports have been combined in order to build an accurate database of all ORC projects that have been commissioned since 1975. A map of all references is available at [5]. Some manufacturers do not publish their references and declined to take part to that survey. Therefore, this database is not 100% exhaustive. As of Feb 2017, we can consider that the remaining references do not represent more than 50 MW of total installed capacity, out of 2701 MW (1.9%). In large geothermal projects that combine steam and binary cycles, only the binary power production has been taken into account. Table 1 reports in alphabetical order the list of the ORC manufacturers that are included in the database with the number of installed units and the total installed capacity until December 31st, 2016.

Table 1. List of ORC manufacturers/designers, with number of installed units and total installed capacity **before Dec 31st, 2016**

Manufacturer	ORC units	Total MW	Manufacturer	ORC units	Total MW	Manufacturer	ORC units	Total MW
ABB	2	3.8	Enogia	11	0.26	Orcan	16	0.3
Adoratec	23	16.4	Enreco	1	0.15	ORMAT	1102	1701
BEP – E-rational	20	3.6	Exergy	34	300	Rank	5	0.07
Calnetix / CETY	50	6.3	General Electric	6	101	TAS	17	143
DürrCyplan	6	1.2	GMK	18	5.3	TMEIC	1	1
Electratherm	55	3.14	gT – Energy Tech	2	0.7	Triogen	37	5.2
Enerbasque	3	0.13	Johnson Control	1	1.8	Turboden	267	363
Enertime	2	1.6	Kaishan	40	27.2	UTC Power	10	2.8
Enex	1	9.3	Opcon	3	2.0	Zuccato	21	1.7

2. Current situation: applications and manufacturers of ORC

As of December 31st, 2016, the ORC technology represents a total installed capacity around 2701 MW, distributed over 705 projects and 1754 ORC units. Figure 1 (left) depicts the total installed capacity and the total number of plants divided by application. Power generation from geothermal brines is the main field of application with 74.8% of all ORC installed capacity in the world; however the total number of plant is relatively low with 337 installations as these applications require large investment and multi-MW plants. As a result, only a few companies (ORMAT, Exergy, TAS and Turboden) have been active in this capital intensive sector as reported on Figure 2.a. ORMAT is the indisputable leader in this field with more than 75% of installed capacity and plants, Exergy and TAS are following with around 13% and 6% of the market respectively while Turboden has recently penetrated the geothermal market with about 2% of the installed capacity.

Waste heat recovery is an emerging field for ORC with an interesting potential for all unit sizes: all the big players are active on that market with medium – large size plants recovering heat from gas turbines, internal combustion engines or industrial processes (Figure 2.b). Most of the other manufacturers are focused on small waste heat recovery applications with products ranging from 10 to 150 kW_{el}. Waste Heat recovery applications cover 13.9% of the total market with a relevant number of operating plants. However, it is worth noting that about 800 of these units are very small (<4 kW) plants installed by ORMAT for valve operation and cathodic protection along pipelines in remote areas.

Biomass applications represent a similar share at 11% and a considerable number of plants. As shown in Figure 2.c., Turboden is the main player on this market with more than 228 plants (most of them CHP units) and many others in construction.

Solar applications are negligible mainly because of the high investment cost of the solar field that makes ORC coupled with concentrating collectors more expensive than photovoltaic panels and battery systems.

In conclusion Figure 1.b. depicts the market share of the different manufacturers in terms of installed capacity and number of plants. The American company ORMAT is the world leader, with 62.9% of the total installed capacity, followed by the Italian companies Turboden (13.4%) and Exergy (11.1%). General Electric and Turbine Air Systems (TAS) have installed a limited number of big plants and it is not totally clear if their ORC business is still active. 23 other companies have been identified and they share 3.2% of the market with a focus on small to medium size applications.

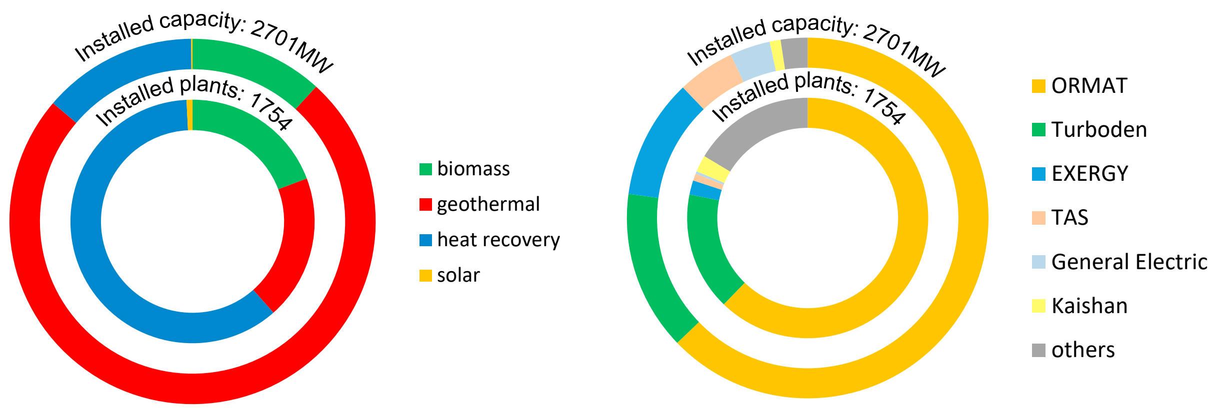

Fig. 1. Total installed capacity per application (a); per manufacturer (b).

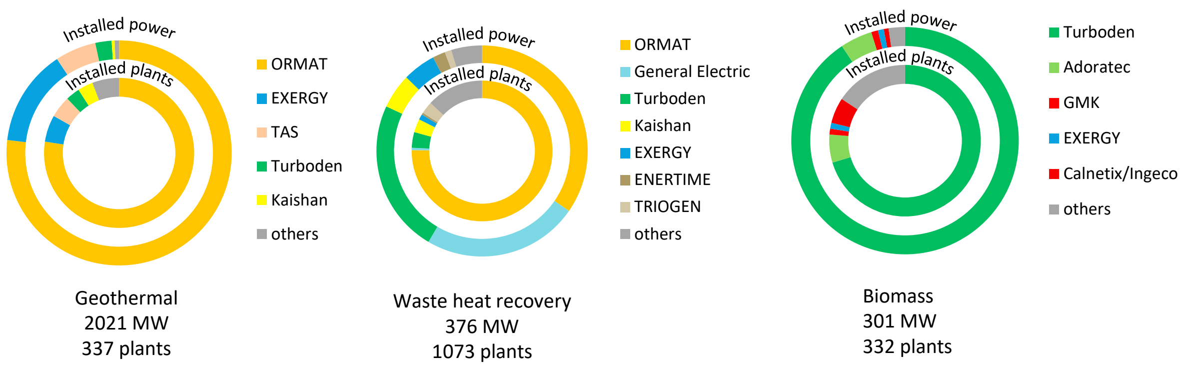

Fig. 2. Market share per application and per manufacturer

2.1. Waste Heat Recovery

With 376 MW of installed capacity in the world, and 39 MW of new capacity in construction (16 projects), the heat recovery market is still at an early stage but has long passed the demo/prototype phase. The main application is largely heat recovery from Diesel or gas engines and turbines, with 65% of the total installed capacity. ORMAT has been very active in this field with 24 plants around 3-8 MW installed along gas pipelines in the USA and Canada. Turboden follows with 9 plants of average size around 1 MW. Using exhaust heat from combustion engines or turbines is easier than industrial heat recovery and was the low-hanging fruit for a long time, but engines are becoming more efficient and this application is not considered as renewable in many countries developing energy transition roadmaps [6].

Waste to Energy is the second market and has experienced a fast growth over the last years, mostly in France and Turkey, with 19 new projects since 2013. Primary or Fabricated metals represents a similar share, with about 28 projects largely dominated by China and Italy. Despite their apparently large heat recovery potential, Cement & Lime (9 projects) and Glass (8 projects) industries count for only a small share of the heat recovery market with 81 units and 8.9 MW while landfill and biogas engines are the focus of many ORC manufacturers that offer small ORC units (up to 200 kW), benefiting from favorable incentives in different countries.

Many studies have assessed the strong potential of industrial heat recovery in Europe [7], North America [8] or China [9]. However, there are a number of barriers that prevent the growth of this market, such as regulatory issues and the lack of recognition of environmental benefits [10]. In addition, industrial capital budgets are limited and there is a strong competition for new capital investment, with priorities given to alternatives that are closer to a company's core business. Long-term paybacks also increase the financial risk of this kind of projects, and limit the access to low-cost financing. Finally, high utility standby rates often undermine the potential cost savings of on-site power generation [10].

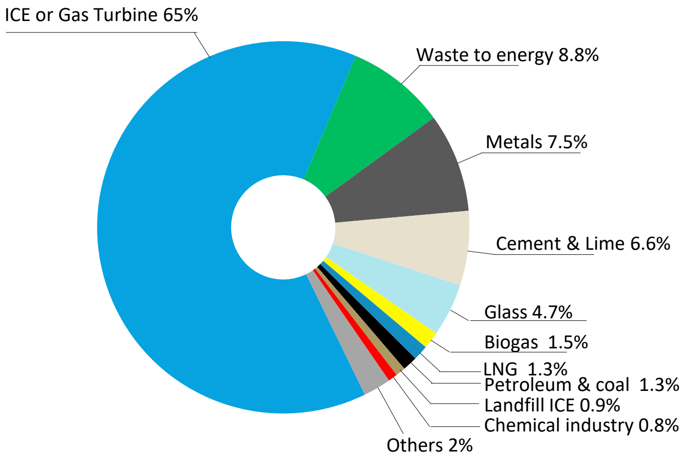

Fig. 3. Shares of installed capacity per heat recovery application.

3. Evolution over time and new trends

3.1. Market evolution

Figure. 4.a. represent the yearly installed capacity per application (biomass, geothermal, heat recovery, solar) with regards to the evolution of WTI crude oil price (as a reference of global energy price). The last x-label refers to projects in construction. Even if incentives and local market conditions can affect this trend, we can observe a strong correlation between global energy prices and new installed capacity. The development and construction of large projects typically take more than 12 months, so changes in yearly installed capacity are largely due to economic analysis carried out during the previous years. Figure 4.b depicts the new installed power per year for the major manufacturers.

After a few decades (from 1980 to 2003) focused exclusively on geothermal applications, the ORC market has experienced a significant growth since the early 2000s, with an average yearly capacity between 75 and 200 MW, reaching up to 352 MWel in 2015. Geothermal power generation has always been the most important application, with a strong increase after 2009 and the entrance of Exergy and TAS in the market. The fast growth of biomass after 2003 is strongly related to Turboden that installed on average 15 to 25 units per year and has 43 new units in construction. Despite a high potential, the Waste Heat Recovery market has declined between 2008 and 2013, before experiencing a new growth until 2015. The share of installed capacity per specific application does not change significantly over time compared to Figure 3, with ICE & Gas Turbines representing 68% of the market from 2013 to 2015. During the same period, applications in the cement industry becomes negligible, while the shares of metals (11.3%) and waste to energy (9.3%) increased.

In 2016, 255 MW of new ORC capacity has been commissioned, a decrease of 28% compared to 2015. This is largely due to the drop in heat recovery applications with only 15 MW of new capacity in 2016, compared to the all-time record of 122 MWel in 2015 and 53 MW in 2014. Possible reasons could be a strong decrease in electricity and gas prices, and competition against other renewable energies such as solar and wind.

More than 460 MW of new installed capacity have already been announced or are in construction. This includes the large Sarulla geothermal project in Indonesia (3 x 110 MW in flash and binary cycles) that should be completed in 2019 and represents an estimation of 150 MW in new binary cycles [11].

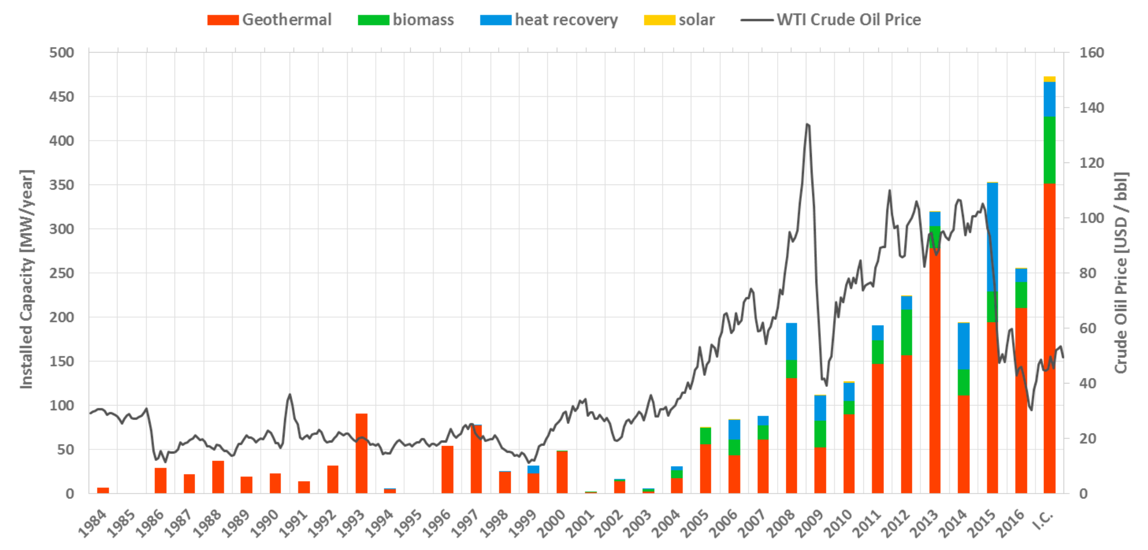

Fig. 4a. Evolution of installed capacity over time, per application

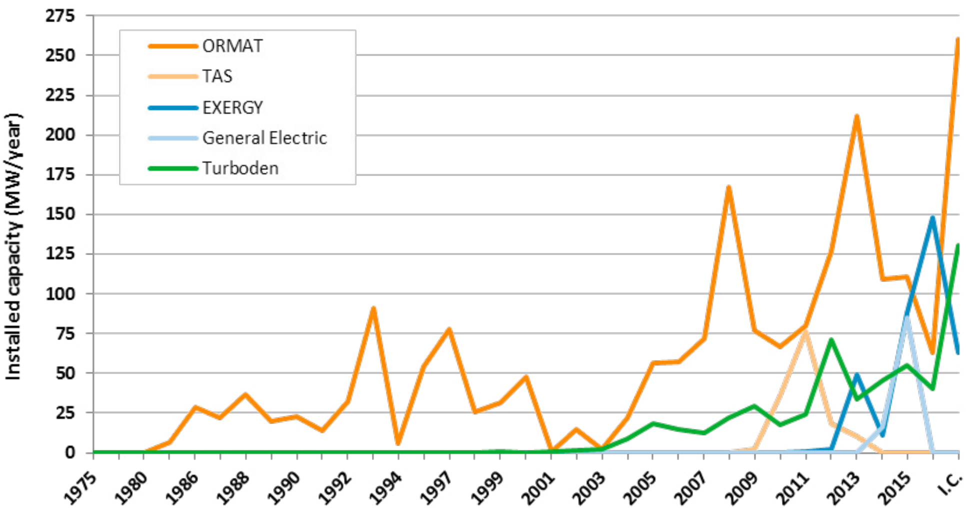

Fig. 4b. Evolution of installed capacity over time, per major manufacturer

3.2. Average unit size per application

Charts in Fig. 5 show the variation in average ORC unit size over time and the distribution of the number of plants with regards to their power output. Geothermal ORCs have progressively increased in size following the ability of manufacturers to design and produce larger turbines. Geothermal projects in the 1980s would typically involve multiple ORC units in parallel. For example, in 1987, the ORMAT Ormesa II project in East Mesa, USA, utilized 20 modular energy converters in two cascading levels, for a 20 MW power plant [12]. In the early 2000s, larger units with electrical power above 15 MW have been installed especially in large geothermal applications. A good example is the Velika Ciglena geothermal project in Croatia, currently under construction, with a 16 MW turbine designed by Turboden [13]. In recent years, some companies such as E-Rational have also built small ORC units for power generation from hot springs.

The Heat Recovery market is divided in small (<1 MW) and large ORCs (up to 18 MW). Between 2000 and 2010 this market was focused on large projects on compressor stations, but the average unit size has then significantly decreased with the construction of many small plants by ORC manufacturers like TriOgen, Electratherm, Calnetix and Zuccato.

The biomass market has experienced the most stable evolution thanks to the possibility to replicate the same design in different plants that allows Turboden to commercialize off-the-shelf ORCs. In addition, this market has been largely driven by financial incentives in central Europe that are favorable to 1 MW plants. Larger units (up to 8 MW) also became more common since 2012.

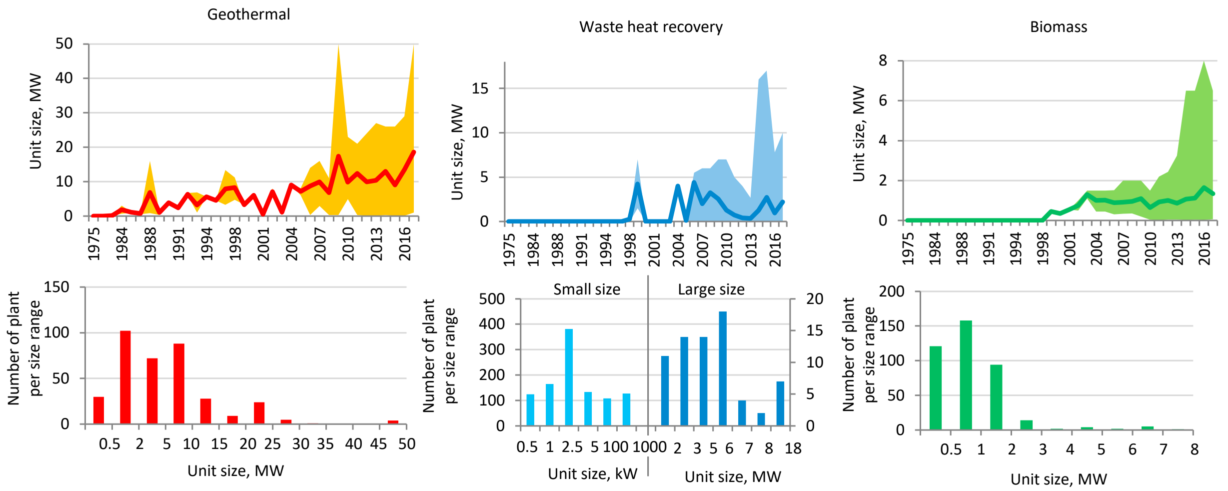

Fig. 5. At the top, evolution of ORC unit size divided by application: colored area defines maximum and minimum unit size per year while the line depicts the average installed size. Bar charts at the bottom show the distribution of plants versus the unit size for the three fields considered.

3.3. Transcritical technology

Apart for a 500 kW unit built by Turboden in 2012 for Enel in Italy [14], transcritical cycles have only been implemented commercially by TAS for three geothermal projects in the USA: Neal Hot Springs (23.4 MW, 2010), San Emidio (8 MW, 2010), and Patua (76 MW, 2011). Therefore, in spite of a strong research interest showing the interest of supercritical heating to match the heat source temperature gradient, there is no clear sign of commercial development of transcritical applications, especially in the recent years.

3.4. ORC market financial evaluation

Comparing the available information about financial revenue from Turboden (2002 to 2010) [15] and ORMAT (2012 to 2015) [16] to their actual installed capacity over the same period gives an average ratio between $1410/kW (ORMAT) and $1580/kW (Turboden). Therefore, it is possible to estimate the total value of the ORC market to be between $359 million and $402 million per year in 2016. This includes only the sales of equipment and direct engineering services, excluding complementary revenues such as electricity or heat generation, exploration and subsurface engineering for geothermal projects. Small ORC units have a much higher cost per kW, but units less than 500 kW do not represent more than 2% of the total installed capacity and can be neglected.

4. ORC Market geographical breakdown

The United States has the largest installed capacity per country, followed by Turkey and New Zealand. These three countries benefit from abundant geothermal resources. Germany, Austria, Italy and Canada are the most important for biomass applications, due to the combination of available resources and favorable incentives.

Fig 7 gives the geographical breakdown of the new ORC projects that have been built in 2016 or that are currently in construction. We can see that most of the new geothermal development is focused on Turkey, with 257

MW (12 projects). The large share of Indonesia and Kenya is due to only two large geothermal projects in each country. Biomass development continues to grow in Italy (20 projects), the United Kingdom (9 projects) and Russia (3 projects).

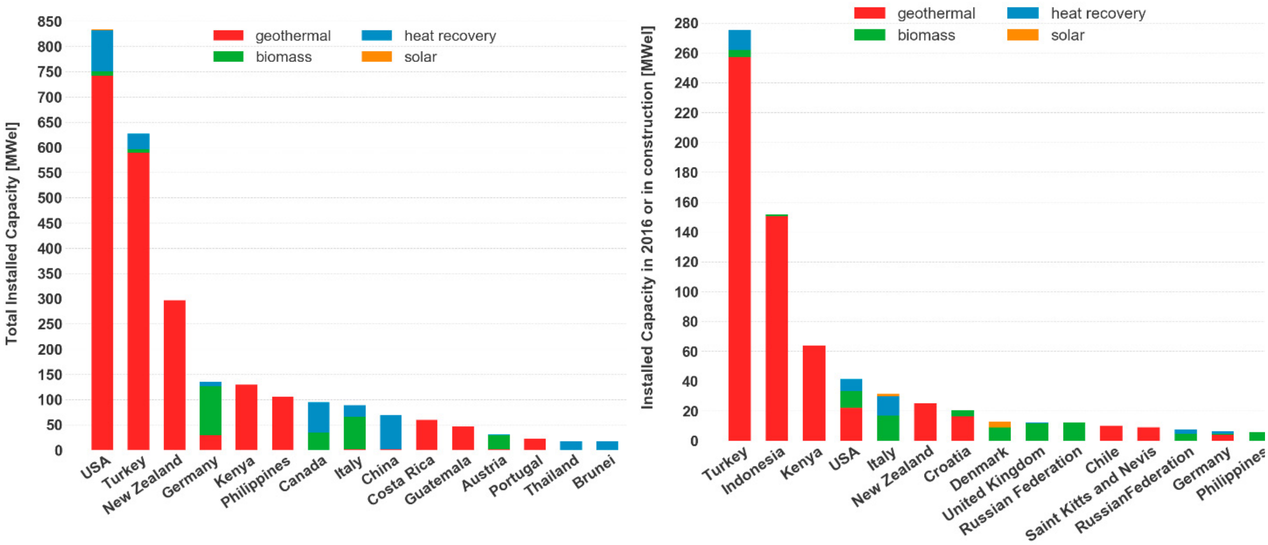

Fig. 6. Total installed capacity per country: until end of 2016 (left) and in 2016 or in construction (right).

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