New Energy Solutions Optimised for Islands

NESOI

EUROPEAN ISLANDS FACILITY

D1.3: Critical technologies for islands' energy transition

WP1, T1.3

Authors: RINA-C, CIRCE, CERTH, DEL, E.ON

Technical references

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* PU = Public

PP = Restricted to other programme participants (including the Commission Services)

RE = Restricted to a group specified by the consortium (including the Commission Services)

CO = Confidential, only for members of the consortium (including the Commission Services)

Version	Date	Authors	Beneficiary
1	28 September 2020	Emilio De Gaetani, Stefano Galleno, Francesco Peccianti, Stefano Barberis	RINA-C
		Jesus Rubio Conde, Angela Viela, Cristina Gordo	DEL
		María Dolores Mainar, Victor Ballestin, Felipe del Busto	CIRCE
		Joanna Snape, Sven Tischer	E-ON
		Avraam Kartalidis, Nikolaos Nikolopoulos	CERTH

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List of Acronyms

NESOI	New Energy Solutions Optimised for Islands
H2020	Horizon 2020
SWOT	Strength, Weakness Opportunity, Threats
HVAC	Heating, Ventilation and Air Conditioning
CHP	Combustion, Heat and Power
EV	Electric Vehicle
IPC	International Patent Classification
IRENA	International Renewable Energy Agency
WEC	Wave Energy Converters
INPADOC	International Patent documentation
LCOE	Levelized Cost of Electricity
CAPEX	CAPital Expenditure
OPEX	OPerating Expense
PCT	Patent Cooperation Treaty
PV	Photovoltaic
CIGS	copper indium-gallium diselenide
CIS	copper indium selenide
PV/T	Photovoltaic Thermal
WECS	Wind Energy Conversion Systems
MPTS	Maximum Power Point Tracking system
RES	Renewable Energy Source
CFB	Circulating Fluidized Bed
BFB	Bubbling Fluidized Bed
CF	Capacity Factor
CSP	Concentrating Solar Power
ISCC	Integrated Combined Cycle Solar Power Plants
GHG	Green House Gases
CCS	Combined Charging System
TRL	Technology Readiness Level
ESU	Energy Storage Unit
V2G	Vehicle to Grid
BEV	Bactery Electric Vehicles

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PHEV	Plug-in Hybrid Electric Vehicles
UAV	Unmanned Aerial Vehicle
WWTP	Wastewater Treatment Plants
LED	Light Emitting Diode
LIFO	Last in /First Off
THD	Total Harmonic Distortion
VRDT	Voltage Regulation Distribution Transformer
VRF	Variable Refrigerant Flow
DHW	Domestic Hot Water
BEMS	Building Energy Management System
BESS	Battery Energy Storage Systems
FLA	Flooded Lead Acid
SLA	Sealed Lead Acid
PHES	Pumped Hydroelectric Energy Storage
TES	Thermal Energy Storage
SHS	Sensible Heat Storage
LHS	Latent Heat Storage
PCM	Phase Change Materials
LT-TES	Low temperature thermal storage systems
TCS	Thermal Chemical Energy Storage

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1 Introduction

The EU Island Facility NESOI (New Energy Solutions Optimised for Islands) is a four-year Horizon 2020 project funded under call topic LC-SC3-ES8-2019 (European Islands Facility -Unlock financing for energy transitions and supporting islands to develop investment concepts). It began on 1 October 2019 and will finish on 30 September 2023 and is made up of a multi-disciplinary consortium consisting of 10 partners from 9 EU member states. It has a total budget of €10 million of which approximately €3 million is dedicated to a cascade funding mechanism to provide direct financial support to EU Islands. Coupled to consortium capacity building activities, the facility aims to mobilize more than 100 M€ of investment in sustainable energy projects to an audience of 2.400 inhabited EU islands by 2023, giving the opportunity to test innovative energy technologies and approaches in a cost-competitive way and leading to an expected 440 GWh/year in energy savings.

1.1 Scope and Objectives

A research of critical technologies to be applied in islands for the promotion of energy transition has been carried out in this task. Starting from the results of the co-creation survey prepared in Task 1.1, a technology scouting has been carried out in this task. This scouting has a double aim: i) to identify the critical technologies that should boost the energy transition in islands to be promoted through the NESOI platform, ii) to identify relevant stakeholders with the capabilities and interest to invest in energy related projects on islands. In this framework a market technology research will be performed, and weaknesses and strengths of existing players/technology clusters are assessed.

1.2 Document Structure and Methodology

The Document has been structured reporting in the initial paragraphs a review of the survey results from a point of view of the emerged technologies.
The analysis of the results of the Survey have been organized such that clusters of critical technologies to be applied on island energy transition projects have been defined.
Each of the identified Technology Clusters has been then thoroughly analyzed in terms of a scenario analysis, depicting main trends in terms of publications in patent literature, geographical areas of interest and main players.

Then a technology scouting is carried out, where the technology cluster (or the technologies pertaining to the identified cluster) are analyzed highlighting latest developments and commercial or active pilot or demonstrating projects available (further enlarging main players identified in the scenario analysis).

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At the end a SWOT analysis is reported for each of the analyzed technology cluster while at the end there is a comparison and resume of main characteristics of the analyzed technologies in terms of the following parameters:

- Technology Readiness Level
- Cost Factors
- Potential interest of stakeholders of the survey
- Etc.

1.3 Relations to other Work Programmes

The analysis conducted contributes in WP3, specifically Task 3.2 where a comprehensive technology pairing will be developed with the aim to benchmark technologies with respect to the addressed need(s). Strenghts, weaknesses, threats and opportunities highlighted through the detailed technology scouting in Task 1.3 will help define the most suitable technologies (from technical, marker readiness, social, environmental etc. point of views) to be supported both via private financing and public financing (including various EU-based schemes) will be evaluated. The outcomes of this task contribute to the aboce mentioned activities together with the outcomes of Task 1.4 “Overview of regulatory situations and sustainable business models on islands”.

2 Analysis of the results from the survey

Results gathered from the Technology Survey have been analyzed in order to retrieve main results related to Task 1.3 objectives. About 800 projects have emerged from the survey at the time when the deliverable has been prepared.
Projects cited in the survey can be classified in 4 main categories, according to their main objectives:

- Energy Efficiency Projects
- Renewable Energy Projects
- Sustainable Mobility Projects
- Energy Management Projects

Each category has been analyzed in order to define what are the main applications and related specific technological solutions or initiatives that have been developed, according to the description that the subjects involved in the projects gave during the survey:

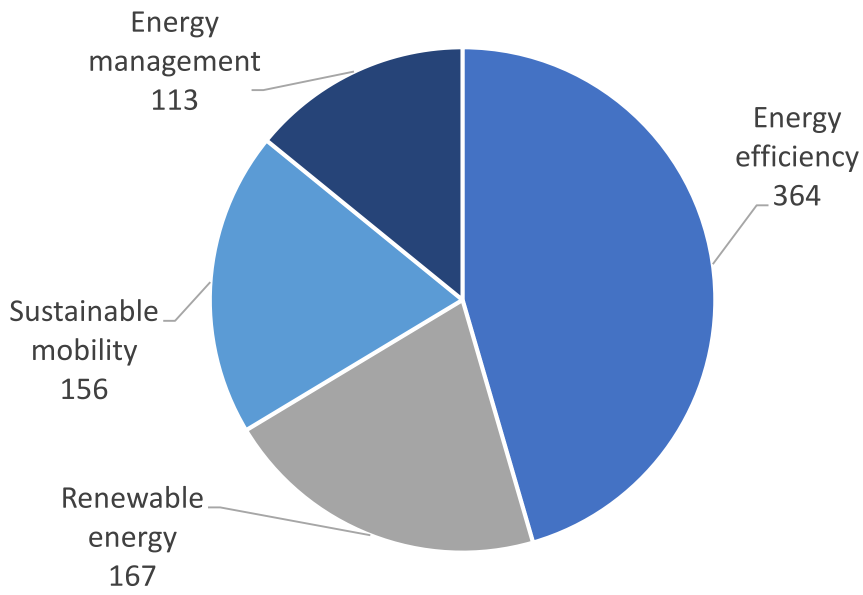

Figure 1 Macro-categories of the islands initiatives and projects emerged from the survey

2.1 Energy Efficiency related Projects – Survey Analysis

When considering Energy Efficiency projects, main applications emerged from the survey are related to electricity generation and distribution and HVAC systems.
No projects related to industrial heat production emerged from the survey.

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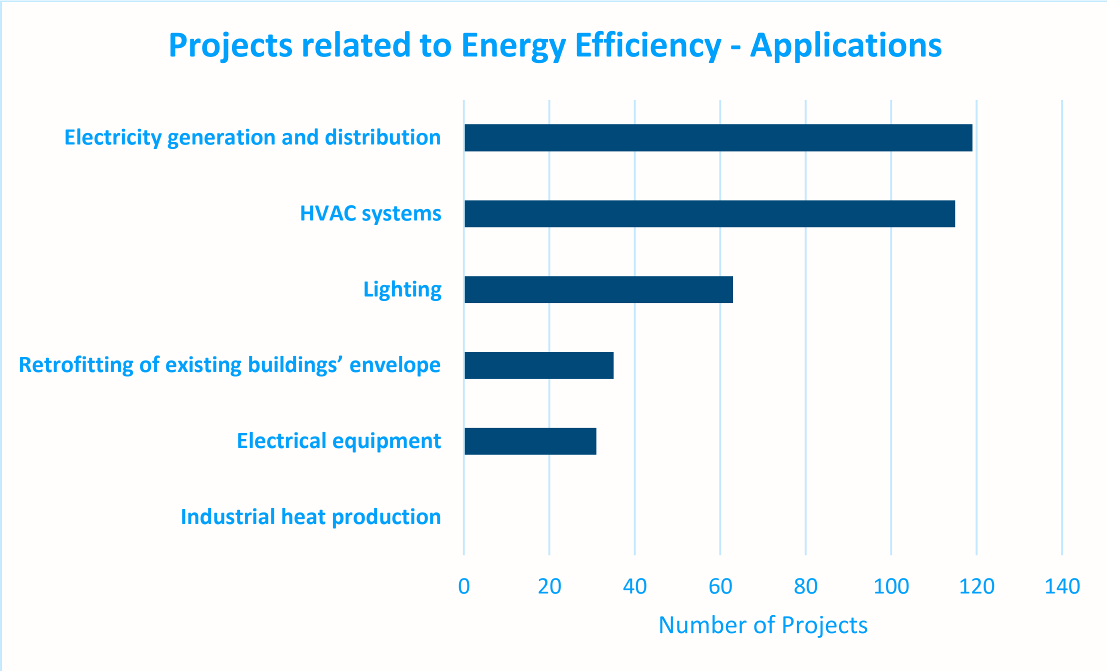

Figure 2 Application areas in energy efficiency related projects emerged from the survey

In **Electricity Generation and Distribution applications**, the main technological solutions equally share the same quote of projects.
This can indicate a non prominent solution emerged for the specified application.

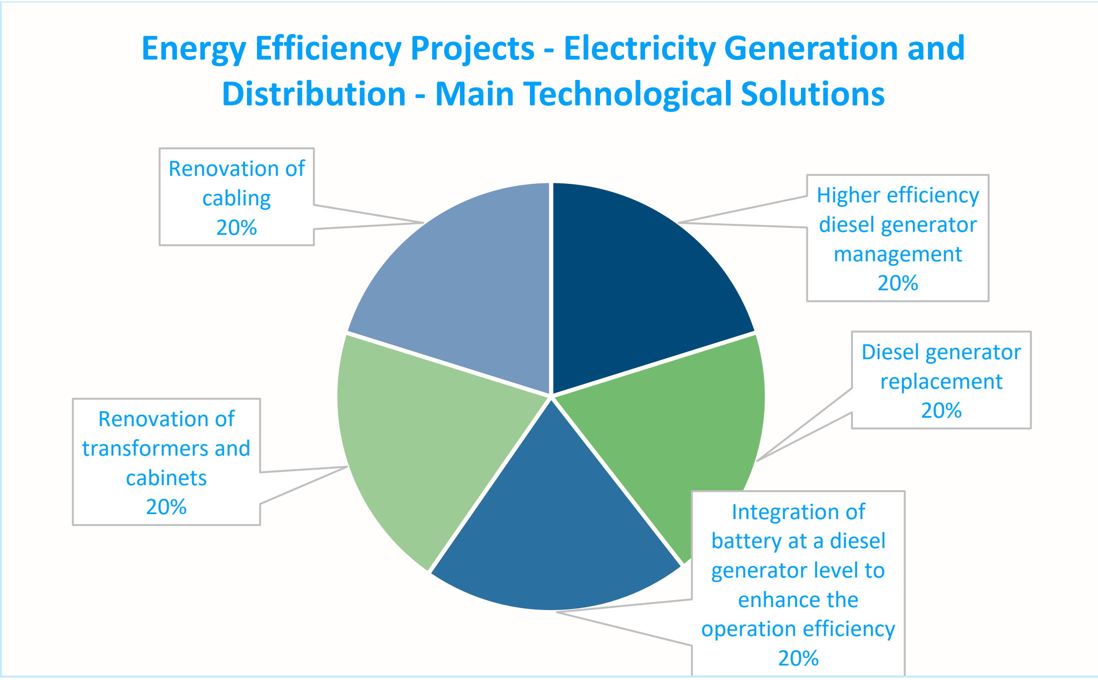

Figure 3 Main technological solutions in the application area of Electricity Generation and Distribution – Energy Efficiency projects emerged from the survey

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In HVAC systems applications emerged in energy efficiency related projects, the specific technological aspects are:

- retrofitting of existing heating/cooling installations on a single building level
- Solar thermal facilities (applications for domestic and industrial use)
- replacement of heating units or installation of systems that help save energy

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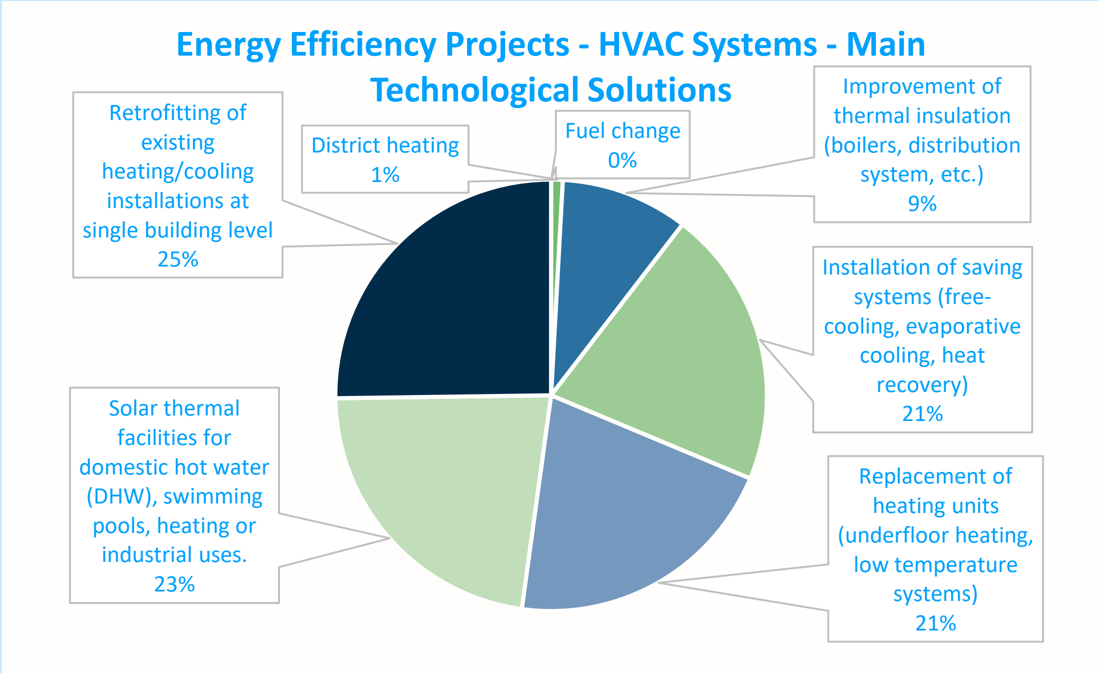

Figure 4 Main technological solutions in the application area of HVAC Systems – Energy Efficiency projects emerged from the survey

Lighting is the third sector where energy efficiency projects find application. As can be seen from the pie chart in Figure 5, initiatives are mostly targeted to public (street lighting or public buildings):

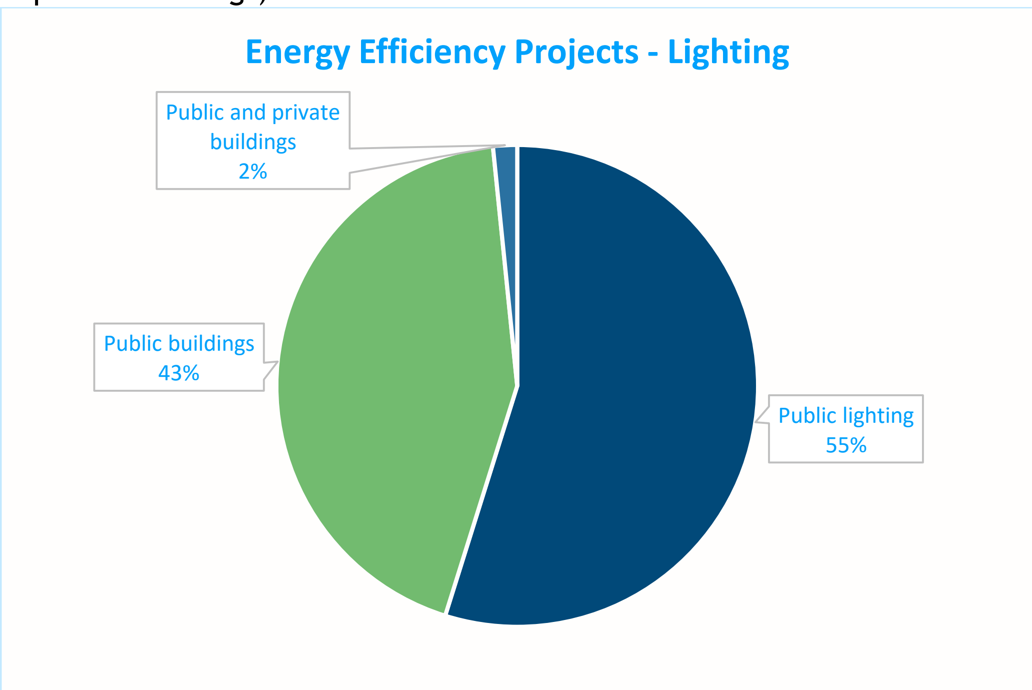

Figure 5 Main initiatives in the application area of lighting – Energy Efficiency projects emerged from the survey

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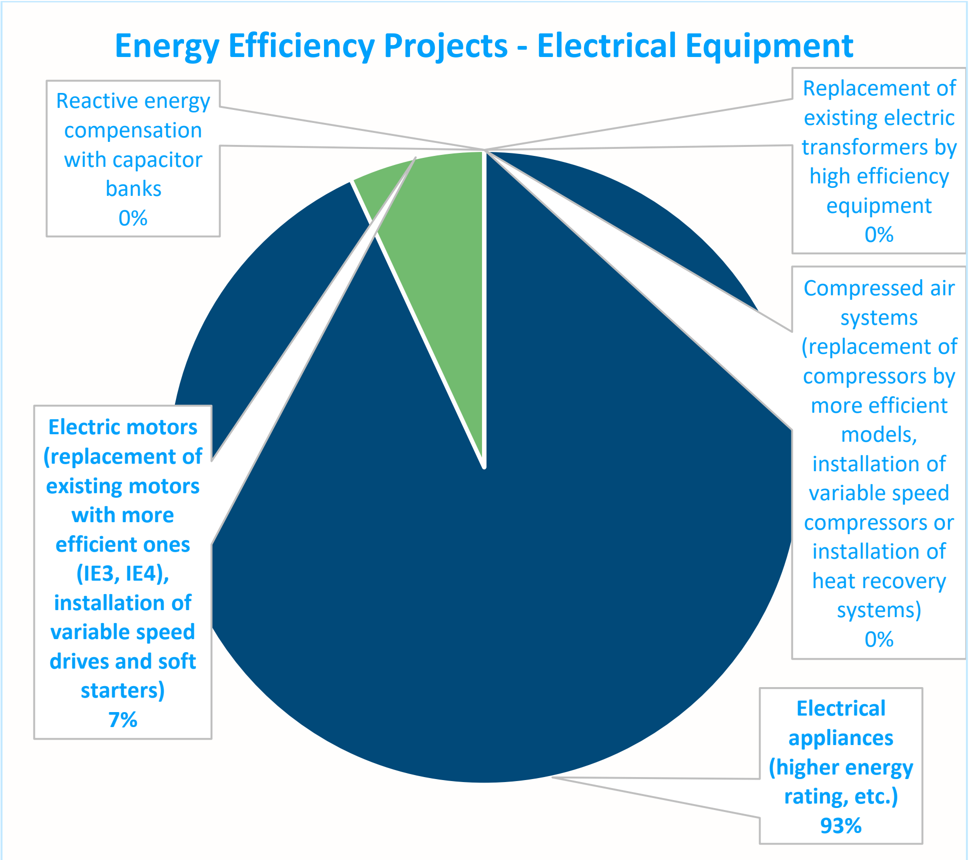

Figure 6 Main technological solutions in the application area of Electrical Equipment Upgrading - Energy Efficiency projects emerged from the survey

In the application area related to electrical equipment upgrading, it is interesting to observe that mostly initiatives are directed to facilitate the substitution of electrical appliances with more energetically efficient ones.

2.2 Renewable Energy related Projects – Survey Analysis

Coherently to what already emerged from the answers received in Energy Efficiency related projects (Paragraph 2.1), the main applications, when **Renewable Energy** projects have been analyzed from the survey, are related to electricity production aspects.
It is interesting to observe that only 4 projects of the ones present in the survey at the moment of the analysis involve the use of CHP plants and technologies:

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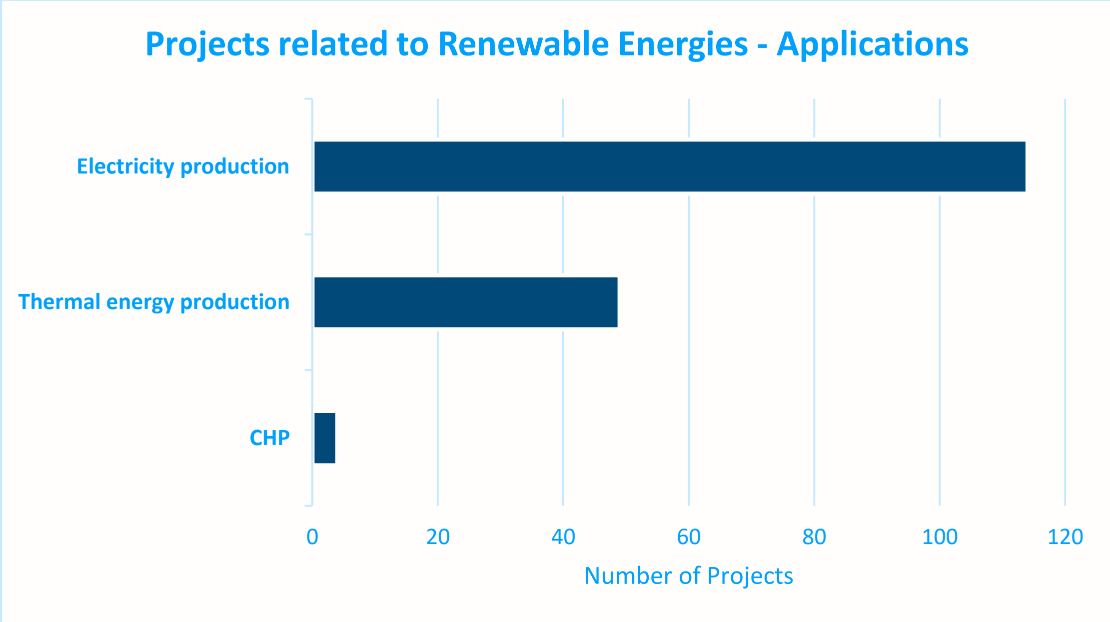

Figure 7 Application areas in renewable energies related projects emerged from the survey

When considering renewable electricity production, main adopted technologies seem to be related to solar (thermal and/or photovoltaic). Some technological solutions regard the exploitation of wind, hydro-electric power or marine (waves).

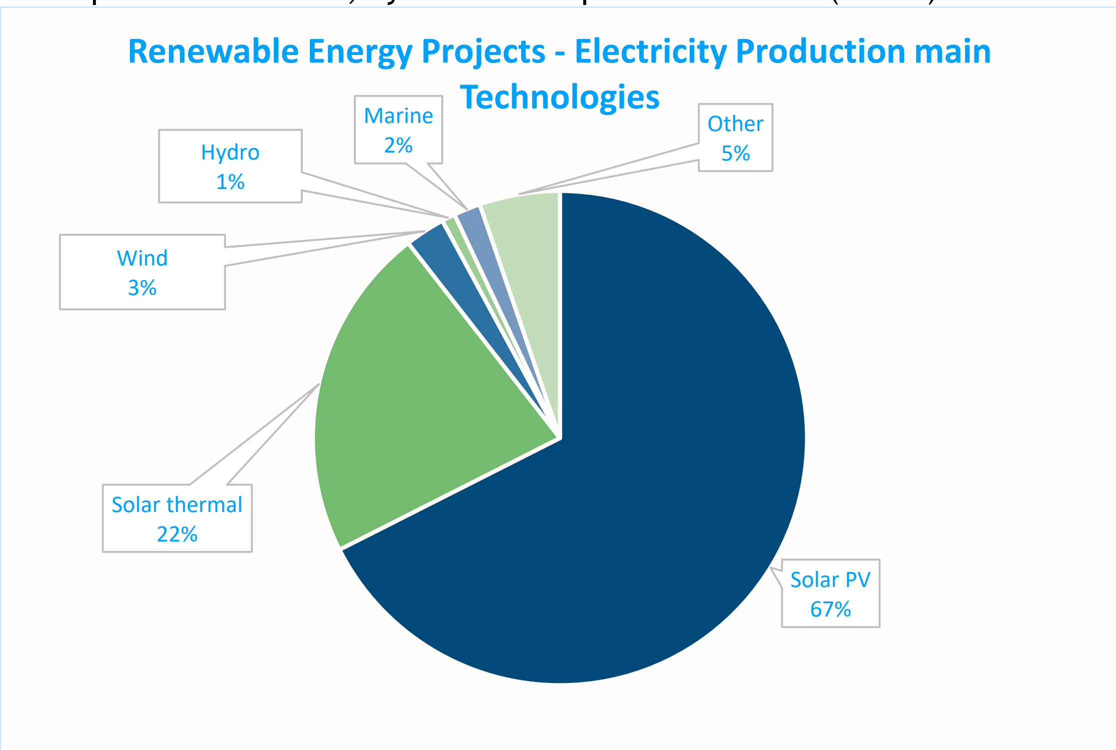

Figure 8 Main technologies in the application area of electricity production - Renewable Energy projects emerged from the survey

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When considering projects related to thermal energy production it is interesting to observe that almost no adopted solutions referred to biomass or biogas. Solar thermal and geothermal (where it can be applied) appear to be the most adopted technological solutions for the renewable thermal energy production:

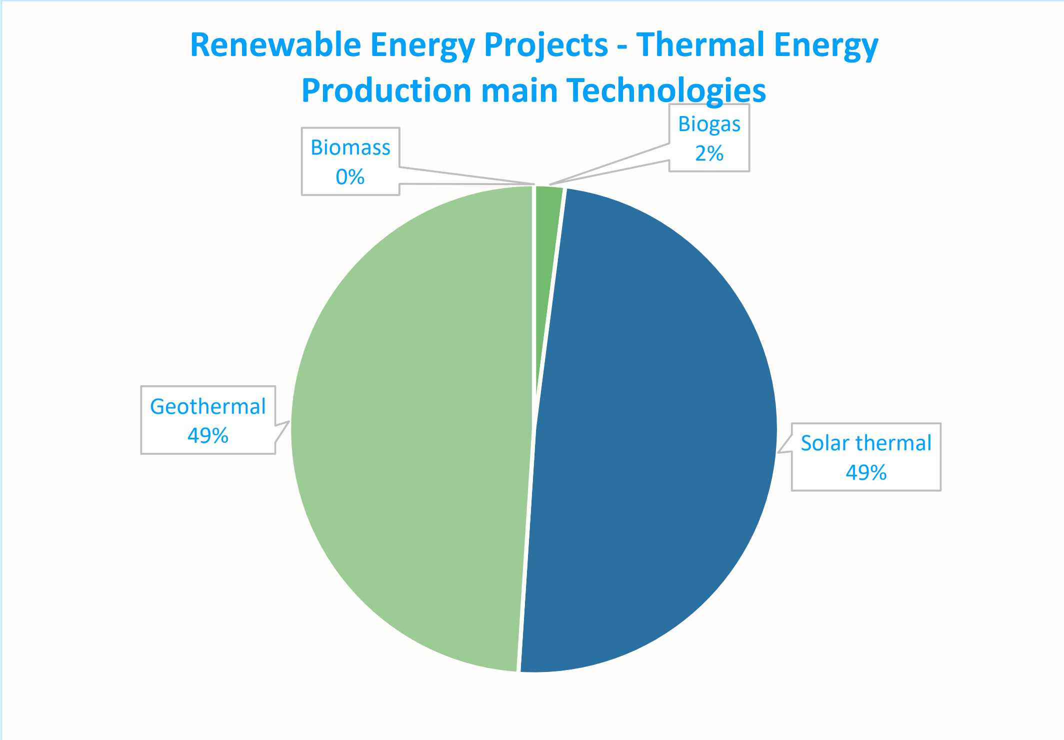

Figure 9 Main technologies in the application area of thermal energy production – Renewable Energy projects emerged from the survey

2.3 Sustainable Mobility related Projects – Survey Analysis

In the field of Projects developed for a **Sustainable Mobility**, initiatives are mainly oriented to the acquisition of low-carbon vehicles and, consequently, the installation of charging infrastructures (electric vehicles).

A minor quote of projects is focused on the development of urban level measures, such as:

- vehicle sharing platforms
- installation of bike-sharing systems

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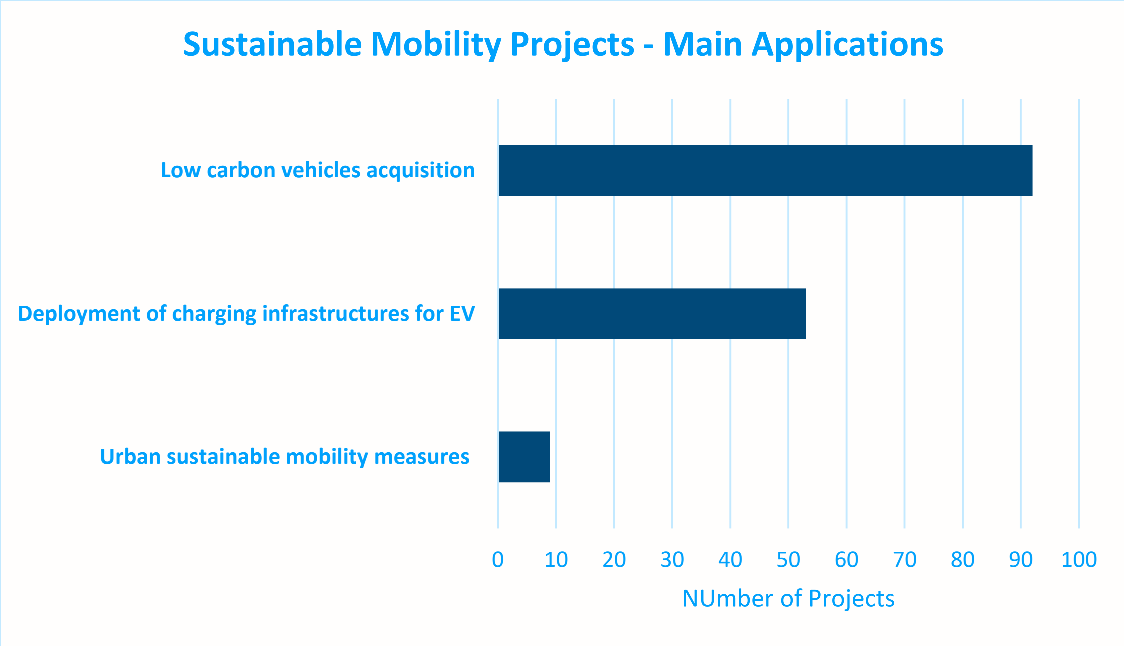

Figure 10 Application areas in sustainable mobility related projects emerged from the survey

Following (Figure 11) is the percentage sharing of initiatives in the application area of low carbon vehicles acquisition, that involve mostly the upgrade of the public asset of the islands; municipal fleet renovation and/or acquisition of electric vehicles for public transportation. Minor but significative percentage of projects targeted the private sector through initiatives aimed at facilitating the acquisition of electric mobility solutions:

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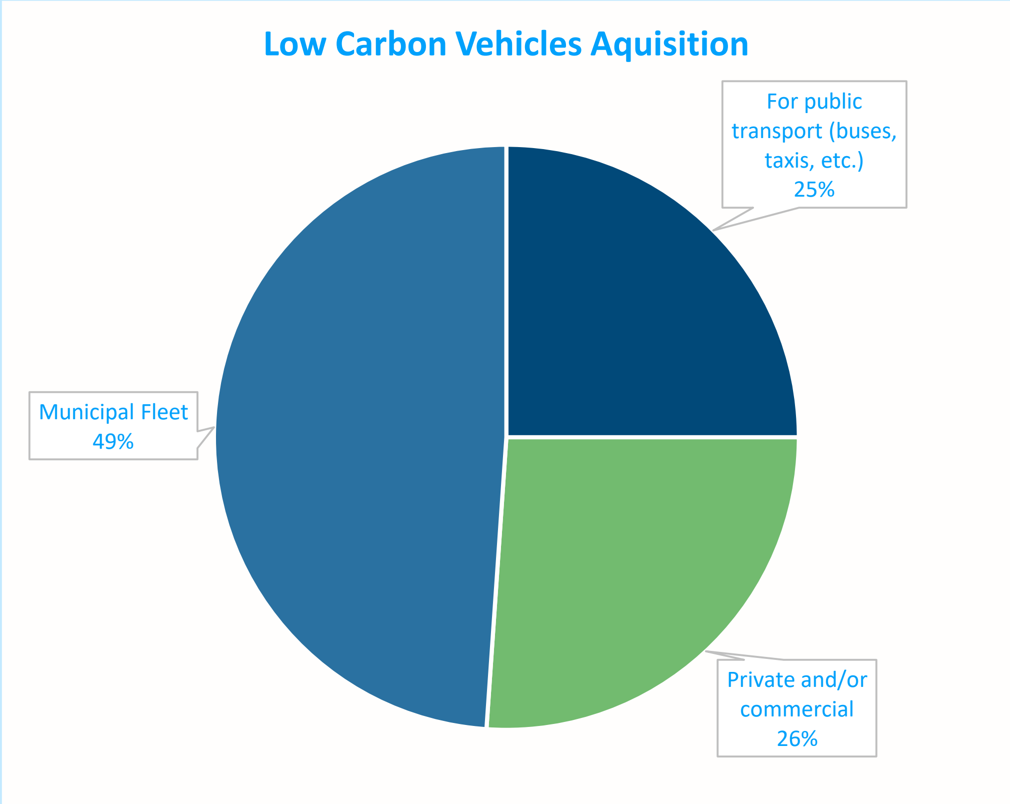

Figure 11 Main initiatives in the application area of low carbon vehicles acquisition – Sustainable mobility projects emerged from the survey

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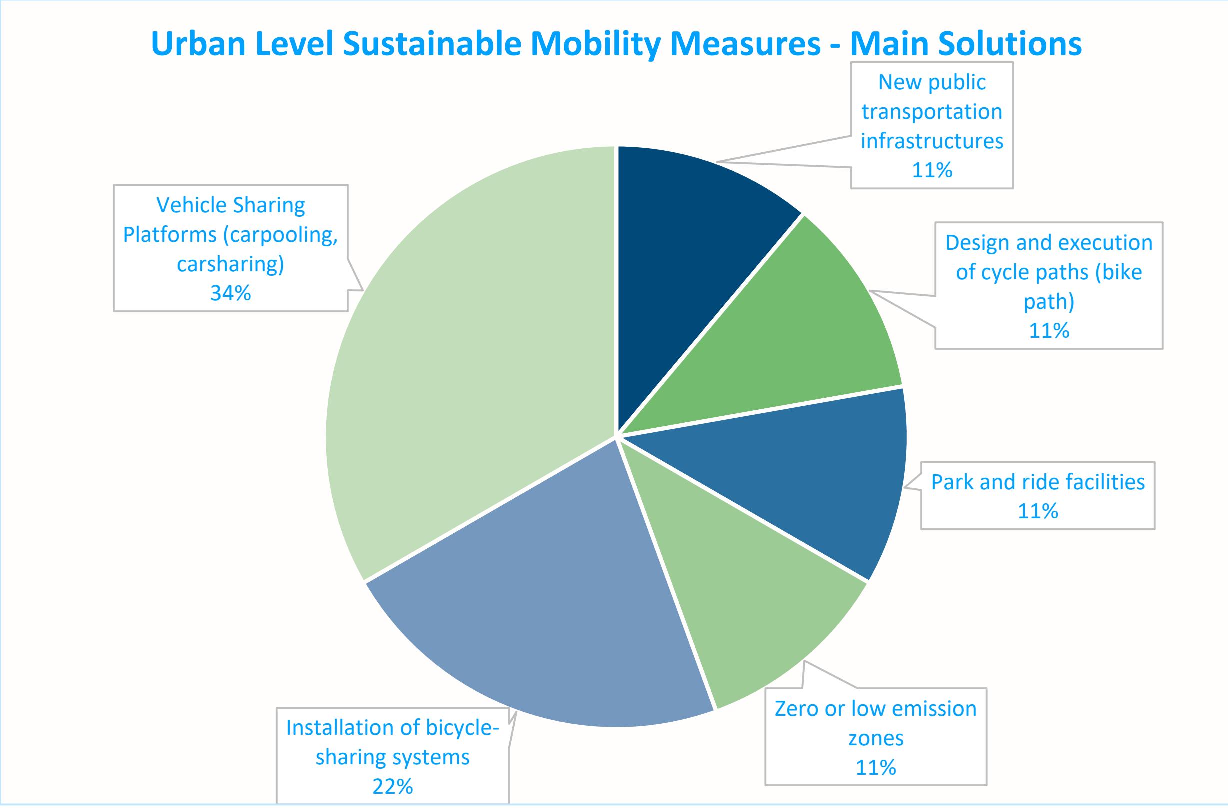

Figure 12 Main initiatives in the application area of urban level sustainable mobility measures - Sustainable mobility projects emerged from the survey

Even if in less percentage it is interesting to report the main initiatives practiced from the islands at urbanistic level and exploiting internet and social media communication technologies. Hence, the development, financing and facilitation of vehicle sharing platforms use (both car and bikes), redesign of bike paths, construction of park and ride facilities and designation of zero or low emission zones.

2.4 Energy management related Projects – Survey Analysis

Energy Management projects are equally distributed among **facility monitoring/management** and **energy storage** (Figure 13).

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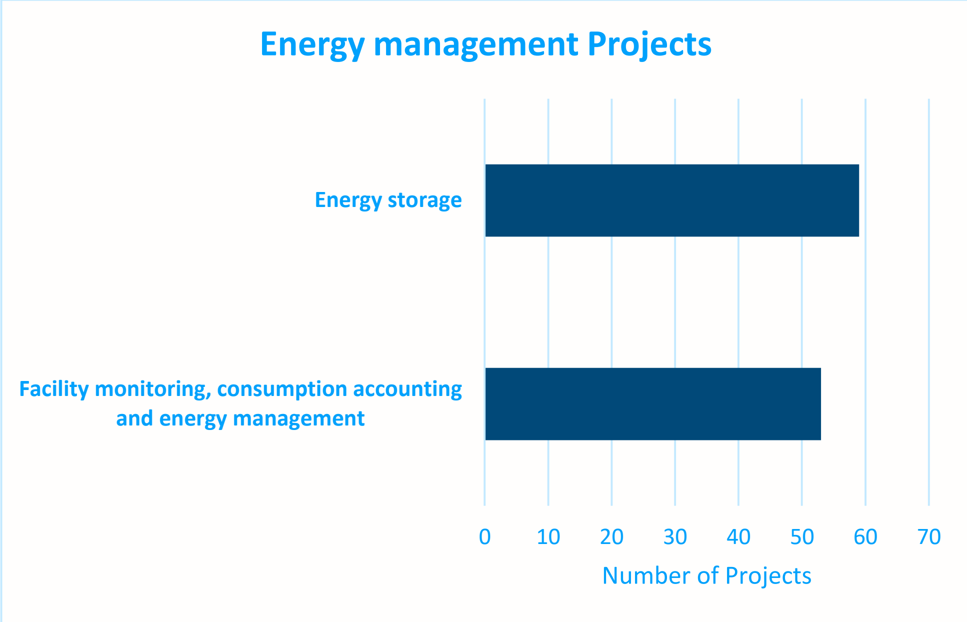

Figure 13 Application areas in energy management related projects emerged from the survey

In the energy storage domain, **batteries** represent the most applied technological solution (Figure 14):

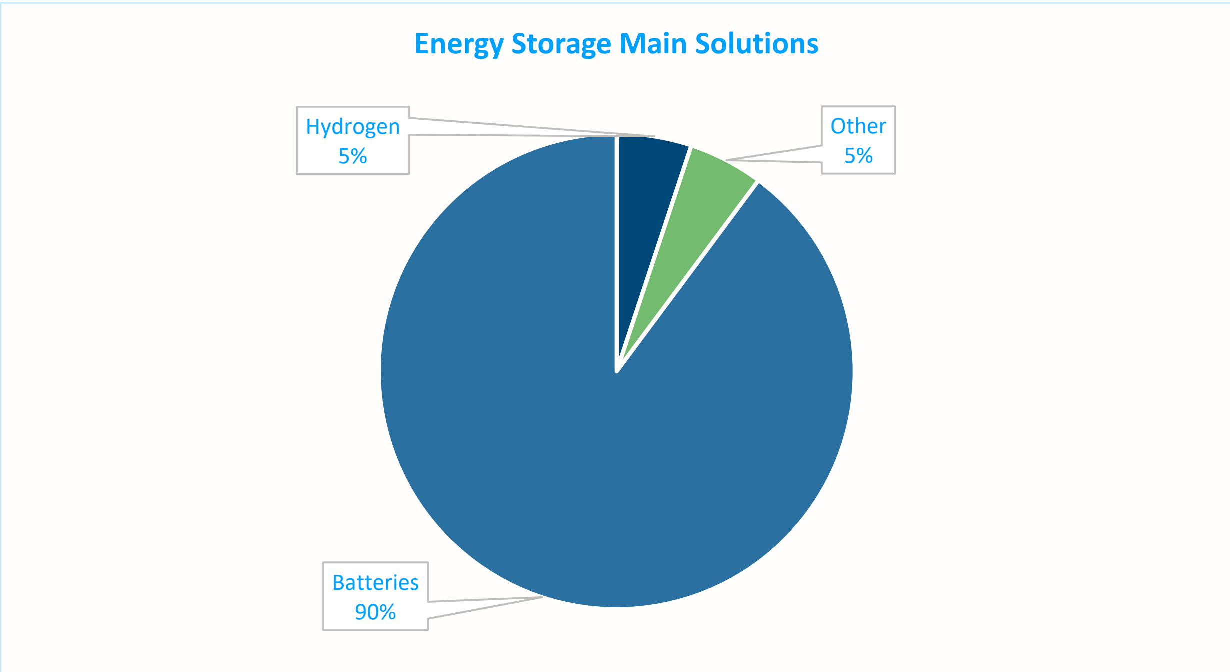

Figure 14 Main technologies in the application area of energy storage solutions - Energy Management projects emerged from the survey

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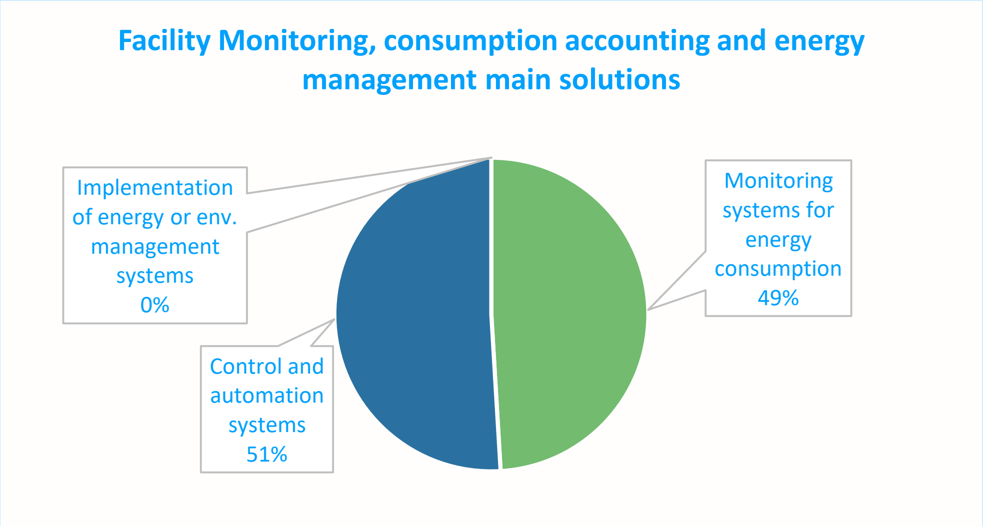

Figure 15 Main technologies in the application area of facility monitoring, consumption accounting and energy management solutions - Energy Management projects emerged from the survey

2.5 Considerations emerged from the analysis of the answers to the islands technology survey

The analysis of the results of the technology survey allowed us to define technology clusters, that can be used to group technologies according to main areas of intervention or application. The subdivision that has been proposed and from which the structure of the deliverable derives is:

- Renewable electric generation
- Thermal energy renewable technologies
- Electric mobility
- Upgrade/Efficiency of local public assets
- Building retrofitting
- Storage technologies
- Low carbon Heat&Cooling Technologies

Each technology cluster has been analyzed depicting main technologies at the state of art and trying to define, through a SWOT analysis, elements of intrinsic strength, together with opportunities that can help the application on specifically dedicated projects in islands.

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3 Renewable electric generation

3.1 Marine technologies

3.1.1 Marine Technologies - Technology scouting[1,2]

Following is reported a brief scenario analysis describing patent literature trend data related to the investigated technology; i.e. tide or wave power plants and the utilization of wave or tide energy to generate electricity.
The data have been extracted through the access to a database of patent literature (Derwent innovation[3]) and the utilization of specific search queries, including IPC codes in the case of patent searches. The time interval ranges from 2010 to date, even if, considering that patent applications are kept unpublished for a period of about 18 months at least, data related to 2020 are not reported in the graphs; their number can indeed be strongly influenced and underestimated due to the explained reasons.

Table 1 Search Query – Marine Wave Energy Electric Generation Technologies

Search Query - Marine Wave Energy Electric Generation Technologies
IPC=((C01B003302 OR C01B0033021 OR C01B0033023 OR C01B0033025 OR C01B0033027 OR C01B0033029 OR C01B003303 OR C01B0033031 OR C01B0033033 OR C01B0033035 OR C01B0033037 OR C01B0033039) OR (C23C001414 OR C23C001416 OR C23C001418 OR C23C001420) OR (C23C001624) OR (C30B002906) OR (F21L0004) OR (F21S000903) OR (G05F000167) OR (H01G000920) OR (H01L0025) OR (H01L0027142) OR (H01L0031) OR (H01M0014) OR (H02J000735) OR (H02S0010))

The number of inventions extracted from the database and related to the investigated technology amounts to about 13000, when considering publications started from 2010. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:

[1] "A review of the technologies for wave energy extraction"; E. Rusu and F. Onea; Clean Energy, 2018, Vol. 2, No. 1, 10–19
[2] Wave Energy Technology Brief; IRENA 2014
[3] https://www.derwentinnovation.com/

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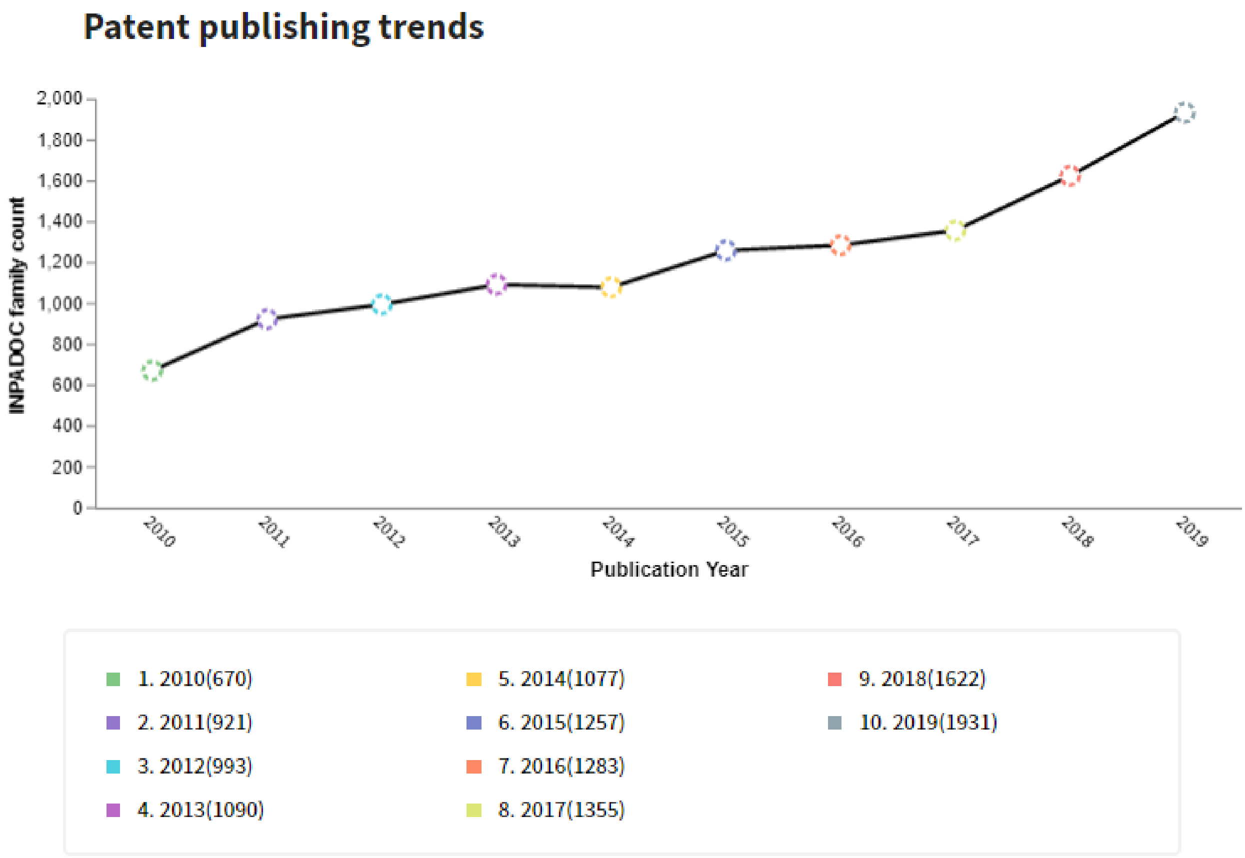

Figure 16 Marine Technologies - Trend of Published Patent Documents (INPADOC families) - (2010-2019)

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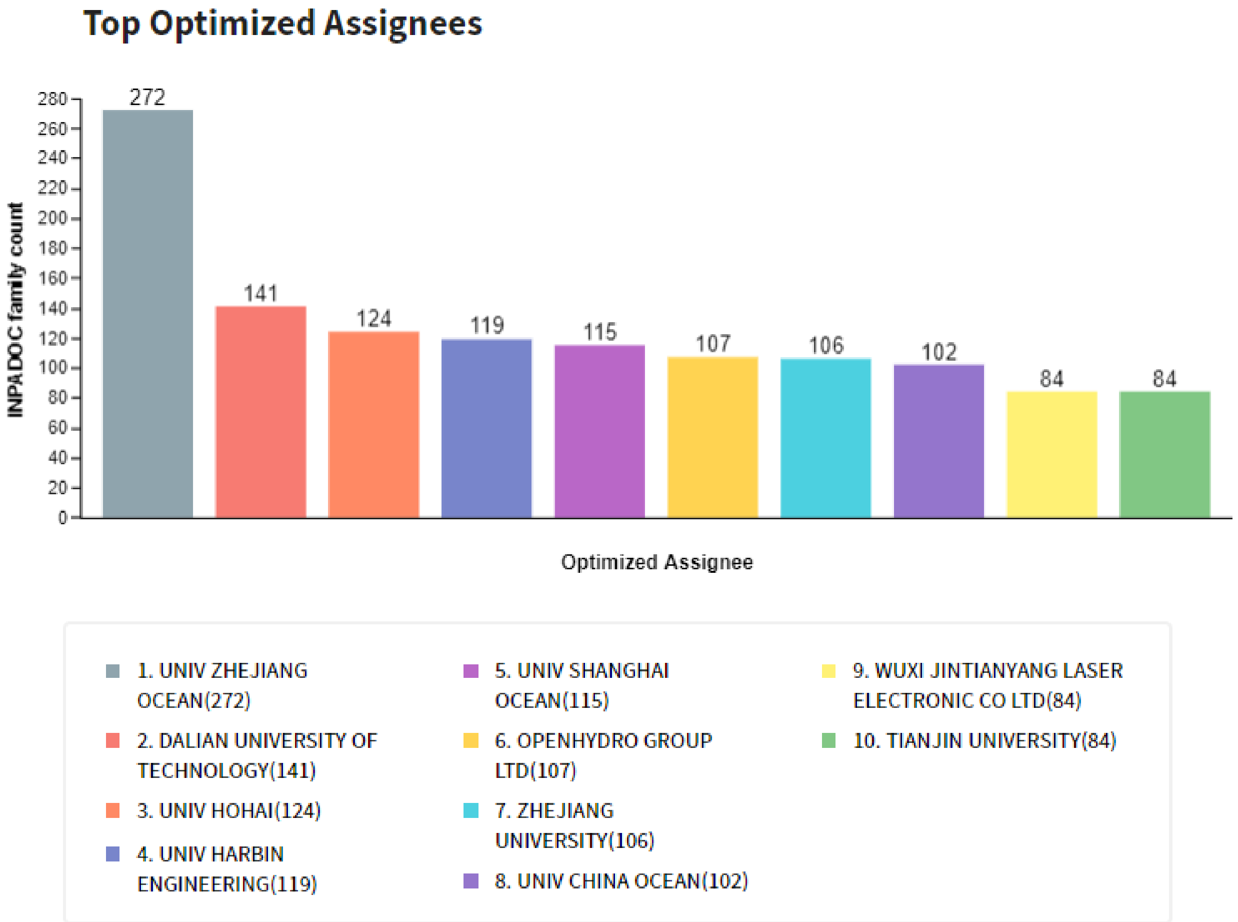

Figure 17 Marine Technologies – Main Assignees of Published Patents (2010-2019)

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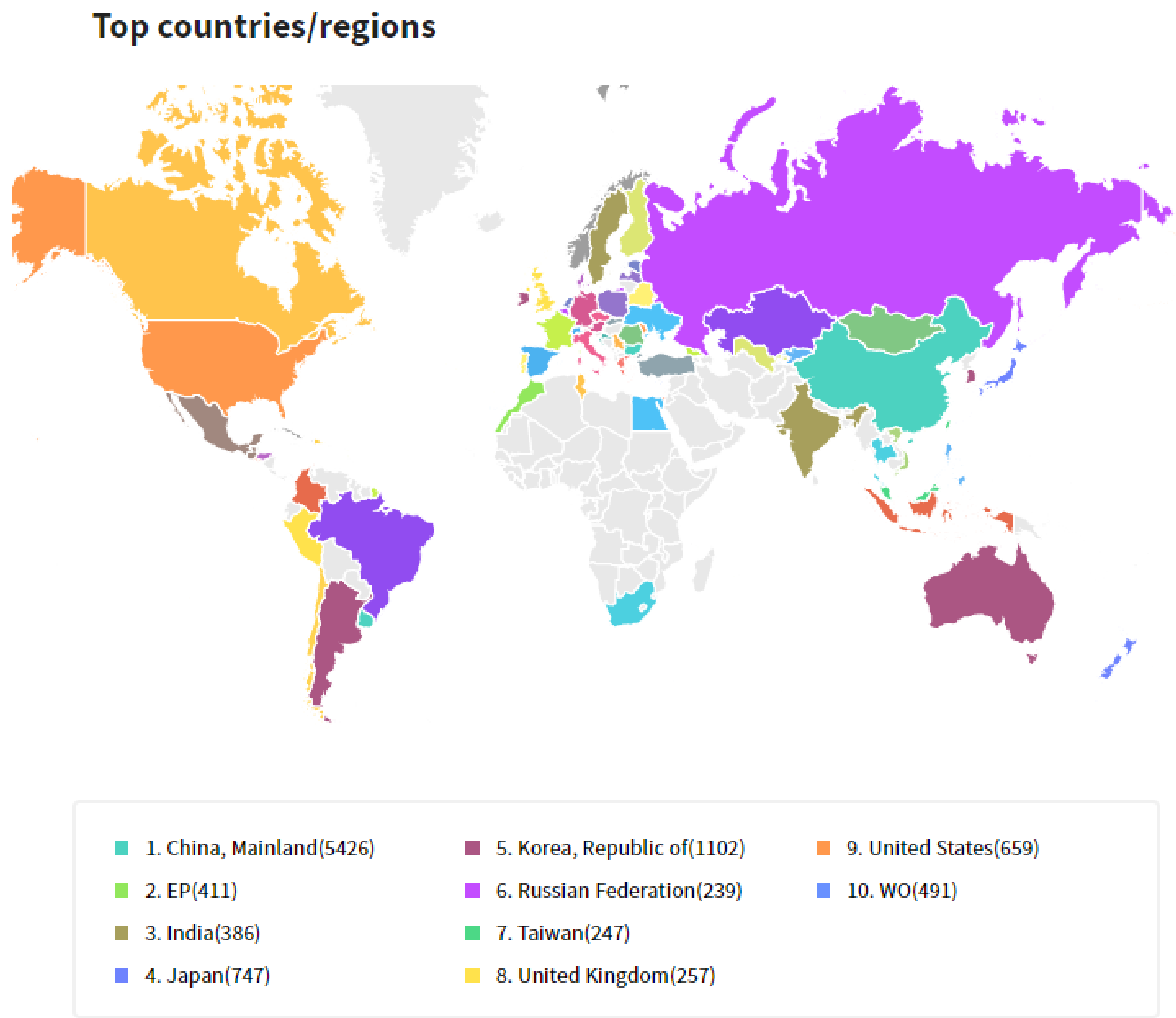

Figure 18 marine Technologies - Main Country Codes (2010-2019)

Patent publications have increased steadily in the analyzed time interval (obviously the number of patents in 2019 can be underestimated due to the time interval of latency before a patent can be published), showing a strong interest to invest in marine technologies; China, Republic of Korea, United States and Japan are the main geographical areas where patents have been published.

Marine energy converter technologies are still in a stage of development, even if companies are thoroughly investing economic resources to introduce innovations in this field. When considering wave energy there are two components that can be extracted: potential energy (where the water is forced against gravity from the wave trough and crests) and the kinetic energy component (the water oscillating velocity). It is important to design a structure that can efficiently capture and harvest the energy transmitted by the waves. Moreover the structure must be able to survive the marine environment (storm events). One means to convert the wave energy into mechanical energy is by using a generator that is fixed (on the sea bottom or shoreline) with parts of this system in motion. During recent decades, floating systems were introduced that are capable of being deployed offshore. The systems can be designed and targeted to take advantage of both potential and kinetic energy, individually or at the same time.

From a technology classification point of view, there are three main categories of wave energy converters:

- oscillating water columns that use trapped air pockets in a water column to drive a turbine;
- oscillating body converters that are floating or submerged devices using the wave motion (up/down, forwards/ backwards, side to side) to generate electricity; and
- overtopping converters that use reservoirs to create a head and subsequently drive turbines.

According to IRENA report [1], there are hundreds of pilot projects around the world, only a few at a commercial level, with the demonstration of 10 MW wave energy farms as a key prove for success of this technology.

Systems may be fixed, submerged or floating. The systems can be used as independent generators or as part of breakwaters or harbor infrastructure. **Most of the systems are still in the R&D stage, and the rated capacity may vary from 15 kW to 5900 kW**; some point absorbers appear underrated and they could be developed into wave farms in the future. In the following figure (IRENA Technology Brief; 2014) is reported an overview of the wave energy converter technologies:

Technology	System	Principle
Oscillating water column	Fixed	Isolated; in breakwaters; nearshore
	Floating	—
Oscillating bodies	Fixed-shoreline	—
	Floating	Translation (heave)
		Rotation
	Submerged	Translation (heave)
		Rotation
Overtopping	Fixed	Shoreline
	Floating	—

Figure 19 Main wave energy converter technologies, systems and principles (IRENA; 2014)

While in the following figure[4,5] are reported main features (dimensions, companies and devices involved, energy generation capacity, project advancement) of some commercial or demonstration wave energy converters:

[4] Rusu E, Onea F. Estimation of the wave energy conversion efficiency in the Atlantic Ocean close to the European islands. Renew Energy 2016; 85:687–703.

[5] Rusu L, Onea F. The performances of some state of the art wave energy converters in locations with the worldwide highest wave power. Renew Sustain Energy Rev 2017; 75:1348–62.

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Category	Device	Dimensions	Capacity (kW)	Projects to Date
Point absorber	Pontoon Power Converter (PPC)	80 m	3619	R&D phase
	Ocean Energy buoy (OE)	50 m	2880	R&D phase (1:4 scale model)
	Wavebob	20 m	1000	R&D phase (1:4 scale model)
	CETO	7 m	260	Garden Island, Western Australia Wave Hub, Cornwall, UK Pre-consented (3 MW each project)
	Seabased AB	3 m	15	Sotenäs, Sweden Pre-consented, 10-MW demonstration plant
Attenuator	Sea Power	16.75 m	3587	Galway Bay, Ireland, test site
	Wave Star	70 m	2709	Hanstholm, Denmark (1:2 scale model, 600-kW machine)
	Pelamis	150 m	750	Aguçadoura, Portugal (2.25-MW project) Company – Financial problems
	Oceantec	52 m	500	Sea trials – 1:4 scale model
Terminator	Wave Dragon	–	5900	Nissum Bredning, Denmark, prototype testing

Figure 20 Main characteristics of some commercial available wave energy converters [4,5]

Geographical aspects influencing the exploitation of Wave Energy Converters[1]

The best wave conditions for exploitation are in medium-high latitudes and deep waters (greater than 40 m deep), since wave energy is found to reach power densities of 60-70 kW/m in those locations. For example, countries like Australia, Chile, Ireland, New Zealand, South Africa, the UK and the US have excellent wave sources with average power densities of 40-60 kW/m. In order to get an hint on which geographical areas can be more profitable involved in wave energy projects, it can help to consider the fact that from the energy aspect, the most attractive areas are found between 30–60° in both hemispheres, with the total theoretical energy potential around 32000 TWh/yr[6].

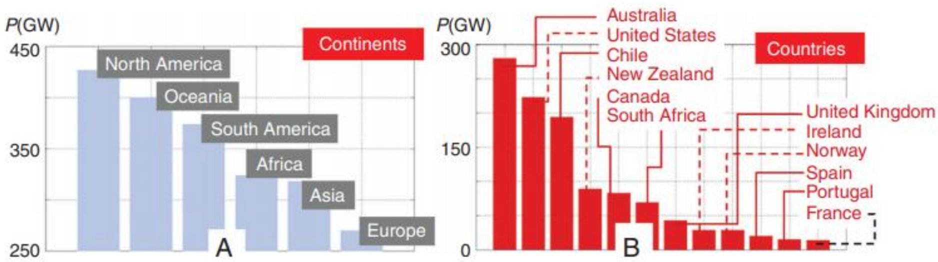

Figure 21 Total wave power: annual means estimated for (a) continents and (b) countries [1]

Figure 21 reports the total wave power distribution (expressed in gigawatts) for various coastal environments based on the National Oceanic and Atmospheric Administration's WaveWatch III data[7]. As can be seen, wave power is more consistent around Australia, followed by the USA and Chile, while Portugal and France show much lower values. A possible explanation for these results may be that, for this work, the entire coastal area

[6] Lewis A, Estefen S, Huckerby J, et al. Ocean energy. In: The IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge/New York: Cambridge University Press, 2011

[7] Gunn K, Stock-Williams C. Quantifying the global wave power resource. Renew Energy 2012; 44:296–304

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was considered, which in the case of Australia or North America is much greater compared to other regions such as Portugal.

The Opportunity of off-shore Wind-Wave Hybrid Farms[1]

An opportunity to accelerate the development of off-shore wave energy farms characterized by bigger dimensions can derive from the development that the off-shore wind industry is gaining in the last years, especially in Europe, where, in 2020 is expected a total capacity of about 25 GW.
This technology, that is seeing a significant increase in Europe, can be even regarded as a **potential competitor respect to the wave energy.**
The attractiveness of such projects is given by the mixed energy output defined by a higher density power and a smooth integration into the grid network, which will be less influenced by the variability of a single resource. Moreover, if the generators share the same infrastructure, it will be possible to cut the initial installation cost, especially in the case of the wave systems. **Consequently, it could be possible to accelerate the WEC's transition from the R&D stage to a full operational wave farm.**

Consideration about the cost factors

Because there are no large-scale wave farms, it is difficult to predict the future of this industry, although **opportunities are expanding as the technology evolves. The successful development of wave technology in the European wave market could generate 188 GW (10%) of Europe's electricity needs by 2050.** However, **for this to happen would mean the successful development and operation of new wave generation systems planned for 2022-2040**. A promising option to cut costs is the combination of WECs with existing offshore wind parks by sharing the same infrastructure.
Since a **renewable marine project** is designed to be a sustainable project, it is important to understand its impact on the local marine ecosystem. In general, this **seems to be beneficial for the fish population**, since there will be exclusion zones prohibiting fishing around the generators. In addition, because the wave energy converters will work like a breakwater, they will calm the sea, thus providing a nesting area for local bird species.

In comparison to other sources of renewable energy, wave energy is still too expensive. However, the potential of wave energy is the best option to accelerate the use of wave technology. Research on reducing the costs is a key element in encouraging the development of wave energy. In general, it is estimated that the main costs of a wave project are related to initial investments (34.68%), operation and maintenance (O&M; 40.19%), replacement (24.81%) and preoperating costs/decommissioning (0.33%), respectively.
Examples of wave energy converters prices are Wave Dragon (rated power 7000 kW), €14238 652/unit; Pelamis (750 kW), €21188 470/unit; and AquaBuoy (250 kW), €169 507/unit[8].

[8] Astariz S, Iglesias G. Enhancing wave energy competitiveness through co-located wind and wave energy farms. A review on the shadow effect. Energies 2015; 8:7344–66.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266

When comparing to other renewable energy technologies, we can collect the following information:

- for onshore wind industry analysts estimated that the LCOE may have values in the range of 40–115 €/MWh, which correspond to capacity factors of 15–46%. (Europe has an average value of 80 €/MWh compared to the USA, where an average value of 83 €/MWh is reported).
- The offshore wind industry operating in the Western Europe has an average LCOE of 218 €/MWh corresponding to a capacity factor of 32–42%.
- In the case of solar PV, we expect LCOE values in the range 67–372 €/MWh obtained for capacity factors of 11–21%.
- In terms of geothermal systems, a maximum LCOE of 234 €/MWh may cover a capacity factor of 95%.
- For hydroelectricity, a small system can be expected to obtain values in the range of 16–266 €/MWh compared to a larger system where the values are 20–256 €/MWh.

The tidal and wave energy sectors reveal similar trends, being divided between high-, medium and low-cost scenarios. The following numbers give an estimated cost, from high to low, of generating wave energy:

- **high cost, €14/MW (CAPEX), €127130/MW/yr (OPEX), 25% (capacity factor), €897/MWh (LCOE);**
- **medium cost, €7.44/MW, €127130/MW/yr, 30%, €420/MWh;**
- **low cost, €4.64/MW, €127130/MW/yr, 35%, €241/MWh**[9].

The information on some of the commercially available technologies and pilot or demonstrating projects are reported in the following paragraphs, in order to depict the situation in terms of main players involved (probable stakeholders in future islands related projects) and the level of development of the technology (TRL).

[9] World Energy Council. World Energy Perspective: Cost of Energy Technologies. Buntingford, England: Regency House, 2013

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3.1.1.1 EcoWave Power

Eco Wave Power is a Swedish company that developed a technology for the wave energy exploitation characterized by the fact that is installed on-shore, with all the advantages of such installation respect to an off-shore installation, in terms of both economic and environmental aspects. It holds 12 Israeli Patents and Patents Pending as well as an International PCT. In the following table a brief description of the company, the technology key features and active projects are reported.

Table 2 Eco Wave Power

<table>
<tr><th colspan="2">Eco Wave Power</th></tr>
<tr><td></td><td>EWPG Holding AB (publ) (“Eco Wave Power” or the ”Company“) is a Swedish company, founded in Tel Aviv, Israel, in 2011, that has developed a patented, smart and cost-efficient technology for turning ocean and sea waves into green electricity. Eco Wave Power is the only wave energy company in the world, to own and operate a wave energy array, which is connected to the grid in accordance with a Power Purchase Agreement (PPA)</td></tr>
<tr><td colspan="2">The development of the Eco Wave Power technology began at the Institute of Hydromechanics in Kiev in 2011, with wave tank testing. In December 2011, Eco Wave Power concluded its wave tank testing and received a protocol from the Hydro Mechanic Institute, which stated as follows:

“All the floaters of Eco Wave Power Company have proved their workability… According to the results of the tests, we have reached a decision to recommend continuing the development of the energy generation system that is based on such principles and enlarge the model to larger sizes.”

In April 2012, Eco Wave Power installed the company’s first real conditions power plant on two breakwaters in the Black Sea for the purpose of data collection and stress testing of its unique technology. The Black Sea was chosen to conduct the system’s initial real-condition installation, because it is known for its sudden storms (this is how it got its name), and it was important for EWP to test its technology in severely stormy conditions to prove that its power stations could withstand such storms.

The power plant had combined two different floater shapes; the Wave Clapper and the Power Wing. The system operated in different wave regimes for a significant period of time, and then was shipped to Israel and installed in Jaffa Port, where it is operational until today.

The company nowadays operates several projects and has an extensive projects pipe line, to be gradually executed.</td></tr>
</table>

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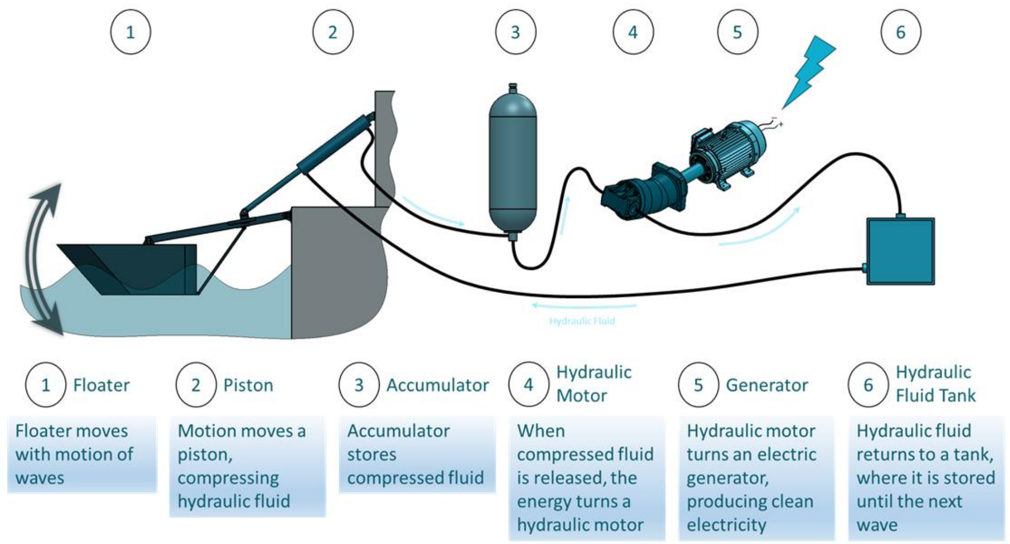

The floaters draw energy from incoming waves by converting the rising and falling motion of the waves into an clean energy generation process. More precisely, the movement of the floaters compresses and decompresses hydraulic pistons which transmit bio-degradable hydraulic fluid into land located accumulators. In the accumulators, at a pressure is being built. This pressure rotates a hydraulic motor, which rotates the generator, and then the electricity is transferred into the grid, via an inverter.

The fluid, after decompression, flows back into the hydraulic fluid tank, where it is then re-used by the pistons, thus creating a closed circular system.

The system commences production of electricity from wave heights of 0.5 meters.

The whole operation of the system is controlled and monitored by a smart automation system. Also, when the waves are too high for the system to handle the floaters automatically rise above the water level and stay in the upward position until the storm passes. Once the storm passes, the floaters return to operation mode.

Key features:

- ✓ Easy to build and operate, due to its' accessible location on land. In addition, low costs of maintenance and connection to the grid, due to proximity to grid connection points.
- ✓ Fully modular and scalable.
- ✓ Cost-efficient – construction and production costs per KWh are highly competitive, and the forecasted levelized cost for energy (LCOE) for commercial scale installation will be around EUR 42 per MWh (SEK 0.45/KWh). The Company has several patents in place and additional applications pending, putting strong focus on IP development and protection.
- ✓ Fully insurable – current damage protection coverage provided by global reputable insurance companies.
- ✓ No adverse environmental impact – due to the connection of the system to mostly existent man-made structures. Already existing structures (e.g. pier, jetties and breakwaters) are becoming a source of clean electricity.

Active Projects

In 2014, Eco Wave Power signed a 5MW PPA (Power Purchase Agreement) with the Government of Gibraltar and the Gibraltar Electricity Authority.

The construction was co-funded by The EU Regional Development Fund as well as private investments groups.

In May, 2016, EWP and the Government of Gibraltar held an official opening ceremony of the newly constructed wave energy power station on the east side of Gibraltar.

Now, at a former World War II Ammunition Jetty, sits the initial 100KW of a 5MW power station.

EWP's Gibraltar project is our first grid connected project and a significant step towards the the commercialisation of the EWP technology. Today, the station is the only grid-connected wave energy array in the world, operating through a PPA (Power Purchase Agreement).

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Contacts
Web site: https://www.ecowavepower.com/
Address: 7A Strandvägen, Stockholm, 11456, Sweden
Phone: +972-3-509-4017
E-mail: info@ecowavepower.com

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266

3.1.1.2 Orbital Marine[10]

Orbital Marine Power (formerly known as Scotrenewables Tidal Power) is an innovative Scottish engineering company (privately held employing 32 staff with offices in Orkney and Edinburgh). It has developed and commercializes a pioneering wave energy technology.

Orbital Marine Power's radical technology enables lower cost of tidal energy production through incorporating:

- Easy onsite accessibility to all major components and systems allowing low cost maintenance in parallel with ensuring high generator uptime.
- Optimization of turbine designs, simplified and modularised for low cost and high-volume manufacturing through existing supply chains.
- No heavy or precision onsite construction activities with Orbital turbines being manufactured in safe, controlled onshore facilities, shipyards and at quaysides.
- Offshore construction activities are familiar operations of installing moorings and cables with non-specialist, low cost vessels.
- Whole turbines can be easily towed and installed onsite using only low-cost vessels.
- Multiple turbines can be built into arrays exporting power down a single cable without the need for new underwater hub technology.

In the following table main information on company and innovative technology:

Table 3 Orbital Marine

Orbital Marine	
ORBITAL MARINE POWER	**Orbital Marine Power (formerly known as Scotrenewables Tidal Power) is an innovative Scottish engineering company (privately held employing 32 staff with offices in Orkney and Edinburgh). It has developed and commercializes a pioneering wave energy technology.**
SR 2000 In 2016, following over a decade of intensive research, development and scale model testing, Orbital Marine Power launched the full commercial scale SR2000 2MW, the world's most powerful tidal turbine, at the European Marine Energy Centre in Orkney. During the demonstration programme the SR2000 delivered multiple world-firsts including exporting over 3,250 MWh of electricity to the Orkney grid during a 12 month period – more power than the entire wave and tidal sector in Scotland had exported over the 12 years prior to the launch of the SR2000. Up until completion in September 2018, the SR2000 produced unrivalled performance whilst validating both the engineering and conceptual benefits of Orbital's technology.	

[10] https://orbitalmarine.com/company/about-orbital

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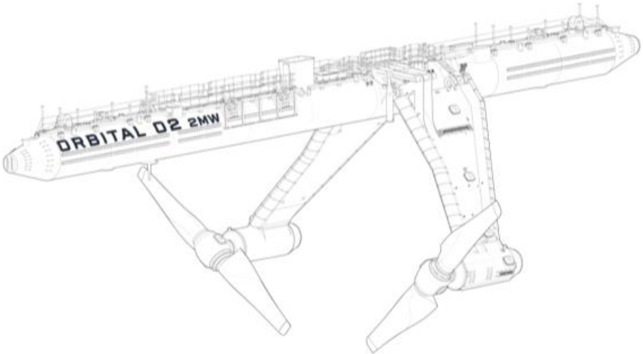
Orbital O2 2MW

The other technology developed by Otbital Marine has the following main characteristics:

- O2 is capable of powering more than 1,700 UK homes per year
- Two 1 MW turbines integrated into a single floating hull
- O2 rated power of 2MW is achieved at a flow speed of 2.5m/s
- Raised £7m in crowd funding debenture to support the build of the O2 turbine within 10 weeks (via London-based Abundance Investment platform)
- O2 project awarded a £3.4m grant from the Scottish Government (August 2019) from the £10m Saltire Tidal Energy Challenge Fund
- Over 600sq metre rotor area largest ever on a tidal turbine to date
- Effective rotor diameter: 20m
- Total swept area: 628.3 m2
- Nameplate generation: 2 X 1MW
- Maximum shaft power: 2.5MW
- Power and brake control: Variable pitch
- Export voltage: 11kV ac



The O2 will launch at The European Marine Energy Centre (EMEC)'s grid-connected tidal test site at the Fall of Warness, situated just west of the island of Eday - lying in a narrow channel between the Westray Firth and Stronsay Firth. Established in 2003, EMEC is best known as the world's leading facility for testing and validating wave and tidal energy devices in the sea. It is the first and only centre of its kind to provide developers of both wave and tidal energy converters – technologies that generate electricity by harnessing the power of waves and tidal streams – with purpose-built, accredited open-sea testing facilities.

Active Projects

Horizon 2020 FloTEC

The development and construction of the O2 is being facilitated by the European Union's Horizon 2020 research and innovation programme under the FloTEC (Floating Tidal Energy Commercialisation) project (Grant agreement No. 691916).

The FloTEC project supports a range of cost reduction innovations that will be incorporated on the O2 tidal turbine, complementary innovations in the areas of energy storage and mooring load reduction and wider commercialisation activities.

TIGER (Tidal Stream Industry Energiser Project)

The TIGER project will demonstrate that tidal stream energy is a maturing industry, capable of achieving an accelerated cost reduction pathway.

The project will build cross-border partnerships to develop new technologies, test and demonstrate up to 8 MW of new tidal capacity at a number of locations around the Channel region, and use the learning from this development to make a stronger, cost-effective case for tidal energy as part of the France/UK energy mix. The project is the largest ever to be approved not only by the France (Channel) England Programme but by any Interreg programme.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266

Timescale: 2019 – 2023 (47 months) Funder: Interreg France (Channel) England Programme Funding: ERDF funding € 29 million / Total project budget € 45. Million
Contacts
Web site: https://orbitalmarine.com/ **Address:** Edinburgh Office, Exchange Place 2, 5 Semple Street, Edinburgh, Scotland EH3 8BL **Phone: -** **E-mail: contact form at** https://orbitalmarine.com/news/contact

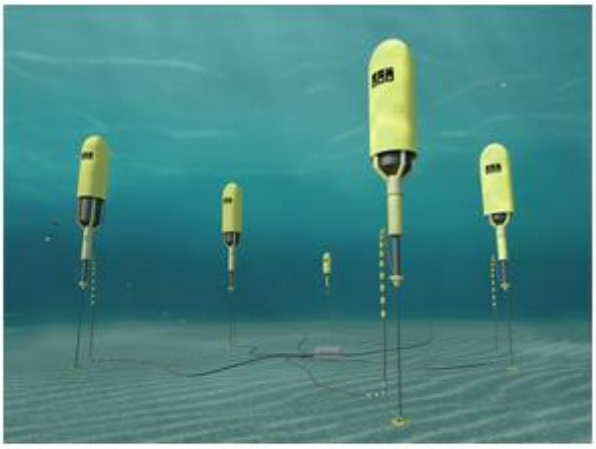
3.1.1.3 AWS Ocean Energy

AWS Ocean Energy Ltd. Is a UK company that creates and delivers marine energy; it offers offshore wave energy generator technologies.

Table 4 AWS Ocean Energy

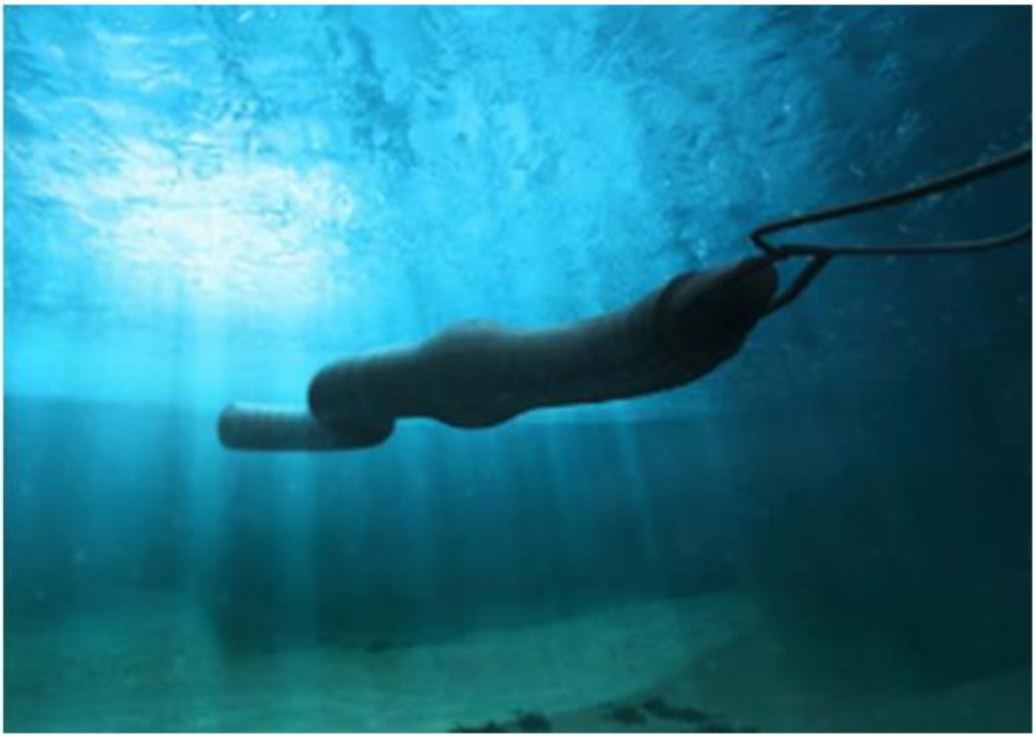
AWS Ocean Energy	
AWS	**AWS Ocean Energy and predecessor projects have been developing marine energy systems for over 20 years. They work with customers and development partners to produce solutions to offshore power needs from isolated power supplies for remote communities and aquaculture through to the multi-MW AWS-III utility-scale wave power generator.**
ARCHIMEDES WAVESWING SUBMERGED WAVE POWER BUOY – RELIABLE AND AFFORDABLE WAVE POWER SOLUTION The patented Archimedes Waveswing submerged wave power buoy is a unique device designed to provide reliable and affordable power for maritime communities and offshore applications. The Waveswing reacts to changes in sub-sea water pressure caused by passing waves and converts the resulting motion to electricity via a direct-drive generator. The system is suitable for deployment in water depths in excess of 25m and can be configured for ratings between 25kW and 250kW by selecting the appropriate scale. The technology was tested offshore Portugal in 2004 and narrowly missed a world first for delivery of offshore wave power to a national electricity grid, being beaten by Pelamis by some 6 weeks. Since that time, the Waveswing has been refined and developed to focus on customer needs in an emerging market. Key benefits of the Waveswing technology derive from its elegant and unique operating principle, its sub-sea location and the use of direct-drive technology. These combine to produce a system that is inherently survivable and reliable whilst providing best-in-class efficiency and cost and a minimal environmental foot-print.	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266




ELECTRIC EEL FLEXIBLE WAVE POWER ATTENUATOR

The Electric Eel™ wave power concept represents the next generation of wave power devices. It consists of a long elastic tube which is tethered below the surface of the sea. A passing wave causes a pressure or 'bulge' wave to propagate along the elastic tube. Power is extracted by smart electro-active polymer panels built into the sides of the tube. These panels are entirely flexible and produce an electric current when stretched. The Electric Eel™ represents an advance over other 'bulge wave' based devices in that it is capable of continuous power extraction along its length, thus avoiding the limits which would occur otherwise when the bulge wave grows too large. It is also capable of active control to tune to the incoming wave frequency by regulation of stiffness through control of the EAP electronics.They have completed the concept designs for this technology, have granted patents in a number of jurisdictions and are now seeking technology partners to advance to the next stage of development.

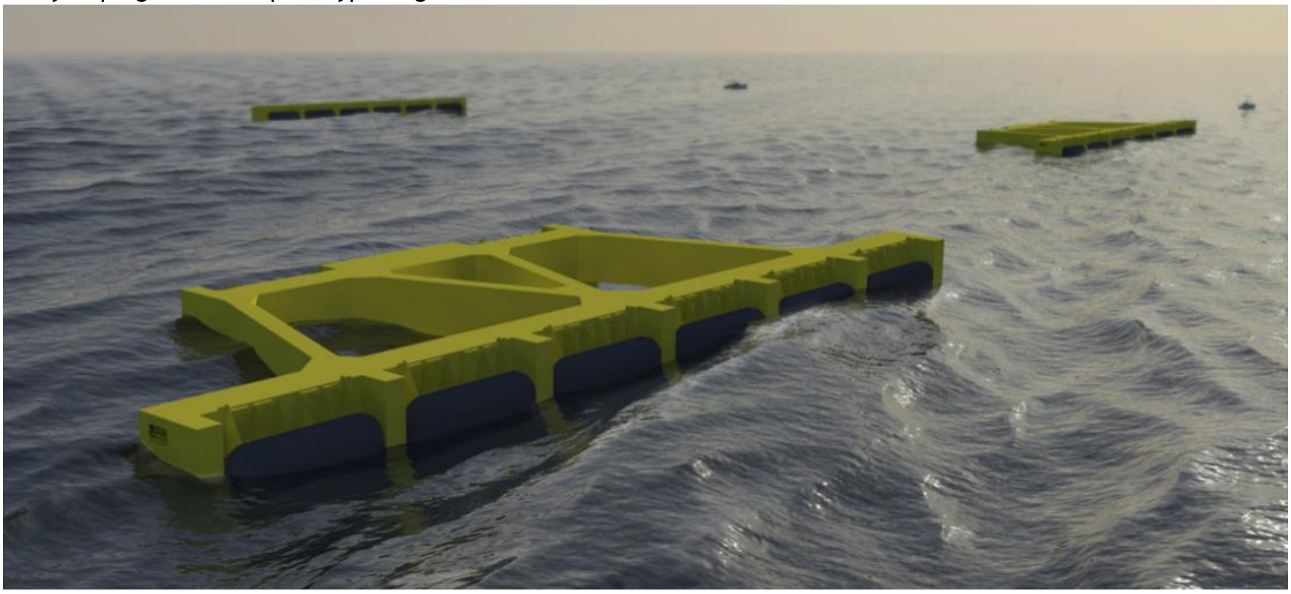


MULTI-CELL WAVE POWER GENERATION

The AWS-III is a multi-cell array of flexible membrane absorbers which covert wave power to pneumatic power through compression of air within each cell. The cells are inter-connected, thus allowing interchange of air between cells in anti-phase. Turbine-generator sets are provided to convert the pneumatic power to electricity. A typical device will comprise an array of 9 cells, each measuring around 16m wide by 8m deep, arranged around a catamaran structure. Such a device is capable of producing an average of 2.4 MW from a rough sea whilst having a structural steel weight of less than 3500 tonne. The AWS-III will be slack moored in water depths of around 100m using standard mooring spreads.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266

The AWS-III has a number of significant advantages for utility-scale offshore wave-power. The flexible absorbers are highly efficient and are the only moving part of the power-train exposed to the sea. The use of air as a transmission medium removes end-stop issues whilst the air turbines employed are reliable proven technology. The large hulls provide a stable and safe working environment to allow on-board maintenance of the turbines, generators and all ancillary systems to ensure high reliability. Transformers and switchgear are adequately housed on-board and again easily accessed for maintenance. The diaphragms are designed with maintenance in mind using a patented 'cassette' system to allow change-out at sea. AWS Ocean Energy has completed a rigorous programme of tank testing to establish the performance and survival conditions for the AWS-III, allowing us to complete a full FEED study for a prototype device. A half-scale cassette was built, deployed and tested at sea during 2014 and the technology is now ready to progress to full prototype stage.



Contacts

Web site: http://www.awsocean.com

Address: AWS Ocean Energy Ltd - Findhorn House - Dochfour Business Centre; Dochgarroch Inverness IV3 8GY

Phone: +44(0)1463 725 410

E-mail: info@awsocean.com

3.1.1.4 Pontoon Power AS

Pontoon Power AS is a Norwegian company, established in 2010. The company's primary purpose is to develop electric power production based on offshore wave power by means of our patent pending wave power converter, the Pontoon Power Converter (PPC).
The technology seems that have not been developed further the R&D phase. It has been however reported in order to give a picture of the concepts that are being designed in this energy sector.

Table 5 Pontoon Power AS

Pontoon Power AS

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Pontoon Power Harvesting wave energy on a large scale	**Pontoon Power AS is a Norwegian company, established in 2010. The company's primary purpose is to develop electric power production based on offshore wave power by means of our patent pending wave power converter, the Pontoon Power Converter (PPC).**

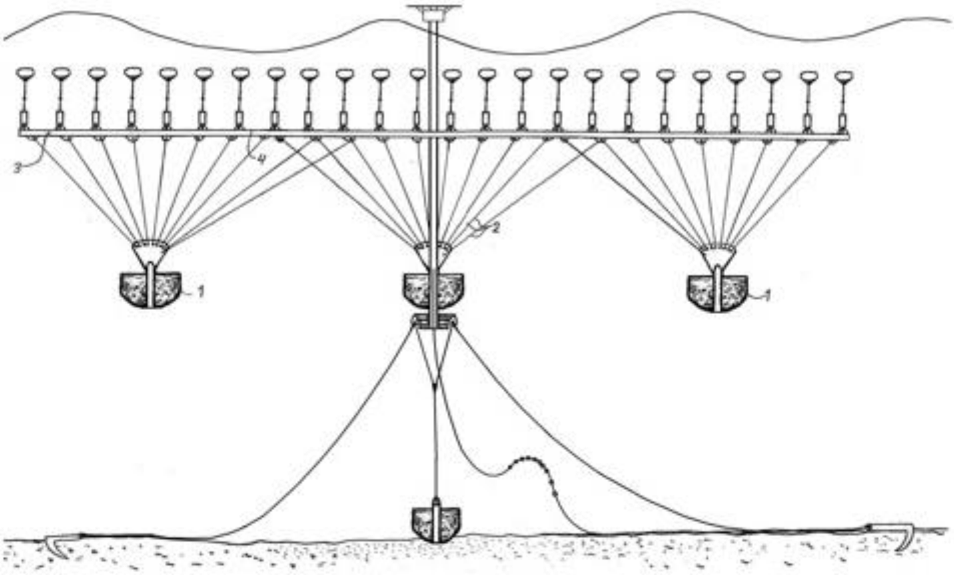
Pontoon Power Converter

The Pontoon Power Converter (PPC) is a floating wave energy converter based on working pontoons, hydraulic pumping cylinders, hydroelectric turbine and generator mounted on a patent pending ballasting and load-bearing structure, with slack moorings suitable for a wide range of water depths and many offshore locations.

Relatively large-scale power production (15-20 MW) produced on one turbine/generator. A solution to avoid the extreme wave conditions is incorporated and will protect the system against extreme environmental forces. Profitable production compared with other offshore renewable energy production according to their estimates. The Pontoon Power Converter provides easy access via helicopter for service personnel and serviceable from seagoing vessels.

Hurricane Protection Design. Wave power converters have shown to be vulnerable to damage during extreme sea states and weather conditions. The PPC features a Hurricane Protection Design where the vulnerable parts are submerged before an approaching storm, which is considered to be an innovative solution to that problem.

Better utilization of the electric grid in co-production with wind turbines. The PPC may increase the power production from a given ocean area if in co-production with wind power turbines, and it will also contribute to maintain the electric power production for an extended part of the time and therefore better utilize the electric grid.



Hurricane Protection Design

Contacts

Web site: http://www.awsocean.com

Address: Pontoon Power AS - Dr. Eyvin Dahlsgt. 3 4011 Stavanger Norway

Phone: General Manager Cel.: +47 91695168

E-mail: jm@pontoon.no

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266

3.1.1.5 Wave Dragon Aps

Wave Dragon is a large-scale technology for the generation of electricity from ocean wave energy. Invented by Erik Friis-Madsen, it has been developed with funding support from the European Union, the Welsh Development Agency, the Danish Energy Authority and the Danish Utilities PSO Programme.

Table 6 Wave Dragon APS

Wave Dragon APS	
	Wave Dragon is a large-scale technology for the generation of electricity from ocean wave energy. Invented by Erik Friis-Madsen, it has been developed with funding support from the European Union, the Welsh Development Agency, the Danish Energy Authority and the Danish Utilities PSO Programme.

The Wave Dragon is a floating slack moored wave energy converter with a rated capacity of 1.5MW – 12MW.

The Wave Dragon device allows ocean waves to overtop a ramp which elevates water to a reservoir above sea level. This creates a 'head' of water which is subsequently released through a number of turbines and in this way transformed into electricity. Water is returned to the vents in the base of the unit. Water is elevated to the reservoir where it is stored temporarily before falling into the turbine chambers thus converting mechanical wave energy to electrical output directly. The only moving part is the turbine itself.

The unit comprises:

- central housing, with a large water reservoir which receives water from oncoming waves via a ramp, and an array of hydro turbines. A transformer is located on top of the housing
- two lateral wave reflecting wings which concentrate the power of incoming waves.

Wave Dragon has formed a project development company, TecDragon - Tecnologia da Energia das Ondas SA, in cooperation with a group of Portuguese and German investors with the purpose to develop a wave energy project in Portuguese waters. The initial project will be an approximately 50 MW wave farm.

In 2017 the development of a 1.5 MW Wave Dragon demonstrator initiated. The design work is based on experiences from >20.000 test hours with a smaller prototype. The plan was to deploy the 1.5 MW demonstrator offshore Hanstholm at the test center DanWEC, Denmark. Aalborg University is responsible for basin tests of a 1:50 model, performing the necessary tests to establish the forces in the mooring cables for varying floating positions of the platform. ESB International establishes the necessary design base for the grid connection. The project is supported by the Danish Energy Authority's EUDP program.

No recent news could be retrieved on the results of this project.

Contacts

Web site: http://www.wavedragon.net/

Address: Wave Dragon Frederiksborggade 1, DK-1360 Copenhagen K Denmark

Phone: General Manager + 45 3536 0219

E-mail: info@wavedragon.net

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266

3.1.2 Marine Technologies - Swot analysis

From the information that has been retrieved in the previous paragraphs (level of development of the technologies, main players, cost factors, geographical aspects, etc.), a SWOT analysis has been conducted headlining elements that intrinsically characterize the exploitation of waves for the generation of energy and the external factors that are going to influence the outcomes in the near future.

STRENGTH	WEAKNESS
Vast potential across multiple countries and regions around the globe The relative benign environmental impacts even when compared to other renewable energy technologies Small visual impacts on the shoreline Support of both governments and private sector: broad public support (77%) for tidal and wave energy technologies The technology can rely on different typologies of plants (water columns, body converters, overtopping converters, etc.) adapting to the installation location characteristics	No clear dominant designs have appeared Engagement from large engineering firms and utilities is still in a nascent stage The need for investments: considering current and projected costs, a market pull attracting private investment is necessary Insufficient infrastructure: offshore grid connections, such as port facilities to perform O&M, are extremely expensive and non-existent In addition to the research development and demonstration (RD&D) requirements, funding and government grants, and policy support are needed to attract the private investment required for large scale deployment
OPPORTUNITIES	**THREATS**
Many young companies are working on the development of new concepts Development of offshore wind industry, that can help overcome troubles related to O&M, installation and deployment costs The EU encouragement to increase the share of the electricity produced from the renewable sources Growing commercial interest for the ocean-power sector The existence at EU level of the provisions to facilitate the development of the renewable energy sources;	Uncertainty on environmental regulation and impact Environmental impacts still need to be clarified in all aspects (electromagnetic, noise, etc.). Guidelines are under development from EU, that could threaten the technology Concerns raised by stakeholders involve issues relating to the creation of non-navigation and non-fishing areas affecting the shipping and fishing industry, concerns over maritime safety and effects on marine mammals Offshore wind industry that can be seen even as a threat

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3.2 Solar/PV systems

3.2.1 Solar/PV Systems - Technology scouting

Following is reported a brief scenario analysis describing patent literature trend data related to the investigated technology; i.e. photovoltaics.
The data have been extracted through the access to a database of patent literature (Derwent innovation[11]) and the utilization of specific search queries, including IPC codes in the case of patent searches. The time interval ranges from 2010 to date, even if, considering that patent applications are kept unpublished for a period of about 18 months at least, data related to 2020 are not reported in the graphs; their number can indeed be strongly influenced and underestimated due to the explained reasons.

Table 7 Search Query – Photovoltaic based Electric Generation Technologies

Search Query - Photovoltaic based Electric Generation Technologies
IPC=((C01B003302 OR C01B0033021 OR C01B0033023 OR C01B0033025 OR C01B0033027 OR C01B0033029 OR C01B003303 OR C01B0033031 OR C01B0033033 OR C01B0033035 OR C01B0033037 OR C01B0033039) OR (C23C001414 OR C23C001416 OR C23C001418 OR C23C001420) OR (C23C001624) OR (C30B002906) OR (F21L0004) OR (F21S000903) OR (G05F000167) OR (H01G000920) OR (H01L0025) OR (H01L0027142) OR (H01L0031) OR (H01M0014) OR (H02J000735) OR (H02S0010))

The number of inventions extracted from the database and related to the investigated technology amounts to about 315000, when considering publications started from 2010. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:

[11] https://www.derwentinnovation.com/

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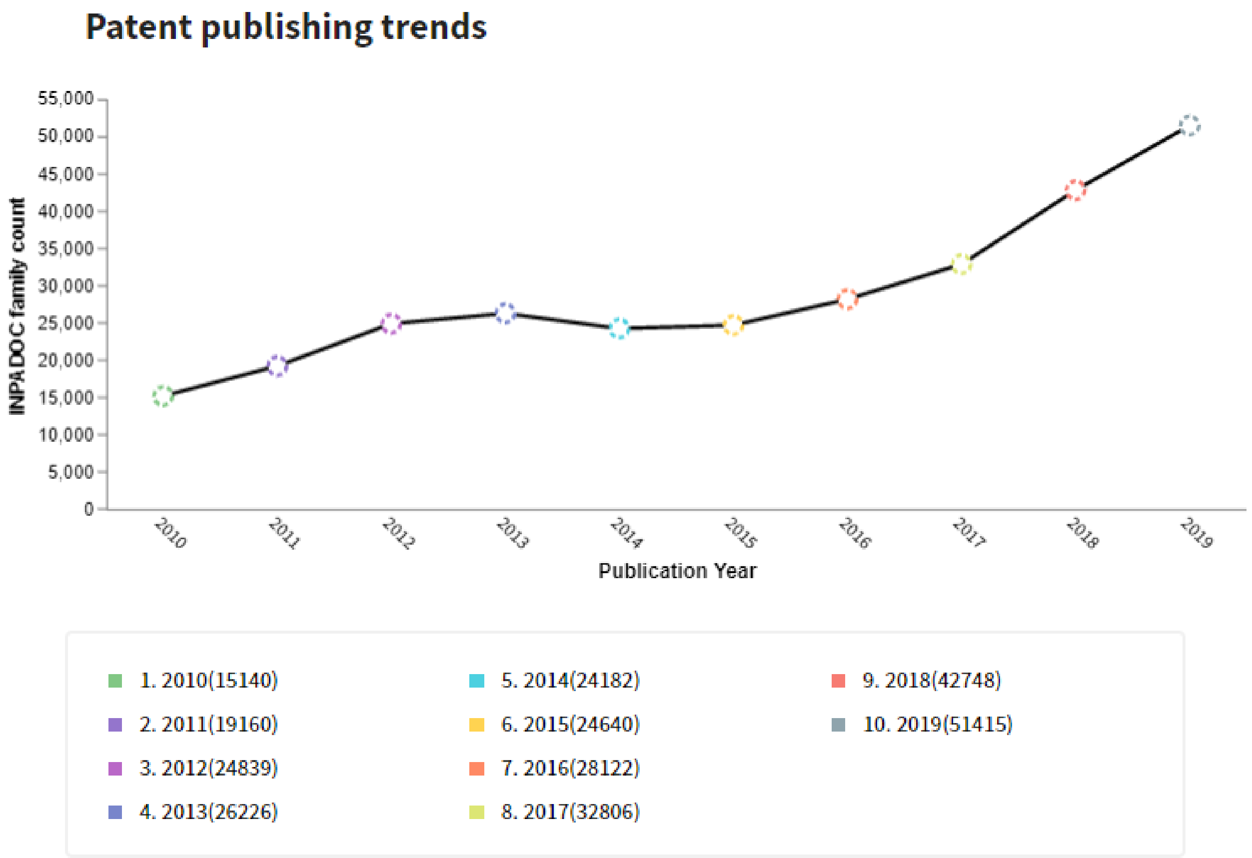

Figure 22 Photovoltaics Technologies - Trend of Published Patent Documents (INPADOC families) – (2010-2019)

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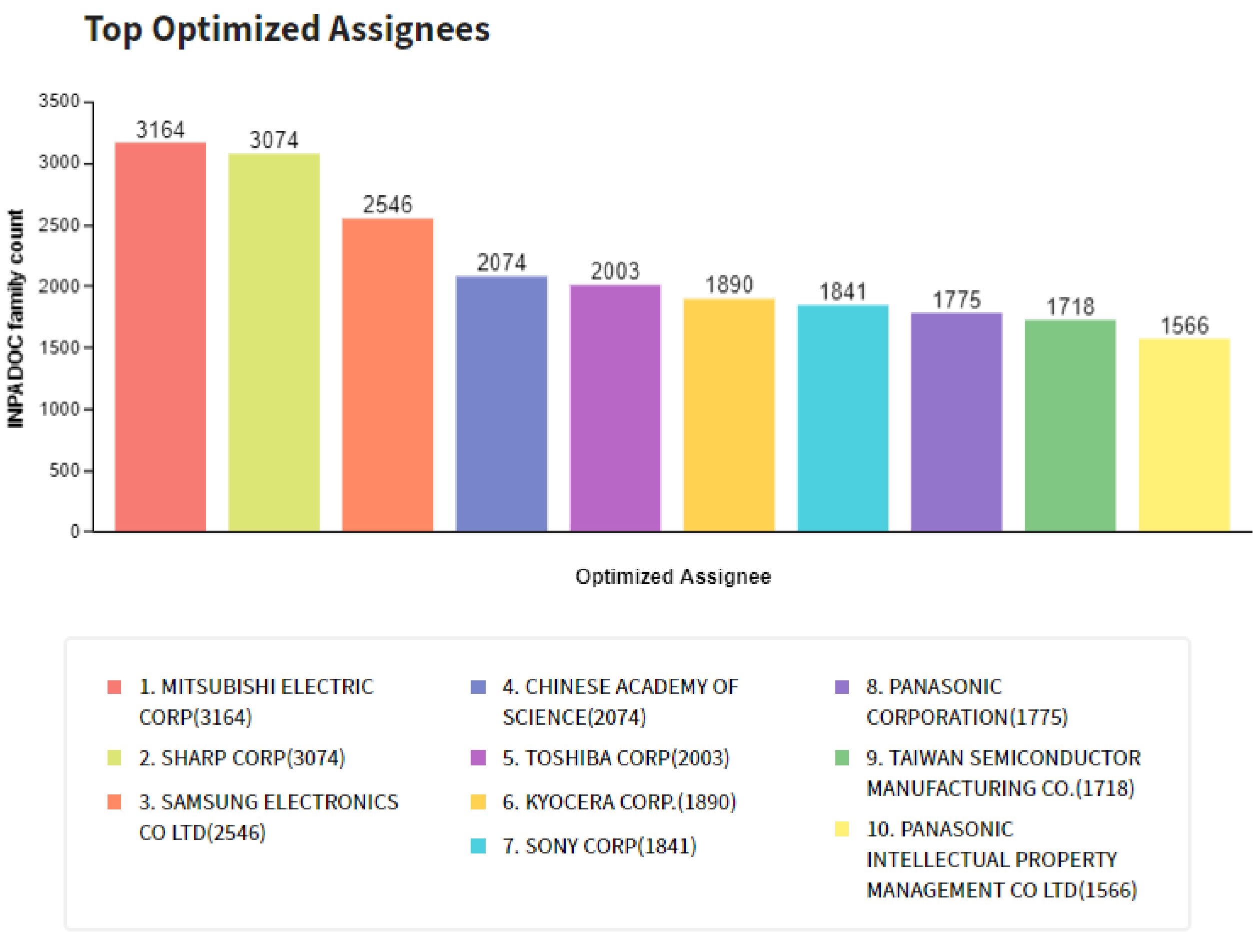

Figure 23 Photovoltaic Technologies - Main Assignees of Published Patents (2010-2019)

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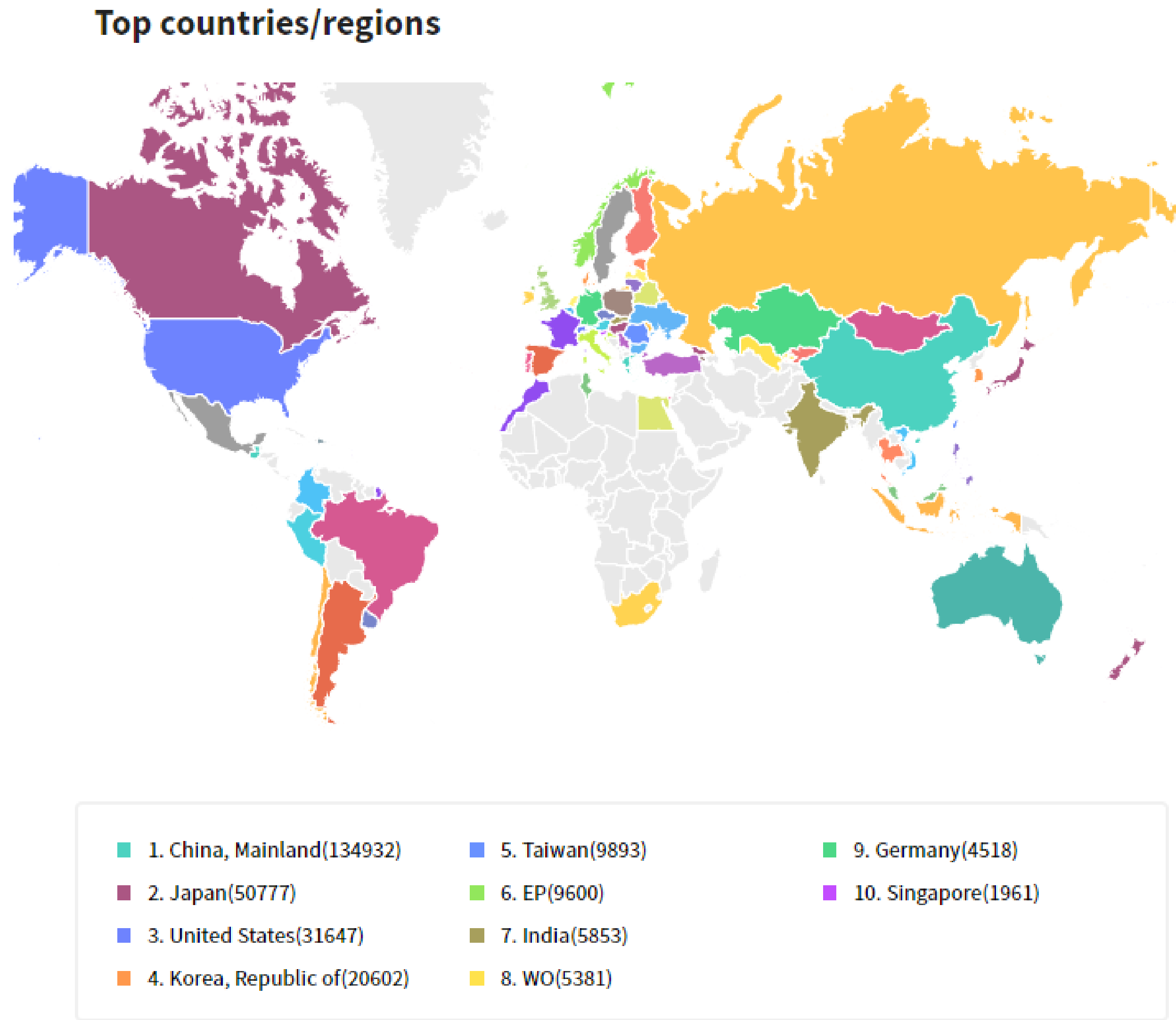

Figure 24 Photovoltaic Technologies - Main Country Codes (2010-2019)

Patent publications have increased steadily in the analyzed time interval, showing a strong interest to invest in photovoltaic technologies; China, Japan and United States are the main geographical areas where patents have been published.

Depending on the processes and the systems that are used in order to exploit solar energy, the solar technologies can generally be distinguished into either passive or active. The passive systems are broadly used for heating, cooling, and lighting the buildings, naturally recirculating the ambient air inside some structures and a wide variety of other commercial and industrial uses.
The active systems suitably convert the solar energy into other useful forms of energy. Based on the vector of energy output after the conversion, these technologies are majorly categorized in two subgroups, namely the solar Photovoltaic (PV) and Concentrated Solar Power (CSP) for electricity production and the solar thermal, for

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266

thermal energy production[12]. There are also hybrid Photovoltaic-Thermal systems (PV/T) which produce both electricity and thermal energy.

Photovoltaic Systems

In these systems, solar energy is harvested from the sun, through PVs which are arrays of cells containing an appropriate material, such as crystal silicon, that converts solar radiation into electricity through the photovoltaic effect (Figure 25). A broad range of applications use this technology nowadays, ranging from residential rooftop power generation arrays to medium-scale utility-level energy generation. The PV produce direct current electricity, which in turn is converted into alternating current and injected through the electrical grid.

Figure 25: Photovoltaic (PV) solar panels[13]

These systems can have a specific constant tilt, or they can adjust their inclination using a single or dual axis mechanism for tracking the sun[14]. The extra required systems and modifications provide better efficiency but raise the overall installation cost simultaneously. In the early days of the technology the cost of electricity generation using these specific technologies was substantially higher compared to other means of generation, due to their high initial investment cost. However, this financial gap is progressively closing due to a various of factors such as the cost of production and power electronics. The operating cost of the PV system is very low, limited to light maintenance activities such as cleaning the panels. On the other hand, the incomes are mainly affected by the sale price and the final electrical output. Consequently, the PV technology is nowadays established as very promising option for covering the global energy needs and contributing to the environmental protection.

[12] U. Gangopadhyay, S. Jana, S. Das, State of art of solar photovoltaic technology, in: Conference Papers in Energy, 2013, p. 9.
[13] http://www.rvrengineering.com/commercialsolar/
[14] C.R. Landau, Optimum Tilt of Solar Panels, 2001. http://www.solarpaneltilt.com/.

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The PV technologies are usually classified into three generations depending on the used materials and the commercial maturity of the technique[15]:

- First generation PVs, which use wafer-based crystalline silicon (c-Si) technology, either single crystalline (sc-Si) or multicrystalline (mc-Si).
- Second generation PVs, which use thin-film systems constructed by one of the following choices: (1) amorphous and micromorph silicon, (2) cadmium telluride (CdTe), or (3) copper indium selenide (CIS) and copper indium-gallium diselenide (CIGS). This specific technology is lately commercialized.
- Third generation PVs, which include technologies which are in a vast majority still under research and not in commercial use, such as concentrating or organic PV cells [16].

Apart from these main technologies, there are also technologies with new materials, not as widespread and not yet commercialized, which are summed up in Figure 26.

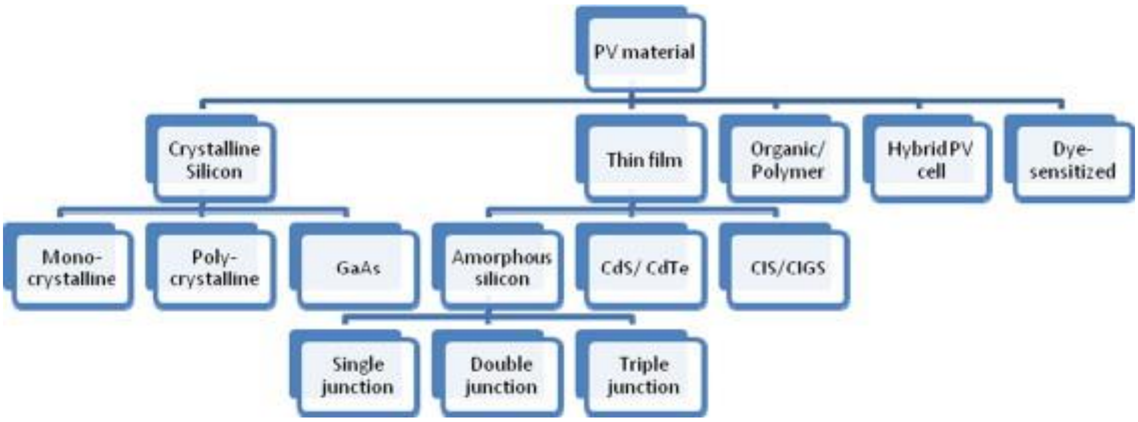

Figure 26: PV material chart[17]

The main types of solar panels which have been widely commercialized, along with their advantages and disadvantages are presented in Table 8.

Table 8: Main types of solar panels'[18]

Solar panel type	Advantages	Disadvantages
Monocrystalline	• High efficiency/performance • Aesthetics	• Higher costs
Multicrystalline	• Low cost	• Slightly lower efficiency
Thin-film	• Portable and flexible • Lightweight • Aesthetics	• Lowest efficiency/performance • Gradual material wear and consequent efficiency

[15] Itskos, G., Nikolopoulos, N., Kourkoumpas, D. S., Koutsianos, A., Violidakis, I., Drosatos, P., & Grammelis, P. (2016). Energy and the Environment. In *Environment and Development* (pp. 363-452). Elsevier.
[16] M.A. Green, et al., Crystalline silicon on glass (CSG) thin-film solar cell modules, Sol. Energy 77 (2004) 857e863.
[17] Tyagi V.V., Rahim N.A.A., Rahim N.A., et al. Progress in solar PV technology: Research and achievement Renew. Sustain. Energy Rev., 20 (4) (2013), pp. 443-461
[18] https://www.energysage.com/solar/101/types-solar-panels/

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degradation.

Concentrated Solar Power

Another method for utilizing solar energy for electricity generation is through the technology of Concentrated Solar Power plants (CSPs). These systems (Figure 27) use mirrors or reflective lenses to focus sunlight on a fluid to heat it to a high temperature. The heated fluid flows from the collector to a heat engine as a working medium for the production of electric energy through a Rankine cycle. An advantage of this technology is that some types of CSP allow electricity generation during the night, as the heat can be stored for many hours [19] in heat storage tank using materials such as molten salts.

Figure 27: Concentrated Solar Power plant (CSP)[20]

Photovoltaic Thermal Collectors (PV/T)

In the PV/T systems, the heat from the photovoltaic modules is extracted using various techniques and is utilized in thermal systems separately[21]. PV/T collectors combine PV cells with a solar thermal collector, which transfers the (otherwise) unused waste heat from the solar panel to a heat transfer fluid. A great advantage of using the waste energy and combining electricity and heat generation within the same module is that these technologies can reach a higher overall efficiency than solar photovoltaic (PV) or solar thermal (T) alone and efficiency for electric production specifically is also higher as the PV is cooled from the fluid[22]. **Although the concept of PV/T systems is not new, the technology is still not widely commercialized**. The PV/T systems' classification can be accomplished on the basis of several parameters, including a) heat extraction

[19] M.Z. Jacobson, M.A. Delucchi, Providing all global energy with wind, water, and solar power, Part I: technologies, energy resources, quantities and areas of infrastructure, and materials, Energy Policy 39 (2011) 1154e1169.

[20] Current status of concentrated solar power (CSP) globally, July 25, 2018. Online article: https://www.evwind.es/2018/07/25/current-status-of-concentrated-solar-power-csp-globally/64041

[21] Joshi, S. S., & Dhoble, A. S. (2018). Photovoltaic-Thermal systems (PVT): Technology review and future trends. *Renewable and Sustainable Energy Reviews*, *92*, 848-882.

[22] Zenhäusern, Daniel; Bamberger, Evelyn (2017). *PVT Wrap-Up: Energy Systems with Photovoltaic-Thermal Solar Collectors*. EnergieSchweiz.

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arrangement, b) working medium used (propylene glycol mix, ethylene glycol mix, water, nanofluids mix)[23], c) type of solar irradiation input (concentrated/non-concentrated), and d) end applications, etc., as depicted in Figure 28. The range of applications of PV/T collectors can also be divided according to their temperature levels[24] in:

- low temperature applications up to 50 °C
- medium temperature applications up to 80 °C
- high temperature applications above 80 °C

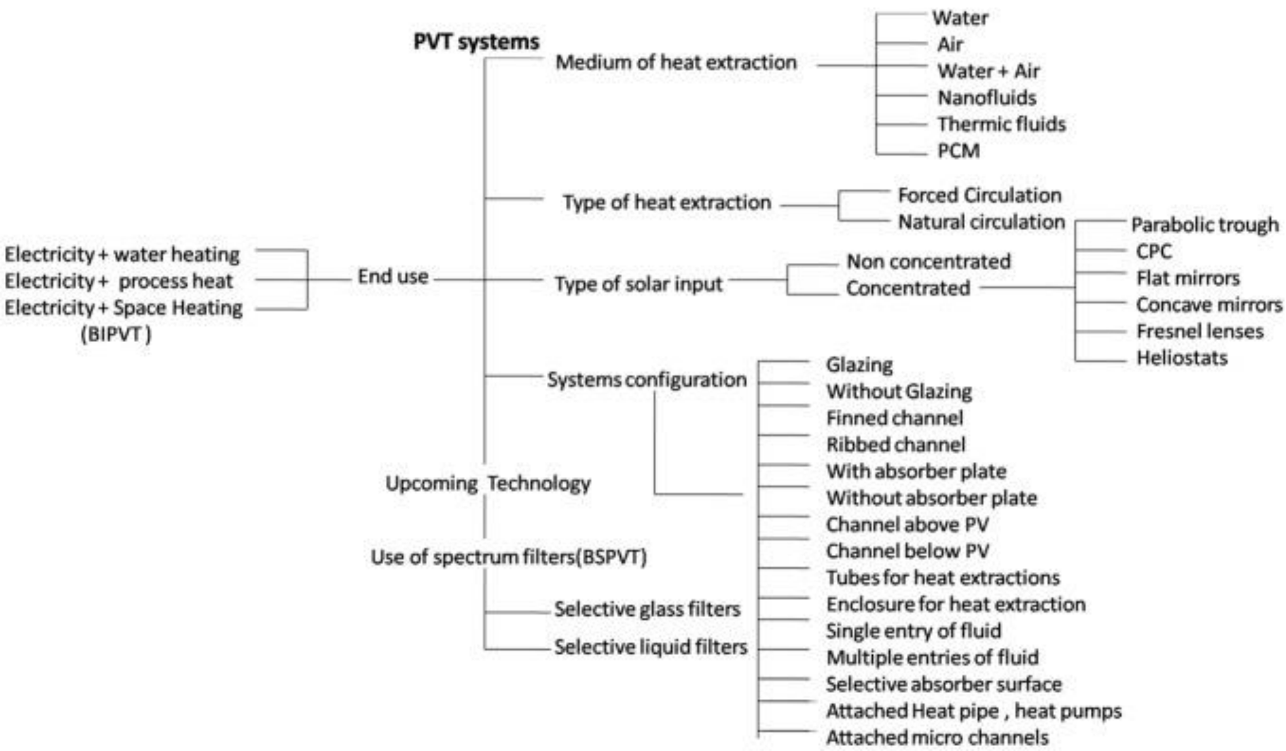

Figure 28: Classification of PV/T systems[21].

Floating PV

Besides the land-based PV systems, there are also floating solar PV plants[25] which are an emerging form of PV systems that float on the surface of potable water reservoirs, irrigation canals, quarry lakes or remediation and tailing ponds (Figure 29). Those types of PV plants use mostly crystalline solar PV modules. They also consist of a floating system, also known as pontoon, which is a solid structure that holds the solar panel and

[23] A. H. A. Al-Waeli, M. T. Chaichan, K. Sopian, and H. A. Kazem, *Influence of the base fluid on the thermo-physical properties of PV/T nanofluids with surfactant*, Case Studies in Thermal Engineering, vol. 13, p. 100340, Mar. 2019, doi: 10.1016/j.csite.2018.10.001.

[24] Kalogirou, SA (2014). Solar Energy Engineering: Processes and Systems (Second ed.). Academic Press. doi:10.1016/B978-0-12-374501-9.00014-5.

[25] Floating PV plants: a promising future for solar energy, https://www.trace-software.com/blog/floating-pv-plants-a-promising-future-for-solar-energy/

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is composed of a structure and a floater upon which the installation of the PV module stands. A mooring system is also included, which is a permanent structure used to halt the free movement of the floating structure in water. This allows adjusting to water level fluctuations while maintaining position in a southward direction. The floating structure can be fixed to a point on the bottom of the waterway, eliminating the need to connect the floating structure to the shore. This can be done with the help of anchor mooring. Finally, an underwater cable is also required, which is used to transfer generated power from water bodies to the substation.
Some of the advantages that floating PV systems present, are related with a) increased generating efficiency due to the natural cooling effect of the water below the solar cells and less settled dust on them which also means b) less maintenance costs, c) they are faster to be deployed and easier to manage since they don't require fixed structure as the foundations used for the land-based plants, d) they avoid all the hurdles of land acquisition and all the concerns of land consumption, and e) they can be installed in any water bodies with abundant sunlight, converting unutilized areas into profitable generators of renewable energy. They also have other benefits for the water body on which they are installed, such as reduced water loss due to evaporation, and improved water quality, by blocking algae growth through shading the water[25,26].

Figure 29: The floating solar farm in Huainan, China is made up of 160,000 panels, attached to each other in a huge mosaic structure[27]. ©STR / AFP

Solar PV and PV/T module marketing and cost trends

By the end of 2019, over 580 GW of solar PV systems had been installed, worldwide[28]. This represents a 14-fold growth for the technology since 2010. About 98 GW of newly installed systems was commissioned just during 2019. These new capacity additions were the highest among all renewable energy technologies for the year. There is a continuing downward trend in solar PV module costs: between December 2009 and December 2019, crystalline silicon module prices declined between 87% and 92% for modules sold in

[26] https://www.solarfloat.com/
[27] "Huainan: Largest Floating Solar Farm in the World ", 11 July 2018, Online article: https://www.planete-energies.com/en/medias/close/huainan-largest-floating-solar-farm-world
[28] Renewable Power Generation Costs in 2019-IRENA

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Europe, depending on the type. The cost of high efficiency crystalline modules at 0.37 $/W (USD) was slightly above thin film modules, which sold for 0.36$/W at the end of 2019[28].

The average monthly solar PV module prices by technology and manufacturing country sold in Europe from 2010 to 2020 and a comparison of the average yearly prices between 2013 and 2019 are presented in Figure 30.

Furthermore, for PV/T modules, by the end of 2019, a total cumulative thermal capacity of 606 MW_{th} and a nominal PV power of 208 MWp were installed worldwide. The total area of installed collectors amounted to approx. 1.17 10^6 m^2 and 58% of them was in Europe. This is a significant global growth of 9% compared to the previous year. This trend was also seen in the European market with a growth rate of 14%. The country with the largest installed capacity was France (41.5 %), followed by South Korea (24.1 %), China (11.5 %) and Germany (9.6 %) [29].

[29] Weiss, Werner; Spörk-Dür, Monika (2020). Solar Heat Worldwide - Global Market Development and Trends in 2019 - Detailed Market Data 2018

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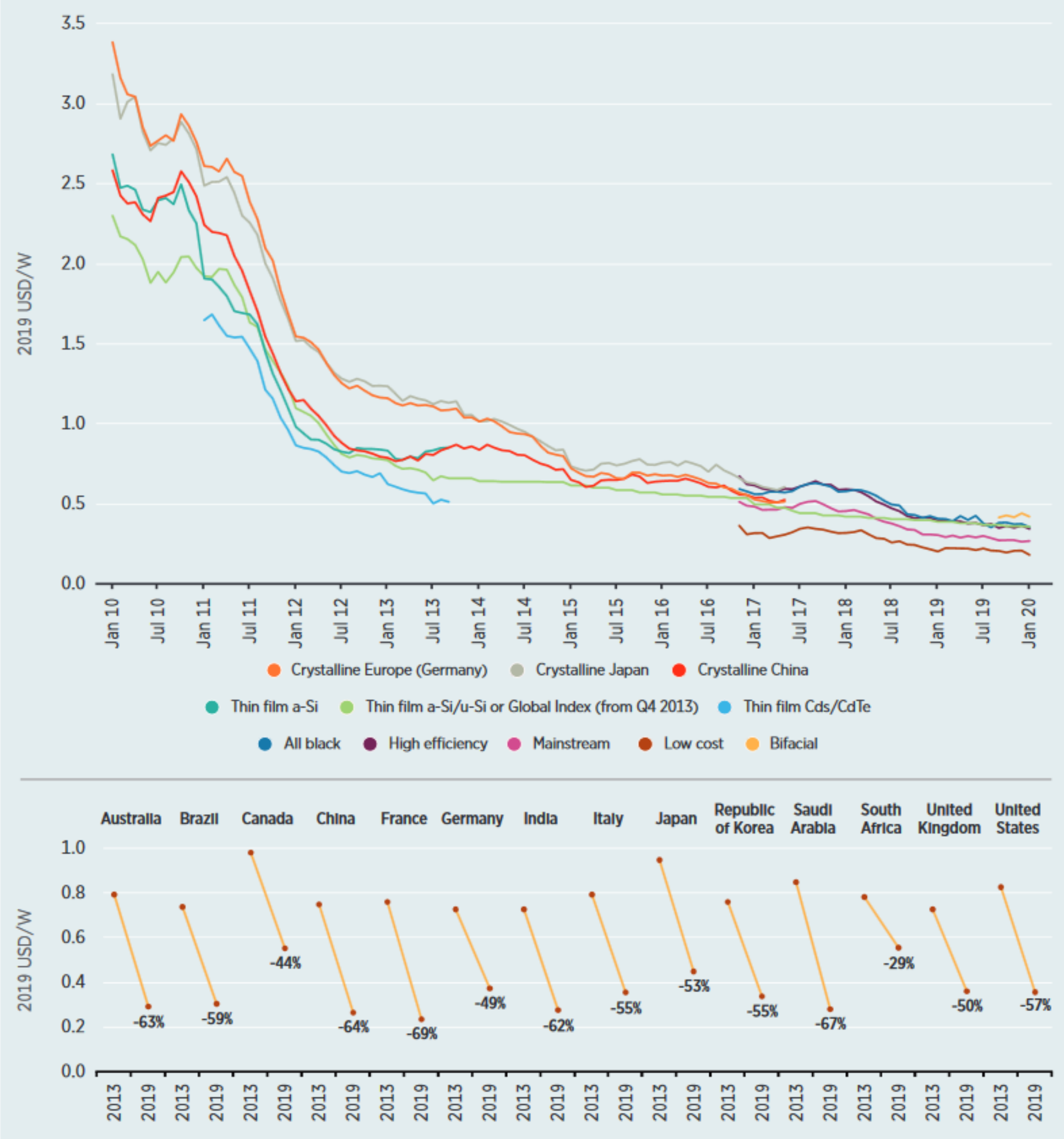

Figure 30: Average monthly solar PV module prices by technology and manufacturing country sold in Europe, 2010 to 2020 (top) and average yearly module prices by market in 2013 and 2019 (bottom)[28]

3.2.2 Solar/ PV Systems - SWOT Analysis

Gathering all the Strengths, Weaknesses, Opportunities and Threats of the solar PV systems based on existing literature, the following SWOT analysis is presented in the following table[30].

[30] F. M. Guangul and G. T. Chala, "Solar Energy as Renewable Energy Source: SWOT Analysis," 2019 4th MEC International Conference on Big Data and Smart City (ICBDSC), Muscat, Oman, 2019, pp. 1-5, doi:10.1109/ICBDSC.2019.8645580.

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STRENGTH	WEAKNESS
Sustainable and "limitless" since it depends on the solar energy which originates from the sun which provides abundant free energy Environmentally Friendly Ease of usage/harvest since photovoltaic systems produce directly electricity and installation of solar energy system can be done anywhere Less overall cost in the long run since running costs are very low, it demands no fuel and maintenance cost is low Versatile since solar power can be used for multiple applications, for either electricity or thermal energy production	Solar power is available only in day time Solar Panels are inefficient, with very low conversion efficiency compared to other energy conversion systems Large space required for PV to absorb enough energy for larger applications High initial investment cost
OPPORTUNITIES	THREATS
Creates New Business Opportunities through growing market of solar systems, and also gives landowners the opportunity to rent their unused land for solar farms Increase of concerns regarding using fossil fuels and nuclear energy opens the door for use of renewable energy source Availability of subsidy and support from governments which offer great incentives Cost reduction and improved efficiency due to quick development of the technology and competition in the field	Health risks since unsafe waste from used and disposed solar panels present a worldwide environmental danger High carbon footprint despite renewable energy production, since manufacturing main components of PV systems which are usually made from crystalline silicon is an energy-intensive process and on a lifecycle basis the total amount of greenhouse gases produced indirectly is high Largely fossil-fuel based energy sector with well-established technologies presents a barrier for shifting focus to other renewable sources such as solar power

3.3 Wind energy systems

3.3.1 Wind energy Systems - Technology scouting

Following is reported a brief scenario analysis describing patent literature trend data related to the investigated technology; i.e. wind energy systems for electric generation. The data have been extracted through the access to a database of patent literature (Derwent innovation[31]) and the utilization of specific search queries, including IPC codes in the case of patent searches. The time interval ranges from 2010 to date, even if, considering that patent applications are kept unpublished for a period of about 18 months at least, data related to 2020 are not reported in the graphs; their number can indeed be strongly influenced and underestimated due to the explained reasons.

[31] https://www.derwentinnovation.com/

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Table 9 Search Query – Wind energy based Electric Generation Technologies

Search Query - Wind energy based Electric Generation Technologies
IPC=(F03D or (F03D and H02K000718) or (F03D and B63B003500) or (F03D and E04H001200))

The number of inventions extracted from the database and related to the investigated technology amounts to about 70000, when considering publications started from 2010. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:

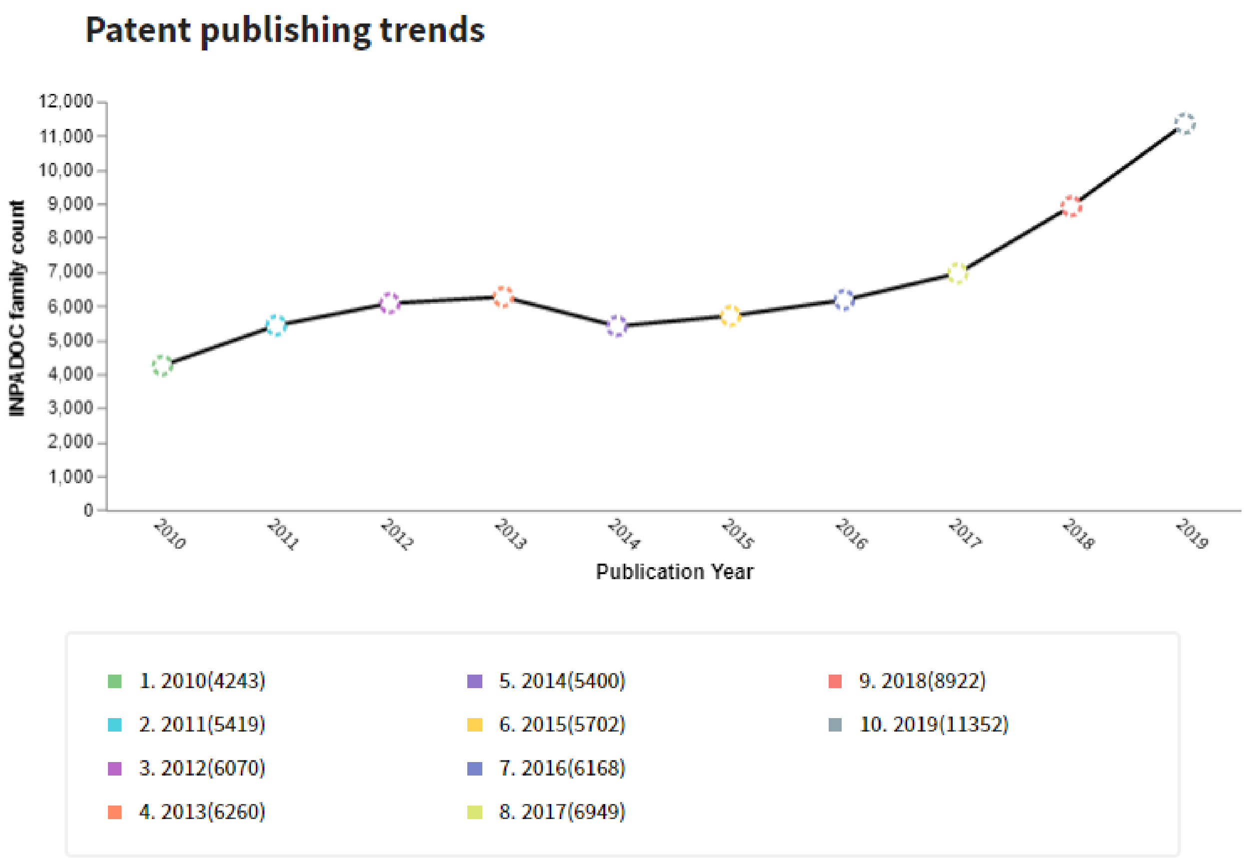

Figure 31 Wind energy systems Technologies - Trend of Published Patent Documents (INPADOC families) – (2010-2019)

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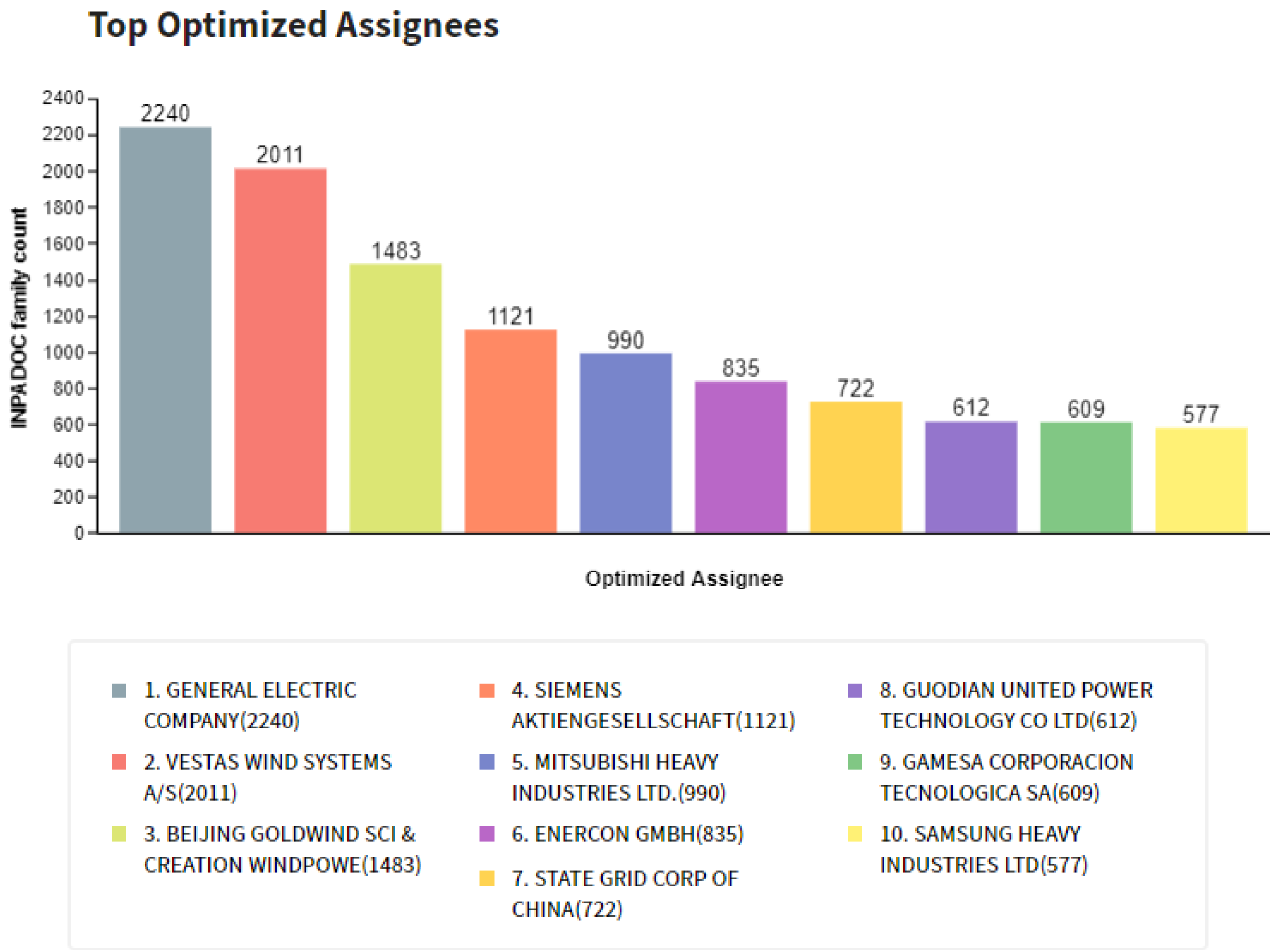

Figure 32 Wind energy systems Technologies – Main Assignees of Published Patents (2010-2019)

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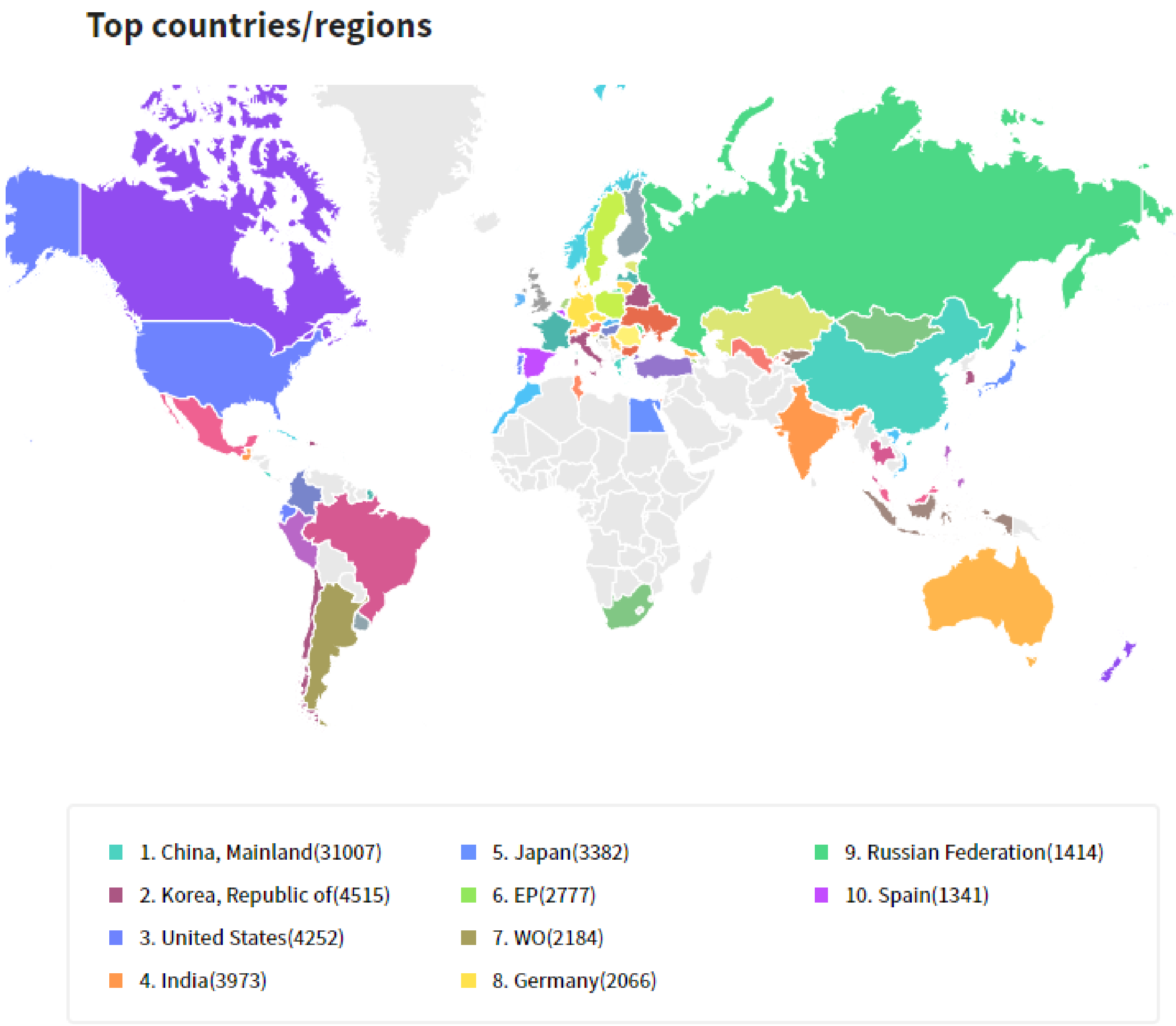

Figure 33 Wind energy systems Technologies - Main Country Codes (2010-2019)

Patent publications have increased steadily in the analyzed time interval but if compared to PV and wave energy technologies, the increase trend has seen a really strong acceleration in last three years; China, South Korea, United States, India and Japan are the main geographical areas where patents have been published.

The rapid development of the Wind Energy Conversion Systems (WECS) was performed in early 90's, by establishing wind energy sources as a significant part in the global renewable energy market[32]. Those systems are mainly divided into two main categories based on whether the turbine blades rotational speed is varied or constant:

- fixed speed turbines and
- variable speed turbines

The first developed and commercially used technologies belong to the first group, due to mainly technological restrictions[33,34].

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[32] Zhe, C., J.M. Guerrero, and F. Blaabjerg, A Review of the State of the Art of Power Electronics for Wind Turbines. Power Electronics, IEEE Transactions on, 2009. 24(8): p. 1859-1875.

[33] Freris, L.L., Wind Energy Conversion System. 1990, London: Prentice Hall.

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Fixed Speed WECS[35]

In a fixed speed WECS, the turbine speed is determined by several factors such as a) the grid frequency, b) the generator pole pairs number, c) the machine slip and d) the gearbox ratio. The turbine speed is not affected to a large extent by any change in wind speed, but the electromagnetic torque is, and consequently the electrical output power. Some of these systems implement aerodynamic control of the blades for optimization of performance, but this introduces additional costs and complexities for the control systems. As for the generating system, most wind turbines use either one of the following systems: squirrel cage induction generator, doubly fed (wound rotor) induction generator and direct-drive synchronous generator. The use of induction generators maintains an almost fixed speed with only minor variation (approx. 1-2%). The methods to limit the power aerodynamically are either by stall, active stall or by pitch control[36,37]. Those systems are an attractive solution due to their simplicity, low cost and high reliability. One characteristic type of this category, largely applied by many Danish wind turbine manufacturers during the 1980s and 1990s, so that it is also referred to as 'Danish concept', is the constant speed, stall-regulated, three-bladed WECS with multiple-stage gearbox and a squirrel-cage induction generator (SGIG) directly connected to the grid through a transformer. However, in a fixed-speed system like this, the fluctuations of the rotational speed directly affect the electrical output and impose mechanical fatigue on the structure[15]. Furthermore, this system cannot extract as much energy from the wind as a variable speed WECS, which are continuously increasing their market share, as they can track the changes in wind speed by adapting shaft speed and thus maintaining optimal energy generation[38].

Variable Speed WECS[35]

The variable speed generation system is able to store the varying incoming wind power as rotational energy, by changing the speed of the wind turbine. In this way the stress on the mechanical structure is reduced, which also leads to smoother electrical power delivered.

The control system maintains the mechanical power at its rated value by using Maximum Power Point Tracking system (MPPT)[39]. These WECS are generally divided into two categories: a) systems with partially rated power electronics and, b) systems with full-scale power electronics interfacing wind turbines[36,40,41]. One characteristic type of WECS

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[34] S.Heier, Grid Integration of Wind Energy Conversion Systems. 1998, New York: Wiley.

[35] Amirat, Y., Benbouzid, M.E., Bensaker, B., & Wamkeue, R. (2007). Generators for Wind Energy Conversion Systems : State of the Art and Coming Attractions.

[36] B. Blaabjerg et al., "Power electronics as efficient interface in dispersed power generation systems," IEEE Trans. Power Electronics, vol. 19, n°5, pp. 1184-1194, September 2004.

[37] H. Polinder et al., "Basic operation principles and electrical conversion systems of wind turbines s," In Proceedings of NORPIE'04, Paper #069, Trondheim (Norway), June 2004.

[38] P. Thoegersen et al., "Adjustable speed drives in the next decade. Future steps in industry and academia,"Electric Power Components & Systems, vol. 32, n°1, pp. 13-31, January 2004.

[39] E. Koutroulis et al., "Design of a maximum power tracking system for wind-energy-conversion applications," IEEE Trans. industrial Electronics, vol.53, n°2, pp. 486-494, April 2006.

[40] J.A. Baroudi et al., "A review of power converter topologies for wind generators," in Proceedings of IEEE IEMDC'05, pp. 458-465, San Antonio (USA), May 2005

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belonging on this category uses doubly-fed induction generator and a partial-scale power converter. The rotor of the generator is connected to the grid, while the stator its connected with a back-to-back converter. This type of generator can deliver the electrical grid with a wide varying speed energy, from supersynchronous to subsynchronous speeds, namely ±30% compared to the synchronous speed. An additional alternative option belonging on this specific category is the wind generator systems with an arrangement comprised of SCIG and a full-scale back-to-back converter which allows the operator to affect the generator speed by controlling the generator side converter and the energy output by similarly adjusting the grid-side converter. However, a major disadvantage of this particular type is its high cost. A variation of the latter wind turbine system replaces the SCIG with a permanent magnet synchronous generator (PMSG), which offers high efficiency and robustness. However, this technology is the one with the highest cost compared to all the aforementioned, mainly due to the use of permanent magnetic materials[42].

Onshore wind turbine

Onshore wind turbines (Figure 34) are land-based installations, usually in hilly or mountainous regions, in order to exploit the topographic acceleration of wind as it passes over a ridge, which results in increased energy production. Onshore wind technology has made significant advances over the past decade, offering increased capacity factors due to larger and more reliable turbines, along with higher hub heights and larger rotor diameters. In addition to these technology improvements, total installed costs, O&M costs and (subsequently) LCOEs have been falling as a result of economies of scale, increased competitiveness and maturity of the sector[28].

Onshore wind turbines have the following major advantages[43]: a) low cost which allows for mass farms of wind turbines, b) shorter distance between the generation location and the consumer which means less voltage drop off on the cabling, c) quicker installation (only a few months required) compared to other types of power stations. On the other hand, their disadvantages[43] are a) aesthetic disturbance in the landscape, b) non-continuous operation due to variable wind speed, c) obstruction by physical blockages such as buildings or hills, and d) noise pollution.

The cumulative capacity of onshore wind has increased more than threefold during the past decade, from 178 GW in 2010 to 594 GW in 2019.

[41] B. Blaabjerg et al., "Power electronics as an enabling technology for renewable energy integration," J. Power Electronics, vol. 3, n°2, pp. 81-89, April 2003.

[42] Semken, R.S., et al., Direct-drive permanent magnet generators for high-power wind turbines: benefits and limiting factors. Renewable Power Generation, IET, 2012. 6(1): p. 1-8.

[43] Offshore and Onshore Wind Farms: What are the Pros and Cons?, July 19, 2019, Online article: https://www.nesgt.com/blog/2019/07/offshore-and-onshore-wind-farms

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Figure 34: An onshore wind farm in the UK[44] [Source: *Steve P2008, Flickr*]

Offshore wind turbine

Offshore wind energy is the use of wind farms constructed in bodies of water, usually in the ocean, to harvest wind energy to generate electricity (Figure 35). A major advantage is that offshore wind speeds tend to be higher and firmer than on land as there aren't physical obstacles such as hills or buildings to block the wind flow. Thus, offshore wind power's electricity generation is higher. Offshore wind power can serve proximal coastal areas which usually have a high population concentration and high energy needs. Offshore wind farms have many of the same advantages as land-based wind farms but they are much less intrusive to neighboring areas and with small impact on the environment, since they tend to be far out at sea and away from fishing areas or shipping areas. On the other hand, the biggest disadvantage of an offshore wind farm is the cost. The cost of building and maintenance can be high due to their hard to reach locations and their susceptibility to damage from very high-speed winds during storms or hurricanes[43,45].

Global cumulative installed capacity of offshore wind increased by over nine-fold between 2010 and 2019, from 3.1GW to 28.3GW. This was largely driven by installations in Europe, which accounted for 78% of cumulative global deployment by the end of 201928.

[44] Europe's largest onshore wind farms, by Robin Whitlock, February 27, 2016, Online article: https://interestingengineering.com/europes-largest-onshore-wind-farms

[45] "What are the advantages and disadvantages of offshore wind farms?", American Geosciences Institute (AGI), Online article: https://www.americangeosciences.org/critical-issues/faq/what-are-advantages-and-disadvantages-offshore-wind-farms

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Figure 35: Offshore wind turbines[28]

Micro-Wind Turbine

Micro-wind turbines, with capacity of 100 kW_e or less, are used in micro-wind generation and are quite smaller in size than those used in conventional wind generation making them appropriate for residential power production. There are two major types of wind turbines that can be used for residential energy production: a) horizontal axis wind turbines and b) vertical axis wind turbines (Figure 36)[46,47]. Vertical axis wind turbines (Darrieus or Savonius type, Figure 37) have some advantages over horizontal axis wind turbines such as fewer moving parts, lower tip speed ratio, quieter, lower cost, and insensitive to wind direction. Furthermore, in urban built-up areas, where the wind becomes highly turbulent and shows significant fluctuations in speeds and high variability of wind direction caused by structures and buildings, horizontal axis wind turbines are less effective. The power coefficients for various drag-based wind turbines (Savonius type) have been reported in the literature to vary from 4% to 24%[48].

[46] J.M.K.C. Donev et al. (2020). Energy Education - Micro-wind turbine [Online]. Available: https://energyeducation.ca/encyclopedia/Micro-wind_turbine. [Accessed: July 22, 2020].
[47] J.M.K.C. Donev et al. (2020). Energy Education - Types of wind turbines [Online]. Available: https://energyeducation.ca/encyclopedia/Types_of_wind_turbines. [Accessed: July 22, 2020].
[48] Loganathan B, Chowdhury H, Mustary I, Rana MM and Alam F 2019 Design of a micro wind turbine and its economic feasibility study for residential power generation in built-up areas Energy Procedia 160 812

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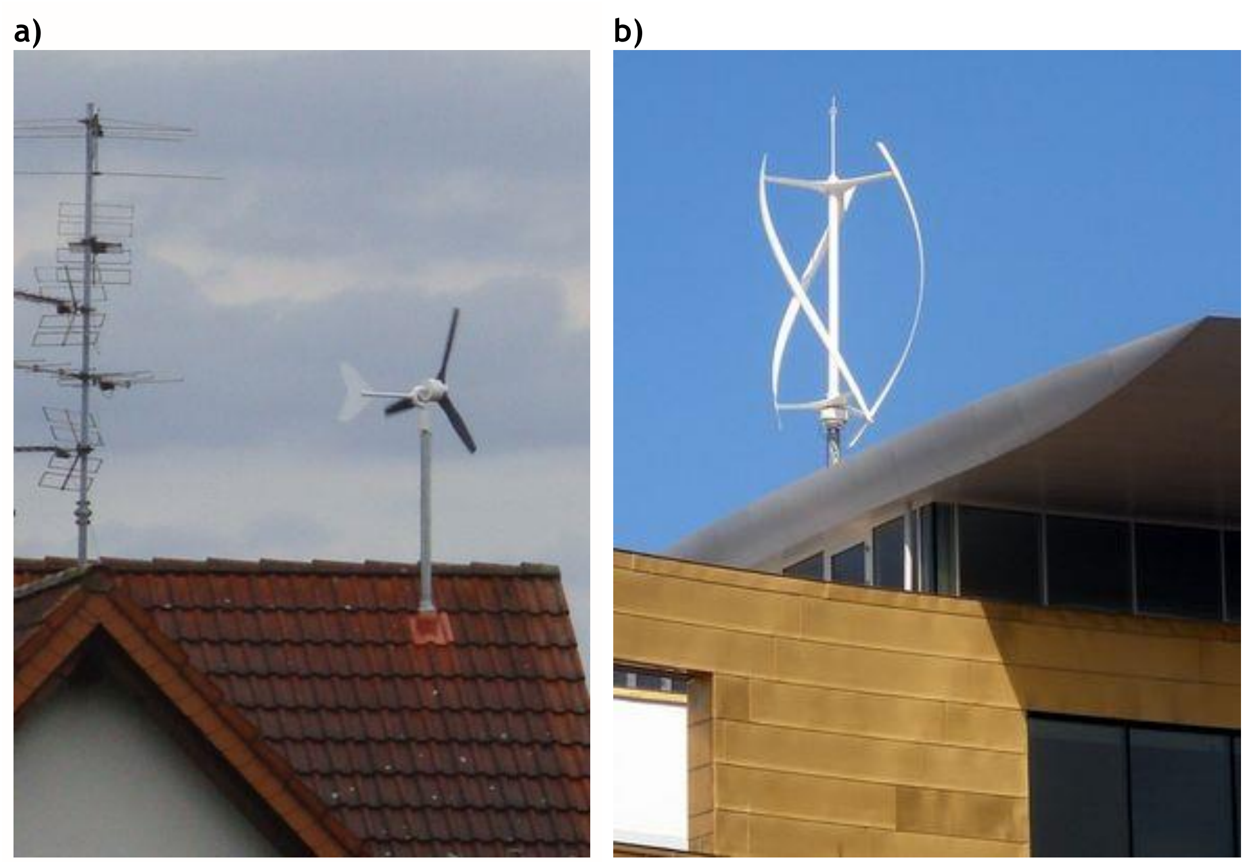

Figure 36: Micro-wind turbines for residential energy production[47], a) horizontal axis, b) vertical axis.

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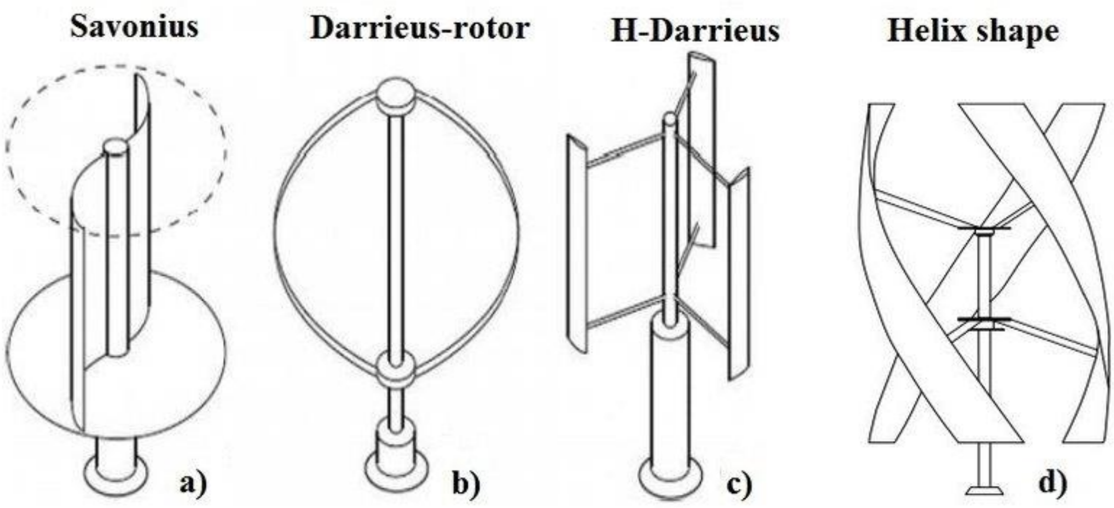

Figure 37: Different kinds of vertical axis wind turbines (VAWT)[49]: (a) Savonius; (b) Darrieus with "egg beater" design rotor; (c) H-shape blades; (d) helix shape blades.

Wind turbine marketing and cost trends

The global weighted-average LCOE of projects using onshore wind turbines and commissioned in 2019 was 0.053 $/kWh — 9% lower than in 2018 and 39% lower than in 2010, when it was 0.086 $/kWh[28]. The cumulative capacity of onshore wind has increased more than threefold during the past decade, from 178 GW in 2010 to 594 GW in 2019. The global weighted-average total installed cost has fallen by 24%, from 1949 $/kW in 2010 to 1473 $/kW in 2019, when it was down 5% on the 2018 value of 1549 $/kW.

On the other hand, the global weighted-average LCOE of offshore wind declined by 29% between 2010 and 2019, from 0.161 to 0.115 $/kWh, with a 9% reduction year-on-year in 2019. Auction and tender results suggest that from 2023, the cost of electricity will fall to between 0.05 $/kWh and 0.10 $/kWh and can be achieved even in relatively new markets. Between 2010 and 2019, global weighted-average total installed costs fell 18%, from 4650 $/kW to 3800 $/kW. The global weighted-average total installed cost peaked at 5740 $/kW in 2013, representing a 33% drop to its 2019 value.

[49] Castellani, Francesco & Astolfi, Davide & Peppoloni, Mauro & Natili, Francesco & Buttà, Daniele & Hirschl, Alexander. (2019). Experimental Vibration Analysis of a Small Scale Vertical Wind Energy System for Residential Use. Machines. 7. 35. 10.3390/machines7020035.

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3.3.2 Wind energy Systems – SWOT Analysis

The Strengths, Weaknesses, Opportunities and Threats for wind energy systems which have been identified in literature[50], are presented in the following table:

STRENGTH	WEAKNESS
Wind is a source of clean energy Wind power is sustainable energy Wind power is cost effective Requires less space	Geographical limitations since they cannot be installed anywhere due to low-speed wind Fluctuation of wind speed depending on meteorological conditions and surrounding environment (buildings, high structures etc.) High initial investment Noise and aesthetic pollution
OPPORTUNITIES	THREATS
Focus given to Renewable Energy by the Governments Technology advancement which results in decreased cost, making it competitive to other conventional technologies	Largely fossil-fuel based energy sector presents obstacles for shifting focus to other renewable sources such as wind power. Endangering the wildlife

[50] F. M. Guangul and G. T. Chala, "SWOT Analysis of Wind Energy as a Promising Conventional Fuels Substitute," 2019 4th MEC International Conference on Big Data and Smart City (ICBDSC), Muscat, Oman, 2019, pp. 1-6, doi: 10.1109/ICBDSC.2019.8645604.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266

3.4 Biomass/ Biogas systems

3.4.1 Biomass/Biogas Systems - Technology scouting

Following is reported a brief scenario analysis describing patent literature trend data related to the investigated technology; i.e. biomass energy systems for electric generation and biogas based electric energy generation technologies.
The data have been extracted through the access to a database of patent literature (Derwent innovation[51]) and the utilization of specific search queries, including IPC codes in the case of patent searches. The time interval ranges from 2010 to date, even if, considering that patent applications are kept unpublished for a period of about 18 months at least, data related to 2020 are not reported in the graphs; their number can indeed be strongly influenced and underestimated due to the explained reasons.

Table 10 Search Query – Biomass based Electric Generation Technologies

Search Query - Biomass based Electric Generation Technologies
IPC=((C10B0053) OR (C10J) OR (C10L000540 OR C10L000542 OR C10L000544 OR C10L000546 OR C10L000548) OR (C10L0009))

The number of inventions extracted from the database and related to the investigated technology amounts to about 40000, when considering publications started from 2010. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:

51 https://www.derwentinnovation.com/

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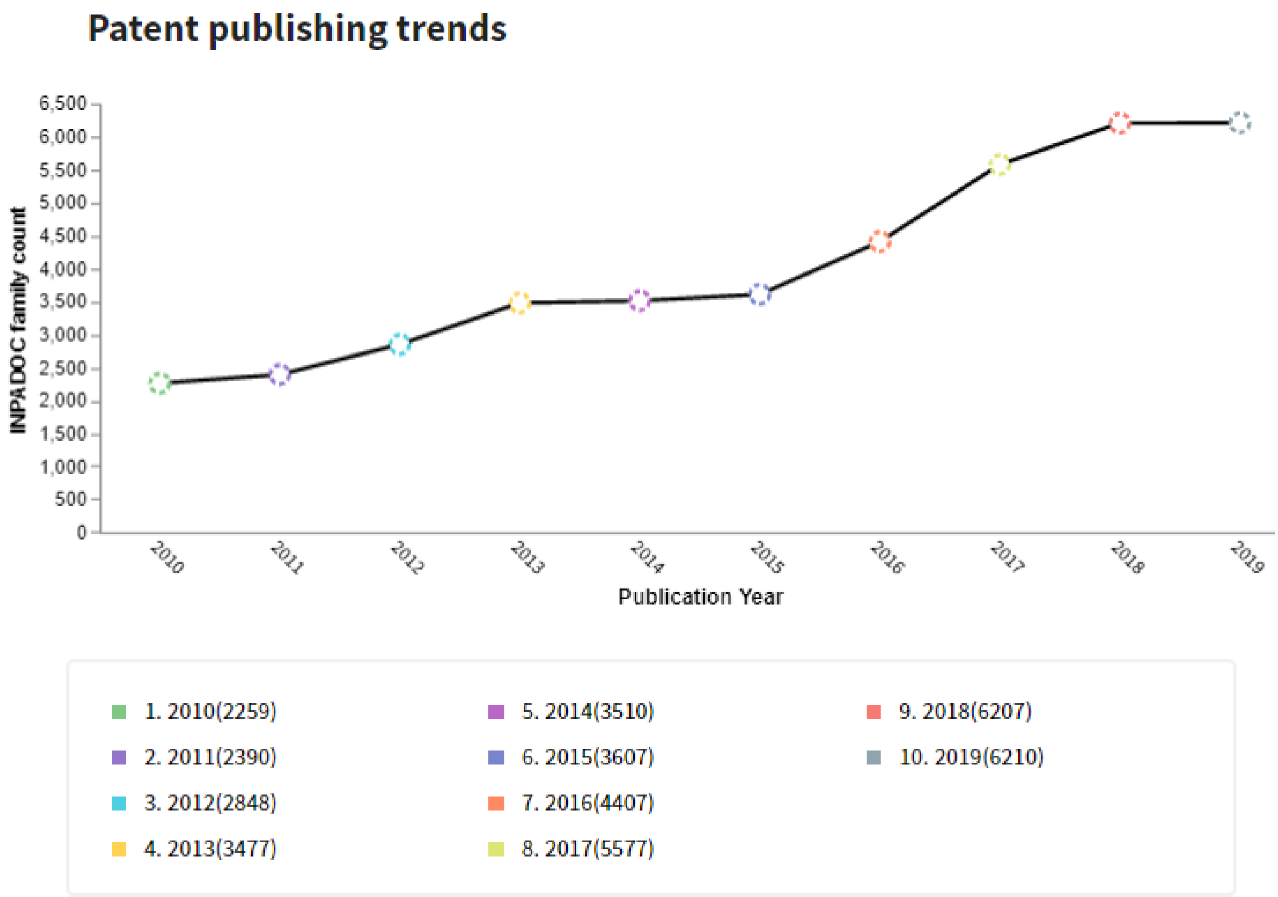

Figure 38 Biomass Electric Generation Technologies - Trend of Published Patent Documents (INPADOC families) – (2010-2019)

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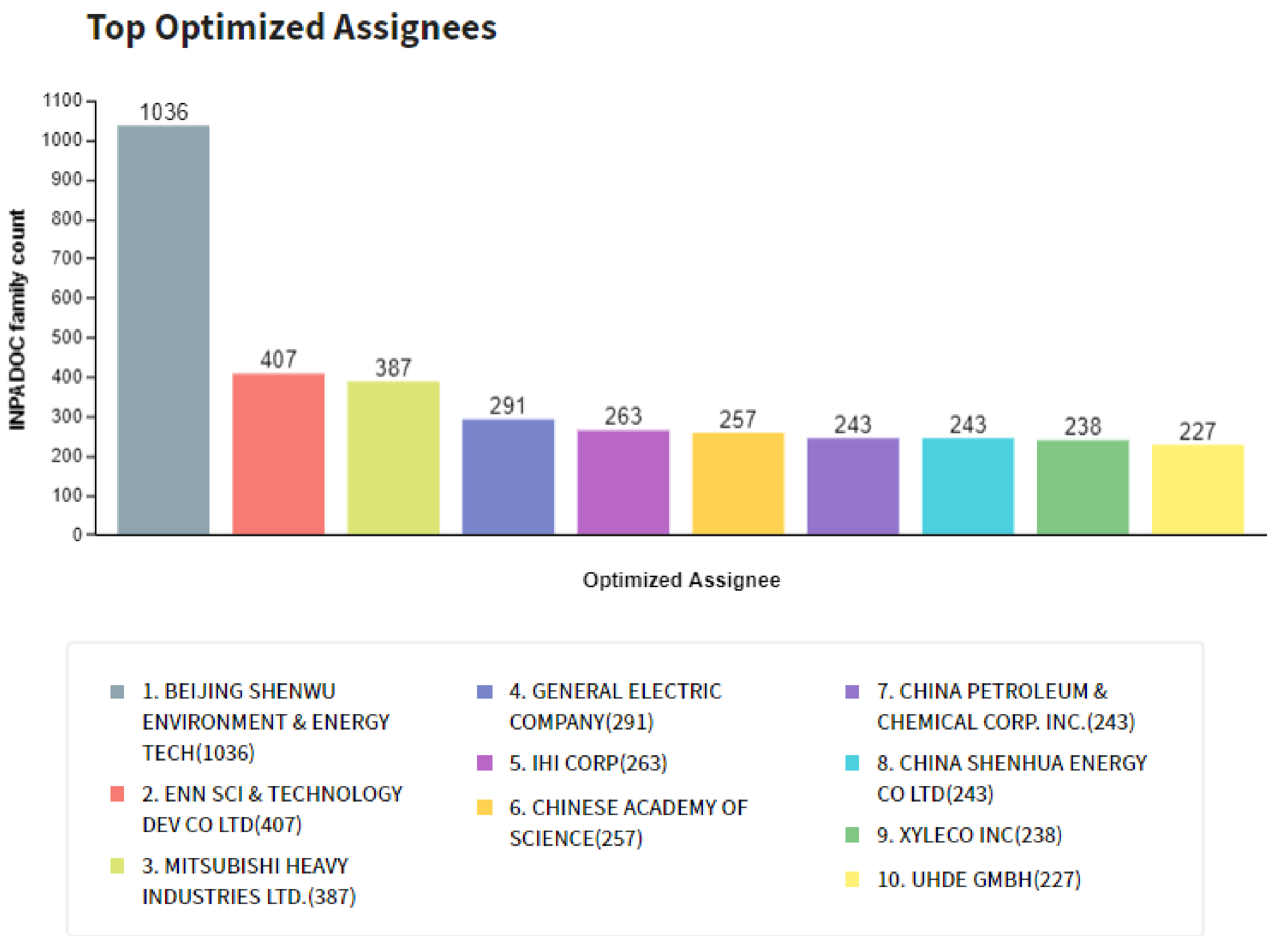

Figure 39 Biomass Electric Generation Technologies – Main Assignees of Published Patents (2010-2019)

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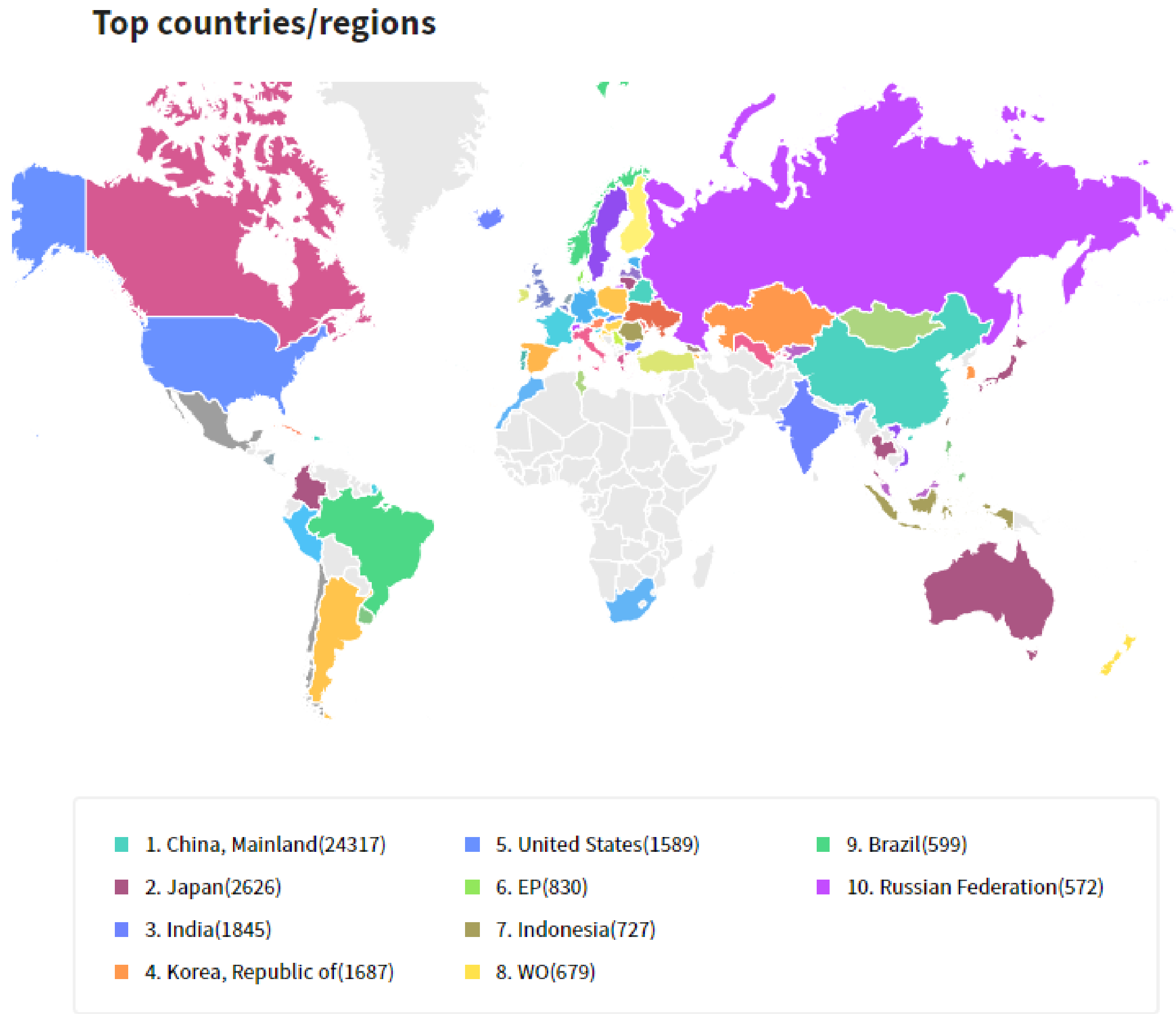

Figure 40 Biomass Electric Generation Technologies - Main Country Codes (2010-2019)

Patent publications have increased steadily with an acceleration starting in 2015; China, South Korea, United States, India and Japan are the main geographical areas where patents have been published.

Following are reported the graphs related to the biogas based electric generation technologies

Table 11 Search Query – Biogas based Electric Generation Technologies

Search Query - Biogas based Electric Generation Technologies
IPC=((C02F000328) OR (C02F001104) OR (C10L0003) OR (C12M0001107 OR C12M0001113) OR (C12P000502))

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The number of inventions extracted from the database and related to the biogas related technologies amounts to about 40000 (mostly the same number of patents as for the biomass related technologies), when considering publications started from 2010. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:

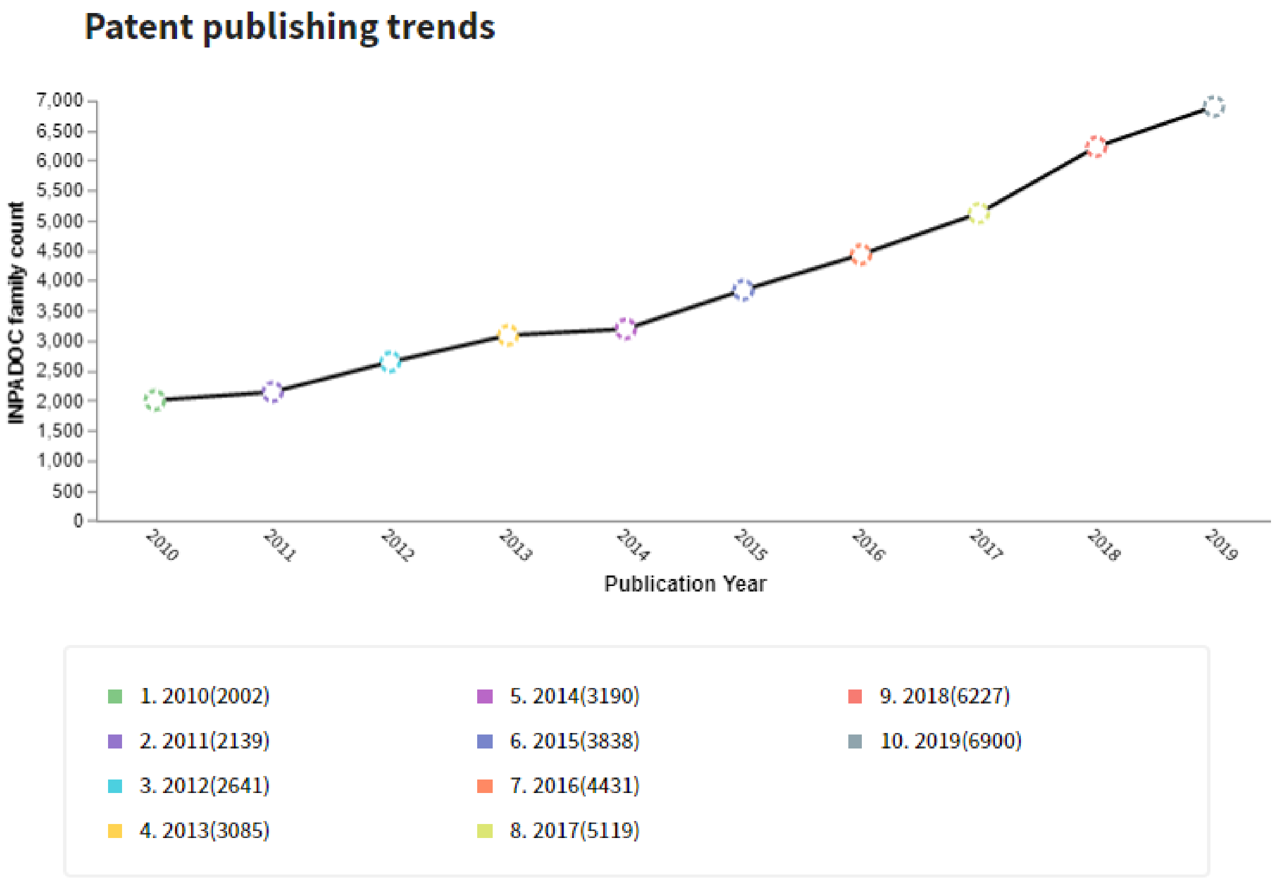

Figure 41 Biogas Electric Generation Technologies - Trend of Published Patent Documents (INPADOC families) – (2010-2019)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266

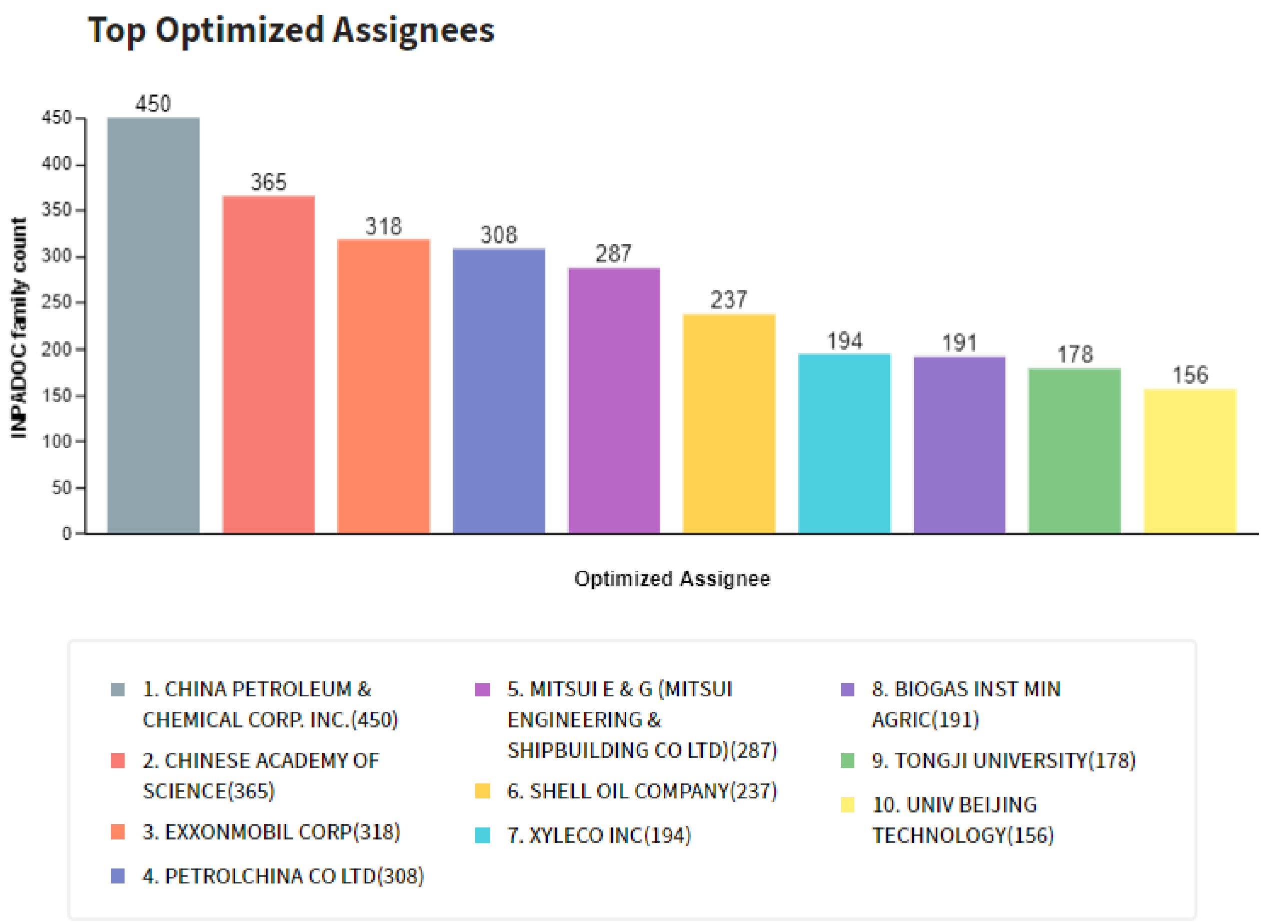

Figure 42 Biogas Electric Generation Technologies – Main Assignees of Published Patents (2010-2019)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266

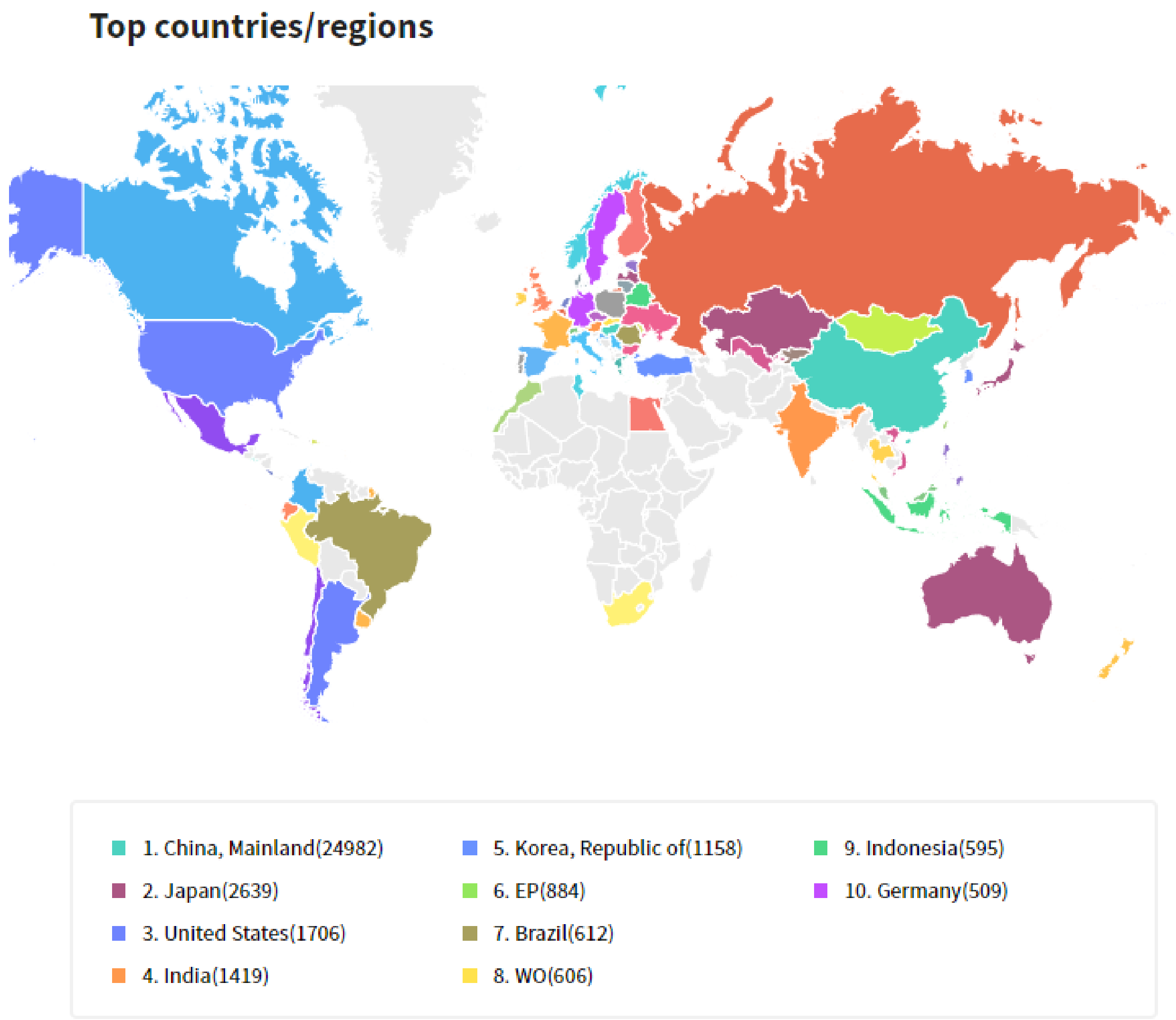

Figure 43 Biogas Electric Generation Technologies - Main Country Codes (2010-2019)

Patent publications have increased more steadily if compared with biomass technologies; China, Japan, United States and India are the main geographical areas where patents have been published.

The main advantage over other major RES, such as solar and wind energy, is that biomass can be stored and thus be used to produce power and heat on demand. In specific, biomass systems can be used in combination with the solar or wind systems, in order to balance the intermittent behavior of an electricity system[52,53].
Electricity generation technologies from biomass can be distinguished into two main categories. The first one corresponds to the direct use of raw biomass for energy

[52] Karampinis, E., et al., New power production options for biomass and cogeneration. Wiley Interdisciplinary Reviews: Energy and Environment, 2015.
[53] (IEA), I.E.A., Technology Roadmap: Bioenergy for Heat and Power. 2012.

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production, while the second one corresponds to the production of advanced biofuels such as biogas through pre-treatment/refining technologies of raw biomass (Figure 44). Additional, technologies and processes for the production of hydrogen from biomass are in development[54]. The produced biofuels can substitute fossil fuels in the energy sector. Biomass technologies can be grouped into two major categories: a) thermochemical and b) biochemical processes. Thermochemical processes are commonly applied to dry biomass fractions, while the biochemical technologies are widespread for the case of wet biomass fractions. Comparing the two categories, thermochemical processes have higher conversion efficiencies than the biochemical technologies, good destructive ability of organic compounds, and require shorter reaction times[15].

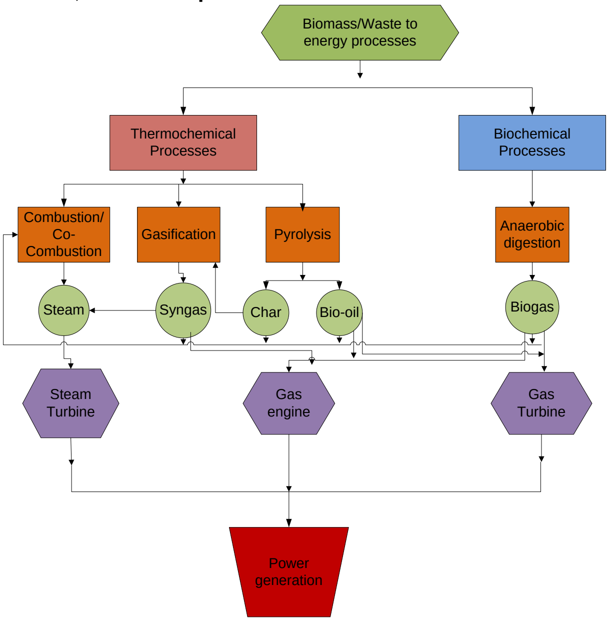

Figure 44: Categorization of biomass/Waste to energy processes

Thermochemical processes[15]

The thermochemical processes can be classified in three technologies:

- Direct combustion
- Gasification
- Pyrolysis

Direct combustion is the process that converts the chemical energy stored in biomass into heat through its full oxidation. The hot flue gas produced during the process consists of carbon dioxide, water, nitrogen, excess oxygen, and minor quantities of other compounds, such as nitrogen and sulfur oxides, carbon monoxide, and other partially oxidized chemical species. The heat generated by combustion can be used to produce electricity. It is considered the simplest conversion process with a wide range of applications from 1 MW_{th} to a number of hundred megawatts. There are three types of technologies for biomass combustion: fixed beds, fluidized beds, and pulverized fuel units (Figure 45).

[54] M. Ni, D. Y. C. Leung, M. K. H. Leung, and K. Sumathy, "An overview of hydrogen production from biomass," Fuel Processing Technology, vol. 87, no. 5, pp. 461–472, May 2006, doi: 10.1016/j.fuproc.2005.11.003.

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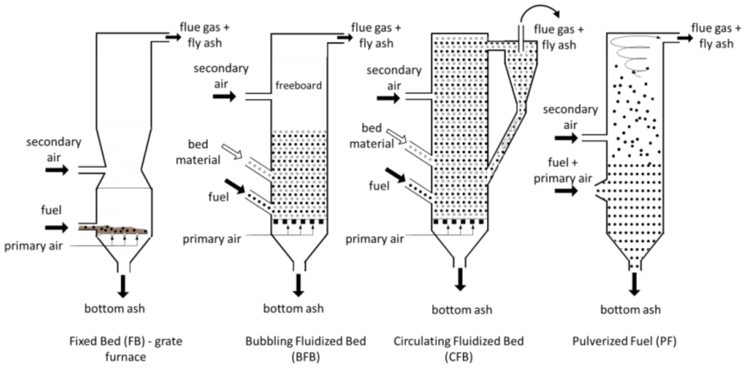

Figure 45: Principal combustion technologies for biomass[55]

Biomass gasification is a thermochemical partial oxidation process in which organic or fossil-based carbonaceous materials are converted into gas, which consists mostly of carbon monoxide, hydrogen, and the carbon dioxide in the presence of a gasification agent (air, steam, oxygen, CO_2, or a mixture of these). The gasification process is divided into two main categories, based on the heat source to the reactor: the first one is the autothermal gasification, where heat for the gasification process is provided by the partial oxidation of the fuel inside a single reactor, while the second one is the allothermal gasification, where heat is provided by an external source to the reactor. The reactors used for gasification process can be fixed beds or fluidized beds (BFBs and CFBs), such as those in Figure 45. More specifically, the fixed bed gasifiers can be distinguished as counter-current and co-current gasifiers according to the relative flow configuration between the fuel and the gasification agent. The syngas produced by the co-current gasifier has slightly higher lower heating value (LHV) and lower concentration of tars compared to the counter-current configurations. Fluidized bed gasifiers have stricter requirements in terms of fuel particle size but are more flexible in terms of operating load compared to fixed bed gasifiers[56].

In **pyrolysis processes**, the organic material of biomass is decomposed by exposure to elevated temperatures in the absence of oxygen. It involves the simultaneous change of chemical composition and physical phase. The main products of the process are gas, liquid, and char. Their relative proportion depends on process parameters such as temperature range and residence time, as well as on feedstock properties.

Biochemical Processes[15]

The biochemical conversion processes are distinguished in two categories: the fermentation process and the anaerobic digestion process. The fermentation process is a metabolic process in the absence of oxygen for production of liquid fuels, such as ethanol. This process finds commonly an application in transport sector. Anaerobic digestion fits directly to the power sector. In specific, the *anaerobic digestion* of organic material-biomass or organic fraction of waste - is a complex process, involving four degradation steps in which micro-organisms break down the biodegradable material in

[55] Loo, S.v. and J. Koppejan, The Handbook of Biomass Combustion and Co-firing. 2008, UK and USA: EARTHSCAN, London, Sterling VA.

[56] Asadullah, M., Biomass gasification gas cleaning for downstream applications: A comparative critical review. Renewable and Sustainable Energy Reviews, 2014. 40(0): p. 118-132.

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the absence of the oxygen. The main product of anaerobic digestion process is biogas which, depending on the process and feedstock, is generally composed of 48–65% methane, 36–41% carbon dioxide, up to 17% nitrogen, <1% oxygen, and traces of hydrogen sulfide and other gases.

1. One-Stage Continuous Systems: Low-solids or Wet and High solid or Dry
2. Two-stage Continuous Systems: Dry-Wet and Wet-Wet
3. Batch Systems: One stage and Two stage

The temperature range is the basic parameter for the selection of reactor and can vary according to the thermal stage between mesophilic or thermophilic area and in some cases, mainly for experimental purposes, in psychrophilic area (Table 12).

Table 12: Temperature and residence time ranges for Psychrophilic, mesophilic and thermophilic area.

Thermal stage	Temperature (°C)	Residence time (days)
Psychrophilic	<20	70-80
mesophilic	30-42	30-40
thermophilic	43-55	15-20

The biogas yield is affected by many factors including type and composition of substrate, microbial composition, temperature, moisture and bioreactor design etc. More specifically lower temperature during the process are known to decrease microbial growth, substrate utilization rates and biogas production. In contrast, high temperature lower biogas yields due to production of volatile gases such as ammonia which suppresses methanogenic activities. Moreover, a range of pH values suitable for anaerobic digestion has been reported by various researchers, but the optimal pH for methanogenesis has been found to be around 7.0. Another factor is the moisture. High moisture contents usually facilitate the anaerobic digestion; however, it is difficult to maintain the same availability of water throughout the digestion cycle[57]. Furthermore, the rate of anaerobic digestion affects the biogas yield production, through the type availability and complexity of the substrate. Different types of carbon source support different groups of microbes. Nitrogen is essential for protein synthesis and primarily required as a nutrient by the microorganisms in anaerobic digestion. Ammonia in high concentration may lead to the inhibition of the biological process and it inhibits methanogenesis at concentrations exceeding approximately 100mM. Finally, the C/N ratio in the organic material has a crucial role in anaerobic digestion. The unbalanced nutrients are regarded as an important factor limiting anaerobic digestion of organic wastes. The C/N ratio of 20-30 may provide sufficient nitrogen for the process.

Biomass/biogas systems marketing and cost trends

Between 2010 and 2019, the global weighted-average LCOE of bioenergy for power projects reduced from 0.076 $/kWh to 0.066 $/kWh – a figure at the lower end of the cost of electricity from new fossil fuel-fired projects[28]. Bioenergy for electricity generation offers a suite of options, spanning a wide range of feedstocks and technologies. Where low-cost feedstocks are available – such as by-products from

[57] Kourkoumpas, D., et al., An Environmental Assessment for Anaerobic digestion of biowaste based on Life Cycle Analysis Principles, in 3rd International Exergy, Life Cycle Assessment, and Sustainability Workshop & Symposium (ELCAS3) 2013: Nisyros, Greece.

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agricultural or forestry processes onsite – they can provide highly competitive, dispatchable electricity.

For bioenergy projects newly commissioned in 2019, the global weighted-average total installed cost was 2141 $/kW. This represented an increase on the 2018 weighted-average of 1693 $/kW[28].

Capacity factors for bioenergy plants are very heterogeneous, depending on technology and feedstock availability. Between 2010 and 2019, the global weighted-average capacity factor for bioenergy projects varied between a low of 65% in 2012 to a high of 86% in 2017.

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3.4.2 Biomass/Biogas Systems - SWOT Analysis

SWOT analysis based on literature[58,59] and other findings has been performed for biomass systems and presented in the following table:

STRENGTH	WEAKNESS
Biomass is a widely available and sustainable source of energy Biomass is a renewable energy source with lower environmental impact Large potential of forest and agricultural biomass as well as residues from agriculture and agrifood Possibility for storing biomass and using on demand Technology is developed and well established Potential for co-generation/tri-generation Potential for converting conventional technologies to biomass (co-firing or full conversion).	Geographic limitations for biomass cultivation and collection Need for long-term cultivation of energy crops There is often the need for pre-processing (conversion to pellets or briquettes) for utilization Local availability of biomass isn't always adequate, necessity for imports Sometimes feed-in tariffs are necessary, otherwise the technology is unprofitable.
OPPORTUNITIES	**THREATS**
New energy crops cultivation Potential for utilization of waste/reduction of landfills Reduced interest for fossil fuels Subsidies (feed-in tariff) provided by many governments for use of biomass Potential new source of income in the agricultural sector	Seasonal/annual price fluctuations and volatility of commodities Other competitive RES which don't require fuel Growing environmental requirements Capture and contraction of agricultural land for food

3.5 Hydropower Systems

3.5.1 Hydropower Systems - Technology scouting

Following is reported a brief scenario analysis describing patent literature trend data related to the hydro-electric power technology.
The data have been extracted through the access to a database of patent literature (Derwent innovation[60]) and the utilization of specific search queries, including IPC codes

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[58] Dragun, Łukasz. "Key strengths and weaknesses of biomass and coal combustion in cogeneration energy system." Zeszyty Naukowe. Organizacja i Zarządzanie/Politechnika Śląska (2017).
[59] Obrecht, Matevz & Denac, Matjaž. (2011). Biogas — a sustainable energy source: new possibilities and measures for Slovenia. Journal of Energy Technology. 4. 11.
[60] https://www.derwentinnovation.com/

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in the case of patent searches. The time interval ranges from 2010 to date, even if, considering that patent applications are kept unpublished for a period of about 18 months at least, data related to 2020 are not reported in the graphs; their number can indeed be strongly influenced and underestimated due to the explained reasons.

Table 13 Search Query – Hydro- Electric Generation Technologies

Search Query - Hydro- Electric Generation Technologies
IPC=((C10B0053) OR (C10J) OR (C10L000540 OR C10L000542 OR C10L000544 OR C10L000546 OR C10L000548) OR (C10L0009))

The number of inventions extracted from the database and related to the investigated technology amounts to about 43000, when considering publications started from 2010. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:

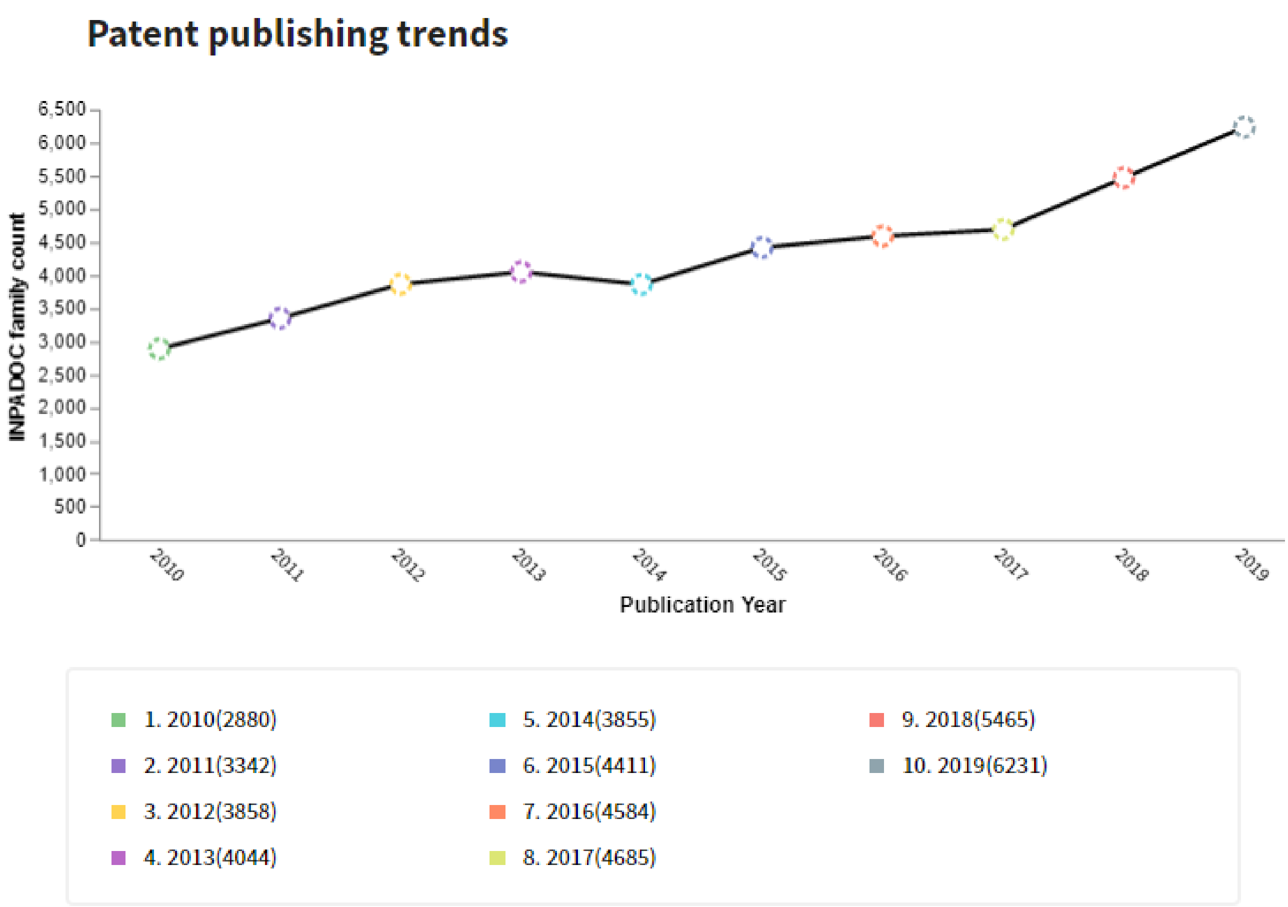

Figure 46 Hydro-Electric Generation Technologies - Trend of Published Patent Documents (INPADOC families) – (2010-2019)

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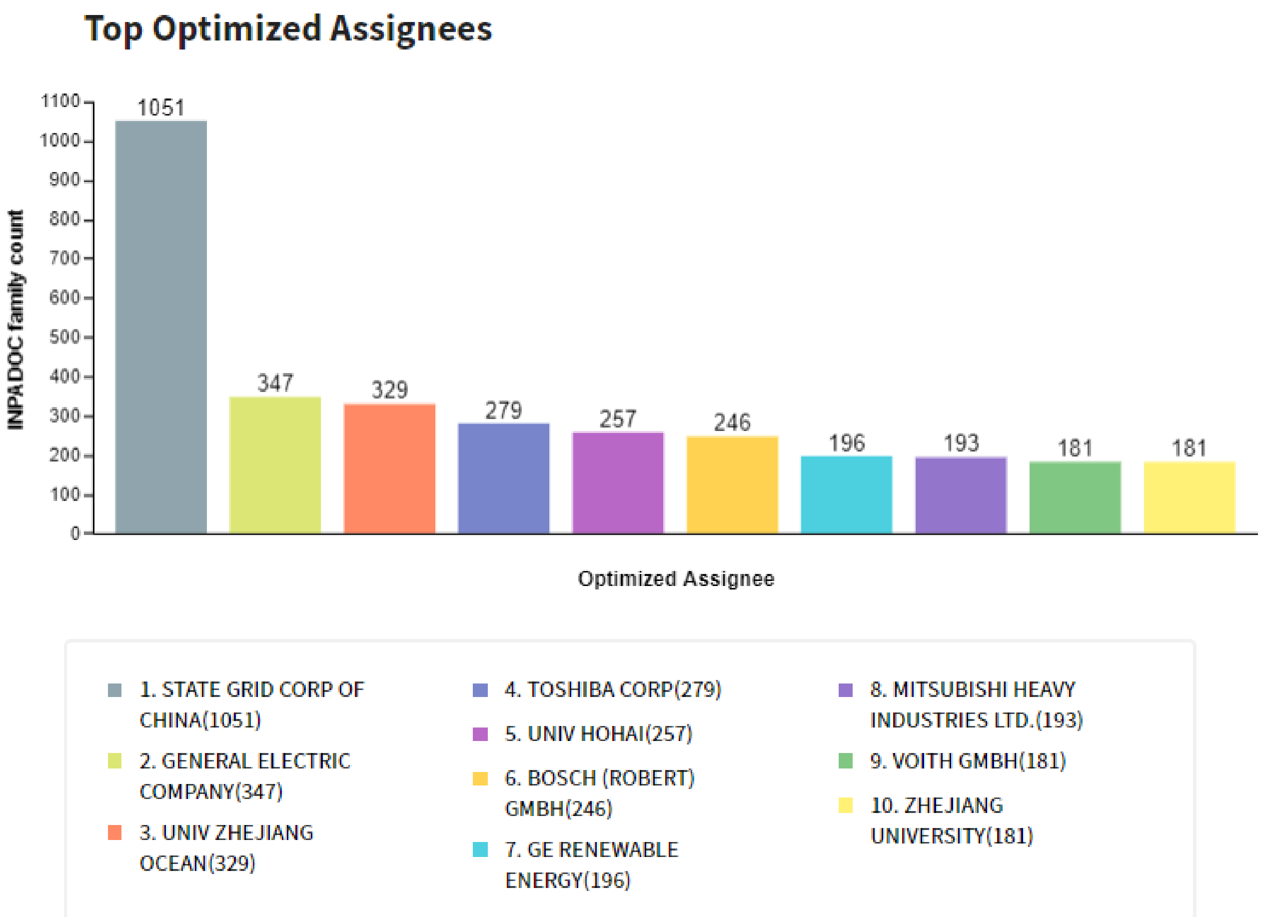

Figure 47 Hydro-Electric Generation Technologies – Main Assignees of Published Patents (2010-2019)

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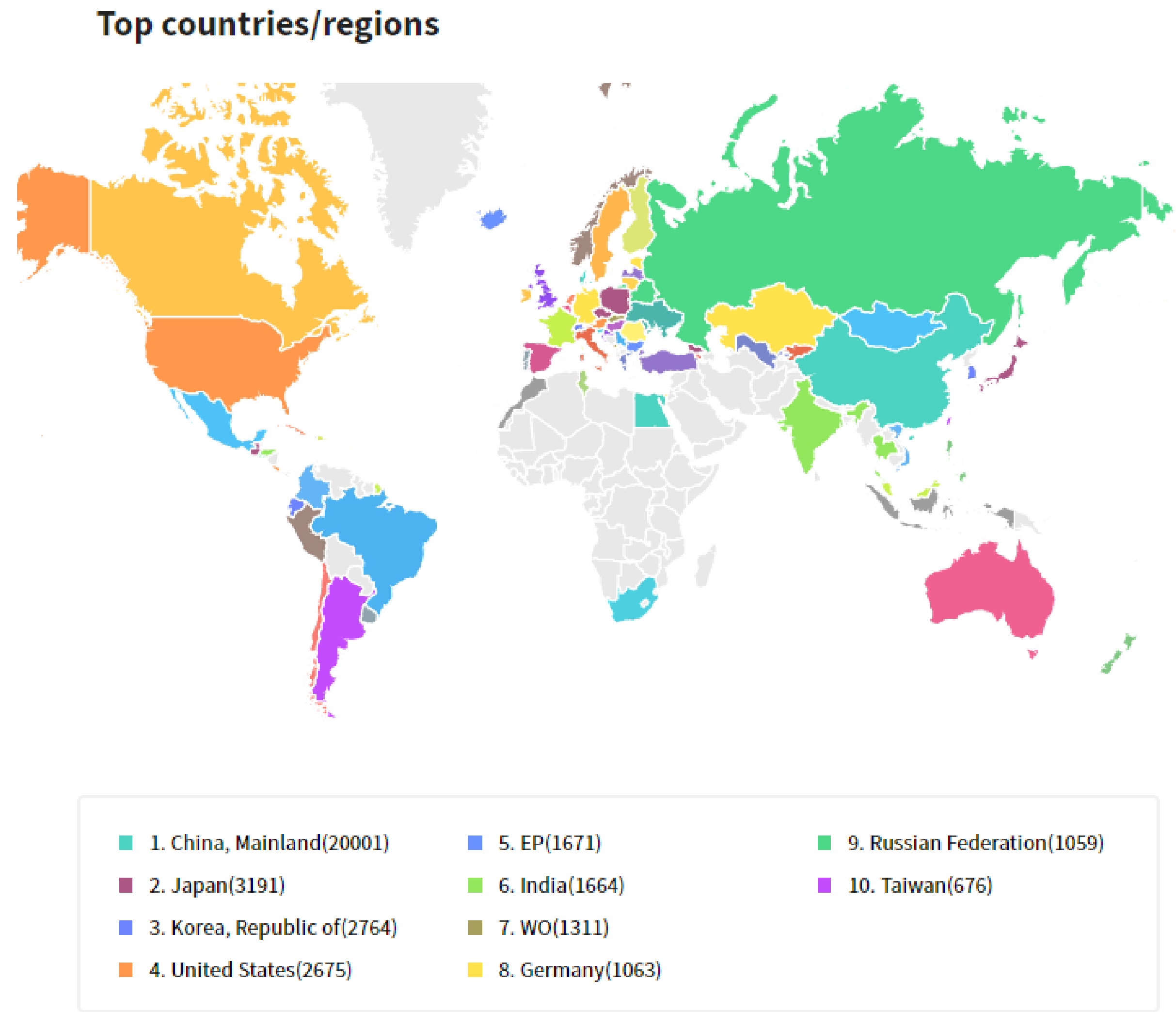

Figure 48 Hydro-Electric Generation Technologies - Main Country Codes (2010-2019)

Patent publications have increased steadily in the considered time interval; China, South Korea, United States, Japan and the European Office are the main geographical areas where patents have been published. Strong is the role of Chinese companies (especially state-owned), but remarkable is even the number of patents published by General Electric.

Hydroelectric or hydro power systems are called the hydrodynamic systems that generate electricity by exploiting the kinetic and dynamic energy of water. The first categorisation takes places regarding the system power. There is not an acceptable definition on which power unit is a large or a small one[61] as usually, since the classification is based primarily according to each country legislation. A common classification categorize the large systems to be those with installed power higher than

[61] J.-C. Sabonnadière, Ed., Renewable energies. Hoboken, NJ: ISTE Ltd/John Wiley & Sons, 2009.

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15 MW_e, the small systems those with installed power greater than 1 MW but lower than 15 MW_e, and all the systems lower than 1 MW_e are consider to be micro hydro systems.
Another common categorization is based on the net head. Usually systems with head lower than 30 m are classified as low head, with heat from 30 m to 150 m are classified as medium head and higher than 150 m are classified as high head.
Finally, the last classification can be made between systems with the existence of water reservoir (Figure 49) or not (Figure 50). There are some systems with small reservoirs for balancing purposes only.
Usually small and micro hydro systems are constructed without reservoirs and they are placed in rivers runoff or in rivers with small balancing dams.
Small and micro hydro systems with small reservoirs or river runoff are consider as RES.

Figure 49: A typical medium size Hydropower plant with reservoir. Penstock (left) and Dam (right) (MYHS Ladonas, Greece)[62].

The most important component of a hydropower system is the turbine. There are three main turbine types (Figure 51):

- Pelton
- Francis
- Kaplan

Figure 50: A micro hydropower plant in the island of Crete (MYHS Almyros, Chania Crete, Greece)[63]

[62] "Τεχνητή λίμνη Λάδωνα." [Online]. Available: http://www.inarcadia.gr/tourism/fo/liladona/index.htm.
[63] "ΜΥΗΣ ΑΛΜΥΡΟΣ, ΧΑΝΙΑ ΚΡΗΤΗ." ppcr.gr, [Online]. Available: https://www.ppcr.gr/el/hydroelectric/almyros-chania-kriti.

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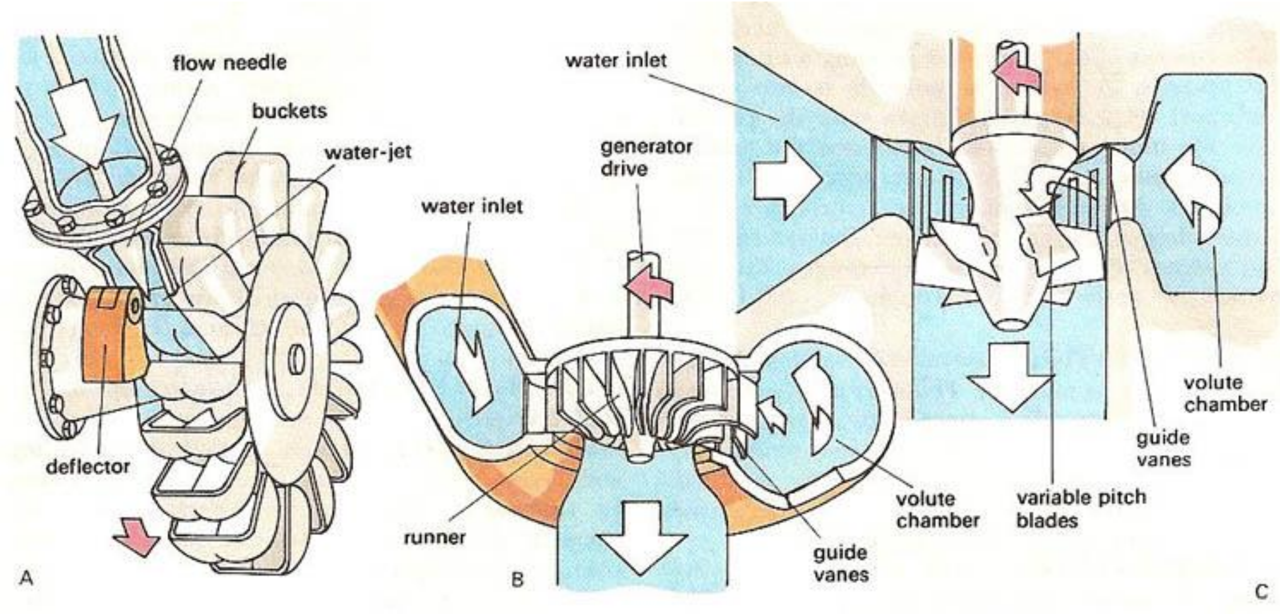

Figure 51: The three main types of hydro turbines: A) Pelton; B) Francis; C) Kaplan[64].

Each turbine type extracts power from the water in a different way (e.g. working principle in terms of fluid mechanics) which makes a turbine more suitable than other, in terms of efficiency. Selection criteria are based on the set Head and water Flow. In general, Kaplan turbine is more efficient in low head and small to medium flow, Francis is more suitable for medium to high flow and for medium to high net head and Pelton is suitable for high net head and low to medium flow (Figure 52).

Hydropower marketing and cost trends[28]

Global installed hydropower capacity (excluding pumped hydro) was 1,189 GW at the end of 2019. The global weighted-average LCOE of newly constructed hydropower projects in 2019 was 0.047 $/kWh, 6% higher than the 0.045 $/kWh recorded in 2018 and 27%, higher than the projects constructed in 2010. In 2019, the global weighted-average total installed cost of newly constructed hydropower projects increased to 1704 $/kW, 17% higher than in in 2018. This increase is explained by the lower share of deployment occurring in China (3.8 GW in 2019) and the higher share of installed capacity deployment in other countries/regions with higher average installed costs. In Brazil, 4.6 GW was added in 2019, while there was also a higher share of deployment in Africa and other Asian countries in 2019 compared to 2018 – all locations with higher than average installed cost[28].

[64] Courtesy of Schenck Trebel Corp.

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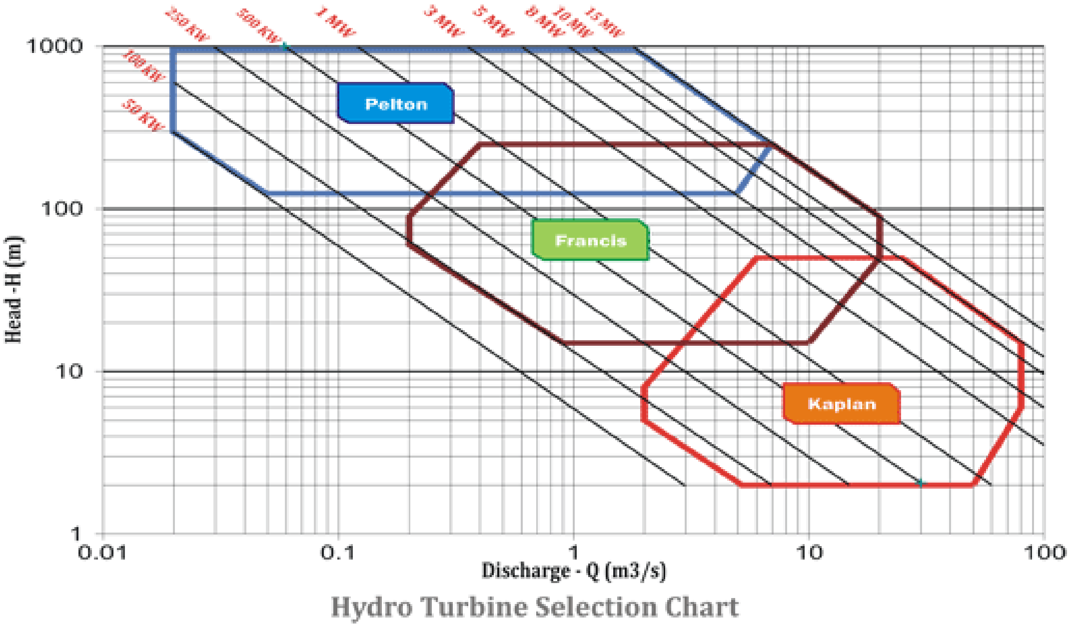

Figure 52: Hydro turbine selection chart for different sets of Head and Flow (Discharge)[65]

[65] "ABOUT HYDROPOWER." Energy Development Company Limited (EDCL), [Online]. Available: http://www.edclgroup.com/who-we-are/about-hydropower/

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3.5.2 Hydropower Systems - SWOT Analysis

The Strengths, Weaknesses, Opportunities and Threats for hydropower systems which have been identified in literature, are presented in the following table:

STRENGTH	WEAKNESS
Dispatchable and easy to control - high response time Reliable and mature technology Water is not degraded and can be used for other purposes such as irrigation and water supply Low M&O cost Zero CO2 emissions Long Life duration	High installation cost Licensing process might be complex due to water use permit Water quantity has important seasonal variations and hydrological years have variability Large area needed (In case of systems with reservoir)
OPPORTUNITIES	**THREATS**
In cases of small dams, habitats are created Water use and water pollution awareness to the local people Cooperation through river committee Possibility for recreational activities and tourism promotion	Structural problems may occur in construction Social acceptance Landscape downgrading Climate change might have negative impact on water cycle and thus, energy production

3.6 Geothermal Systems

3.6.1 Geothermal Systems - Technology scouting

Data on patent publications are reported in the paragraph related to geothermal heat generation, where a major number of patents is present in order to depict trend graphs (Paragraph 4). However the technologies that patents illustrate in the field of geothermal generation technologies can be referred both to electric and heat generation purposes. Specifically the patents are related to the he use of the heat and the production of mechanical power from geothermal energy.

Geothermal energy is called the thermal energy which contained on Earth. The term **geothermal energy production** includes all the processes of exploitation of geothermal energy in domestic, rural or industrial level. Its origin is a combination of two natural phenomena. The first concerns the slow cooling of Earth's molten metals outer core, while the second concerns the heat that produced by the natural radioactivity of materials at depths up to 30 km from the surface of the Earth.

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Geothermal exploitation is achieved by using drillings for access to the heat source (geothermal fluids). With the use of heat exchangers, geothermal energy can then be used, directly as heat or for electricity generation or even for cooling.
The enthalpy of geothermal fluids is the most important categorization parameter on potential intensity and consequently defines the technologies that can be used in each case. In general, geothermal fields/sources are divided into:

- high enthalpy: >160 °C
- medium enthalpy: >90 C and <160 C
- low enthalpy: >30 C and <90 C
- very low enthalpy: <30 °C

High and medium enthalpy fields are suitable for electricity generation, medium and enthalpy for heating purposes in agricultural activities, district heating or other industrial activities and very low enthalpy are used in heat pumps for cooling and heating spaces.
The exploitation of a geothermal field, for heat production with purpose of space heating or use in processes is the most common application of geothermal energy.

Geothermal Desalination in the Island of Kimolos

View of the geothermal unit desalination plant of Kimolos. The condenser on the left and one evaporator on the right side

Kimolos is one of the arid islands of the Cyclades which cannot meet its needs in drinking water. In the period 1997-98, as part of a research project, a desalination unit using MED (Multiple - Effect Distillation) was installed on the island exploitation a low enthalpy geothermal fluid about 61 °C.

The desalination method was distillation in vacuo (ie at low pressure). The production rate of drinking water was 3.24 m^3/h while the use of geothermal fluid reached 50 m^3/h. An important feature of the unit was that in addition to seawater, the unit could desalinate the geothermal fluid itself, if it had the appropriate characteristics.

The suitable technologies for each temperature can been found in the literature in the so-called Lindal tables (Figure 53).

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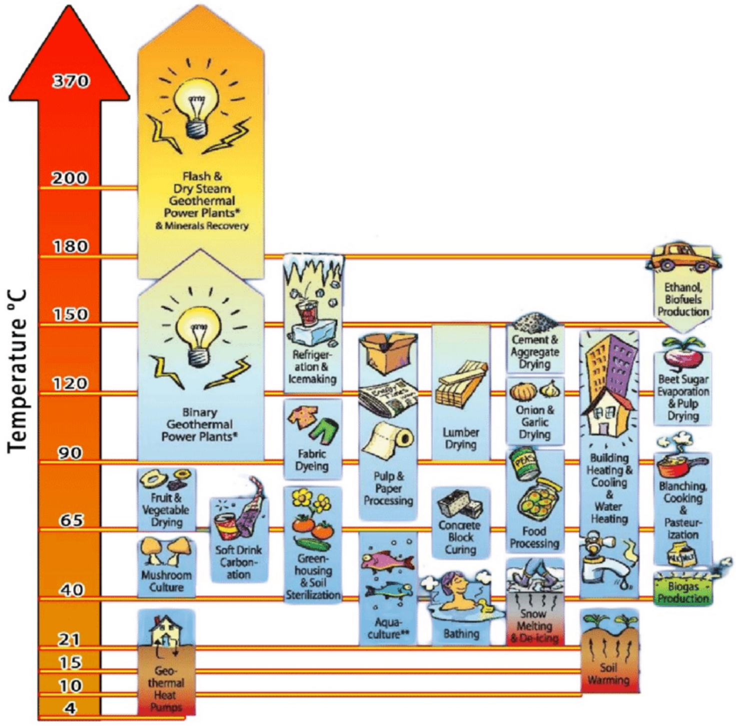

Figure 53: A Lindal table that correlates the geothermal enthalpy level with the applications.[66]

Geothermal Exploitation for Electrical Energy Production

Generating electricity using geothermal energy can carried out with conventional steam turbine units or with binary cycle units. The choice of technology is based on available enthalpy. **Today, geothermal systems generate electricity covering 0.5% of global electricity needs**. The advantage of these systems is that as the power supply does not change and can work continuously achieving operating rates more than 70%.

In the simplest case, the liquid steam coming out of the geothermal source, is separated and enters directly into the conventional steam turbine (open circuit). Conventional steam turbines require fluid temperature at least 150 ºC. The steam after the turbine is released to the environment. Generally, these units are not very efficient due to low operating pressure. But they have the advantage of fast and cheap construction.

The second variant concerns condenser units. The main difference is that the steam after the turbine is directed to a condenser with a cooling tower. These units are much more efficient but cost effective much more since they have more complex layouts and more equipment.

For the exploitation of the geothermal sources of medium enthalpy, the closed-circuit solution is selected. The geothermal fluid does not enter in the turbine but in a heat exchanger and vaporizes an organic fluid (usually n-pentane) which has a low vaporization temperature and high vapor pressure at low temperatures relative to water. The organic circuit works like a typical Rankine cycle.

Geothermal Exploitation for Heat

66 T. Miklovicz, “Investigation on the potential of combined heat, power and metal extraction in Hungary,” 2014, doi: 10.13140/RG.2.2.34823.19367.

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The production of heat is the most direct form of exploitation of geothermal fluids. It usually includes low enthalpy fluids that do not allow electricity production. These fluids are either extracted directly from geological reservoirs, or they come from geothermal electric power plants (thermal effluents). In this latter case, the installation is a device for geothermal cogeneration.

Heat does not hold up economically under long distance transportation; this energy production lends itself to uses than can be located near the source (several kilometers). Urban heating by heat network is, on a worldwide scale.

Geothermal fluid extracted from the ground may be reinjected into the aquifer where it originated by means of a second well (geothermal doublet). A heat exchanger is placed between the circuit of geothermal fluid and the heat distribution network. The transfer of heat is made at the level of this exchanger, then the geothermal fluid is sent back to its natural reservoir

A geothermal district heating system is characterized by three main components: the geothermal doublet, the heat distribution system and the final customer. The geothermal doublet comprises two wells drilled into the ground until they reach the reservoir's depth, where the hot water is located.

One of the wells is the production well, which is used to pump the hot water up from the aquifer with an electric submersible pump located inside the wellbore. The other well is used to pump the cold water back into the aquifer so that a closed loop between production and injection is created. Both wells are drilled in the same location but deviated along their depth 1.5-2 km apart[67].

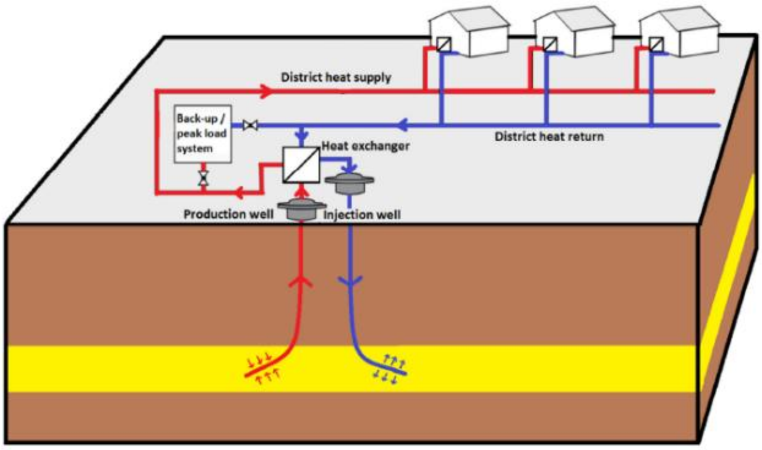

Figure 54: Geothermal District Heating

Geothermal Exploitation for Heat through Heat Pumps

Geothermal heat pumps they have the same operating principle as the simple heat pumps with only difference that they use the ground as heat intake/discharge tank. Their heat exchanger is installed at shallow depths, usually a layer between 0 and 100 m, whose temperature is usually between 10 and 15 °C depending on the geographical location. At the same time, due of the climate and geographical location of

[67] J. F. A. da Silva Pinto, "Refurbishment measures versus geothermal district heating for residential buildings in the Netherlands.pdf," Universidade De Lisboa, Lisboa, 2016.

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our country, solar thermal energy maybe stored in the subsoil is makes it possible exploitation of much larger amounts of energy.
The operation of a thermodynamic conversion device makes it possible to make use of the energy of the ground in order to bring it to the temperature levels that are usable for covering heating and/or cooling needs. The heat pump system exploits the energy from low temperature ground to ensure heating and/or air conditioning needs under satisfactory energy and environmental conditions. This is an efficient energy option for ensuring comfort needs.
A heat pump makes it possible to extract energy from a low temperature heat source (called a cold source) and to reinsert it at a higher temperature in a heat sink (called a hot source). The heat pump is made of a closed circuit in which is circulated a refrigerant that changes state according to the components it passes through (Figure 55):

1. the heat removed from the exterior is transferred to the refrigerant fluid, which evaporates
2. the compressor takes in the vaporized refrigerant fluid,
3. the compression raises the temperature of the refrigerant fluid,
4. the refrigerant fluid gives off its heat to the heating circuit,
5. the refrigerant fluid condenses and returns to a liquid state,
6. an expansion valve lowers the pressure of the refrigerant fluid, which goes on to begin the cycle again.

The attraction of the system resides in the fact that the energy necessary for the transfer is recovered and added to what has been taken out of the cold source.

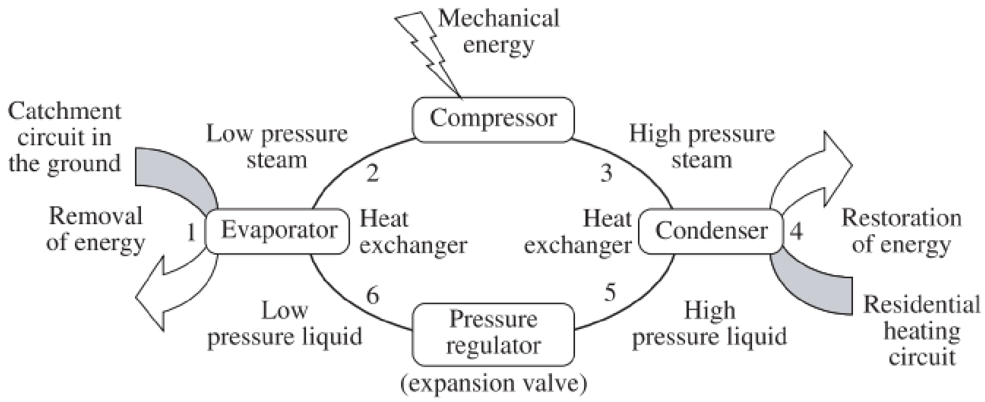

Figure 55: Geothermal Vapor Compression Heat Pump Cycle. Heat production case.

There are various heat pump systems based on the basic operating principle, with different performance and application possibilities.
In the geothermal heat pumps, the extraction of heat is carried out in the soil, the ground or groundwater.
Some procedures for energy collection have been developed by the manufacturers. The main difference is associated with the nature of the fluid circulating in the collectors and emitters of heat, and therefore the technology of the heat pumps used:

- heat pump with fluid intermediary, constituting three circuits:

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    - the closed circuit of the refrigerant of the heat pump
    - the collector circuit or subterranean water (usually water with an antifreeze product added)
    - the circuit that supplies the emitters with hot water
- heat pump with direct contact, made of a single circuit: the refrigerant circulates in the heat pump, the collectors and the emitters of heat
- mixed heat pump, made of two circuits
    - the circuit of the refrigerant of the collectors and the heat pump
    - the circuit of hot water of the emitters

All the various configurations are summarized in Table 14:

Table 14: Geothermal heat pump configurations.

Type of catchment	Liquid collector	Type of HP	Emitter fluid	Designation
Horizontal buried collectors	Fluid refrigerant	HP with direct contact	Fluid refrigerant	Soil/soil
	Fluid refrigerant	Mixed HP	Water	Soil/Water
	Glycol water	HP with intermediary fluid	Water	Glycol water/water
Vertical Buried Collectors	Glycol water			Glycol water/water
	Water (in the case of deep collectors)	HP with intermediary fluid		Water/water
Ground Water	Water	HP with intermediary fluid		Water/water

The energy compensation required to ensure passage of thermal energy from a cold source (low temperature) to a hot source (higher temperature) may be supplied:

- in mechanical form: these are compression heat pumps; the energy compensation corresponds to the mechanical energy supplied to the compressor (electric or gas motor, etc.),
- in thermal form: these are absorption heat pumps; they are most often used to produce cold. The energy compensation is put into play by using, in one part of the system, the phenomenon of absorption of a gas in a fluid and, in the other part, the inverse phenomenon of desorption (the pairs most used now are ammonia-water or lithium bromide-water).

Electric compression heat pumps are currently used almost exclusively for low to medium power geothermal heat pump devices. The choice of a heat pump depends on the application (heating, heating and cooling, etc.), the type of building (new, renovated) and its use (housing, service sector, industry or agriculture, for greenhouse heating or fish culture, for example).

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Geothermal systems marketing and cost trends

The deployment of geothermal power plants remains modest, with the 682 MW_e added in 2019 a new record. The global weighted-average LCOE of the projects commissioned in 2019 was 0.073 $/kWh, broadly in line with values seen over the last four years[28].
Annual new capacity additions for geothermal were 225 MW_e in 2010, 89 MW in 2011, 400 MW in 2012 and 237 MW in 2013. As a result, just a handful of projects often determined the weighted-average costs in these years. However, since 2014 new additions have been at least 440 MW per year and trends have been more stable.
Between 2014 and 2019, total installed costs increased from 3570 $/$kW_e$ to 3916 $/$kW_e$. In 2019, the total installed costs for most of the newly installed plants spanned the range 2000 to 5000 $/$kW_e$. In 2019, the global weighted-average capacity factor for newly commissioned plants was 79%. For the years 2007-2021, the data from the IRENA Renewable Cost Database proposes that over the next couple of years, the global weighted-average LCOE could decrease to just over 0.05 $/kWh in 2021. However, this will depend on whether projects meet their commissioning goals.
Geothermal Heat Pump Market size in 2017 was valued at over 3 billion $ and the annual installation is projected to exceed 720,000 units by 2024.

3.6.2 Geothermal Systems – SWOT Analysis

Gathering all the Strengths, Weaknesses, Opportunities and Threats of the geothermal systems based on existing literature, the following SWOT analysis is presented in the following table

STRENGTH	WEAKNESS
A reliable and constant source of energy High Capacity Factor High Efficiency of Geothermal Systems Zero emissions Good for Heating and Cooling and for Co-generation Not related with weather conditions Proven technology can attract financing	Surface instability High cost of electricity High installation cost Geographical Constraints Unpredictable environmental issues (e.g. Sulfur) Resource assessment high cost (seismic surveys, test wells etc)
OPPORTUNITIES	**THREATS**
Huge untapped potential Heat pump installation is subsidized	Lack of Technical Expertise Availability of better alternatives Unsuccessful estimation of geothermal potential

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4 Thermal energy renewable technologies

4.1 Geothermal energy generation[68] [69] [70] [71]

Following is reported a brief scenario analysis describing patent literature trend data related to geothermal energy generation technology. A said at the beginning of Paragraph 3.6, patents are related to the use of the heat and the production of mechanical power from geothermal energy, but the innovative technologies can in some cased considered to be appliable to the production of electric energy.
The data have been extracted through the access to a database of patent literature (Derwent innovation[72]) and the utilization of specific search queries, including IPC codes in the case of patent searches. The time interval ranges from 2010 to date, even if, considering that patent applications are kept unpublished for a period of about 18 months at least, data related to 2020 are not reported in the graphs; their number can indeed be strongly influenced and underestimated due to the explained reasons.

Table 15 Search Query – Geothermal energy Generation Technologies

Search Query - Geothermal energy Generation Technologies
IPC=(F24T or (F24T and F01K) or (F24T and F24F000500) or (F24T and H02N001000) or (F24T and F25B003006) or F03G 4/00 or F03G 4/02 or F03G 4/06 or F03G 4/04)

The number of inventions extracted from the database and related to the investigated technology amounts to about 3000, when considering publications started from 2010. The number is significantly less numerous to the other renewable energy technologies where patent data have been extracted. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:

[68] Environmental%20impacts%20geothermal%20energy/8.1.GE%20vs%20Environment.pdf
[69] https://www.eia.gov/energyexplained/geothermal/geothermal-power-plants.php
[70] https://www.egec.org/unlocking-potential-geothermal-energy-islands/
[71] https://adventures.is/information/geothermal-energy-iceland/#:~:text=%20Fun%20Facts%20about%20Geothermal%20Energy%20in%20Iceland,are%20known%20for%20their%20long%20showers%20More%20 GECO Project
[72] https://www.derwentinnovation.com/

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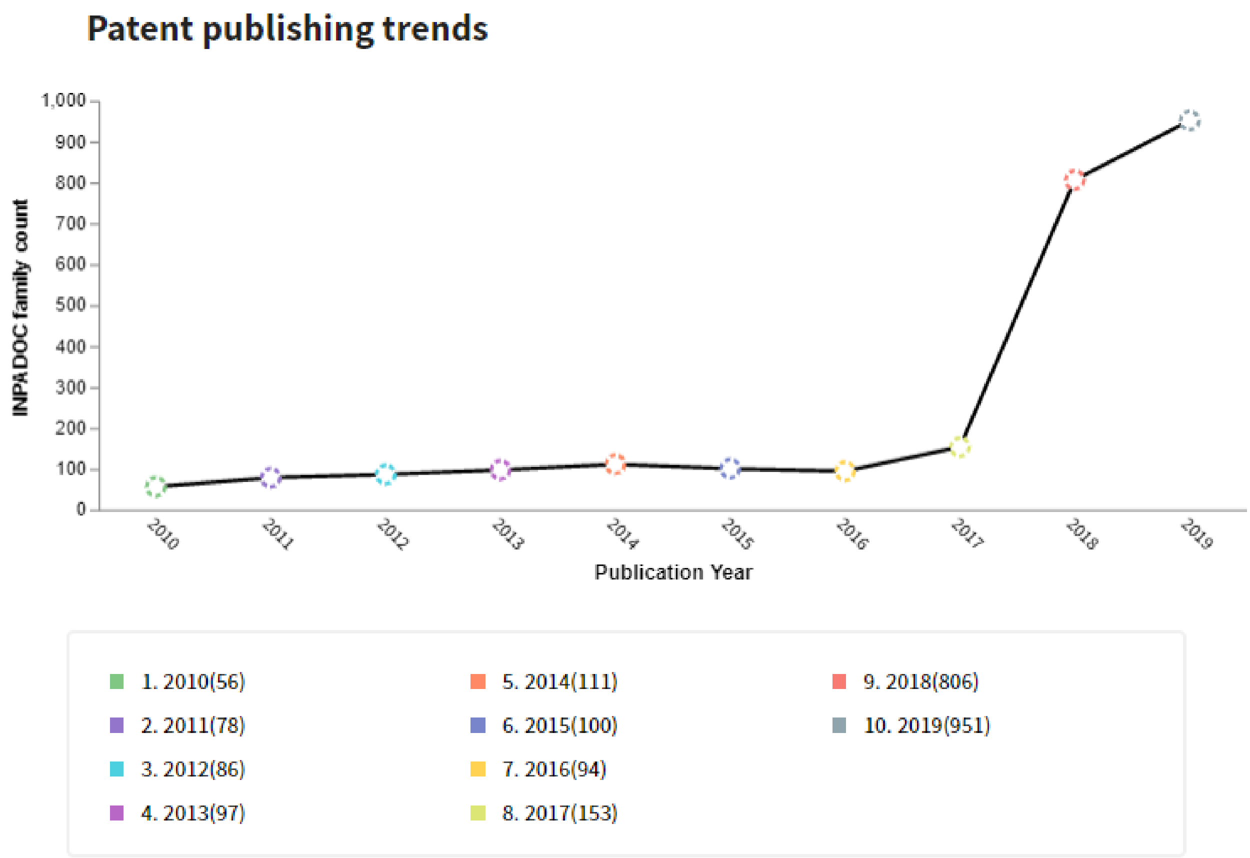

Figure 56 Geothermal energy Generation Technologies - Trend of Published Patent Documents (INPADOC families) – (2010-2019)

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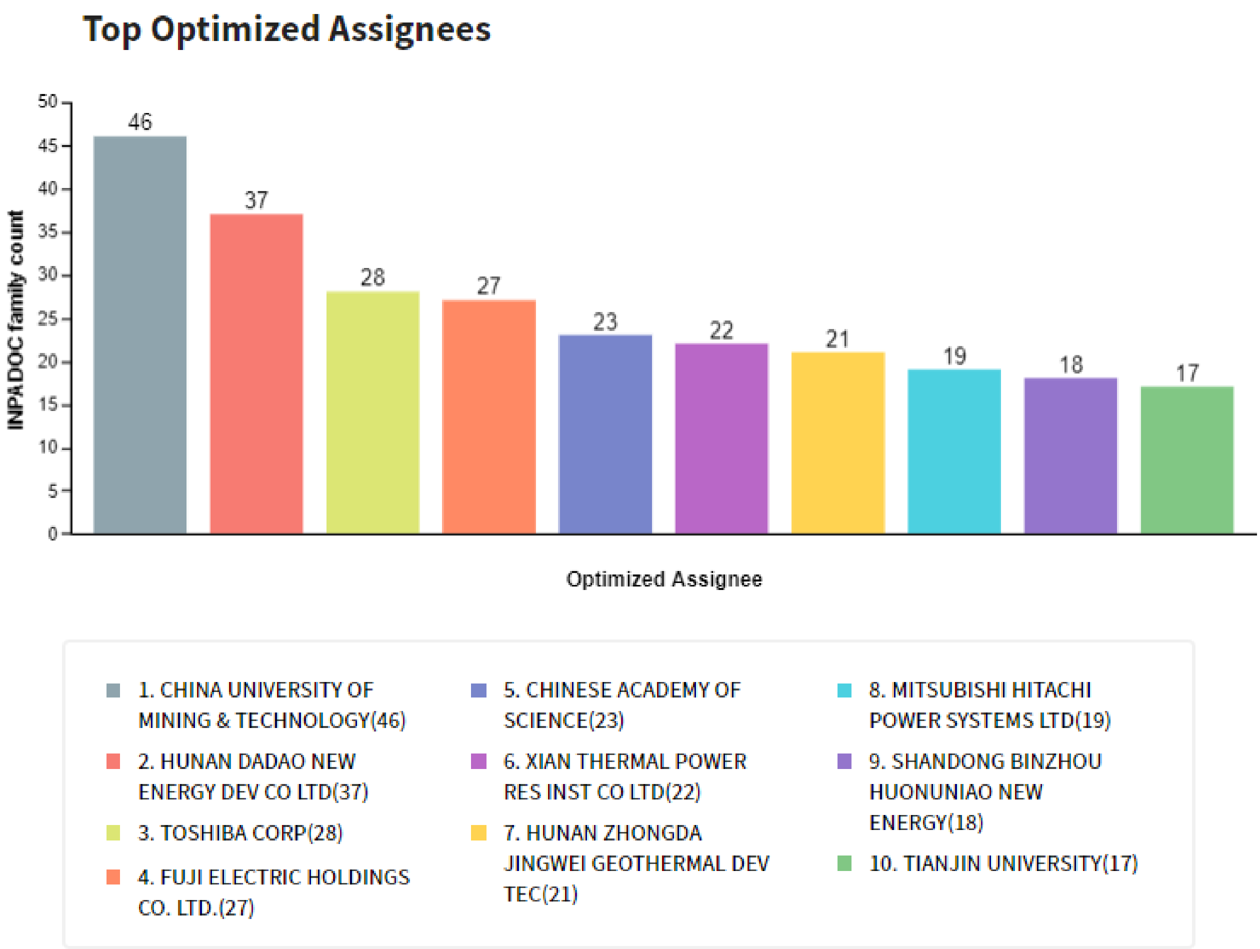

Figure 57 Geothermal energy Generation Technologies – Main Assignees of Published Patents (2010-2019)

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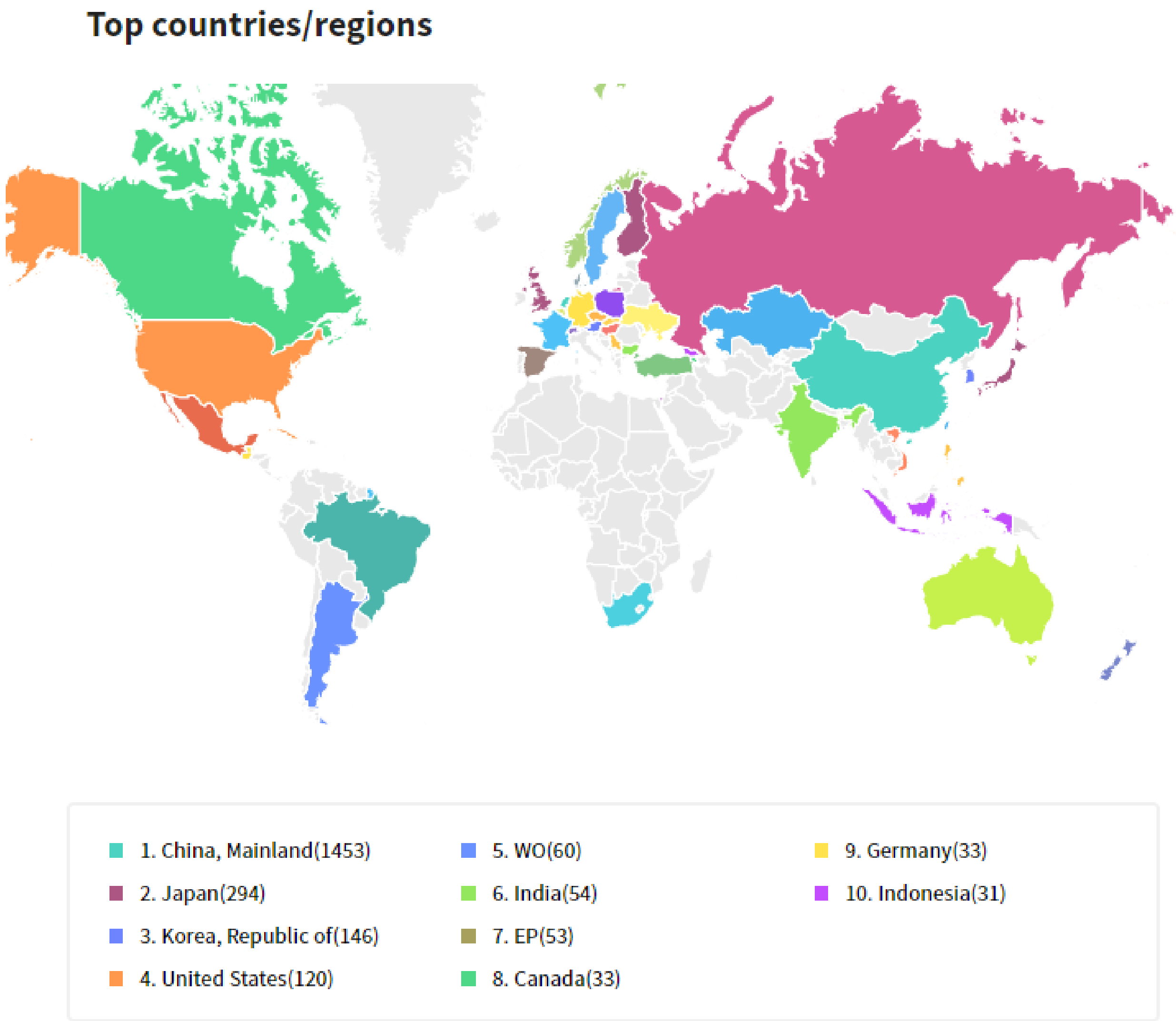

Figure 58 Geothermal energy Generation Technologies - Main Country Codes (2010-2019)

Patent publications started to really increase only in 2016, where a sudden high number pf patents have been registered; China, South Korea, United States, Japan and the WIPO Office are the main geographical areas where patents have been published. Main assignees are mainly Chinese or Japanese companies.

According to the International Panel on Climate Change (IPCC), geothermal energy is defined as a renewable resource if the utilization rate is in balance with the natural heat rate and the recharge of fluids to the geothermal well.

Geothermal resources are extracted from specific sites associated with permeable sites with the presence of geothermal fluids. Most geothermal deposits are underground, well below groundwater deposits. Geothermal power plants use hydrothermal resources that have both water (hydro) and heat (thermal). Geothermal power plants require medium or high temperature (150 ° C to 400 ° C) hydrothermal resources (low or high enthalpy) that come from dry steam wells or hot water wells that are drilled or reach the earth's

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surface Naturally, the geothermal fluid is channeled to the surface, then this fluid powers a turbine to generate electricity.

Natural geothermal fluids contain varying concentrations of potentially toxic minerals and other elements, such as uncondensed gases, that are at extremely high temperatures when they reach the earth's surface. Due to the above, the geothermal fluids used to generate electricity are re-injected into the geothermal deposits and their release is not allowed in the surface waterways. When geothermal fluids are re-injected into a geothermal system, the fluids are isolated from the shallow groundwater by thick coating on the wellbore. Injection is generally done in separate wells that are designed to properly handle the nature and characteristics of injection fluids.

European islands with volcanic nature are likely potential for energy transition through geothermal development. As this type of energy present a sustainable, competitive and stable form of electric and thermal energy generation. Mostly in high seasonality islands this type of energy could be able to cover the demand on heating and air conditioning in hotels and other facilities, even for recreational uses and for other applications.

This potential, however, remains largely untapped. In the Spanish Canary Islands, for example, only a few facilities make use of geothermal energy, despite the long debate over the development of geothermal energy for many years. All the Canary Islands underestimate and do not take advantage of their enormous geothermal potential, although some of them offer many options to take advantage of the heat of the earth. The Caribbean is another region with significant potential. The French territory of Guadeloupe is the only Caribbean island that uses geothermal energy to produce electricity, through a geothermal plant with an installed power of 15.7 MWe, although it is far from taking advantage of its full potential, up to 3500MWe. Within the Mediterranean region there is also a lot of potential: Sicily, Italy, for example, or the Aegean islands in Greece. The main uses are for greenhouse heating and thermal uses, although they show a particular potential for high and low temperatures. The Azores is an example of good use of its geothermal potential. It currently covers 42% of the electricity consumption on the island of Sao Miguel and more than 22% of the total demand for the archipelago.
Iceland is the island taking advantage of its fully potential for energy generation through geothermal energy. It has 99,96% renewable energy supply. One its biggest geothermal plants is the Hellisheidi Power Plant with 303 MW installed.

4.1.1 Types of geothermal power plants

Geothermal power plants can be classified into, according to the nature of the geothermal fluid:

- Flash steam plants take high-pressure hot water from the depths of the earth and convert it into steam to generate electricity. When the steam cools, it condenses in

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water and is injected back into the soil to be used again. Most geothermal power plants are flash steam plants.

- Binary cycle power plants transfer heat from geothermal hot water to another liquid within a closed cycle. The heat from the first fluid causes the second liquid to turn into steam to generate electricity.

- Dry steam plants use steam directly from a geothermal reservoir to generate electricity through steam turbines.

4.1.2 GECO - Geothermal Emission Gas Control

- ✓ Dates: **October 2018 – September 2022**
- ✓ Lider: **Reykjavik Energy**
- ✓ Grant agreement number: **818169**
- ✓ Entidad financiadora

Overview

The GECO Project, "Control of Geothermal Emissions" contributes to the supply of cleaner and more profitable geothermal energy, with reductions in carbon and sulfur emissions, for use on a European and global scale. The fundamental objective of the project is the application of an innovative technology, recently developed and successfully demonstrated on an experimental scale in Iceland, which is capable of limiting emissions from geothermal plants through condensation and reinjection of gases in the subsoil (or even transform them into commercial products).
GECO seeks to increase public acceptance while generalizing this new approach. For this application, the reinjection method will be applied in 4 demonstrations with different geological characteristics in different European countries.

- ✓ Iceland: High Temperature Basaltic Reserve
- ✓ Italy: High temperature gneiss reserve (metamorphic rock composed of the same minerals as granite, but in bands)
- ✓ Turkey: High temperature vulcan-clastic reserve
- ✓ Germany: Low-temperature sedimentary reserve

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A detailed and uniform monitoring program will analyze and model the reactivity and behavior of the re-injected fluids in the different demosites. This will create new and more modeling tools to predict the reactions that can take place in the subsoil in response to the induced changes.
Along with GECO, different methods of gas capture and purification will be affected, bringing the reduction of resource consumption (electricity, water and chemicals) closer. GECO's approach is to:

- ✓ Capture waste gases from the geothermal process
- ✓ Dissolve them in geothermal water flows, reinjecting the aqueous solution
- ✓ The re-injected fluid causes the variation of rocks on the surface, increasing the permeability of the reserve and fixing the gases dissolved by mineralization

Thus, waste gases are stored in the long term, in a sustainable way, while emissions from geothermal energy are reduced, compared to traditional techniques.
Finally, the capture of gases for reuse will be tested through the production of purified CO2 streams with negligible levels of Hydrogen Sulfide (H2S). The valorization of this product will be demonstrated through different ways of subsequent use as part of the GECO project.

Objectives

GECO's objective is the development of an innovative technology that seeks to:

- ✓ Reduce or limit emissions from geothermal plants.
- ✓ Bringing the benefits of geothermal energy closer to the public, increasing its acceptance.
- ✓ Generalize this new approach to geothermal energy, which has previously been successfully tested on an experimental scale.
- ✓ Develop market niches from the project solutions.

4.2 Energy generation trough solar thermal [73] [74] [75] [76]

Following is reported a brief scenario analysis describing patent literature trend data related to solar thermal technologies. Specifically the search query has been constructed in order to extract information on the use of solar heat for domestic hot water systems; space heating or swimming pools; solar updraft towers; for treatment of water, wastewater or sludge; gas turbine power plants using solar heat source.
The data have been extracted through the access to a database of patent literature (Derwent innovation[77]) and the utilization of specific search queries, including IPC codes

[73] https://energyeducation.ca/encyclopedia/Solar_thermal_power_plant
[74] https://www.energy.gov/eere/solar/articles/solar-energy-technology-basics
[75] https://www.ulpgc.es/noticia/investigadores-ulpgc-participan-diseno-instalacion-colectores-solares-termicos-concentracion
[76] https://www.eoi.es/blogs/mermesev/2012/05/11/islas-solares/

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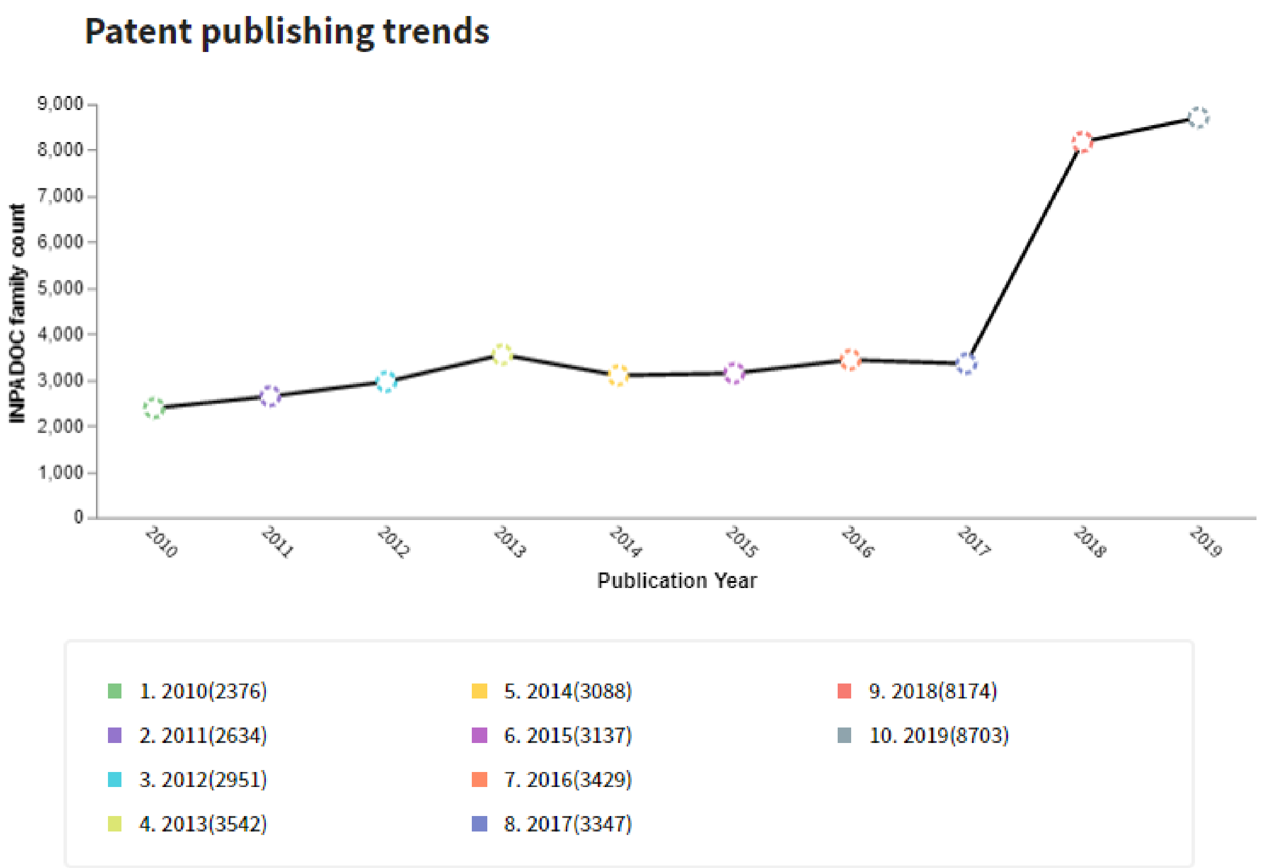
in the case of patent searches. The time interval ranges from 2010 to date, even if, considering that patent applications are kept unpublished for a period of about 18 months at least, data related to 2020 are not reported in the graphs; their number can indeed be strongly influenced and underestimated due to the explained reasons.

Table 16 Search Query – Solar Thermal Technologies

Search Query - Solar Thermal Technologies
IPC=((C02F000114) OR (F02C000105 OR F02C000106) OR (F03G0006) OR (F24S) or (F24S and F24D 17/00) or (F24S and F24D 3/00) or (F24S and F24D 5/00) or (F24S and F24D 19/00) or (F24S and F24D 11/00) or (F24S and F23D 1/04) or (F24S and F23D 9/00) or (F24S and F23D 13/20))

The number of inventions extracted from the database and related to the investigated technology amounts to about 41000, when considering publications started from 2010. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:



[77] https://www.derwentinnovation.com/

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Figure 59 Solar Thermal Technologies - Trend of Published Patent Documents (INPADOC families) – (2010-2019)

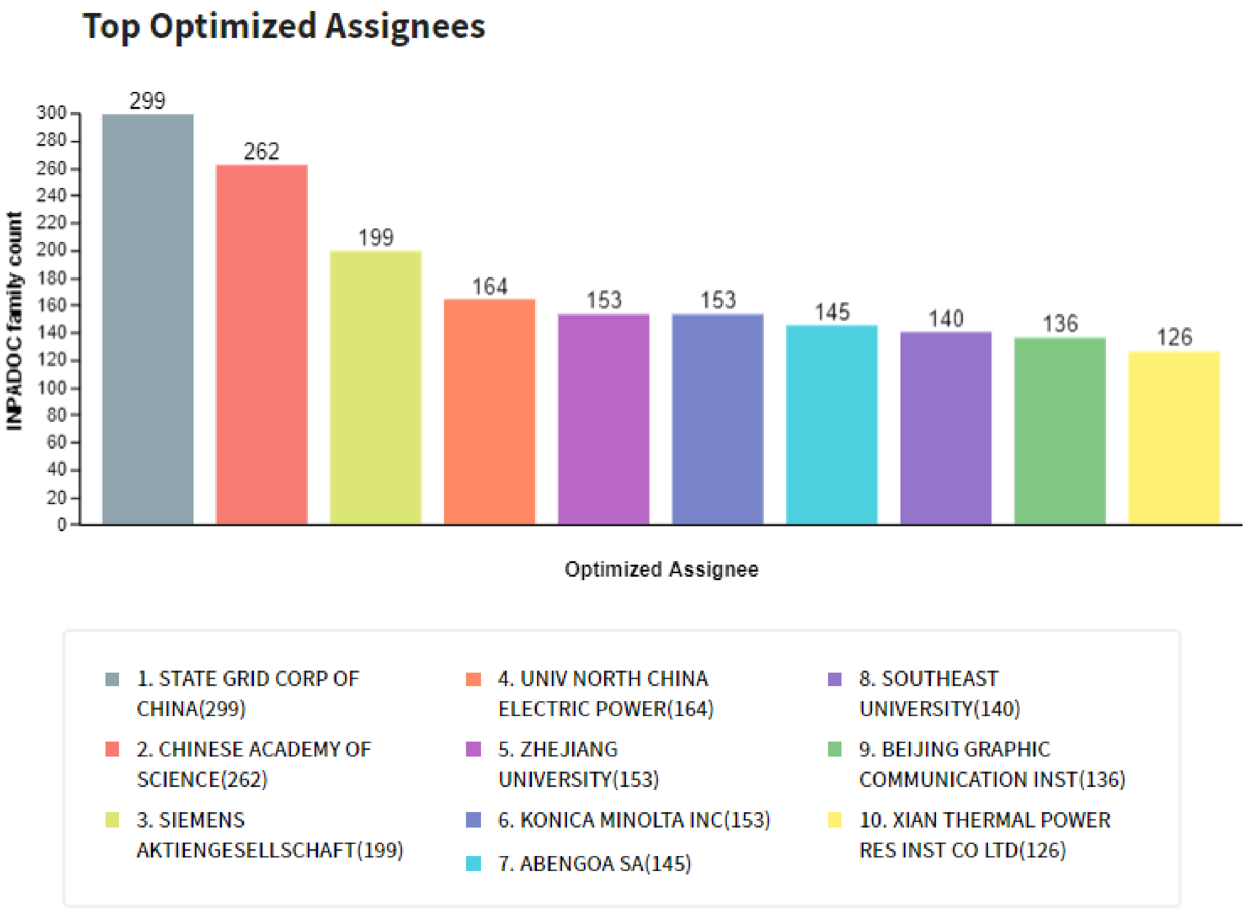

Figure 60 Solar Thermal Technologies – Main Assignees of Published Patents (2010-2019)

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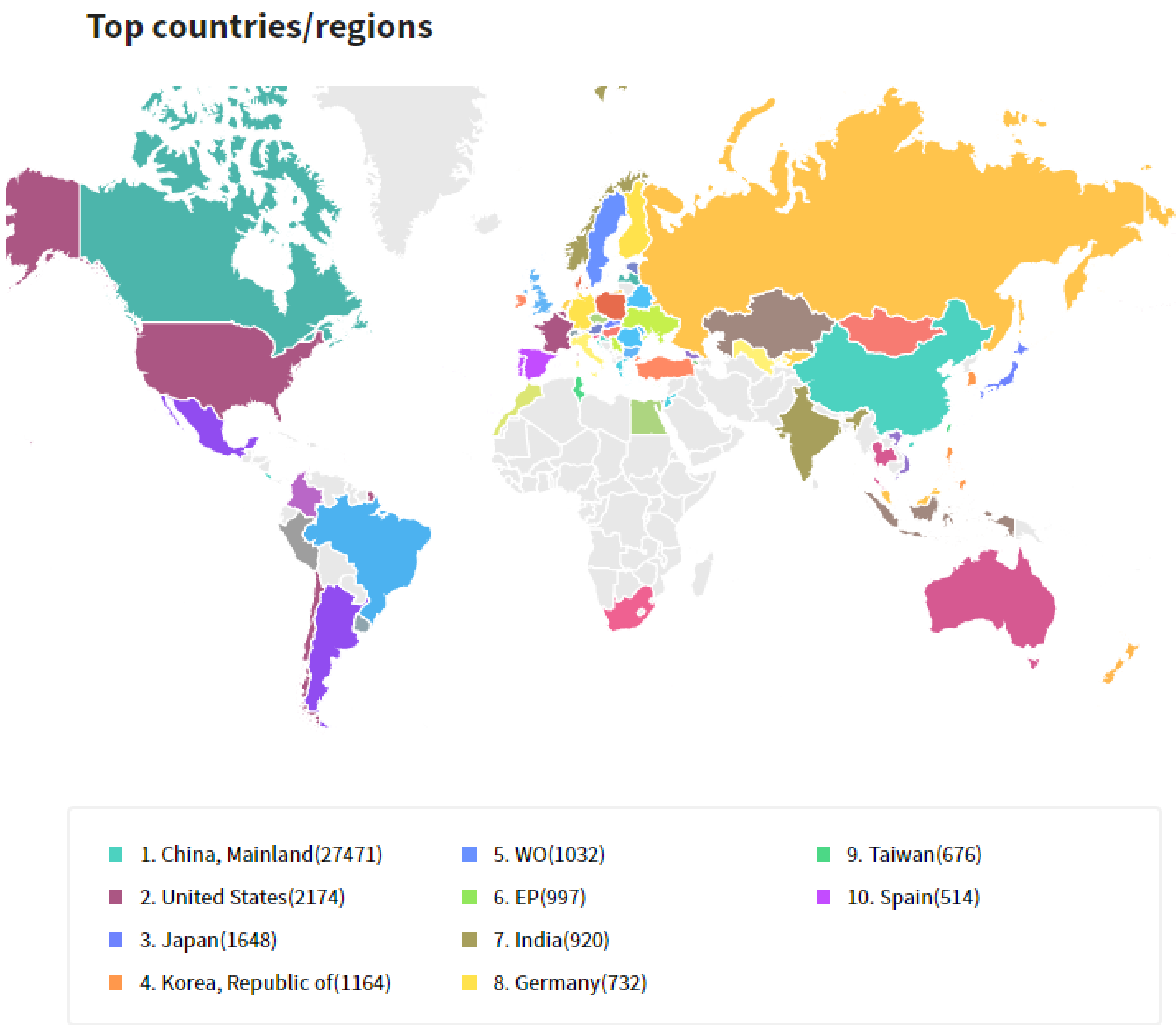

Figure 61 Solar Thermal Technologies - Main Country Codes (2010-2019)

Patent publications have been almost constant till 2017, then a rapid increase in patent publications started; China, South Korea, United States, Japan and WIPO offices are the main geographical areas where patents have been published.

The concentrating solar power, or CSP is used primarily in very large power plants and is not appropriate for residential use. This technology uses mirrors to reflect and concentrate sunlight onto receivers to produce the high temperature heat needed to generate electricity. Concentrating solar radiation allows higher temperatures and/or energy flows to be obtained, reducing the costs of conversion (eg electricity) and increasing thermal and thermodynamic efficiencies.
The components of a CSP are the **reflectors** (mirrors) which include tracking systems with the purpose of keeping the sunlight focused onto the **receiver** to heat a thermal

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fluid that circulates through the receiver. The fluid that is heated inside the receiver usually is directed to a steam cycle to produce electricity through a steam turbine.

The systems composing a thermo-solar plant are:

- Solar field: capture and concentration of solar radiation
- Heat transfer fluid system: absorption of field heat and input to Rankine cycle water, field heat and input to Rankine cycle water.
- Rankine water-steam cycle: transformation of thermal energy into electrical energy
- BOP (Balance of Plant): ancillary systems of the
- Electrical system for power evacuation

They are characterized by the solar concentration factor: $C=A_c/A_{Rec}$ (A_c Concentration area, A_{Rec} Receiver area)
For CSP there are three types of solar thermal power plants:

- Linear concentrating systems, including parabolic troughs and linear Fresnel reflectors (30<c<90).
- Solar power towers (200<c<1000)
- Solar dish/engine systems (1000<c<5000)

The design of solar thermal power plants can be designed:

- For solar only generation, ideally to satisfy daytime peak demand.
- With storage systems, to extend its operation to cover the base load. Facilitate the continuous and stable operation of the receiver system and the power system
- Hybrid plants with fuel support: Integrated Combined Cycle Solar Power Plants (ISCC) to operate at medium or base load.

Some of the benefits of CSP technologies are their electricity conversion is more efficient comparing with a conventional system of energy generation based on fossil fuels due to the high temperatures of generating steam.
On the other hand, these technologies are unable to efficiently store electricity, in the opposite they are able to store heat in a more efficient and cost-effective way than storing electricity. They can set a baseload energy generation, which means these plants produce a reliable amount of energy, meeting the energy demand load.

Thought, there are still some drawbacks, such as the environmental impacts of the plants in terms of GHG emissions associated to the plants building. However, direct emissions generated are still lower than the associated to fossil fuels generation plants. Another aspect is the huge amount of land necessary to install these plants as well as the huge water demand. And lastly but not less important is their impact on biodiversity (specially birds) as the concentrating mirrors (receivers) represent a harmful effect on them, as they could be incinerated if they pass through the area of concentration.

Currently, some islands are betting to implement CSP, even in low dimensions. One example is the Canary Islands, specifically in Las Palmas de Gran Canaria, where the University of the city have designed a plant of parabolic throughs to cover the energy

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demand of a touristic site, they intend to produce around 45 MWh/year. Additionally, out of Europe, in The United Arab Emirates a research project called Solar Islands is being developed, which is a prototype of solar island which will produce electricity through a solar thermal plant. The islands could convert the ocean water into hydrogen to self-supply and transport the electricity to the coast through the electricity connection. With this the feasibility of the solar thermal energy will be tested on islands.

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5 Electric mobility

5.1 Charging infrastructures

5.1.1 EV charging technologies

Following is reported a brief scenario analysis describing patent literature trend data related to Electric Vehicles Charging Infrastructures technologies.

The data have been extracted through the access to a database of patent literature (Derwent innovation[78]) and the utilization of specific search queries, including IPC codes in the case of patent searches. The time interval ranges from 2010 to date, even if, considering that patent applications are kept unpublished for a period of about 18 months at least, data related to 2020 are not reported in the graphs; their number can indeed be strongly influenced and underestimated due to the explained reasons.

Table 17 Search Query – EV Charging Infrastructures Technologies

Search Query - EV Charging Infrastructures Technologies
TAB=(((electr* ADJ vehic*) or (hybrid ADJ electr* ADJ vehic*) or (HEV) or (PHEV) or (plug*in ADJ hybrid)) and (charg*)) AND IC=(H02J000700) AND DP>=(20100101) AND DP<=(20191231);

The number of inventions extracted from the database and related to the investigated technology amounts to about 17000, when considering publications started from 2010. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:

[78] https://www.derwentinnovation.com/

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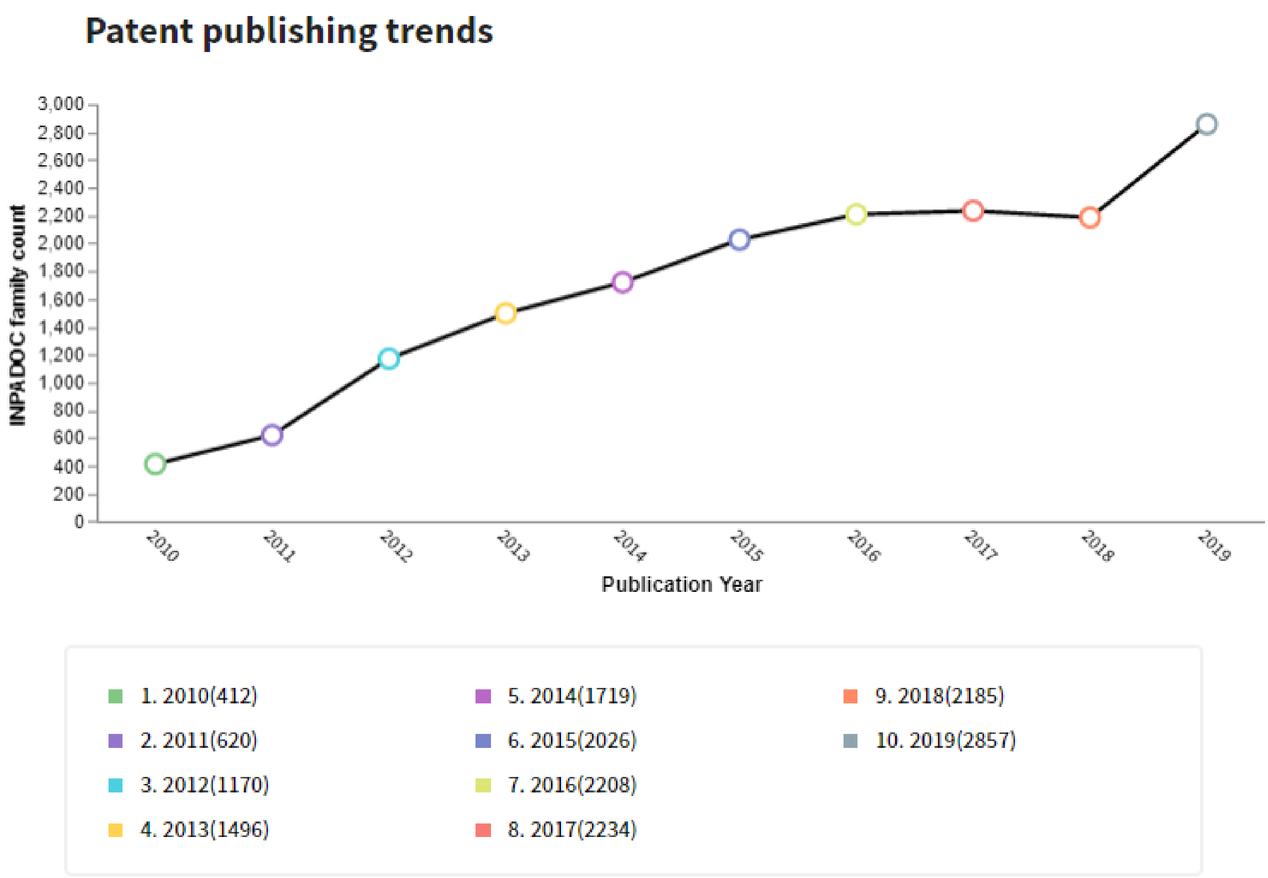

Figure 62 EV Charging Infrastructures - Trend of Published Patent Documents (INPADOC families) – (2010-2019)

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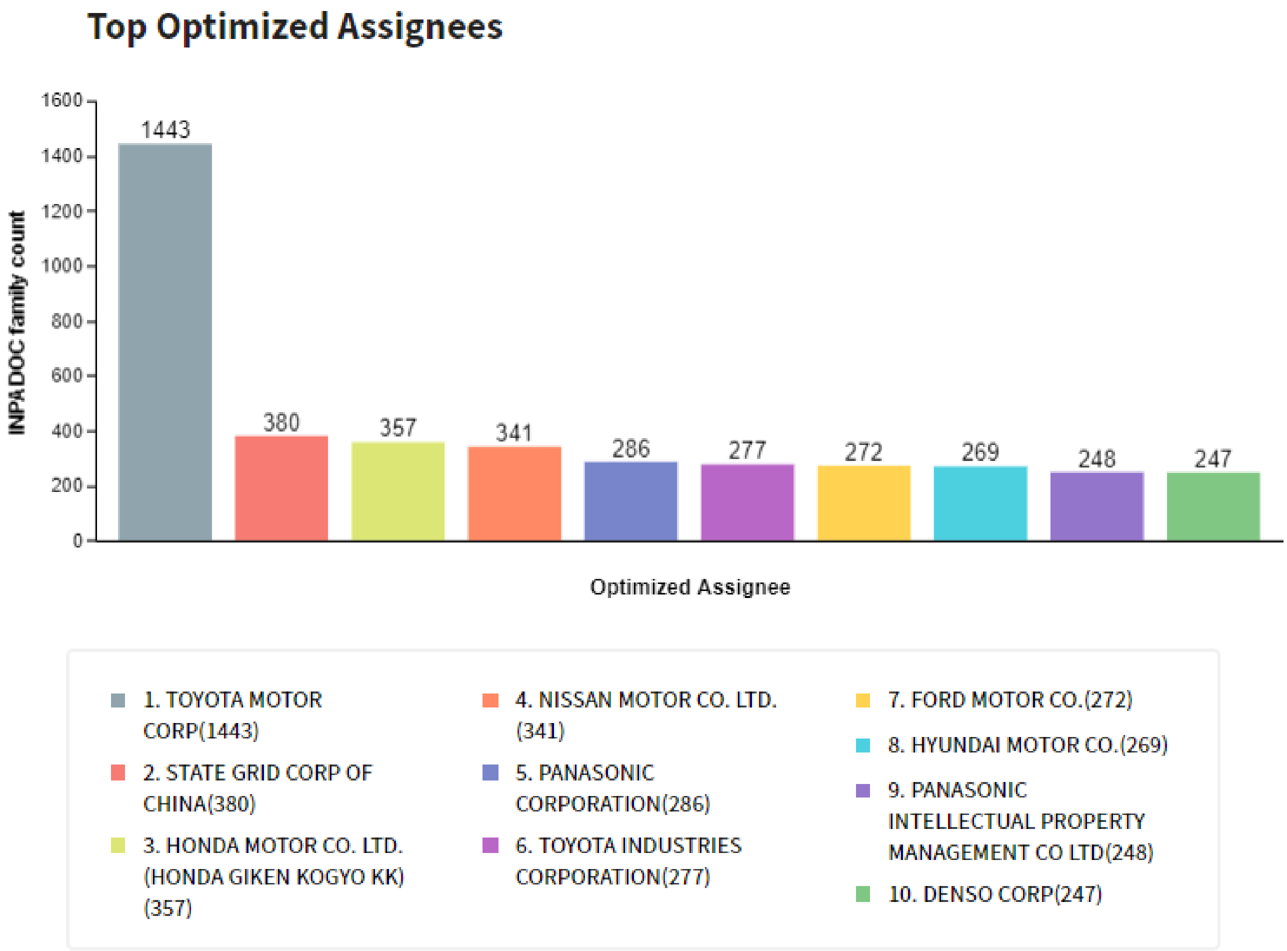

Figure 63 EV Charging Infrastructures – Main Assignees of Published Patents (2010-2019)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement N° 864266

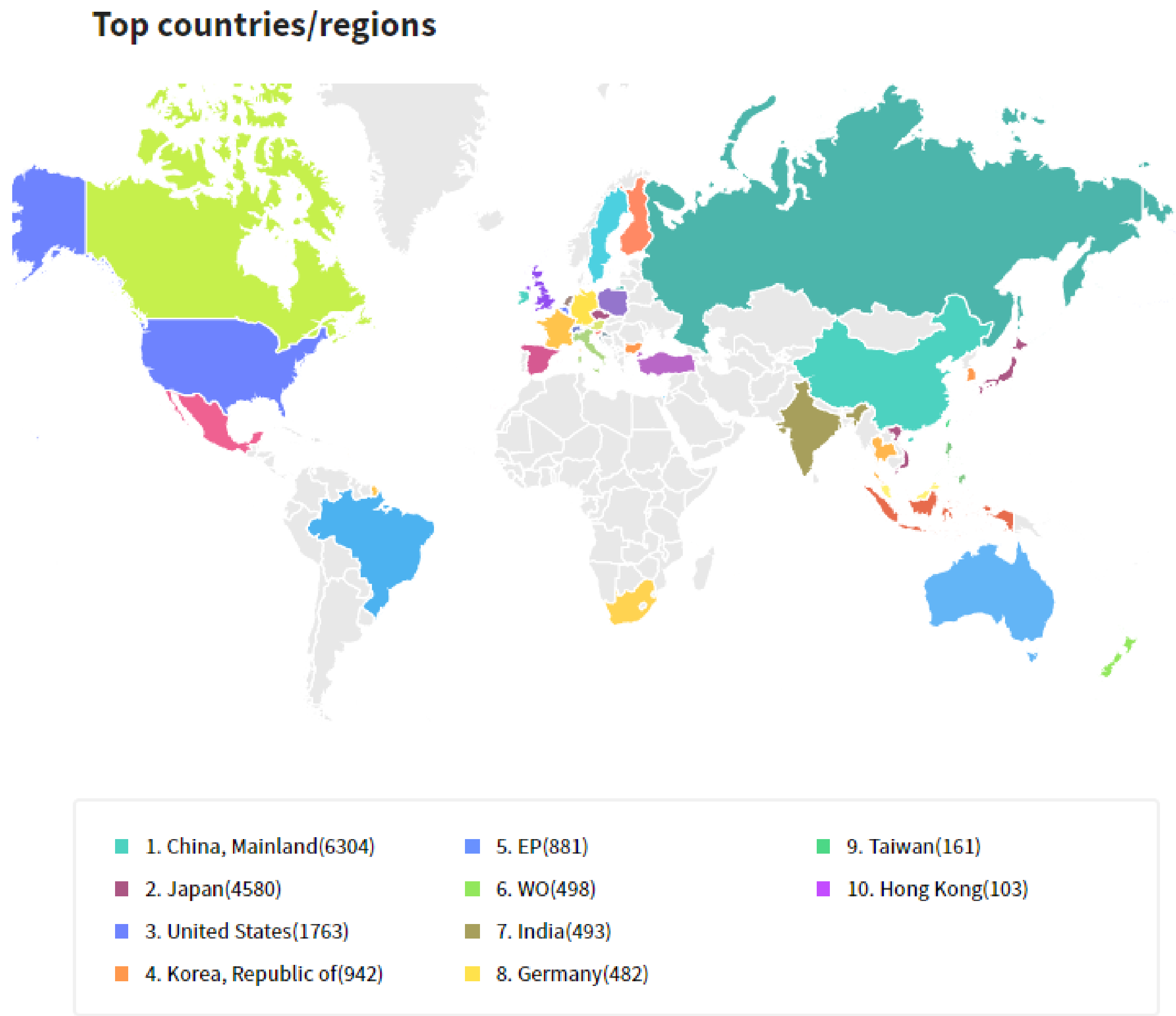

Figure 64 EV Charging Infrastructures - Main Country Codes (2010-2019)

Patent publications where starting to reach a plateau but it seems that a new sudden increase is to be expected in next years; China, Japan, South Korea, United States, South Korea and EPO offices are the main geographical areas where patents have been published. Japanese and South Korean car companies are obviously among the main assignees as will be found for electric vehicles patents (Figure 67).

5.1.1.1 Types of charging technologies

Types of charging technologies can be categorized into conductive and inductive charging. Conductive charging utilizes a direct, cable-based contact between the EV connector and charge inlet which can be from a standard socket-outlet, a wallbox or a

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fixed installed or even movable charging station. There are two methods employed in EV charging stations using conductive charging which are AC and DC chargers. Another specific type is the combined charging system CCS.

As required by the Directive 2014/94/EU, conductive charging in European member states shall be equipped with type 2 respective combined CCS plugs. Type 2 is considered to be the standard model where in private spaces, charging power levels of up to 22 kW are common, while charging power levels of up to 44 kW can be used at public charging stations. Most public charging stations are equipped with a type 2 socket. All mode 3 charging cables can be used with this plug. The CCS (Combo 2) plug is an enhanced version of the type 2 plug, with two additional power contacts for the purposes of fast charging and supports AC and DC charging power levels of up to 400 kW. In practice, the performance is usually around 50 kW.

Currently, the inductive charging of passenger cars and light commercial vehicles can reach performance values of up to 22 kW.

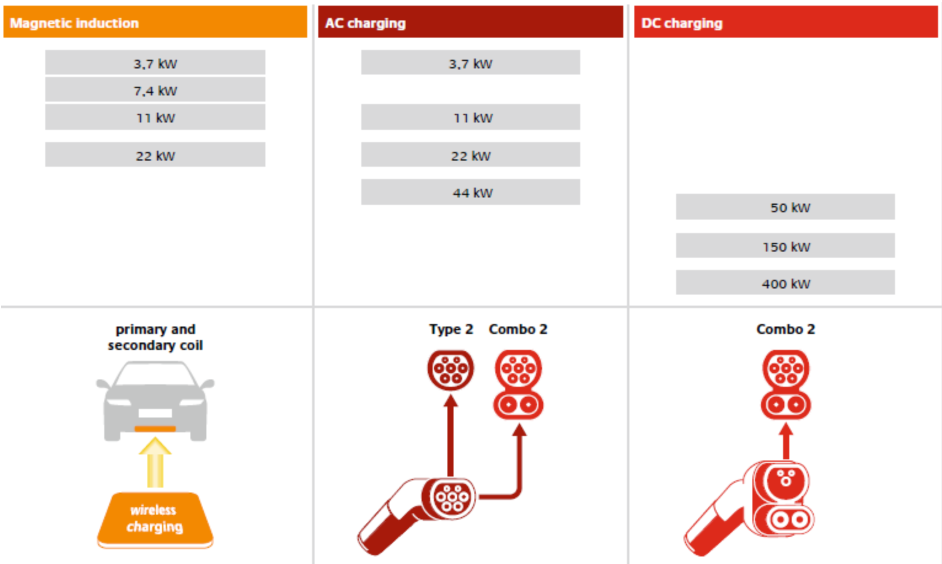

Figure 65 - Overview of the charging options and their typical charging capacities (Source: The German Standardisation Roadmap Electric Mobility 2020)

5.1.1.2 AC Charging

AC charging is carried out by utilizing AC chargers. It is the most commonly used technology and can be categorized into 3 different charging modes.

Mode 1 is the connection of the EV to the AC supply network (mains) utilizing standardized socket-outlets. It shall not exceed 16 A and not exceeding 250 V AC single-phase or 480 V AC three-phase at the supply side, and utilizing the power and protective earth conductors.

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Mode 2 is the connection of the EV to the AC supply network (mains) utilizing a control pilot function and system of personnel protection against electric shock between the EV and the plug or as a part of the in-cable control box. It shall not exceed 32 A and not exceed 250 V AC single-phase or 480 V AC three-phase utilizing standardized single-phase or three-phase socket-outlets. Current limitations are also subject to the standard socket-outlet ratings in different countries.

Mode 3 is the connection of the EV to the AC supply network (mains) utilizing dedicated EV supply equipment where the control pilot function extends to control equipment in the EV supply equipment, permanently connected to the AC supply network (mains).

Along with the typical charging capacities, maximum performance values possible under the present normative specifications are

- 3.7 kW (230V, 16A)
- 11 kW (400V, 16A)
- 22 kW (400V, 32A)
- 44 kW (400V, 64A)

The TRL for all AC charging technologies is considered as very high. Prices for a standard AC wallbox up to 22 kW are in the range between 500 – 2,500 €. A fixed charging station is in the range between 5,000 – 15,000 € excluding costs of installation.

5.1.1.3 DC and Combined Charging Systems (CCS)

DC charging is carried out by utilizing DC chargers. It can provide a higher capacity than AC charging and is categorized by charging mode 4.

Mode 4 is the connection of the EV to the supply network utilizing a DC EV charging station (e.g. off-board charger) where the control pilot function extends to the DC EV charging station.

For wired charging, it is recommended to use the Combined Charging System CCS, which basically comprehends AC charging, DC charging and the respective communication interface between the electric vehicle and the charging station. It has been laid down as a minimum standard in the EU Directive 2014/94/EU on the installation of charging infrastructure.

Along with the typical charging capacities, maximum performance values possible under the present normative specifications are

- 50 kW
- 150 kW
- 400 kW

The TRL for all DC charging technologies is considered as very high. Prices for a standard DC/CCS wallbox up to 50 kW are in the range between 10,000 – 20,000 €. A fixed charging station is in the range between 30,000 – 50,000 € excluding costs of

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installation, while fast chargers of >50kW can cost between 50,000 € - 100,000 € and more due to expensive high power converters.

5.1.1.4 Inductive charging

Inductive charging (also referred to as wireless charging) uses magnetic induction technology of coils that allows EV, independent from the type or size, to charge by flexible positioning over a charging pad (primary coil), through any materials like concrete or asphalt. The wireless charging pad can be installed above the ground or mounted into the floor of a garage or road. Wireless power delivers similar charge speeds and efficiency levels as traditional plug-in charging methods when placed correctly.

Inductive charging can be of either static or dynamic type. Static inductive charging is used while parking the EV, e.g. during the night. Dynamic charging is generally used to describe the wireless power transmission to a moving vehicle. The most common technical principles are based on magnetic fields, called

- magnetic inductive resonance charging where wo copper coils are tuned to resonate at the same natural frequency which is between 20 kHz for heavy and 85 kHz for light duty vehicles.
- magnetic inductive charging using a band of frequencies from 20 to 300 kHz. Without the need for the exact same frequency between the coils, the system complexity is reduced.

Based on the requirements and standards today the most suitable technology for heavy duty mobility is magnetic inductive resonance charging with power ratings up to 300 kW at efficiency ratios of >90%.

The TRL for all inductive charging technologies is considered as very high. The implementation costs vary strongly with the actual location and the already available electrical infrastructure.

5.1.1.5 Information and communications technology (ICT)

Information and communications technologies (ICT) constitute the link between vehicles, charging infrastructure and the energy ecosystem. They control the charging at private and public charging points and enable the communication of electric vehicles with EMS, Smart Grids and other smart technologies by offering smart charging solutions. ICT also ensures that users have comfortable and comprehensive access to publicly accessible charging infrastructure via roaming platforms.

ICT based smart charging is the charging of an EV controlled by bidirectional communication between two or more actors to optimize all customer requirements, as well as grid management and energy production including RES with respect to system limitations, reliability, security and safety.

Charging cycles can be altered by external events, allowing for adaptive charging habits, providing the EV with the ability to integrate into the whole power system in a grid and

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user-friendly way. Smart Charging must facilitate the security (reliability) of supply and while meeting the mobility constraints and requirements of the user. To achieve those goals in a safe, secure, reliable, sustainable and efficient manner information needs to be exchanges between different stakeholders.

Smart charging is often referred to as vehicle to grid (V2G) and V2X because of the variety of value streams, such as 'V2Home', 'V2Office' and 'V2Building'. Larger V2G projects focused on flexibility markets. V2G is controlled by EMS or load management and can be integrated in all charging use cases as outlined in the following section.

In the context of smart charging there are also Value Added Services like location and reservation of charging spots, easy and secure identification methods and other services that could make charging easier for the user. However, Value Added Services interact with Smart Charging sequences in several ways. Key to the requirements outlined for smart charging is interoperability between actors, e-mobility and smart grid technologies.

Car manufacturers and suppliers of charging infrastructure and energy are interconnected on so-called roaming platforms. They offer cross-provider authentication and billing procedures, e.g. by smartphone apps, charging cards or the plug & charge system by providing interoperable cross-vendor charging. The creation and operation of such platforms requires consistent technical framework conditions that will serve as a basis for according legal provisions and can be included in the business models of the different market players.

The objective is to establish a common and open basic IT protocol to interconnect the providers of charging stations and of electric mobility systems. Such a roaming protocol will give the user access to all charging stations. Even if he uses stations of different providers, the costs he incurs will be billed centrally.

Alongside this contract-based charging, all charging stations are likewise to enable ad-hoc charging with mostly digital payment, such as Mobile Payment, SMS, smartphone apps or credit cards.

5.1.2 High-level use cases

Based on the implementation of available EV charging technologies, different clusters of high-level charging use cases can be considered and assessed by a SWOT analysis for geographical islands as follows.

5.1.2.1 Home charging

Home charging is normally performed in residential environments by final customers, utilizing conductive AC and DC charging technologies up to 22 kW depending on the capacity of the connected system. Besides EV, it often also charges e-bikes as well. Also inductive charging technology can be applied.

Strenghts	- Low price infrastructure, therefore affordable for most citizens

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	- Low risk of vandalism - High market availability
Weaknesses	- Mostly low connection capacity resulting in slow charging
Opportunities	- Domestic RES and storage integration via EMS
Threats	- Creation of grid constraints on specific transformer feeders

5.1.2.2 Public charging

Public charging is performed outside of residential environments, such as in public areas, garages, supermarkets and office buildings. It is offered by utilities, car manufacturers or service providers, often utilizing conductive AC and DC charging stations up to 50 kW depending on the capacity of the connected system. Also inductive charging technology can be applied.

A specific subtype of public charging is on-street residential charging, as many EV drivers charge their EV when it is parked overnight. On-street residential charge points is installed in or onto lamp posts, removing the need for additional street furniture and potentially keeping costs down.

Other commonly available types are free-standing or pillar units, that look much like public charge points, and positioned near to the kerb to keep the length of cable trailing to the vehicle to a minimum. Developments in this area also include lamp posts or telescopic charge points, that can retract into the pavement when not in use.

Strenghts	- High accessibility of infrastructure - No need to invest into own residential charging infrastructure - High market availability - Utilization of existing connections such as lampposts
Weaknesses	- Performance depending on the capacity at grid connection point - Sharing of capacity in case of parallel charging by multiple EV - Availability of charging spots and parking spaces
Opportunities	- Local RES and storage integration via EMS - Optimization of capacity at the grid connection point through EMS / Charging management system - Facilitator for EV development on islands
Threats	- Negative business model in case of high infrastructure costs with low utilization - Creation of grid constraints on local scale - Risk of vandalism

5.1.2.3 Fast and ultra-fast charging

Fast and ultra-fast charging is a specific subtype of public charging with up to 400 kW utilizing specific high-cost DC charging infrastructure which is offered by specific car manufacturers and service providers. It requires a very high performance of the grid connection and is connected via separate transformers on MV level, which limits the application to islands with strong distribution systems.

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Strenghts	- Extremely high performance, EV can be charged in tens of minutes
Weaknesses	- High capacity of grid connection point required - Very high infrastructure costs incl. separate MV connection - Limited applicability for islands
Opportunities	- Local RES and storage integration via EMS - Strong facilitator for EV development on islands
Threats	- Negative business model in case of very high infrastructure costs with low utilization - Creation of grid constraints on wider system scale - Risk of vandalism

5.1.2.4 Mobile charging

Mobile charging is a specific subtype of public charging especially in absence of an appropriate grid connection or where only temporary charging is required, such as in leisure areas during the holiday season. Mobile chargers (also called boosters) are utilizing battery technologies and can help to close the gap between infrastructure, the lack of stationary charging stations and the growth of EV.

Strenghts	- High accessibility of infrastructure - No grid connection required for up to fast charging, causing no grid constrains - No costs for installation, civil works etc.
Weaknesses	- Logistics for charging and replacement of mobile charger required - Charging capacity is limited by the capacity of the batters
Opportunities	- Local RES utilization at the place of recharging - Facilitator for EV development on islands in areas with no or weak grid connections
Threats	- Negative business model in case of very high infrastructure costs for mobile charger with low utilization - Risk of vandalism

5.1.2.5 On the way charging

On the way charging is a specific subtype of public charging utilizing dynamic inductive charging technologies. Charging panels are integrated within the road to charge the vehicle while it is driving or waiting, e.g. before traffic lights. The technology needs no exact positioning with a range long enough to overcome the distance between the primary and secondary coils, allowing for movement of EVs.

Strenghts	- Hassle free solution without need to plug - Automatic charging without waiting time
Weaknesses	- High cost solution with high amount of civil works - Access to many grid connection points required - Low accessibility of infrastructure, lack of EV with conductive charging
Opportunities	- Systematic use for public transport such as taxis and buses with optimized scaling of the technical solution
Threats	- Negative business model in case of very high infrastructure costs for mobile charger with low utilization

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5.1.2.6 Charging at work

For employees, charging at work can be convenient to charge their EV whilst parking during the day. From a business point of view, having a charge point at the workplace will become increasingly important as a facility for employees and visitors, while for businesses with an EV fleet it can be an essential operating factor. It can also include depot charging which is predominantly applied for public transport (buses) and trucks using pantographs.

Strengths	- High accessibility of infrastructure for employees - High market availability - Possible tax advantages for employers - Technical solution can be scaled and optimized for company EV fleets
Weaknesses	- Performance depending on the capacity at grid connection point - Sharing of capacity in case of parallel charging by multiple EV - Availability of charging spots and parking spaces
Opportunities	- Company RES and storage integration via EMS - Optimization of capacity at the grid connection point through EMS / Fleet management system - Facilitator for EV development on islands
Threats	- Creation of grid constraints on local scale

5.1.2.7 EV Charging Using PhotoVoltaics

The Republic of the Marshall Islands is a nation that is vulnerable to the effects of climate change due to rising sea levels – there is high incentive to reduce green-house emissions. It consists of 1156 remote islands near the equator, and thus, is an area of high solar potential. Honda worked with the local government, to install and test a solar-powered AC normal charging station called the Honda Power Charger.

A study was done on the remote island Uligamu, on the use of a real-time energy management scheme for PV-microgrid EV Charging systems. With PV as the main source of energy, the burden on the microgrid system was minimized. The system proved to be more economical to run compared to a standalone generator for charging. The microgrid system consisted of the PV array, 2 diesel generators, AC load, energy storage unit (ESU: lead acid battery stacks), and the EV with onboard charger. The microgrid was divided into 6 operating modes for optimised usage of available energy, with the aim of minimizing fuel usage for the diesel generators.

1. PV to EV
2. ESU to EV
3. Diesel Generators to EV
4. PV to ESU
5. PV to AC Load
6. Diesel Generators to AC Load.

Barbados relies heavily on fossil fuels to generate more than 96% of its electricity. Barbados is not only known for its abundance of sunshine but also known for its dense road network, and high vehicle ownership relative to population. There was a significant opportunity to combine PV with EV and thus, ‘Megapower’ was launched. The company

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is driving forward the use of renewable energy in the Carribean and Barbados is now the world's third highest user of EV. Megapower is responsible for the whole charging infrastructure on Barbados and has managed the import of electric vehicles. Their first renewable energy project was the creation of a modular solar carport system. The EV charging solution has been successfully rolled out across to other Carribean islands. The largest solar carport in Barbados covers 56 parking bays, thus doubling as shaded parking, and also powers a large office complex.

5.1.2.8 Vehicle to Grid

Vehicle to Grid (V2G) is a technology that enables energy stored in electric vehicles to be pushed back into the national electricity network. The complex technology has the potential to assist in coping with short-term increases in electricity demand in the grid.

Renault have been collaborating with island authorities on a project based on an island in Portugal, Porto Santo, titled 'Sustainable Porto Santo / Smart Fossil Free Island'. This project includes the use of bidirectional charging for V2G functionality, using AC technology, which aims to help the grid cope with demand peaks.

The Isles of Scilly in the UK have launched the 'GO-EV' project, which will involve a car share scheme in which 10 V2G electric vehicles are used, in the same way as previously mentioned, to discharge electricity back to the grid at high demand times and are charged by either locally generated renewable energy or from the grid. This project explores the feasibility of V2G technology in conjunction with a car share scheme to offer locals further choice in travel options.

The island of Bornholm (Denmark, 588 km^2, 40 000 residents) is normally connected to the mainland grid (Sweden via 60 kV sea cable), however, at times it must retain its power system in an islanded mode. V2G technology has been investigated to allow increasing amounts of wind during islanded situations and contribute to frequency regulation. Simulations show that power system operates satisfactory for the case of replacing most of the conventional generator reserves with V2G systems, which may represent a future operation scenario. In the meantime, 22 EVs are used daily homecare and social care workers managed by the Regional Municipality to provide care to citizens, 20 of the EVs (Nissan leaf and env-200) are using V2G (8 10 KW DC chargers) to support the grid during parking hours.

5.1.2.9 Inductive charging

Inductive charging was successfully tested on the Swedish island of Gotland (2.994 km2, 57 000 residents) in an innovative electric road project with Electreon technology. On a 1.6 km test track a series of electrical coils were placed below the asphalt surface of the road and transferred power to special receivers that can be installed in all kinds of vehicles (e.g. cars and buses). Therefore, there is no need for electric vehicles to stop for charging or utilizing batteries with big capacity. The test of a 40-ton truck was

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conducted in early 2020 when harsh weather conditions devastated the road. The truck was charged on a 50-meter road section both in static and in dynamic conditions (driving at a maximum velocity of 29km/h). 5 receivers, each of 20kW, were installed in the truck and they managed to recharge it with 90% efficiency in static conditions. During the next months the goal of the test is to increase to 125 energy transfer kW and motorway speed. After that, a shuttle bus is to be tested.

5.1.2.10 Public transport: depot and on the way charging

Schiermonnikoog is a Dutch tourist island (199 km2, 1000 residents), coming to life only during the summer season with 250 000 tourists. It was one of the first European islands to convert its bust fleet to electric busses back in 2013. 6 electric BYD busses with 220 kWh storage capacity are being charged at the depot with slow charging (40 KW AC charger, 5h).

According to a study completed for the city of Auckland, on-the-way charging can help mitigating depot grid reinforcement costs. Another city of New Zealand, Wellington, has tested opportunity charging for its electric buses in real life. The charging infrastructure for a fleet of 10 electric double-deckers delivered in 2018 consisted to be Heliox 450 kW ultra-fast chargers for roof-mounted pantographs. The other chargers are be five DC 2x30kW Twin Chargers and one DC 25kW Mobile Charger with a plug-in option for ultimate flexibility in the depot charging. Roof-mounted pantographs are used by the busses for opportunity charging on the way, each opportunity 450 KWh charger can recharge a battery in 2-5 minutes.

5.2 Electric Vehicles

5.2.1 Electric Vehicles types and technologies

Following is reported a brief scenario analysis describing patent literature trend data related to Electric Vehicles technologies. Specifically the search query has been constructed in order to extract trend data on patent applications relating to propulsion of purely electric, hybrid and plug-in hybrid vehicles, as well as patent applications of other electric vehicle (EV) specific components including charging equipment. In part considering even patent applications relating to batteries, as long as the focus of the invention is on the integration of these batteries in the electric vehicles[79].

The data have been extracted through the access to a database of patent literature (Derwent innovation[80]) and the utilization of specific search queries, including IPC codes in the case of patent searches. The time interval ranges from 2010 to date, even if, considering that patent applications are kept unpublished for a period of about 18

[79] "Patents and progress; intellectual property showing the future of electric vehicles"; G. Schmitt et al.; World Electric Vehicle Journal Vol. 8 - ISSN 2032-6653 - ©2016 WEV

[80] https://www.derwentinnovation.com/

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months at least, data related to 2020 are not reported in the graphs; their number can indeed be strongly influenced and underestimated due to the explained reasons.

Table 18 Search Query – EV related Technologies

Search Query - EV related Technologies
TAB=((electr* ADJ vehic*) or (hybrid ADJ electr* ADJ vehic*) or (HEV) or (PHEV) or (plug*in ADJ hybrid)) AND IC=(B60L or B60K000620 or B60W0020) AND DP>=(20100101)

The number of inventions extracted from the database and related to the investigated technology amounts to about 51000, when considering publications started from 2010. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:

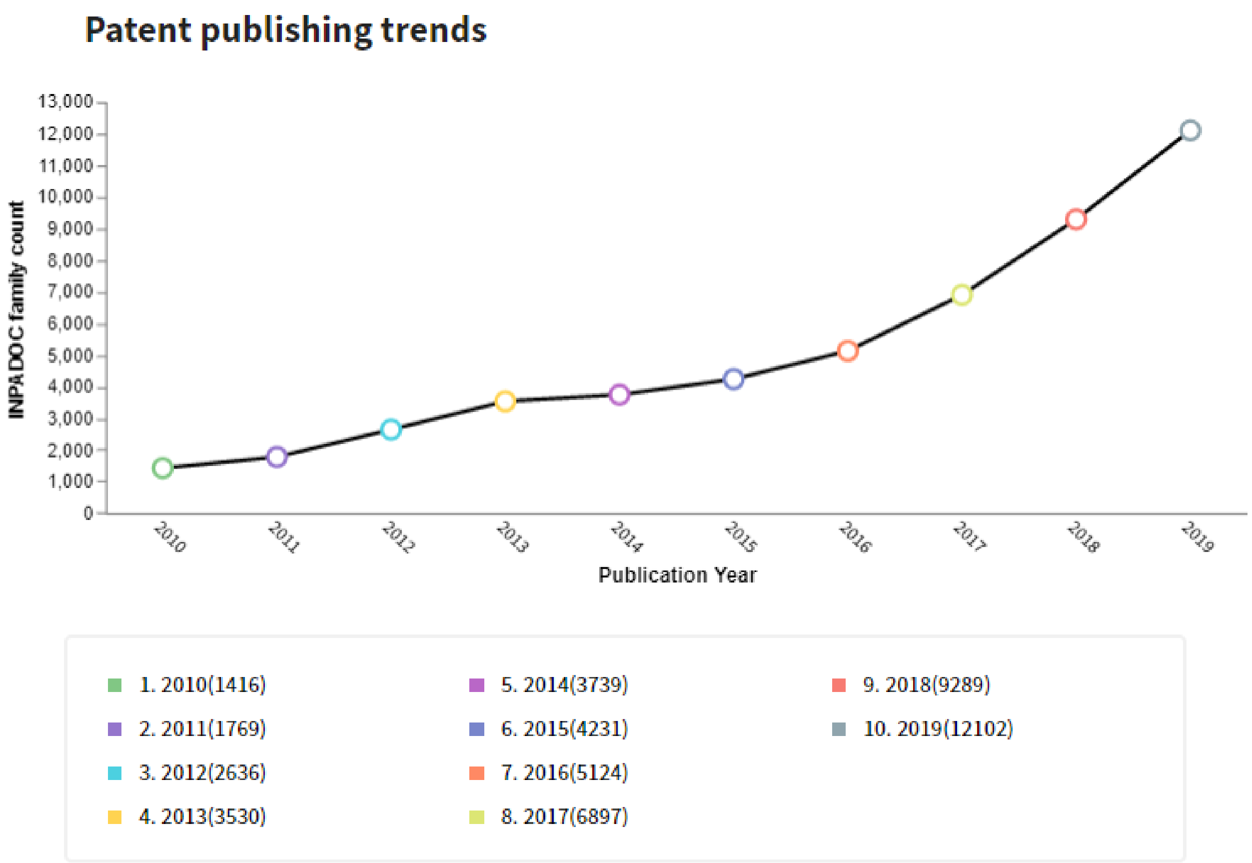

Figure 66 EV Technologies - Trend of Published Patent Documents (INPADOC families) – (2010-2019)

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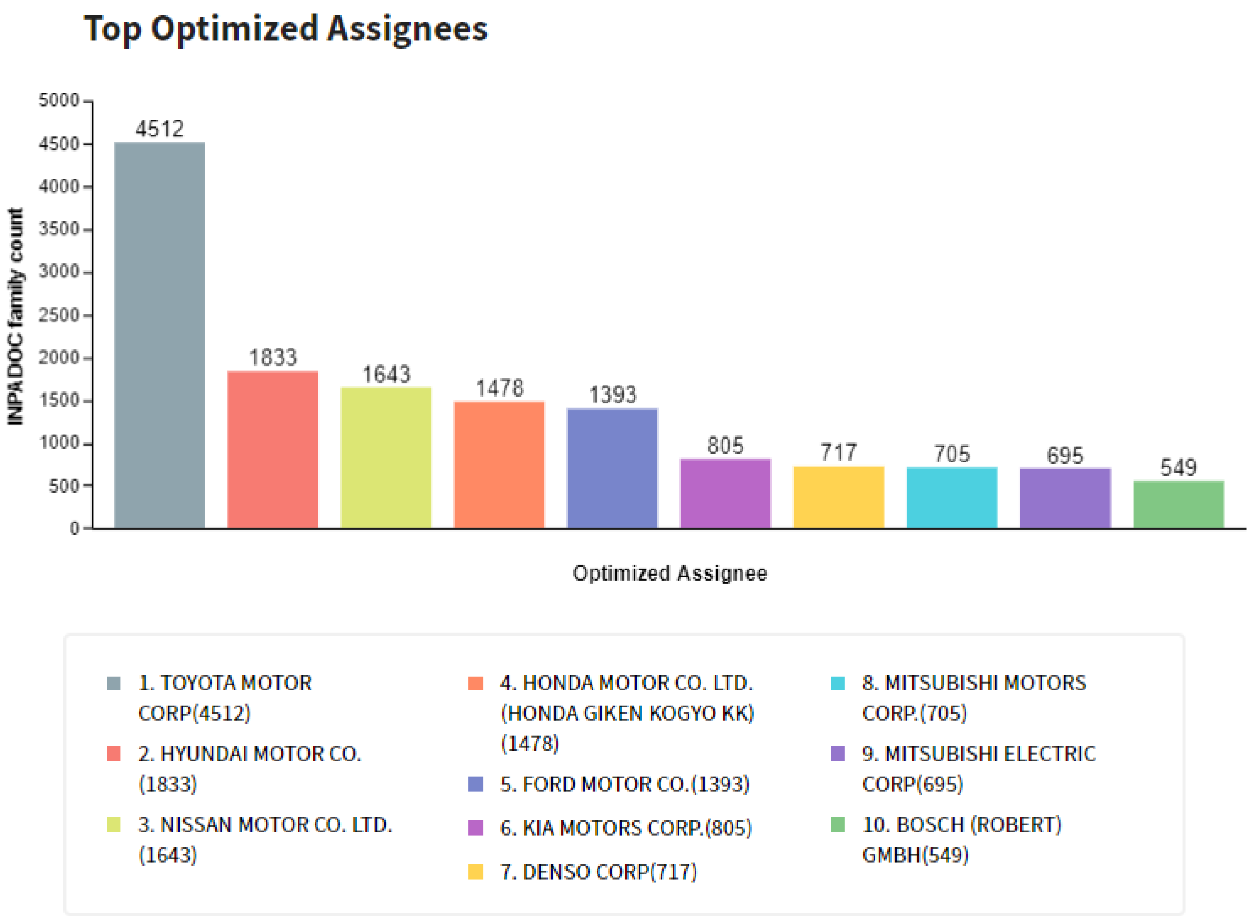

Figure 67 EV Technologies – Main Assignees of Published Patents (2010-2019)

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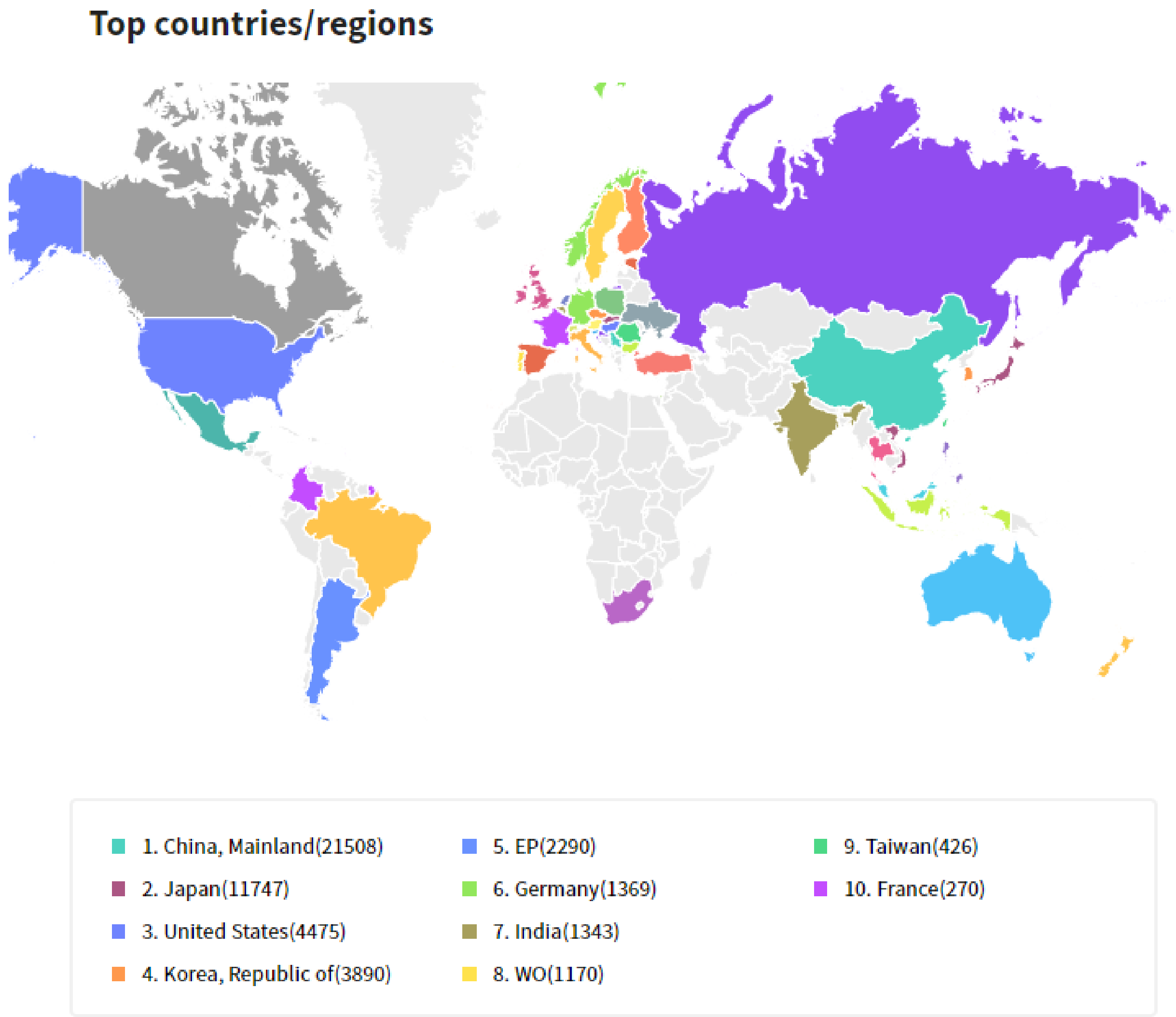

Figure 68 EV Technologies - Main Country Codes (2010-2019)

Patent publications see a steep increase; China, Japan, South Korea, United States, Japan, EPO offices and Germany are the main geographical areas where patents have been published. Japanese and South Korean car companies are obviously among the main assignees.

An electric vehicle (EV) is a vehicle which is equipped with one or more electric motors or traction motors for propulsion. An electric vehicle is powered through a system which collect electricity from off-vehicle sources, or may be self-contained with a battery, solar panels, fuel cells or an electric generator to convert fuel to electricity. EVs include, but are not limited to, road and rail vehicles, surface and underwater vessels, and electric aircrafts. Nowadays, terrestrial vehicles, such as electric cars, are the most widespread thanks to a number of reasons: easier access to the technology by common people, higher development stage and interest by the big automotive companies at worldwide level. Surface and underwater vessels, and electric aircrafts represent a niche of the market because they still need a technological development to be

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competitive with the current solutions available on the market today. For this reason, the chapter is mainly focused on road electrical vehicles.

5.2.1.1 Road Vehicles

According to the current scenario, there are three main types of electric vehicles (EVs), classed by the degree that electricity is used as their energy source. BEVs, or battery electric vehicles, PHEVs of plug-in hybrid electric vehicles, and HEVs, or hybrid electric vehicles.[81] [82]

5.2.1.1.1 Battery Electric Vehicles

Battery Electric Vehicles, also called BEVs, and more frequently called EVs, are fully-electric vehicles with rechargeable batteries and no gasoline engine. Battery electric vehicles store electricity onboard with high-capacity battery packs. Their battery power is used to run the electric motor and all onboard electronics. BEVs do not emit any harmful emissions and hazards caused by traditional gasoline-powered vehicles. BEVs are charged by electricity from an external source. Electric Vehicle (EV) chargers are classified according to the speed with which they recharge an EVs battery.

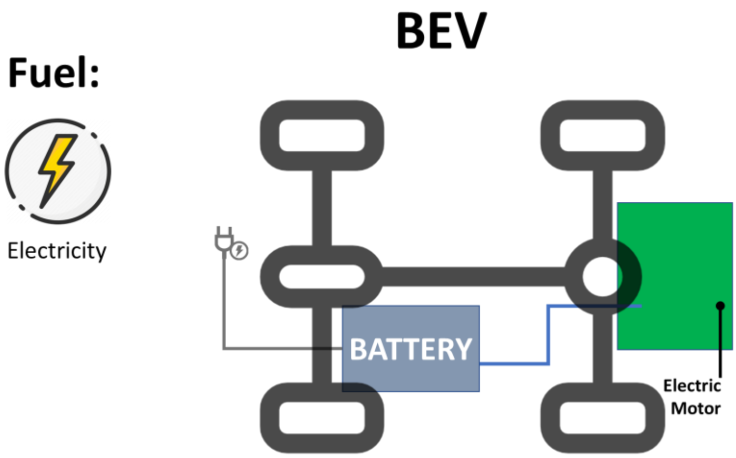

Figure 69: Schematic drawing of a Battery Electric Vehicle

The classifications are Mode 1, Mode2, Mode 3 and Mode 4 or DC fast charging this kind of classification depends on the voltage, wattage and type of plugs of the charging systems (as discussed deeply in Paragraph 5.1).

5.2.1.1.2 Plug-In Hybrid Electric Vehicles

Plug-in Hybrid Electric Vehicles or PHEVs can recharge the battery through both regenerative braking and "plugging in" to an external source of electrical power. While "standard" hybrids can (at low speed) go about 1-2 miles before the gasoline engine turns on, PHEV models can go anywhere from 10-40 miles before their gas engines provide assistance.

[81] https://www.evgo.com/why-evs/types-of-electric-vehicles/#:~:text=There%20are%20three%20main%20types,level%203%2C%20DC%20fast%20charge.

[82] https://www.enelx.com/it/en/electric-mobility/guide/electric-vehicles

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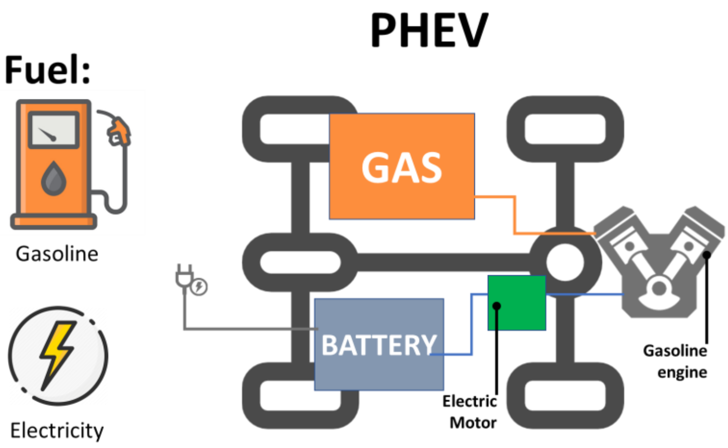

Figure 70: Schematic drawing of a Plug-In Hybrid Electric Vehicle

5.2.1.1.3 Hybrid Electric Vehicles

HEVs are powered by both gasoline and electricity. The electric energy is generated by the car's own braking system to recharge the battery. This is called 'regenerative braking', a process where the electric motor helps to slow the vehicle and uses some of the energy normally converted to heat by the brakes.
HEVs start off using the electric motor, then the gasoline engine cuts in as load or speed rises. The two motors are controlled by an internal computer, which ensures the best economy for the driving conditions.

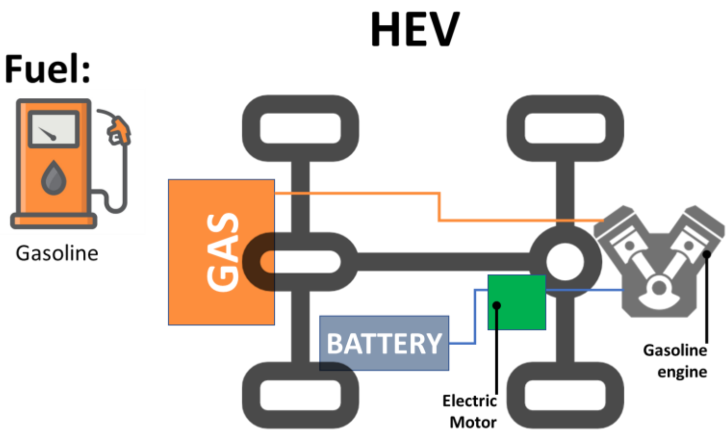

Figure 71: Schematic drawing of a Hybrid Electric Vehicle

5.2.1.2 Airborne Electric Vehicles

Carbon-based fuels, like kerosene and gasoline hold a lot of energy for their weight, rendering them able to power the largest aircrafts. As we all know, however, the future of conventional fuel sources for aviation looks uncertain, as carbon-based fuels are a major contributor to CO2 emissions. With decreasing oil resources, the industry is dependent on finding an alternative power source.

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The switch to electric propulsion in aircraft is one such area of investigation. For instance, the E-Fan X is a hybrid-electric aircraft, which is currently under joint development between Airbus, Rolls Royce, and Siemens[83]. E-Fan X is a major milestone on Airbus' decarbonisation journey and this demonstrator has the ambition to test the technologies that would help decarbonise the skies. In the test aircraft, one of the four jet engines was slated to be replaced by a 2MW electric motor, which would significantly reduce fuel burn and decrease local atmospheric emissions. However, there are yet more advantages of electrification within aviation than reduced emissions. One of the main obstacles to this electric revolution is the power to weight ratio of the batteries and motors which are needed to supplant a conventional kerosene-powered engine. A battery's efficiency, or ability to hold power, is measured in specific energy. Right now, even the best batteries have a specific energy of only 250 watt-hours per kilogram, but we have to get closer to 800 to really start flying, and that is still nothing compared to jet fuel's specific energy, which is nearly 12,000 watt-hours per kilogram[84]. For this reason, nowadays, the electric propulsion in the aviation sector is mainly focused on Unmanned Aerial Vehicles of light planes, such as two-seat aerobatic monoplanes.

An unmanned Aerial Vehicle (UAV) (or uncrewed aerial vehicle, commonly known as a drone) is an aircraft without a human pilot on board, the flight of UAVs may operate with various degrees of autonomy: either under remote control by a human operator, autonomously by onboard computers or piloted by an autonomous robot. While they originated mostly in military applications, their use is rapidly expanding to commercial, scientific, recreational, agricultural, and other applications, such as policing and surveillance, product deliveries, aerial photography, infrastructure inspections, smuggling, and drone racing[85].

5.2.1.3 Seaborne Electric Vehicles

As hybrid gas/electric cars such as Tesla and Prius have grown in popularity and become more practical options for mainstream consumers and in a not really far feature, boat manufacturers will follow this stream thanks to the technology development.
Today, a technical solution in the marine sector is the hybrid power generation. A hybrid marine propulsion system is any combination of a combustion engine and an electric motor. Electricity can be produced by one or a combination of the following: a combustion engine generator, a wind generator, a towed water generator or solar panels. A purely electric solution with solar panels is desirable due to its zero carbon footprint and low operating costs, these systems are gaining popularity on alternative energy vessels. Advances in both energy storage and solar panel technology have reduced costs and physical footprint making solar power propulsion systems more feasible for use on boats. There are numerous benefits to electric motor propulsion including that it's quieter, more efficient at lower speeds and less smelly. It's also expected to lower overall costs of ownership by reducing or eliminating the needs for oil

[83] https://www.airbus.com/innovation/zero-emission/electric-flight/e-fan-x.html
[84] https://www.businessinsider.com/electric-planes-future-of-aviation-problems-regulations-2020-3?IR=T
[85] https://www.britannica.com/technology/unmanned-aerial-vehicle

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and transmission fluid changes, filter and impeller replacements and starter problems. Additionally, unlike diesel or gas engines, electric motors provide full torque instantly so boats get up on plane faster. In other hand, the absence of a combustion engine limits the boat speed and the autonomy. Aftermarket conversions, which currently make up the lion's share of the market, can use existing drive shafts and components so there is a cost-savings when re-powering.
As mentioned, now that hybrid and pure electric propulsion systems have proliferated within the automotive industry, hybrid or electric boats are beginning to gain interest. Still, the marine world is a relatively small niche market that tends to follow rather than lead other industries in terms of innovation. This slow adaption is partly due to the unique issues of boating. Boats have a different frequency and variance of use than cars and the market has many segments (ferries, sailboats, small high speed planers, large distance cruising yachts, etc.) where boats are used differently, making it hard to build one solution to fit all applications.[86] Finally, because e-propulsion is in its infancy in the marine market, available solutions are few and they're expensive. So far, most electric boats have been slow and small and had very restricted range but that is changing. There's also the problem of infrastructure, which is the same for automotive: What is the range of these new vessels and where do they recharge? Just like a Tesla that you'd probably not take on a cross-country road trip, a boat may need charging stations close together to "fuel" quickly.[87]

5.2.2 High-level use cases

Based on the market availability and technologies, different clusters of high-level electric vehicles use cases can be considered and assessed by a SWOT analysis for geographical islands as follows. In particular, this part will be focused on the road vehicles, today, the most widespread solutions based on electric propulsion.

5.2.2.1 E-cars

E-cars are the most widespread solutions in terms of road electric vehicles, the market offers a wide range of models based on vehicle segment, usage, type of charging and price. Here below a table which summarize the most common models available on the European market taking into account the motorization type, the distance autonomy and the plug-in type:

Table 19: Summary of the most common E-cars available on the market

	BEV	PHEV	HEV	Autonomy (km)[88]	Plug-in type
Tesla Model 3	Yes	No	No	300	CCS
BMW i3	Yes	No	No	225	CCS

[86] https://www.ntnu.edu/documents/139799/1279149990/33+Article+Final_trulstv_fors%C3%B8k_2017-12-07-17-25-18_TPD4505+Truls+Tveitdal.pdf/4523bd20-1024-4179-8dde-878d847a7e29
[87] https://www.boattrader.com/resources/hybrid-and-electric-boats/
[88] Max mileage autonomy with battery only

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Chevy Bolt	Yes	No	No	300	CCS
Nissan LEAF	Yes	No	No	250	CCS / CHAdeMO
Ford Focus Electric	Yes	No	No	185	CCS
Hyundai Ioniq	Yes	No	No	310	CCS
Kia Soul	Yes	No	No	390	CCS / CHAdeMO
Mitsubishi i-MiEV	Yes	No	No	160	CCS / CHAdeMO
Tesla Model S	Yes	No	No	600	CCS
Tesla X	Yes	No	No	325	CCS
Volkswagen e-Golf	Yes	No	No	230	CCS
Chevy Volt	No	Yes	No	85	CCS
Ford C-Max Energi	No	Yes	No	32	CCS
Mercedes GLE550e	No	Yes	No	20	CCS
Audi A3 E-Tron	No	Yes	No	48	CCS
BMW i8	No	Yes	No	55	CCS
Fiat 500e	No	Yes	No	n/a	CCS
Hyundai Sonata Plug-in	No	Yes	No	47	CCS
Kia Optima	No	Yes	No	54	CCS
Porsche Cayenne S E-Hybrid	No	Yes	No	35	CCS
Toyota Prius Plug-in	No	Yes	No	50	CCS
Volvo XC90 T8	No	Yes	No	30	CCS
Toyota Prius Hybrid	No	No	Yes	Not possible	No battery inlet
Honda Civic Hybrid	No	No	Yes	Not possible	No battery inlet
Suzuki Swift	No	No	Yes	Not possible	No battery inlet
Ford Puma	No	No	Yes	Not possible	No battery inlet
Hyundai Kona	No	No	Yes	Not possible	No battery inlet
Fiat Panda	No	No	Yes	Not possible	No battery inlet

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Mazda 3	No	No	Yes	Not possible	No battery inlet

Here below the SWOT analysis based on the E-cars:

Table 20: E-cars SWOT analysis

Strengths	- Eco-friendly - Silent - Cheaper to run - Simpler mechanisms (electric motor)
Weaknesses	- Need time to recharge - Battery change may be expensive - Still high prices - Low distance autonomy
Opportunities	- Home charging - Government subsidy for ownership - Lower taxes - Lower dependence from fossil fuel
Threats	- Rise in cost of electricity - Competition from gasoline cars - Lack of recharging infrastructures

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5.2.2.2 E-buses

The following table summarize some commercial available solutions relevant to the sector of the electric vehicles for the passenger transportation. The analysis is focused on European and Chinese companies which are some of the main players in the European market. The investigation take into account two kind of product: 12 meters, under 9 meters and 6 meters bus length, the most widespread solutions on the market for the passenger transportation in a urban context. For each product is reported the model, the dimension, the distance autonomy and the recharge type, there are two kind of solutions: plug-in (electrical connector to connect the charging station(type: CCS, GB/T, CHAdeMO)) or pantograph (apparatus mounted on the roof of the e-bus to collect power through contact with an overhead line.)

Table 21: Summary of the most common European and Chinese E-buses manufacturers

	Product name	Autonomy (km)	Plug-in type	Pantograph
Rampini	E120 (12m)	200	Yes CCS2	No
	E60 (6m)	150	Yes CCS2	No
Yutong	E12 (12m)	260	Yes GB/T or CCS2	Yes
Solaris	Urbino 12 electric (12m)	n/a	Yes CCS2	Yes
	Urbino 8,9 LE (9m)	150	Yes CCS2	Yes
Bollorè Bluebus	Bluebus 12 M (12m)	280	Yes CCS2	No
	Bluebus 6 M	180	Yes CCS2	No
CaetanoBus	e.City Gold (12m)	300	Yes GB/T or CCS2	Yes
BYD	12m eBUS (12m)	260	Yes GB/T or CCS2	No
	8.7m Midibus (9m)	n/a	Yes GB/T or CCS2	No
Alfabus	ECITY L12 (12m)	280	Yes GB/T or CCS2 or CHAdeMO	Yes

Here below the SWOT analysis based on the E-buses:

Table 22: SWOT analysis E-buses

Strengths	- Eco-friendly - Silent - Cheaper to run - Pantograph recharging - Recharging at bus stations
Weaknesses	- Need time to recharge - Creation of recharging infrastructures - Battery change may be expensive - Still high prices

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	- Low distance autonomy
Opportunities	- Government subsidy for ownership - Lower taxes - Lower dependence from fossil fuel
Threats	- Rise in cost of electricity - Competition from gasoline buses - Competition from other passengers transport (trams, car sharing etc..)

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6 Upgrade/efficiency of Local Public Assets

6.1 Interventions on cabling

Power grid interconnections between islands or between mainland and one (or more) isolated islands are key to ensure a secure and cost-efficient energy supply for islands. The electricity grids of isolated islands are less reliable because of lower number of generation sites and absence or insufficient interconnection, limiting their capacity to install RES plants.

Interventions on cabling for this interconnection intend to provide a long-term solution for the electrification of the islands. There are three main actions to consider in that regard:

- Connection of island(s) electrical grid to mainland
- Repowering an existing connection to lower on site fossil fuel generation
- Interconnection between islands to facilitate grid management

These investments are mainly motivated by the high generation cost in the island and the low reliability of supply. Fossil fuel-based installations operate mainly at low load factors since they are designed to meet seasonal demand, making them less efficient. Also, severe regulatory limitations in existing oil power plants (EC Dir. 2010/75/EE & 2015/2193/EE) difficult efforts to repower existing generation infrastructures.

The increased possibilities for power supply management further the potential for RES integration in the grid. This is very relevant due to the high potential of these resources in EU islands.

The process of an interconnection project follows these steps:

- Selection of the provisional path for the cabling
- Obtaining permission from the relevant authorities
- Survey of the path with hydro jet machines
- Designing the cable system according to the path conditions
- Laying the cable, including burial if possible
- Post-lay inspection

These actions pose the following benefits for the islands

- Significant savings of fuel costs (the generation cost in the island varies from 80 up to 180 €/MWh compared to 50-60 €/MWh in the mainland). In some cases, such as Spain or Greece, uplift costs are distributed to all consumers in the country

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- Avoided high investment costs for the development and conversion of local power plants
- Reliability of supply
- Interconnection allows the exploitation of the high RES potential of the islands
- Contribution to the reduction of environmental impacts
- Increased competitivity in the energy market

6.2 Public lighting

Renovation of municipal street lighting with LED lamps is a common low carbon action among cities that account for electricity savings of minimum 50%. The payback periof of such renovation, including also savings in maintenance, may be of 4 years or less. In the case of the **Spanish assistance programme for the renovation of municipal street lighting 2014-2015, 97% of renovation cases included replacement by LED and the regulation of public lighting schedule. Results suggest a minimun electricity savings of 65% that could be increased with flow regulation system.**

Currently, EU islands such as Guadeloupe (FR) and Cres (HR) are planning to renovate their outdated public lighting to lower costs and reduce carbon footprint. In the first case, counting with ERDF funds, Guadeloupe intends to improve the performance of its public lighting system that represents 58% of its electricity consumption. It is expected to achieve a reduction of energy consumption by around 21 GWh/year and of CO2 emissions by 20600 tonnes. In the case of Cres, the municipality has already replaced more than 1225 luminaries with a project worth 0,6M €. It is estimated that the project will cut the city’s expenses for public street lighting with up to 85%.

Main barriers towards this upgrading of public assests are limited institutional training and equipment. Municipal governments may require capacity building for the design of efficient street lighting.

6.3 Special project to be related to energy topics[89] (Water network, Sewage, Waste disposal and management)

On islands, especially on small ones, waste management could be a difficult task due to several constrains, such as limited land availability to store and conduct a correct treatment, not enough production of waste to explore energy generation alternatives or high variability in tourist seasons that increase the complexity for planning and operating waste systems. Islands with high seasonality the accumulation of marine litter might be 3 to 4 times higher if compared with low season. Water consumption and the

[89] https://blueislands.interreg-med.eu/fileadmin/user_upload/Sites/Sustainable_Tourism/Projects/BLUEISLANDS/D.5.8_Waste_Management_Handbook_EN.pdf

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demand for sewage treatment is also highly increased, leading to a greater contamination of marine coastal areas by nutrients of anthropogenic origin.

A first measure, also impacting the generation and consumption of energy, is to follow the hierarchy of solid waste management: reduction, reusing, recycling, and other recovery measures, including waste-to-energy applications. Separation of organic waste from other materials open the possibility to energy generation from biogases. In Mallorca, for example, separation of organic waste has allowed the production of biogas resulting from the methanisation plant. In 2018, 23.350 tonnes of organic waste and 14.040 tonnes of sewage sludge were treated by this plant. The biogas is used as fuel in a cogeneration engine for electrical production, the resulting energy is used by the plant itself and to feed the power grid.

Similarly, Wastewater Treatment Plants (WWTP) may produce energy from processes such as:

- At plants with anaerobic sludge treatment, electric and thermal energy from digestor gas (biogas) combustion.
- Thermal energy from wastewater heat (and cold) recovery.
- Thermal energy from solar installations on the premises of WWTPs.
- Electric energy from hydropower in the effluent and wind power at the premises of WWTPs.

6.4 Shore-side electricity in ports

Besides Energy-aware operational strategies, several technologies are currently being adapted by ports to achieve energy efficiency and reduce GHG emissions. These solutions include[90]:

- **Onshore power supply:** also known as cold-ironing, it consists on supplying electric energy to the vessel directly from the port, avoiding the use of ship's auxiliary engines for hotelling activities (i.e. power system maintenance, lighting, refrigerating). The electricity can be supplied by the grid, renewable sources or other sources, replasing the use of diesel oil, heavy fuel oil or LNG. This is an option useful for bulk carrier services and for cruise ports. In the first case, economic savings could be expected for islands in which the electricity price is less than 0.19 USD/kWh. Also, a reduction on energy consumption and operating costs of 75% might be achieved depending on the shoreside power source. Whereas for cruise ports, that do not stop activities while docking, case studies have shown potential of CO_2 mitigation of 99.5% (Norway), 85.0% (France) and 9.4% (US) in the cruise port regions.
- **Electrification and automation for equipment:** operation in all functional areas of a port, namely quayside, yardside and landside, are electrifying their

[90] Çağatay Iris, Jasmine Siu Lee Lam (2019), A review of energy efficiency in ports: peratational strategies, technologies and energy management systems, Renewable and Sustainable Energy Reviews, Volume 112,Pages 170-182

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equipment to reduce energy consumption and operational cost. In the yardside, for example, stacking operations done with electrical Rubber-Tired Gantry cranes, that can switch between grid power and power from a diesel generator, obtain around 85% reduction in energy costs and 67% reduction in GHG emissions. Other technologies, such as Battery-powered Automated Guided Vehicle for horizontal transport of containers shows that the energy consumption could be reduced by 64% on average. Quay Cranes, that represent around 35% of total consumed electricity in ports, could be converted to direct current technologies to reduce peak energy demand. In combination with energy storage devices to save the energy recovered in the hoist-down movements, Quay Cranes might reduce peak power by 70%.

- **Reefer containers:** trade of refrigerated containers is a port operation that has been steadily growing in the recent years, in some cases, the energy consumption for reefer container operations is around 20% and 45% of the total energy consumed by ports. Solutions may stem from specific planning and scheduling of such operations. For instance, determining the number of plugs for reefers, minimizing travel distances with optimal location of reefer area, designing better electrical distribution systems, etc.
- **Lighting:** switching to LED lamps, instead of high-pressure sodium ones, in port facilities and buildings (administrative, terminals, etc.) and outdoor lightning. Lighting represents around 3-5% of total energy in ports.

Similarly, the adoption of energy management systems, integration of RES and clean fuels, such as biofuels and LNG, and the implementation microgrids and smart grids are alternatives being tested by ports to improve their energy performance. A combination of the described technologies, together with energy management systems and an adequate operation planning has the potential to reach up to 90% savings in terms of energy efficiency.

6.5 Electrical Distribution Grids

6.5.1 Summarized Technology Analysis

6.5.1.1 Swot Analysis

Strenghts	- Grid upgrades can lead to better grid stability, resilience and reliability of power supply to island communities. - Better control and balancing of supply and demand can reduce costs for island residents.
Weaknesses	- No clear mechanism for return of investment - High infrastructure costs for grid upgrades - Installation of RES typically require large footprints - RES can be unpredictable and can make grid balancing difficult. - Complex logistics of technology transportation: grid infrastructure upgrades may require significant machinery and access to complete

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	works.
Opportunities	- Lack of existing central grids on small islands - Geographical conditions of islands allow for the connection to RES which can support a large portion of island demand with effective balancing of supply and demand. - Islands often experience intermittent power supply and power-cuts.
Threats	- Limited grid capacity may limit ability to accommodate for additional RES - Balancing supply and demand can be complex. - Tourism can significantly increase demand, making it harder to balance the grid. - Successful grid balancing requires careful design of controls.

6.5.1.2 Technology Readiness Level

Sucessful use-cases suggest that upgrades to grid infrastructure can be implemented effectively, providing that the systems and controls are designed carefully to achieve balance between island power supply and demand.

6.5.2 High-level use cases

This section describes Island grid infrastructures, and the factors to consider when maintaining reliable grid performance with increasing penetration of renewable energy sources (RES).

There is no latent storage of electricity in electrical grids, which you will find in gas and, to a smaller extent, water grids / networks. Electricity 'inventory' does not exist in the overhead / underground lines. When designing a new grid or reviewing an existing grid for retrofit/expansion, the supply and demand must always balance.

6.5.2.1 Balanced Grids

A balanced grid allows control of the grid **frequency**, **voltage**, **total harmonics distortion (THD)**, **thermal constraints**, **transient stability** and **loss of main power**. These topics apply to all island and micro-grids, as well as Earthing and synchronization / disconnection. Fault detection and isolation for the grid is essential to maintain a reliable grid, prevent long term power outage and avoid expensive repairs.

6.5.2.2 Frequency management

When running connected to the main grid, **frequency** is controlled by the main grid. However, in island mode, frequency must be controlled by the microgrid. This requires a mix of controllable generation and demand. In main grids, this function is traditionally provided by controllable generation, but in small island systems controllable demand is commonly used for this function. Controlling frequency requires matching the demand and generation. Frequency is the same at all points in the microgrid and hence can be controlled by any adjustable generation of demand. The use of poorly controllable or intermittent generation such as wind and solar is a problem and the control of frequency

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in island mode has commonly led to the use of controllable diesel generation, storage devices and controllable demand.

6.5.2.3 Voltage management

When running from the main grid, **voltage** will in part be controlled by the main grid and largely be defined by the main grid at the point of common coupling (PCC). However, voltage within the microgrid will tend to be harder to control further from the PCC and if being transformed to different voltages from the PCC through fixed tap transformers. In island mode, the generation in the microgrid will largely set voltage where it is connected, but away from, the voltage will be determined by the power and reactive power flows through the wires. Unlike frequency, voltage is a local variable requiring careful local control. Careful up-front design of the microgrid is a key aspect in ensuring voltage is suitably controlled in operation, particularly in island mode.

6.5.2.4 Harmonics

Total harmonic distortion (THD) is a measure of the harmonic distortion present in a signal. Distortion factor, a closely related term, is sometimes used as a synonym. In power systems, lower THD implies lower peak currents, less heating, lower electromagnetic emissions and less core loss in motors.

6.5.3 Realization of use cases specifically on islands

Some islands will have existing central grids to connect to, or expand from, to increase RES connections. Some islands will have no existing central grid, such as the Isle of Egg, Scotland that relied on individual household generators to supply power. For the Isle of Egg, the power supply was intermittent with several power outages across the island before a centralized micro grid was built into the island to provide resilience and more reliable power to the community.

For larger islands, the topology of the grid will consist of HV, MV and LV networks with multiple substations across the island. These grids would have been built out with either a centralized diesel generator or with an interconnector from the mainland, as with the Isle of Wight, UK which connects to the mainland providing power to the island. Interconnectors are not without faults, as with the Isle of Gigha, Scotland where its interconnect is prone to faults and power cuts because of distant faults occurring over a wide area on the mainland. For the Isle of Wight, there are limits on the interconnector on how much power can be imported or exported. This is due to capacity of the interconnector and constraints on the mainland grid. For grids developed with centralised diesel generation or interconnectors, where RES will create bi-directional flow, this will change distribution networks into something more like transmission networks. For these cases, supply and demand should be balanced on the part of the grid that additional demand or generation is connected. If this is not the case, there would be expensive infrastructure costs to the parts of the LV, MV and HV grid not designed to export larger loads from a new cluster of, for example, a batch of solar PV farms.

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To prevent over-investment on island grid infrastructure, the designers should avoid specifying the distribution network to firm capacity requirements, as this would lead to under-utilization of assets since these have been sized to maximum requirements. Flexible connection schemes can greatly reduce the requirement for network reinforcement. Flexible connections can unlock capacity, and these can be achieved using Active Network Management real time monitoring software.

Storage is briefly discussed in this section as it provides services to the grid like peak shaving network loads, reduce network loadings at predicted times, a substitute for network enhancement works, reduce future network infrastructure costs. Electric storage also allows fast response to balance network loads, and resilience against winter resource limitations / blackouts.

Most islands have relied on diesel generators to supply reliable power to island communities. Diesel generators are dispatchable, balancing grid supply with demand 24 hours a day, allowing ease of stability to the island grid. Diesel has a very high energy density, which allows a lot of energy to be stored in a relatively low footprint. In many cases, the diesel generators are maintained in island communities to act as back-up generators.

The next sections discuss the impact of available natural resources of individual islands with the demands that need to be satisfied, and the role of how short- and long-term storage supports the penetration of RES to the island grid.

6.5.3.1 Islands with focus on solar resources

Depending on geographic locations, each island of micro-grid community will have an amount of natural resources that can be harnessed to provide carbon free energy. For islands near to the equator, there will be surplus solar irradiation all year round, and for islands closer to the north / south poles there is surplus wind energy. For Island, like TaU, American Samoa solar PV contributes 100% to the island energy needs, alongside a 6 MWh battery system supports cloudy days and night time periods for up to 3 days. For Ta U, American Samoa, the low island demand can be balanced with PV supply at all periods, with support from its very large relative battery storage system. The battery system allows control of the grid's voltage, frequency and THD.

For most islands with high solar PV resource, due to ihabitants and tourist demand, and industry demand solar PV will not satisfy the complete load balancing. This is not only due to space constraints, but also to real time balancing of supply and demand, where a lot of demand occurs when there is no sunshine.

6.5.3.2 Islands with focus on wind resources

Wind is a common natural resource across the islands, and there are many examples where large RES is from wind turbines. Wind is renowned for its random nature and their unpredictability which can upset micro-grid stability. This is a challenge that island grids, moving to the uptake of renewable penetration, will face. To support wind

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turbines RES penetration to micro-grids, wind turbines can be installed with storage devices like electric batteries, electric boilers or flywheels.

Flywheels involve spinning a mass in a low frictional environment – normally a vacuum. The flywheel is connected to a motor-generator which links into the localized electrical network. Electrical energy is transformed into kinetic energy by the motor-generator and put into the flywheel. At times of power requirement, the flywheel's inertia will keep it spinning, but it will lose some of its kinetic energy as this is transformed back into electricity by the "generator side" of the motor-generator. Flywheels tend to be low-maintenance, long-life technologies; desirable characteristics for remote communities without masses of technical expertise. It's important to note that the flywheel comes with a parasitic load to maintain the 'spinning'.

Case studies of wind turbines installed with storage devices to maintain grid stability are: **El Hierro** achieves 100% renewable supply using wind turbines with pumped storage; **Bonaire**, part of the Carribbean Islands uses wind turbines with batteries; the **Falkland Islands** use wind turbines with flywheels; **Coral Bay**, Australia also uses wind turbines with flywheels; **Mawson Station**, Antarctica uses wind turbines and an electric boiler that acts as an energy balance; **Isle of Gigha**, Scotland uses wind turbines, and batteries; and finally **Shetland Islands**, Scotland has some of the highest wind resources and uses wind turbines, electric boilers and batteries.

100% renewable penetration is achieved on the Island of El Hierro, because the island benefits from a long term pumped storage system, where excess RES pumps water up to a volcano crater, 700 meters elevation, which reverses when there is low RES, to generate electricity. The islands desalination plant provides the largest base demand, which helps balance the micro grid. For volcanic islands, where sea depths increase rapidly as you move away from the shore, interconnects are not viable.

For the Falklands Island, to maintain grid stability against a strong wind resource, the wind turbines are given a set point target power and vary their blade pitch to maintain output. Diesel generators are then run at minimum load fluctuations. A flywheel is installed to smooth the transition between wind turbine and diesel ramp up / ramp down periods.

For the Coral Bay, Australia, a low load diesel generator is installed to maximise the penetration of wind energy, while maintaining stability to the grid. A flywheel is also installed to support the transitioning between diesel ramp up and wind turbine power fluctuations.

Mawson Station, Antarctica has been included as its constant wind provides surplus energy. An electrical boiler provides direct load control capability where its demand can be turned up and down to match generation. The boiler is connected to a smart inverter, to provide voltage and frequency support to the micro-grid. The boiler acts as a 'spinning reserve' as the boiler can ramp up and down its output in response to the wind energy.

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The Isle of Gigha, off the coast of Scotland is connected to the mainland via an interconnect that has a history of faults and power cuts. The islands micro grid is fitted with a multi-level converter that can provide both voltage control and load balancing for the connected wind turbines and installed Redox Flow Battery. The island cannot supply all it's energy needs, so the system uses the battery to support connection / disconnect to the main grid and mobilise the diesel back-up generator when it cannot connect to the mainland grid.

Disconnection from the main grid is reportedly a relatively straight forward process but requires rapid instigation of frequency control and other control actions to keep a true microgrid running. Synchronising back to the main grid requires a synchronizing relay and control of the generation or demand within the microgrid to match frequency and voltage waveforms with the main grid. Synchronising itself is a well-known process but the microgrid must have the fine control to facilitate it.

The Shetland Island, north of Scotland balances the wind RES with an electrical battery and large-scale thermal store. The local grid is subject to voltage, transient stability and thermal constraint issues, common to most networks, but also critical frequency constraints which limit penetration of wind turbines, this can cause significant generation-to-demand imbalance. The island incorporated an Active Network Management (ANM) system to real time monitor the grid, also direct load control of household hot water tanks to help balance load and demand, which greatly supports the grid. Direct load control allows the demand to be isolated during a fault in the network, therefore automatically balancing load and demand to maintain the grid to within voltage and thermal limits.

6.5.3.3 Island with mixed renewable energy sources

As briefly discussed, battery storage, flywheels and thermal stores do not provide enough storage capacity to balance supply and demand at all times of the year. These technologies support the short-term RES drop out, grid faults and switch over electricity supply between generators and mainland grid. It also increases the demand to the grid, when demand does not meet the RES generation. Large scale storage like pumped storage on El Hierro (up to a volcanic crater, 700 meter above sea-level) does allow longer term energy storage due to the vast storage capacity on offer, and hydrogen storage is being investigated on the Orkney Islands, Scotland.

Balancing supply and demand are not as easy as maximizing generation to meet demand on an annual basis, some islands will develop more renewable energy in the winter months, while experience a short fall in summer months due to the natural resources. Therefore, increasing generation capacity in winter months where there are more resources does not support the summer months with less resources, therefore brings more instability to the grid;

To bring stability to the network, renewable generation should be introduced during periods where there is low generation. i.e. for an island with large solar resources, additional renewable generation should be introduced during the darker winter months.

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For islands with large winter resource (wind and hydro) additional resources should be introduced during the summer months;

The use of poorly controllable or intermittent generation mix of wind, hydro and solar is a common problem for the control of frequency in island mode. This has commonly led to the use of controllable diesel generation, storage devices and controllable demand to improve the network balancing.

ANM allows system balancing algorithms to process load and generation forecast data to support the creation of schedules for each controllable device.

Islands with mixed RES, which require generation and load management are: Kodiak, Alaska which has wind turbines, hydro turbines, batteries and flywheels; King Island, Tasmania which has wind turbines, solar PV, flywheels and batteries; Isle of Egg, Scotland which has wind turbines, solar PV, hydro-power turbines and batteries; Necker Islands, British Virgin Islands which has solar PV, wind turbine and batteries; SIMRIS, Sweden which has a wind turbine, solar PV, and batteries.

Multiple RES increases the sophistication of the control system. Kodiak used batteries to resolve intermittent wind resource, which led to batteries being charges and discharge 1000 times a day, therefore a flywheel was used instead. The flywheel allowed larger instantaneous short term load to be applied to the grid, without any negative impact. Kings Island had issues with the wind generation and used a dynamic resistor to help regulate frequency. The island incorporated smart meters to monitor consumer energy, hot water loads and PV production. Direct load control accessed heating and cooling systems. Isle of Egg uses inverters to control the frequency and voltage of the grid, balancing the demand and supply and controlling power into and out of the batteries. Direct load control activates heaters during high RES to pre-heat community buildings. Necker Island installed a smart control to balance generation between the different RES and balance it with the islands demand. SIMRIS is able to connect and disconnect to the Swedish main grid to test out island advanced control capabilities with performance of direct load control on heat pumps within the village.

6.5.3.4 Changing demands of islands

As well as the changing RES to the grid, the impact of reduced demand is also crucial to the performance of the electrical grid. As distribution networks act as transmission networks for distributed RES, they rely on constant loads (like a desalination plant) to remove a certain volume of electricity from the grid. If this demand is reduced or removed, the additional generation load will impact the capacity and performance of the rest of the grid, as more power is diverted to other sections of the grid. Also, the impact of a district heating scheme to replace electrical heating could also have the same impact on a grid with an expected base load to minimize flow of power to other parts of the grid.

The increase of demand from electrical vehicles, and electrification of heat and chill will affect the ADMD (after diversity, maximum demand) of individual homes, and need

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to be factored into the performance of the grid and the option for direct load control to peak shave and load shift high demand to off peak periods.

In certain cases, like Isle of Egg, Scotland households and businesses have power limits, coupled with red and green light day warnings via household devices informing end users to reduce their electrical consumption from the grid.

6.5.3.5 Grid barriers to entry for RES

Islands with enough natural resources and funding for solar, wind or hydro technologies will still face barriers to entry for delivering the RES. On some islands there may be ques for connecting RES to the islands grid, and limits to how much generation can be applied to the point of connection. This is due to insufficient capacity on the grid to accommodate the additional RES, also no clear mechanism for return of investment for grid upgrades and developments and who will pay for it. In many cases of grid upgrades and development funding have come from support bodies like the local government, with socialization of transmission constrained management costs.

Additionally, for existing island constrained grids there is a last in, first off (LIFO) policy where the last to connect would be the first to be curtailed. This affects return of investments for RES.

Heat maps to show constrained on the network are available in the UK, these allow RES suppliers and investors areas where RES can be implemented within an island’s grid.

6.5.3.6 District heating / cooling grids;

In cases where electric boilers are used as storage devices, during surplus RES, district heating networks can be utilized to store energy and supply hot water or space heating at parts of the day with low RES, reducing the demand on the balancing services like back-up generators or electrical storage systems.

6.6 Power transformer technologies

6.6.1 Types of power transformers

A power transformer is defined as a static piece of apparatus with two or more windings which, by electromagnetic induction, transforms a system of alternating voltage and current into another system of voltage and current usually of different values and at the same frequency for the purpose of transmitting electrical power.

A power transformer is furthermore defined by relevant characteristics such as

- Power, voltage and frequency ratings

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- Tapping
- Connection phase displacement
- Service and ambient conditions
- Cooling mode
- Classification
- Windings
- Efficiency and load losses
- Noise level

The TRL and maturity level for all transformers is generally very high. The cost of a power transformer varies significantly based on BIL rating, MVA rating, core design, guaranteed losses requirement, tank design, etc. Costs are also mainly determined by the current costs of materials, mainly copper, based on indices. Average prices are typically:

- Small power transformer with on-load tap changer – 10MVA or lower: ~ 600,000 €
- Medium power transformer with on-load tap changer – 10MVA to 50MVA: ~800,000 €
- Large power transformer with on-load tap changer – 50MVA to 100MVA: ~1,500,000 €
- Large power transformer – 100MVA or larger: ~ 2,500,000 €
- Specialty phase shifting transformer – 100MVA+: ~4,000,000 €
- Although there are different kinds of transformer such as separate winding transformer, auto-transformer or series transformer, types of transformers can generally be distinguished as follows.

6.6.1.1 Liquid-immersed type transformer

This is specified as a transformer in which the magnetic circuit and windings are immersed in liquid. The body of the liquid immersed transformer is installed in the welded steel tank filled with insulation liquids, namely specific insulating oil or synthetic liquids.

The liquid serves both the purpose of insulating against electric fields and cooling. When oil immersed transformer in operation, the heat of the coil and the iron core is transformed to the insulation oil and then to the cooling medium. According to the capacity sizes, it can be divided into immersed natural cooling transformer and immersed forced air cooling transformer.

Due to the oil immersed transformer is immersed in the oil tank, a leakage may result in fire. Thus, oil immersed transformer is generally used in separate room or exterior places. If the climate of the installation region is relatively heat and humidity, the oil immersed transformer is also a good choice.

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6.6.1.2 Dry-type transformer

This is specified as a transformer in which the magnetic circuit and windings are not immersed in an insulating liquid. It utilizes air cooling method to reduce its operating temperature. Compared with oil-immersed transformer, a dry-type transformer is kind of transformer whose iron core and winding are not immersed in the insulation oil. The cooling methods of dry-type transformer are divided into natural air cooling (AN) and forced air cooling (AF). When in the condition of natural air cooling, dry-type transformer can be operated long-term continuously under the rated capacity. When in the condition of forced air cooling, the output capacity of dry-type transformer can increase by 50%.

With no risk of fire or explosion, dry-type transformers are usually used for places where fireproof and explosion-proof transformers are required, such as populated buildings, malls, local lighting, airports, or places with other mechanical equipment. At the same time, the dry-type transformer can also be installed in load areas to reduce voltage and electrical power losses.

6.6.2 High-level use cases

Based on the implementation of available power transformer technologies, different clusters of high-level use cases can be considered and assessed by a SWOT analysis for geographical islands as follows.

6.6.2.1 Energy efficient transformer replacement

In a typical supply grid, electric transformer power loss typically contributes to about 40-50% of the total transmission and distribution losses, even if a modern power transformer can reach an efficiency grade up to 99,8%. Replacement of aged, low-efficient transformers by energy efficient transformers are therefore an important means to reduce transmission and distribution losses. By using the improvement of electrical steel (silicon steel) properties, the losses of a transformer can be reduced significantly. With new magnetic materials such as amorphous metals, it is possible to reach even higher efficiency grades.

Small power transformers, medium power transformers and large power transformer shall meet the ecodesign requirements as set out in Annex I of (EU) 548/2014. New power transformers shall meet higher efficiency grades commissioned from 1st July 2021 onwards.

Strenghts	- Significant reduction of transmission and distribution losses
Weaknesses	- High CAPEX solution - Long return on invest
Opportunities	- Lower operational costs due to lower electrical losses
Threats	- Potential ancillary costs such as new foundations due to higher weight or housing to reduce additional resulting noise

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6.6.2.2Voltage Regulation Distribution Transformer

The Voltage Regulation Distribution Transformer (VRDT) means a medium power transformer equipped with additional components, inside or outside of the transformer tank, to automatically control the input or output voltage of the transformer for on-load voltage regulation purposes. It can be either based on liquid-immersed of dry-type transformers.

The highly volatile feed-in of electricity from DER and RES produces much greater fluctuations in voltage, especially in the medium and low voltage grids. This makes compliance with the limit values defined for safe and reliable grid operation increasingly difficult, especially the requirements for voltage stability defined in EN 50160. There is often a need for DSOs for network reinforcement which is often very costly.

Over the last few years, however, numerous alternative technical solutions have been developed. One effective solution to overcome voltage fluctuations in the distribution grid is the replacement of standard type transformers by VRDT. In many cases, the VRDT is an economical alternative to conventional grid reinforcement.

Strenghts	- Significant increase of voltage stability in distribution systems - Economic solution compared with opportunity costs of conventional network reinforcement
Weaknesses	- High CAPEX solution - New or revised transformer station required in many cases
Opportunities	- Decreased need for conventional network reinforcement
Threats	- Potential ancillary costs such as new foundations due to higher weight or housing to reduce additional resulting noise

6.6.3 Realization of use cases

6.6.3.1 Transformer Replacement Program of US National Grid

US based DSO National Grid started early 2018 with their transformer replacement program of LV dry type transformers 25-300 KVA in order to raise efficiency of the distribution system as an alternative to necessary network reinforcement.
This program focuses on incentives provided for the early replacement of low-voltage dry-type transformers in commercial, industrial, and municipal facilities, installed prior to state and Federal adoption of the US TP-1 efficiency standard. These older transformers have much lower efficiencies, varying from 92% to 95% at rated load conditions, and even lower efficiencies at typical loading conditions.

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6.6.3.2 VRDT rollout program of E.ON in Germany

Already back in 2012, the German DSOs of the E.ON group (Bayernwerk, Avacon, Hansewerk and E.DIS) have significantly pushed the development of the first commercial VRDT solution.

Until end of 2014, German E.ON DSOs commissioned 180 VRDT for the economic integration of renewable energies into their distribution systems. According to academic DENA calculations, VRDT have the potential to save around 1.4 billion EUR in grid expansion costs in the low-voltage grid by 2030.

The use of VRDT noticeably increases the absorption capacity of the distribution grids for renewable energies and enables economical, stable operation even with massive feed-in, thus reducing the need for grid expansion. As a reliable, cost-effective technology, VRDT fully fulfil the requirements of the energy industry with its demand for security of supply, economy and environmental compatibility.

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7 Building retrofitting

Many cities are putting efforts to develop an urban transformation strategy by transitioning traditional cities to develop sustainable plans. In these plans, improving the energy efficiency of buildings, especially existing ones, is key to mitigate the effects of climate change.

The sustainability of buildings is important for the future of society and the available resources. Therefore, improving the energy efficiency of existing buildings should be essential.

Retrofitting involves the study of the building, virtually modernized, considering an architectural plan and the use of common retrofitting methods to meet current requirements.
These retrofitting alternatives are evaluated based on structural, cost and environmental aspects.

7.1 Building retrofitting – Scenario Analysis

Optimal use of limited natural resources is one of the most important problems for modern countries. Buildings require a large amount of investment and financial resources.

The construction sector represents almost 40% of total energy demand, and buildings are the main emitters of greenhouse gases in cities.

The results of this latest research, combined with property data from McGraw-Hill Construction[91], show a growing momentum of green building participation in the market for modernization (new construction) and renovation (existing buildings).

Growth in green building modernization projects represents a significant opportunity for the industry.

The retrofitting figures are as follows:

- Green Building Renovation and Renovation Market share: 20-30% by value.
- Market opportunity for large projects (those over € 1 million): € 10.1–15.1 billion.

There is a significant opportunity in the modernization market for energy efficient buildings that places its market share at around 66 to 75% in value and is expected to grow to 85-95% in five years.

The following graph shows the activities for the energy improvement of the buildings that are most accepted by the owners:

[91] Source: McGraw-Hill Construction. "Green Building Retrofit and renovation". Smart Market Report.

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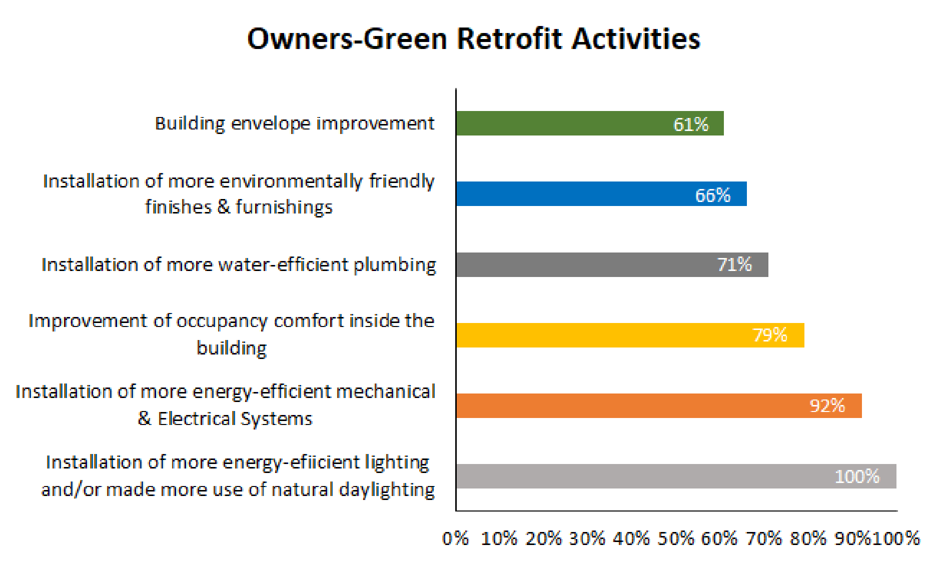

Figure 72 Green Retrofit activities. Source: McGraw-Hill Construction[92].

As the graph shows, the owners of the buildings prioritize the importance of electricity savings over the rest of the energy efficiency measures. It could be explained because the measure shows the least investment, short installation times and a quick impact on the savings shown on the electricity operator's bill.

Also, it is necessary to make a differentiation according to the property of the construction, since based on it, the investment agents show different valuations and priorities.

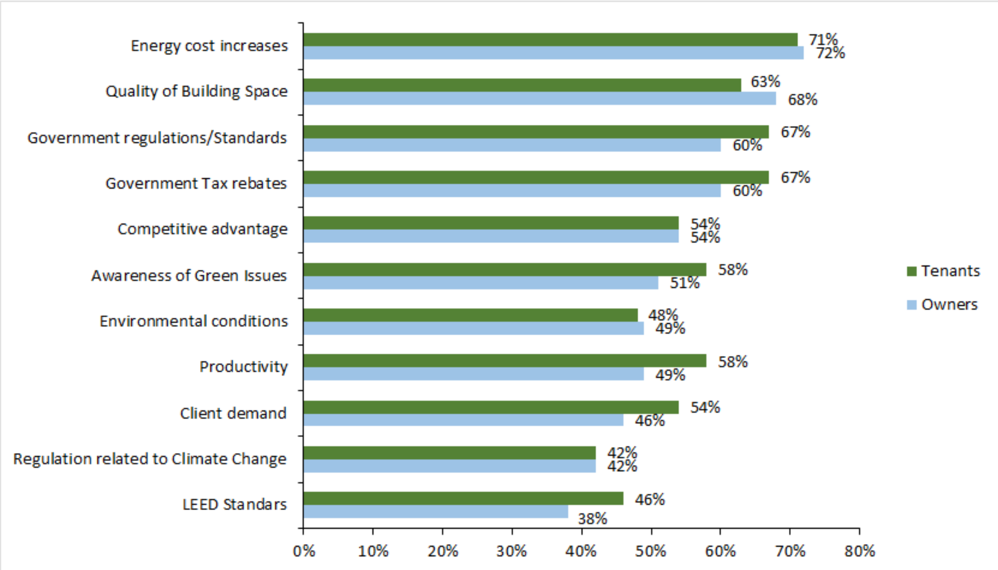

Figure 73 Environmental motivations for Green Retrofit Projects. Source: McGraw-Hill Construction[10].

[92] Source: McGraw-Hill Construction. "Green Building Retrofit and renovation". Smart Market Report.

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The graph confirms that it is necessary to reach agreements between the owners of the buildings and the new rented inhabitants, since their interests diverge.It is important to highlight the concern for both actors for the energy cost volatility.

However, it could be considered seriously that when it is proposed to install efficiency measures, the acquisition of certificates endorsing these measures is not welcomed by both the owners and the renter. Nevertheless, the acquisition of quality and efficiency awards (LEED Standards) would facilitate the promotion of the measures and would make the project more attractive to potential investors.

7.2 Building retrofitting – Technology scouting

The structural components used in the modernization of the building consume natural resources and are responsible for energy consumption. For this reason, the sustainability criteria must be included directly in the retrofitting requirements.

The construction sector represents almost 40% of total energy demand, and buildings are the main emitters of greenhouse gases in cities. The unit cost value and CO_2 emission factors change according to the quality of the material.

To carry out an efficiency plan in the rehabilitation of buildings, it is necessary to consider 3 stages:

- Budget for sustainable development.
- Impact assessment of the conversion (building remodeling).
- Development of a conversion control system (energy efficiency measures).

As modernization improvements that should have for the following building elements:

- Covers and porches:
    - Fixing possible leaks due to rain.
    - Maintaining the temperature inside the building (reflective roof).
- Windows and doors:
    - Improvement of insulation.
    - Avoiding leakages of cold and heat from outside.
- Exterior equipment and cover-up of the façade:
    - Thermal isolation measures.
- Lighting and electrical systems:
    - Improvements that enable electricity savings.
    - Replacement of conventional lighting by Diode lighting (LED).
- Solar water heating, heat recovery and thermal storage:
    - Efficient heating systems.

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- Lifting system.
  - Improvement of the system energy efficiency, adapting power and speed (m/seg).
  - Adaptations of the interior lighting system of the elevator using presence sensors.

That energy efficiency measures show different volumes of savings:

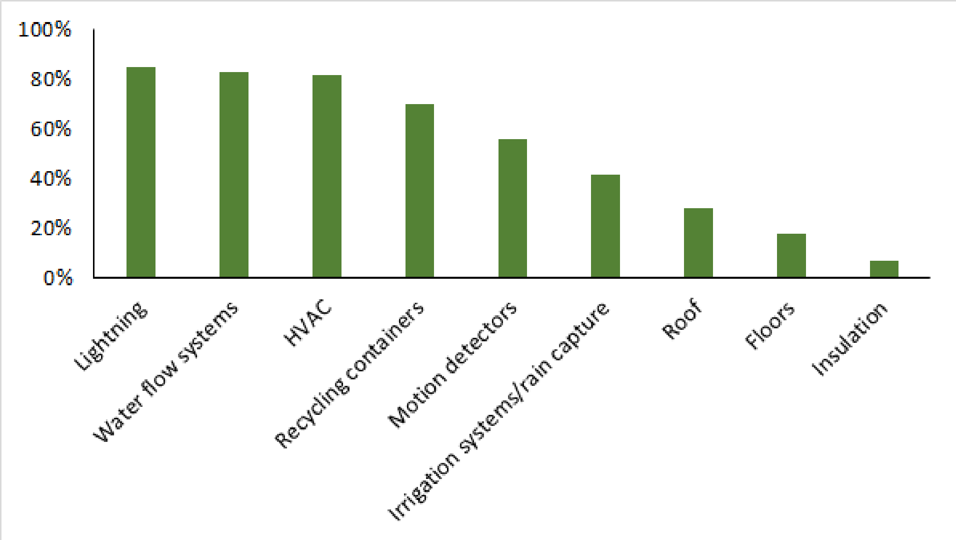

Figure 74 Major improvement during Retrofitting[93].

7.2.1 Lightning

7.2.1.1 Change of conventional luminaires for LED technology

The application of the energy efficiency measure based on the substitution of conventional luminaires by led ones, aims to achieve three objectives[94]:

- Rationalize the use of energy with facilities of the highest possible energy efficiency.
- Comply with quality recommendations and visual comfort.
- Create comfortable environments for facility users.

For this, it is intended to establish: a procedure to be followed by the technician, in the design, calculation, equipment selection and energy and economic study of alternatives, as well as for the maintenance and operation aspects of the installation, from the point of view of energy efficiency and saving.

Five fundamental types are distinguished:

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[93] "The application, benefits and challenges of retrofitting the existing buildings" (IOP Conference Series: Materials Science and Engineering).
[94] Source: Guía Técnica de Eficiencia Energética en Iluminación (IDAE).

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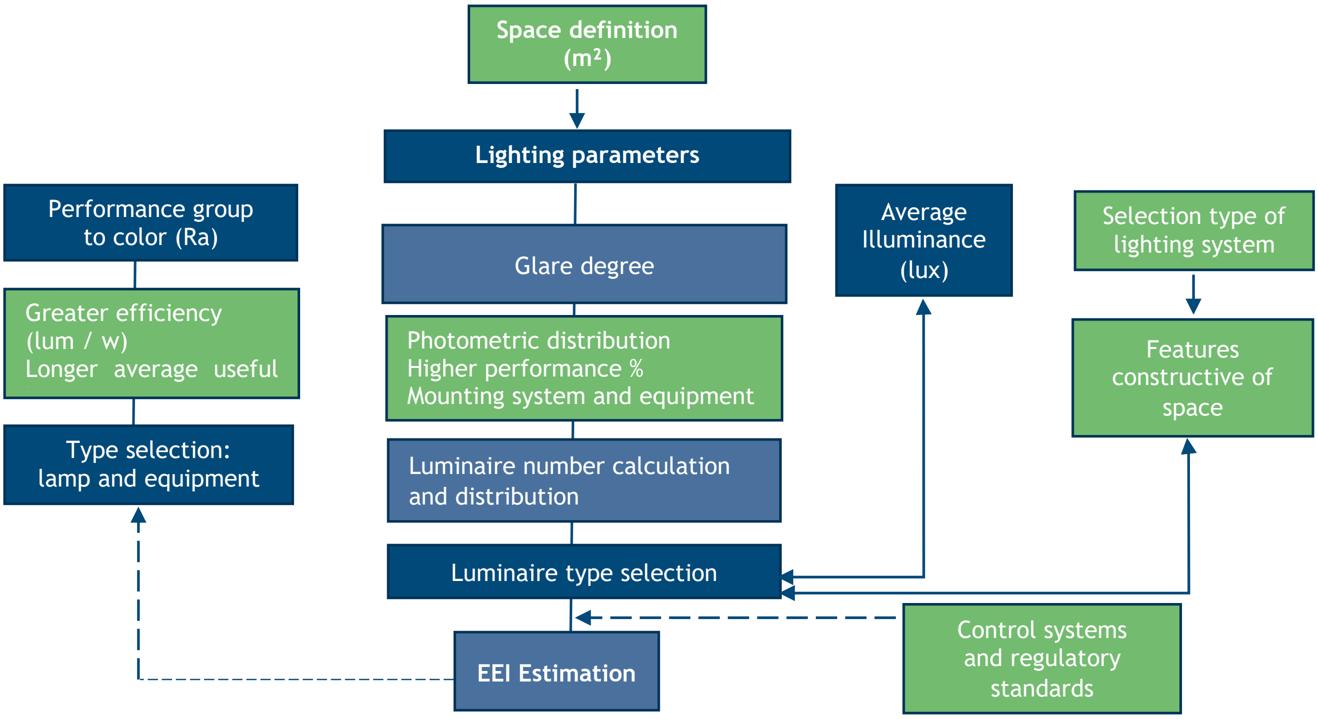
1. Change of conventional luminaires for LED technology.
2. Regulation of artificial lighting according to contribution of natural light through windows, windows, or skylights.
3. Control of on and off- depending on presence in the room.
4. Regulation and control on user demand by push button, potentiometer or remote control.
5. Regulation and control by a centralized system management.

The Energy Efficiency Index (EEI) can be expressed in function of the watts installed per square meter, to a level of illumination determined and referenced to 100 lux.

$$EEI = W / m^2 \times 100\ lux$$ [95]

To determine which luminaire is optimal depending on the space to be illuminated, it is necessary to carry out the following procedure:



By replacing conventional luminaires with LED technology, savings of 50-80%[10] are estimated.

7.2.1.2 Light control systems

The installation of detectors for light control allow the lighting of any space to be switched on or off according to the existence or not of people in it, achieving great energy savings.

Their installation is simple, and they can be easily integrated into existing systems.

[95] Source: Guía Técnica de Eficiencia Energética en Iluminación (IDAE).

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7.2.2 HVAC (Heating, Ventilating and Air Conditioning)

Heating, ventilation and air conditioning (HVAC) systems constitute approximately 35%[96] of the energy consumed in commercial and residential buildings.

Through the application of innovative technologies that help to achieve a remarkably higher heat transfer efficiency in heat exchangers and an energy saving of up to 50% in the total energy consumption of an HVAC system.

The heating or thermal conditioning of a building is normally carried out by ventilation and air conditioning systems. The objective is to use equipment that minimizes the use and consumption of energy.

In addition to energy consumption, these systems have a strong impact on air quality and indoor environment (Indoor Environmental Quality, IEQ).

Among the related measures, the following stand out:

- **Aerothermal heat pumps.** Based on the use of energy stored in the ambient air to provide heating, cooling and / or domestic hot water. This equipment is capable of transforming one unit of electricity or gas into three or more heating or cooling units[97]. This means that this system can be used throughout the year with the consequent savings in the energy bill.
- **High-performance gas condensing boilers**, low operating temperatures or floor heating installation. Betting on systems such as underfloor heating to condition the interior of the building, where the hot water will circulate in a temperature [98] range between 34°C and 46°C. Therefore, an interior temperature of between 18°C and 22°C is achieved.

- **Biomass boiler installation.** Investment in monitoring systems and periodic maintenance systems of the boiler will ensure its optimal efficiency, enabling that these systems will have a larger useful life than an average conventional boiler (~20 years)[99]. There are different types of biomass boilers on the market:
  - **Wood chip boilers.** Not recommended for home use unless a system over 60 kW is needed. This is because fuel delivery costs and large storage needs make it inconvenient for most households.
  - **Wood log boilers.** These systems need more care in terms of preparation and cleaning, but they are the most sustainable option for those who can supply their own wood.
  - **Wood Pellet Boilers.** These are the most popular systems for medium-sized homes. They are more compact than other biomass boilers, but still require more storage space compared to normal boilers. Pellets are an excellent fuel option due to their easier transportation and lower costs.

[96] Source: European Commission
[97] Source: Asociación de Fabricantes de Equipos de Climatización (AFEC)
[98] Source: "Energy saving measures in buildings". SlowHome.
[99] Source: efENERGIA

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- **Variable refrigerant flow (VRF)** for HVAC systems. This system allows to vary the volume of refrigerant depending on the needs. They can be used to keep different temperatures depending on the zone of the building, even heating some zones and cooling others.
- **Inverter technology.** The devices that integrate inverter technology regulate the speed of the compressor so that it does not work at a constant speed and, therefore, more efficiently. The speed varies depending on the proximity with the set or desired temperature. A conventional system uses a fixed-speed compressor, with only two options of capacities: 0% or 100%. This leads to inefficiencies, losses and breakdowns. The energy efficiency of current inverter units is usually up to almost double[100] that of those that do not use this technology.

7.2.3 Sanitary hot water

This includes the volume of water intended for human consumption. It is used for own consumption, sanitary uses and for other cleaning uses.

To reduce consumption, and therefore also energy investment, we can opt to:

- Low flow taps and water sprayers.
- Closed hot water circuits (with return and use thereof).

7.2.4 Roof and covers

7.2.4.1 Green covers

Vegetation acts as protection against solar radiation in summer, preventing overheating and temperature fluctuation inside buildings.

Organic insulation prevents internal energy losses. It is mainly used on flat and slightly sloping roofs.

7.2.4.2 Installation of thermal solar panels or photovoltaic modules

The solar thermal energy collection system is a technology that takes advantage of solar radiation to produce thermal energy, which can then be used as DHW (Domestic Hot Water), heating or to heat domestic water.

In addition, with the installation of the photovoltaic modules, it is possible to generate its own electricity for the self-consumption of the building.

These systems can generate up to 70%[101] of the energy required in buildings, residential and commercial establishments.

7.2.5 Domotics and Building Energy Management System (BEMS)

Domotics and BEMS are computer-based systems that consist on automation, control and monitoring applied to residential and commercial buildings. This equipment allows to

[100] Source: Toshiba
[101] Source: "Energy saving measures in buildings". SlowHome.

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control lighting, climate, entertainment systems and appliances, using better the natural resources and minimizing energy tariffs.

The functions provided by these technologies include:

- Optimization of building.
- Provision of energy management information.
- Remote monitoring and control.
- Automatic control of services and functions.
- Monitoring building status and environment conditions.

This technology is still in an early stage. However, thanks to its development, nowadays it offers solutions for almost all kind of buildings, increasing the quality of life of their occupants. Some solutions that can be adopted are:

- Lightning control systems: such as efficient illumination systems that adapt to the illumination level of the room, automatic on/off control of all lights.
- Climate systems: heating and air conditioning regulation systems to adapt the building temperature to outside temperature, depending on the time, the area of the house, occupancy of the building, etc.
- Appliances: control of start-up of household appliances to benefit from the lowest energy bills.
- Water management: regulation of water flow and water temperature.
- Leak detection, smoke and CO detectors.

Adopting these systems can achieve between 5% to 20%[102] of energy savings overall.

7.2.6 Smart metering

Smart meters are electronic devices that record information of energy consumption, voltage levels, current and power factor. Smart meters give the possibility of sharing bidirectional data between consumers and energy suppliers, giving the users information about their hourly and daily energy use, their consumption profile and energy prices and allowing distributors to monitor the consumption and manage the electricity demand, adapting the service to the user necessities.

Usually they record real time data and report regularly consumption over time, previous payments, annual consumption, climate information, etc.

Some benefits that this technology provides are:

- Access to information at any time.
- Aggregation of energy consumption/analytical measurements.
- Advanced reports including regression modelling, auditing, data heat maps, load profiling and model baselines.

[102] Source: "Mitigation of Climate Change". IPCC

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- Energy usage optimization.
- Control of the system by smoothing peaks and valleys of demand curves and creating less overhead of lines at peak times, reducing losses in transport and distribution, with the consequent energy savings.
- Possibility of dividing electricity consumption by time bands, which allows to use energy when it is cheaper.

Thanks to remote management using smart meters, energy savings up to 10%[103] can be achieved.

7.2.7 Construction structure envelope

It has a very important role in regulating the environment and environmental conditions of the interior. One of the most relevant factors is solar radiation. The envelope receives irradiation throughout the day, due to its constant exposure to the sun. It captures the radiation that flows into the interior, altering its environmental quality.

A well-designed envelope ensures the comfort and efficiency of the entire building.

7.2.7.1 Vinyl or insulating filter for windows. Transparent and opaque surfaces

Filters allow maintaining the appropriate temperature, both in hot and cold times, in buildings, thus avoiding localized sources of cold, considerably increasing comfort.

Many old buildings can be modernized without spending a lot of money or slowing down the pace of work. It is not necessary to remove any windows, the film/vinyl can be installed.

In winter, they reduce temperature leaks. Thanks to its insulating properties, it prevents by 33%[104] the loss of heating.

7.2.8 Appliances and white goods

Before choosing a new appliance for purchasing, it is necessary to pay attention to the consumption classification it shows. For example, a class A+++ household appliance consumes 70%[105] less than a conventional model.

Household appliances (white goods) are categorized into five product groups, according to the European Commission scales:

- Fridges.
- Dishwashers.
- Washing machines.
- Electronic displays including televisions.
- Lamps.

[103] "Contribución del material eléctrico a la eficiencia energética de las instalaciones". IDAE
[104] Source: Minnesota Mining and Manufacturing Company (3M).
[105] Source: Fundación para la Eficiencia Energética y el Medioambiente de la Comunidad Valenciana.

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To provide information on energy efficiency to the final consumer, the following sticker with the data is shown (standardized and endorsed by the European Commission):

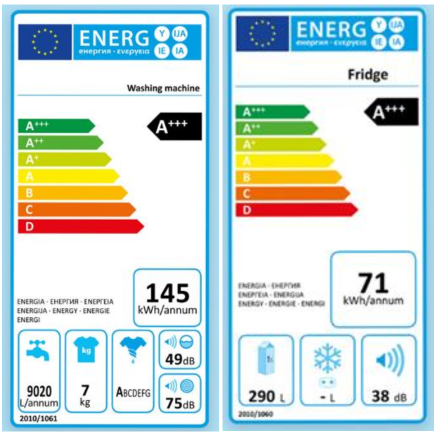

Figure 75 energy efficiency label on white goods. Source: European Commission.

Also, the replacement of the conventional boiler (energy performance around 70-80%[17]), for more modern condensing (up to 105%[17] of energy performance) or low operating temperature boilers (around 90-95%[17] of energy performance), will achieve savings of up to 25-30%[17].

7.3 Building retrofitting – Case Study

Below is a real case where the changes made in an existing building where energy efficiency measures are installed are shown. In turn, the savings figures achieved are shown:

- Geographic location: San Francisco (California)
- Building Typology: Office building (100 Montgomery)
- Size of building; 434,454 m^2 (25 floors)
- Project cost: €30M
- Measures:
  - Building-wide recycling and composting system
  - Energy efficient lights and lighting fixtures
  - Clean power offsets
  - Low-flow restroom fixtures
- Expected payback:
  - Energy-related upgrades: 2.3 years
  - Water-related upgrades: 5 years

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Through the application of energy efficiency and sustainability measures, the following savings[106] were achieved:

- ✓ 13.7% electricity (1.49 kWh per m^2 savings)
- ✓ 29.5% steam
- ✓ 16.1% water (~€544/year savings)

The retrofitting of a conventional building to a sustainable building, allowed to acquire the LEED-EB Gold certificate.

7.4 Building retrofitting – SWOT Analysis

After having analyzed the main values and circumstances that motivate and enhance the installation of energy efficiency measures in existing buildings, the positive and negative aspects, aspects to highlight and challenges to overcome for this type of technology are detailed below:

STRENGTH	WEAKNESS
▪ Energy efficiency model emphasizes saving energy costs. ▪ Appearance optimization, structural member materials / structural performance. ▪ Reduction of energy demand through appropriate technical and management strategies.	▪ Complexity of large-scale renovations. ▪ Specific structural and organizational characteristics neighborhoods volumetric and constructive structure. ▪ Transformation of non-structural elements into structural elements, partial demolition.
OPPORTUNITIES	**THREATS**
▪ Improvement of the comfort of the inhabitants of the buildings where the measures are applied. ▪ Adaptability in political and economic programs. Preservation and innovation in existing buildings.	▪ Lack of information and awareness of energy and environmental problems. ▪ Absence of aid and subsidies for financing (both private and public). ▪ Tax system for improvement of buildings and preservation of the historical memory of buildings.

8 Storage technologies

8.1 Electrical Battery Storage Systems

[106] Source: MHC Green Building Retrofit & Renovation SMR-Smart Market Report. McGraw Hill Construction.

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Following is reported a brief scenario analysis describing patent literature trend data related to electrical energy storage technologies. Specifically, the search query has been optimized in order to investigate the following technological aspects:

- Systems for storing electric energy in general;
- Arrangement or mounting of plural diverse prime-movers for mutual or common propulsion, e.g. hybrid propulsion systems comprising electric motors and internal combustion engines, with the prime-movers consisting of electric motors and internal combustion engines, e.g. HEVs and specifically characterised by the **electric energy storing means**, e.g. batteries or capacitors;
- Conjoint control of vehicle sub-units of different type or different function including **control of energy storage means for electrical energy, e.g. batteries or capacitors;**
- Secondary cells; manufacture thereof, methods for charging or discharging and specifically accumulators structurally combined with charging apparatus
- Hybrid capacitors, i.e. capacitors having different positive and negative electrodes; Electric double-layer [EDL] capacitors; Processes for the manufacture thereof or of parts thereof
- Circuit arrangements for ac mains or ac distribution networks, specifically arrangements for **balancing the load in a network by storage of energy**
- Circuit arrangements for charging or depolarising batteries or for supplying loads from batteries

The data have been extracted through the access to a database of patent literature (Derwent innovation[107]) and the utilization of specific search queries, including IPC codes in the case of patent searches. The time interval ranges from 2010 to date, even if, considering that patent applications are kept unpublished for a period of about 18 months at least, data related to 2020 are not reported in the graphs; their number can indeed be strongly influenced and underestimated due to the explained reasons.

Table 23 Search Query – Electrical Energy Storage Technologies

Search Query - Electrical Energy Storage Technologies
IPC = (B60K 6/28 or B60W 10/26 or H01M 10/44 or H01M 10/46 or H01G 11/00 or H02J 3/28 or H02J 7/00 or H02J 15/00)

The number of inventions extracted from the database and related to the investigated technology amounts to about 52000, when considering publications started from 2010. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:

[107] https://www.derwentinnovation.com/

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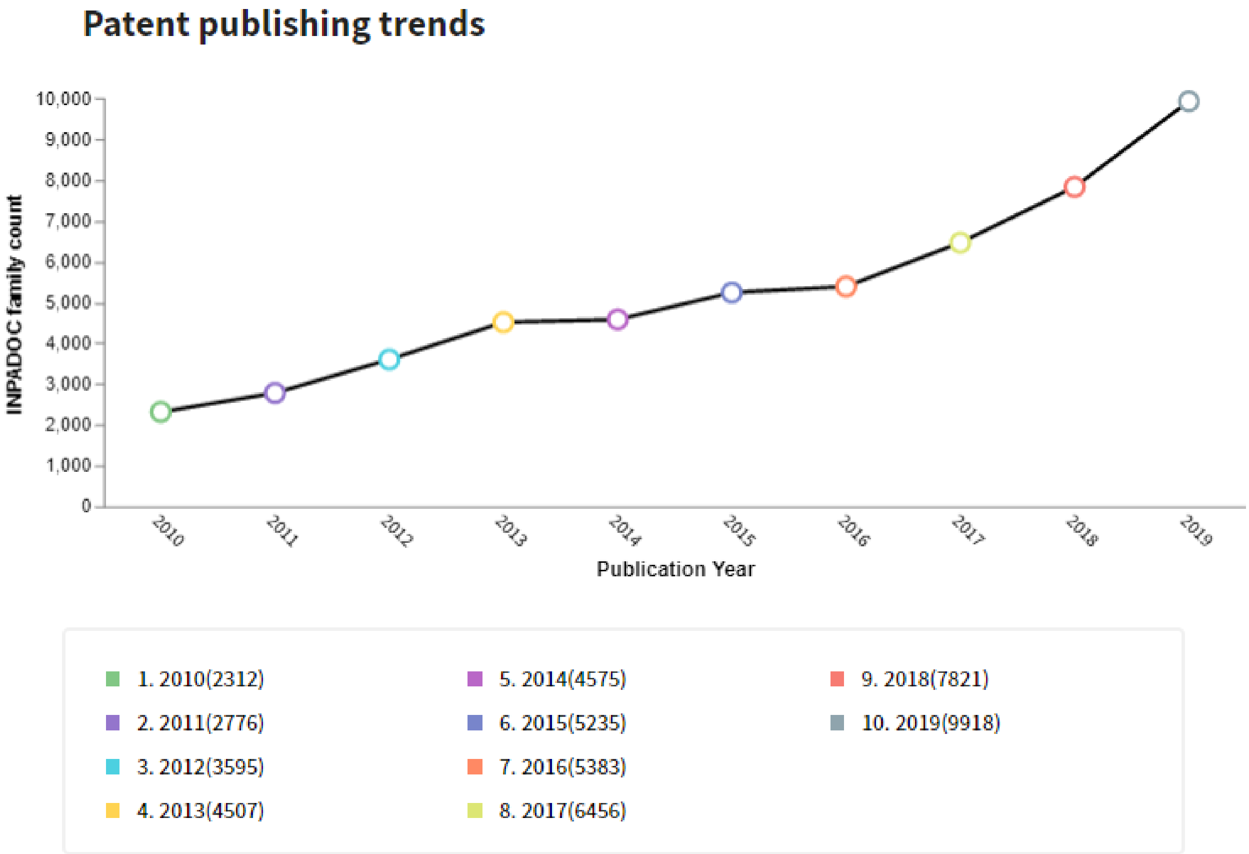

Figure 76 Electrical Energy Storage Technologies - Trend of Published Patent Documents (INPADOC families) – (2010-2019)

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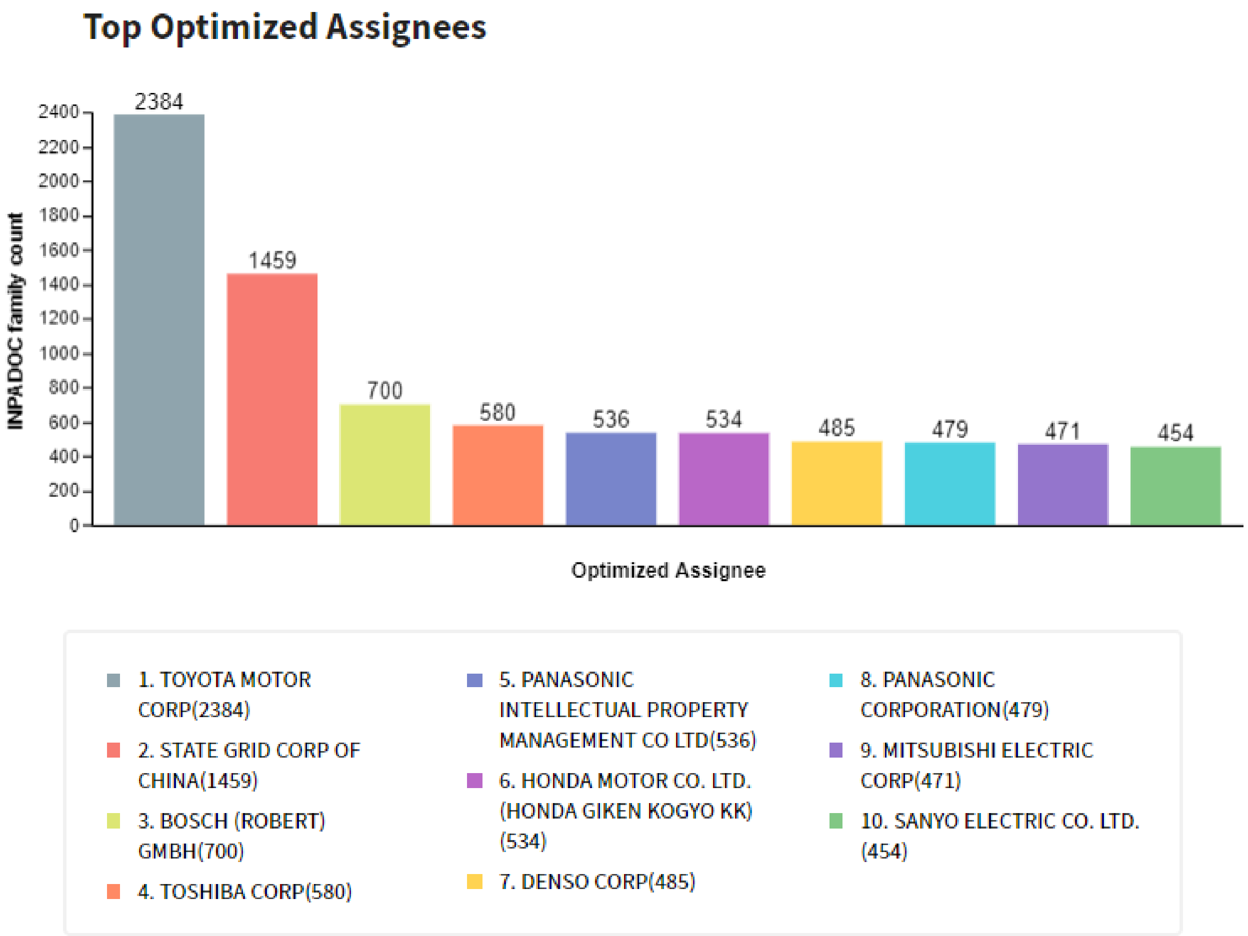

Figure 77 Electrical Energy Storage Technologies – Main Assignees of Published Patents (2010-2019)

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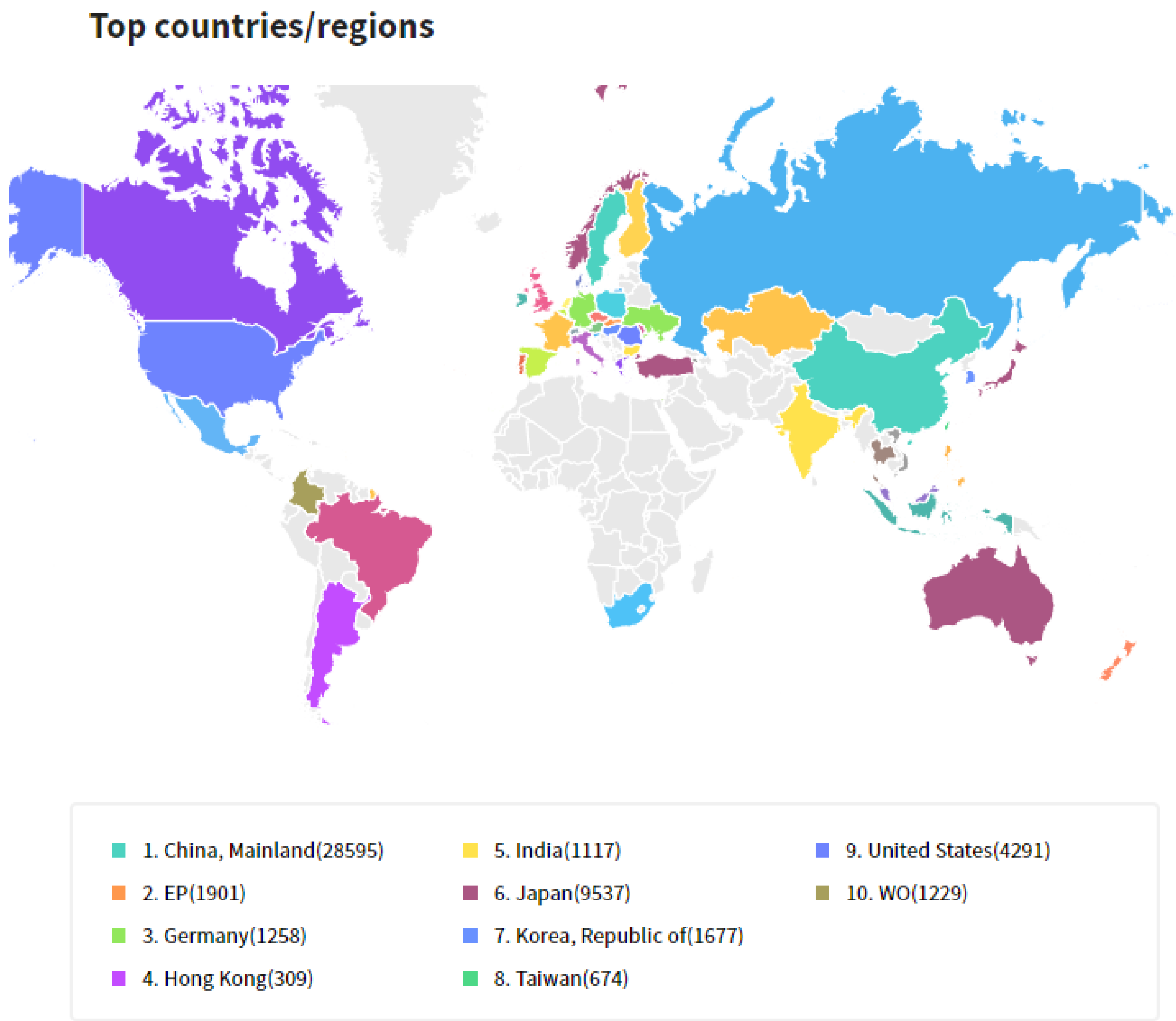

Figure 78 Electrical Energy Storage Technologies - Main Country Codes (2010-2019)

Trend in publication of patents has seen an increase in the investigated time interval. Compared to other patent scenario, apart China, Europe and specifically Germany have a stronger role in the development of innovative technologies. It is interesting to observe that Toyota Motor Corp appears as the main assignee even if thermal storage technologies; Bosch is the first European company.

8.1.1 Electrical Battery Storage Systems – Technology scouting

Batteries are one of the most cost-effective energy storage technologies available, with energy to be stored electrochemically. Battery energy storage systems (BESS) are modular, quiet, and non-polluting. They can be positioned almost anywhere and can be installed relatively quickly. Charging a battery causes reactions in the compounds, which then store the energy in chemical substances. Upon demand, reverse chemical reactions cause electricity to flow out of the battery and given back to the grid. Instead of two

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separate ac/dc converters for charging/discharging, a sole bidirectional converter can be utilized[108].

Fast response is one of the strong points of the battery technology: some batteries can respond to load changes in about 20 milliseconds. The efficiency of battery modules is in the range of 60–80 %. Batteries, however, present some very unique challenges. During an electrical charge and discharge cycle the temperature change in the battery and must be controlled or it can affect the battery's life expectancy. The type of battery being used will determine how resistant it is to life degradation due to temperature.

Another major concern is the battery's life cycle. This is defined as the number of charge/discharge cycles that a battery can supply depending on the depth of discharge (DoD).

The battery cycle application may require the BESS to charge and discharge numerous times a day. As long as DoD is quite low the battery's cycle of life will remain unaffected. However, if DoD is high, then the battery's life cycle will be degraded. If the desired cycle of life of a battery is 20,000 cycles, then DoD cannot be greater than approximately 15 %.

Their electrical behavior is complex as:

- Calculating the charging status is not a straightforward task
- They are discharging even if they are not used
- For some types of BESS their capacity depends on how fast or slow they are discharged
- Their degree of efficiency is not constant and changes based on charging status and current
- Their temperature affects all technical characteristics
- Electrical characteristics change during their lifetime
- Their lifespan depends on:
    - Their construction characteristics,
    - Charge-discharge cycles
    - Operating conditions and temperature.

There are several types of batteries depending on the desired use. The main uses of batteries combined with renewable energy sources are to cover loads, to provide grid flexibility, for use in starting machines and for the use in emergency systems. Lead-sulfuric acid (Pb/H_2SO_4) batteries was commonly used in renewable energy applications due to their low specific cost (€/kWh) and high reliability. In recent years however, most of the market growth has been attributed to lithium ion (Li-Ion) batteries (Figure 79)[109]. The increasing share of Li-ion batteries in storage capacity has been mainly driven by decreasing costs in Li-ion technology, which has in turn been driven by the ramp-up in production to meet the growing demand for electric vehicles.

Other common BESS technologies are the Nickel cadmium (NiCd) batteries and sodium-sulfur (NaS) batteries. A comparison is presented in Table 24

[108] A. Andrijanovits, H. Hoimoja, and D. Vinnikov, "Comparative Review of Long-Term Energy Storage Technologies for Renewable Energy Systems," Electronics and Electrical Engineering, vol. 118, no. 2, Feb. 2012, doi: 10.5755/j01.eee.118.2.1168.

[109] A. Anisie and F. Boshell, "Utility-scale batteries: Innovation Landscape Brief," IRENA, Abu Dhabi, 2019. [Online]. Available: www.irena.org/publication.

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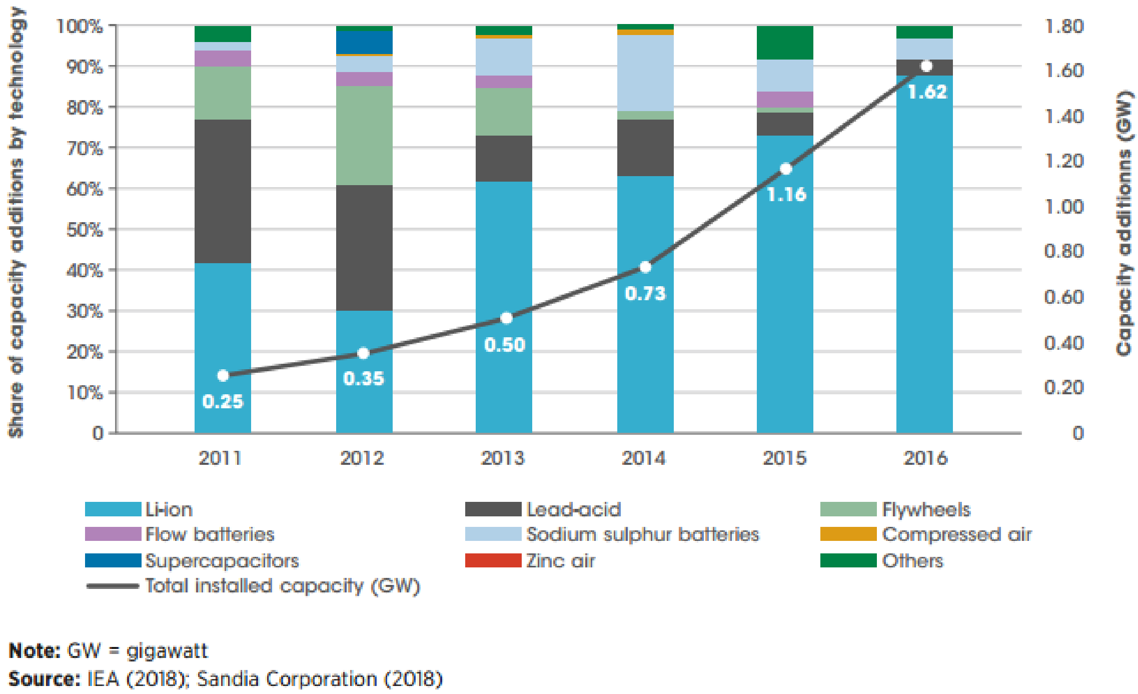

Figure 79: Increasing share of Li-ion in annual battery storage capacity additions globally

Table 24: Summary of different BES Technologies[110]

Attributes	Lead Acid	Li-ion	NaS	NiCD
Life time (Years)	5-15	5-15	10-15	10-15
Cycles	500-1000	1000-10000	2500	2000-2500
Discharge Efficiency	85	85	85	85
Cycle Efficiency	70-80	90-97	75-90	60-70
Self-Discharge	0.1-0.3	0.1-0.3	~0	0.2-0.6
Response Time	ms	ms	~tens of ms	ms
Energy Density (Wh/L)	50-80	200-500	150-250	60-150
Power Density (W/L)	10-400	1500-10000	140-180	80-600

The two major categories of lead - sulfuric acid batteries are:

- open type (FLA - Flooded Lead Acid) and
- closed type (SLA - Sealed Lead Acid)

with the latter prevailing. In particular, in recent years VRLA (Valve Regulated) closed type batteries have prevailed.

[110]]D. Agwu Daberechi, F. K. Opara, and N. Chukwuchekwa, “Review Of Comparative Battery Energy Storage Systems (Bess) For Energy Storage Applications In Tropical Enviroments,” presented at the 2017 IEEE 3rd International Conference on Electro-Technology for National Development (NIGERCON), Owerri, Nov. 2017.

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In general, closed type batteries do not require any maintenance (e.g. addition of liquid) as they have electrolyte in the form of GEL or AGM type (Absorbed Glass Mat) and thus allow the reconstitution of hydrogen and oxygen in water.
In Europe, an attempt has been made to standardize sulfuric acid batteries in technical and geometric features so that they can be easily interchangeable. Thus, most applications now use OPzS type batteries for open type and OPzV for closed type.
A promising battery technology is the flow battery technology (also known as redox flow batteries). Flow batteries can also be described as regenerative fuel cells and exist in a variety of forms and designs. They differ from conventional rechargeable batteries in that the electroactive materials are not stored within the electrode; rather, they are dissolved in electrolyte solutions. The electrolytes are stored in tanks (one at the anode side, the anolyte tank; one at the cathode side, the catholyte tank). These two tanks are separated from the regenerative cell stack. The electrolytes are pumped from the tanks into the cell stacks (i.e. reaction unit) where reversible electrochemical reactions occur during charging and discharging of the system. In “pure flow” (i.e. “true flow”) systems, electroactive materials are stored externally from the power conversion unit (i.e. cell stack) and only flow into it during operation.

Figure 80: A BESS array of 12 batteries

Generally, with proper electrical connection similar batteries can achieve the required operating voltage of a system (Figure 80). The operating voltage of a system is a design parameter and in general the transfer of more power also requires a higher operating voltage. Transferring high power under low voltage, the current is large resulting in large ohmic losses according to Joule's law and is not recommended.

BESS systems marketing and cost trends

Levelized cost of storage is not always the best metric in order to compare the various technologies as the applications are usually not the same, as for example storage size might be the same but the demanded power might be higher as the flexibility might be the primary goal of the storage system and not the long-term provision of energy.

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Cost analysis for storage per type of application and for various types of storage technologies are given in 109, 111, 112 and 113.

8.1.2 Electrical Battery Storage Systems - SWOT Analysis

Gathering all the Strengths, Weaknesses, Opportunities and Threats of the electrical battery storage systems based on existing literature, the following SWOT analysis is presented in the following table

STRENGTH	WEAKNESS
Distributed storage. Good configurability - Modular. Easy to be installed Can provide auxiliary services. Quiet. Fast response. Remote and off-grid use. Transportable.	High investment costs. Cycle life. Temperature dependent. Low capacity Short duration of life Sophisticated power electronics Disposal of hazardous material
OPPORTUNITIES	**THREATS**
Emerging technologies. Market Opportunities. Recycle of materials can be an option. Extra flexibility income.	Constant development phase complicates selection. Raw materials limited. Bad operation might destroy equipment. As usually they are installed in arrays a bad battery cell can be hard to be replaced.

8.2 Hydro Storage

8.2.1 Hydro Storage Systems - Technology scouting

Pumped hydroelectric energy storage (PHES) has been in use worldwide for more than 70 years. Pumped hydro units operate on the principle of a hydro-electric powerplant. However, their generator units usually serve also as motors or pumps used as turbine (PAT). During off-peak hours surplus power is used to pump water from a lower reservoir to a higher-level reservoir whilst pump/turbine operates as a pump and a motor/generator as a motor. At peak demand hours, water is released from the higher reservoir to turn the turbine and to produce electricity, and the motor operates in the generating mode and the pump as a turbine (Figure 81)[111].

PHES can produce a great amount of energy for continuous periods of time. In addition, these plants have round trip efficiencies in the range of 70 to 80 %. Their storage capacity dependent on the size and the height of the reservoir. Thus, instead of having

[111]]P. Ralon, M. Taylor, A. Ilas, H. Diaz-Bone, and K.-P. Kairies, “Electricity storage and renewables: Costs and markets to 2030,” IRENA, Abu Dhabi, 2017. [Online]. Available: www.irena.org/publications.

[112] A. Anisie and F. Boshell, “Behind-The-Meter Batteries: Innovation Landscape Brief,” IRENA, 2019. [Online]. Available: www.irena.org/publications.

[113] O. Schmidt, S. Melchior, A. Hawkes, and I. Staffell, “Projecting the Future Levelized Cost of Electricity Storage Technologies,” Joule, vol. 3, no. 1, pp. 81–100, Jan. 2019, doi: 10.1016/j.joule.2018.12.008.

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only a few hours of energy storage it could be days. The major drawback of this design is the significant area required to create the reservoirs and the elevation needed between them. Many of the sites are already in use and others have encountered opposition from environmental groups. The environmental impact of large-scale PEHS facilities is becoming more of an issue, especially where existing reservoirs are not available. Environmental considerations such as impacts on fisheries, recreation, water quality, aesthetics, and land use have sharply limited the further development of this technology. There is, however, an alternative to avoid the environmental impacts of the large reservoirs by placing them underground, for example, flooded mine shafts or other cavities can be used as lower reservoir.

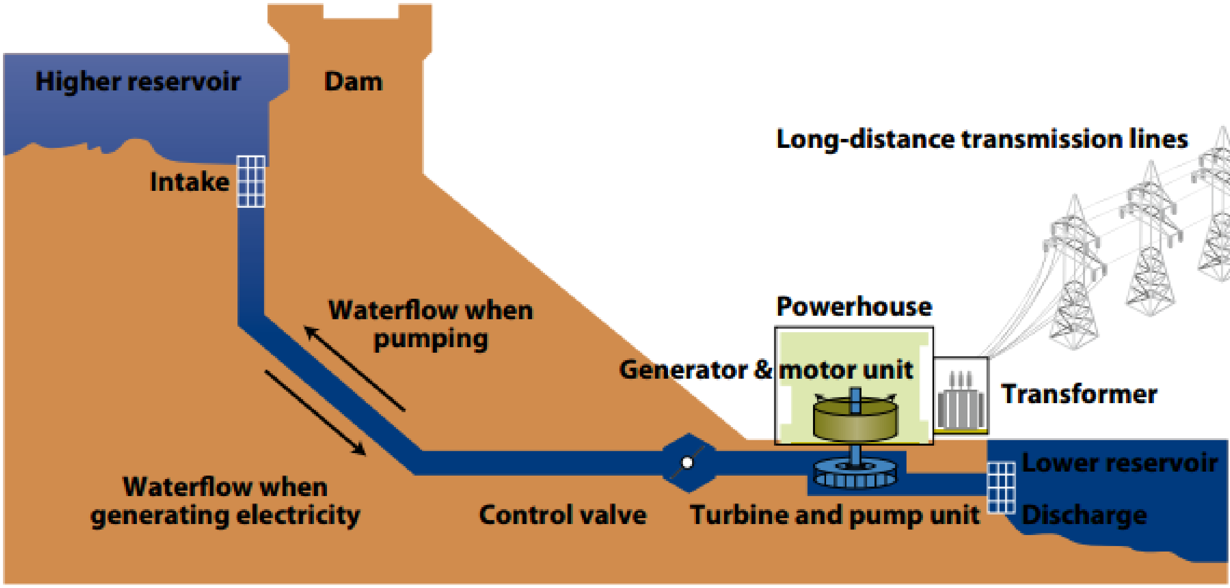

Figure 81: Schematic of a typical conventional pumped hydro storage system

Pumped storage, also provides an array of energy services beyond firm power, including black start capability, frequency regulation, inertial response, spinning and non-spinning reserve and voltage support, among others. These ancillary services are increasingly important to the stability of the energy system and may also offer an alternate revenue stream for hydropower generators. These services are priced differently in various markets around the globe, although it is increasingly recognized that they are often not appropriately or sufficiently rewarded by energy markets[114].

Hydrostorage systems marketing and cost trends

At least 150 GW of PHS power was installed and operational by the end of 2016. Pumped hydro storage currently dominates total installed storage power capacity, with 96% of the total of 176 gigawatts (GW) installed globally in mid-2017 (Figure 82)[111]. Pumped hydro exhibits the lowest LCOS in 2015 (150–400 US$/MWh) due to lifetimes beyond 30 years[113].

[114] M.-J. Nadeau, Y. D. Kim, K.-D. Barbknecht, L. Birnbaum, and O. Budargin, "Charting the Upsurge in Hydropower Development," WORLD ENERGY COUNCIL, United Kingdom, 2015.

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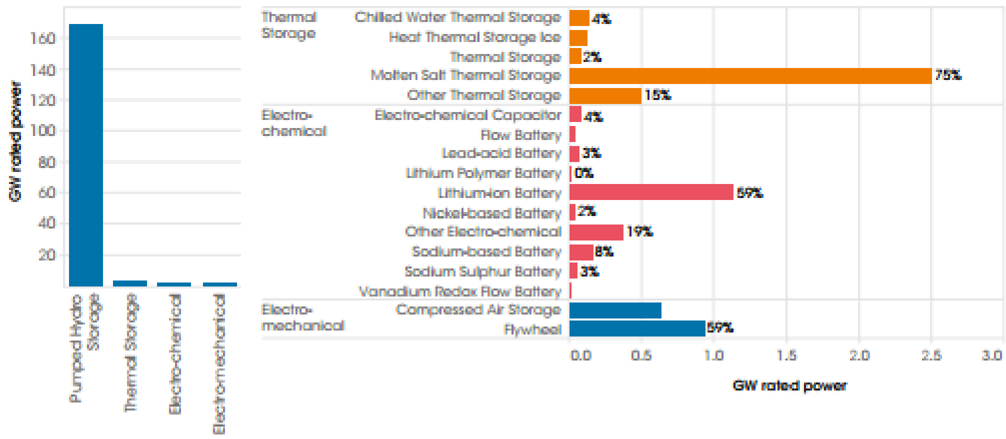

Figure 82: Global operational electricity storage power capacity by technology, mid-2017

Hybrid Power Plant of Ikaria Island - NAERAS

Lower Reservoir

Pump Station

The main objective of the project is to increase the penetration of Renewable Energy Sources (RES) into the Ikaria Electricity Network and to reduce the quantity of conventional fuel oil used at the Local Production Station in Agios Kirikos to produce energy, thus reducing substantially the carbon footprint of this iconic Aegean island.

The successful operation of the project will create a new, much needed, example of how to accomplish energy autonomy of non-interconnected islands and complexes, using only RES and thus pave the way for the energy transition, which is a requirement to tackle the climate crisis.

It is estimated that Naeras will produce a total net clean energy of 9.8 GWh a year, covering much of the island's annual energy needs, especially during the winter months.

The project technical characteristics:

1. A Wind Park (W/P) in the hill area of Stravokoundoura, consisting of three wind turbines of 900 kW power output each.
2. A Small Hydroelectric Power Station (SHPP) of Proespera, with a 1.05 MW hydro turbine, fed only by the excess water of the reservoir of the Pezí dam (after meeting the needs for water supply, ecological supply and local irrigation).
3. A Kato Proespera SHPP with two hydro-turbines of total capacity of 3.1 MW, fed from the excess water of the reservoir in Proespera and the pumped water.
4. Two reservoirs of 80,000 m^3 of water one in each of the Proespera and Kato Prospera areas, which will serve the needs of the pumped water for the storage of wind energy and a water reservoir of a total capacity of 910,000 m^3 at Pezi.
5. The pump station of Kato Proespera with 12 pumps of rated power 250 kW each, 4 of which are of variable speed.
6. The energy control and load distribution centers of Naeras and Ikaria, installed in an area within the local electricity production station of PPC at Agios Kirikos, that facilitates the communication between various parts of the system and ensures the reliability of the electricity system of the island.

Main Benefits

1. Reducing CO2 emissions by approximately 13,800 tonnes per year.
2. Enhancing the energy efficiency of the island for most part of the year, and limiting its dependence on fossil fuels.

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Upper Reservoir

3. Grid reliability enhancement.
4. Reversing the environmental impacts from the construction of the Project by implementing environmental rehabilitation measures (e.g. tree planting).
5. Strengthening the finances of the local community through withholding taxes, resulting from the operation of the Project, which amount to 3% of the revenues.
6. Enhancing Ikaria's tourism sector as the innovations and the 'green' nature of the Project are expected to attract students, scientists and environmentally aware citizens to the island.

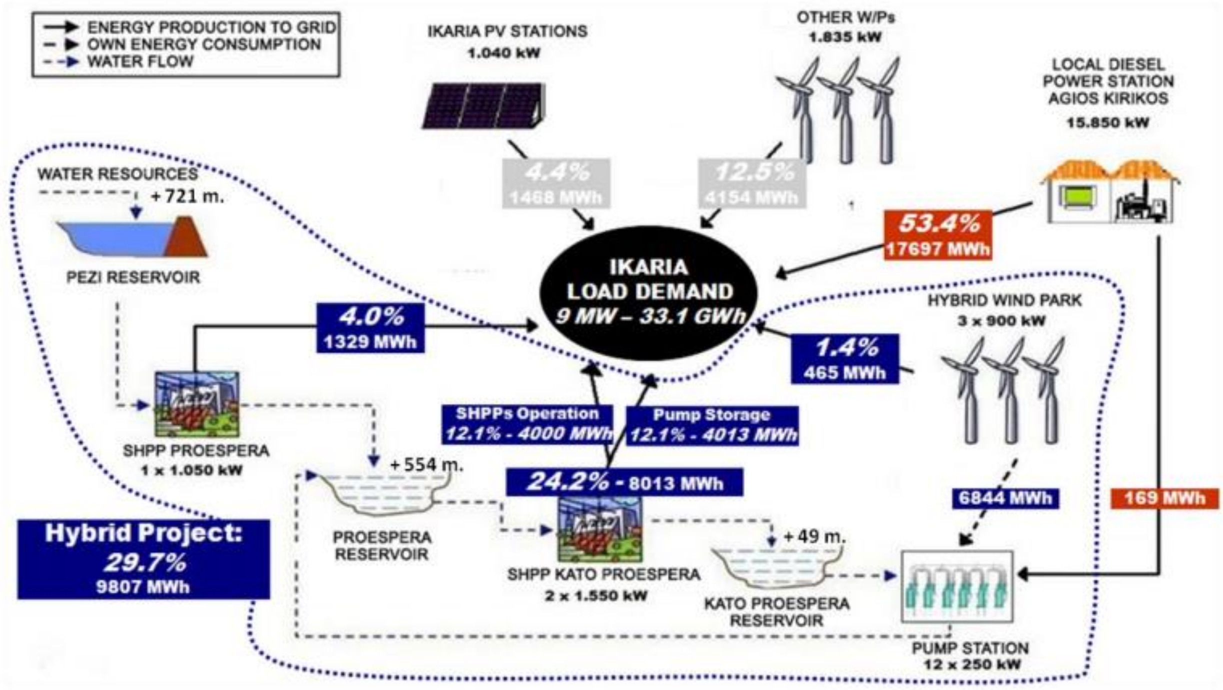

Diagram of the Ikaria Hydro Storage System

8.2.2 Hydro Storage Systems – SWOT Analysis

Gathering all the Strengths, Weaknesses, Opportunities and Threats of the hydrostorage systems based on existing literature, the following SWOT analysis is presented in the following table

STRENGTH	WEAKNESS
High capacity. Low cost per installed kWh. Minor needs for power electronic converters. Long storage periods are possible Very low self-discharge. Established technology with high technical maturity and extensive operational experience. Reasonable round-trip efficiency. Good start/stop flexibility Long expected lifetime	Centralised storage. Geographical restrictions. High installation cost. Low energy density (large footprint). Social acceptance. Landscape downgrading
OPPORTUNITIES	THREATS

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Can be used for offshore wind parks and with lower reservoir under seabed. Local people can have financial benefits Can be a tourist attraction due to eco-friendliness	Can become obsolete when distributed storage preferred. Structural problems may occur in construction. Social acceptance Landscape downgrading

8.3 Thermal Energy Storage Systems

8.3.1 Thermal Energy Storage systems - Technology scouting

Following is reported a brief scenario analysis describing patent literature trend data related to thermal energy storage technologies. Specifically, the search query has been optimized in order to investigate the following technological aspects:

- Heat-transfer, heat-exchange or heat-storage materials, e.g. refrigerants; materials for the production of heat or cold by chemical reactions other than by combustion;
- Storage heaters, i.e. heaters in which the energy is stored as heat in masses for subsequent release
- Heat storage plants or apparatus in general; Regenerative heat-exchange apparatus

The data have been extracted through the access to a database of patent literature (Derwent innovation[115]) and the utilization of specific search queries, including IPC codes in the case of patent searches. The time interval ranges from 2010 to date, even if, considering that patent applications are kept unpublished for a period of about 18 months at least, data related to 2020 are not reported in the graphs; their number can indeed be strongly influenced and underestimated due to the explained reasons.

Table 25 Search Query - Thermal Energy Storage Technologies

Search Query - Thermal Energy Storage Technologies
IPC = (C09K 5/00 or F24H 7/00 or F28D 20/00 or F28D 28/02)

The number of inventions extracted from the database and related to the investigated technology amounts to about 11000, when considering publications started from 2010. From this dataset the following graphs have been extracted that describe trends in terms of number of publications per year, main assignees and main country codes:

[115] https://www.derwentinnovation.com/

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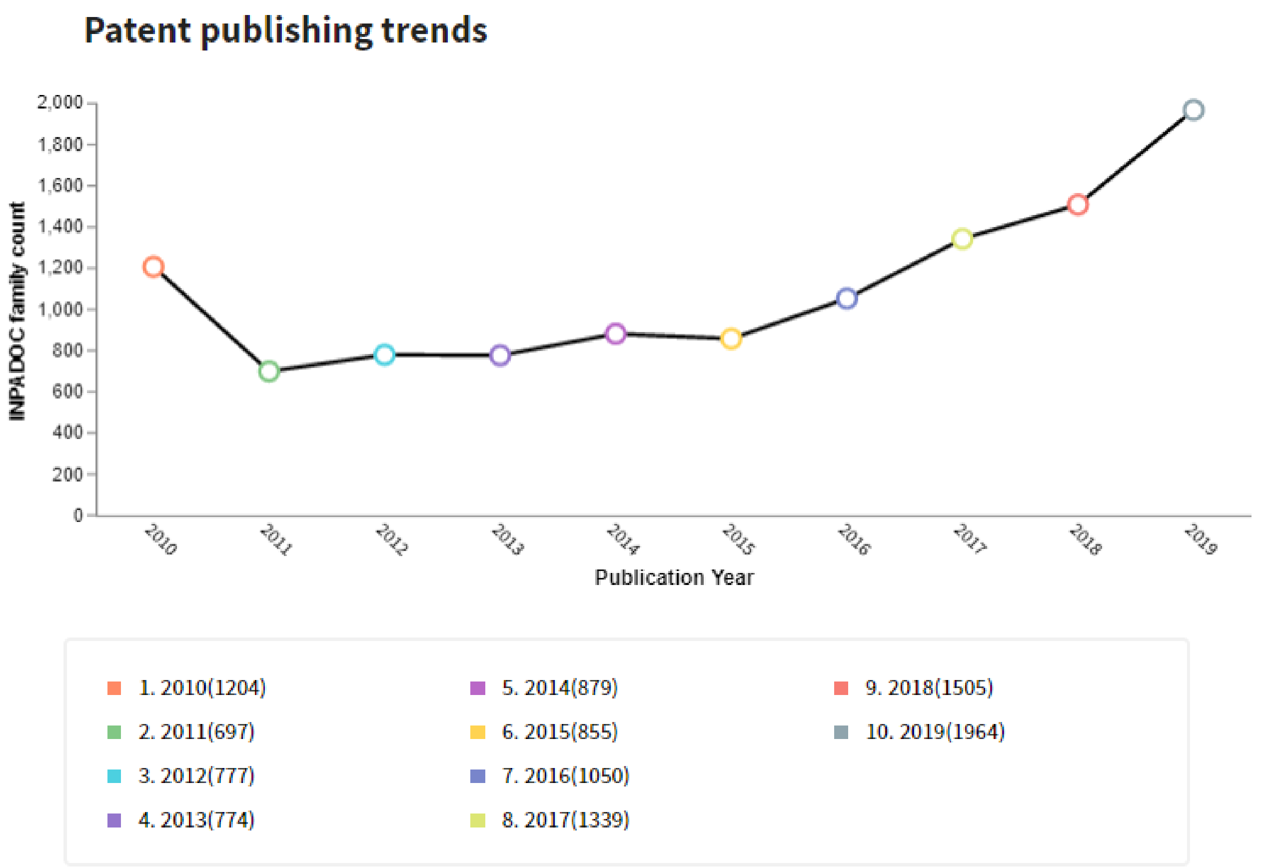

Figure 83 Thermal Energy Storage Technologies - Trend of Published Patent Documents (INPADOC families) – (2010-2019)

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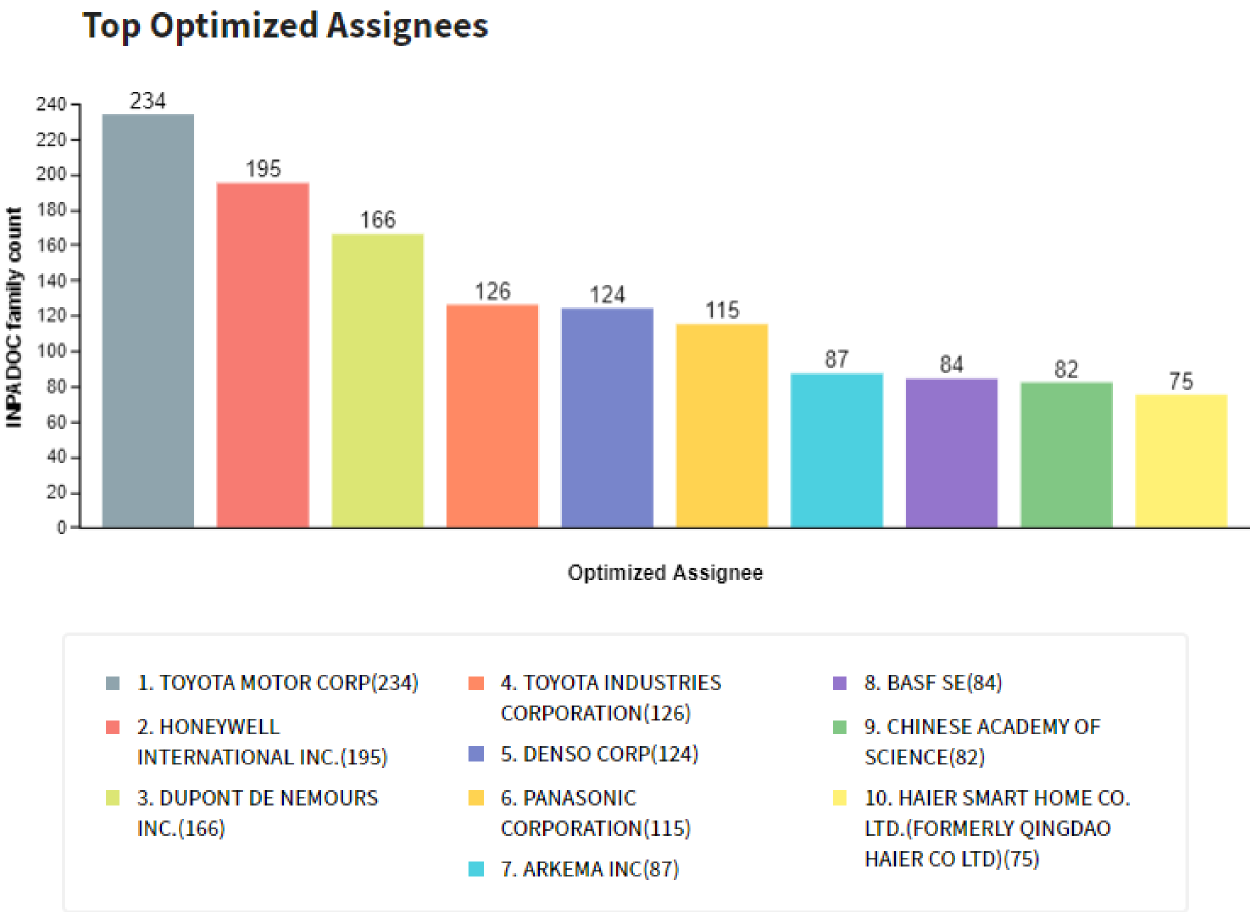

Figure 84 Thermal Energy Storage Technologies – Main Assignees of Published Patents (2010-2019)

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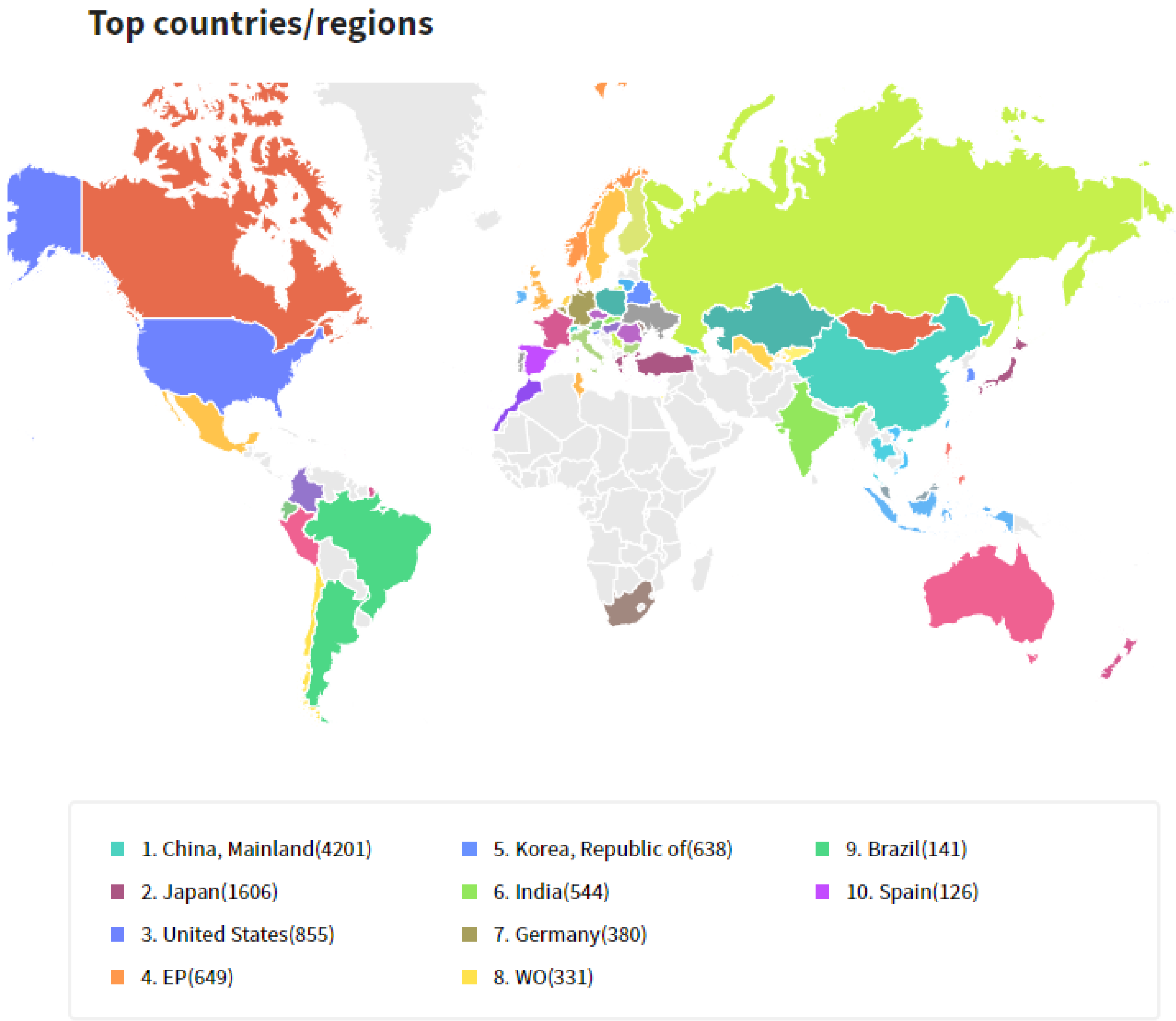

Figure 85 Thermal Energy Storage Technologies - Main Country Codes (2010-2019)

Compared with other technologies scenario analysis, in this case we observe a decrease in number of publications at the beginning of analyzed time interval, before publications start to increase continuing in this trend. China, Japan, United States, and EPO office are the main geographical areas where patents have been published. Among main assignees, together with big chemical companies it is interesting to observe the position of Toyota Motor corporation giving an indication that thermal storage technologies are thoroughly exploited in order to make internal combustion engines more energetically efficient.

There are several solutions for Thermal Energy Storage (TES) which can be applied in either industrial or residential scale. Thermal energy can be stored as a change in

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internal energy of a material mainly as sensible heat or latent heat[116], but there are also other options in which thermochemical energy or combination of these is stored[117]. TES can be classified by technology, storage material, application or end user, according to Figure 86.

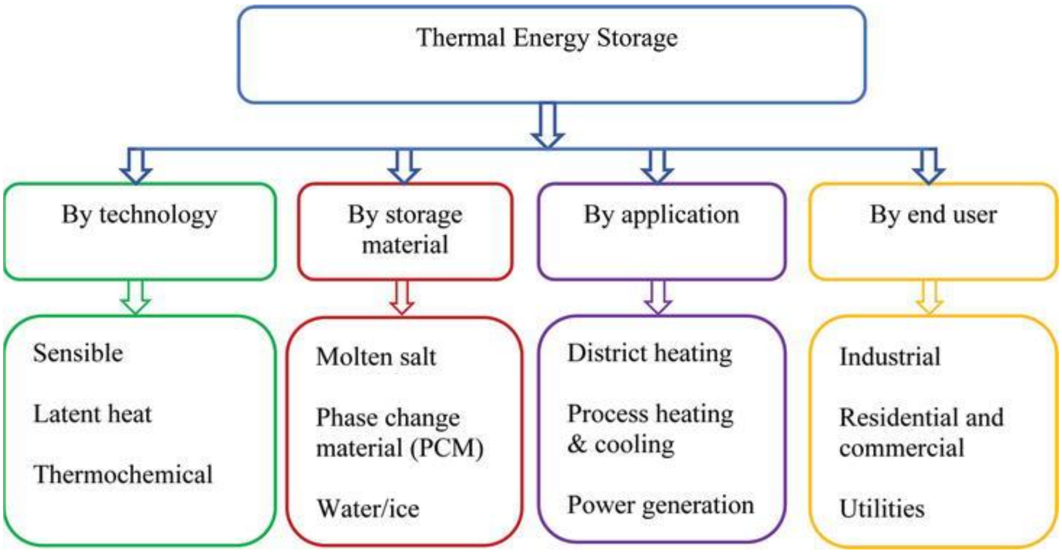

Figure 86: Classification of thermal energy storage systems.

As seen in the figure above, TES technologies can be classified according to the technology and method of storage into three categories:

- Sensible heat
- Latent heat
- Thermochemical

Sensible heat storage

The most common TES systems are the ones which store sensible heat[118]. In sensible heat storage (SHS), thermal storage materials store heat energy by changing temperature. The storage medium can be liquid (water) or solid (rock, earth). In this case, sensible heat storage materials are heated during heat storage and cooled by heat release[119]. Among the advantages of those systems are the increase in overall efficiency and better reliability when applied in an energy framework, resulting in better economics, reductions in investment and operating costs, as well as reductions in greenhouse gas emissions[116]. They are flexible decentralized solutions where large-scale heat transfer systems such as district heating and cooling are not practical or are too expensive to apply. However, most present systems are water-based, and their capacity

[116] I. Dincer, M. Rosen, Thermal Energy Storage: Systems and Application; , Chichester, UK, 2011.
[117] A. Sharma, V.V. Tyagi, C.R. Chen, D. Buddhi, Review on thermal energy storage with phase change materials and applications, Renewable and Sustainable Energy Reviews, 13 (2) (2009) 318-345.
[118] A. Kumar, S.K. Shukla, A Review on Thermal Energy Storage Unit for Solar Thermal Power Plant Application, Energy Procedia, 74 (2015) 462-469.
[119] Sun, J.; Zhang, G.; Guo, T.; Che, G.; Jiao, K.; Huang, X. Effect of anisotropy in cathode diffusion layers on direct methanol fuel cell. Applied Thermal Engineering 2020, 165.

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is limited by the fact that water capacity depends on the operating temperature difference of the heating system used.

Latent heat storage

In latent heat storage (LHS), the materials used, also known as phase change materials (PCMs), store latent heat during a phase change from solid to liquid[120,121]. This heat is released reversing the process, during a phase change from liquid back to solid. Latent heat also appears in the phase change from liquid to gas, but this is not used in thermal energy storage systems, because it involves large volumes or high pressures of steam or gas[122]. LHS is a purely physical process and has no chemical reaction when charging or discharging. It is suitable for applications where temperature must be maintained stable in a narrow range[119]. PCMs that are used in LHS are divided into organic (paraffin, stearic acid), inorganic (salts, salt hydrates), and eutectic (a mixture of organic or inorganic PCM). Phase change temperatures of the PCMs range depending on the application[123]:
Cooling applications up to 21 ºC, 22-28 ºC for comfort in building applications, 29-60 ºC for hot water applications, high-temperature applications requiring PCM range from 61 to 120 ºC.
Latent heat storage systems that use Phase Change Materials (PCM) offer a considerably higher energy density compared to water-based sensible heat storage systems and have the advantage of the isothermal nature of the storage process i.e storing heat compactly in a narrow temperature range[118,124]. Low temperature thermal storage systems (LT-TES) have been sufficiently developed and are currently being used in commercial level. Companies such as Sunamp ltd, PCM products ltd etc. have commercialized such applications of low-temperature PCM based TES systems in domestic or industrial scale.

Thermochemical storage

Thermal Chemical Energy Storage (TCS) is based on the utilization of heat of reaction released by reversible chemical reactions. For example, a chemical compound of type A–B can be separated reversibly into the components A and B by supplying heat. In this process the supplied heat is used to break the A–B bond into independent substances A and B. If the reverse reaction of turning products A and B into the compound A–B is avoided the energy stored in the chemical bonds can be stored without energy loss for any length of time. Thermochemical processes are divided into two main branches: sorption processes, which again can be divided into adsorption and absorption; and

[120] Mehari, A.; Xu, Z.Y.; Wang, R.Z. Thermal energy storage using absorption cycle and system: A comprehensive review. Energy Conversion and Management 2020, 206.
[121] Poblete, R.; Painemal, O. Improvement of the solar drying process of sludge using thermal storage. Journal of Environmental Management 2020, 255.
[122] Chen, G.; Su, Y.; Jiang, D.; Pan, L.; Li, S. An experimental and numerical investigation on a paraffin wax/graphene oxide/carbon nanotubes composite material for solar thermal storage applications. Applied Energy 2020, 264.
[123] Norouzi, N.; Talebi, S.; Fani, M.Thermal Energy Storage for the Complex Energy Systems. Mat Int2020, 2, 0175-0190.
[124] R. Waser, F. Ghani, S. Maranda, T.S. O'Donovan, P. Schuetz, M. Zaglio, J. Worlitschek, Fast and experimentally validated model of a latent thermal energy storage device for system level simulations, Applied Energy, 231 (2018) 116-126.

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reversible chemical reactions, which in turn can be divided into solid-gas reactions and solid-liquid reactions [125].

TCS systems have certain advantages against SHS and LHS, such as higher density for energy storage (due to higher reaction enthalpy), possibility for long-term storage, and long-range transport at ambient temperature. On the other hand, there is still a necessity for reduction of volume and improvement of materials used in this technology. More demonstrations are needed to assess their commercial use[123].

The advantages and disadvantages of each storage system are presented in Table 27 below:

	Sensible	Latent	Chemical
Storage medium	Water, gravel, pebble, soil, etc.	Organics, inorganics	Metal chlorides, metal hydrides, etc.
Type	Water, rock, and ground-based system	Active and passive storage	Thermal sorption and chemical reaction
Advantage	Environmentally friendly, cheap material, relatively simple system, easily control, and reliable	Higher energy density Than sensible heat storage, and provide thermal energy at a constant temperature	Highest energy density, compact system, and negligible heat losses
Disadvantage	Low energy density, huge volumes required, self-discharge and heat losses problem, high cost of site construction, and geological requirements	Lack of thermal stability, crystallization corrosion, and high cost of storage material	Inadequate heat and mass transfer property under high-density condition, uncertain cyclability, and high cost of storage material
Present status	Large-scale demonstration projects	Laboratory-scale prototypes	Laboratory-scale prototypes
	Optimization of a control strategy to advance the solar fraction and reduce the power consumption, optimization of storage temperature to reduce heat losses, and simulation of ground-based system with the consideration of affecting factors	Researching for better phase change material materials with higher heat of fusion, an optimal study on store process and concept, and further thermodynamic and kinetic study, noble reaction cycle	Optimization for particle size reaction bed structure to get constant heat output, optimization of temperature level during the charging/discharging process, screening for more suitable and economical materials, and further thermodynamic and kinetic study, noble reaction cycle

Table 26: Comparison of the available technologies for TES[123].

TES Systems performance and cost trends

TES systems based on sensible heat storage offer a storage capacity ranging from 10-50 kWh_{th} and storage efficiencies between 50-90%, depending on the specific heat of the storage medium and thermal insulation technologies. Phase change materials (PCMs) can offer higher storage capacity and storage efficiencies from 75-90%. In most cases, storage is based on a solid/liquid phase change with energy densities on the order of 100 kWh/m^3 (e.g. ice). Thermo-chemical storage (TCS) systems can reach storage capacities of up to 250 kWh_{th} with operation temperatures of more than 300 °C and efficiencies around 75% to nearly 100%. The cost of a complete system for sensible heat storage ranges between 0.1-10 €/kWh_{th}, depending on the size, application and thermal insulation technology. The costs for PCM and TCS systems are higher. In these systems, major costs are related with the heat (and mass) transfer technology, which has to be

[125] Kerskes, H. (2016). Thermochemical Energy Storage. Storing Energy, 345–372. doi:10.1016/b978-0-12-803440-8.00017-8

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installed to achieve a sufficient charging/discharging power. Costs of latent heat storage systems based on PCMs, range between 10-50 €/kWh_{th} while TCS costs are estimated to range from 8-100 €/kWh_{th}. The economic viability of a TES depends heavily on application and operation needs, including the frequency of the storage cycles[126]. Typical parameters of TES systems are presented in Table 27.

Table 27: Typical parameters of TES systems[126]

	Capacity (kWht)	Power (MW_e)	Efficiency (%)	Storage Period	Cost (€/kWh)
Sensible	10-50	0.001-10	50-90	d/m	0.1-10
PCM	50-150	0.001-1	75-90	h/m	10-50
Chemical Reactions	120-250	0.01-1	75-100	h/d	8-100

8.3.2 Thermal Energy Storage Systems - SWOT Analysis

Gathering all the Strengths, Weaknesses, Opportunities and Threats of the thermal energy storage systems based on existing literature, the following SWOT analysis is presented in the following table

STRENGTH	WEAKNESS
Can be useful for a wide range of applications. Coupled with many RES and non-RES technologies	High installation cost. Immature technology. Not specialized personnel. Not easily controllable. Thermal losses. Low energy concentration. Large area for installation.
OPPORTUNITIES	**THREATS**
TES can replace heat and cold production from fossil fuels and reduce CO_2 emissions. TES can lower the need for costly peak power and heat production capacity[126].	Cost is a major issue. Storage systems based on TCS and PCM need improvements in the stability of storage performance, which is associated with material properties126.

[126] Thermal Energy Storage-Technology Brief, IEA-ETSAP and IRENA© Technology Brief E17 – January 2013

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9 Conclusions

In this paragraph, according to the information collected in the previous chapters, relevant data on technology meaningfulness for NESOI Project will be reported:

The table contains parameters (mostly qualitative) in order to prepare a preliminary comparison among them.

- Cost factors: in case of renewable energy technologies the information is related to the cost of the technology in order to produce energy; when available the LCOE range values obtained from the literature review analysis are reported; in other cases considerations about the cost impact of the technology implementation from the point of view of the users and/or involved authorities are reported;
- Technology Readiness Level: the considerations here are related to the level of development of the technology, according to data retrieved from the technology scouting; solutions that are already available at commercial scale compared to technologies that are still mostly in an R&D phase or developed by a strict number of companies, etc.
- Type of islands (dimensions): some technologies can be influenced in their impact by the dimension of the islands;
- Geographical meaningfulness: geographical features (e.g. latitude, ocean/closed sea/…, weather, environmental protection/nature reserve, electrical connection, land availability, …)
- Stakeholders type: which subjects should be involved in order to integrate effectively the technology. For example big companies, research centers and universities, local authorities, etc.

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TECHNOLOGY	Cost Factors	TRL	Type of island (Very Small/Small/medium/large)	Geographic meaningfulness	Stakeholders Type (PUBLIC/PRIVATE and category)
Solar / PV Systems	LCOE in PV is strongly depended on the solar potential. LCOE varies from 42 €/MWh to 20 €/MWh	Photovoltaics are mature and commercial systems and have TRL 9. Thermal systems vary in technology and their TRL can be from 7 to 9	PV systems are suitable for all islands. Solar thermal systems, due to their size are best suitable for medium/large islands	Best conditions for higher exploitations are the south climates. For thermal systems, dry atmosphere is preferred.	For PV systems, the stakeholder's involvement is based on size. For small size, the investor and the facilitator are only involved. For large systems, the public authorities or the government have to be involved. For large solar thermal systems, usually, an advanced engineering team such as research centers are involved.
Biomass/Biogas Systems	The global weighted-average LCOE of bioenergy for power projects is 56 €/MWh	Biomass and biogas systems are fully commercialized products and use mature technologies, so most of them have TRL9. Some biogas production techniques might have significantly lower e.g. TRL 5 or 6.	Usually medium to large islands are suitable for these investments. The constant source of organic matter is required for viable operation, and this might not be easy to have In small islands. Additionally, these systems might be coupled with District heating and CHP systems, that are not suitable for small islands.	No special conditions are applied. Northern islands, due to climate, can produce more plant biomass.	This technology is mature so only silencing procedures are required. Usually these systems require an advanced supply chain and for this reason, stakeholders from various domains might be involved such as agricultural cooperatives.
Electrical Distribution Grids	Generally High - Complex to determine as cost is dependent on multiple factors and impact to existing grid.	9 actual systems proven in operational environment	Not significantly affected by island dimensions.	Dependent on RES (e.g. wind: Northern Europe, solar: southern Europe. Islands in the UK and Sweden show successful use-cases for Europe.	PUBLIC •DSOs •Energy Suppliers •Island Residents •Tourists •Technology Suppliers •Local Government

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Charging infrastructure	From 500 € to >100 k€	Generally around 9	Not significantly affected by island dimensions, but capacity of grid is important for some use cases	Independent from geographic situations	•DSOs •Energy Suppliers •Island Residents •Tourists •Technology Suppliers •Local Government •E-mobility Service Providers •Housing developers •Employers
Power transformer technologies	Generally high - from 500 k€ up to > 2.5 Mio €	Generally high - around 9	Not significantly affected by island dimensions.	Independent from geographic situations	•DSOs
Hydropower Systems	The global weighted-average LCOE of newly constructed hydropower projects in 2019 was 40 €/MWh	Hydro power systems are fully commercialized systems and use mature technologies. They have TRL 9.	They are suitable for medium to large islands. Large islands usually have the required water sources for these investments and have considerable energy demand that can be covered by hydropower systems.	No specific conditions are applied in terms of location. The relief of each area is important, so areas without considerable height differences cannot be used no matter their water availability.	This technology is mature, but these systems required many licenses to be installed and operate as well as water use permits. Additionally, systems with reservoirs require high civil works with considerable impact on the local population.
Geothermal Systems for Electric Energy Generation	The global weighted-average LCOE of the projects commissioned in 2019 was 62.2 €/MWh,	Geothermal power systems are fully commercialized in many areas of the world. Currently, new promising technologies are emerging (organic Rankine cycles) and their TRL is around 6.	There is no limitation on the island's size. Usually, these infrastructures require considerable capital investment, make them suitable for medium to large islands	They can be installed in all areas, providing that there is suitable geothermal potential	Local population has to be enabled in the process of consultation
Geothermal for thermal energy generation	In 2019, LCOE are around 62 €/kWh for geothermal power plants, being similar to the most economic cost ranges for fossil fuels generation.	Mature technologies are district heating, geothermal heat pumps, greenhouses and even electricity generation from hydrothermal reservoirs. Most of the power plants are dry steam plants or flash plants (single, double and triple) with temperatures of more than	Geothermal power plants implementation could be affected by the density of inhabitants and size of the island, depending on the power to be installed. Small islands could think about their available area and economic and technical feasibility of the energy geothermal plant.	For geothermal power plants, plants suitable locations are near volcanic activity, geysers, hot water springs and areas near the union of tectonic plates are also potential places, with medium-high temperatures of water or steam (more than 180ºC).	The implementation of the technology would require firstly the involvement of the companies that develop the systems, often to be supported by public bodies (research centers and universities to validate the technology) in order to provide the necessary infrastructure support.

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		180ºC. Medium temperatures plants are being more used and new technologies such as Enhanced Geothermal Systems (EGS) are less extended and most of them are in the demonstration stage.	Not significantly affected by island dimensions and/or population density for the rest of the technologies.	The rest of the systems require favourable geothermal conditions with high enthalpy resources.	
Concentrating Solar Power (CSP) for thermal energy generation	In 2019, LCOE are around 155 €/kWh, being similar to the most economic cost ranges for fossil fuels generation.	Less developed technology among solar and wind technologies. CSP has been implemented increasingly since 2006. The generation capacity is the 2% of the global PV industry.	Not significantly affected by island dimensions and/or population density.	It would be necessary at least 2000 KWh of irradiation /m2.	The implementation of the technology would require firstly the involvement of the companies that develop the systems, often to be supported by public bodies (research centers and universities to validate the technology) in order to provide the necessary infrastructure support.
Electrical Battery Storage Systems	BESS levelized cost of storage depends highly on the proposed applications and battery type, ranges from 92 €/MWh to 1043 €/MWh[127]	Electrical Battery Storage Systems may use a mature, proven and highly used technology, the battery cells (TRL 9), but for covering energy needs in a grid-scale, the technology (based on power electronics) is not so mature or widely used. These systems have TRL 7-8. Additionally, some battery storage solutions such as Flow Batteries might have TRL 8	Battery size capacity is flexible and can be fully adapted to the island size to cover the needs	Can be installed everywhere	Depending on the final use of the battery, specific stakeholders' involvement might be necessary.
Hydro Storage Systems	Hydro Storage Levelized Cost of storage ranges from	Similar to the hydropower systems	Similar to the hydropower systems, but water availability is not a	Similar to the hydropower systems, but water availability is not a	This technology is mature, but these systems required many licenses to be installed and

[127] M. Wilson, "Lazard's Levelized Cost of Storage Analysis—Version 4.0

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	137.7 to 340.6 €/MWh		problem	problem	operate as well as water use permit. Additionally, systems with a reservoir require high civil works with considerable impact on the local population.
Thermal Energy Storage Systems	Hydro Storage Levelized Cost of storage ranges from 330 to 690 €/MWh for sensible heat technologies, and from 580 to 800 €/MWh for sensible heat technologies[128]	Different types of thermal energy storage have a different level of maturity. PCM materials have TRL around 8-9. Some types of TES have 9, but most of them 3 to 7. Molten Salt Technology has TRL 7-8.	Some commercial types of Energy Storage (PCM) come to modular cells and the capacity of the battery can be fully adapted to the island size to cover the needs. Molten salts are usually coupled with larger installations, which make them suitable for larger islands.	Can be installed everywhere	They don't require specific stakeholders' involvement
Wave Power Electric Generation Technology	LCOE can range from 897 €/MWh (high cost range) to 240 €/Mwh (low cost range). This data position the wave energy production among the most expensive for renewable energy production	No largescale wave farms are present to date; only pilot/demonstration projects mostly developed by young and innovative companies that necessitate the support of public funding and infrastructure	Not significantly affected by island dimensions and/or population density	Best conditions for exploitation are medium-high latitudes (30-60° latitude in both hemispheres). Annual estimates position North America and Oceania as the most producing areas	The implementation of the technology would require firstly the involvement of the companies that develop the systems, often to be supported by public bodies (reaserach centers and universities to validate the technology) in order to provide the necessary infrastructure support.
Electric vehicles	There is large availability of solutions on the market (buses, cars, etc.) where relating to terrestrial vehicles.	High development stage and interest by the big companies helped position this solutions among the most readily applicable	Not significantly affected by the island dimension	Not affected by the geographical characteristics of the islands	Big transport sector companies should be involved not only as vehicles providers but as actively involved in the energy transition projects. Public energy provider companies contribute for the creation of the necessary infrastructure (charging points)

[128] P. Blackmore, "Generating Renewable Energy Business Enterprise: Advice Notes on Energy Storage Economics for the NPA Region," 2017. [Online]. Available: www.grebeproject.eu.

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Upgrade/efficiency of Local Public Assets: Public lighting	Renovation of more than 1000 luminaries with LED lamps may cost around 0,5M€. The cost savings of a project this size Is estimated up to 85%.	LED technology is widely used and proven. Smart functionalities for public lighting are also commonly adopted by cities.	Not significantly affected by island dimensions and/or population density	Not significantly affected by island location and climate.	Being a public asset, the main stakeholder to consider are local and regional authorities.
Upgrade/efficiency of Local Public Assets: Shore-side electricity in ports (paragraph 6.4)	Respecting LCOE, it is complex to define a price range given the multitude of options existing for ports: on-shore power supply to vessels, electrification and automation of equipment, reefer container operation, RES integration, smart grids, etc.	Some options, such as electrification of equipment and reefer containers operation, are measures ready to be implemented. Study cases are available regarding on-shore power supply, so its development is still premature.	Island dimension might limit the type of solutions than can be implemented. On-shore power supply may depend on in-situ energy generation plants. Also, larger islands are expected to have more robust and complex port operations. Solutions on lighting and RES integration might be feasible for smaller islands.	Port operations might vary depending island location. For example, Mediterranean touristic islands might experience higher levels of cruise traffic. Also, some options like onshore power supply might not be economically feasible if electricity price is greater than 0.16 €/kWh.	Being a public asset, the main stakeholder to consider are local and regional authorities together with port authorities.
Building retrofitting: Lightning/ Light control systems	Regarding to LCOE and given the variety of LED products that are marketed in the market, it is difficult to specify cost prices. The type of luminaire must be considered: its technology, manufacturer, power, type of ballast, number of luminaires ...The same can be applied to light control	LED technology is widely used and proven, endorsed by the main manufacturing companies and by consumer organizations and government institutions, aimed at saving energy and money. Energy Efficiency Index (EEI): EEI = W / m² x 100 lux[129] By replacing conventional luminaires with LED technology, savings of 50-80%[10] are estimated.	Not significantly affected by island dimensions and/or population density. It is a technology to be used in any building, no matter its size.	The replacement of luminaires can be carried out on any type of building, including residential buildings, work centers, service buildings (toilets, transport, etc.)	The implementation of the technology is easily accessible to the whole population given the expansion of its commercialization in large specialized or general stores. There are many manufacturers with endorsements and guarantees. Government institutions promote its use as an energy and economic saving measure, with positive impact on the environment

[129] Source: Guía Técnica de Eficiencia Energética en Iluminación (IDAE).

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	systems.				
Building retrofitting: HVAC	Respecting LCOE, it is complex to define a price range given the multitude of options that exist in terms of types of boiler, cooling systems and their power capacity depending on the use: residential or industrial.	There are different technologies, including aerothermal heat pumps, high-performance gas condensing boilers or biomass boilers, as well as the inverter technology and the VRF. All of them are widely proven and are installed in any new building.	Not significantly affected by island dimensions and/or population density. It is a technology to be used in any building, no matter its size.	Regarding the geographical location, heating systems are installed (or at least much more used) in islands located in colder climates. Similarly, systems aimed at generating cold will be used in areas with warmer climates.	Both governments and installers should promote their installation through awareness campaigns and campaigns that show energy savings and the real economic benefits derived from the use of these systems. in the same way, the certifying companies (ISO, AENOR) may guarantee the savings. Both public and private stakeholders can benefit from these systems.
Building retrofitting: Solar panels or PV modules	The cost of a photovoltaic installation cannot be determined without budgetary data on the number of modules to be installed, technology, type of structure on which it is supported, as well as the location of the facility (on the top of the roof or on ground). This will be decisive to specify cost ranges.	Solar PV facilities have evolved greatly during the last years, and its installation cost has been reduced dramatically. For this reason, these facilities are becoming more common and accessible to a higher part of the population. Besides, changes in the energy regulation are making this technology more attractive.	Not significantly affected by island dimensions and/or population density. Solar PV panels are more suitable for one-family houses than for apartments, due to the higher availability of space in the roofs.	The facilities must be located in optimal places for hours of sunshine, avoiding areas of excessive rainfall or even risk of flooding in the case of installations on the ground. Similarly, environments with greater incision of particles that dirty the modules, which would damage the system internal technological equipment should be avoided.	Public entities are encouraging investments in renewable energy projects through subsidies to the population. In addition, private entities such as banks and investment funds make it possible to carry out these facilities through facilities to finance the projects.
Building retrofitting: Domotics and Building Energy Management System (BEMS) - Smart metering	This cost is complex to be delimited because home automation systems, currently, can either be installed on site and adapted to	Domotics technology makes the use of electronic systems and devices adapted to the user's needs, reducing their activity and expenses. This is a technology in	Not significantly affected by island dimensions and/or population density. It is a technology to be used in any building, no matter its size.	Due to an increasing public awareness about the planet and to energy and economic savings, home automation and automation systems are increasingly used.	Manufacturers and public institutions encourage the use of energy-efficient appliances that reduce consumption and increase their utility by adapting to the user's life.

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	existing devices or, the electrical appliances and systems themselves already have it incorporated.	continuous development and innovation. The user can view and control consumption, available energy, adapting their activity and hours when he/she consumes energy to the availability of energy and its cost. Adopting these systems can achieve between 5% to 20% of energy savings overall.		Citizens are gradually incorporating them, due to the fact that new appliances which are bought include these systems.	
Construction structure envelope - Vinyl or insulating filter for windows	The costs of installing vinyl on building windows and in elevators will depend on the square meters that need to be covered and the quality of the vinyl used. Its cost ranges from €15 to €30 per square meter, according to quality and filter typologies.	The high inhibitory capacity of the solar protection films can absorb up to 80% of the heat coming from the outside of the building and reduce much of the heat loss that occurs through the windows. Currently, the quality and effectiveness of films containing alloys and UV radiation inhibitors that filter the sun's rays without reducing visibility continue to improve. Thanks to its insulating properties, it prevents by 33% the loss of heating.	Not significantly affected by the island dimension and/or population density. It is a technology to be used in any building, no matter its size.	It is designed to be installed in any type of building exposed to both hot and cold climates, as they protect both from heat and cold; reducing spending on air conditioning and heating.	This energy efficiency system presents a lower cost to the user, so no aid or subsidies are usually offered for its financing.
Construction structure envelope - Appliances and white goods	The range of costs for efficient electrical appliances (class A+++) varies according to the brand, type and features of the appliance. It is	Currently, the appliances with the highest energy efficiency categories are common in the market. Users who need to change their appliance and buy a new one will in any case use a much more efficient	Not significantly affected by the island dimension and/or population density. It is a technology to be used in any building, no matter its size.	Not significantly affected depending on the location or location of the product.	Governments are promoting Home- White goods Appliances Renovation Plans to promote the replacement of conventional appliances by efficient ones.

	difficult to offer costs, since it depends greatly on the type of appliance (a coffee maker is much cheaper than a fridge).	appliance than before.			

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