This Project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement N. 957752

Smart integRation Of local energy sources and innovative storage for flexiBle, secure and cost-efficIent eNergy Supply ON industrialized islands

D 6.2 – Market Assessment report

Lead partner: Technical University of Crete - TUC

Project Contractual Details

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[1] Dissemination level: **PU** = Public, PP = Restricted to other programme participants (including the JU), **RE** = Restricted to a group specified by the consortium (including the JU), **CO** = Confidential, only for members of the consortium (including the JU)
[2] Creation, modification, final version for evaluation, revised version following evaluation, final

Executive summary

Deliverable 6.2 aims to identify marketing opportunities for the Follower and other involved islands, undertaken under the framework of the European H2020 project: Smart integRation Of local energy sources and innovative storage for flexiBle, secure and cost-efficIent eNergy Supply ON industrialized islands (ROBINSON). The final outcome of the market analysis under the task 6.2, will provide the essential information for the identification of innovative energy technologies, and the efficient energy management system as products for future exploitation.

The present version of D6.2 is based on an extensive desk research and analysis of newly established questionnaires distributed to the project's partners. Market analysis will be utilized as a basis for the development of the suggested system's business planning for local communities, which is scheduled in Task 6.3, aiming to exploiting the project's outcomes.

During the market analysis, the following questions are attempted to be answered:

- Which are the main determining factors for accelerating the HRES development?
- Which are the most appropriate suggestions for promoting HRES in the target markets?
- Who are the key customers within each market?
- Why would industrialized islands choose a flexible energy system?
- What are the current RES market trends?

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List of abbreviations

AD	Anaerobic Digestion	Mtoe	Million Tonnes of Oil Equivalent
AD-BES	Anaerobic digestion with a Bioelectrochemical System	MW	MegaWatts
BECCS	Bioenergy coupled with carbon capture and storage	NESOI	European Islands Facility
CCS	Carbon Capture and Storage	NZE	Net-Zero Emissions Scenario
CETA	Comprehensive Economic and Trade Agreement	O&M	Operation and Maintenance
CHP	Combined Heat and Power	OfGEM	Office of Gas and Electricity Markets
CO2	Carbon Dioxide	P2H	Power-to-Heat
C&I	Commercial & Industrial	P2L	Power-to-Liquid
CRE	Commission de Régulation de l'Énergie	PJ	Petajoule
CSP	Concentrated Solar Power	PV	PhotoVoltaics
DERs	Distributed Energy Resources	RE	Renewable Energy
DNOs	Distribution Network Operators	RED	Renewable Energy Directive
EC	European Commision	RES	Renewable Energy Sources
EEII	European Energy Intensive Industries	REST	Renewable Energy Systems & Technology
EMS	Energy Management System	RET	Renewable Energy Technology
EnTS	The Environmental Trading Scheme	RHC	Renewable Heating & Cooling
ETIP	European Technology and Innovation Platform	SWOT	Strengths-Weaknesses-Opportunities-Threats
ETS	Emissions Trading System	TES	Thermal Energy Storage
EU	European Union	TRL	Technology Readiness Level
EV	Electric Vehicle	TWh	TeraWatt hours
GHG	Greenhouse Gas	UK	United Kingdom
GW	GigaWatt	US	United States
HRES	Hybrid renewable energy systems	USD	United States Dollar
IEA	International Energy Agency	VAT	Value-Added Tax
IoT	Internet of Things	WECS	Wind Energy Conversion Systems
IRENA	International Renewable Energy Agency	WP	Work Package
km	kilometres	WtE	Waste-to-Energy
kWe	kilowatts of electrical power		
LCoE	Levelized Cost of Electricity		
MECs	Microbial Electrolysis Cells		
MFCs	Microbial Fuel Cells		

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1. Introduction

The ROBINSON project "smart integRation Of local energy sources and innovative storage for flexiBle, secure and cost-efficIent eNergy Supply ON industrialized islands" aims at developing an integrated energy system to reduce CO_2 emissions in islands with industrial symbiosis.

Market analysis is the process of collecting data about a specific market in order to obtain insights and comprehension about its characteristics, trends, and potential opportunities. It involves analyzing the market's size, growth rate, competition, customer requirements and preferences, distribution channels, and pricing. Existing and potential markets can both be analysed using market analysis. It can assist businesses in identifying new markets to enter and areas in which they may need to enhance their offerings to remain competitive. Overall, market analysis is an indispensable instrument for businesses in today's dynamic business environment in order to make informed decisions and maintain a competitive edge.

Undertaking a market analysis for a HRES necessitates recognizing the intended market, estimating the requirement, appraising the competition, studying the regulatory setting, carrying out a SWOT examination, and ascertaining pricing and distribution approaches. Through the examination of the relevant market, businesses can acquire a more comprehensive comprehension of the possible prosperity of their hybrid renewable system in a given market, in addition to pinpointing key elements that can facilitate uptake and commercialization. This data can be utilized to formulate informed corporate choices, promotional tactics, and evaluate potential rewards and liabilities associated with entering a novel market.

This deliverable is connected to task 6.2 "Market Assessment" of Work package 6. The main purpose of this deliverable is to make available a market review concerning Robinson's technologies. This document will further provide inputs to work to be done in task 6.3 of Work package 6.

The deliverable consists of 5 chapters and their subchapters, presented as follows:

- Chapter 1 provides introduction to this document and its purpose,
- Chapter 2 describes market conditions, energy from RES, energy generation of isolated areas in Europe,
- Chapter 3 analyses the results of the questionnaire which has been distributed to the partners,
- Chapter 4 presents Robinson's technologies and SWOT analysis of each technology,
- Chapter 5 identifies Robinson's marketability and positions the proposed solution in a way that will create value to its stakeholders.

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2. Market Condition

The successful integration of societal trends such as the sharing economy and sustainability with energy policies is essential for achieving a sustainable energy future. Policies that encourage energy efficiency, conservation, and the use of Renewable Energy Sources (RES) can help reduce energy demand and minimize the impact of these trends on energy consumption. By aligning these trends with energy policies, a more sustainable and resilient energy system can be established, able to can meet the needs of present and future generations.

2.1. Clean Energy Vision

The exigent necessity of transitioning to RES, especially in islanded territories, has been brought to the spotlight due to the current energy dilemma on a global scale. The remoteness of these islands along with restricted access to traditional fossil fuel sources and susceptibility to extreme weather conditions often render them susceptible to significant energy dilemmas. Consequently, numerous geographically isolated islands are highly dependent on the importation of fossil fuels, which can be costly and vulnerable to supply chain disturbances.

Isolated islands have the potential to rely on RES, e.g., solar, wind, biomass to provide a dependable and sustainable energy. The utilization of these RE can be localized, thereby diminishing the reliance on imported fossil fuels and escalating energy autonomy. Concomitantly, RES are often more cost-effective in the long run as they do not depend on the unsteady international energy markets. The evolutions of RE targets in Europe are demonstrated in Figure 1.

Figure 1 - Evolution of RE targets (Fraboni et al., 2023)

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The implementation of RES can produce considerable environmental advantages, including the diminishment of greenhouse gas emissions and the preservation of local ecosystems. Renewable energy (RE) projects have the potential to generate employment opportunities and bolster local economies. However, European Commission (EC) had already proposed in 2016 a Clean Energy package for all Europeans, which is further adopted in 2019. It will help in the decarbonization of European Union's (EU) energy system in line with the European Green Deal objectives.

The EU has established ambitious goals regarding climate change, aiming to reduce its Greenhouse Gas emissions (GHGs), primarily in the energy sector. It has been estimated that a substantial fraction (over 75%) of the EU's GHGs is attributable to energy production and consumption, thus making it a pivotal area for reducing emissions. In order to meet its objectives pertaining to climate change, the EU has established a target of augmenting the proportion of renewable energy inside its overall energy portfolio. It is the EU's ambition to have, by 2030, at least 32% of its total energy consumption derived from renewable sources (Figure 2). This objective forms a section of a more extensive plan to decarbonize the energy industry and lessen emissions. The augmentation of RES in the energy portfolio has the potential to considerably decrease carbon dioxide emissions. Based on estimations, the EU could potentially reduce GHGs by a minimum of 55% in comparison to the figures recorded in 1990 if the proportion of renewable energy within its energy mix is augmented. The diminishment of emissions could assist the EU in realizing its envisioned aim of becoming carbon-neutral by 2050. In order to realize these ambitions, the EU is implementing a number of regulatory policies and initiatives in order to facilitate the wider usage of RES (*Renewable Energy Targets*)
EC proposes in 2016 a Clean Energy package for all Europeans which is further adopted in 2019. It will help in the decarbonization of EU's energy system in line with the European Green Deal objectives. This package will provide important contribution and benefits for environment, economy and consumers (*Clean Energy for All Europeans Package*)

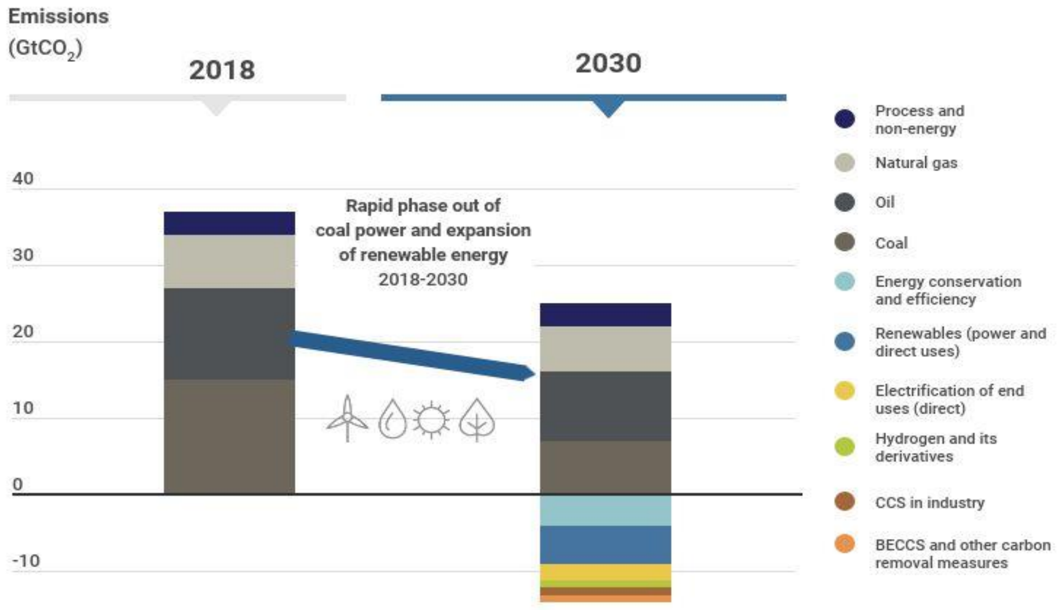

*Figure 2 - Impact on emissions of replacing fossil fuels with RES until 2030 (*World Energy Transitions Outlook 2022*)*

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2.2. "Net-zero emissions by 2050"

In the Net-Zero Emissions Scenario (NZE) by 2050, fossil fuel usage is decreased dramatically, and no new oil and natural gas fields are needed beyond those that have already been confirmed for advancement. No new coal mines or mine extensions are required. Low emissions fuels and biogases, hydrogen, and hydrogen-based fuels, notice accelerated growth. They are responsible for almost 20% of global final energy in 2050, compared to 1% in 2020. Electricity demand reaches drastically growth in the NZE, being increased 40% from today till 2030, and more than two-and-a-halftimes to 2050. Renewable energy sources are the leaders of this evolution, up from 29% of generation in 2020, reaching 60 in 2030 and almost 90% in 2050.

Reducing emissions from industry is an important step towards achieving a sustainable and low-carbon economy. The targets you mentioned - a 20% reduction by 2030 and a 90% reduction by 2050 - are consistent with the goals set by many countries and international organizations to limit global warming to well below 2°C above pre-industrial levels. To achieve these targets, industries will need to implement a range of measures, such as improving energy efficiency, transitioning to low-carbon energy sources, investing in research and development of new technologies, and implementing carbon capture and storage (CCS) technologies. (Net Zero by 2050: A Roadmap for the Global Energy Sector - A Special Report by the International Energy Agency | UNFCCC)

Six technological avenues of future energy transition, concerning the 1.5°C decrease of the Paris climate goal:

1. **Renewable energy sources (RES)**: This category includes sources such as solar photovoltaic and wind power, as well as the direct use of renewable energy sources like solar thermal and biomass.

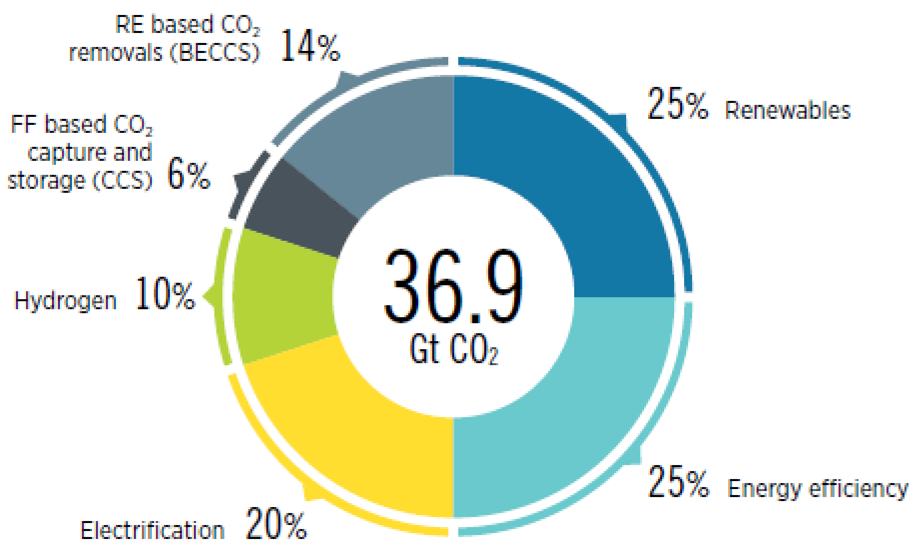

Figure 3 - Reducing Emissions by 2050 through six technological avenues. Source: IRENA

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2. **Energy conservation and efficiency**: This category encompasses measures aimed at reducing energy demand and improving the energy efficiency of end-use applications. This may involve structural changes, such as relocating steel production with direct reduced iron, or circular economy practices, such as using alternative cement materials.
3. **Electrification of end-use sectors**: This category involves the direct use of clean electricity in applications such as transport and heating.
4. **Hydrogen and its derivatives**: This category includes the direct use of clean hydrogen, primarily green hydrogen, as well as synthetic fuels such as green ammonia and methanol. These fuels can also serve as clean hydrogen-based feedstocks.
5. **Carbon capture and storage (CCS)**: This category involves the capture and storage of carbon emitted by point-source fossil fuel-based and other emitting processes, primarily in industrial settings.
6. **Bioenergy coupled with carbon capture and storage (BECCS) and other carbon removal measures:** This category includes the use of bioenergy to produce energy, while simultaneously capturing and storing the carbon emitted during the process. Additionally, other carbon removal measures may be employed to remove carbon from the atmosphere, (*World Energy Transitions Outlook 2022: 1.5°C Pathway*, 2022).

2.3. Energy from Renewable Energy Sources

2.3.1. Wind Energy

Even though the development of wind energy in Europe is slow, and the climate goals set for 2030 is unachievable, 2021 net wind turbine capacity is the second of the best performances of the last decade. According to Eurostat, the net wind turbine capacity in EU countries in 2021, is 188.4 GW (15.1 GW offshore included) (EurObserv'ER, 2023). The generation of wind energy relies on investments in new wind farms and weather patterns in primary production regions. In contrast to the previous year, several EU nations experienced inadequate wind conditions, with Germany, Ireland, France, Belgium, and countries in the north particularly affected. Despite the addition of new production capacities, both onshore and offshore wind energy output declined by 2.7% from 397.8 to 386.9 TWh (a decrease of 10.9 TWh) between 2020 and 2021 (Figure 4). This contrasts with 2020, when significantly stronger winds led to an 8.4% increase from the 2019 output of 367.2 TWh.

Numerous significant undertakings are presently being built within the European Union, which will considerably enhance its installed potential within the next three years. France has formally initiated its offshore energy project and is now the ninth EU member state with its own offshore sector. In November 2022, the Saint-Nazaire wind farm (480 MW) was completely commissioned with 80 General Electric Haliade 150 turbines, each with a capacity of 6 MW. On December 16, 2020, the German energy company RWE fully integrated its Kaskasi offshore wind farm (342 MW), which features 38 Siemens-Gamesa SG 8.0-167 DD turbines located 35 km from the north coast of Heligoland Island. This wind farm incorporates recyclable turbine blades, which is a significant milestone. The farm is expected to commence commercial delivery at the beginning of 2023 (EurObserv'ER, 2023).

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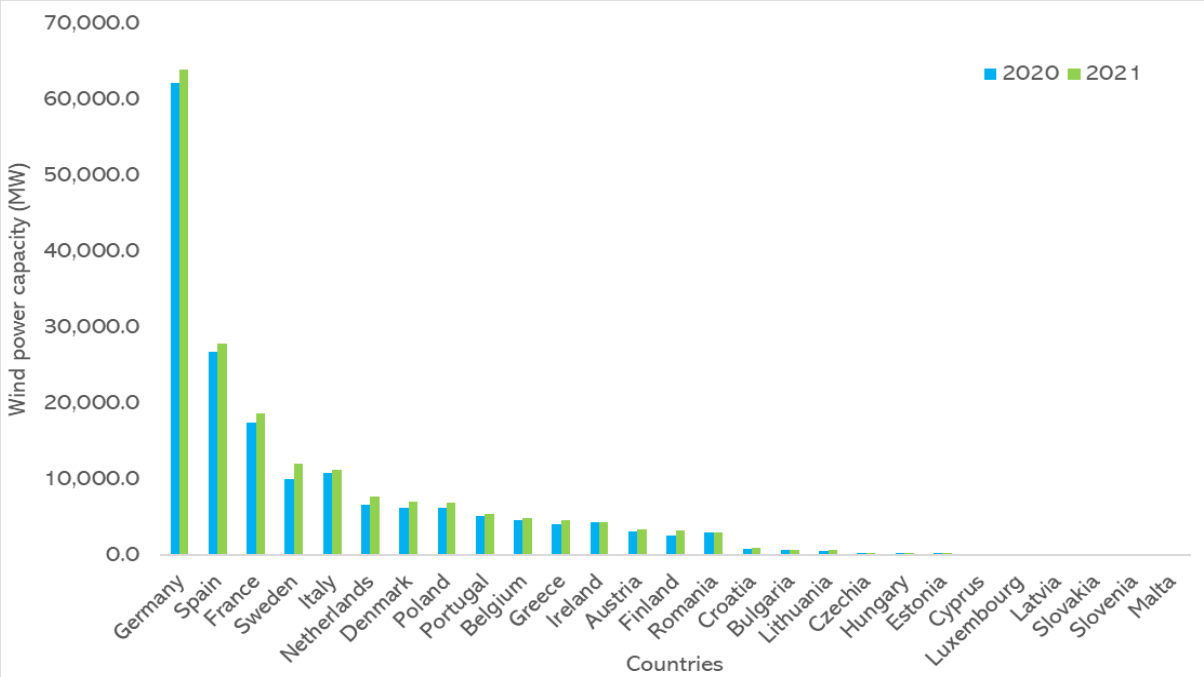

Figure 4 - Wind power capacity installed in the European Union at the end of 2021 (MW). Source: Eurobserver

The data shows that Germany has the highest total wind power capacity in both years, followed by Spain, France, and Sweden. It is indicated that the majority of countries maintained their offshore wind power capacity between the years 2020 and 2021. However, the offshore capacity of the Netherlands and Denmark experienced a notable increase during this period.

2.3.2. Solar Energy

Despite the challenging post-COVID economic environment, characterized by supply chain disruptions and costlier solar system components, the EU's solar photovoltaic market remained robust throughout 2021. The high prices of electricity within the electricity market, coupled with the competitiveness of solar electricity, made solar photovoltaic an attractive option in 2021. Eurostat data revealed that the European Union's net capacity of 27 increased by 40.7%, equivalent to 25,702.9 MW, compared to the sector's 2020 performance (18,272.8 MW). As a result, the combined installed capacity of the EU reached 161,879.2 MW by the conclusion of 2021 (161.9 GW), signifying an 18.9% increase from the previous year.

The European Union achieved a new record in 2021 for the net addition of photovoltaic capacity, surpassing its previous record set a decade ago in 2011 when 22,253.8 MW was added. However, the 2021 record is different from 2011 as it is not a peak but a steppingstone towards even higher installation levels. The installation rush in the late 2000s was mostly speculative and driven by the attractive guaranteed feed-in tariffs, but today's growth is more sustainable and based on market mechanisms. This growth is also shared by a majority of EU countries rather than just a few trailblazers. In 2021, 21 EU countries experienced double-digit increases in their photovoltaic capacity bases, with some countries doubling their installed capacity in just twelve months.

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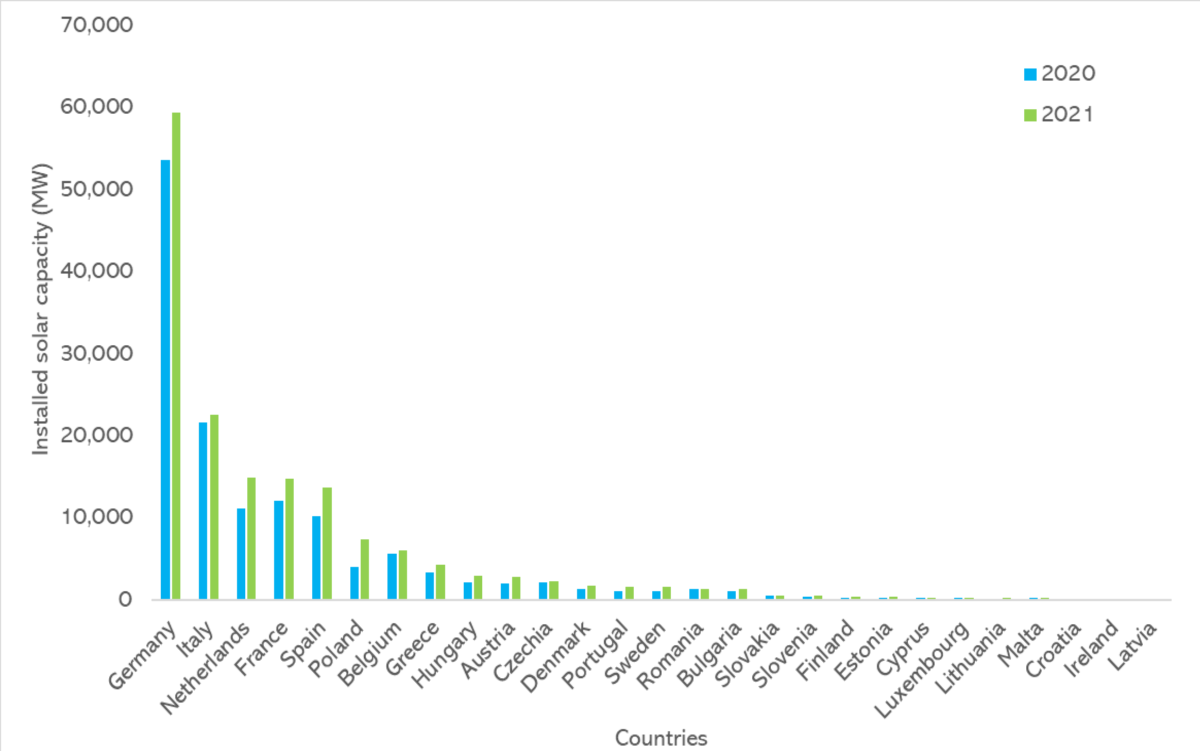

Figure 5- Solar power capacity installed in the European Union at the end of 2021 (MW). Source: Eurobserver

The European Commission has outlined the need to end the EU's reliance on Russian fossil fuels, which would require a significant increase in the use of renewable energy and the electrification of heat production in industries, buildings, and transportation. To address this issue, the REPowerEU plan was introduced in May 2022, which aims to stimulate the deployment of solar photovoltaic power to inject more than 320 GW into the grid by 2025, double the amount of 2020, and almost 600 GW by 2030.

The additional capacity installed at the start of this period would replace the annual consumption of 9 million m3 of fossil gas until 2027. However, the installation pace needs to accelerate significantly to meet the European Commission's proposed 2030 renewable energy target and the REPowerEU targets, which would require installing about 45 GW per annum during the current decade. The strategy includes a European solar panel installation initiative, encouraging self-consumption and energy communities, a European alliance for the solar photovoltaic industry, and a European skills partnership to create local jobs throughout the EU. The implementation of these initiatives is of utmost importance in the context of the energy crisis and geopolitical tensions, (EurObserv'ER, 2023).

2.3.3. Biomass

In 2021, there was a surge in solid biomass energy consumption in the EU. This trend was observed across various forms of biomass, including log wood, pellets, wood waste, and by-products, and in most of Northern Europe, France, Germany, and a few other countries. According to Eurostat, the energy consumption from solid biomass reached a record high of 104.1 Mtoe, representing an 8.3% increase from the previous year. This significant increase can be attributed to the longer heating period in the EU climate zones due to the harsher winter of 2021 and the rise in fossil energy prices in

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the second half of the year, which made biomass fuels more competitive. The increased consumption also led to higher solid biomass electricity output, which rose by 9.8 TWh to reach 92.8 TWh compared to 2020. Additionally, heat consumption (from the processing sector or directly consumed by end-users) increased by almost 6.2 Mtoe to reach 84.4 Mtoe.

Primary energy refers to the energy present in natural resources before undergoing any processing, while final energy is the energy consumed by end-users after processing and transportation. Eurostat differentiates between two types of final solid biomass energy use: electricity and heat. The distinction is also made between solid biomass heat from the processing sector, which is distributed via heating networks, and the heat used directly by end-users in the residential, industrial, and agricultural sectors.

In the EU-27, the solid biomass electricity output in 2021 was 92.8 TWh. Of this total, combined heat and power plants supplied 76.3%, representing an 11.8% increase from the previous year. Finland regained its position as the top biomass electricity producer in 2021 with 12.7 TWh, generating 1.9 TWh more than in 2020. Sweden came second with 11.2 TWh, a 1.7 TWh increase from the previous year. Germany fell to third place, producing 10.9 TWh, with the output dropping by 0.4 TWh,(EurObserv'ER, 2023) (Figure 6).

Germany had the highest production of solid biofuels in both years, with 12.648 Mtoe in 2020 and 13.971 Mtoe in 2021. France and Sweden followed closely with 9.765 Mtoe and 9.502 Mtoe in 2020 and 10.745 Mtoe and 10.264 Mtoe in 2021, respectively. Other countries with significant energy production of solid biofuels include Finland with 7.935 Mtoe in 2020 and 9.040 Mtoe in 2021, and Poland with 8.964 Mtoe in 2020 and 8.881 Mtoe in 2021. Energy production of solid biofuels in some countries, such as Malta and Cyprus, was negligible or non-existent.

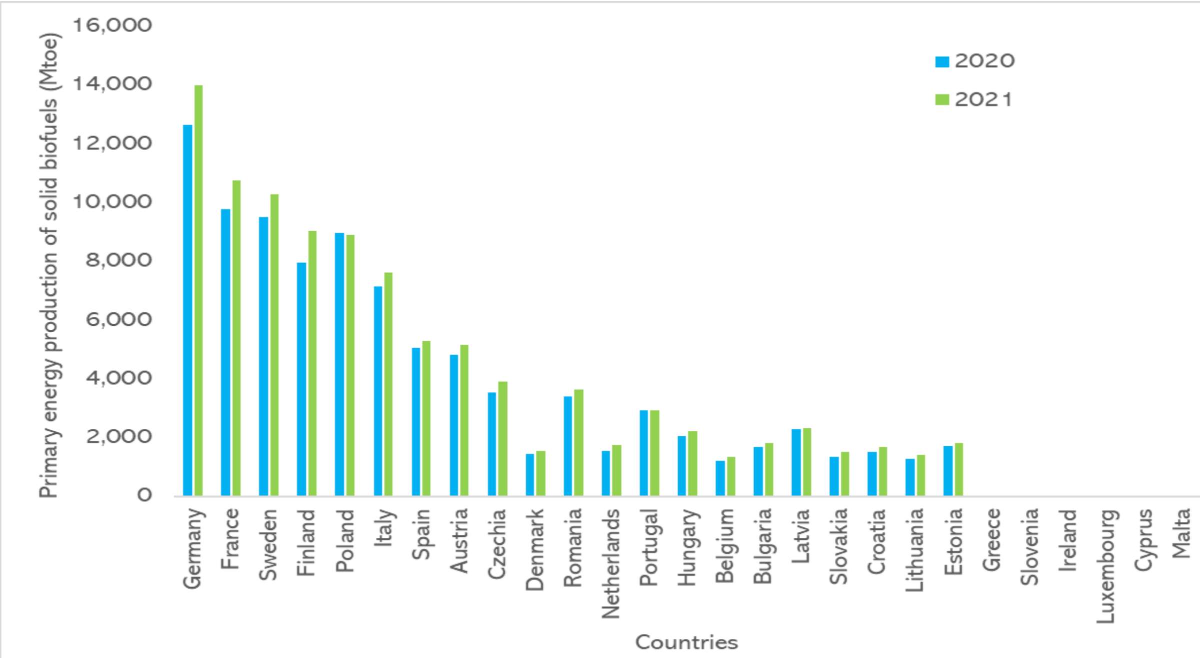

Figure 6 - Primary energy production of solid biofuels (Mtoe) in EU at the end of 2021 (Mtoe) Source: Eurobserver,2023

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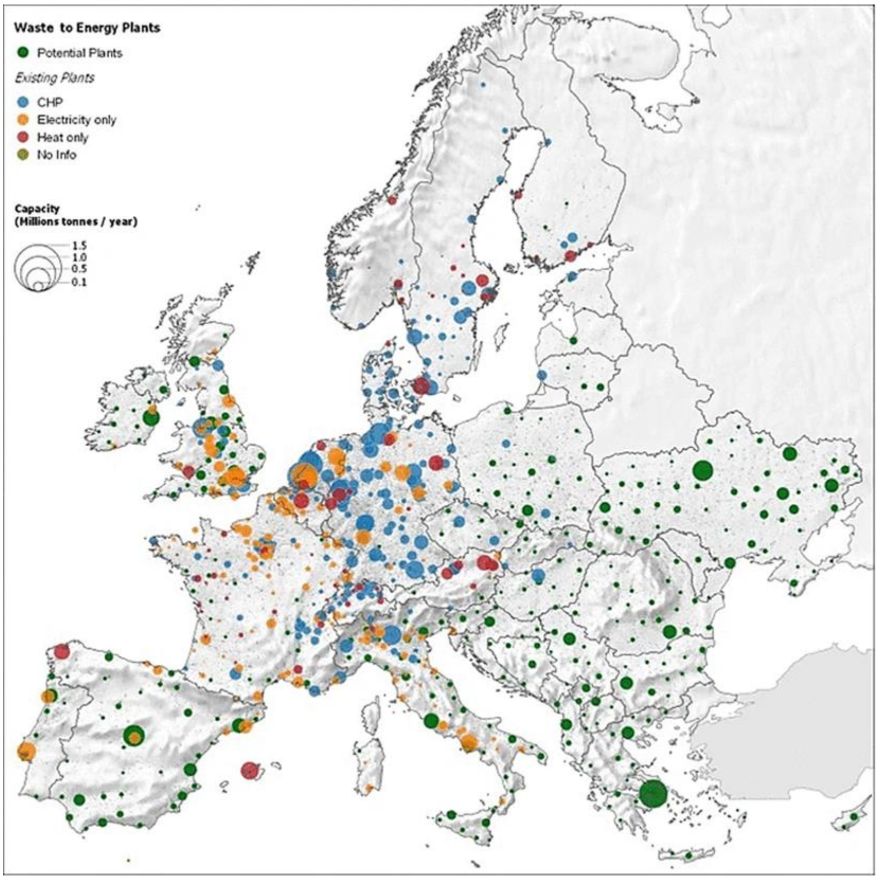

Figure 7 - Waste to energy plants in EU (Scarlat et al., 2019)

According to Eurostat, primary biogas energy output in the EU increased by 1.6% in 2021, reaching 14.9 million tons of oil equivalent. Other biogas from non-hazardous waste or raw plant matter dominated this output at 83.5%, followed by sewage sludge gas (7.8%), landfill biogas (7.7%), and thermal biogas (0.9%). The growth rate was lower than the previous year, with Germany and Austria experiencing lower outputs while France, Denmark, and Italy saw sharp growth. Figure 7 illustrates "waste to energy" plants. The potential plants are represented with the green color. Blue represents CHP existing plants, orange electricity only, and red heat only.

Following Russia's invasion of Ukraine, the investments made in the biogas sector have gained significance due to the EU's excessive reliance on Russian gas, which has resulted in high energy bills for households, local authorities, and businesses. The EU responded by launching its REPowEREU plan in May 2022, aimed at reducing its dependence on Russian gas by 2027 and combatting the climate crisis. The EC has prioritized transforming the European energy system to reduce reliance on Russian fossil fuels and combat the climate crisis. One of the Commission's landmark measures is its action plan for biomethane, which includes financial incentives and a new industrial partnership to increase output to 35 billion m³ by 2030. The renewable gas sector players are ready to help the EC achieve its goals, highlighting the advantages of gas distribution networks for managing renewable electricity production fluctuations and the benefits of a hybrid energy infrastructure built on the gas and electricity grids (EurObserv'ER, 2023).

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2.4. Final energy consumption by end use

The term "final energy consumption" refers to the total amount of energy that is delivered to end users for various uses, such as in households, industry, and agriculture. It includes energy used for activities like heating, lighting, and transportation.

According to the International Energy Agency (IEA), renewable energy accounted for 10.4% of total final energy consumption in 2019 (*Final Consumption – Key World Energy Statistics 2021 – Analysis*). The World Bank's Sustainable Energy for All database also shows that renewable energy consumption accounted for 10.4% of total final energy consumption in 2019. The IEA reports that renewable electricity generation is expected to expand by more than 8% in 2021, with solar PV and wind contributing two-thirds of renewables growth (Figure 8). The IEA also forecasts that renewable energy consumption will more than double between 2020 and 2050, with renewable energy consumption nearly equaling liquid fuels consumption by 2050. However, renewable energy still accounts for a relatively small portion of global energy consumption, and non-renewable energy sources continue to dominate. As shown in Figure 8, transport is the sector that consumes larger shares of energy the last 30 years. In 2020, it is observed a common decrease at all sectors, during Covid-19. Here is a breakdown of the final energy consumption of end use of all renewables, based on the latest available data from the IEA in 2019:

- Industry: 21.3%
- Transport: 3.3%
- Buildings: 47.3%
- Other sectors: 28.1%

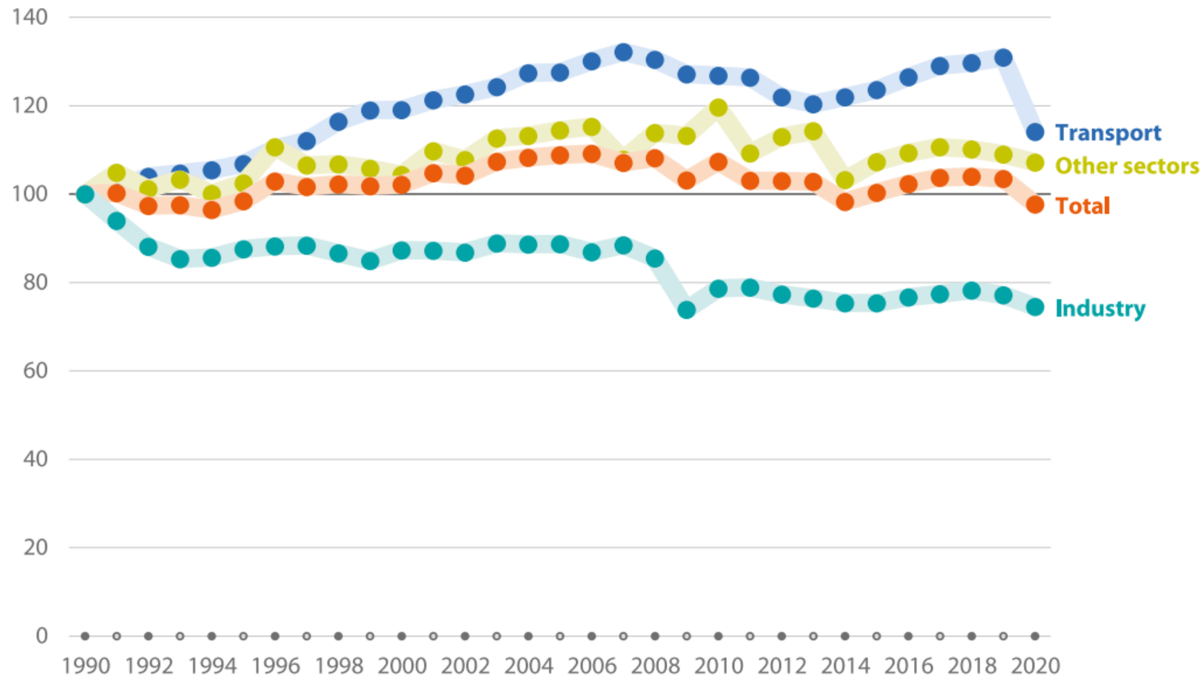

Figure 8 - Final Energy Consumption by end use. Source: Eurostat,2022

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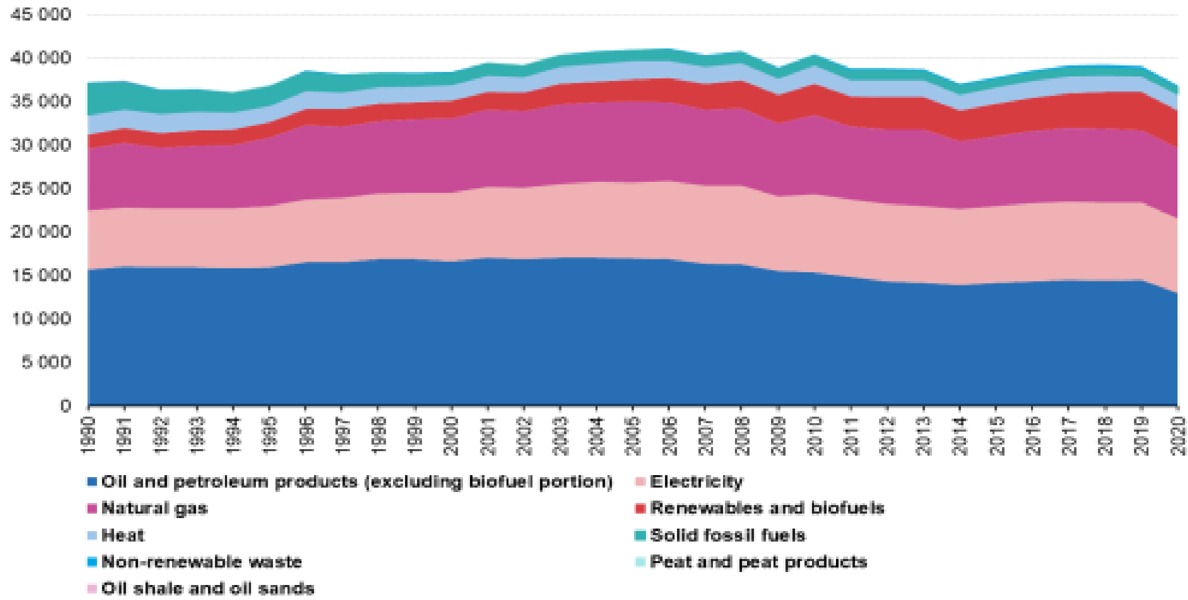

Figure 9 - Final Energy Consumption by fuel (in PJ). Source: Eurostat

According to Eurostat, in 2020, the final energy consumption in the EU was 37,086 PJ, which was 5.6% lower than that of 2019, as shown in Figure 9. After a gradual increase from 1994, the final energy consumption reached its peak of 41,445 Mtoe in 2006. However, by 2020, the final energy consumption had dropped by 10.5% from its highest recorded level.

Between 1990 and 2020, a significant decrease was observed in both the quantity and the proportion of solid fossil fuels consumed in the EU's final energy consumption. The decline was notable from 9.6% in 1990 to 3.6% in 2000, 2.8% in 2010, and 2.1% in 2020. Over the same period, RES increased their share of the total final energy consumption, rising from 4.3% in 1990 to 5.3% in 2000, 8.8% in 2010, and finally reaching 11.8% in 2020. The share of natural gas remained relatively stable over the period, fluctuating between 18.8% (in 1990) and 22.6% (in 2005), and eventually reaching 21.9% in 2020.

In the year 2020, oil and petroleum products made up the highest proportion of the final energy consumption structure, accounting for 35.0%, followed by electricity at 23.2%, and natural gas at 21.9%. Conversely, the contribution of solid fossil fuels to the final energy consumption at the end-use level was minimal, representing only 2.1% of the total,(*Energy Statistics - an Overview*).

2.5. Origin of energy imports

Europe's energy imports originate from a variety of sources worldwide. The primary suppliers of energy to Europe as also shown in Figure 6, are Russia, Norway, and Algeria, which are the largest exporters of oil, natural gas, and coal. Other countries, such as Kazakhstan, Nigeria, Qatar, and the United States (US), also contribute to Europe's energy imports. In addition, Europe increasingly relies on RE imports, such as solar panels and wind turbines, which are manufactured in countries such as China and South Korea. The specific mix of energy import sources varies by country and changes over time based on market conditions, geopolitical factors, and national energy policies.

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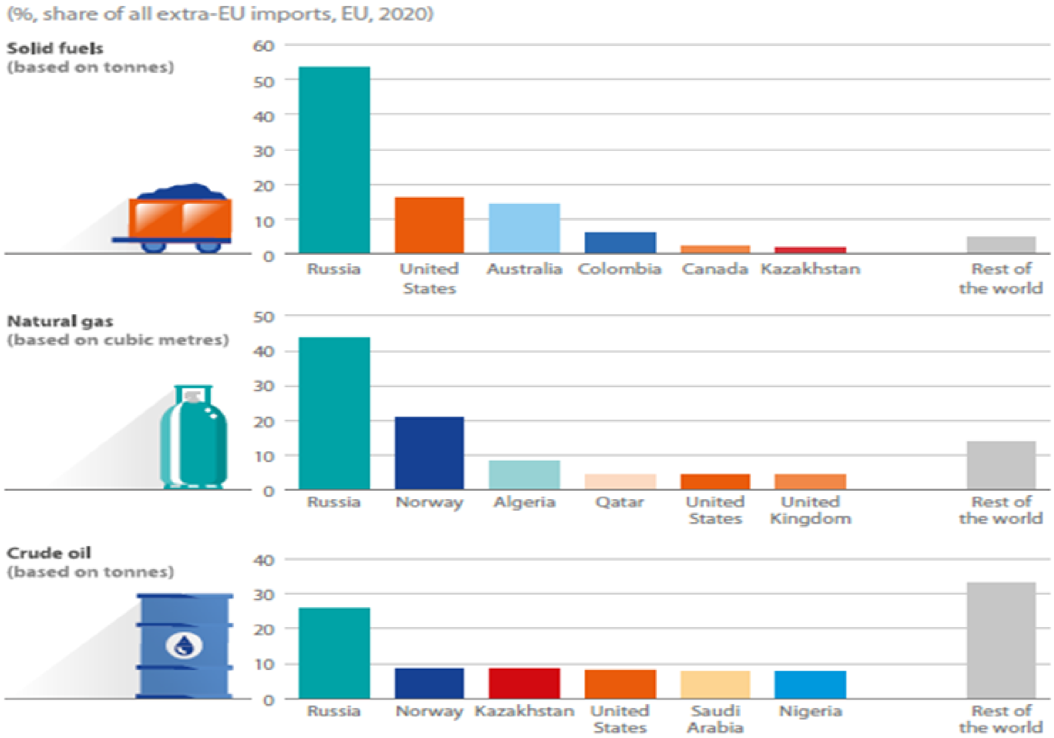

Figure 10 - Origin of Energy Imports. Source: Eurostat,2022

According to Eurobserver (Figure 10), the EU saw significant import activity in photovoltaics, wind energy equipment, biofuels, and hydropower equipment in 2020, with Germany, the Netherlands, and Spain being the largest importers, respectively. The same three countries were also the main exporters of renewable energy technology (RET), with Germany and the Netherlands ranking first and second, exporting €4,664 million and €3,437 million, respectively. China emerged as the dominant trading partner, importing €6,379 million and exporting €22,228 million in 2020.

Net exports, a measure of the trade balance of an economy, provide further insights into these trends. China had a highly favorable trade balance, followed by Denmark, Germany, Hungary, Slovakia, France, Bulgaria, and Slovenia. These countries recorded more RET exports than imports in 2020, while all other countries in the comparison showed negative net exports. In terms of the export shares of the four selected RES, China dominated with a share of 33% in 2020. The EU-27 came second with a 23% share in the same year. Germany, the U.S., the Netherlands, Japan, and Denmark had the largest shares after China, while Malta, Cyprus, Latvia, Finland, Romania, Ireland, and Norway had the smallest shares (EurObserv'ER, 2023).

Figure 11 depicts the trade of RET between the EU-27 and its major trading partners. A negative net trade balance with China was observed, meaning larger volume of imports from China to the EU-27 than exports from the EU-27 to China. The EU-27 also experienced a negative trade balance with Japan, India, Brazil, and Canada in 2021. Conversely, a positive trade balance in RET was recorded with the United States, the UK, Turkey, Switzerland, and Norway. Meanwhile, the trade balance with Russia showed a decrease of around €100 million from 2020 to 2021, although it remained positive.

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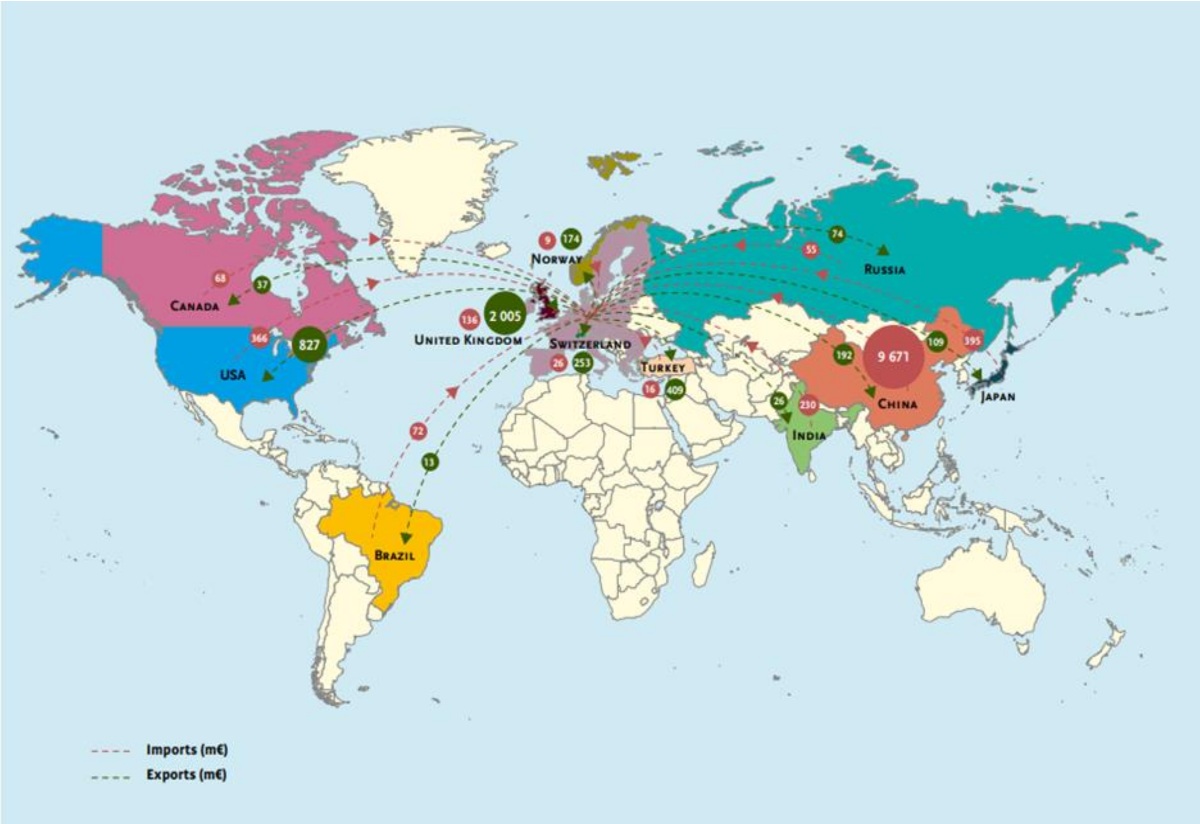

Figure 11 - Europe trade with trading partners 2021-all RES. Source: Eurobserver,2023

In general, the EU unveils robust competitiveness across all RES sectors and maintains high market shares in 2021. Conversely, the U.S. shows strength primarily in biofuels and is exerting efforts to enhance its position in that sector, while lagging the EU in other RES. Europe enjoys a favourable trade balance with the U.S., the U.K., Turkey, Switzerland, Norway, and Russia.

2.6. Energy flexibility on unexpected events

The COVID-19 pandemic has presented an unprecedented challenge for modern societies, with governments grappling with a novel and highly infectious disease that has proven to be lethal in many cases. The rapid spread of the virus has put healthcare systems under tremendous pressure, and experts have had to develop new models of behavior based on limited scientific knowledge due to the newness of the situation. Despite the interconnectedness of European countries, their responses to the epidemic have varied in terms of severity and timing, and the effectiveness of their measures, as well as their impact on industries, stock markets, environment, and energy markets, remains uncertain. As governments attempt to revive economies and ease restrictions, it is essential to comprehend the short- and long-term effects of their actions, not only to better prepare for future crises but also to uncover potential opportunities, particularly for research on sustainable electricity, (*Impact Analysis of COVID-19 Responses on Energy Grid Dynamics in Europe | Elsevier Enhanced Reader*).

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According to IEA, in Europe, the combination of decreased electricity demand and increased renewable energy production has led to a decline in non-renewable generation. From February through the first week of July of 2020, weekly renewable production exceeded fossil fuel generation; however, this trend reversed in July due to a reduction in wind production. The low cost of natural gas and higher carbon prices have stimulated an increase in natural gas generation to offset the decline in energy production from other sources. Despite strong wind conditions and high precipitation, weekly renewable production showed sporadic peaks during the fourth quarter of 2020. Natural gas and coal power outputs adapted to the fluctuations in renewable production to meet overall electricity demand levels, which typically decrease during holiday seasons.

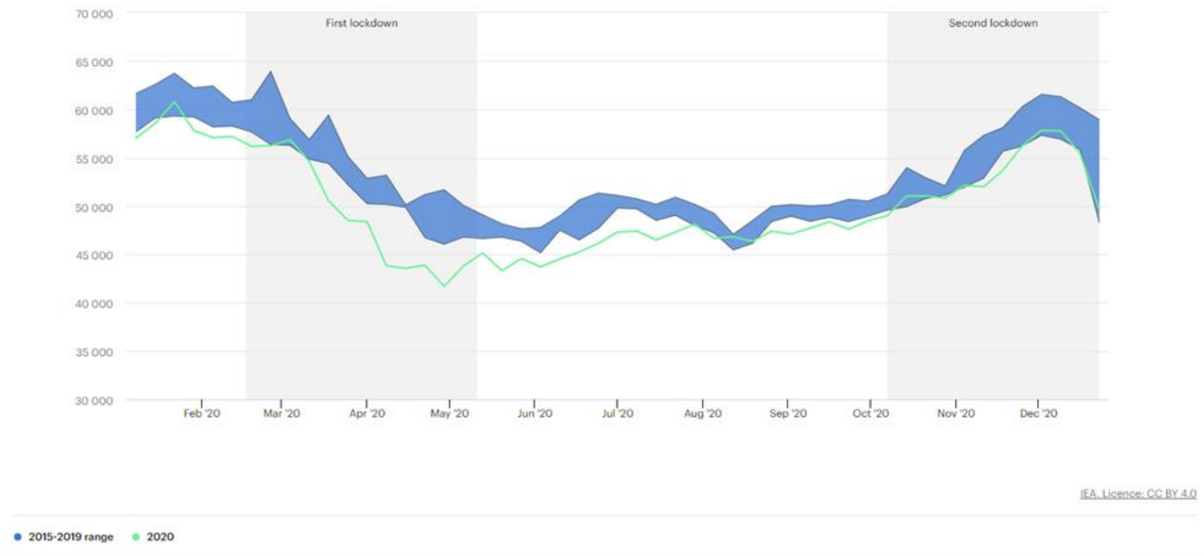

Figure 12 - Weekly electricity net generation in the EU, 2015-2019 range compared with 2020. Source: IEA

2.7. Share of energy from renewables and electricity prices

Energy is considered vital for every nation especially for Europe, due to the reliance on Russian source imports. Over the past decade, Europe has made significant progress in transitioning away from fossil fuels. This shift has been driven by a range of factors, including concerns about climate change, the increasing cost competitiveness of renewables, and policies aimed at reducing greenhouse gas emissions. Despite this progress, however, fossil fuels remain a significant source of energy for many European countries. According to data from the EC, in 2020, 48% of primary energy consumed in the EU came from fossil fuels, with oil being the most significant source at 34%, followed by natural gas at 20%. Figure 11 represents the share of energy from renewable sources in EU, from 2004, until 2021. In 2021, 37.5% of renewable energy was used in electricity sector.

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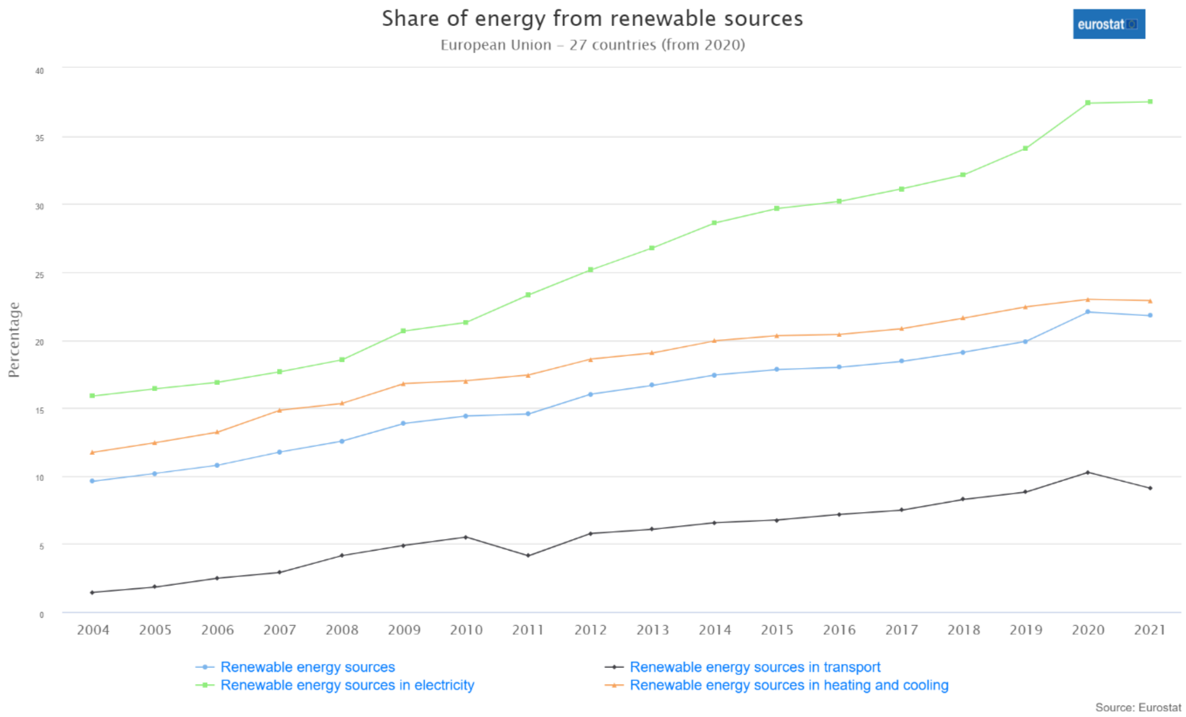

Figure 13 - Share of energy from RES, source: Eurostat.

Electricity prices are of vital importance for the society and the economy; prices for households affect quality of life. At the same time, prices for non-households have a significant impact on production costs and affect energy efficiency. The past few years, price increasement is taking place in great acceleration, with Greece being at first place in Europe for non-household consumption. Italy and Bulgaria are following with total 0.2499 €/kWh. The average of Euro area, including 19 countries, is 0.1809 €/kWh.

In 2011, fossil fuels contributed to EU'S electricity production in percentage of 49% and renewable made up only 18%. Within ten years, solar and wind generation have doubled to replace declining coal use. Despite its share, hydropower is the most commonly used source of European electricity generation (*How Does Europe Get Its Electricity?*, 2023). Germany has a substantial dependence on coal power, accounting for 31% of the nation's electricity from 2017 to 2021. Nonetheless, wind and solar energy sources have a greater contribution to electricity generation in Germany, comprising a combined 33% (23% from wind and 10% from solar). France, being the largest economy in Europe, relies primarily on nuclear power, which accounts for more than 50% of the country's electricity production.

In recent years, there has been a shift towards cleaner energy sources in some European countries, resulting in notable changes in the pattern of electricity generation away from traditional fossil fuels. The utilization of natural gas is one of the primary methods of electricity generation in Europe. The ascent of its usage can be attributed to its more budget-friendly expense and cleaner emissions in comparison to other fossil fuels. A substantial proportion of electricity generation in multiple European nations, including Italy, the United Kingdom, and the Netherlands, is derived from natural

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gas. In 2021, natural gas constituted 42% of Italy's electricity generation. Since 2016, the UK has largely relied upon natural gas as its primary source of electricity, and in 2021, it constituted 38% of the nation's total electricity generation. In 2021, natural gas accounted for 40% of the Netherlands' electricity generation.

Despite the reliance on natural gas, many European countries are actively engaging in diversifying their energy sources and decreasing their carbon footprint. Utilization of renewable energy sources such as solar, wind, and hydropower is becoming increasingly more common in various regions across the continent. The EU has set a goal of attaining 32% of its electricity from RES by the year 2030. In Germany, for instance, there has been a significant investment into RES, which allowed the nation to generate more electricity from RES than from non-renewable sources in 2020 for the first time. Spain has experienced a dramatic rise in its renewable energy capacity, with wind energy contributing more than a fifth to the nation's total electricity generation in 2020.

The cost of electricity in EU is subject to marked variation contingent upon numerous components, containing the origin of electricity, government regulations, and taxes and levies. Whilst nations that vigorously depend on natural gas generally have lower electricity prices, there is a burgeoning accentuation on transitioning to cleaner, RES, which may decrease the cost of electricity (Figure 14).

The latest figures from Eurostat (Figure 15) indicate that the electricity prices for non-household consumers in the EU rose to €0.1072 per kWh during the first half of 2022, compared to the €0.0834 per kWh observed in the same period of 2008. This price does not include applicable taxes and is higher than the amount listed. The mean price of electricity for non-household users in the EU, excluding applicable Value-Added Tax (VAT) and other recoupable taxes and levies, was estimated to be roughly 11.5 Euro per 100 kilowatt-hours during the latter half of 2018, which was a 2.8% increase from the second half of 2017 (*Mapped*).

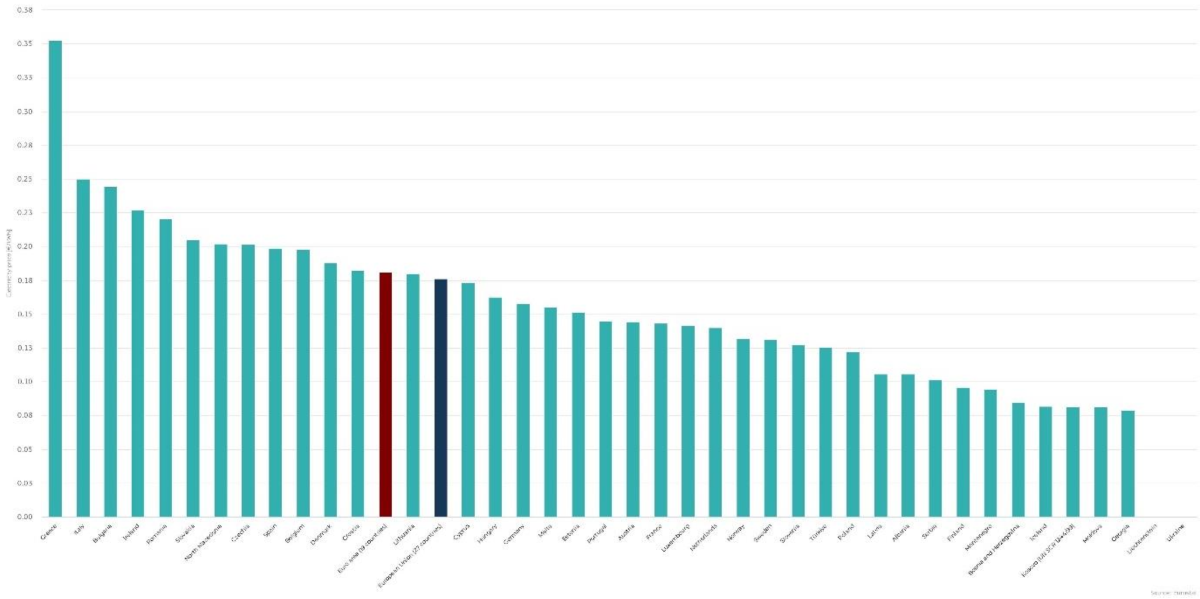

Figure 14 - Electricity prices for non-household consumers in 2022. Source: Eurostat

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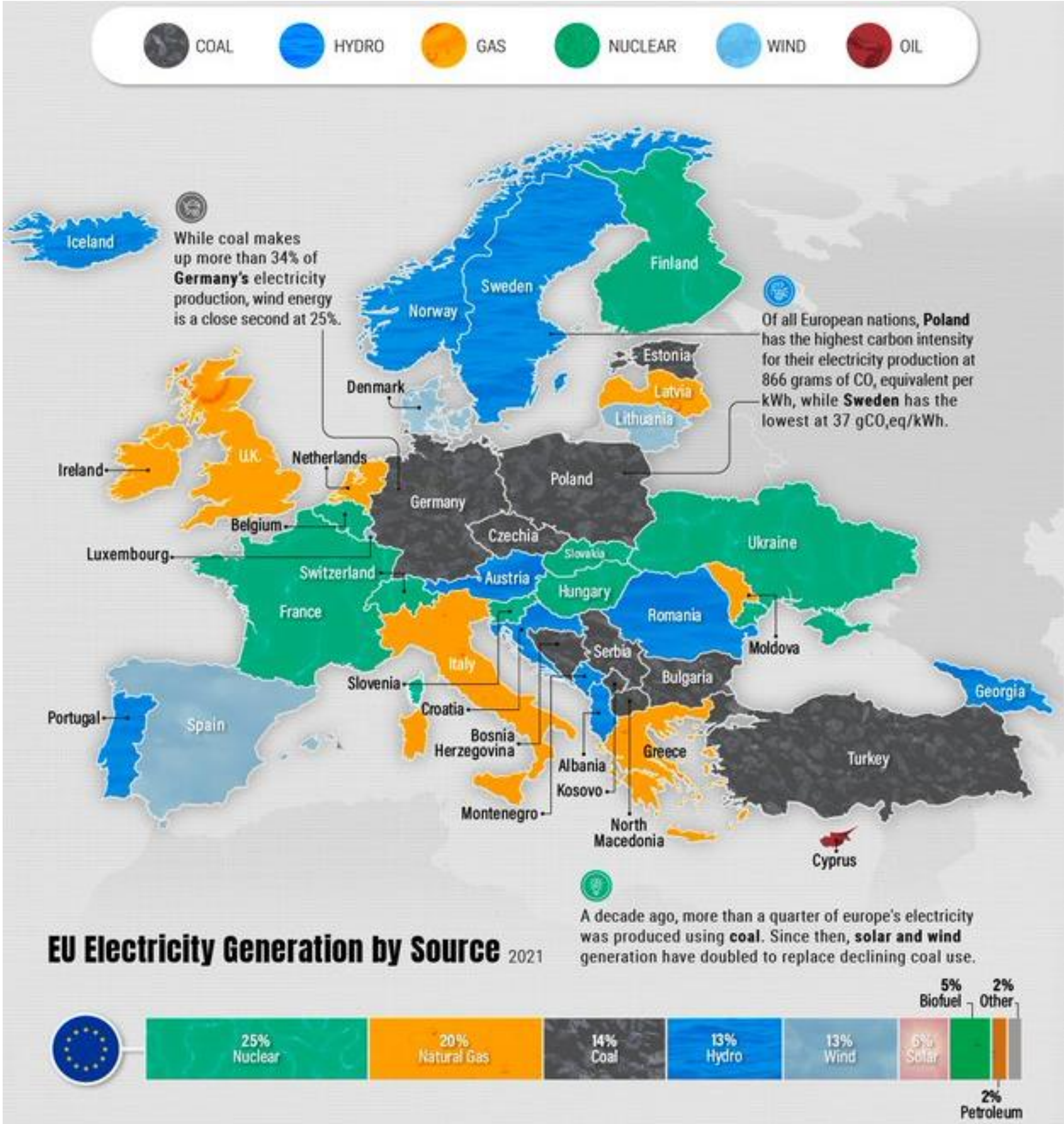

Figure 15 - Electricity prices for non-household consumers in 2022. Source: Eurostat

The Russian incursion into Ukraine has brought to the forefront the insecurities of energy distribution in Europe, with Russia's monopoly over fossil fuel reserves being utilized as a political and economic tool. Consequently, European stakeholders have formulated ambitious strategies to diminish their reliance on foreign sources of Russian oil, gas, and coal. It is evident from the EU's reliance on Russian natural gas that diversifying energy sources is paramount to achieving energy security. The pandemic situation has unveiled the susceptibilities of the European energy sources, thereby necessitating swift action to abate imports from Russia.

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The incursion of Russia into Ukraine in 2022 has had a profound effect on international energy markets, causing fluctuations in price, a contraction of supply, and economic insecurity, thus manifesting the inaugural global energy crisis, as described in the IEA's report. A heightened urgency for attaining energy self-sufficiency within the EU has been necessitated by the current predicament. Given the urgency of the situation, the EU has implemented measures to secure and distribute gas supply due to the pressing need for RES, thereby responding to a potential crisis of shortage of gas supply (Cui et al., 2023).

2.8. EU Levelized Cost of Electricity (LCOE) per Renewable System

A valid observation that can be made from the data presented in Table 1 is that the period spanning from 2010 to 2021 has seen a significant improvement in the competitive position of renewable energy technologies. The table provides information on the total installed costs, capacity factor, and levelized cost of electricity for various renewable energy technologies in 2010 and 2021, as well as the percentage change between the two years. The data is presented in 2021 €/kW for installed costs, in percentage for capacity factor, and in 2021 €/kWh for levelized cost of electricity (LCoE).

	Total installed costs (2021 €/kW)			Capacity factor (%)			Levelised cost of electricity (2021 €/kWh)		
	2010	2021	Percent change	2010	2021	Percent change	2010	2021	Percent change
Offshore wind	4 876	2 858	-41%	38	39	3%	0.188	0.075	-60%
Geothermal	2 714	3 991	47%	87	77	-11%	0.050	0.068	34%
Onshore wind	2 042	1 325	-35%	27	39	44%	0.102	0.033	-68%
Solar PV	4 808	857	-82%	14	17	25%	0.417	0.048	-88%
CSP	9 422	9 091	-4%	30	80	167%	0.358	0.114	-68%
Hydropower	1 315	2 135	62%	44	45	2%	0.039	0.048	24%
Bioenergy	2 714	2 353	-13%	72	68	-6%	0.078	0.067	-14%

Table 1 - Global weighted average total installed cost, capacity factor and levelized cost of electricity trends by technology, 2010&2021. Source: IRENA,2022

In 2021, the installed costs for Bioenergy and Geothermal were 2,353 €/kW and 3,991 €/kW, respectively. Bioenergy experienced a decrease of 13% in installed costs since 2010, while Geothermal experienced an increase of 47%. Hydropower had the smallest installed cost increase of 62%, going from 1,315 €/kW in 2010 to 2,135 €/kW in 2021. Regarding capacity factor, the highest values were for Solar PV and Bioenergy, with 17% and 68%, respectively, in 2021. The lowest value was for CSP, with 80% in 2021, but this represented a significant increase of 167% since 2010.

In terms of levelized cost of electricity, Solar PV had the most significant decrease of 88%, going from 0.417 €/kWh in 2010 to 0.048 €/kWh in 2021. CSP, on the other hand, had the most significant increase of 167%, going from 0.358 €/kWh in 2010 to 0.114 €/kWh in 2021. Onshore wind, offshore wind, and concentrated solar power (CSP) had a decrease in installed costs, but the LCoE also decreased significantly for onshore wind (-68%) and offshore wind (-60%), while CSP had a decrease of 68%.

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From 2010 to 2021, the total installed costs for bioenergy have seen a 13% reduction, along with a 6% decrease in capacity factor and a 14% reduction in the levelized cost of energy. The amendments occurring in the bioenergy sector in Europe point to an increased cost-effectiveness over time, manifested in decreased production costs and higher energy generation efficiency. Despite the cost reductions and improved efficacy of bioenergy, the sector has yet to overcome such challenges as the affordability and accessibility of feedstocks, regulatory impediments, and competition with other forms of RE. For bioenergy to remain a viable factor in Europe's energy portfolio and in support of Europe's renewable energy objectives, the various challenges associated must be adequately addressed to guarantee cost-effectiveness.

2.9. Hybrid Renewable Energy Systems

Hybrid renewable energy systems (HRES) are technologies which combine multiple RES, and/or energy storage systems, to provide a more economical, dependable, low-carbon, and affordable source of electrical energy. HRES may be instrumental in addressing the present-day shift in energy sources by contributing to the lessening of carbon emissions in electrical systems, and potentially providing other advantages. Investigating approaches to enhance the efficacy of the design, management, and regulation of energy markets and policies associated to HRES remains a challenge, and more reliable methods of assessing the financial costs, value, and systemic effects of these systems are required. The implementation of HRESs has numerous advantages, including the augmentation of capacity and fortification of the reliability of uninterrupted electrical service (*Are Hybrid Systems Truly the Future of the Grid?*). The integrated ROBINSON HRES on Eigeroy is presented in Figure 16.

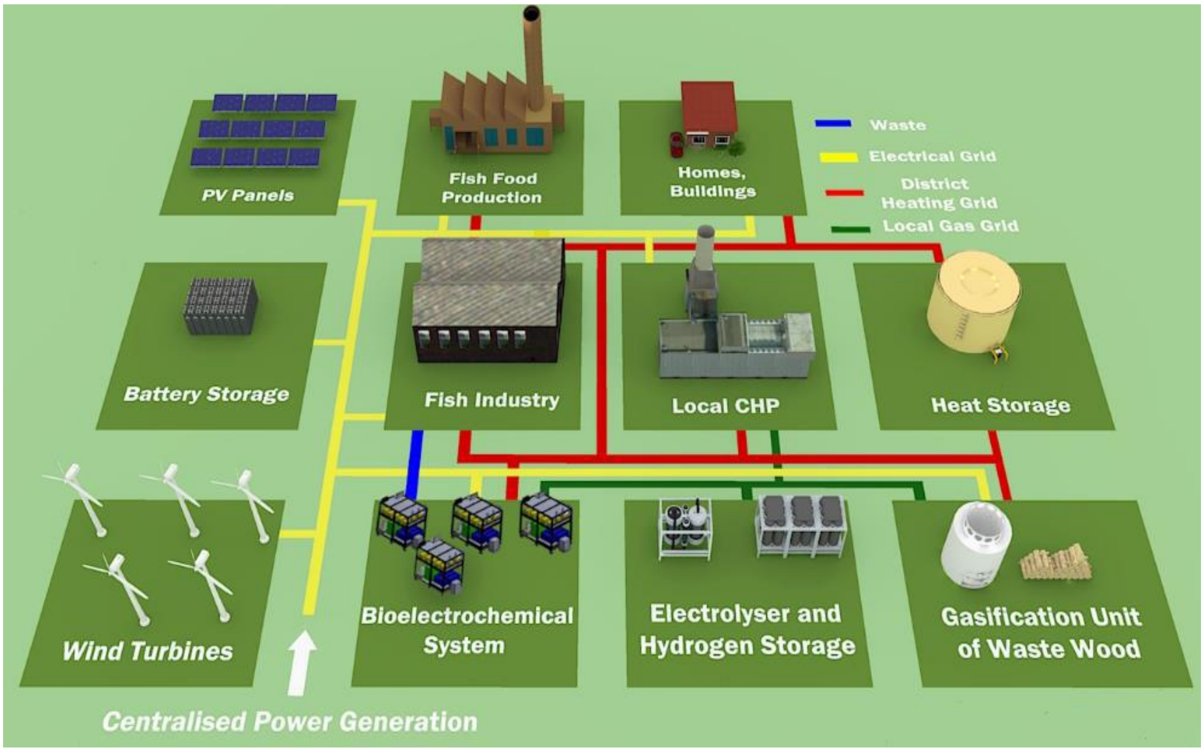

Figure 16 - The integrated ROBINSON system on demo island

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The market condition of hybrid power systems is projected to grow significantly, with a compound annual growth rate of approximately 6.20% from 2021 to 2028. The global market was worth around USD 581.50 million in 2021 and is estimated to grow to about USD 834.25 million by 2028. These systems can contribute to reducing GHG emissions, achieving a net-zero economy, and enhancing capacity while offering several benefits over a stand-alone system (*Hybrid Renewable Energy Systems | Wiley*; Research). Today, investments in system integration are fundamental. It is considered as the preparation of the way for a smooth energy transition until 2050, in both power and highly electrified sectors.

Market design, policies, and resilience investments in the next decade will accelerate and lower the cost of the shift. Solar and wind energy generate most of the green electricity, so power systems must be more flexible. With abundant, cheap renewable power, a master plan for decarbonizing energy demand is to electrify it as much as possible. Smart electrification helps power systems handle the new load cost-effectively and use it as a flexibility source to combine more RE (*World Energy Transitions Outlook 2022: 1.5°C Pathway*, 2022).

2.10. Island Conditions and perspectives

The EU established an ambitious goal to reduce carbon emissions in its energy system, as well as to augment the energy generated from renewable sources. The conversion to RES is particularly paramount for islands, which generally encounter high energy expenses and limited access to non-RES. Consequently, islands have become sites for trialing novel energy sources, like HRES with battery storage. The Greek Island of Tilos has developed an HRES with battery storage, setting a precedent for other remote communities exploring sustainable energy solutions (Goode, 2021). The EU's **Renewable Energy Directive (RED)** provides a regulatory framework for the EU to meet its objective of attaining a 32% share of RES in the energy mix by 2030. In addition, the directive creates an enabling environment for the implementation of RE projects and the streamlining of the associated permissions processes (*Renewable Energy*).

The shift to HRES in islands can yield multiple advantages, including fostering local employment and possibilities for ecologically friendly tourism. Geographical islands pose a significant challenge for testing RE integration strategies and cutting-edge technologies because they alternate between grid-connected and island mode. Energy system flexibility is seen as a viable solution to integrate a higher share of renewables and reduce adverse events on the power grid. Despite this, storage options for supporting HRES share are still not widely implemented in many countries, particularly in Europe.

The transition to RES in the EU since 2005 has resulted in a pronounced diminution of carbon emissions, to the extent that by 2019 it had surpassed the amount emitted by coal. Studies have been conducted to investigate the viability of nuclear-renewable hybrid energy systems, which involve the integration of nuclear reactors, RE generation, and industrial processes; results of such studies indicate that hybrid systems can be evaluated from various angles. The Clean Energy for EU Islands initiative, launched in 2017 by the EU, is focused on the provision of a long-term framework to allow EU islands to generate their own affordable and ecologically sustainable energy (*Clean Energy for EU Islands*-a).

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European island regions typically incur significant energy costs, and they are particularly susceptible to the effects of climate change. The energy intensity in the national economy is presented in Figure 17. The utilization of a creative collaborative approach is expediting the process towards full energy autonomy via the integration of disparate energy sources, including solar, wind, hydroelectric, and energy storage technology. Islands are becoming testing grounds for pioneering alternative energy sources, with some already ahead of the curve in transitioning towards clean energy (*Europe's Islands Are Leading the Charge in the Clean Energy Transition | Research and Innovation*).

The EU has approved a 1.4-billion-euro aid program to encourage the production of RE in the 29 isolated, self-contained electrical grids in Greece that encompass 47 islands. This financing will allow these isles to put money into hybridized RE systems and shift to a more sustainable and cost-effective energy pattern (*State Aid: Commission Funding for Renewable Electricity | Clean Energy for EU Islands*-a). In addition, other isles in the EU, as mentioned before, (such as Tilos and Ikaria in Greece) are adopting HRES; these systems fuse various technologies and power sources to maximize efficiency and ensure sustainability. By embracing these processes, EU Islands are not only diminishing their carbon footprint but are also giving rise to localized positions and encouraging renewable tourism.

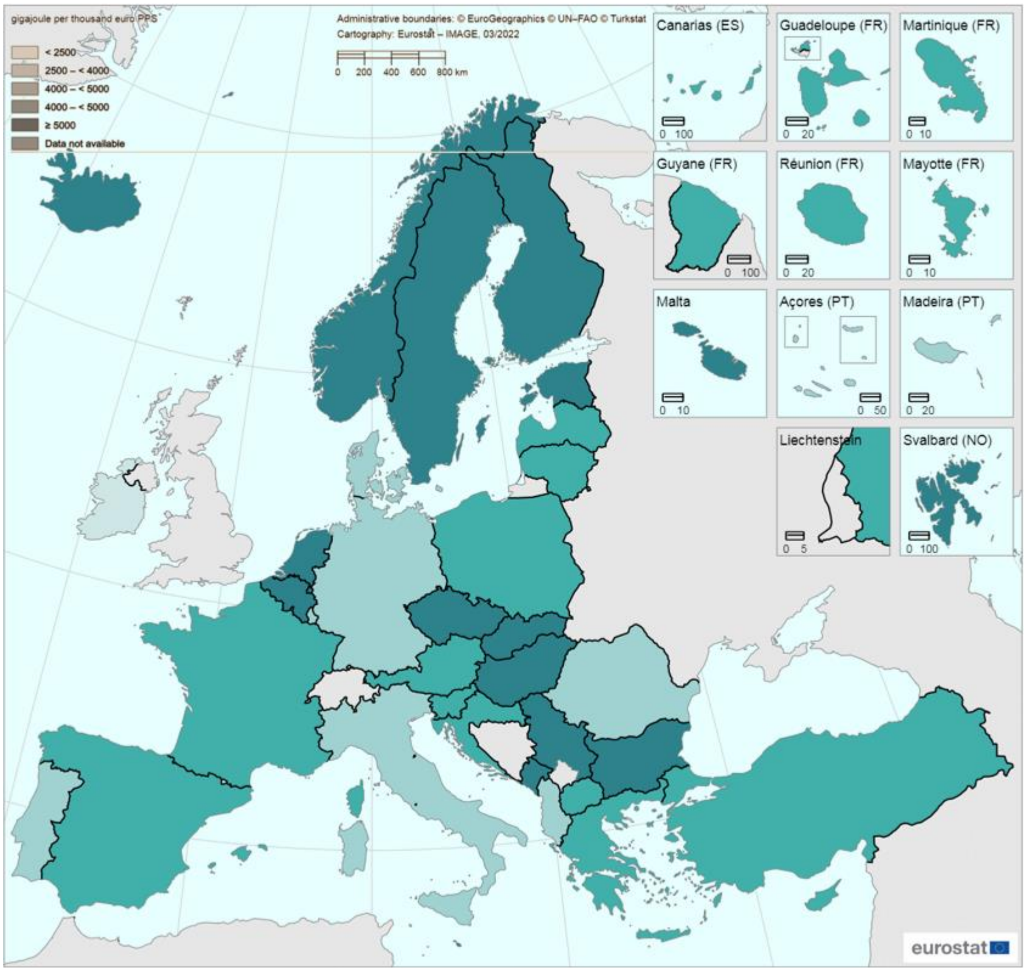

Figure 17 – Energy Intensity of the EU economy in 2020 (Source: Eurostat)

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2.11. European energy generation and distribution

The energy generation and distribution in Europe is complex and diverse due to the varying energy resources and infrastructure available in each country. The EU aims to ensure secure, sustainable, and affordable energy for all member states and their citizens through its energy policy.

2.11.1. European energy generation and distribution schemes

In terms of energy production, the EU has set a target of at least 32 percent renewable energy sources by 2030. In the EU, the use of RES such as wind, solar, and hydropower is on the rise, with countries such as Denmark and Sweden achieving high levels of RE penetration. However, fossil fuels continue to play a substantial role in the energy balance of many EU countries, with natural gas being the most used fossil fuel for electricity generation.

The EU has implemented numerous measures to reduce GHGs and increase energy efficiency. The EU Emissions Trading System (ETS) is a market-based approach that places a cap on the total quantity of greenhouse gases that certain industries can emit and allows them to trade emissions allowances. This has served to incentivize the power and industrial sectors to reduce their emissions. In addition, the EU has policies in place to promote energy efficiency, such as the Energy Performance of Buildings Directive, which requires member states to ensure that all new buildings are virtually zero-energy by the end of 2020 (*EU Emissions Trading System (EU ETS)*).

Regarding energy distribution, the EU has created a transnational internal energy market to facilitate the free movement of energy between member states. The EU has also implemented measures to ensure the security of energy supply, including the Gas Security of Supply Regulation, which mandates that member states develop and maintain emergency plans for potential gas supply disruptions (*Secure Gas Supplies*). Additionally, the EU promotes interconnection between member states to increase the energy system's resilience and facilitate the incorporation of RES.

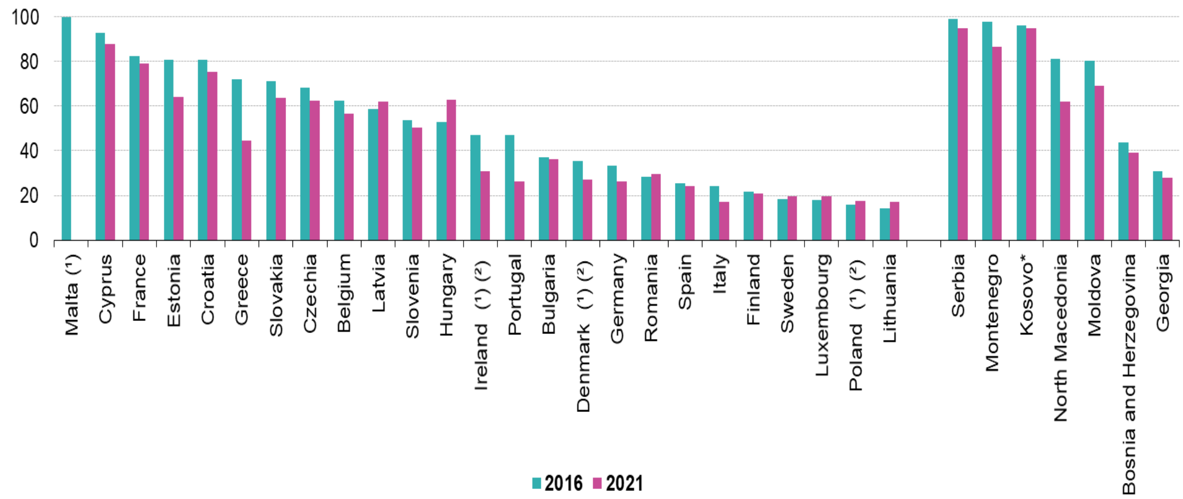

Figure 18 - Market share of the largest company-electricity generation, 2016 and 2021 (%) (File)

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The possession and management of energy infrastructure in EU member states varies. Some nations have completely or partially liberalized their energy markets, whereas others have retained state possession of their energy infrastructure (Figure 18). The EU regulates energy markets through its energy policy and various bodies, including the European Network of Transmission System Operators for Electricity and the Agency for the Cooperation of Energy Regulators.

On the other side of the coin, the generation and distribution of energy in remote areas of Europe, such as small islands, presents distinct challenges and opportunities when compared to the continental mainland and larger islands. In such areas which are typically not unified with the mainland power grid, there is a higher degree of reliance on imported fossil fuels, thus making it more susceptible to disturbances in the energy delivery system (Kuang et al., 2016). Consequently, these remote regions confront exorbitant electricity charges and have restricted admittance to contemporary energy services (Li et al., 2022).

Nevertheless, the copiousness of RES in these regions introduces a chance for them to make a transformation to renewable and sustainable energy. Small islands in Europe are exemplifying the shift to clean energy, with a goal of energy autonomy via renewable resources including solar, wind, and hydropower. The progression of the clean energy transition for over two thousand two hundred inhabited European islands is often advanced by projects and initiatives determined by the EC, for example, the Clean Energy for EU Islands Secretariat which serves as a core platform.

The Clean Energy for EU Islands initiative endeavors to create a lasting structure to aid islands in producing their own eco-friendly and cost-efficient energy. The optimization of the utilization of resources and infrastructures of islands, the execution of energy efficiency initiatives in buildings and industry, the creation of microgrids, and the employment of demand-side management and storage technologies are all measures which need to be taken into consideration. Islands are taking advantage of their topographical characteristics to implement RES and hasten sustainable advancement. Examples of RE technologies can be seen in the implementation of hydropower in mountainous islands and the utilization of offshore wind energy installations (*Clean Energy Vision to Clean Energy Action | Clean Energy for EU Islands*-a).

Plans are being formulated to construct energy islands which will function as centers for offshore wind turbines and may also be utilized for the production of green hydrogen and storing battery power, powered by these offshore winds. The Secretariat for Clean Energy for EU Islands facilitates the advancement of lucrative clean energy ventures on European islands. The efficacy of deploying multiple financial instruments to facilitate private-sector investment in clean energy projects in Small Island has been demonstrated, with the potential to optimize access to modern energy services in these places.

Small islands may face a range of technical barriers to the implementation of RES, which include natural phenomena such as natural disasters or alterations to the environment, technological limitations such as the absence of suitable personnel or appropriate technology, as well as economic, political, and social elements. An investigation conducted by the Clean Energy for EU Islands Secretariat identified any regulatory and policy obstacles to the clean energy transition on the islands,

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with suggestions formed to address these issues. This study was conducted through an interactive process comprising of representatives from a variety of nations within online Focus Groups and physical National Stakeholder Meetings (*WEBINAR: Regulatory Barriers and Opportunities for Clean Energy Transition on the EU Islands – Results of 2 Year Studies | Clean Energy for EU Islands*). Ultimately, the production and distribution of energy in rural locations across Europe face both distinct difficulties and prospects.

✓ **Islands in Europe are demonstrating a pioneering attitude in the transition to clean energy, through the implementation of RES to achieve autonomy in terms of energy supply and quicken the process of sustainable development.**

2.11.2. European energy producers

Energy in Europe can be generated by various entities, including:

- **Power generation companies**: These companies are responsible for generating electricity and selling it to end-users, either directly or through a distribution network.
- **Industrial facilities**: Some large industrial facilities, such as factories or refineries, may have their own power generation capabilities to meet their energy needs.
- **Individuals and households**: With the increasing availability and affordability of RE technologies such as solar panels, individuals and households can now generate their own electricity and even sell excess power back to the grid.
- **Governments and public utilities**: Governments and public utilities may also invest in energy generation infrastructure to meet the energy needs of their citizens and ensure energy security.

Energy production involves various challenges and limitations that must be faced by each of the entities involved. An illustrative example would be the increasing regulatory and public pressures that are being placed upon conventional energy companies to transition over renewable energy. It is necessary for them to allocate considerable resources to infrastructure and technology advancement to modernize their energy production and delivery networks (Horstink et al., 2020). Furthermore, they may experience difficulties pertaining to land utilization and obtaining resources like water and fuel. Upfront investments may be required for the procurement of necessary equipment, in addition to the installation costs, and additionally there may be a need to allocate resources for continual maintenance expenses.

The companies in the RE sector are faced with difficulties due to the unpredictable nature of their energy sources, in addition to the considerable initial investment required in technology and infrastructure. They may experience challenges in obtaining financial resources for their endeavors, in addition to contending with intricate regulatory frameworks (Zhan & Santos-Paulino, 2021). Individuals and households may come across regulatory obstacles when attempting to connect distributed energy resources (DERs) such as rooftop solar panels or small wind turbines to the grid for the purpose of generating their own energy and implementing net metering.

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- ✓ **The production of energy is subject to a multifaceted regulatory, economic and technological framework, meaning each participant in the energy production process must grapple with a distinct set of obstacles and limitations (De Vidovich et al., 2023).**

2.11.3. Energy regulation on innovative generation technologies

Innovative technologies related to energy generation and distribution are typically subject to various regulations, depending on their specific characteristics and potential impacts on the environment and society. RES such as solar, wind, hydro, and geothermal are generally regulated to ensure their safe and sustainable implementation (Rahman et al., 2022).

- ✓ **There are regulations regarding the location and design of RE facilities, their capacity and output, and their impact on local ecosystems and communities.**

Energy storage technologies, such as batteries and pumped hydro storage, are also regulated to ensure their safe and efficient use. For example, there may be regulations regarding the maximum capacity and output of storage facilities, the use of specific materials and chemicals, and the potential risks associated with their operation and maintenance. On the other hand, some innovative technologies related to energy generation and distribution may not be subject to regulation or may have fewer regulatory barriers.

- ✓ **EMS do not have specific regulations in place in all regions. However, there are guidelines and recommendations regarding their safe and effective use, as well as their data management and privacy protection (Inês et al., 2020).**

2.11.4. RES-grid connectivity

Generally speaking, many RES are able to be grid-connected provided they adhere to the technical and safety regulations necessary for grid-connection. Depending on the type of renewable energy source and country, there may be varying specifications and laws applicable. One of the most commonly employed RES for residential and small commercial applications is Solar PV systems that are connected to the grid (Piekut, 2021; Sommerfeldt & Pearce, 2023). Electricity generated from wind turbines, hydroelectric power plants, and biomass systems can be integrated into the power grid. In certain instances, novel technological solutions such as wave and tidal energy systems may be linked to the electricity grid.

In certain jurisdictions, there may be constraints on the magnitude of RES that can be linked to the electrical grid, particularly in the context of small-scale installations. Furthermore, grid interconnection regulations may necessitate the implementation of certain safety and technical components into the RE System, such as grid-linked inverters and safety disconnects.

- ✓ **The integration of variable RES into the grid may pose certain difficulties, particularly in terms of ensuring grid stability and ensuring a balance between supply and demand. Consequently, numerous nations have instituted grid rules and statutes to guarantee that RES are suitably formulated and connected to the grid.**

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2.11.5. Energy prices

The cost of energy in Europe is determined by a mix of free market mechanisms and government mandated tariffs. In certain nations, household customers have the option of either subscribing to a tariff regulated by the government or acquiring electricity from the unrestricted market. The operation of a free-market economy permits energy prices to be determined through the interplay of supply and demand (Mulder & Willems, 2019).

The fluctuations in energy prices can be attributed to a variety of factors, including meteorological conditions, production amounts, and international events that can alter the balance between supply and demand. The mechanism of the free market permits consumers to select their energy supplier and contractual arrangement (Wang et al., 2021).

Regulated tariffs, conversely, are established by regulatory authorities and customarily take into account the expenses pertaining to the production, distribution, and other affiliated expenditures as well as the cost of incentivizing renewable energy production (von Graevenitz & Rottner, 2022). The imposition of these tariffs is frequently intended to guarantee that energy costs remain accessible to consumers, particularly those with low incomes. The European Union has implemented policies that strive to increase renewable energy production, most notably the Renewable Energy Directive, which stipulates a requisite percentage of renewable energy to be included in the energy mix (Kettner & Kletzan-Slamanig, 2020). The variable cost of renewable energy technologies can affect energy prices, with potential consequences for the total outlay associated with energy production.

Furthermore, the imposition of the European Union's Emissions Trading System (ETS) has had the effect of raising the cost of carbon emissions allowances, which has in turn had an impact on energy prices.

- ✓ **The Environmental Trading Scheme (EnTS) is an economic approach to curbing greenhouse gas emissions from industrial sectors by implementing a restricted limit on emissions as well as allowing corporations to partake in the trading of emissions-allowances (Raufer et al., 2022).**

2.11.6. Electricity grid ownership and regulation

Energy network ownership varies based on the nation in question and its legal system. Energy networks are held and run by public organizations, like state-owned businesses, in some nations, while private businesses are in charge of them in others. For instance, in the UK, commercial businesses known as Distribution Network Operators (DNOs) and the National Grid, which owns and manages the high-voltage transmission network, are responsible for the ownership and operation of the energy networks. The national grid operator RTE in France owns and runs the transmission network, while local distribution firms own and run the distribution networks.

Countries also have different regulatory bodies in charge of regulating the energy industry. In the EU, national governments, national regulatory agencies, and the EC all have a part to play in policing and controlling the energy market. The regulatory framework is intended to guarantee honest competition, supplier security, and consumer safety. For instance, the Office of Gas and Electricity Markets

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(Ofgem), which is in charge of fostering competition and making sure that energy markets serve customers, is the country's energy regulator. The Commission de Régulation de l'Énergie (CRE), France's energy regulator, is in charge of managing the country's power and gas markets. Similar to this, every nation in the EU has a national regulatory body that manages the energy market within its boundaries. In conclusion, different countries in Europe have different regulatory systems and ownership of the electricity networks.

- ✓ **The EC, national governments, and national regulatory authorities play a part in regulating and overseeing the energy market throughout Europe, even though private companies may own and run energy networks in some nations.**

2.11.7. Small islands regulatory conditions

Certain EU-member small islands' energy networks and insularity require a specialized regulatory and policy framework. The regulations governing small islands are usually determined by the particular nation to which said island is affiliated. Nevertheless, the EU has suggested protocols and rendered assistance via numerous plans with the intent of facilitating the passage to clean and sustainable energy infrastructures for smaller islands (Busch et al., 2021).

One of the initiatives that arose from the Clean Energy for All Europeans package is the Clean Energy for EU Islands Secretariat, which was founded in 2017. This endeavour acts as the foremost impetus for the transition to clean energy on more than 2,200 populated islands situated within Europe. The Clean Energy for EU Islands initiative endeavors to establish a long-term architecture to enable islands to generate their own cost-effective and sustainable energy, thus enabling them to make the transition from being dependent on expensive fossil fuel imports to clean, renewable, and sustainable energy sources (*Clean Energy for All Europeans Package*-b).

- ✓ **The Clean Energy for EU Islands Secretariat has identified technical, regulatory, and financial impediments which are impeding the clean energy transition on islands.**

Technical impediments may comprise of physical elements such as natural catastrophes or their effect on the environment, technical impediments such as the absence of adequately trained personnel or appropriate technology, as well as economic, political, and social reasons. Regulatory impediments may take the form of antiquated regulations, statutory edifices, and inadequate collaborative efforts among relevant parties. Obstacles of a financial nature may include the substantial expenditure required for infrastructure and technology (*Clean Energy Vision to Clean Energy Action | Clean Energy for EU Islands*-b).

To surmount these obstructions, the Clean Energy for EU Islands Secretariat proposed proposals that incorporate maximizing the use of islands' natural resources and infrastructures, executing energy efficiency initiatives in buildings and industry, creating microgrids, and applying demand-side management and storage technologies.

The Comprehensive Economic and Trade Agreement (CETA) between the EU and Canada is a bilateral free trade agreement. Although the agreement does not expressly address the ownership of energy

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systems, it does include provisions regarding energy commerce and venture that may have an impact on the ownership and regulation of energy infrastructure. CETA includes provisions relevant to the maintenance of sustainable development, which may result in changes to the energy sector on minor islands. This agreement is exemplified by the commitment to support the transition to a low-carbon economy and to increase sustainable energy production and use.

- ✓ **The implementation of these regulations could encourage the development of renewable energy projects on small islands and promote the use of sustainable solutions.**

2.11.8. Identification of the islands' RES potential

EU's small islands hold significant potential for harnessing natural resources such as wind, solar, hydro, and biomass energy. Many European countries are investing in sustainable energy sources to offset their reliance on imported oil and transition towards a more sustainable future (*Europe*). Sustainable islands within the EU tend to have good and accessible renewable resources, making them an ideal platform for testing new technologies or implementing existing technologies to drive sustainable development.

- ✓ **Small islands are privileged with ample RES which are readily attainable, thus making them the ideal sites for both the exploration of new technologies and the implementation of existing ones.**

The efficacy of RE on EU small islands is contingent on a range of variables, including the technology type, the local environment, and relevant legislation. To guarantee the successful deployment of RE systems, it is essential to take into account these factors in conjunction with the expenses of establishment and upkeep.

When devising an energy system based on RES in EU small islands, it is imperative to consider elements such as the presence of resources, economic and monetary aspects, the configuration, magnitude and placement of the system, as well as installation and upkeep considerations (*Planning for Home Renewable Energy Systems*). The efficacy of RES on small islands is contingent upon the technology employed as well as the local geographical context. An example of this is that solar and wind energy are impacted by the local weather conditions and geographic characteristics.

- ✓ **The installation of small-scale RE systems can be economically viable in locations where the implementation of traditional power lines is either expensive or infeasible.**

The expenses associated with the setup and upkeep of RE systems fluctuate depending on the technology, locale, and magnitude. It is essential to consider any potential obstacles, including legal requirements and guidelines that could influence the feasibility and cost of RE initiatives on small islands (*Sustainable Island and Renewable Energies*).

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3. Questionnaire Analysis

A commonly used method for collecting information is through questionnaires. In this case, the questionnaires were specifically designed to record the attitudes, perceptions, and considerations of the HRES market. They were aimed at investigating opinions on market growth, the adequacy of the existing workforce, the quality of current installations, as well as measuring the satisfaction level of HRES investors concerning the quality of the installation process.

The questionnaire was divided into two parts:

1. RES in the country of the respondents.
2. Installation quality and performance.

The first part focuses on the presentation of RES categories in the country of the respondents, their opinion about RES market growth in the past and the next five years, and the second part refers to the installation of the systems, the operational problems that may occur, and the importance of efficiency parameters of the systems. Based on the survey feedback, it can be observed that the market growth of RES in European countries has not reached its maximum potential in the last five years. In fact, 45% of the respondents indicated that the growth has been moderate. Nonetheless, the feedback suggests that there is a positive outlook for the utilization of RES over the next five years.

3.1.1. HRES end-users

According to the survey, the industry sector ranks first in terms of end-users of RES and at the same time households, which represent 35% of the total percentage. This indicates that RES can be exploited across multiple energy sectors simultaneously. The agriculture sector, ground transport, and tertiary sector follow suit in terms of utilization of RES.

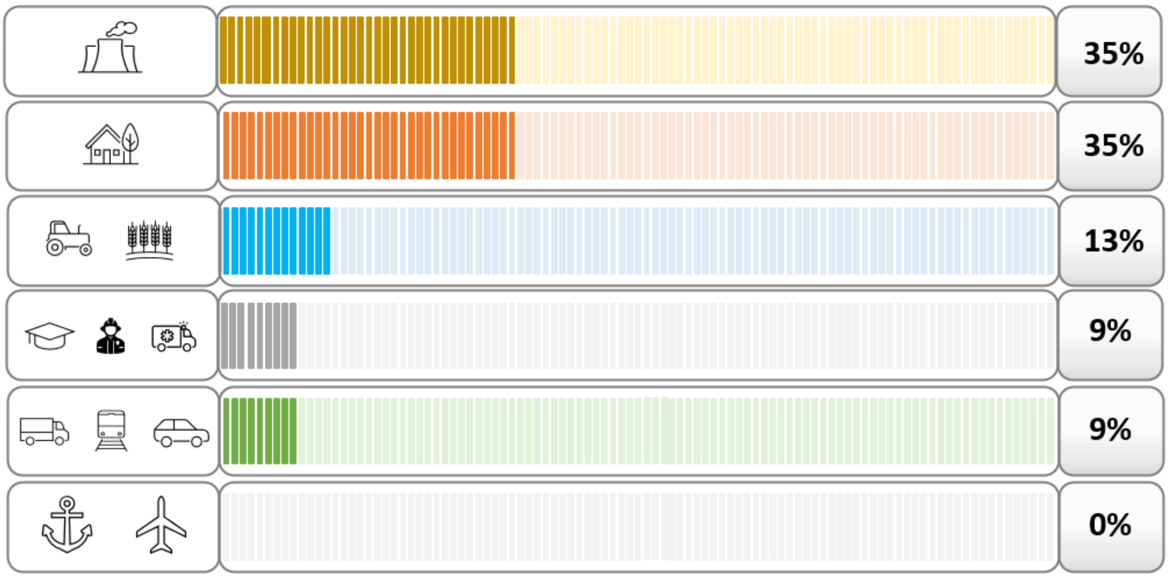

Figure 19 - Categories of end-users by RES

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3.1.2. Distribution of different energy sources for power generation

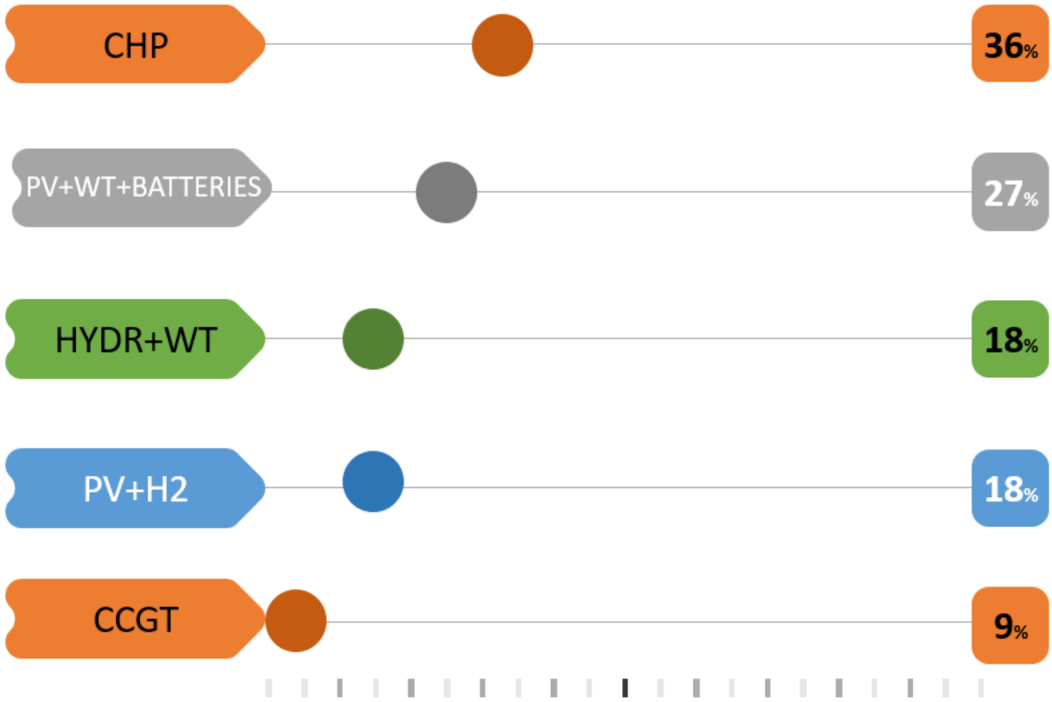

Figure 20 – Different HRES schemes

CHP accounts for the highest percentage at 36%, followed by PV+WT+BATTERIES (Photovoltaic + Wind Turbine + Batteries) at 27%. PV+H2 (Photovoltaic + Hydrogen) and HYDR+WT (Hydrogen + Wind Turbine) account for 18% each, while CCGT (Combined Cycle Gas Turbine) accounts for the lowest percentage at 9%. Overall, it appears that the power generation is diversified across multiple sources, with a relatively high percentage from CHP, followed by a mix of RES such as photovoltaic, wind turbine, and hydrogen. The use of gas turbines appears to be the least utilized source for power generation.

Thermal storage technologies, batteries, and hydrogen storage are among the most widely used options for energy storage in the European Union. This demonstrates a diverse mix of energy storage technologies being deployed across various sectors. According to the analysis of the questionnaire, thermal storage technologies are the most used option, accounting for 31% of the total usage. Electrochemical (batteries) and hydrogen storage come in at a close second, being the preferred energy storage option for 23% of respondents (Figure 21).

The findings of the questionnaire analysis suggest that there is still room for improvement in the development and implementation of energy storage technologies. As the RE sector expands, there will be an increasing need for creative and affordable energy storage solutions to ensure the stability and dependability of the electricity grid.

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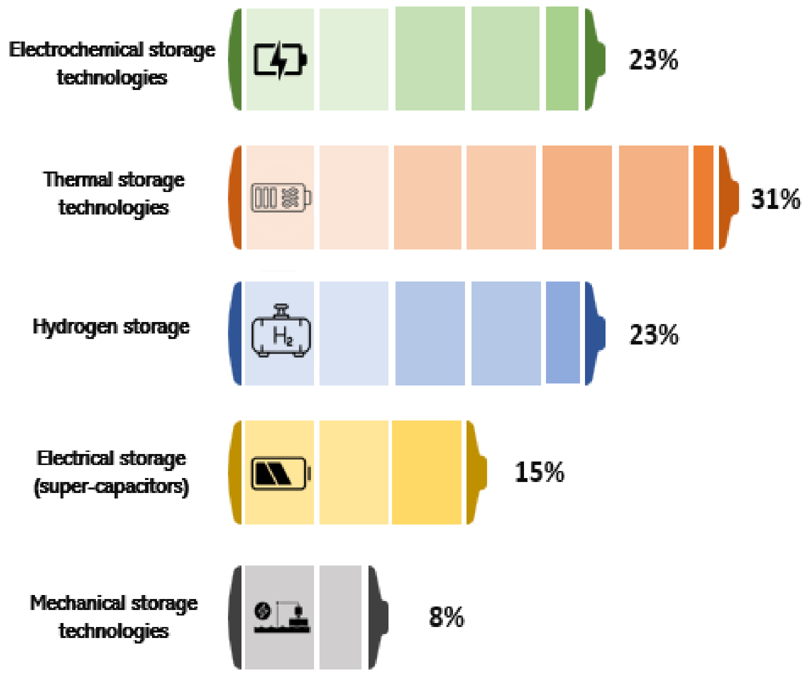

Figure 21 – Energy storage technologies preferences

The use of thermal storage technologies is likely due to their ability to store large amounts of energy at a relatively low cost. They are often used in conjunction with solar thermal energy systems to store heat during the day and release it at night or during periods of peak demand. Batteries are a popular choice for energy storage due to their ability to provide power quickly and reliably, making them a suitable option for smoothing out fluctuations in electricity demand. Hydrogen storage is also gaining traction as an energy storage option, with many researchers exploring its potential as a clean and renewable fuel source.

3.1.3. Criteria that play a significant role in the selection of HRES

Recently, an increasing number of energy consumers have expressed concerns about rising power prices, leading to a growing need for energy independence. To this extent, consumers are seeking ways to explore and secure their own sources of energy. Concerning the selection criteria, compared to the independent regional alternatives, the most important decision driver is the reduction of energy costs, especially in countries like Greece, due to the increasingly raise of electricity prices in the last two years.

3.1.4. Barriers hindering the deployment of HRES

The deployment of HRES on EU islands faces a range of barriers, including challenges related to high energy costs, limited access to financing, technical constraints, inadequate political support, and low levels of public awareness. These barriers have significant impacts on economic, social, and environmental aspects, such as higher energy costs, limited investment opportunities, grid instability, political underrepresentation, and limited public support.

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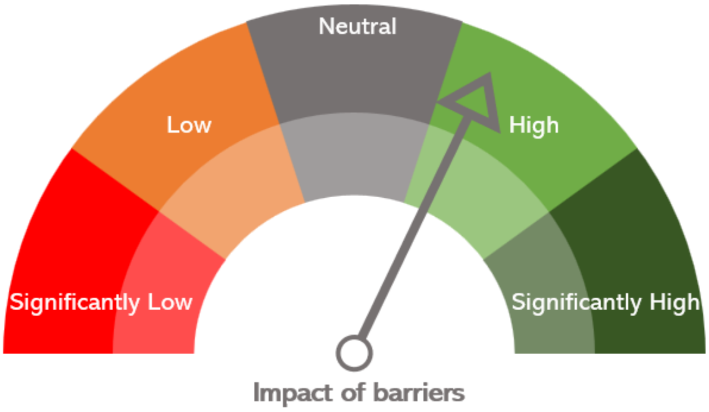

Figure 22 – Impact of barriers hindering the deployment of HRES

Therefore, addressing these barriers through tailored policies and investments can facilitate the integration of renewable energy systems in these regions, decrease dependence on imported fossil fuels, and expedite the transition to a low-carbon economy. According to the findings of the questionnaire analysis, the impact of the current barriers is relatively high (3.8 out of 5) (Figure 22).

3.1.5. Number of RES according to current market conditions

The ratings are on a scale of 1 to 5, with 1 indicating a low satisfaction and 5 indicating a high satisfaction. The average rating for all respondents is shown as 2.7 out of 5 (Figure 23).

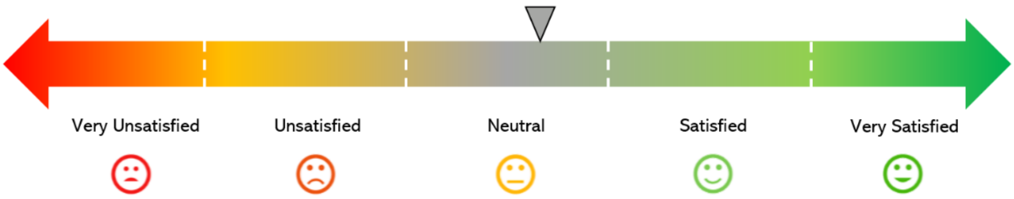

Figure 23 – Satisfaction of RES number regarding the current market conditions

Based on the available data, it can be inferred that the survey received mixed opinions as half of the respondents rated it at 4 or higher, while the remaining half gave a rating of 2 or lower. The average rating of 2.7 indicates a somewhat negative or cautious overall opinion.

3.1.6. Usage of RES in the next 5 years

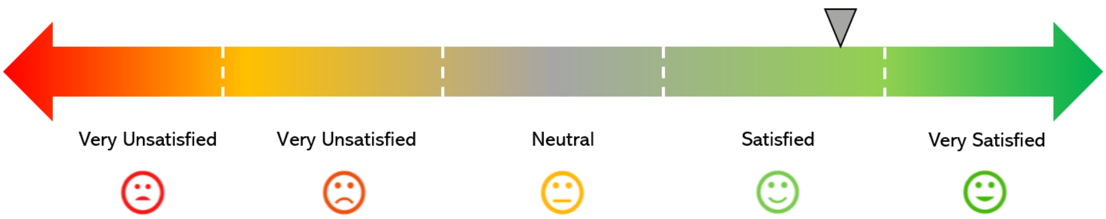

Figure 24 – Satisfaction of HRES usage in the next 5 years

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This scheme appears to show the perspectives regarding the usage of RES for the next 5 years. Ratings are ranging from 3 to 5, indicating the level of agreement or approval with the usage of RES. The average rating given by the responders is 3.8 out of 5 (Figure 24), which highlights that RES have great future potentials and prospects, as they offer a sustainable and environmentally friendly alternative to traditional energy sources.

3.1.7. Current quality of HRES

The ongoing progress in technology and research is consistently enhancing the caliber of HRES in contemporary times, thereby expanding the limits of feasibility. HRES integrate multiple renewable energy sources to generate electricity, frequently integrating energy storage technologies to guarantee a dependable power supply. Likert scale represents a rating scale that is likely used to evaluate the quality of HRES today. The scale ranges from 1 to 5, where 1 represents the lowest quality and 5 represents the highest quality. The absence of any ratings below 2 suggests that the quality of HRES systems is not perceived to be very poor. The most frequent ratings appeared to be 3 or 4, with an average of 3.4/5, that depicts satisfaction (Figure 25).

Overall, the questionnaire findings suggest a positive trend towards the development of sustainable and efficient energy systems through the use of HRES.

Figure 25 – Satisfaction of the current HRES quality

3.1.8. Frequency of HRES problems

HRES that integrate solar, wind, and diesel generators, along with battery storage, have become increasingly popular due to their ability to manage the intermittent generation of RE. However, the intermittency in wind speed and solar radiation can cause fluctuations in power angle control and charge/discharge, leading to frequency deviation in low and high-power systems. The total penetration level of RES can be equally supplied by PV and wind, while conventional generators, such as hydro and thermal, can be used to represent the conventional generators in the system.

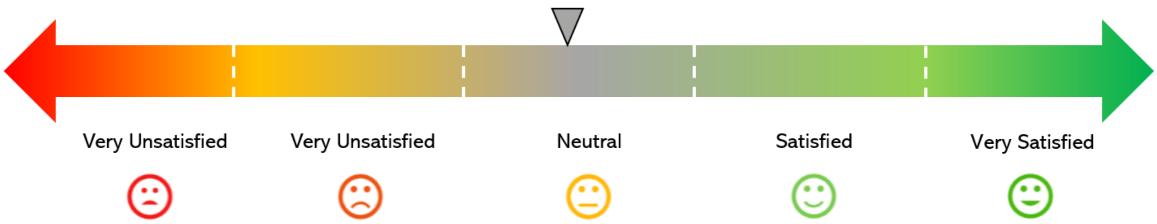

Figure 26 - Frequency of operational problems in HRES

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The scheme represents the frequency of operational problems in HRES. The average frequency of operational problems is **2.4** out of 5.0, indicating that HRES are experiencing operational problems to some extent.

3.1.9. HRES selection criteria

The enhancement of energy supply is incorporated within the most critical selection criteria of HRES, as well as the energy independence. The respondents took into consideration the enhancement of the environmental footprint, giving it high priority. Since not all the RES technologies are mature enough across all European countries or have the existing infrastructure to be applied and exploited in the best way, the efficiency and stability are still low compared to fossil fuels. HRES promotion can be transitioned by several actions as presented in Figure 27.

The absence of policies pertaining to HRES in industrial markets is impeding the complete exploitation of RE. The implementation of a policy-making strategy mandating industries to meet a minimum threshold of their energy consumption through the utilization of renewable sources, specifically solar or wind power, is imperative for the attainment of a sustainable energy future. The plan to promote the adoption RES should incorporate incentives for companies that exceed the minimum threshold, as well as public awareness campaigns aimed at promoting the advantages of renewable energy. To facilitate a smooth transition towards renewable energy, it is imperative that the policy-making framework incorporates measures to tackle potential obstacles such as time-consuming licensing protocols, etc. The incorporation of sustainable energy sources has the capacity to address climate change, generate employment prospects, and foster economic advancement, rendering it an indispensable measure towards a more sustainable and just future.

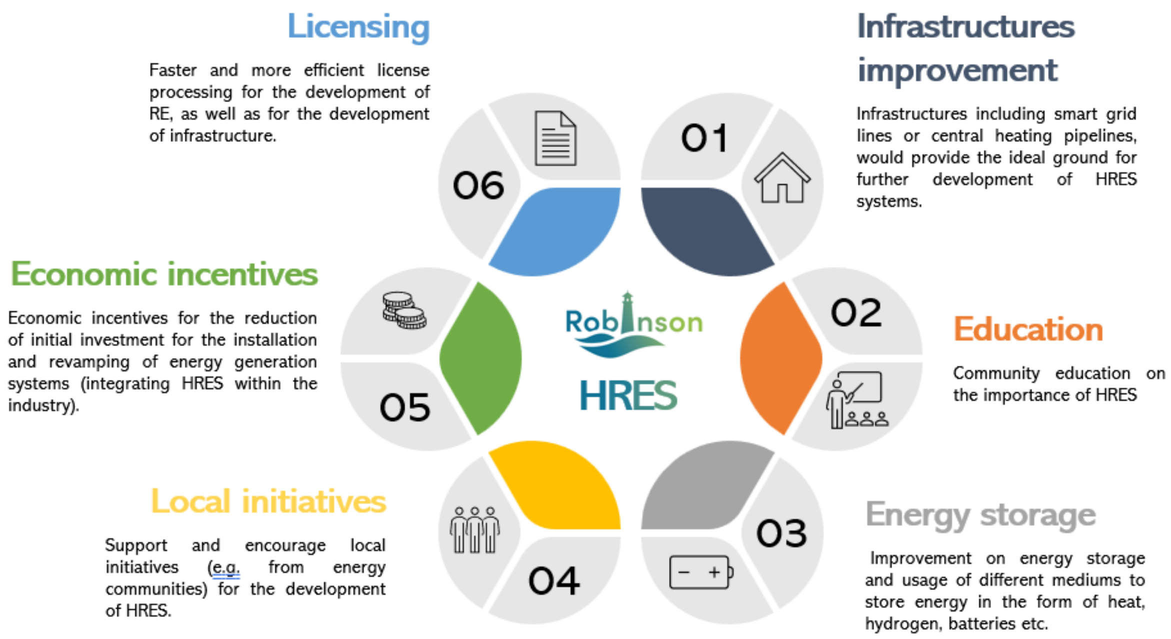

Figure 27 – HRES promotion steps

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Many countries have a great potential of RE. Unfortunately, in 2023, there is a lack of HRES policy in industry markets. Meanwhile, it is necessary to setup a policy making plan, which will oblige industries to cover a minimum percentage of their energy consumption by HRES (for example 30% of their energy consumption to be covered by renewable sources).

3.1.10. Concerns-Requirements associated with investing in an HRES

Figure 28 – Crucial concerns in ROBINSON's HRES investment

In Figure 28, six concerns-requirements are classified, according to responders. The first and most crucial concern is stability. This includes factors such as the durability of the system components, the expected lifespan of the system, and the ability of the system to withstand harsh environmental conditions. By assessing the stability of an HRES system, investors can make more informed decisions and mitigate potential risks. Efficiency follows, as another key concern. HRES systems that are highly efficient are more likely to deliver reliable and consistent energy output over the long term, which can result in higher returns on investment.

Investors also evaluate HRES system **applicability** on third place. This involves natural resource availability, regulatory environment, and system economics. Before investing, it's crucial to assess local market conditions and determine if an HRES system is suitable. **Safety**, fourth in HRES spending, is crucial. Investors must verify that the HRES system fits safety requirements. This involves system design, component quality, and installer/maintainer training. Safety can reduce mishaps and liability for investors. **Economic feasibility** is another HRES business issue. Investors must consider HRES system design, installation, and maintenance fees and return on investment. This covers energy prices, natural resource prices, and government subsidies. Investors can evaluate HRES investments based on fiscal feasibility. Investors also worry about **HRES stability**. HRES system reliability depends on component quality, design, and upkeep. Investors can maximize returns on HRES investments by emphasizing reliability.

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3.1.11. Expertise of technicians

Figure 29 represents the rating of the level of training of technicians in various categories. The categories include Design/Sizing, Electrical Design, Mechanical Design, Safety Rules, Integration in Buildings, and System's Maintenance. The ratings for each category are represented as a fraction, with the numerator being the score and the denominator being the maximum possible score. Based on the data of the survey, the technicians scored highest in the category of Mechanical Design, with a rating of 4.0 out of 5.0. Electrical Design and Design/Sizing categories follow closely behind, with scores of 3.8 and 3.9 out of 5.0, respectively. The lowest scores were in the Integration in Buildings and Safety Rules categories, with ratings of 3.3 and 3.7 out of 5.0, respectively. The System's Maintenance category had a score of 3.5 out of 5.0. Overall, the data suggests that the technicians have a relatively high level of training in most categories, with Mechanical Design being the strongest area of expertise. The lowest scores in Integration in Buildings and Safety Rules categories suggest that there may be room for improvement in those areas.

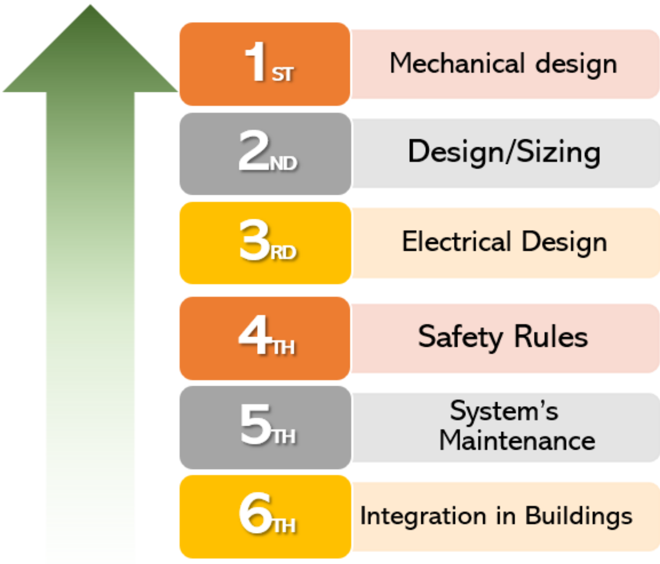

Figure 29 – Ranking of technician's expertise and level of training

3.1.12. Determining factors of HRES market development

The market development of HRES can be influenced by various factors that need to be considered. Factors to be taken into account when developing a new market strategy for HRES include an accurate picture of budget and resources, target audience, their needs and potential benefits, and the growth potential of the market. In addition, environmental factors such as air and water quality could also affect the valuation of HRES properties in the market. Other general factors that affect market development in different sectors include the characteristics of entrepreneurs, access to resources such as finance and manpower, demographics, and political risks. Moreover, the development of stock markets in emerging economies is influenced by various factors such as foreign direct investment, economic growth, infrastructural development, banking sector development, and stock market liquidity. Therefore, a comprehensive analysis of these factors is essential for the successful market development of HRES (Figure 30).

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One of the primary concerns in the energy sector in recent years, has been the fluctuating prices of energy products, which make it difficult to predict future prices with certainty. Additionally, investors are keen to ensure a satisfactory return on their investments. Moreover, the tax policies applicable to energy markets have been subject to significant changes over the years, leading to HRES projects across many European countries being considered a high-risk investment. It is therefore necessary to establish a fixed taxation policy for energy products in many countries to alleviate these risks.

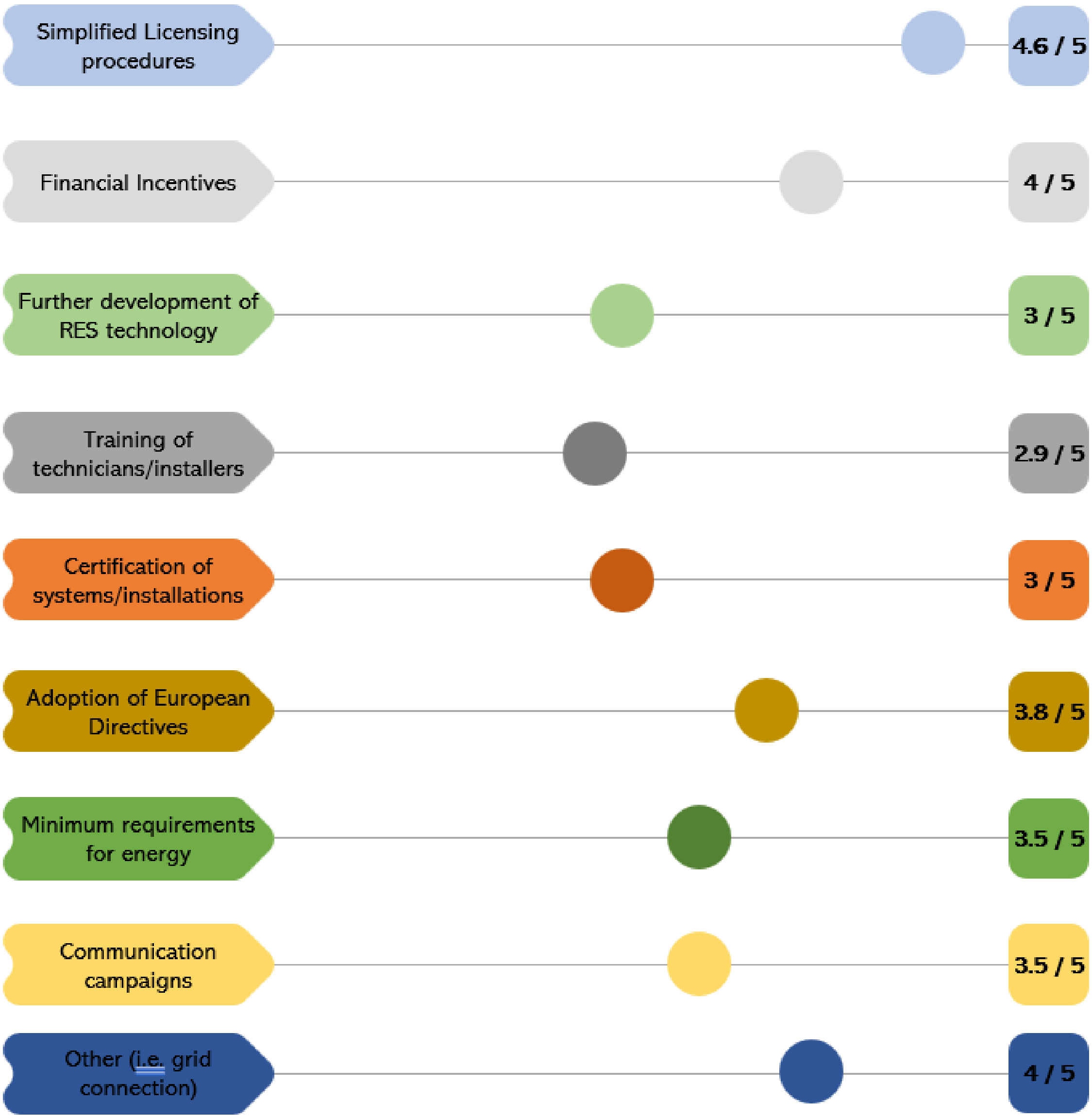

Figure 30 – Determining factors of the HRES market development

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3.1.13. Importance of parameters of system's installation

Figure 31 – Ranking of the parameters regarding HRES installation

Investing in a system requires careful consideration of several key factors to ensure optimal performance, efficiency, and reliability. First, a proper system design is crucial, taking into account the intended use, available resources, and expected lifespan of the system. Additionally, the location of the installation must be carefully chosen based on factors such as natural resources, climate, and proximity to end-users. By selecting a suitable installation location, investors can ensure that the system operates optimally and delivers the expected energy output.

Besides, selecting appropriate equipment and ensuring the technical staff is properly trained in installation, operation, and maintenance are essential for system success. The equipment selection process must consider the system's intended use, expected lifespan, and availability of replacement parts. Technical staff training should include safety procedures, troubleshooting techniques, and preventive maintenance practices. Finally, certification to international quality standards is critical to minimize risks and ensure long-term performance. Certified systems meet relevant safety and quality standards, ensuring proper design, installation, and maintenance according to applicable codes and standards. By considering these factors, investors can make informed decisions and achieve higher returns on investment.

3.1.14. Potential investors in HRES

Investing in RES can be influenced by several factors, as indicated by the results of a questionnaire (Figure 32). One of the most important characteristics that can influence potential investors is the reduction of GHGs. HRES can help to mitigate climate change by reducing carbon dioxide and other GHG emissions by RES like solar, wind, and hydropower. Investors who prioritize environmental sustainability are more likely to consider investing in HRES. Additionally, HRES can offer money-saving benefits, as investors can save on energy bills and potentially generate revenue by selling excess energy back to the grid.

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Reliability is another critical factor that can influence potential investors in HRES. HRES systems can be designed to provide reliable energy generation even in remote or off-grid locations, using backup energy storage systems, redundancy in equipment, and other measures. HRES systems often incorporate new and innovative technologies, such as energy storage, smart grid integration, and advanced control systems, which can be an attractive characteristic for investors interested in new technology. Finally, potential investors may be attracted to HRES due to the potential for economic profits. HRES can generate revenue by selling excess energy back to the grid and can help to reduce energy costs, resulting in significant long-term savings.

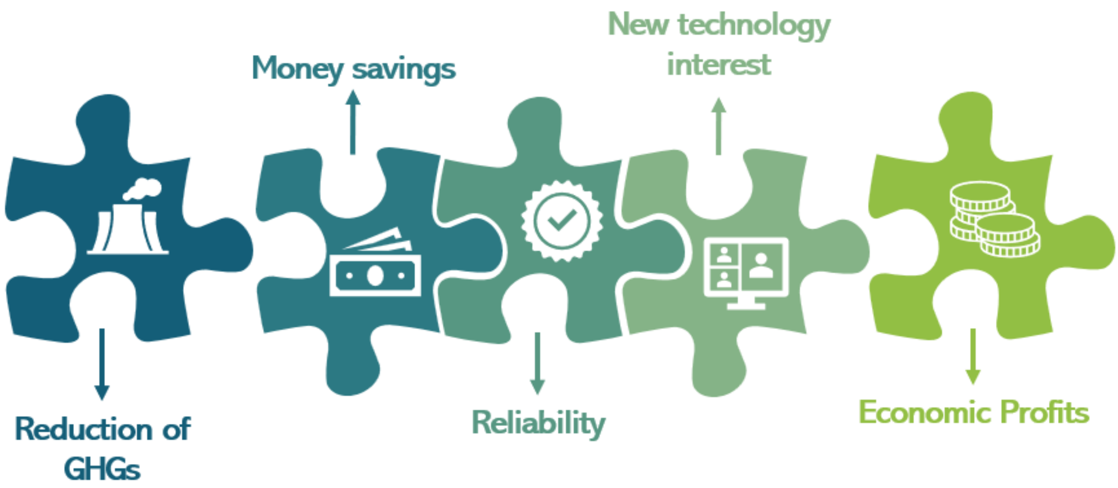

Figure 32 – HRES influencing characteristics for potential investors

3.1.15. Installation quality standards

Figure 33 – Ranking of quality standards

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Figure 33 presents the stance of responders towards specific quality standards of installation. The establishment of specific quality standards is crucial in ensuring the reliability and effectiveness of HRES systems. At the forefront of these standards is the certification of systems according to international quality standards. This involves assessing HRES systems for quality and performance criteria through independent testing and certification bodies. By adhering to these standards, potential investors can be assured of the quality and reliability of HRES systems, increasing their willingness to invest in them.

The certification of training for technicians and installers and the certification of equipment used in HRES systems are also essential quality standards. Certified training ensures that technicians and installers are properly trained and certified, reducing the risk of system failure or damage. Similarly, equipment certification ensures that the equipment used in HRES systems meets quality and performance standards, reducing the risk of equipment failure or damage. By establishing and adhering to these quality standards, the overall quality and reliability of HRES systems can be improved.

3.1.16. Questionnaire's key takeaways

According to questionnaire responses, there is a sizable possibility for the development of RES in European nations over the course of the next five years. Although RES growth has been sluggish over the previous five years, the prognosis is promising. The survey's findings indicate that households and the business sector are the main RES end consumers. The most well-liked technologies among respondents for area energy storage are electrochemical and thermal storage technologies. It's interesting to observe that consumers now have a greater desire for energy independence due to rising power prices.

Additionally, the survey's findings offer some critical suggestions for enhancing the marketing of HRES. Some suggestions for promoting the use of HRES include assisting and encouraging neighborhood efforts, facilitating quicker and more effective license processing for RE development, and offering financial incentives to lower upfront investment costs. There are various crucial criteria that must be considered before investing in HRES. Some of the essential factors that must be considered include dependability, effectiveness, stability, and usefulness. HRES system installation must be done correctly for them to work properly. For HRES to function at their best, factors like design and location are crucial. The decision to invest in RES is affected by several factors, including the need to protect capital, improve the reliability of the energy supply, and generate income. These elements are frequently the main deciding factors for consumers when deciding whether to engage in RES. More consumers are anticipated to invest in renewable energy technologies as the use of RES increases to meet their energy requirements.

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4. ROBINSON's system technologies

The aim of the ROBINSON project is to develop and assess an integrated energy infrastructure suitable for developed island s that utilizes RE, existing power and heating infrastructure, and advanced energy storage options. The project endeavors to enhance the reliability and stability of the energy system, while also reducing its adverse impact on the environment and promoting the move away from extensive fossil fuel usage. The overarching objective of the project is to facilitate the transition to RE on both the case-study and follower islands by creating a highly replicable and adaptable system.

The utilization of local RES, such as wind and sunlight, to reduce the dependence of European islands on fossil fuels is hindered by the unreliability and inflexibility of their energy systems. An accurate evaluation of RE potential is critical for effective planning, design, and operation of RES (Gong et al., 2021). It enables informed decisions regarding the type, size, and placement of energy infrastructure and helps identify potential barriers to RE integration. Ultimately, it maximizes the utilization of RE and leads to a sustainable system.

The ROBINSON case studies' suggested energy systems will incorporate RES, sustainably produced heat sources, and a newly proposed EMS that aims to balance energy supply and demand while integrating all DERs and storage capabilities available on each island. The integrated system will offer a dependable, cost-effective, and resilient energy supply while contributing to the decarbonization of the three European islands (Figure 34). The actual design and sizing of the incorporated systems is strengthened by the market analysis provided in this deliverable, justifying the selection of these specific technologies providing their pros and cons, both individually and as a complete hybrid renewable energy system. A Strengths-Weaknesses-Opportunities-Threats (SWOT) Analysis is provided and discussed for each technology, as well.

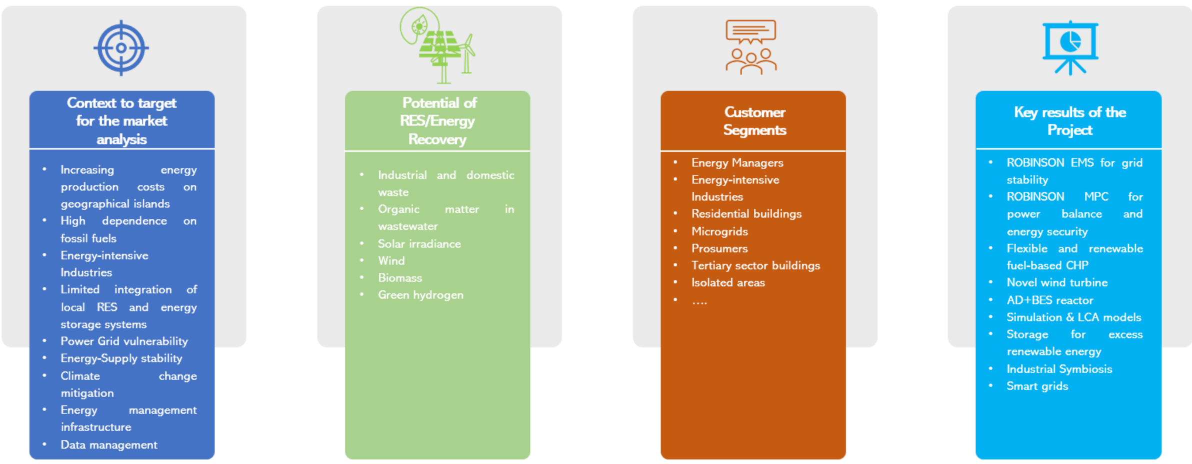

Figure 34 – Schematic diagram of the market analysis report

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4.1. Solar/PV systems

Depending on the processes and systems used to harvest solar energy, solar technologies can be classified as either passive or active. Widespread use of passive systems for heating, cooling, and illuminating buildings, as well as naturally recirculating the ambient air within certain structures and a vast array of commercial and industrial applications, is prevalent. PVs are arrays of cells containing an appropriate material, such as silicon crystal, that convert solar radiation into electricity via the photovoltaic effect; solar energy is harvested. This technology is currently employed in a vast array of applications, ranging from residential rooftop power generation arrays to medium-scale utility-scale energy generation. PV produce direct current, which is then converted to alternating current and fed into the electrical grid (Kalogirou, 2013).

In recent years, Europe has experienced significant growth in photovoltaic panel applications. In 2022, Europe added 41.4 GW of new solar capacity, marking a 47% increase from the 28.1 GW installed in 2021. This surge in solar power installations is evident in the almost 50% increase in solar power in Europe in 2022. The European Technology and Innovation Platform for Photovoltaics (ETIP PV) "Solar Manufacturing Accelerator" project, coordinated by SolarPower Europe, aims to facilitate the rapid development of solar manufacturing projects across the region. Italy is also investing in solar PV manufacturing, dedicating €400 million in support to reach a national target of 2 GW annual manufacturing capacity by December (*The Weekend Read*, 2022).

Belgium has made progress in deploying solar capacity, with its grid operator reporting a 31% increase in RE production, including solar, to 15.1 TWh in 2020. The Netherlands is another European country at the forefront of solar energy innovation, with advancements in crystalline silicon PVs and thin-film and tandem solar cells (Team, 2021). Innovative applications of PV panels are also emerging, such as tents with embedded PV cells that store solar energy during the day to provide illumination at night and power devices and small appliances (*9 Innovations in Solar PV Technology - ASME*). These developments in PV panel applications in Europe demonstrate the region's commitment to expanding the use of solar energy and reducing its reliance on fossil fuels (*Putting Europe in the Lead in Solar Panel Production*, 2023).

SolarPower Europe estimates that PV in Europe increased by 47% in 2022, from 28.1 GW in 2021 to 41.4 GW in 2022. Germany installed 7.9 GW the most, followed by Spain with 7.5 GW and Poland with 4.9 GW. The top 10 European solar markets added at least 1 GW for the first time. The EU's total solar power capacity increased by 25% from 167.5 GW in 2021 to 208.9 GW in 2022. According to the "most likely" scenario projected by the industry association, annual PV growth in Europe will reach 53.6 GW by 2023 and 85 GW by 2026. This indicates that the EU solar market will more than double within the next four years, reaching 484 GW by 2026. Solar PV module prices continue to fall, even after the war in Ukraine; between December 2009 and December 2019, the price of crystalline silicon modules sold in Europe fell by between 87% and 92%. High efficiency crystalline modules cost marginally more than thin film modules, which sold for 0.36$/Watt at the end of 2019, at 0.37$/Watt (*IEA SHC || Solar Heat Worldwide - Past Issues || Solar Heat Worldwide*).

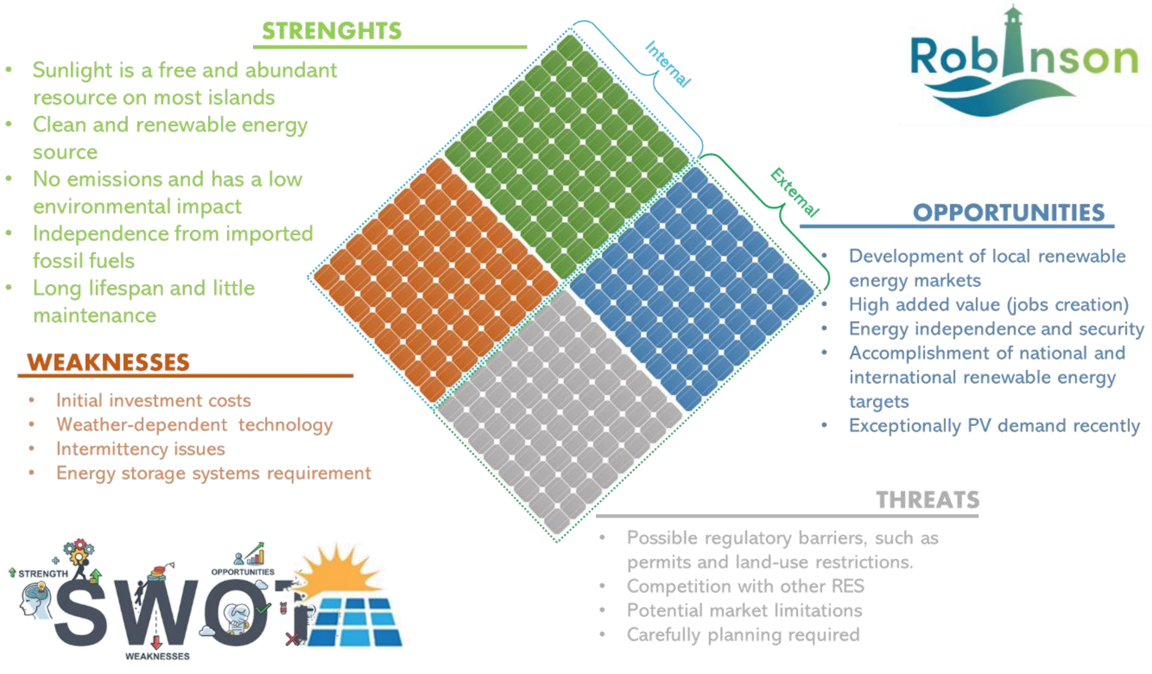

Figure 35 - SWOT Analysis of PV systems

In recent years, islands have increasingly turned to solar PVs as a cost-effective and sustainable solution for electricity generation. For example, Mauritius has good potential for solar PV installations, with 1.6% of the total power generated on the island coming from solar PV parks, although not many parks have been installed yet (Rughoo & Ramasesha, 2020). This trend is consistent with the global growth in solar PV capacity, which has been expanding due to the technology's cost-effectiveness and ability to generate clean energy (cycles & Text).

In the **ROBINSON's project case**, the use of such cells in the three (3) island case studies, seems to be the ideal solution due to their modular nature, which makes them well-suited to such environments, where grid infrastructure is limited or stressed. It is essential to note, however, that the cells' efficiency is highly dependent on several factors of each island. Auxiliary power systems, such as batteries or hydrogen storage are proposed to ensure the reliable and unhampered electricity supply during times of minimal sunlight or high demand.

Based on extant literature, the following SWOT analysis of solar PV systems compiles all their Strengths, Weaknesses, Opportunities, and Threats and presents them in Figure 35.

4.2. Wind Turbines

Wind turbines generate power through wind resources harvesting, by taking advantage of a tower with blades that move in the wind. They can power homes, or even towns; large wind turbines can power entire towns. Large wind turbines collect more wind energy, making them more efficient than the smaller ones. They take up more space and are installed in windy rural areas. Small-scale wind turbines power homes, farms, and small companies. They have rotor sizes under 50 feet and heights

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under 100 feet. Large turbines occupy more space than residential turbines. However, their smaller size makes them less efficient than large-scale turbines and unsuitable for low wind speeds. Small wind turbines are cheaper and easier to place, making them popular to homeowners and small businesses seeking to generate their own electricity.

Deploying wind turbines on islands can reduce reliance on imported fossil fuels, lower energy costs, and provide a dependable and sustainable energy source. However, there are obstacles to installing wind turbines on islands, including limited space, grid limitations, and potential impacts on local fauna and communities. To ensure the successful deployment of wind turbines on islands, careful planning and consideration of these factors are required.

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 RE market (Z. Chen et al., 2009). Also, the WECs are split into two categories: (a) Onshore WECS, and (b) Off-shore WECS. In addition to these technological advancements, total installed costs, Operation and Maintenance (O&M) costs, and (consequently) LCoEs have been decreasing as a result of scale economies, enhanced competitiveness, and maturity (*Renewable Power Generation Costs in 2019*, 2020). Offshore wind speeds are stronger and more constant because there are no hills or buildings to block them. Offshore wind generates more energy. Offshore wind power can meet energy needs in densely populated coastal areas. Offshore wind farms' biggest drawback is cost; these structures are hard to reach and vulnerable to damage from cyclones and hurricanes, making construction and upkeep costly (*Onshore vs Offshore Wind Energy*).

Micro-wind turbines, with 100 kWe or less capacity, are suitable for domestic power production. Horizontal and vertical axis wind turbines can produce domestic energy. Vertical axis wind turbines have fewer moving parts, a lower tip speed ratio, are silent, cheaper, and insensitive to wind direction. Horizontal axis wind turbines are less effective in urban built-up areas where structures and buildings cause wind to become highly unstable and vary in speed and direction. The literature reports power ratings of drag-based wind turbines (Savonius type) ranging from 4% to 24% (Loganathan et al., 2019). By altering the speed of the wind turbine, the variable speed generation system is able to store the variable incoming wind power as rotational energy (Yin et al., 2019).

In Europe, there have been significant developments in wind turbine applications recently. In 2021, Europe installed 17 GW of new wind capacity, with 81% of the new installations being onshore wind. This was a record amount and an 18% increase compared to 2020. Despite these increases, the installation rate is still not enough to meet the EU's 2030 Climate and Energy goals. According to WindEurope, wind energy could grow by 90 GW in Europe in the next five years, potentially reaching 277 GW of installed capacity by 2023 (*WIND ENERGY IN EUROPE: OUTLOOK TO 2023*). Germany, Spain, and the UK are expected to have the most wind energy capacity by 2023. Denmark is leading the way, generating 58% of its electricity from wind turbines. Northwestern European countries such as Ireland, the UK, Netherlands, and Belgium also have a significant number of wind turbines installed. In Southern Europe, there are also large concentrations of wind turbines (*WIND TURBINES IN EUROPE*).

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The World Economic Forum suggests that Europe has the potential to install more than 11 million additional wind turbines over nearly 5 million square kilometers of suitable terrain. If this potential were fully exploited, Europe could provide the entire planet with all the energy it would require up to 2050 (*Turning to Wind Power in Europe Could Power the Entire World*, 2019). The 2019 weighted-average global Levelised Cost of Energy (LCOE) for onshore wind turbine projects was 0.053$/kWh, a 9% reduction in comparison to 2018 and a 39% reduction when compared to 2010 (when the LCOE was 0.086$/kWh). Since 2010, there has been a threefold increase in onshore wind power from 178 GW to 594 GW. The global average accumulated capital expenditure decreased by 24% from 1949 US dollars per kilowatt in 2010 to 1473 US dollars per kilowatt in 2019, witnessing a decrease of 5% from 1549 US dollars per kilowatt in 2018. Notwithstanding, the global mean Levelized Cost of Energy (LCOE) for offshore wind decreased by 29% from 2010 to 2019, falling from 0.161 to 0.115 USD/kWh, with a 9% declination in 2019. The results of auctions and tenders suggest that by the year 2023, the cost of energy will be in the range of 0.05 to 0.10 US dollars per kilowatt-hour, even in new markets. Between 2010 and 2019, the global mean weighted total establishment costs decreased by 18%, from 4650 USD/kW to 3800 USD/kW. In 2013, the global mean total operational cost per kilowatt reached a maximum of 5740 USD, then decreased by 33% by 2019(*Irena_future_of_wind_2019.Pdf*).

ROBINSON's novel wind turbine (V-Twin 100) is designed by Renewable Energy Systems & Technology UG (REST) to optimize the use of wind as the (primary) energy source on Eigeroy. The wind turbine will be incorporated into Prima Protein's microgrid. The installation of a modular design with two-blade rotors made primarily of steel reduces the number of components and space requirements. The absence of a transmission in the wind turbine reduces complexity and material requirement. The based-on-literature-SWOT analysis of the WECs is presented in Figure 36.

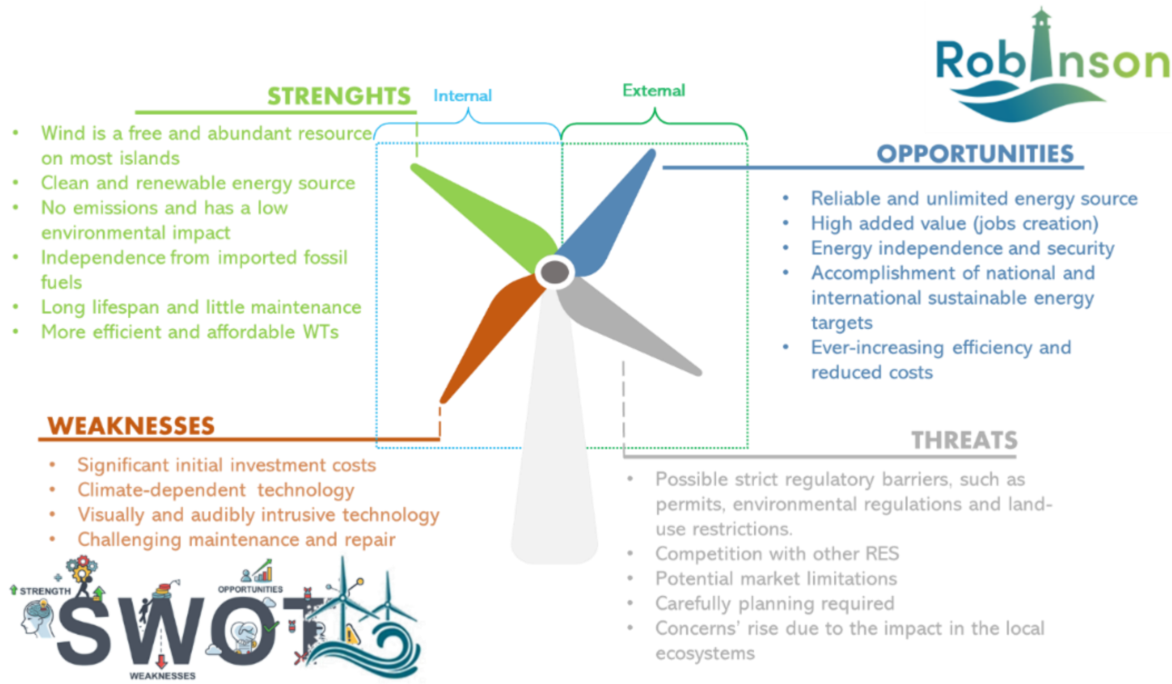

Figure 36 - SWOT Analysis of WECs

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4.3. Gas Turbine – CHP Unit

Combined Heat and Power (CHP) units, also known as cogeneration systems, are an efficient way to generate both electrical and thermal energy simultaneously from a single fuel source. These systems are designed to reduce energy waste and improve overall energy efficiency by capturing and utilizing the heat generated during the power production process, which would otherwise be lost. In summary, gas turbine CHP units are an efficient and environmentally friendly way to produce both electrical and thermal energy. They offer several advantages, including higher energy efficiency, reduced emissions, cost savings, and operational flexibility (Benalcazar, 2021). These systems are suitable for various applications and can play a significant role in improving overall energy efficiency and sustainability.

Recent years have witnessed an increase in popularity for small gas turbines in CHP applications across Europe. As of now, approximately 20% of the total installed capacity of conventional power plants in Europe is based on CHP, with 11 out of the 28 countries included in the statistics making up for over 85% of the total CHP capacity (*Recent Developments of the OP16 Gas Turbine to Meet the Requirements for Flexible CHP Applications*). The gas-fired CHP plant in Marzahn, which began commercial operation in June 2020, stands as arguably the most modern CHP plant in Europe, showcasing a path for cities to transition away from fossil fuels towards a decarbonized future (*Urban Decarbonization*).

Germany has established ambitious targets to decrease greenhouse gas emissions and augment the proportion of renewable energy sources in the energy mix as part of its energy transition and climate objectives. The German government has instituted a range of policy measures and incentives aimed at fostering the advancement and utilization of renewable energy technologies and low-carbon fuels, such as biofuels and hydrogen. As per the given data, it has been determined that the plant has been engineered to operate for a minimum of 40 years. Throughout this period, the plant ought to be adapted to enable the gas turbine to burn hydrogen at a maximum of 40% by volume. Experiments have been conducted at Siemens Energy's Clean Energy Center in Ludwigsfelde to fulfill this objective, and Vattenfall is striving to acquire further knowledge in the operation of its CHP plants utilizing hydrogen and natural gas blends; it is implied a deliberate effort to transition towards fuel sources with reduced carbon content, with hydrogen being a potentially feasible alternative for the Marzahn facility. Furthermore, there is a wider commitment to mitigating emissions and shifting towards more environmentally-friendly energy sources as Vattenfall is exploring alternative low-carbon fuel alternatives, including biogases and synthetic gases.

CHP applications have found their way into various sectors, including municipal and residential settings. Municipal wastewater treatment plants, for instance, can particularly benefit from CHP, as anaerobic digestion (AD) produces biogas that can fuel onsite generators (*Combined Heat and Power (CHP) Systems | GE Gas Power*). Meanwhile, the CHP market for low-capacity systems ranging from 1 kW to 0.5 MW is expected to grow at a 9.7% rate until 2028, with these systems predominantly deployed in small residential and commercial establishments such as restaurants, small-scale industries, and office buildings (*Combined Heat and Power (CHP) Market, Growth Report 2028*).

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Reliability and resilience are essential for islands requiring stable power systems that can withstand extreme weather events. Gas turbine CHP systems offer operational flexibility with the ability to start and stop quickly, making them an attractive solution for fluctuating energy demands. Furthermore, integrating gas turbine CHP systems with RES, such as solar or wind power, can create hybrid systems that further increase energy efficiency and reduce environmental impact, helping islands transition towards a more sustainable energy future.

CHP systems are well-suited for island communities due to their ability to efficiently generate both electricity and heat simultaneously, thereby saving primary energy (*COMBINED HEAT AND POWER (CHP) GENERATION*). These systems can incorporate renewable fuels such as biomass and biogas, which are particularly relevant for islands with limited resources (US EPA, 2015). By using local resources and optimizing energy generation, CHP gas turbines contribute to the energy security and sustainability of European islands, while also reducing their reliance on imported fossil fuels.

Lastly, implementing gas turbine CHP systems on isolated islands can contribute to local economic development by creating jobs in construction, operation, and maintenance (Chua et al., 2014). It also helps retain revenue within the local economy by reducing the need to import energy from external sources. Overall, gas turbine CHP systems present a viable solution for isolated islands, offering energy independence, improved efficiency, reliability, resilience, and local economic development while supporting a sustainable and self-sufficient energy future. In conclusion, a SWOT analysis reveals that gas turbine CHP systems offer several strengths and opportunities for isolated islands, including energy efficiency, integration with renewables, and local economic development.

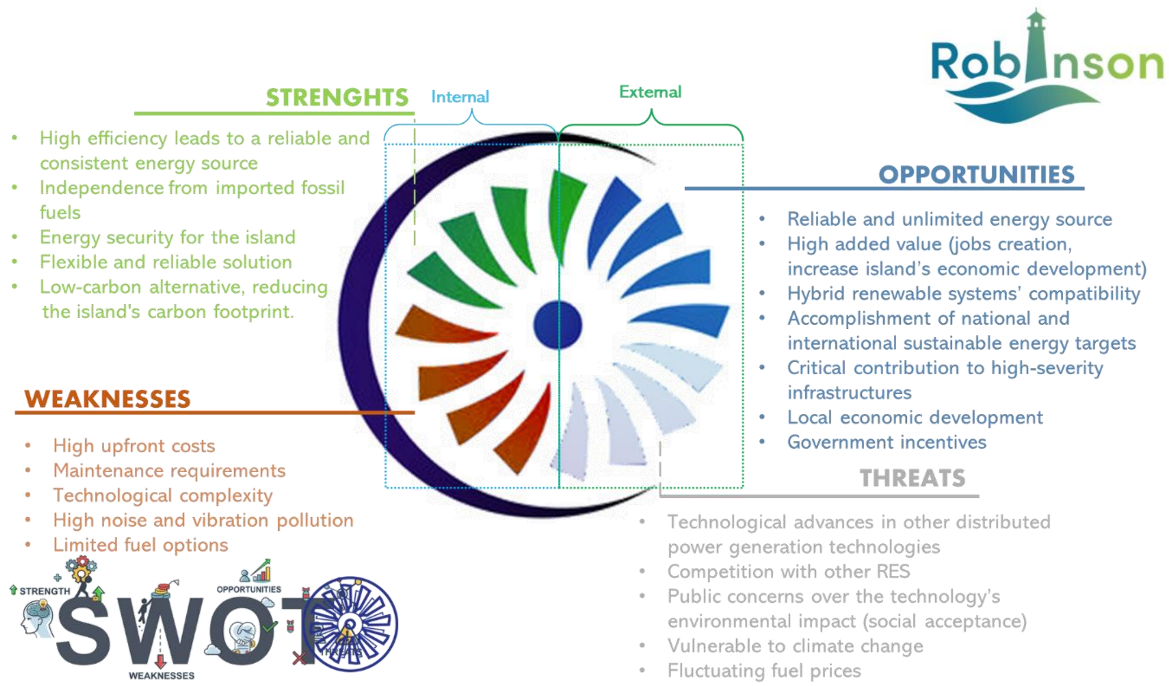

Figure 37 - SWOT Analysis of a Gas Turbine – CHP unit

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However, addressing weaknesses such as high initial capital costs, maintenance requirements, and limited fuel options on local context, due to availability and transportation), as well as mitigating potential threats from regulatory changes, fluctuating fuel prices, and competition with alternative technologies, is crucial for the long-term success and viability of these systems. The SWOT analysis of the Gas Turbines is presented in Figure 37.

4.4. Electrolyzer

The process of electrolysis involves the use of electricity to split water into hydrogen and oxygen (L. Chen et al., 2016). While hydrogen production is most cost-effective during periods of excess renewable electricity generation or when grid electricity prices are low or negative, the importance of oxygen has become more pronounced in the wake of the COVID-19 pandemic. In recent times, the COVID-19 pandemic has led to a surge in demand for medical oxygen, which has highlighted the importance of oxygen production. As a result, there is increasing interest in the economic potential of oxygen and its applications in the medical, industrial, and environmental sectors. This has led to a renewed focus on optimizing the electrolysis process for the production of both hydrogen and oxygen, with the aim of maximizing economic value and sustainability. This has led to increased attention on oxygen and its potential for economic value (Terlouw et al., 2022).

Electrolysis is a promising technology for producing clean energy, as it uses renewable electricity to produce hydrogen and oxygen from water, which can then be used for a variety of applications, including energy storage, transportation, and industrial processes. However, the production costs of hydrogen can be high, making it less economically feasible in some circumstances (A. Pinaud et al., 2013). To address this, hydrogen production is typically prioritized during times when renewable electricity generation exceeds demand, or when grid electricity prices are low or even negative (Kakoulaki et al., 2021; Mueller-Langer et al., 2007). The output of the electrolyzer, hydrogen gas, can be used as a biomass resource for CHP units, which convert it back into electricity and heat. This process allows for the storage of excess renewable energy and decarbonizes the heating and transportation sectors (Hu et al., 2022). However, challenges include the high cost of the electrolysis process and the need for demineralised water and additional infrastructure.

Despite these challenges, using electrolyzer output as a biomass resource is a promising application of electrolysis technology for a more sustainable energy system (Widera, 2020). The use of electrolyzer output as a biomass resource for CHP units is still a developing technology, and it is not yet widely used on a commercial scale. However, there are several pilot projects and demonstration plants around the world that are exploring the feasibility of using hydrogen as a fuel for CHP units (Maestre et al., 2021). Electrolysis technology can be used to produce hydrogen from RES, such as wind or solar power. This hydrogen can then be stored and used as a fuel for CHP units, which can provide heat and electricity to homes and businesses on the island (Parra et al., 2019). In addition, hydrogen can be used to power transportation, such as fuel cell vehicles and boats. Several islands around the world are already exploring the use of electrolysis technology for energy storage and transportation (Kyriakopoulos & Arabatzis, 2016).

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The use of this technology in islands has the potential to be particularly beneficial, as islands often face challenges related to energy security, high energy costs, and limited access to energy resources. By using hydrogen produced by electrolyzers as a biomass resource for CHP units, islands can reduce their dependence on fossil fuels and increase their energy resilience. Islands face unique energy challenges due to their isolation and often limited access to conventional energy resources. For example, islands may rely on imported fossil fuels for electricity generation, which can be expensive and subject to supply chain disruptions. The use of electrolysis technology for energy storage and transportation can help islands reduce their dependence on imported fossil fuels and increase their energy resilience (Kartalidis et al., 2021).

The EU has been actively promoting the development and application of electrolyzers to produce hydrogen for use as biomass fuel. Germany, for instance, has pledged €9 billion ($10.8 billion) to develop renewable hydrogen, with €2 billion allocated for international partnerships. The country aims to achieve 5 GW of electrolysis capacity by 2030, dedicating 2 GW to the transport sector, and plans to install an additional 5 GW by 2040 at the latest (*Hydrogen Fever in EU Puts 2024 Target of 6-GW Electrolyzer Capacity in Reach | S&P Global Commodity Insights*). One notable example is the Refhyne plant, an EU-funded consortium that opened a 10 MW hydrogen electrolyzer facility in Germany. The consortium has already set its sights on expanding the facility to a 100 MW capacity, which would boost green fuel output (Reuters, 2021).

The EC has also been working on defining carbon footprint thresholds within their laws and policies to increasingly reserve the label of 'sustainable' hydrogen for renewable-connected electrolysers only. On April 21st, 2021, the EC approved a Draft Delegated Act encompassing a new taxonomy for 'sustainable' hydrogen (Review, 2021). Electrolysis is a promising option for carbon-free hydrogen production from renewable and nuclear resources, as it uses electricity to split water into hydrogen and oxygen (*Hydrogen Production*). As the demand for electrolyzers grows, companies like Bosch are focusing on industrializing components and leveraging scaling effects for higher volumes to make electrolyzer technology more accessible and efficient (*EU's Electrolyzer Plan Wins Broad Support, Faces Challenges | Reuters Events | Renewables*).

Electrolyzer efficiency improvements have been identified as the main driver for decreasing LCoE over time. For example, one study reported an increase in total system efficiency from 32.4% to 48.4% due to improvements in electrolyzer efficiency (Janowski, 2022). Additionally, cost estimates for hydrogen production using existing technology with low volume electrolyzer capital costs as high as $1,500/kW and grid electricity prices ranging from $0.05/kWh to $0.07/kWh indicate that the cost of hydrogen can range from approximately $4 to $6 per kg-H2 (*DOE Hydrogen and Fuel Cells Program Record*).

One of the strengths lies in the potential for electrolysis to produce carbon-free hydrogen from renewable and nuclear resources, which is a promising option for sustainable energy production. The current conversion efficiency of an electrolyzer is 55.5 kWh of electricity to produce 1 kg of hydrogen, which has roughly the same energy as a gallon of diesel (weakness). Additionally, the process of producing hydrogen using electrolyzers is energy-intensive and requires a significant amount of electricity to split water into hydrogen and oxygen.

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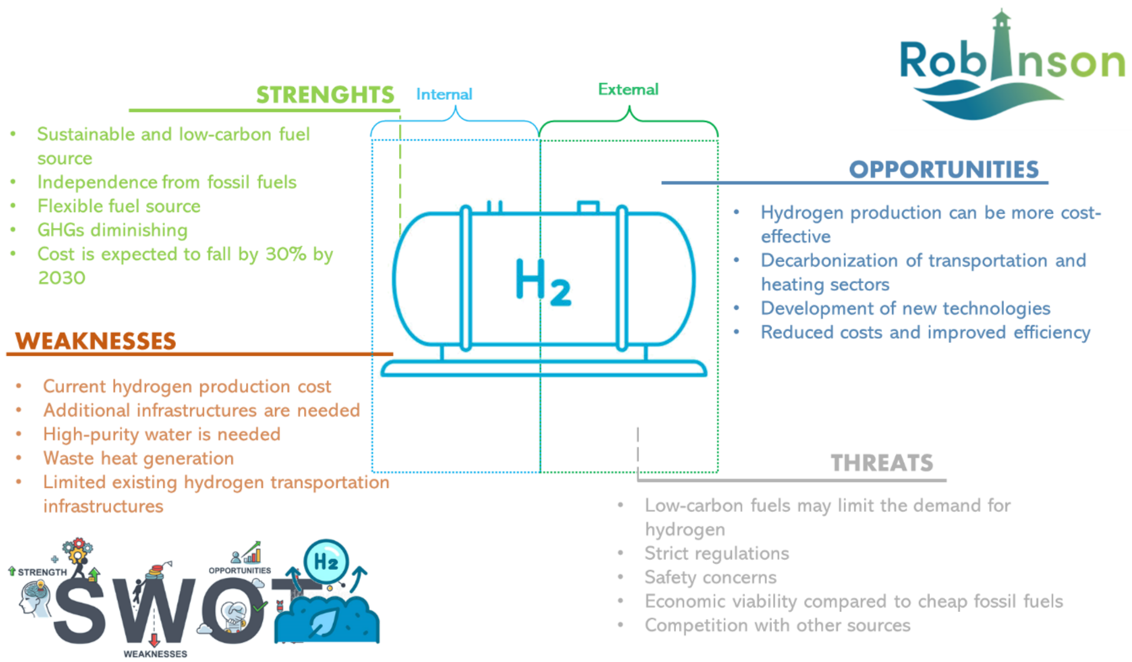

Figure 38 - SWOT Analysis of the electrolyzer unit

Also, electrolysers must be protected during the electrolysis process, as common water contains a variety of minerals that deposit on the electrodes, reducing the efficiency of the electrolysis process and causing damage to the equipment over time; protecting the electrolysers also reduces the risk of contamination and ensures their consistent performance (demineralized water is preferred). Opportunities include its potential use in Microbial Electrolysis Cells (MECs) for hydrogen production from organic matter, including renewable biomass and wastewaters. The SWOT analysis of the Hydrogen system is presented in Figure 38.

4.5. Thermal Energy Storage

Thermal Energy Storage (TES) is a technology that allows for the storage of excess thermal energy generated during periods of low demand for use later when demand is higher (Arteconi et al., 2013). TES systems are commonly used in a variety of applications such as solar thermal energy systems, district heating and cooling systems, and industrial processes (L. Kumar et al., 2019). In solar thermal energy systems, TES can store excess RE heat during the day, which can then be used to generate electricity or provide heat during periods of low solar radiation (Powell & Edgar, 2012).

In summary, TES is a promising technology that has the potential to play an important role in the transition to a more sustainable and low-carbon energy system. By allowing for the storage of excess thermal energy, TES can help to increase energy efficiency, reduce energy costs, and increase the use of RES (*SMILE_D9.5_final_rev0.Pdf*). TES can be particularly beneficial for island cases and isolated islands, where there may be limited access to conventional energy resources and higher energy costs (Liu et al., 2022). In isolated island cases, TES can be even more critical. These islands are often dependent on imported fossil fuels for electricity generation, which can be expensive and subject to supply chain disruptions.

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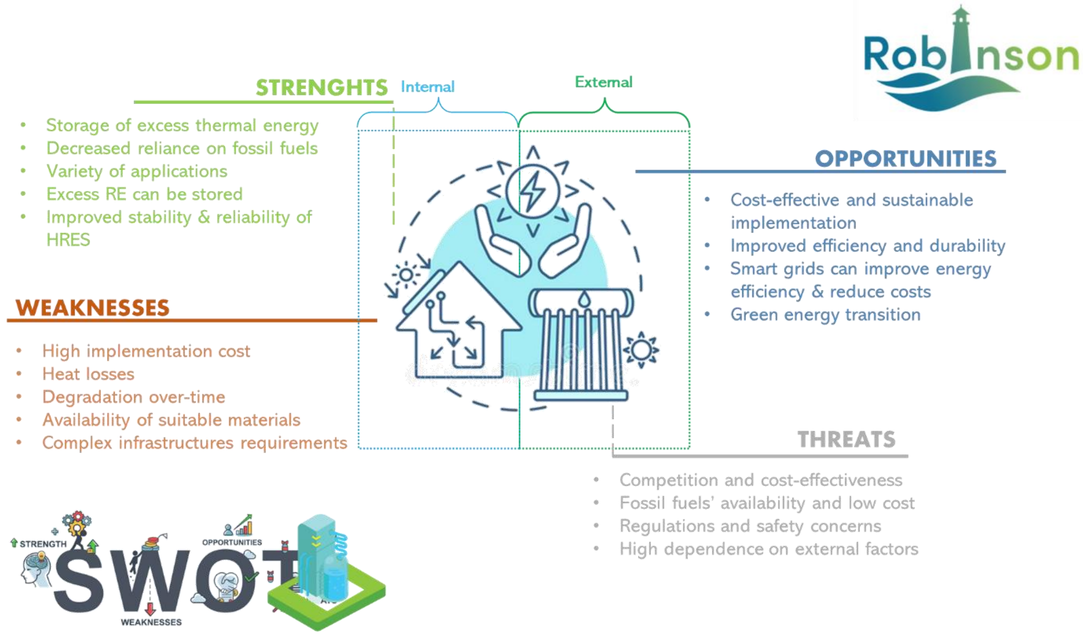

Figure 39 - SWOT Analysis of TES

TES can help to reduce their dependence on imported fossil fuels, increase the use of RES, and improve the stability and reliability of energy systems. Several islands around the world have already implemented TES systems to improve their energy efficiency and increase their use of RES(Dinçer & Rosen, 2021). The SWOT analysis of the TES is presented in Figure 39.

4.6. Biomass

Biomass is a RES derived from organic materials that can be converted into heat, electricity, and fuel. It is carbon-neutral and can be stored and used on demand (Kaushika et al., 2016). Biomass systems can be used with other renewables to balance electricity systems, but require careful management of feedstock resources and can have environmental impacts (Khan et al., 2015). Compared to solar and wind energy, biomass has the advantage of being storable and available on demand for producing power and heat (Savvakis et al., 2022). It can be used alongside solar or wind systems to balance the intermittent nature of electricity systems (Karampinis et al., 2015; *Technology Roadmap - Bioenergy for Heat and Power – Analysis*).

Biomass electricity generation can be done directly or by producing advanced biofuels like biogas. Biomass technologies can be divided into two groups: thermochemical and biochemical. Thermochemical processes have higher conversion efficiencies, shorter reaction times, and good destructive ability of organic compounds, while biochemical technologies are commonly used for wet biomass fractions. Both can substitute fossil fuels in the energy sector. Technologies for hydrogen production from biomass are also in development (*D1.3_critical_technologies_for_islands_energy_transition.Pdf*).

Thermochemical processes for biomass include direct combustion, gasification, and pyrolysis. Direct combustion converts biomass to heat by complete oxidation and can produce electricity. There are two main types of gasification processes based on the heat source to the reactor: autothermal

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gasification, which uses partial oxidation of the fuel within a single reactor to provide heat, and allothermal gasification, which uses an external heat source to provide heat to the reactor. Gasifiers can be fixed beds or fluidized beds (*D1.3_critical_technologies_for_islands_energy_transition.Pdf*).

Pyrolysis decomposes biomass at high temperatures in the absence of oxygen, producing gas, liquid, and char. Each process has different products and process parameters affecting their relative proportions (Asadullah, 2014).

Biomass gasifiers are devices that convert solid biomass feedstock, such as wood, agricultural residues, or other organic materials, into a combustible gas known as producer gas or syngas. This process involves the application of heat in a low-oxygen environment, causing the biomass to undergo a series of thermochemical reactions, including pyrolysis, combustion, and reduction. The resulting syngas is a mixture of carbon monoxide, hydrogen, methane, and other trace gases, which can be used for various applications, such as electricity generation, heating, or as a feedstock for producing chemicals and biofuels (A. Kumar et al., 2015). Biomass gasification is considered a sustainable and environmentally friendly technology, as it utilizes renewable resources and has the potential for carbon-neutral or even negative emissions, depending on the feedstock and system configuration.

A Syncraft gasifier is being evaluated for wood gasification in Eigerøy, converting forest residues into syngas for the CHP unit. The gasifier is flexible in terms of feedstock and has high conversion efficiency but limited operational flexibility. Pyrolysis heating and a floating bed reactor filter out impurities and select gas particles for use in driving a gas engine or as feedstock in follow-up processes the gas and charcoal produced from biomass gasification can be utilized for various applications, such as biomass drying, air compression, air blowing, and water pumps. Moreover, biochar, a byproduct of biomass gasification, can potentially be used to achieve negative greenhouse gas (GHG) emissions when applied to soils. Biochar has a high carbon content and can sequester carbon in soils for long periods, thereby reducing GHG emissions. Therefore, the gas and charcoal produced from biomass gasification can have multiple applications, including the potential for negative GHG emissions through biochar application.(Terlow et al., 2021)

Anaerobic digestion with a bioelectrochemical system (AD-BES) is an innovative approach that combines AD and bioelectrochemical systems, such as microbial fuel cells (MFCs) or microbial electrolysis cells (MECs), to enhance the conversion of organic waste materials into valuable outputs like biogas, electricity, or hydrogen (Chandrasekhar et al., 2022). In this integrated system, AD breaks down complex organic matter into simpler compounds in the absence of oxygen, primarily generating methane and carbon dioxide (biogas). AD-BES technology has promising applications in wastewater treatment, agriculture, and waste management sectors, where it can simultaneously treat organic waste, produce RE, and reduce the environmental impact of waste disposal (Beegle & Borole, 2018).

Prima Protein's liquid wastewater will be used as feedstock in the AD-BES on Eigerøy, which combines AD and BES to produce biomethane of up to 95% purity from organic matter. The technology has advantages such as high process efficiency, flexibility in power fluctuation and plant size, and seasonal energy storage. Leitat and Hysytech develop and build the AD-BES unit, with current Technology Readiness Level (TRL) of 4 and the objective of reaching TRL 6 through the ROBINSON project.

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Operation parameters and target biogas productivity will be updated during the project after laboratory trials.

A biomass gas mixer is used in a CHP system to blend different types of gases produced from biomass, such as hydrogen, syngas, and biomethane, into a mixture that can be used as fuel in the CHP unit (Razmi et al., 2021). The gas mixer ensures that the gas mixture meets the requirements of the CHP unit, such as the required heating value and gas composition, to ensure efficient and reliable operation. The CHP unit generates electricity and heat simultaneously from the gas mixture, which can be used to meet the energy needs of various applications, such as industrial processes, district heating, and buildings (Widera, 2020). The gas mixer blends hydrogen from the electrolyzer, syngas from gasification, and biomethane from the AD-BES unit to create gas mixes for the Aurelia CHP unit. The gas mixes must meet the requirements of the CHP unit and the PSI developed a tool to determine their characteristics.

The Aurelia® A400 gas turbine can run on a mixture of biomethane, hydrogen, and syngas generated from waste wood. A mixing station blends the renewable fuels, and the turbine can process different fuel mixtures and energy sources. The CHP unit provides dispatchable energy and exhaust heat to the grid without heat recovery equipment. The turbine has an electrical efficiency of almost 40% and a thermal efficiency of up to 50% and is assembled in Finland with components sourced from suppliers in several European countries.

Biomass hybrid systems have recently garnered attention in the EU due to their potential to integrate multiple renewable energy sources, such as thermal, solar, and biomass energy, in power plants (Mohaghegh et al., 2021). These HRES are essential for continuous operation, supplementing each form of energy seasonally and offering several benefits over stand-alone systems, such as enhanced capacity and greater security of continuous electricity supply (Sahoo, 2021). The European Technology and Innovation Platform on Renewable Heating & Cooling (RHC-ETIP) brings together stakeholders from the biomass, geothermal, solar thermal, and heat pump sectors, as well as related industries such as district heating and cooling, thermal energy storage, and hybrid systems, to define a common strategy for increasing the use of RETs(*EU-Funded Projects: List of Completed and Ongoing Projects*).

Biomass applications are particularly suited to rural areas without gas grid supplies, and countries such as Austria and the Scandinavian states have demonstrated the potential of biomass-fueled heating systems (*Recent Advances in Biomass Energy Technology in Europe and Applications for SE Asia*). The LCoE for biomass power generation has remained relatively stagnant over the past decade. According to the International Renewable Energy Agency (IRENA) data, the annual average total installed cost of biomass systems is USD 2,289 per kW, with an LCoE of USD 0.069 per kWh (*Cost Of Biomass Power Generation Stagnates, With Downward Pressures For The Future*, 2022).

The system's strengths include being a renewable and sustainable energy source that is storable and available on demand. However, careful management of feedstock resources is required to prevent environmental impacts, and capital costs can be high. The opportunities of implementing this system include reducing energy costs and boosting local economies by using locally sourced feedstocks.

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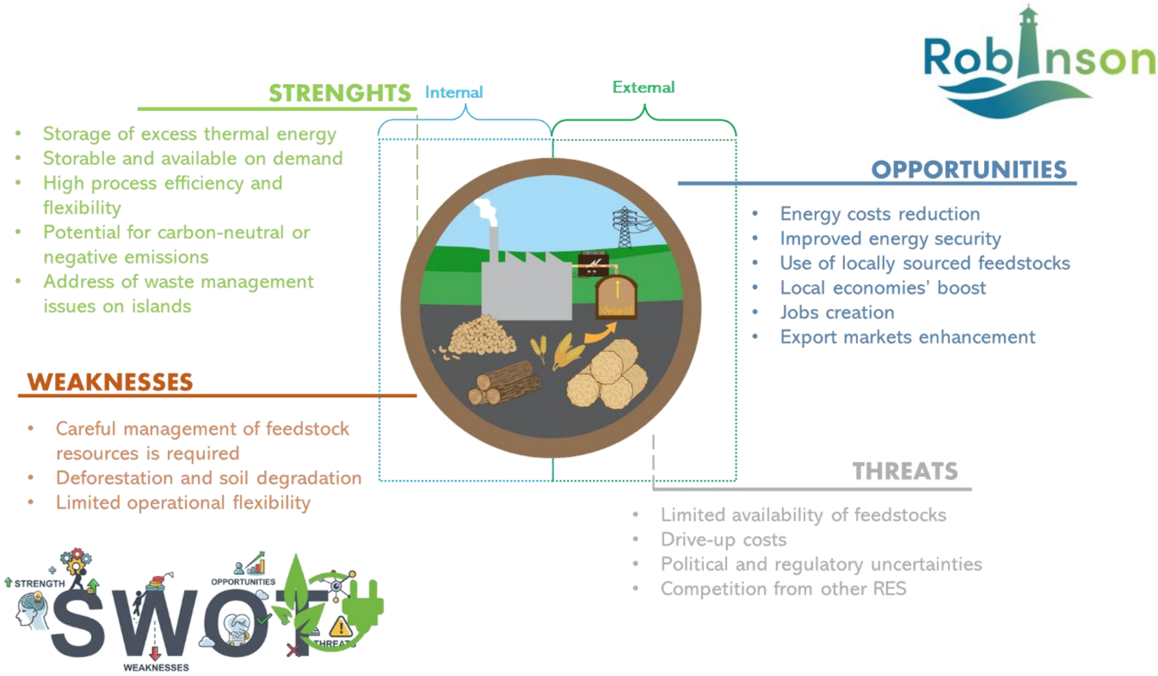

Figure 40 - SWOT analysis of the Biomass system

However, threats include limited availability of feedstocks, environmental concerns, political and regulatory uncertainties, and competition from other RES. Overall, the SWOT analysis suggests that the implementation of this biomass system can bring significant benefits to island communities, but careful planning and management are necessary to address the challenges and risks associated with it. The SWOT analysis of the Biomass system is presented in Figure 40.

4.7. Hybrid Renewable Energy Systems (HRES)

HRES integrate multiple renewable sources like solar PV, wind, hydro, and biomass, along with energy storage technologies to improve efficiency, reliability, and cost-effectiveness while reducing environmental impacts (Emrani et al., 2022). Notable developments include microgrid systems for enhanced resilience and energy security, AI and machine learning for forecasting and optimization, Internet of Things (IoT) devices for real-time monitoring and control, vehicle-to-grid technology for bi-directional energy exchange with Electric Vehicle (EV) batteries, flexible grid integration for adapting to energy supply and demand fluctuations, and green hydrogen production using excess RE for diverse applications (Sifakis et al., 2021).

HRES can be designed in various configurations, combining multiple RES such as PV, wind, hydro, and biomass, along with energy storage technologies like batteries or pumped hydro storage (Javed et al., 2020). Some HRES may also incorporate conventional fossil fuel generators for backup power, or advanced technologies like green hydrogen production and fuel cells. These systems can be tailored to suit different applications, ranging from small-scale off-grid solutions for remote areas to large-scale grid-connected installations that enhance overall grid stability and resilience (Kittner et al., 2016). The versatility and adaptability of HRES make them a promising approach to addressing the

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challenges of intermittency, efficiency, and environmental impact associated with RE(Al-Othman et al., 2022).

HRES offer advantages over single-source RES by integrating multiple RES, capitalizing on resource complementarity, and mitigating intermittency issues. HRES improve reliability by ensuring a stable and continuous power supply, even when individual sources experience fluctuations.

These systems enhance efficiency through advanced control algorithms and smart grid technologies, enabling better energy management and reduced system costs. HRES provide scalability and flexibility, accommodating various sizes and types of energy sources, making them suitable for diverse applications. Integration of energy storage technologies in HRES further improves system reliability and grid stability. As the costs of RES and ESS continue to decline, HRES become increasingly cost-competitive with conventional energy systems, especially when considering long-term environmental and social benefits (Sifakis et al., 2022).

HRES face several challenges that need to be addressed for successful implementation. Technical challenges arise from the need to integrate multiple RES and storage technologies into a single, complex system (Come Zebra et al., 2021). High initial investment costs can deter potential users, although costs are expected to decrease as technology advances. Regulatory and policy barriers may hinder HRES deployment, necessitating incentives and regulatory reforms that support the integration of various RES and storage technologies. Grid integration presents its own set of challenges, such as managing voltage fluctuations, frequency stability, and power quality, possibly requiring significant investments in grid infrastructure and advanced grid management systems. Limited resource availability due to location-specific factors may also constrain HRES potential (Mahesh & Sandhu, 2015). A lack of knowledge and expertise in various fields related to HRES calls for specialized training and education programs to develop the necessary workforce. Finally, public acceptance is crucial for widespread adoption, emphasizing the importance of education campaigns and community engagement initiatives to promote understanding and acceptance of HRES.

Implementing HRES in islands and isolated islands offers numerous benefits, including energy independence by harnessing local renewable resources, increased resilience and reliability through integrating multiple energy sources and storage technologies, and long-term cost savings by reducing reliance on imported fossil fuels (*D1.3_critical_technologies_for_islands_energy_transition.Pdf*, n.d.). By utilizing microgrid systems, island communities can enhance energy security and adaptability during extreme weather events or disruptions. Moreover, adopting HRES can attract eco-conscious tourists and boost local economies by improving the green credentials of these areas, leading to a more sustainable, reliable, and cost-effective energy solution for islands (Sifakis & Tsoutsos, 2021).

Despite having potential access to abundant RES like solar, wind, or wave energy, many EU islands still depend on costly diesel imports or interconnection to the mainland or a neighboring larger island for their energy supply (*Sustainable Energy Islands in Action | Clean Energy for EU Islands*, n.d.). The European Islands Facility (NESOI), a Horizon 2020 project, aims to fund 60 successful energy transition projects, mobilizing more than €100 million of investment and significantly reducing CO_2 and GHGs (*Clean Energy for EU Islands*-b).

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The EU has also approved a €1.4 billion support scheme to promote renewable electricity in the 29 autonomous non-interconnected island electricity systems in Greece, covering 47 islands (*State Aid: Commission Funding for Renewable Electricity | Clean Energy for EU Islands*-b). Out of this measure, Greece intends to establish 264MW of new RE by 2026.

Additionally, Denmark is building two energy islands to accelerate Europe's green transition, which will consist of one artificial island in the North Sea and another built on an existing island (Graham). One notable example of the implementation of hybrid renewable energy systems in EU islands is Tilos, which became the first island in southern Europe to build a hybrid power station with battery storage ('The Greek Island Where Renewable Energy and Hybrid Cars Rule', 2021). The 7th International Hybrid Power Systems Workshop addresses the challenge of maintaining the balance between production and consumption in island grids and microgrids, as diesel generators are still frequently used for this task (*7th International Hybrid Power Systems Workshop | Clean Energy for EU Islands*, n.d.).

The focus on HRES demonstrates the EU's commitment to transitioning towards greener and more sustainable energy sources, ultimately reducing the region's dependence on fossil fuels, and lowering GHGs. A SWOT analysis of island HRES reveals that their strengths include energy independence, resilience, reliability, environmental benefits, and cost savings in the long run, along with job creation opportunities. However, weaknesses include high upfront costs, resource availability, technological challenges, and the need for a skilled workforce. Opportunities for HRES in island communities arise from microgrid development, technological advancements, green tourism, and international funding and support. Potential threats encompass climate change impacts, policy and regulatory challenges, land-use conflicts, and social acceptance issues. The SWOT analysis of the HRES is shown in Figure 41.

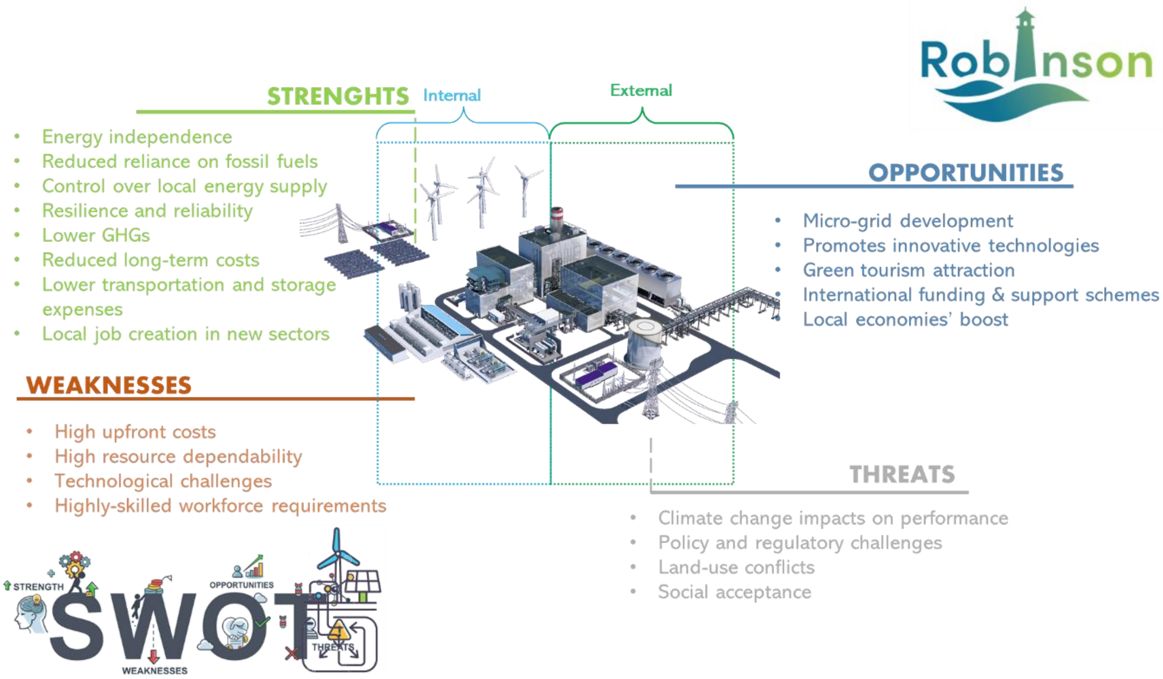

Figure 41 - SWOT analysis of HRES

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4.8. Energy Management Systems (EMS)

EMS are advanced, computer-based platforms designed to optimize energy generation, distribution, consumption, and storage within a facility or across a network of facilities. Combining data acquisition, communication infrastructure, analytics and decision support, control and automation, and visualization and reporting, EMS aims to improve energy efficiency, reduce operating costs, and minimize environmental impact. Applicable to various sectors, including commercial buildings, industrial facilities, and utility grids, EMS offers benefits such as lower energy costs, improved equipment performance and lifespan, and enhanced sustainability efforts.

HRES implementations utilize specialized EMS to optimize the integration and operation of multiple RES, such as solar, wind, and hydro power, alongside energy storage systems and conventional power sources. These advanced EMS platforms monitor and control the energy generation, distribution, consumption, and storage within various applications, including residential, commercial, industrial, and utility-scale projects. By leveraging sophisticated analytics, decision support, and control mechanisms, HRES-focused EMS solutions ensure the stability and reliability of the energy supply, maximize the use of RE, and minimize environmental impact, while reducing overall energy costs.

Innovative applications of EMS span various sectors, including microgrid management for stable and efficient operation, optimization of EV charging infrastructure, integration into smart buildings and homes for energy efficiency, and collaboration with Industrial IoT for real-time monitoring and control in manufacturing. Additionally, EMS supports the development of virtual power plants by aggregating DERs, enables transactive energy systems through peer-to-peer energy trading, and participates in demand response programs and grid ancillary services to maintain grid stability. These diverse applications demonstrate the potential of EMS to address energy challenges and contribute to a more sustainable and efficient energy landscape.

EMS in island HRES enhances stability, reliability, and sustainability of energy supply in remote locations. By optimizing resource management, balancing loads, managing energy storage, maintaining grid stability, and implementing demand-side management strategies, EMS enables efficient use of renewable sources and reduced dependency on fossil fuels. Additionally, the seamless integration of backup generators, advanced data analysis and forecasting, and remote monitoring capabilities ensures efficient operation, maintenance, and resilience to environmental and supply-related challenges in island communities. A survey conducted on about 800 projects in European islands revealed that nearly half of these projects were related to energy efficiency, approximately one-fifth were focused on RE, a similar number on sustainable mobility, and the remaining projects were associated with energy management (*European Islands – Top Technologies for the Energy Transition*, n.d.)

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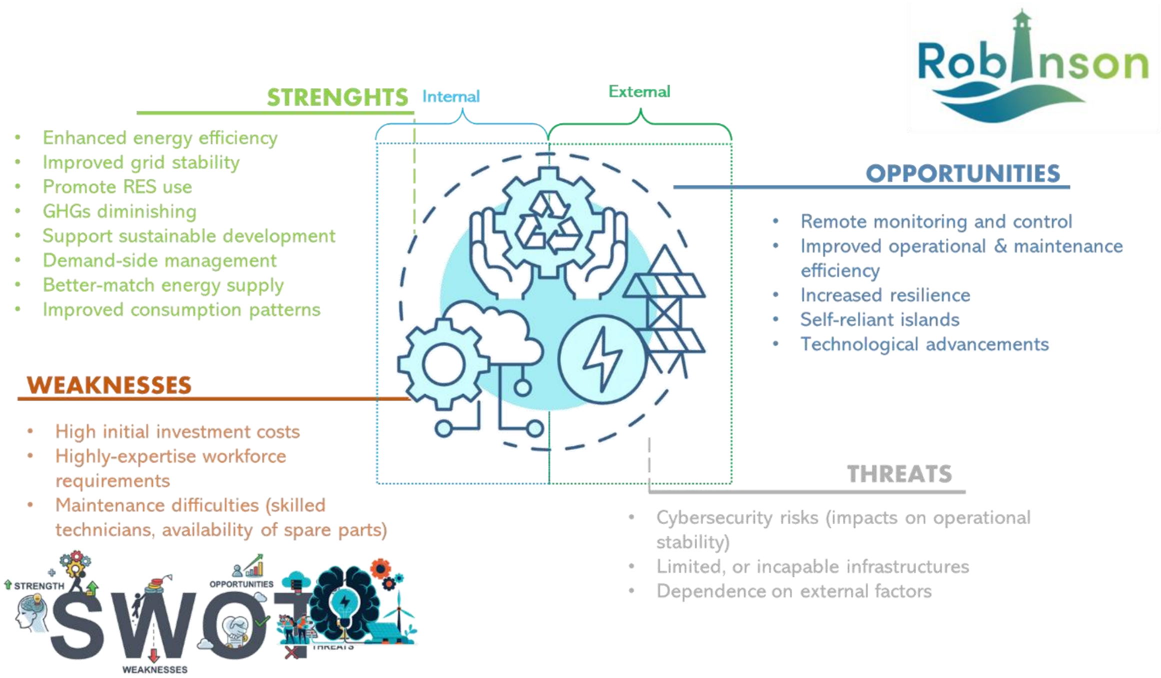

Figure 42 - SWOT analysis of EMS

Implementing EMS in island HRES offers strengths such as enhanced energy efficiency, improved grid stability, sustainability, and demand-side management. However, challenges like initial investment costs, technical expertise requirements, and maintenance can pose difficulties. Opportunities for remote monitoring, increased resilience, and technological advancements can further improve the systems, while threats like cybersecurity risks, limited infrastructure, and dependence on external factors must be carefully considered. A comprehensive understanding of these factors can guide stakeholders in making informed decisions and developing strategies to maximize benefits while addressing potential challenges. The SWOT analysis of the EMS is presented in Figure 42.

4.9. ROBINSON's system customer segments

In order to develop and assess an integrated energy system for developed islands, the ROBINSON project will make use of readily available local energy sources, electrical and thermal networks, and cutting-edge storage technologies. Additionally, it hopes to reduce energy waste, improve the energy system's reliability and stability, lessen negative environmental effects, and result in fossil fuel savings. The project's overarching goal is to contribute significantly to the islands' energy transition through the creation of a scalable answer.

The ROBINSON project is a modular system designed to provide sustainable and resilient energy solutions for European islands. The customer segments for the ROBINSON project could be broadly categorized into two groups: local communities and businesses, and energy service providers. Local communities and businesses on the islands could benefit from the ROBINSON project's sustainable and reliable energy supply, which can help reduce energy costs and improve energy security.

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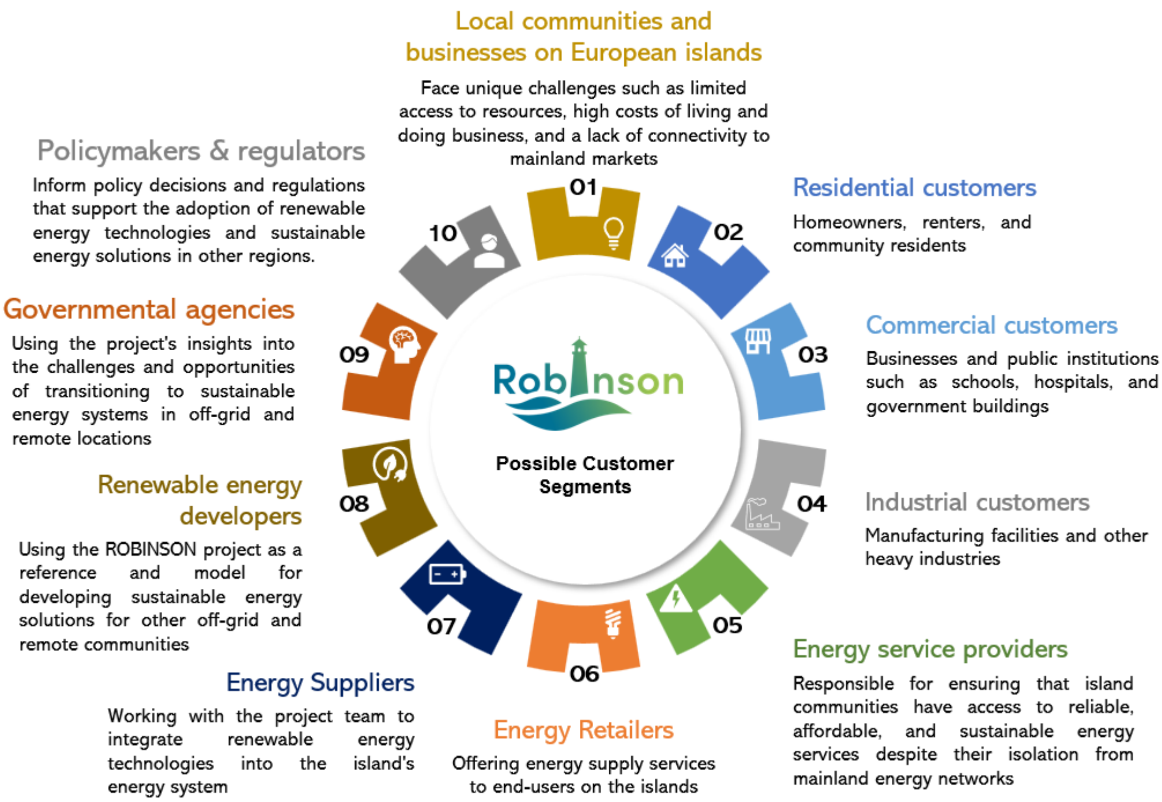

Figure 43 - ROBINSON's HRES customer segments

The project's energy storage and demand response capabilities can also provide backup power during times of low RE availability, which can be crucial for critical infrastructure and emergency services. The customer base for the ROBINSON project includes local communities and businesses on European islands, energy service providers, RE developers, governmental agencies, policymakers, and regulators. The project's modular design and innovative technologies provide opportunities for scalability and replication, making it relevant to a broad range of stakeholders interested in sustainable and resilient energy solutions for remote and off-grid locations. The customer segments for the ROBINSON's project HRES are demonstrated in Figure 43:

Energy service providers, such as utilities and RE developers, could also benefit from the ROBINSON project's modular design, which can be replicated and scaled up for other island communities facing similar energy challenges. The project's innovative technologies and EMS can also provide valuable insights for the development of sustainable energy solutions for other remote and off-grid communities.

Local communities and businesses can be further segmented into residential, commercial, and industrial customers. Residential customers would include homeowners, renters, and community residents who rely on electricity and heat for their daily needs. Commercial customers would include businesses and public institutions such as schools, hospitals, and government buildings that require energy for their operations. Industrial customers would include manufacturing facilities and other heavy industries that consume large amounts of energy.

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Within the energy service provider segment, there could be further segments such as energy retailers, energy suppliers, and RE developers. Energy retailers could offer energy supply services to end-users on the islands, leveraging the ROBINSON project's sustainable and reliable energy supply. Energy suppliers could work with the project team to integrate RE technologies into the island's energy system and help meet RE targets. RE developers could use the ROBINSON project as a reference and model for developing sustainable energy solutions for other off-grid and remote communities.

Another potential customer segment for the ROBINSON project is governmental agencies, policymakers, and regulators. These stakeholders could benefit from the project's insights into the challenges and opportunities of transitioning to sustainable energy systems in off-grid and remote locations. They could use these insights to inform policy decisions and regulations that support the adoption of RE technologies and sustainable energy solutions in other regions.

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5. Market Analysis

5.1. Understanding Island Energy Systems

The energy supply challenges faced by islands are unique due to their small size and isolation, setting them apart from more significant regions such as the EU mainland. Around 4.6 % of the EU's population resides on islands, and their energy supply is heavily reliant on fossil fuels, with constraints arising from a lack of electricity and gas interconnections. As a result, energy costs exceed the average EU levels, and power plant efficiency is lower due to more expensive fuel and high-demand seasonality. Increased utilization of local RES offers islands an opportunity to address several challenges, including reducing the need for costly energy imports and interconnections. Examples of such approaches already exist in Europe, including the Canary- and Greek Islands, Bornholm, Brittany, Slovenia, and the European Association of Small Islands. Moreover, islands offer fascinating opportunities for developing and testing future energy systems on a smaller scale (Kielichowska et al., 2021).

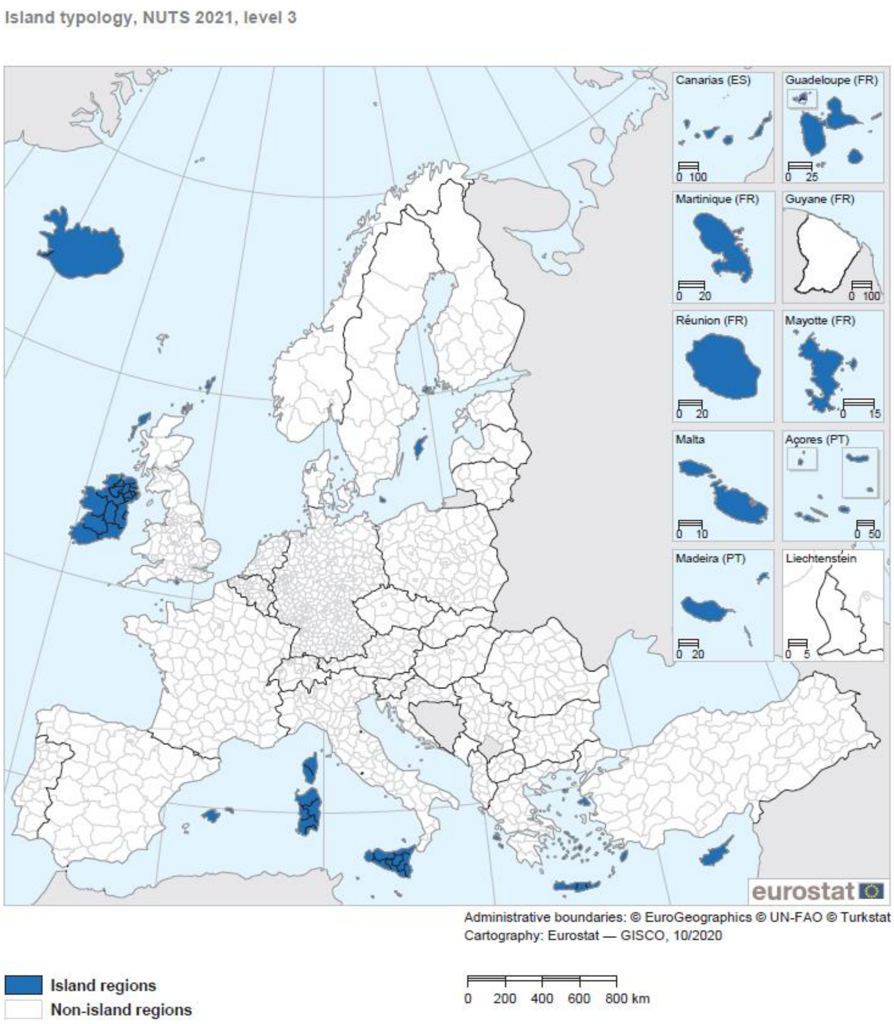

*Figure 44 - Island typology, NUTS 2021, level 3 (*Statistical Atlas NUTS and Territorial Typologies*, 2021)*

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Eurostat data from 2020 reveals that the European NUTS 3 island regions, which include Italy, Ireland, Spain, France, and Greece, were home to more than 20.5 million people. These countries have the highest number of NUTS 3 island regions and island populations:

- Italy: 14 NUTS 3 island regions in 2021, which had a total population of over 6,400,000 inhabitants in 2020, and a population decrease of 4% compared to 2016. (The values presented are for the same territory, regardless of the change in the NUTS 3 classification over the years).
- Ireland (insular Member State): 8 NUTS 3 island regions in 2021, which had a total population of over 4,900,000 inhabitants in 2020, and a population increase of 5% compared to 2016.
- Greece: 12 NUTS 3 island regions in 2021, which had a total population of over 1,300,000 inhabitants in 2020, and a population increase of 3% compared to 2016.
- Spain: 10 NUTS 3 island regions in 2021, mostly ORs, which had a total population of over 3 400,000 inhabitants in 2020, and a population increase of 5% compared to 2016.
- France: 6 NUTS 3 island regions in 2021, mostly ORs, which had a total population of over 2 200,000 inhabitants in 2020, and a population increase of 1% compared to 2016.

In 2020, Portugal had two NUTS 3 island regions with a total population of nearly 500,000 inhabitants, which had decreased by 1% since 2016. On the other hand, Denmark, Finland, and Sweden had only one NUTS 3 island region each, with a population of less than 60,000 people per region. Two insular Member States, Cyprus (1 NUTS 3 region) and Malta (2 NUTS 3 regions) have registered an increase in the number of inhabitants since 2016: Cyprus' population increased by 4%, to over 880 000 inhabitants in 2020, while Malta's population increased by a record 12%, to almost 500 000 inhabitants in 2019. It is important to note that NUTS 3 regions comprising both coastal and island territories, such as those along the Adriatic coastline in Croatia, cannot be classified as island regions. The same applies to Denmark, which has 99 inhabited or uninhabited islands, but only Bornholm is considered a NUTS 3 island region due to its lack of a physical link to the mainland or inclusion in a region that also encompasses mainland areas.(Haase & Maier, 2021a)

	2016	2017	2018	2019	2020	2020 compared to 2016 (%)
IT	6,732,399	6,709,776	6,675,165	6,639,482	6,486,911	-4
ES	3,270,736	3,305,940	3,343,971	3,395,121	3,447,717	5
GR	1,345,431	1,356,253	1,366,178	1,380,079	1,392,881	3
FR	2,230,702	2,236,921	2,244,613	2,249,563	2,254,154	1
PT	502,190	500,159	498,230	496,791	497,050	-1
MT	450,415	460,297	475,701	493,559	514,564	12
FI	28,983	29,214	29,489	29,789	29,884	3
SE	57,391	58,003	58,595	59,249	59,686	4
DK	39,847	39,773	39,715	39,662	39,583	-1
CY	848,319	854,802	864,236	875,899	888,005	4
IE	4,726,286	4,784,383	4,830,392	4,904,240	4,964,440	5
TOTAL	**20,232,699**	**20,335,521**	**20,426,285**	**20,563,434**	**20,574,875**	**2**

Table 2 - Population living in NUTS 3 island regions across Europe (Haase & Maier, 2021b)

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5.1.1. The water basins of islands

Insular territories are often identified by their location within specific water basins, such as the Baltic Sea Islands, Northern Sea Islands, North Atlantic Islands, Mediterranean Islands, and Outermost Regions. This approach is commonly used in cross-border cooperation initiatives and macro-regional strategic documents that address islands and coastal regions together. The Baltic Sea Islands are in seven Member States (Poland, Germany, Denmark, Sweden, Estonia, and Finland) and are typically small in size, with economic activities primarily focused on fisheries, aquaculture, agriculture, forestry, and services. Tourism is also an important industry, particularly during the summer months. The Baltic Sea basin is also shared with Russian islands. Islands in the Northern Sea are found in three Member States (Netherlands, Denmark, and Germany) and Norway. These islands are typically numerous, small, and fragmented, with similar economic activities to the Baltic Sea Islands. Tourism is also a significant industry, particularly during the summer months. The Northern Sea basin is also shared with islands belonging to the UK. The North Atlantic Islands include Ireland, which has a total population of over 4.9 million inhabitants in 2020 according to Eurostat. The north-eastern part of the Atlantic Ocean, where Ireland is located, is also home to islands belonging to the United Kingdom, which are no longer part of the EU. Additionally, Ireland shares an island territory with Northern Ireland, a part of the UK. Ireland is known for having a strong knowledge economy, with a focus on ICT, financial services, and agribusiness. Islands in the Mediterranean Sea are in seven Member States (Italy, France, Greece, Spain, Croatia, Malta, and Cyprus - the last two being insular countries) and are home to some of the largest and most developed EU islands. The services sector, particularly tourism, is one of the main economic activities for Mediterranean islands, but agriculture and fisheries are also important.(Haase & Maier, 2021a)

5.1.2. Island Group Formation

This section outlines the criteria used to group islands into clusters based on various aspects such as geographical size and population, grid interconnection, seasonality, economic development, and availability of RES.

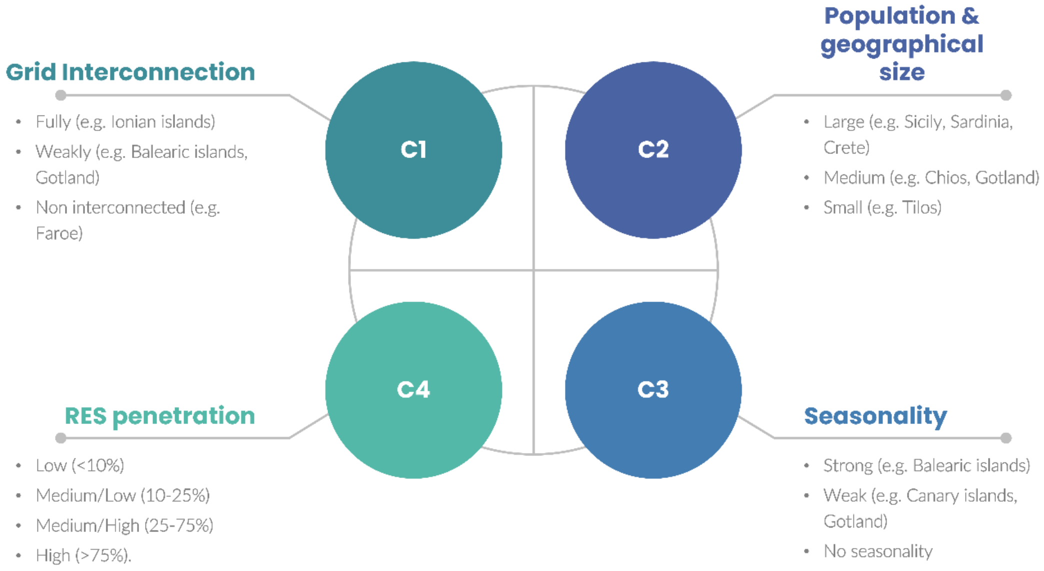

Figure 45 - Proposed categorisation and examples

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The proposed categorisation of islands:

- **Grid-Interconnection level**: The majority of islands in Europe are either weakly interconnected (i.e. lacking sufficient capacity) or not interconnected at all. Weakly interconnected islands have interconnectors with installed capacity that is inadequate to meet full load demand. This means that either a) conventional power plants are also in operation, or b) the island cannot export more electricity than it imports (as is the case with Gotland). There are proposals to improve interconnection to the island in some instances.
- **Population and geographic size**: Islands are classified as big, medium, or tiny based on demographic traits such as people and surface area. However, because most islands are seasonal, the average peak power demand in MW and energy usage in GWh are more pertinent indicators.
- **RES penetration**: All the groups of islands in Europe have operational RES plants, mainly utilizing wind, solar, or geothermal energy sources. The level of penetration of these sources into the energy mix varies.
- **Seasonality**: Most islands in Europe exhibit seasonality due to tourism, whereas only a few islands exhibit mild seasonality (i.e., their highest capacity does not vary significantly throughout the year) or no seasonality.

5.1.2.1. Island Groups by Size, Peak Demand, Seasonality and Grid interconnection

These clusters are based on the analysis executed in NESOI Project and the ASSET database of European islands.

- **A1 – Large Islands**
  These Islands (e.g. Sicily, Sardinia, Balearic islands) have a population of over 1,000,000 and are considered highly populated. Usually, their peak load demand is higher than 800 MW. Large islands are at an advanced stage in terms of transitioning to RE with plans in place to achieve their objectives. Their efforts are driven by national regulations and objectives, as well as the benefits they provide to the environment. However, they face perceived limitations such as economic barriers and funding, as well as challenges in defining roles between public entities. Due to their high-efficiency processes and access to the mainland electricity grid, the need for an energy transition on these islands may be less urgent.
- **A2 – Medium-Sized Islands**
  These islands count from about 250,000 to 1,000,000 inhabitants. Additionally, medium-sized islands have developed energy transition initiatives, with renewable energy integration being the most progressed aspect, and have intentions to expand these efforts. Their primary motivation is the reduction of their negative ecological effect, and their constraints and demands are comparable to those of the larger islands. Peak load demand in these islands may vary from 100 to 800 MW. This cluster includes either interconnected (e.g., Corsica) or weakly interconnected islands (e.g., Crete, Madeira).(Katsaprakakis et al., 2022; Kielichowska et al., 2021; Notton et al., 2019)

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- **A3 – Small Interconnected or Non-Connected Islands with High Seasonality**
  Small islands typically have a population of no more than 150,000 people and experience peak load demands ranging from 5-100 MW. These islands may or may not be connected to the mainland, and they tend to have a high level of seasonality due to their popularity as tourist destinations. As a result, the number of inhabitants can increase significantly during certain times of the year. Despite this, these islands have a long way to go in terms of their energy transition. The primary motivation for this transition is to reduce living costs on the island. The current energy systems on these islands often have low efficiencies, making it difficult to address the variations in energy demand caused by seasonality. Additionally, there may be management issues related to the mainland's electricity grid. To address these challenges, the energy transition should focus on implementing flexible systems that generate electricity from renewable sources, considering the seasonality of these islands.
- **A4 – Small Interconnected or Non-Connected Islands without Seasonality**
  In contrast to the previously mentioned islands, there are some small islands that do not experience seasonality, meaning that the number of inhabitants remains relatively constant. However, these islands still have significant room for improvement in terms of their energy transition status, and many do not have concrete plans to advance. The main motivation for these islands is to reduce their environmental impact, but they also face barriers such as a lack of skilled workforce, legal complexities, and challenges in locating funds. Overall, small islands often face common barriers in their energy transition efforts.

5.1.2.2. Geospatial clustering

Islands with different climates and geographical locations may require different types of energy. This classification helps identify their energy needs; therefore, one technology may perform better than another.

- **Mediterranean Europe Islands**. These islands have a Mediterranean climate, characterized by hot summers and mild and rainy winters.
- **Northern/Central Europe Islands**. In this region, we can distinguish between two types of climates: temperate oceanic climates and cold continental climates. The first one affects the United Kingdom and northern France and is characterized by mild summers (relative to their latitude) and cool, but not frigid, winters, with a limited yearly variation in temperature and only a few temperature extremes. The second climate affects northern Germany and Scandinavia and is characterized by lengthy, frigid winters and brief, mild summers.

5.1.2.3. Groups by Economic Development and Population Distribution

This classification provides insights into the resource and energy demands of islands based on their economic activities.

- **Mainly Tourism:** Islands that rely primarily on tourism are often clustered in areas that experience seasonality (e.g. Greek islands, Cyprus, Croatian islands, Canary islands).
- **Mainly Primary Sector**. Islands that focus on primary sector activities, such as agriculture and livestock farming, are usually flat with fertile soil.

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Presence of Industries. islands with a significant industrial presence tend to be larger or medium-sized, belonging to the A1 and A2 categories mentioned earlier, and are more industrialized than smaller islands.

5.1.2.4. Groups by RES penetration and availability of resources

The islands can be classified based on their available resources for their activities or potential for energy transition processes. This evaluation may consider factors such as the presence of RES and other relevant resources.

- Low-RES penetration (<10%) – e.g. Balearic and Canary islands
- Medium/Low-RES penetration (10-25%) – e.g. Azores, Greek Non-Interconnected Islands, Sicily, Sardinia
- Medium/High-RES penetration (25-75%) – e.g. Corsica, Faroe islands and Madeira
- High-RES penetration (>75%) – e.g. Aland Islands, Gotland

5.1.3. Challenges and barriers for (the transition of) islands' energy systems

This section outlines the primary challenges and barriers facing energy systems on islands. The criticality of these challenges is evaluated for two extreme scenarios: energy systems that rely solely on fossil fuels and those that rely solely on RES. To assess the reliability of these energy systems, the table categorizes it into two fundamental aspects: adequacy and security. Adequacy refers to the energy system's ability to meet consumer demand and operational constraints at any time, including during scheduled and unscheduled outages. Security refers to the system's ability to withstand disturbances caused by faults and unscheduled equipment removal without experiencing further losses or cascading failures.

- **Lack of economies of scale:** The limited size of islands and their smaller populations present a significant challenge to power systems due to the lack of economies of scale. This constraint results in higher costs for electricity generation and distribution than in mainland areas. Consequently, it becomes challenging to attract investment in new infrastructure, limiting these systems' scalability and efficiency. Moreover, the lack of local industry to supply equipment increases the dependency on expensive imports. Island communities can collaborate and share knowledge to develop innovative solutions that capitalize on their unique strengths and resources. These efforts can lead to the creation of more sustainable and resilient energy systems.
- **Limited availability of fuel resources:** Many islands in Europe are remote and do not have easy access to fossil fuels, which can make it difficult and expensive to meet their energy needs. This reliance on imported fossil fuels can also make island communities vulnerable to fluctuations in global energy prices and supply chain disruptions. In addition, the transportation of fossil fuels to islands can have negative environmental impacts, such as air pollution and oil spills. Overall, addressing the challenge of limited availability of fossil fuels requires a holistic approach that includes the development of RES, energy storage technologies, and efficient energy management strategies. By adopting these solutions, island

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communities can build more sustainable and resilient energy systems that can meet their energy needs in a cost-effective and environmentally friendly way.

- **Adequacy and security**: These are two of the most significant challenges for island energy systems, particularly those based on RES. The reliability issues related to adequacy and security are linked to the variability of RES generation and the limited ability to balance the system with neighbouring regions. In traditional fossil fuel-based energy systems, redundancy in generating facilities can be afforded, and synchronous generators can contribute to enhancing voltage and frequency stability. However, for RES-based energy systems on islands, the variable and intermittent nature of RES generation makes it more challenging to ensure system adequacy and security. For non-interconnected or weakly connected islands, there may be limited possibility to share capacity with neighbouring regions to balance the system, which makes it even more challenging. Additionally, inverter-based generation, which is typically used for RES-based energy systems, has a weaker contribution to voltage and frequency stability compared to synchronous generators. However, it is also true that solutions such as oversized inverters and synthetic inertia can be used to improve the contribution of inverter-based generation to voltage and frequency stability. Energy storage systems can also be used to help manage the variability of RES generation and provide backup power during periods of low generation. Overall, addressing the challenges related to adequacy and security in RES-based island energy systems requires a combination of innovative technological solutions, effective energy management strategies, and strong policies and regulations.
- **Limited space**: Another issue that needs to be addressed is the limited space available on small islands, particularly for onshore renewable energy systems. This can be a critical challenge for PV plants, which require a significant amount of space. While this issue is less critical for fossil fuel-based energy systems and offshore wind energy systems, it could pose a significant challenge for onshore RES-based systems.
- **Environmental aspects**: Environmental considerations are crucial for both fossil fuel-based and renewable energy-based energy systems. On the one hand, conventional energy technologies contribute to air and refuse emissions, with smaller units typically having stricter emission standards than larger units. Transitioning to a RES-based energy system requires careful consideration of wildlife and plant habitats, nature and landscape conservation areas, especially for large-scale applications such as hydro, pump storage, utility-scale RES power plants, and grid development. The potential environmental and visual impact of large-scale RES, such as offshore wind, can result in social acceptance issues.
- **Cultural Factors**: Many isolated areas have unique cultural and historical characteristics that can influence the types of products and services that are in demand. For example, island communities may have a strong fishing or agricultural heritage, which can influence the types of products that are produced and consumed.

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CRETE (GREECE)

SIZE: 8,336 km^2

POPULATION: 634,930 inhabitants
TOURISM: 5,349,963 visitors per year (2019)
INTERCONNECTION: Weakly connected via submarine power cable
LOCAL AUTHORITY: Region of Crete
ENERGY TRANSITION STATUS: Medium level

Energy infrastructure: *The current energy infrastructure in Crete is outdated, consisting of three fossil-fuelled power plants. Despite the recent addition of wind farms and photovoltaic stations to the power generation system, their expansion is limited by the current grid infrastructure and weak interconnection between the island and the mainland. Furthermore, there are no other alternative energy networks (i.e., natural gas or decentralized CHP plants) installed in Crete. Considering this status, ensuring a reliable and secure energy supply for the island is a major challenge.*

Final Energy uses: *Electricity, for indoor space conditioning (heating and cooling), lighting, residential and non-residential uses, and industrial activities; Diesel oil, gasoline, and LPG for heating, cooking and industrial activities on the island; RES, biomass and solar energy for indoor space heating and hot water production, respectively.*

Renewable energy potential: *Crete has significant potential for RE production, particularly from solar and onshore/offshore wind power. However, the island's mountainous terrain in certain areas poses difficulties in the installation of wind turbines in some locations. In addition to solar and wind, biomass residues represent another crucial renewable energy source available on the island.*

Government policies and regulations: *Greece has set ambitious targets for renewable energy production, with a goal of 35% RE by 2030. Despite these policies, the development of new renewable energy projects has been slowed by bureaucratic hurdles and legal challenges.*

Challenges:

- *Due to the heavy reliance on imported fossil fuels, the island has high energy production costs for electric, heat, and cooling loads.*
- *Limited grid capacity and interconnection with the mainland grid.*
- *Environmental and cultural concerns limit large-scale RES projects on the island.*
- *Energy losses due to ageing of the equipment.*
- *Tourism leads to a significant rise in electricity consumption (for cooling loads, cooking, etc.).*
- *Limited availability of RES due to the island's weak interconnection with the mainland.*
- *Biomass burnt locally without any control.*
- *Crete's energy system lacks integrated storage systems to support a transition towards a high RES and flexible energy system.*

Opportunities:

- *High potential for solar and wind power generation due to the island's climate.*
- *Various biomass resources (e.g. agricultural organic wastes, animal manure, pruning, olive kernel wood, etc.), exploitable through AD and decentralised CHP cogeneration.*
- *Heating/Cooling demand from RE, because of the gradual transfer of the heating demand coverage from diesel oil to heat pumps.*
- *Seasonal storage (TES, Batteries, Hydrogen) to ensure a stable and reliable supply of RES energy.*
- *Innovative business models like community-based initiatives and energy cooperatives to stimulate local RES investment.*
- *DSM techniques like load shifting and direct load curtailment can optimize power consumption and decrease the requirement for high installed power capacity.*

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WESTERN ISLANDS (SCOTLAND)

SIZE: 3,070 km^2
POPULATION: 27,000 inhabitants
TOURISM: 219,000 visitors per year (2017)
INTERCONNECTION: Connected via submarine power cable
LOCAL AUTHORITY: Western Isles Council
ENERGY TRANSITION STATUS: Medium level

Energy infrastructure: *The Western Isles currently receive electricity from a modular integrated transportable substation through an active current cable. Although peak electricity demand in the Western Isles is 30 MW, the existing AC electricity supply is limited to 22 MW due to subsea section constraints. During peak demand periods, on-island diesel generators are used for top-up demand. Soon, the installation of a new subsea interconnector would unlock energy imports/exports from/to the mainland, creating the conditions for further RES potential exploitation. Except for a small gas network serving about 1,500 households in the Stornoway area, there is no access to natural gas and households are heavily dependent on oil and electricity for heat.*

Final Energy uses: *Fossil fuels account for 74.1% of the total energy consumed in 2018. The domestic sector is the largest consumer in energy terms at 43% in 2018 and residents on the Western Isles consume 25% more energy per capita compared to the mainland (i.e. Electricity, for residential and industrial activities; Kerosene and LPG for heating, cooking and industrial activities)*

Renewable energy potential *Western Islands have significant potential for renewable energy production, particularly from wind, tidal, and wave power. However, the limited capacity of the electricity grid in the area means that there are constraints on the amount of RE that can be produced and exported.*

Government policies and regulations: *The Scottish government has set ambitious targets for RE production, with a goal of 50% RE by 2030. However, there are concerns that the current regulatory framework is not conducive to the development of new RE projects, particularly in remote and isolated areas.*

Challenges:

- *Limited grid capacity and interconnection with the mainland grid, leading to potential grid instability and blackouts.*
- *High energy costs due to reliance on imported fossil fuels*
- *Extreme weather conditions and energy efficiency issues*
- *Exposure to supply interruptions*
- *Dependence on diesel generators for electricity generation in many areas, leading to high emissions and air pollution.*
- *High energy consumption and emissions per capita*

Opportunities:

- *High potential for wind power generation due to the island's strong and consistent winds.*
- *Organic waste used as feed to AD plant (esp. organic, grass, fish processing waste) can be sent to CHP for cogeneration.*
- *Carbon reduction from use of RES and energy storage, along with the production of green hydrogen.*
- *Strong government support for RES exploitation*
- *Potential for energy storage solutions, such as TES to shift energy usage from high-demand periods to low-demand periods, which can help reduce strain on the energy grid and lower energy costs.*
- *Energy management system to control and optimize energy usage, RES production, energy storage, etc.*

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5.2. Understanding Energy Intensive industries across Europe

The European economies heavily rely on energy-intensive industries, specifically the iron and steel, minerals, refineries, and chemical industries, which employ approximately 3.2 million people in the EU28 and contribute around 15% to the total value added of manufacturing in the region. The products generated by these industries are utilized by other sectors within the EU, and they serve as a competitive advantage for high-tech production. Nevertheless, achieving climate balance by mid-century necessitates a significant shift in the production methods of these energy-intensive sectors.(De Bruyn et al., 2020). In 2019, the industry accounted for roughly 26% of EU-28 final energy demand, mainly powered by gas, electricity, coal, and oil. Thus, the industry's transformation towards CO2-neutral production is crucial for European climate goals. High-temperature process heat, typically generated through steam or hot water or direct firing of furnaces, is the primary source of industrial GHG emissions, representing about one-fifth of all direct emissions. In the energy-intensive industries, emissions declined by almost 30% between 1990 and 2018: most profoundly in the iron and steel sector (-41%), followed by the cement and lime (-30%), chemicals (-27%) and refineries (-5%). As a result, reducing emissions by over 90% in the industry by 2050 requires various reduction options since process-related emissions are challenging to mitigate with available technologies (Wachsmuth et al., 2022). There are several energy-intensive industries in Europe, including:

- **Steel production**: The production of steel requires a significant amount of energy, particularly in the form of high-temperature processes like blast furnaces and electric arc furnaces. The EU is one of the largest producers of steel in the world, with major producers in Germany, Italy, and France.
- **Chemical manufacturing**: Many chemicals require energy-intensive processes, such as high-temperature reactions and the use of catalysts. Europe is a major producer of chemicals, with major producers in Germany, France, and the UK.
- **Cement production**: Cement is produced by heating limestone and other materials to high temperatures, which requires a significant amount of energy. Europe is the world's second-largest producer of cement, with major producers in Germany, Italy, and Spain.
- **Paper and pulp production**: The production of paper and pulp requires significant amounts of energy for processing wood, pulping, bleaching, and drying. Europe is a major producer of paper and pulp, with major producers in Sweden, Finland, and Germany.
- **Aluminum production**: The production of aluminum requires a significant amount of energy, particularly for the electrolysis process used to extract the metal from its ore. Europe is a major producer of aluminum, with major producers in Germany, France, and Italy.
- **Glass production**: The production of glass requires significant amounts of energy for melting and shaping. Europe is a major producer of glass, with major producers in Italy, France, and Germany.

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5.2.1. Challenges and barriers to sustainable energy transition of the energy-intensive industries

Nowadays, the sustainable energy transition of the European energy-intensive industries (EEII) faces several challenges and barriers. These challenges and barriers can be summarized as follows:

- **Lack of suitable infrastructure** for renewable energy, such as insufficient transmission and storage systems.
- **The intermittent nature of** some renewable energy sources, such as wind and solar power, also poses a challenge as it requires industries to have backup power sources.
- High capital costs of low-carbon technologies, such as carbon capture and storage, are also a significant barrier.
- **Regulatory barriers**, such as complex permitting procedures and uncertain regulatory frameworks, also hinder the transition towards sustainable energy.
- **Lack of expertise** to implement energy efficiency measures or adopt sustainable energy technologies.
- **Limited awareness among stakeholders**, including investors, policymakers, and industry leaders, about the importance of sustainable energy and the potential benefits of transitioning to RES.
- **Unequal carbon costs** might harm the competitiveness of EEII and cause carbon leakage.

5.3. Understanding food and drink sector across Europe

In Europe, the food value chain involves numerous processes, including farming, production, and transportation. This source of emissions contributes 94Mt CO_2e/year, equivalent to 11% of the emissions from the entire chain. The majority of emissions from European food and drink manufacturing are caused by energy usage, with 62% being consumed as heat and 38% as power from the grid. Cooling requires a relatively high proportion of electricity, a characteristic unique to this sector. However, decarbonizing heat consumed at high temperatures is currently the most challenging process using currently mature technologies. Due to the large number of processes and diverse range of products, creating specific decarbonization solutions for each plant or company in the food industry is more complex than in other sectors such as cement or iron and steel, which have a limited set of processes and fewer decarbonization options. The dispersed geographic location of food and drink manufacturing plants, unlike other industries, limits their access to modern or cleaner fuels infrastructure such as natural gas or green hydrogen networks. Nonetheless, this distribution allows the sector to generate jobs and economic value in rural areas or small cities.

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5.3.1. Challenges and barriers to sustainable energy transition of the food industries

The main challenges facing the food industry in terms of decarbonization include:

- High energy demand: The food industry is highly energy-intensive, requiring significant amounts of energy for heating, cooling, lighting, processing, and transportation. This high energy demand makes it challenging to transition to RES.
- Limited access to financing: The high upfront costs of investing in RE systems can be a significant barrier to adoption, particularly for small and medium-sized enterprises in the food industry.
- Variability in the quantities of energy used in different food manufacturing processes: The energy usage factor of an installation depends heavily on the product portfolio but also on other parameters such as plant age or plant size.
- Complex supply chains: The food industry has complex and fragmented supply chains, making it difficult to coordinate energy-efficient practices and integrate renewable energy systems.
- Waste management requirements
- Limited technical expertise: The food industry may lack the technical expertise and resources necessary to implement and manage RE systems effectively.
- Regulatory challenges: The food industry is subject to a range of regulations related to food safety, labeling, and packaging, which can create additional barriers to the adoption of RE systems.
- Limited availability of low-carbon fuels: The food industry may have limited access to low-carbon fuels such as natural gas or green hydrogen networks, particularly in rural areas or small cities.
- Decarbonizing high-temperature heat processes: High-temperature heat processes used in food manufacturing are currently challenging to decarbonize using mature technologies.

Overall, these challenges present significant barriers to decarbonization in the food industry and will require significant investment, collaboration, and innovation to overcome.

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5.4. Technology Matching

The following section discusses three main approaches for technology pairing to enhance decarbonization on islands and /or industries, which include pairing two or more technologies of the ROBINSON project, pairing islands'/industry's needs with available technologies, and pairing selected technologies with suitable stakeholders.

5.4.1. Matching technologies to enhance decarbonization efforts on islands

The technologies discussed in Chapter 4 can contribute to the decarbonization of islands through energy efficiency and RE production. Although they can be implemented as standalone solutions, many of them can generate greater benefits if combined with other proposed technologies. This section aims to explore potential synergies between different technological solutions for decarbonizing island energy systems. The subsequent paragraphs present potential technology pairings for solutions that impact either the island or building level. Following that, a matrix is presented to summarize the results of the analysis.

5.4.1.1. Island-level matching

The analysis of the selected technologies allows several potential pairings, particularly related to the use of renewable or green energy sources to supply high-efficiency energy conversion systems for different types of final users in island-level projects. The following are potential technological solutions that can contribute to island decarbonization as standalone systems but can also provide higher benefits if combined with other solutions. These solutions are:

- The installation of commercial and industrial (C&I) systems that use non-programmable renewable energy sources such as wind and solar, along with a suitable electricity storage system (battery or hydrogen-based) to meet demand and supply trends and minimize the use of fossil fuels for power generation.
- Combining solar photovoltaic energy with wind energy during the period when there is no sunlight at night.
- The use of cogeneration with biomass can transform 30-35% of its energy content into electrical energy and 50%-55% usable heat (overall efficiency exceeds 80%), respectively. The process involves first converting the biomass fuel into thermal energy, which is then used to generate both electricity and heat. The electrical energy is typically produced using a steam turbine or generator, while the waste heat is captured and utilized for heating or other purposes. Raw biomass collected from the field can be transformed by compacting, chipping, or grinding, while biomass transformed by thermochemical or biological processes can be used as fuel. Biogas produced from wastewater treatment plants, agricultural and livestock farms, and landfills can also be used for cogeneration, thereby generating electricity and useful heat.
- Installing a renewable energy system to supply power to important island-level production units. The need for an energy storage system depends on the size of the renewable power

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plant and the possibility of exchanging power with the local distribution grid, as well as the typical power absorption trend.

- Using produced sludges from wastewater treatment plants waste for biogas production through anaerobic digestion and subsequent cogeneration of heat and power for uses within and around the plant.
- Integrating cogeneration with existing or new district heating networks for thermal energy production. This solution, coupled with thermal energy storage systems where needed, provides heat and power to the final energy users in the island with lower primary energy consumption and GHG/pollutant emissions compared to the separate production of electricity and heat.
- Using locally available biofuels for cogeneration or heat-only production purposes, which can be easily integrated into existing or new district heating networks.
- Producing biogas through anaerobic digestion of organic wastes from residential, agricultural, or industrial activities, and subsequently using them for cogeneration or separate heat/power production.
- Smart-grid projects that incorporate renewable-based power generation plants, and energy storage systems with the latter technologies also play a role in demand management at the grid level.

5.4.1.2. Site-level matching

Beyond the technology pairing possibilities discussed in the previous section at the island level, there are additional opportunities for technology pairing at the site level, which refers to individual buildings or industries. While these opportunities are like those that could be implemented on the mainland, their potential benefits for reducing primary energy consumption and GHG and pollutant emissions are particularly significant in the island context. The opportunities identified are primarily related to heating and cooling, and include:

- Depending on local heating and cooling needs and availability of resources, this could involve using high-efficiency cogeneration of heat and power based on renewable fuels (biomass), using biomass for heat production, or recovering waste heat from a nearby industrial process.
- Installing a small-scale system for power generation from a renewable source in combination with hydrogen-based storage to supply the heating and/or cooling needs of the buildings. This solution is particularly useful as it supports most of production activities avoiding any seasonality issues.
- Combining cogeneration of power and heat with the production of cold through absorption chillers could operate as trigeneration.
- Utilizing locally produced residues and waste from food and/or agricultural product processing plants for biogas production through AD, and then using the resulting biogas for cogeneration or (less efficiently) separate heat/power production.
- Using residues and waste from wood processing and cleaning for biomass production and subsequent cogeneration or (less efficiently) separate production of heat and/or power.

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5.4.2. Combining Islands' Needs and ROBINSON's Technologies

The following sections focus on the groups of technologies presented in part XX and, for each, discuss the relevance and suitability for the different clusters of islands defined (by size/interconnection, latitude, geographical features, economic activities, etc.).

5.4.2.1. Electricity Production from Renewables in the context of ROBINSON project

This group of technologies includes electricity production from solar, wind, biomass. The pairing of the above-mentioned technology with the needs of the different clusters of islands is described in the following bullets:

- **Size/interconnection:** The proposed solutions can be applied to islands of all sizes. Large-scale plants can be installed more easily on larger or interconnected islands due to their higher electricity demand, and the excess electricity produced can be fed into the national grid and providing a backup energy supply when needed. However, non-interconnected island may benefit more in terms of relative decarbonization impact with the proposed solutions. Although interconnection can provide access to a wider range of RES, it may not be practical or cost-effective for all islands, especially those that are remote or have low population density. In such cases, energy storage systems and smart energy management solutions, such as ROBINSON's EMS for load management, are essential.
- **Latitude:** Southern Europe has a higher potential for solar power production systems due to the higher availability of solar radiation. However, the suitability of other technologies depends on the availability of the specific resource (wind, biomass, etc.) rather than latitude.
- **Geographical features:** Renewable power generation systems are applicable to islands regardless of their orographic configuration and urban/rural pattern. Mountainous islands may have slightly more potential for wind power, while rural islands may have higher biomass potential. However, significant variations may exist from case to case.
- **Economic activities:** Islands that rely primarily on tourism as a source of income tend to exhibit pronounced fluctuation in energy consumption over the course of the year, with the popularity of tourists peaking during the summer months. Hence, solar energy generation systems are particularly advantageous for islands, due to the temporal alignment of peak energy production with peak energy demand. Conversely, other sustainable energy production technologies that generate energy more regularly throughout the year must be correctly scaled to maximize their capacity even throughout low-output periods. Islands possessing primary economic activities such as agronomy, animal husbandry, and pisciculture may have a higher capacity for the application of biomass-related technologies. Renewable power production systems are applicable to islands with multiple economic activities, and their applicability is comparable to that of the mainland.

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5.4.2.2. Thermal Production from Renewables in the context of ROBINSON project

The feasibility of biomass as a source of thermal energy on the island is largely predicated upon the accessibility of appropriate feedstock. Despite this, there exists an essential demand for heating, rendering Northern European islands somewhat more feasible for this technology.

5.4.2.3. Cogeneration of Heat and Power

On a site level, CHP is suitable for buildings and industries that have a substantial energy demand for both thermal and electrical energy. In terms of installation in buildings, this solution is particularly advantageous for residential and office complexes in Northern-Central European islands. If the cogeneration plant is combined with an absorption chiller to create a trigeneration system, it may also be suitable for residential and office complexes in Southern Europe since it can fulfil summer cooling needs. In terms of industrial application, cogeneration has a higher potential in larger islands with diverse economic activities as there is a greater presence of industrial activities that require process heat. At the island-level and utility scale, this technology may only be applicable if a district heating system is in place. Therefore, the highest potential for this solution can be found in islands located in Northern-Central Europe and in islands with a concentrated urban population where district heating systems are typically found.

5.4.2.4. Energy Storage

In this paragraph, the topic at hand is energy storage systems within ROBINSON, which include battery storage and green fuel-hydrogen storage. P2G technology is commonly used to convert excess electricity into hydrogen for various industrial purposes, such as injecting it into a gas grid or storing it for later use. Industries are also recognizing the potential benefits of utilizing hydrogen as an energy source for the generation of thermal energy, electricity and/or for transportation purposes on a local scale. By using hydrogen for various energy demands in an industry premise the business can reduce their carbon emissions. However, the combustion of hydrogen for power generation (G2P) may result in increased NOx emissions. Ways to reduce NOx emissions from hydrogen combustion include optimizing combustion parameters, using low-NOx combustion technologies (i.e. lean-burn combustion or exhaust gas recirculation-EGR), and post-treating exhaust gases (i.e. selective catalytic reduction - SCR or lean NOx traps - LNT). Therefore, it is necessary to take appropriate measures to minimize NOx emissions when using hydrogen as a fuel source and ensure that they remain within acceptable limits.

All the cases where Power-to-Gas (P2G) is used to provide energy-related services to different energy sectors (like electricity and district heating) exist as district heating systems are where they are particularly useful (with a higher potential for Northern European islands with a significant population in urban areas) and in industrial applications (with a higher potential for large islands with developed industrial activities). When it comes to electricity storage, these solutions are most beneficial when combined with renewable power production systems or when the local electrical grid is being refurbished for peak shaving purposes as part of a comprehensive smart grid project. Consequently, the highest potential for these solutions is in small, non-interconnected islands.

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	Size/ Interconnection	Latitude	Geographical Features	Economic Activities
Cogeneration of Heat and Power	*No direct link to island area. A promising option for larger and more industrialised islands.*	*Because of the higher heating demand in Northern Europe, it is more practical for heating purposes; for industrial purposes, no specific correlation with the islands' latitude.*	*No correlation with island orography; Better suited to urban settings as part of a district heating system.*	*Greater applicability to areas with industrial activities; if combined with absorption chillers for trigeneration, also suitable to islands with a tourism-based economy.*
Electricity Production from Renewables	*There are no certain restrictions for islands. Utility-scale plants may be feasible to large, interconnected islands. Small non-connected islands could take greater advantages by exploiting small-medium sized renewable systems.*	*Solar systems are more effective in Southern Europe than in Northern Europe. Other technologies have no significant linkage with territory location and latitude.*	*There is no significant connection between geographical characteristics of islands such as orography and rural/urban context.*	*Solar solutions and small wind turbines are more suitable for tourism-based locations. In large areas with diverse economic activities, the suitability of renewable technologies is comparable to that of the mainland.*
Thermal Production from Renewables	*No specific restriction to islands' size. Thermal systems for hot water production are more applicable on islands with notable seasonality or industrialised areas.*	*For biomass, applicability is higher in Northern Europe due to the higher heating demand, bat also in industrialised islands.*	*There is no clear link with island orography. Relevant to industrialised islands. if used to supply heat to a district heating system, more urban-applicable.*	*No specific correlation with the main economic activities. In tourism-based and industrial islands, biomass-based systems on residential/ tertiary buildings fit well.*
Energy Storage	*Battery storage: mainly applicable in small non-interconnected islands for peak shaving purposes. Hydrogen storage: An attractive option for larger and more industrialized islands, but it is necessary to minimize NOx emissions when using hydrogen as a fuel source.*	*No specific correlation with latitude*	*There is no definite relationship between orography and urban/rural context. Thermal storage in district heating systems that are applicable in urban contexts with district heating networks is an exception.*	*In general, no specific correlation with islands' economic activities.*

Table 3 - Islands' Needs and ROBINSON's Technologies combining matrix.

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5.4.3. Matching between Robinson's solutions and Stakeholders

The following subsections focus on four technology categories: Electricity Production from Renewables, Thermal Production from Renewables, Cogeneration of Heat and Power, and Energy Storage. Each group is assessed based on its suitability for different stakeholders, such as public authorities and municipalities, public asset operators including DSOs, local utilities, and district heating network operators, as well as private companies like industries, and finally, energy communities.

5.4.3.1. Electricity Production from Renewables

This category of technologies encompasses electricity production from solar, wind, and biomass. Projects related to the installation of renewable energy systems and plants for the self-production of electricity can be carried out by various stakeholders, ranging from individuals, energy communities, and small companies that own individual buildings to large private complexes like hotels, supermarkets, and industries. On the other hand, large-scale plants such as solar or wind farms and biomass power generation plants are typically implemented by the local utility or private companies in partnership with the local utility and/or grid operator and authorities. These technologies are generally well-developed and readily available in the market, so private installations can be realized with investors' own funding or conventional loans from banks since they can typically generate sufficient cash flows to repay the loan.

5.4.3.2. Thermal Production from Renewables

The group of technologies for heat production includes solar thermal, biomass, and geothermal technologies. These technologies can be implemented on a small scale for self-production of heat by various stakeholders, such as individuals, energy communities, small companies, large private complexes (hotels, supermarkets, industries), and private buildings (schools, hospitals, offices, etc.). However, large-scale utilization of these technologies is only feasible if integrated into a district heating system. Therefore, the investment must involve the local DH operator and the local authorities, and their promotion is necessary. Like the previous group of technologies, these projects are highly mature and available on the market, so they can be realized by private entities with their own funds or conventional loans from banks. However, infrastructural projects related to district heating in cities can be supported by the local municipality and/or institutional national or EU funds.

5.4.3.3. Cogeneration of Heat and Power

Similarly, to the previous group of technologies, two main possible cases are identified for this solution:

- cogeneration plants to self-produce heat and power can be installed by any type of stakeholder with variable size depending on the energy needs;
- larger project foreseeing the installation of a larger cogeneration plant are typically promoted by or agreed with the local DSO and DH operator and the local authorities.

Technologies in this case have become established and readily available in the market. If considering the first scenario, funding must be provided through personal resources or conventional bank loans. However, in the second scenario, district heating projects can receive support from the local municipality and/or institutional national or EU funds.

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5.4.3.1. Energy Storage

This kind of solutions, related to electricity storage (battery or pumped hydro) or thermal energy storage, are almost exclusively of interest of the grid operators on the island (DSO for electricity, DH operator for heat, if present), or of utilities and private companies interested in selling this kind of service to grid operators. However, they might be of interest – at a smaller scale - also for energy communities and final users. They generally are implemented with own funds by the Companies, but being projects related to local infrastructures they may receive support from local authorities, as well as from national or EU funds.

	Municipality/Other Local Authority	Public Asset Operator	Private Company	Energy Community
Cogeneration of Heat and Power	*Such an application can be both small-scale, for self-production on public buildings, and at a larger scale to assist in supplying power and heat to the local grid.*	*It can be employed on a small scale for self-production on individual assets or on a bigger scope to contribute to the local electric or district heating infrastructure.*	*It benefits companies of various sizes that need constant power and heat. As an aggregator at the utility-scale to support both electric and district heating systems locally.*	*On a limited basis, it can provide electric power and thermal energy to community members for their individual use.*
Electricity Production from Renewables	*It is possible to generate electricity from renewables on a small scale for self-production on public buildings, or on a substantial scale to assist the promoter in supplying power to the local grid.*	*It is feasible to generate electricity from RES on a broad basis to aid the energy provider in providing energy to the regional electrical grid.*	*It provides advantages to companies for self-production to supply their operational need. As an aggregator at the utility scale to support electric power generation at the local level.*	*It is relevant at a limited scale for power supply to the own assets of community members*
Thermal Production from Renewables	*For self-production on public buildings or utility-scale help for heat supply to the local grid.*	*It can be executed on a low scale for self-generation or on an extensive basis for delivering surplus heat to neighbouring areas.*	*It can be accomplished either on a small scale as a means of self-generation or on a larger scale to provide thermal output or excess heat to the surrounding built environment.*	*It is applicable on a limited basis for providing thermal energy to community members.*
Energy Storage	*Assisting the responsible public-sector enterprise*	*Depending on the type of business (DSO, utility, DH provider, etc.), it can support nearby developed environment*	*It can support the secure and flexible supply of the system*	*It can be crucial, as it allows them to balance energy supply and demand, optimize energy usage, and increase RES use*

Table 4 - Robinson's solutions and Stakeholders matching matrix

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5.5. Combining industry's needs and ROBINSON's Technologies

Several technologies are available for Europe's energy-intensive industries to achieve carbon neutrality, including those that reduce CO_2 emissions from current processes (i.e. energy efficiency, carbon capture and storage), replace fossil fuels during production (i.e. electrification using renewable electricity, biomass, low-carbon hydrogen or other synthetic fuels), and develop new production pathways with a lower carbon footprint (carbon capture and utilisation; process intensification and circular economy). However, the main challenge is cost, with high upfront and operational costs creating a barrier to technology uptake. While carbon-free energy from these technologies was historically more expensive than energy generated by fossil fuel combustion, their costs have been steadily decreasing over time. Additionally, the external costs of fossil fuels, such as the impact on the environment and public health, are not always factored into the price of electricity generated by these sources. Therefore, it is important for businesses to consider the full costs and benefits of different energy sources when making decisions about their energy supply. Incorporating these expenses into the business plan can be a strategic decision for energy-intensive industries to reduce their long-term costs and increase their competitiveness in the market. Moreover, several of these technologies require integration into a broader framework that goes beyond the scope of the energy-intensive industries themselves, necessitating regulation in other sectors. This includes the establishment of guidelines for the ideal utilization of biomass and the provision of adequate renewable electricity sources to meet the rising demand of the industry. Additionally, significant investments in infrastructure for electricity and hydrogen networks, as well as carbon pipelines, are required for the implementation of several technologies (De Bruyn et al., 2020).

5.5.1.1. Electricity Production from Renewables

Electricity is a versatile power source that can drive multiple processes like heating, cooling, chemical separation, and electrochemistry. Along with the electrification of the industry (e.g., electric arc furnaces, heat pumps, electrical resistance heating, etc.), that could serve in balancing electricity grids, the industry has an increased potential for emission reduction by switching from fossil fuels towards electricity from renewables for the self-production. This category of technologies encompasses electricity production from solar, wind, and biomass. Large-scale plants like solar or wind farms and biomass power production plants are usually adopted by private firms in cooperation with the utility, grid provider, and officials.

5.5.1.2. Thermal Production from Renewables

There are several technologies available for heat production, such as solar thermal, biomass, and geothermal systems. The use of biomass in the industry is quite diverse, covering bio-based products, chemicals, and energy generation. To this end, ROBINSON offers biomass energy subsystems that can produce electricity or heat by utilizing organic materials (i.e., wood, agricultural waste, wastewater) considering the main circular economy principles. During periods of low demand, the energy generated can be stored and released during peak demand. In particular, the produced biogas through gasification or anaerobic digestion can feed biogas installations and convert the gas into electricity and heat locally using CHP systems instead of feeding it into the grid.

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Heat pumps are a highly efficient technology that can generate thermal energy from renewable sources. They operate by extracting heat from the air, water, or ground and then raising its temperature to a level appropriate for industrial processes or heating. Heat pumps require only a small amount of electricity to run, yet they can produce multiple units of heat for each unit of electricity consumed. As a result, heat pumps are widely regarded as a source of renewable energy, with only the electricity-driven movements considered non-renewable, depending on their origin. However, the suitability of heat pumps for some locations may be limited by the availability of renewable heat sources, such as geothermal energy, which can vary. Such types of projects are highly mature and available on the market, so they can be realized by private entities with their own funds or conventional loans from banks.

5.5.1.3. Cogeneration of Heat and Power

Biomass gasification integrated with a gas turbine-based combined cycle is regarded as the most efficient way to convert biomass into power. This technology is highly advantageous for generating high-temperature heat, a task usually performed through the combustion of fossil fuels. With the co-firing of product gas, industrial processes can substitute biomass or waste for fossil fuels when producing heat/steam. Therefore, the cogeneration plants that can produce both heat and power based on varying energy needs can be installed by any stakeholder. This solution is now established and available in the market. However, funding for this option must be sourced from personal resources or conventional bank loans.

5.5.1.4. Energy Storage

In this section, the energy storage system employed by ROBINSON, involving green fuel-hydrogen storage and battery storage is discussed. The utilization of P2G technology is often seen as a viable approach to converting excess electricity into hydrogen for a variety of industrial practices, among them preservation for later use. Stored hydrogen may be utilized in CHP systems to produce thermal energy and electricity for a localized generation. The utilization of hydrogen for satisfying various energy requirements in a sector can have a considerable effect on minimizing carbon emissions. Energy-intensive industries are turning to energy storage solutions to manage costs and reduce greenhouse gas emissions. Lithium-ion batteries are commonly used due to their high energy density, long cycle life, and low maintenance. Other battery technologies like lead-acid, flow, and sodium sulphur are also used based on industry needs. Large-scale battery storage systems are being explored by industries such as steel, mining, and oil and gas, integrating with renewable sources for reliable energy.

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5.6. Competitive landscape

5.6.1. Power to X

Power-to-X technology is a flexible energy storage solution that can help integrate renewable energy sources into the grid and reduce greenhouse gas emissions. By converting excess renewable energy into a storable form of energy, such as hydrogen, methane, or liquid fuels, it can provide a reliable and dispatchable source of energy that can be used when needed, reducing the use of fossil fuel energies and contributing to decarbonization. Additionally, Power-to-X could be used to optimize renewable energy generation in island regions, which have high potential for wind and solar energy, by enabling the use of excess energy for various applications like heat generation, industrial feedstock, power generation, etc.(Dahiru et al., 2022; Sorrenti et al., 2022)

There are three main solutions that are used nowadays:

- **Power-to-Gas (P2G) technology**, which is the process of converting excess renewable energy into hydrogen or methane using electrolysis or other conversion processes. This technology offers several benefits, such as providing a way to store excess renewable energy, decarbonizing the energy sector, and addressing the issue of energy storage for intermittent renewable energy sources. The current natural gas infrastructure can be used to store and move the product. The cost-efficiency of this technology is expected to rise as it advances and spreads. While this technology has the potential to significantly reduce GHG emissions, it also has limitations that need to be addressed. Among them is its high dependency on water resources and the amount of water required to produce hydrogen through electrolysis (9 kg of water per 1 kg of H_2). Additionally, combustion of hydrogen-based fuels can lead to the production of NOx emissions. Therefore, it is necessary to take appropriate measures to minimize these emissions when using hydrogen as a fuel source and ensure that they remain within acceptable limits. (Sorrenti et al., 2022; Malloupas et al.,2022)
- **Power-to-Liquid (P2L)** is a technology that involves the conversion of electricity from renewable sources into liquid fuels. The process typically involves the production of hydrogen through electrolysis, which is then combined with carbon dioxide to create liquid fuels such as synthetic gasoline, diesel, or kerosene. These fuels can be used in various applications, including transportation and industrial processes. The P2L technology offers potential benefits such as reducing carbon emissions from the transportation sector and providing a way to store excess renewable energy. However, the process is currently expensive and not yet commercially viable at scale.(Dahiru et al., 2022)
- **Power-to-Heat (P2H)** is a technology that involves the conversion of electrical energy into heat. P2H systems use excess electricity generated from renewable sources or during periods of low demand to generate heat, which can then be used for space heating, water heating, and industrial processes. This technology offers several benefits, such as reducing the reliance on fossil fuels and contributing to the integration of renewable energy sources into the grid. P2H can also provide a cost-effective and flexible solution for managing electricity demand and supply imbalances. A P2H system can, however, be limited by the characteristics of the heat conversion process and the type of electrical grid.(Monie et al., 2022)

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The principal actions of this technology involve energy capture (power conversion to X), energy storage, energy transport and energy valorisation. Therefore, many stakeholders are usually involved. Regarding the business models the value proposition of this technology satisfies several needs of the market: 1) Control of power markets by converting hydrogen to electricity in the absence of renewable energy, 2) Stability of the electrical system by managing the voltage and frequency, 3) Increasing the use of renewable energy sources and preventing congestion in the grid by storing excess energy as heat or hydrogen for later use, 4) Eliminating the curtailment of produced renewable energy, supporting the energy system's flexibility and reliability and 5) Shifting the load and peak reduction.

In Table 5, some examples of businesses for P2G for industries and/or isolated systems are presented:

Company	Short description	Web address
MAN Energy Solutions	German manufacturer of diesel engines and turbomachinery which has also recently ventured into manufacturing hydrogen electrolyzer. It is part of Volkswagen group.	https://www.man-es.com/
Nel Hydrogen	Norwegian based hydrogen electrolyzer solution provider which was established in 1927. Through years of its presence it has developed unique expertise in electrolyzer technology	https://nelhydrogen.com/
ITM Power	UK based hydrogen energy solution provider. One of the members of UKH2 mobility programme	http://www.itmpower.com/
Alfa Laval	Alfa Laval is a leading global provider of first-rate products in the areas of heat transfer, separation and fluid handling. With these as its base, Alfa Laval aims to help enhance the productivity and competitiveness of its customers in various industries throughout the world	https://www.alfalaval.com/
H2V PRODUCT	H2V is investing in, developing and constructing large-scale renewable hydrogen production plants (100MW or more) to decarbonise particularly carbon-intensive sectors, such as industry and heavy-duty transport.	https://h2v.net/
HydrogenPro	HydrogenPro designs and supplies large scale hydrogen production plants in cooperation with global partners and suppliers, all ISO 9001, ISO 45001 and ISO 14001 certified.	https://hydrogen-pro.com/
H2B2	Provides Innovation, Design, Engineering, Manufacturing, Integration, Financing and O&M for modular hydrogen production systems, using water electrolysis.	https://www.h2b2.es/

Table 5 - Examples of businesses for P2G for industries and/or isolated systems

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5.6.2. Power to Storage

Power to storage (P2S) refers to the technology and process of converting electrical power into stored energy, which can be used later when needed. This technology is critical in supporting the integration of intermittent renewable energy sources such as wind and solar into the power grid, as it helps to manage the variability of these energy sources. Power to storage technology typically involves the use of batteries or other energy storage systems, such as pumped hydro storage, compressed air storage, or thermal energy storage. These systems store electrical energy generated during times of high RE production and low demand and release it back to the grid during times of high demand or when renewable energy production is low. The power to storage technology has several advantages, such as reducing the need for new power generation infrastructure, increasing grid reliability and stability, and reducing GHG Emissions. However, it also has some limitations, such as the cost of storage systems and the limited storage capacity that is currently available. Despite these limitations, power to storage technology is rapidly advancing, and it is becoming an increasingly important component of modern power systems as the world moves towards a cleaner and more sustainable energy future.(Mitali et al., 2022) In Table 6, some examples of businesses for P2S for industries and/or isolated systems are presented:

Company	Short description	Web address
C&D Technologies	C&D's VR Solar line features various battery sizes and shapes that incorporate state-of-the-art DCS Technology, providing a VRLA battery with superior cycle life. For applications that require high energy density and a compact design, C&D Lithium-Ion systems are available. C&D provides also the necessary equipment for these systems such as racks, trays, cabinets, battery monitoring, and battery chargers.	https://www.cdtechno.com/
Tesla	Tesla, Inc. produces the Powerwall and Powerpack, which are lithium-ion battery stationary energy storage products that can be recharged. The Powerwall is designed for home energy storage and can store electricity for various purposes, like solar self-consumption, time of use load shifting, backup power, and off-the-grid use. On the other hand, the Powerpack is a version intended for commercial or electric utility grid use. It can perform multiple functions, including peak shaving, load shifting, backup power, demand response, microgrids, renewables integration, frequency regulation, and voltage control.	https://www.tesla.com/
Samsung	Samsung SDI's ESS technology offers tailored solutions for the various needs of users in the	http://www.samsungsdi.com

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Company	Short description	Web address
	electric power market. With a range of options from kWh to MWh, ESS provides both economic benefits and strong reliability, thanks to its long-lasting life, safety features, and excellent performance. These solutions include utility, residential, commercial, and UPS, making them applicable to everyday life and helping to lead the green energy industry.	
Bosch (Geo Green Power)	Bosch energy storage systems provides ability to store the excess solar energy produced during the day, allowing to power a house throughout the night. A solar panel system will be producing energy, even when it is not needed. Installing a Bosch battery storage system will save this energy for when it is needed.	https://www.geogreenpower.com/battery-storage/bosch/
Mitsubishi Power Europe	Mitsubishi Power is creating a future that works for people and the planet by developing innovative power generation technology and solutions to enable the decarbonization of energy and deliver reliable power everywhere.	https://power.mhi.com/
Rubitherm	Rubitherm® Technologies GmbH is an expert in PCM technology and develops specific product solutions. They deliver inorganic and organic PCMs in large and small quantities. Their products offer various melting and freezing point and characterised by their cycling stability and their heat storage capacity.	https://www.rubitherm.eu/
Piller	Piller offers a kinetic energy storage option (POWERBRIDGE™) that ensures reliable energy storage levels without the need for future environmental disposal management. One crucial advantage of the POWERBRIDGE™ is its ability to absorb energy at the same rate that it can dissipate, making it ideal for ensuring frequency stability under dynamic load conditions., The POWERBRIDGE™ consists of a vertically mounted flywheel and generator that uses magnetic bearing technology. It comes in different sizes to accommodate various power ratings and ride-through autonomy requirements.	https://www.piller.com/en-GB

Table 6 - Examples of businesses for P2S for industries and/or isolated systems

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5.6.3. Waste to Energy

Waste-to-energy (WtE) technology is a process of generating energy in the form of electricity or heat from the thermal treatment of waste materials. This process not only assists to manage waste disposal but also produces a source of renewable energy that can be used to power homes and industries.

There are several types of WTE technologies available, but the most common ones include:

- **Incineration**: This is the most common WtE technology, where waste is burned at high temperatures to generate steam, which then powers a turbine to produce electricity.
- **Gasification**: This is a process of converting waste materials into a gas called syngas, which is then used to produce electricity or heat.
- **Pyrolysis**: This is a process of heating waste materials in the absence of oxygen, which produces a liquid called bio-oil that can be used to generate electricity or heat.
- **Anaerobic digestion**: This is a process of breaking down organic waste materials, such as food waste, into methane gas, which is then used to generate electricity or heat.

The benefits of WtE technology include reducing landfill waste, generating renewable energy, and reducing greenhouse gas emissions. Overall, WtE technologies have been recognized as clean energy technologies which have the capability of ensuring clean society and foster energy security by leveraging on the possibility of reducing the adverse environmental impact occasioned by waste generation and ensuring production of renewable and sustainable energy while achieving circular economy.(Alao et al., 2022)

Table 6 summarises indicative businesses for WtE for industries and/or isolated systems are presented:

Company	Short description	Web address
Veolia Environment SA	Veolia contributes to meet the increasing demand for RE and strives to develop solutions that provide green energy to its customers whenever feasible. Through the combustion of non-recyclable waste, these solutions generate electricity and heat that can be used to meet the energy needs of local industries or households.	https://www.veolia.com/fr
Mitsubishi Heavy Industries Ltd	Mitsubishi Power in Europe, the Middle East and Africa (EMEA) is a leading provider of innovative technology and solutions for the energy sector. Advanced gas engines that use hydrogen, battery energy storage for short-term storage, and hydrogen for long-term storage are among their options. To support regional growth, they offer waste-to-energy products.	https://www.mhi.com/

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Company	Short description	Web address
Martin GmbH	Martin GmbH provides solutions to address present-day challenges and develop tomorrow's technologies, making a significant contribution to shaping our future. Their plants and components enable the optimal and sustainable treatment of waste. As a leading global supplier of plants for thermal waste treatment, Martin GmbH offers our municipal and private customers comprehensive services throughout the entire lifespan of our plants.	https://www.martingmbh.de/
Babcock & Wilcox	With over 150 years of experience, Babcock & Wilcox Company and its subsidiaries specialize in providing efficient energy and environmental systems. B&W's expertise in waste-to-energy (WtE) includes advanced Vølund™ technology which has been developed and refined for the past 80 years. This state-of-the-art technology has been utilized in over 650 applications, demonstrating its ability to offer tangible and sustainable advantages.	https://www.babcock.com/
Hitachi Zosen Inova Steinmüller	. HZI Steinmüller has introduced many innovative technologies into the industry, including the world's first water-cooled grate, Inconel cladding used in Waste to Energy plants, and the first industrial SCR large-scale plant in Europe. All of these demonstrate the company's commitment to innovation and paving the way for the future of the industry.	https://www.hzi-steinmueller.com/
KleanIndustries	Klean Industries Inc. (as in "clean") is an environmentally conscious industrial solutions company focused on providing clean energy and recovered resources to various industrial manufacturing sectors. They pay special attention to the implementation of energy production, resource-recovery, and recycling solutions which aid in the development and creation of the circular economy we all want and need.	https://kleanindustries.com/

Table 7 - Examples of businesses for WtE for industries and/or isolated systems

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5.6.4. Energy Management Systems - EMS

An EMS is an essential component for maintaining the stability of power technology and distribution structures when integrating distributed power generation sources that fluctuate widely. Specifically, the integration of renewable energy sources can cause fluctuations in the energy supply and demand ratio, causing critical problems in the energy grid/system (electricity, heat, gas, etc.). A major function of the EMS is to balance the energy ratio between supply and demand and reduce peak loads during unplanned periods. Optimising the energy flow to meet the demands of the power grid helps manage electricity, heat or gas generation and consumption. As an example, the EMS can automatically moderate the power consumption of non-critical loads when there is a high demand for electricity or use stored energy from energy storage systems to reduce the grid load. Moreover, an EMS can enable the distribution of energy among various energy sources present in the energy grid/system, thereby serving in the preservation of equilibrium in the electricity supply and demand proportion. The surplus renewable energy can be conserved in energy storage systems for utilization during low-generation or high-demand periods. This measure aids in maintaining the stability of the power grid and mitigating the likelihood of power outages and other system disruptions. In addition, an EMS possesses the ability to provide power to loads in a cost-effective, dependable, and efficient manner, while meeting all requirements for the functioning of the power grid. The optimization of energy resource utilization is based on factors such as availability, cost, and reliability. This is done to ensure that the synchronization of power generation and consumption meets the requirements of the grid. The implementation of this measure has the potential to enhance the overall efficacy of the power grid and mitigate the financial burden of electricity expenses for end-users. (Meliani et al., 2021)

The field of energy management encompasses various topics that can be grouped into three categories: smart transmission system, smart distribution system, and demand side. The central optimization of the transmission system is a significant approach in energy management, wherein a highly efficient computing system and secure network communication are used to manage energy use. This centralized structure can be an aggregator or a utility that collects information from each node, such as energy consumption patterns and energy production, to run optimization programs for effective operation, focusing on how RES energy can contribute to large-scale use, as well as the potential of demand-responsive flexible loads. (Meliani et al., 2021)

On the other hand, energy management of the smart distribution system and demand-side optimization involves autonomous cooperation of various rational structures, such as DERs, microgrids, energy storage, smart homes and buildings, plant energy management systems, and others. For example, power sharing between interlinked microgrids can improve economics and reliability in the operations system, and a distributed energy management approach using combined heat and power generation is proposed for interlinked microgrids operations. Quantification methods and other schemes implemented in an EMS include:

- **Uncertainty management techniques:** The integration of new technologies such as RES, demand side management, energy storage facilities, and distributed generation sources is making the power grid smarter. However, these technologies also bring uncertainties that can affect the reliability and safety of the system. Uncertainties can be categorized into two types:

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technical and economical. Technical uncertainties can be further divided into topological and operational parameters, while economic uncertainties can be classified into macroeconomic and microeconomic parameters. To deal with uncertainties, various modelling techniques have been implemented in EMS. (Rathor and Saxena, 2020)

- **Power Quality Management:** Power Quality Management covers two categories of disturbances: variations and events. Variations, such as voltage slow variations, flicker, unbalance, and harmonics, are measured and evaluated continuously, while events occur unpredictably and require a tripping action for measurement. Power Quality Management aims to minimize the impacts of internal and external disturbances or events that may affect the operating time or performance of a specific facility or process. Besides, it ensures that power quality is distributed to users based on the load and source at their premises. In traditional EMS, the focus was on dispatching and scheduling, with power quality dealt with at another control layer. However, due to the deregulation of the electricity market, the preservation of high-power quality has become critical for utilities to attract and retain clients. (Rathor and Saxena, 2020)
- **Demand response and demand management:** Demand response (DER) and demand side management are two distinct but related concepts in the field of energy management. While both aim to improve the efficiency and reliability of the power system, demand response is a short-term, reactive measure that encourages users to reduce energy demand during peak hours or in response to market signals. Demand-side management, on the other hand, is a broader, more proactive approach that includes a range of permanent or long-term measures to increase energy efficiency, such as retrofitting buildings or upgrading appliances. Both Demand response and Demand side management can be valuable tools for managing energy demand, but they operate on different time scales and involve different strategies (Customer load profile, Load shaping, Load shifting, Peak clipping Flexible load shaping). Customer load profile is indeed a useful guide for implementing demand management strategies. By analysing the load behaviour of different customer segments, utilities can identify opportunities to shift or reduce load during peak periods, and to fill in valleys during off-peak periods. Load shaping objectives refer to the different strategies that utilities can use to optimize the load profile of their system. Load shifting involves moving certain loads from peak to off-peak periods, while strategic conservation focuses on reducing overall energy consumption through measures such as energy efficiency upgrades. Peak clipping involves reducing the peak demand of the system by curtailing certain loads or encouraging customers to reduce their energy usage during peak periods. Flexible load shaping strategies aim to maintain a balance between supply and demand by adjusting loads in response to changes in the system. Strategic load growth aims to stimulate demand during off-peak periods to better utilize available capacity, while valley filling involves shifting loads to fill in periods of low demand. By using a combination of these load-shaping objectives, utilities can achieve a more efficient and reliable power system, while also reducing costs and improving customer satisfaction. Overall, demand-side management is a critical component of modern energy management, and utilities must carefully analyse load profiles and develop effective

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strategies to optimize their system's performance. (Bakare et al.,2023; Rathor and Saxena, 2020)

ROBINSON focuses on end-user EMS, which includes basic energy information portals, maintenance programs, energy consumption benchmarking, automated control, energy system layout optimization, ongoing performance analysis, demand response, energy dashboards, measurement and verification, notifications, and alerts. With the rise of DER and IoT, there has been an increasing trend towards energy management systems. Major market players providing such solutions include Siemens, ABB, Schneider Electric, GE, and Eaton.

In Table 8, some examples of businesses for EMS for industries are presented:

Company	Short description	Web address
Advantech	Though IoT technology, the Factory EMS system provides the optimization of energy supply and consumption to reduce CO_2 emission and factory operation costs. The system includes Energy consumption & Heat recovery, as well as RES and gas energy monitoring system	https://www.advantech.com/
ABB	ABB Ability™ Energy Management System for industries helps you deliver on your sustainability commitments and maximize energy cost savings	https://new.abb.com/
Mitsubishi Power	The energy management systems offered by DIASYS Netmation provide integrated monitoring of the various facilities and utilities used inside customer plants, and by visualizing the state of plant-wide energy usage, support customers' analysis work and operational improvements.	http://www.itmpower.com/
Siemens	To lower your energy costs, increase your competitiveness and comply with statutory requirements, end-to-end energy management is essential. Siemens offers SIMATIC Energy Management a comprehensive, scalable portfolio of products and solutions.	https://www.siemens.com

Table 8 - Examples of businesses for EMS for industries

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6. Conclusions

The purpose of Deliverable D6.2, the Market Assessment Report on ROBINSON's solutions, is to provide essential information about relevant markets, including the energy storage market, electricity market, gas market, and district heating. The assessment serves as a foundation for developing future business models (D6.3). Consequently, the analysis methodology and structure have been adjusted to align with the business model approach's future application. The report's structure is based on fundamental questions that must be addressed before entering the market, developing business plans, strategies, and project focus.

The initial section delves into general aspects of the market and explains the clean energy vision and the net zero emission by 2050 strategies. It also analyses several factors related to energy production from RES, final energy consumption by end-use, the origin of imports for energy use, energy flexibility, the share of renewables, EU levelized cost of electricity, hybrid renewable energy systems, and European energy generation and distribution schemes. In addition, the section examines European energy producers, energy regulation on innovative generation technologies, RES-grid connectivity, energy prices, small islands regulatory conditions, and other relevant factors related to energy generation and distribution in Europe. Overall, the first part provides a comprehensive overview of the market conditions that are relevant to the energy sector, including the regulatory environment, cost structures, and other key factors that affect the energy market in Europe.

Section 3 focuses on the executed questionnaire survey executed to map the market aspects in partners' countries. Based on the survey responses, it can be concluded that RES growth in EU countries has not yet achieved its full potential over the past five years. The use of RES is expected to increase over the next five years, though. Industries and households are both RES's end consumers. The survey's participants expressed a strong interest in electrochemical and thermal energy storage systems. The need for energy independence has also increased as a result of rising power costs, with more and more consumers looking to investigate and safeguard their energy sources. Support and encouragement for local initiatives, quicker and more effective license processing for RE development, and financial incentives to lower upfront investment costs are some crucial suggestions for promoting the use of HRES. Requirements like dependability, efficiency, stability, and applicability are crucial when engaging in HRES systems. HRES installation must be done with the utmost care, and correct design and placement are key considerations. Investment in RES is affected by things like keeping money in the bank, boosting the reliability of the energy supply, and making money.

After the previous section, an overview is presented of ROBINSON's modular technologies that are designed to aid in the energy transition of islands and isolated systems. The aim is to provide a goal-oriented perspective, highlighting the strengths and weaknesses of these technologies, as well as identifying potential complementarities that can maximize the decarbonization impact. Additionally, customer segments were identified for the scalable solutions demonstrated in this project, indicating their potential for replication.

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The subsections on Matching Robinson's solutions and Stakeholders provide insights into the suitability of different RE technologies for various stakeholders, such as public authorities, utilities, and private companies. It explores four categories of technologies, including electricity and thermal production, cogeneration, and energy storage. While private installations can be funded through investors or bank loans, larger projects may require support from local authorities or national/EU funds. The matching of Robinson's solutions with stakeholders provides a framework for the successful implementation of renewable energy technologies in isolated systems.

The main challenge for energy-intensive industries to adopt these technologies is cost, with high upfront and operational costs creating a barrier to technology uptake. In addition, several of these technologies require integration into a broader framework that goes beyond the scope of the energy-intensive industries themselves, necessitating regulation in other sectors. Several technologies are offered by ROBINSON, including electricity production from renewables, thermal production from renewables, cogeneration of heat and power, and energy storage are relevant to support industries in reducing their carbon footprint, but funding for their implementation must be sourced from personal resources or conventional bank loans.

The final part of the deliverable focuses on assessing competitors and Robinson's value proposition. Numerous competitors were identified, leading to a highly competitive environment. Despite being in the early stages of development, the Power-to-X market is viewed from an end-user perspective as having significant potential for innovation. However, each solution has its limitations and challenges, such as cost, efficiency, and scalability. The technology's value proposition meets various market needs, such as managing power markets, stabilizing the electrical system, boosting the use of RES, and reducing grid congestion. Several stakeholders participate in the energy capture, storage, transportation, and monetization of Power-to-X technology.

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8. APPENDIX

8.1. Distributed questionnaire

The main objective of this task is to record the attitudes, perceptions, and considerations of the HRES market and to investigate opinions on market growth, the adequacy of the existing workforce and the quality of current installations, as well as to measure the satisfaction level of HRES investors as concerns for the quality of the installation process. The results will be useful for a further Market Analysis for Robinson's Task 6.2

Please fill in your contact details (optionally):

Name:

Title:

e-mail:

Company name:

Your main role/responsibilities within the organization mentioned above

Electrical/ Mechanical engineer	☐	Technology Provider	☐	HRES company owner	☐
Technician /Installer	☐	Consultant/Designer	☐	Public servant	☐
Civil engineer/Architect	☐	Researcher/Academic	☐	Other (Pls specify): ____________________	☐

What is the primary interest of your company in investing in RES technologies?

Decision Driver	**Rank** (0 - 5)	Comments
Reducing energy bills		
Reducing carbon offsets		
Protection from price fluctuations		
Energy independence		
Enhancing energy efficiency		
Energy supply reliability & stability		

Improving environmental footprint		
Other (Pls specify): _______________		

- RES technologies in your country

1. What is your opinion on the RES market growth in your country during the last five (5) years?

Significantly low				Significantly high
1	2	3	4	5

2. Which proportion (%) of the national, regional, and local energy consumption is derived from renewable sources?

National level	Regional level	Local Level

3. What are the most prevalent RES technologies installed in your region?

Energy Source	**Nominal Capacity (KW)**	**Typical configurations and scale of Installation**
Hydro power (HYDR)		
Photovoltaics (PV)		
Solar (ST)		
Wind (WT)		
Geothermal (GT)		
Marine (MA)		
Biomass (BM)		
Biofuels (BF)		
Other (Pls specify): ____________________		

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4. What categories of end-users are commonly served by RES technologies in your region?

Industry	☐	Households	☐	Agriculture	☐
Tertiary sector	☐	Ground Transport	☐	Maritime, Aviation	☐

5. Determine what type of energy storage (if any) is available in your area?

Electrochemical storage technologies (batteries: Lithium-ion, sodium-ion, redox flow, zinc-air, and lithium-sulfur)	☐	Hydrogen storage	☐	Electrical storage technologies (supercapacitors)	☐
Thermal storage technologies (heat fluid storage, PCM)	☐	Mechanical storage technologies (pumped hydropower, compressed air, flywheels)			☐
Other (Pls specify): ________________	☐				

6. What kind (if any) of hybrid renewable energy (HRES) or/and cogeneration schemes exist typically in your region?

CHP	☐	PV+WT+BATTERIES	☐	PV+GT	☐
PV+ST+BM	☐	HYDR+WT	☐	WT+MA	☐
PV+H2	☐	BM+BF+CHP	☐	Other (Pls specify): ____________________	☐

Please define the selection criteria for HRES systems compared to the independent alternatives in your region.

Decision Driver	Rank (0 - 5)	Comments
Reducing energy costs		
Improving energy supply		
Energy independence		

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Energy supply matching to demand		
Energy supply reliability & stability		
Improving environmental footprint		
Other (Pls specify): ________________________		

7. In your opinion, what is the impact of the barriers hindering the deployment of HRES or individual RES?

Significantly low				Significantly high
1	2	3	4	5

8. What are the main determining factors that could accelerate the development of HRES market, in your opinion?

	Not important			Very important	
a) Simplified licensing procedures	1	2	3	4	5
b) Financial Incentives	1	2	3	4	5
c) Further development of the national RES technology	1	2	3	4	5
d) Training (lifelong education) of technicians/installers	1	2	3	4	5
e) Certification of systems/ installations	1	2	3	4	5
f) Favorable legal framework - Adoption of European Directives	1	2	3	4	5
g) Minimum requirements for energy efficiency in industries	1	2	3	4	5
i) Communication Campaigns/ Dissemination	1	2	3	4	5
j) Other (Pls specify): ________________	1	2	3	4	5

9. Please write your suggestions/comments, for any further measures /incentives that have to be considered in order to promote HRES systems in your country.

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10. What is your opinion on the current number of HRES systems, considering the maturity and market conditions in your country?

Totally unsatisfactory				Totally satisfactory
1	2	3	4	5

Please justify your opinion briefly.

11. How do you value the perspectives of RES usage in your country, for the next 5 years?

Totally Pessimistic				Highly optimistic
1	2	3	4	5

12. From a professional perspective, what would be the main concerns associated with investing in an HRES system?

- Installation's quality and performance

13. How do you value the quality of HRES systems' installations in your country today?

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Totally unsatisfactory				Totally satisfactory
1	2	3	4	5

14. How often are there operational problems in HRES systems, due to technical failures during installation?

Never	Rarely	Sometimes	Frequently	Very often
1	2	3	4	5

15. How important do you think the following parameters for the quality and efficiency of HRES system's installation are?

	Not important			Very important	
a) Proper design	1	2	3	4	5
b) Installation's Location	1	2	3	4	5
c) Selection of appropriate equipment	1	2	3	4	5
d) Training /Experience of technical staff	1	2	3	4	5
e) Applied quality standards /Certification	1	2	3	4	5
f) Other (fill in)	1	2	3	4	5

16. How do you rate the level of the relevant experience/training of the technical staff in your country?

	Significantly low			Significantly high	
a) Design/Sizing	1	2	3	4	5
b) Electrical design	1	2	3	4	5
c) Mechanical design	1	2	3	4	5
d) Safety Rules	1	2	3	4	5
e) Integration in buildings	1	2	3	4	5
f) RES system's maintenance	1	2	3	4	5

17. In your opinion, how can the following characteristics influence your decision to invest in RES?

	Not important	Very important

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a) Reduction of Greenhouse Gas Emissions	1	2	3	4	5
b) Saving money from reduced electricityconsumption	1	2	3	4	5
c) Increasing the reliability of your electricity supply	1	2	3	4	5
d) Interest in new technology	1	2	3	4	5
e) Earning money/making profit	1	2	3	4	5
f) Other (fill in)_______	1	2	3	4	5

18. What is your stance towards the establishment of specific quality standards regarding system's installation?

	Very negative				Very Positive
a) Equipment certification	1	2	3	4	5
b) Systems certification according to international quality standards	1	2	3	4	5
c) Certified training of technicians/installers	1	2	3	4	5