RENEWABLE ENERGY SYSTEM FOR FUTURE ENERGY IN EUROPE

Lappeenranta–Lahti University of Technology LUT

Master's degree in Bioenergy System 2023

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ABSTRACT

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This thesis is written and researched based on the actual current situations of European Energy’ crisis happened from 2020 to currently (2023) as well as the outlook of European’s Future Energy in 2030 with different scenarios. In the first part of this thesis, the main topics are the status of Energy uses and production in Europe from 2020 and the changes of energy status in 2030. In the second and third part, the future energy in Europe will be presented with strategic plans and actions which are needed to complete the Green Transition pathway in Europe from 2030 toward to 2050. The final part refers to updated on-going technologies related to Renewable Energy sectors in Europe with example of Nordic’s Green Revolution is given as the great result of successful RES model which is very possible to be able to apply to all other countries in Europe in the future.

Through all of the chapters of this thesis, the overview of Europe’s Energy sector was captured and the picture of future energy for Europe was created which showed clearly the potential part of Europe Renewable Energy resources can be used and which other regions of Europe need to have more clear strategic plans, technology and solution to boost all EU nations to adapt for the same common goals for (climate targets, green energy targets).

This thesis also provides some comparison ideas and personal analysis about conversion transmission pathways from fossil energy to green energy. The analysis and evaluation for this thesis is evaluated from actual on-going in energy engineering and technologies in Europe’s energy transition for period 2023-2035 with number of hand-on studies in over the world, especially from renewable energy companies.

In final, the thesis has identified the needs and actions for EU’s energy policy, investment on the new technologies based on energy trends (Hydro production, Carbon Capture and Storage, Bio-Combined Heat and Power) and taking serious study case from Nordic Green Transition as the good model to study and apply for all the rest of other EU countries.

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I would like to thank Professor Esa Vakkilainen for giving me the clear and correct direction for my thesis topic. Via having discussion with him, I have learnt and got impressed with passion about completing my thesis to the end. Together with him, I would like to also thank Research Doctor Satu Lipiäinen who is my second examiner but also the person who helped and supported me in all questions related to the thesis frameworks and processes for completing my thesis and heading to the final graduation.

Together with support from my university, I also got the support from Renewable Energy Industry Group in Linked In where I have joined since 2017, with all of members who are expertise and engineers who works in the energy fields, it is so honours for me to get to know them and to learn from them as well as to learn the new on-going technologies and innovation which they are working on to make our world better. Thank you all for this big support to my final Thesis at LUT.

Abbreviations

IRENA	International Renewable Energy Agency
IAEA	International Atomic Energy Agency
CCS	Carbon Capture and Storage
DAC	Direct Air Capture
EGD	European Green Deal
EU ETS	European Emissions Trading System
FAWS	Forest Available for Wood Supply
HVO	Hydrotreat Vegetarian Oil
LTES	Long-term energy scenarios
DGT	Digital Grid Technology
NTC	Network Transfer Capacity
ENTSO-E	The European Network of Transmission System Operators
AIT	Advanced Intelligent Transformers
ADT	Advanced Digital Twins
DSS	Digital Secondary Substation
CAPEX	Capital expenditure (CAPEX)
OPEX	Operation expenditure
CHP	Combined Heat and Power
NCES	Nordic Carbon Capture Energy and Storage
ESR	Effort Sharing Regulation

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1 Introduction

The world is living with unpredictable time for energy. In the last 3 years recently, the world has experienced severe crisis related to many problems such as armed political conflicts that have occurred scattered all over the world; global warming and climate change have led to droughts, floods, earthquakes, volcanoes, and wildfires in many countries around the world. The corona pandemic started in late 2019 has spread to all over the world and millions of people have lost their lives or fell into unemployment situations and various other’s difficulties. But these are not the only problems, the world is currently facing serious challenges related to energy crisis, specifically from February 2022 after the invasion of Russia to Ukraine or so call Russian-Ukraine War now, the situation of Europe and the world has changed a lot. The Europe became dependently on the energy import such as oil and natural gas from Russia for a long time before. After the war started, their energy security is unsecured and serious deficiency based on hundreds of sanctions from EU to Russia to stop importing their oils and natural gas into Europe where Russia is the biggest provider energy sources to all of EU countries for decades. The sudden changes have led to many systematically problems to all European countries such as inflation rises, energy price raised, food prices rinsed and living cost of people are under stress. Europe and the rest of the world are also facing to the biggest economic crisis again. By taking serious actions from current problems, the European Union has been trying to unite and work together to find solutions to secure their energy sources and stopping the dependence of energy sources such as oil and natural gas from Russia. This is a good and right time for Europe to take real actions on replacing fossil fuels to renewable energy, cutting down new permits for nuclear power plant construction, zero emission to protect environment. The targets of Europe on the matters of energy are very clear and well instructed by actively actions from European Commission as well as each of member state. In this first chapter, the status of EU’s energy consumption and production will be presented to compare to the future energy consumption and production in 2035 with purpose of finding out what are changes from now to 2025 for Europe’s energy.

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1.1 Status of EU energy's production and consumption in 2021

EU Energy production has different sources and types such as nuclear energy; renewable energy; natural gas, oil, or solid fuels but the Renewable energy plays in important key and keeps the highest share of the energy production in Europe (41%) in 2021.Nuclear Energy plays the second highest shared 31% which included 18% for solid fuels; 6% for natural gas and crude oil (3%). One of the countries in European which produces only the renewable energy, not anything else is Malta while France keeps high record of nuclear energy (76% of total energy production), Belgium 70% and Slovakia 60%. Depend on the regions, each of EU member has different share of energy production based on the fuels type such as Denmark with 35% of crude oil and Ireland (42%), Netherland has 58% of natural gas while other countries such as Poland and Czech Republic use solid fuels as the main source for energy production. The below figure 1 will describe more about the share of energy sources and production to all European Union in 2021:

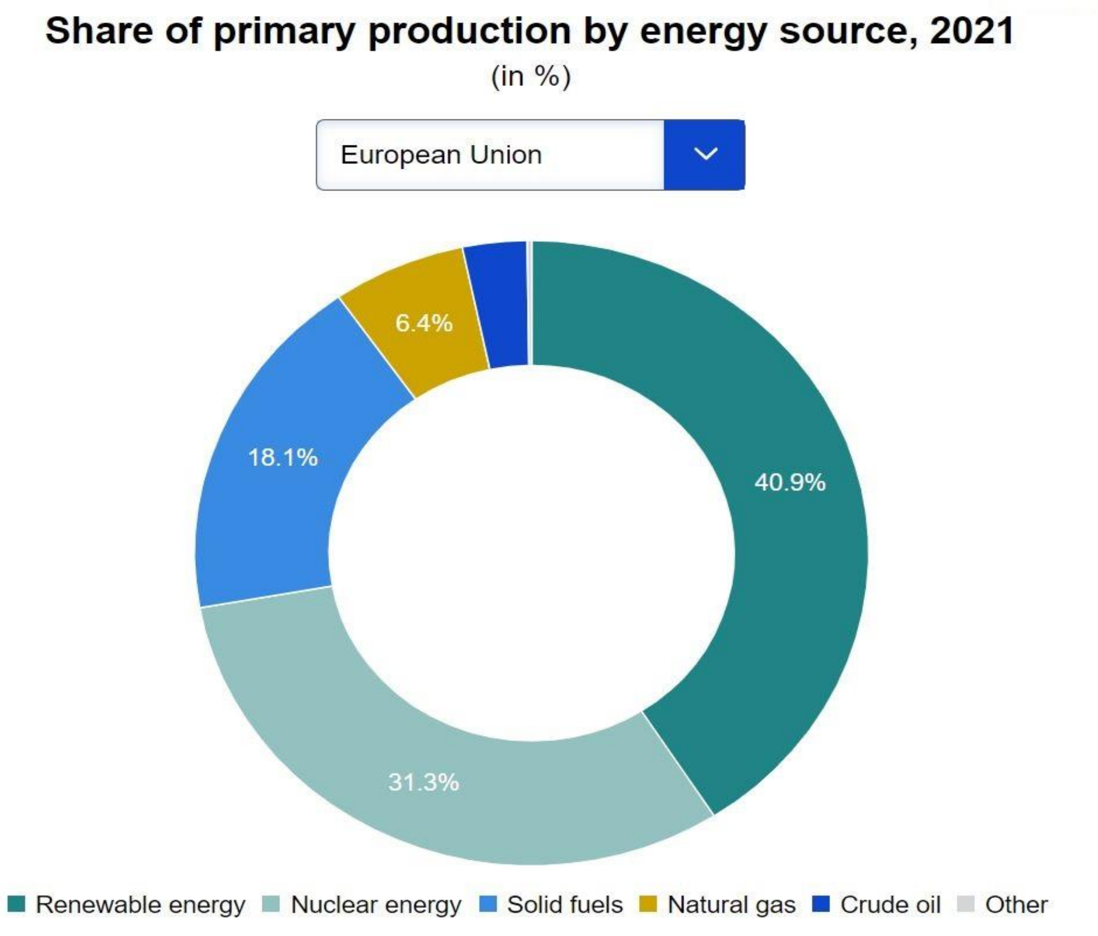
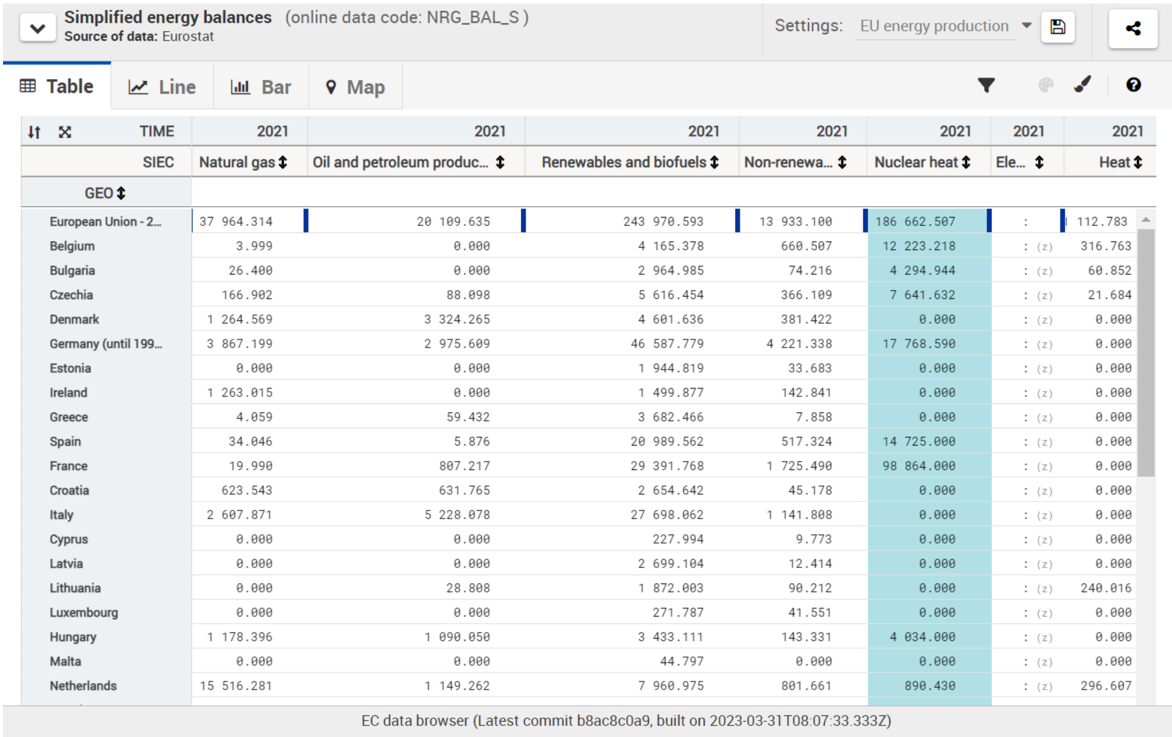


Figure 1: Share of production energy in European Union in 2021. (Eurostat 2023;1)

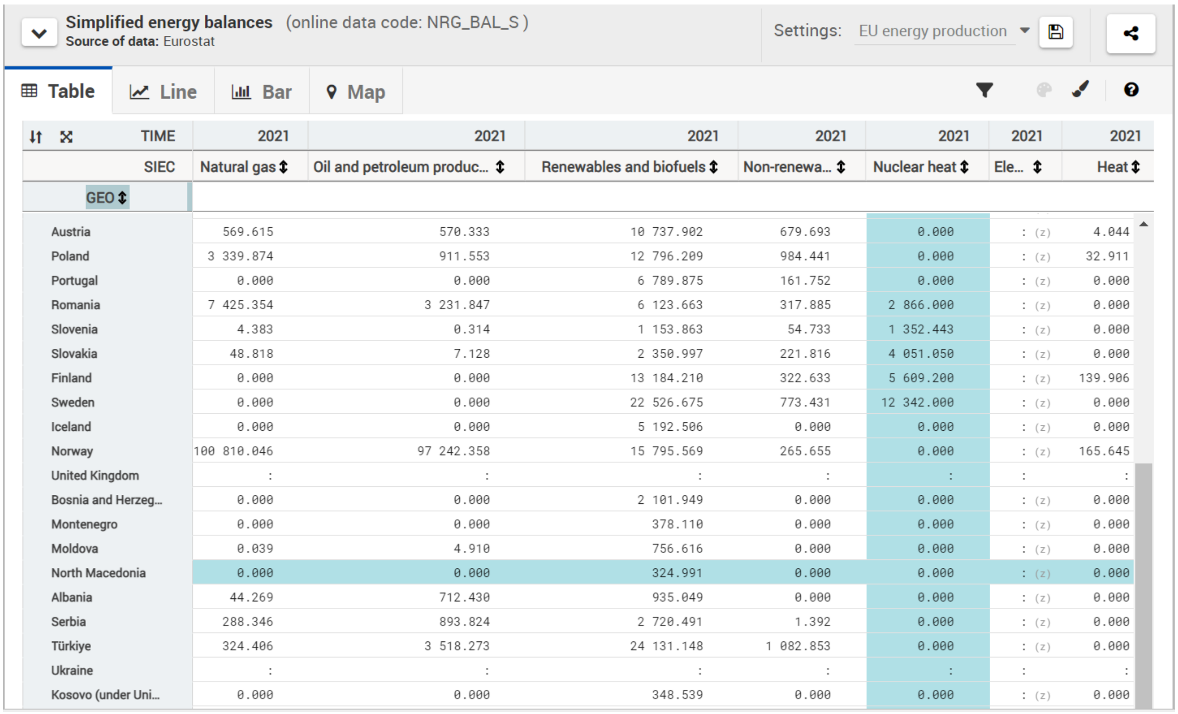
With dataset from European Commission presented in figure 2-4 from (Eurostat 2023,1) shows that there are total 597.595 740 thousand tonnes of oil equivalent as the total annual primary production in all of European countries (27) from 2020 -2021 which the first ranked top country is Norway with 214.360 663 thousand tonnes of oil equivalent as total annual primary production, second ranked country is France with 130.808 45 and 3rd ranked country is Germany with 102.664 223.

The estimation cost saving for the clean energy system transition to all European countries could be 323 billion Euro by 2030 according to (Håkan Agnevall, Wärtsilä 2023;2).



TIME	2021	2021	2021	2021	2021	2021	2021
SIEC	Natural gas	Oil and petroleum produc...	Renewables and biofuels	Non-renewa...	Nuclear heat	Ele...	Heat
GEO							
European Union - 2...	37 964.314	20 109.635	243 970.593	13 933.100	186 662.507	:	112.783
Belgium	3.999	0.000	4 165.378	660.507	12 223.218	: (z)	316.763
Bulgaria	26.400	0.000	2 964.985	74.216	4 294.944	: (z)	60.852
Czechia	166.902	88.098	5 616.454	366.109	7 641.632	: (z)	21.684
Denmark	1 264.569	3 324.265	4 601.636	381.422	0.000	: (z)	0.000
Germany (until 199...	3 867.199	2 975.609	46 587.779	4 221.338	17 768.590	: (z)	0.000
Estonia	0.000	0.000	1 944.819	33.683	0.000	: (z)	0.000
Ireland	1 263.015	0.000	1 499.877	142.841	0.000	: (z)	0.000
Greece	4.059	59.432	3 682.466	7.858	0.000	: (z)	0.000
Spain	34.046	5.876	20 989.562	517.324	14 725.000	: (z)	0.000
France	19.990	807.217	29 391.768	1 725.490	98 864.000	: (z)	0.000
Croatia	623.543	631.765	2 654.642	45.178	0.000	: (z)	0.000
Italy	2 607.871	5 228.078	27 698.062	1 141.808	0.000	: (z)	0.000
Cyprus	0.000	0.000	227.994	9.773	0.000	: (z)	0.000
Latvia	0.000	0.000	2 699.104	12.414	0.000	: (z)	0.000
Lithuania	0.000	28.808	1 872.003	90.212	0.000	: (z)	240.016
Luxembourg	0.000	0.000	271.787	41.551	0.000	: (z)	0.000
Hungary	1 178.396	1 090.050	3 433.111	143.331	4 034.000	: (z)	0.000
Malta	0.000	0.000	44.797	0.000	0.000	: (z)	0.000
Netherlands	15 516.281	1 149.262	7 960.975	801.661	890.430	: (z)	296.607

Figure 2-1: Source of data for EU Energy Production in 2021 via online data code. Unit of measurement: Thousand tonnes of oil equivalent. (Eurostat 2023;1)



Simplified energy balances (online data code: NRG_BAL_S)
Source of data: Eurostat

TIME	2021	2021	2021	2021	2021	2021	2021
SIEC / GEO	Natural gas	Oil and petroleum produc...	Renewables and biofuels	Non-renewa...	Nuclear heat	Ele...	Heat
Austria	569.615	570.333	10 737.902	679.693	0.000	: (z)	4.044
Poland	3 339.874	911.553	12 796.209	984.441	0.000	: (z)	32.911
Portugal	0.000	0.000	6 789.875	161.752	0.000	: (z)	0.000
Romania	7 425.354	3 231.847	6 123.663	317.885	2 866.000	: (z)	0.000
Slovenia	4.383	0.314	1 153.863	54.733	1 352.443	: (z)	0.000
Slovakia	48.818	7.128	2 350.997	221.816	4 051.050	: (z)	0.000
Finland	0.000	0.000	13 184.210	322.633	5 609.200	: (z)	139.906
Sweden	0.000	0.000	22 526.675	773.431	12 342.000	: (z)	0.000
Iceland	0.000	0.000	5 192.506	0.000	0.000	: (z)	0.000
Norway	100 810.046	97 242.358	15 795.569	265.655	0.000	: (z)	165.645
United Kingdom	:	:	:	:	:	:	:
Bosnia and Herzeg...	0.000	0.000	2 101.949	0.000	0.000	: (z)	0.000
Montenegro	0.000	0.000	378.110	0.000	0.000	: (z)	0.000
Moldova	0.039	4.910	756.616	0.000	0.000	: (z)	0.000
North Macedonia	0.000	0.000	324.991	0.000	0.000	: (z)	0.000
Albania	44.269	712.430	935.049	0.000	0.000	: (z)	0.000
Serbia	288.346	893.824	2 720.491	1.392	0.000	: (z)	0.000
Türkiye	324.406	3 518.273	24 131.148	1 082.853	0.000	: (z)	0.000
Ukraine	:	:	:	:	:	:	:
Kosovo (under Uni...	0.000	0.000	348.539	0.000	0.000	: (z)	0.000

Figure 2-2: Source of data for EU Energy Production in 2021 via online data code. Unit of measurement: Thousand tonnes of oil equivalent. (Eurostat 2023;1)

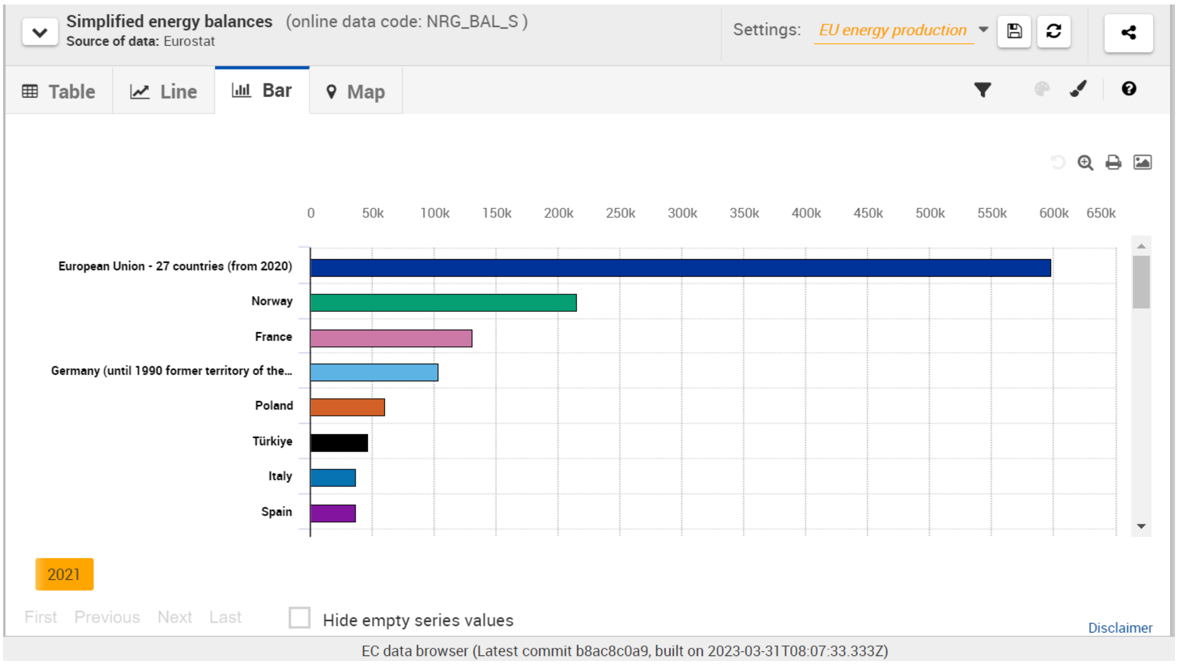


Figure 3: Dataset for total annual primary production, thousand tonnes of oil equivalent of 27 countries in EU in 2020-2021. (Eurostat 2023; 1).

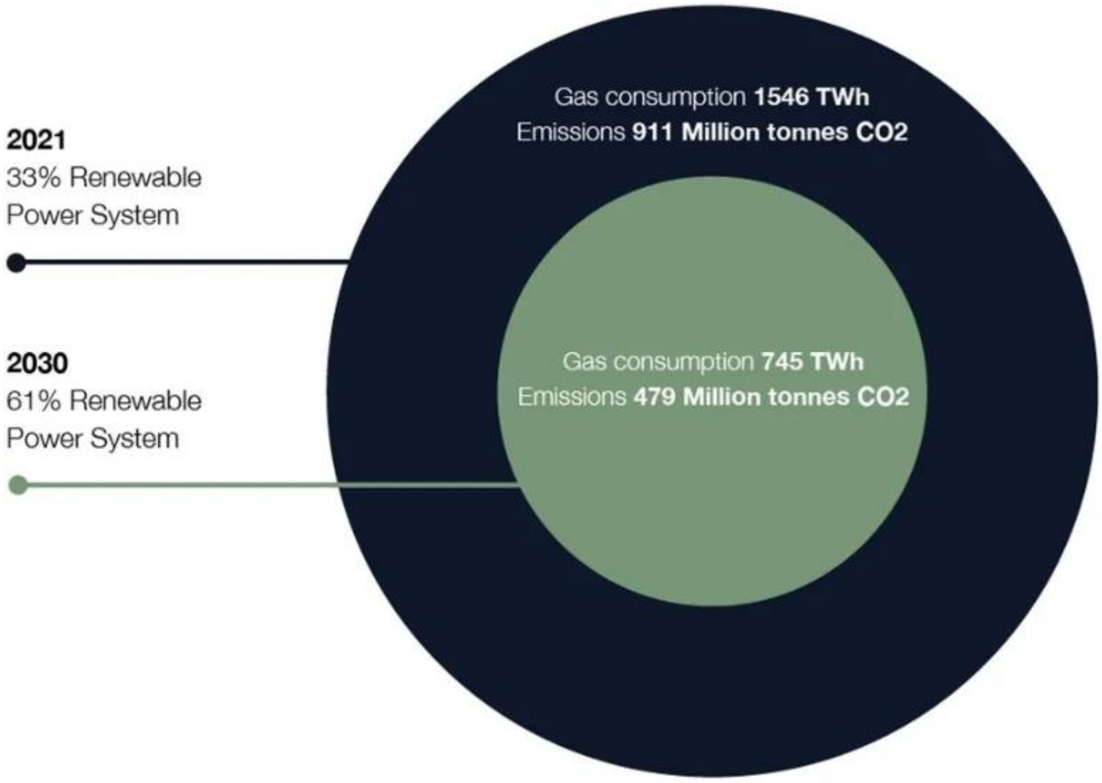


Figure 4: Power Generation emissions and gas consumption by installing 80GW of RES in 2030 (Håkan Agnevall, Wärtsilä 2023;2).

1.2 How EU energy's production and consumption will be changed in 2035.

As mentioned in the introduction part, the European energy crisis from 2022 has clearly demonstrated that Europe needs to strengthen its energy security and completely reduce its dependence on gas imports from Russia. Europe needs to focus on renewable energy transformation sustainably and therefore there will be a rapid green energy transition with 100% renewable sources and high efficiency will be integrated to across European Unions by 2035. This green transition will be applied to all industrial areas such power, heat, transportations, buildings.

In the figure 5 below, the comparison of RES (Renewable Energy System) in 2020, 2035; 2040 and 2050 are presented to see the massively changes between fossil fuels/nuclear energy to renewable energy from 2020 to 2035 and same to 2040 and 2050.

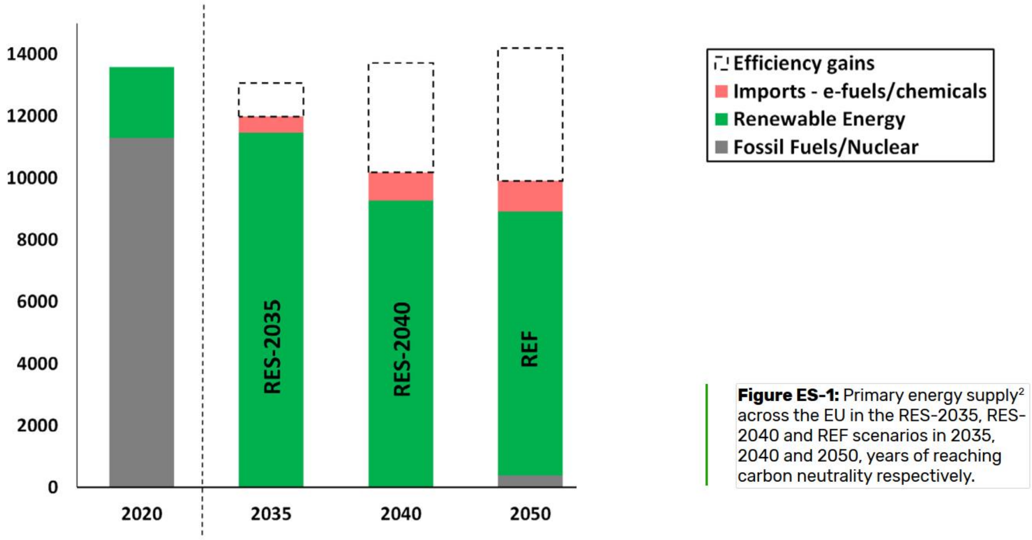


Figure 5: The comparison between 3 scenarios of RES in 2035, 2040 and 2050 by LUT &Green European Free Alliance 200. (Manish Ram and others, LUT, 2023, 4)

Germany, the sixth biggest energy consumer and is also the largest imported natural gas in over the world. In beginning of 2022 when Russian invasion Ukraine, Germany has been affected by natural gas import from Russia and German Economic and Energy Economics are critical affected by the European Sanctions to Russia. Germany has quickly changed the policy related to energy sector and thanks to this, today German's Energy Security is being recured by quickly transmitting their mix energy sector to main driven renewable sources. The figure 6 below presented the current updated energy demand and generation between May and June 2023 from International Energy Agency (IEA). By now, German has 57.95% share of renewable energy in demand.

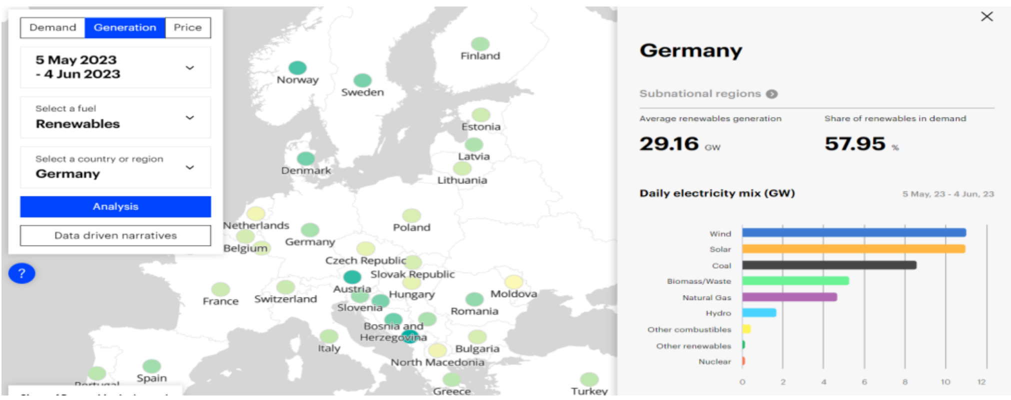
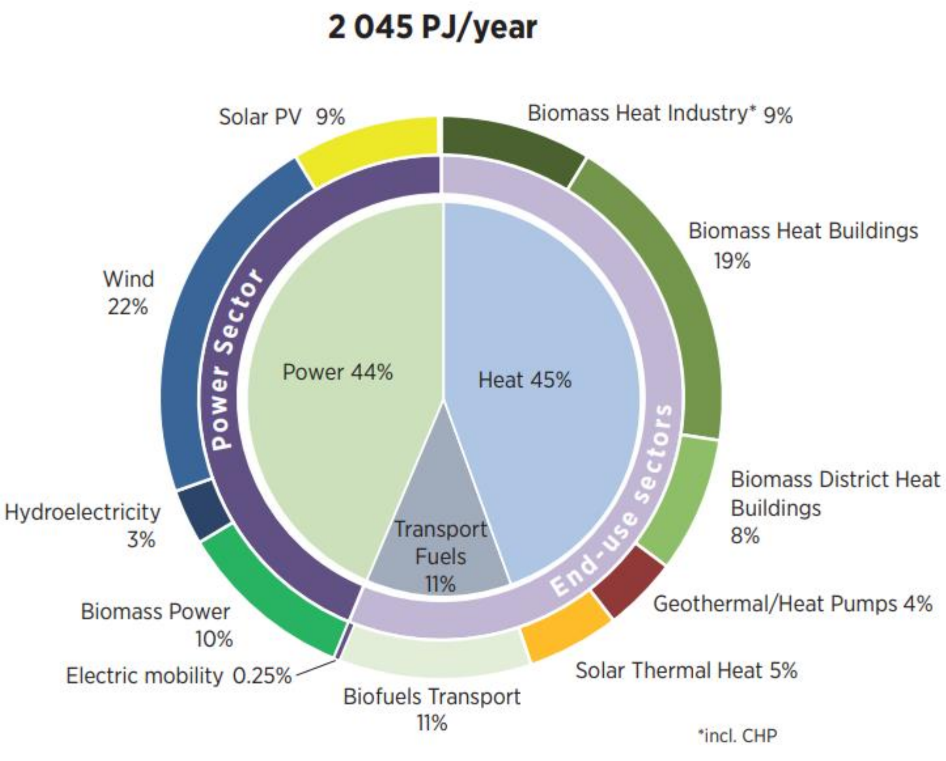


Figure 6: Real Time Tracker of German Electricity Demand from 5th May-4th June 2023 (IEA.ORG, 2023;5)

Germany also has set the target of having 100% renewable power by 2030 by phasing out fossil fuels from country's power mix. Germany has a big motivation to speed up this target with purpose of getting rid of the energy's dependence on import Russia's natural gas and LNG which has dramatically affected on German Heavy Industry and German Economic in 2022. By setting target on 100% renewable power in 2030, German aims to focus on Solar energy which could generate 200GW by 2030 and Offshore Wind to more than 30GW by 2030; 40GW by 2035 and 70GW by 2045 (William Peck, ICIS, 2022;44).

By IRENA, German's Renewable Energy Map by 2030 will committed the RE target when 2/3 of total power generation is from renewable sources where solar and wind plays an important key on Germany's RE map as presented in figure 7 below:



<u>Figure 7</u>: Break down level of RE sector in Germany by 2030 (IRENA,2023;45)

Despite of generating 50% power currently from various renewable resources, Germany will have challenges with power system where needs to be change. In the past 2 years recently from 2020-2023, German Government has decided to make changes by undertaking electricity market reform as well as the cross-border exchange due to that fact that Germany is in central of Europe where Energy market can be linked to neighbours. Together with this action, German has expanded the use of combined heat and power (CHP) generation with heat storage, heat pumps to be able to accommodate with solar and wind power generation.

On 8th July 2022, German Government has informed the publication of new policies package for Renewable Energy Act; Offshore Wind Act; Onshore Wind Act; Energy Industry Act and Federal Natural German electricity by source in 2021Conservation Act. These are the biggest Energy Policies which German has never made before, and it shows how well and quickly German adapt to the current crisis and boost up the RES pathways to be faster and more security.

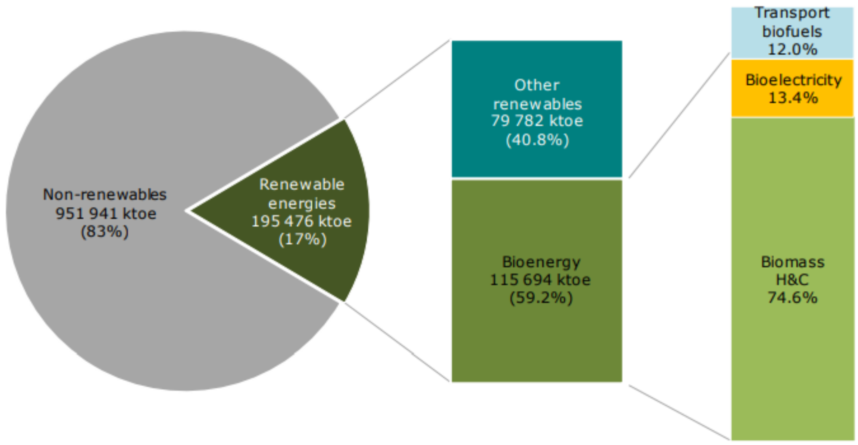
2 Future Energy in Europe

In this chapter, the future of energy in Europe will be captured from the current energy production and consumption in 2021 as well as the renewable energy production and consumption with their distribution shared in total Europe's energy for the same period. With statistic data collected from many research and reports where have found out that biomass plays an important key for renewable energy sector and it will be main potential resources for stopping using fossil fuels, helping Europe to commit the zero-emission target and high efficiency energy and energy security. Biomass and Biotechnologies will be the key factors for future energy in Europe.

2.1 How biomass is important to EU's future energy.

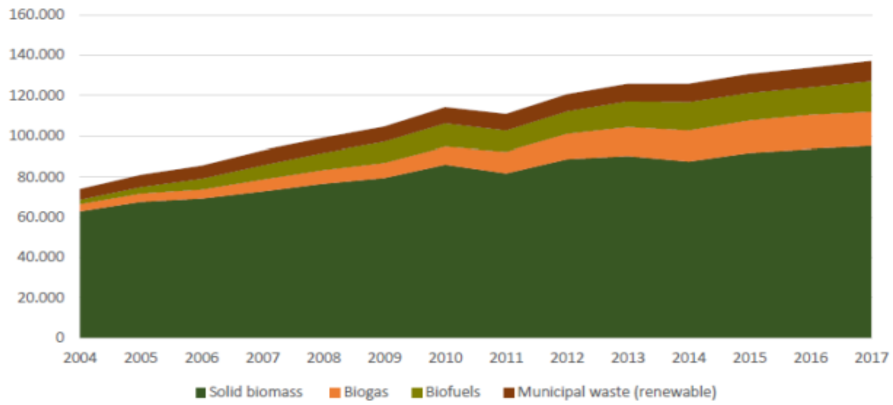
Biomass is the key source of renewable energy which plays the most important role in EU's future energy due to the high capacity to produce electricity, heat, and transport fuels. Besides having sustainable capacity, biomass also has lowered the greenhouse gas emission and possible to increate thousands of jobs in the future.

The below figure 8 presents that the share of current heating and cooling users which used 74.6% from biomass. The contribution of bioenergy derived from biomass such as forestry, agriculture, or biological waste. Together with sustainable energy from wind and solar, bioenergy from biomass contributed around 59% of gross final energy consumption. This figure above has clearly reflected the continuous growth of bioenergy from biomass sources which will be the main source of renewable energy.



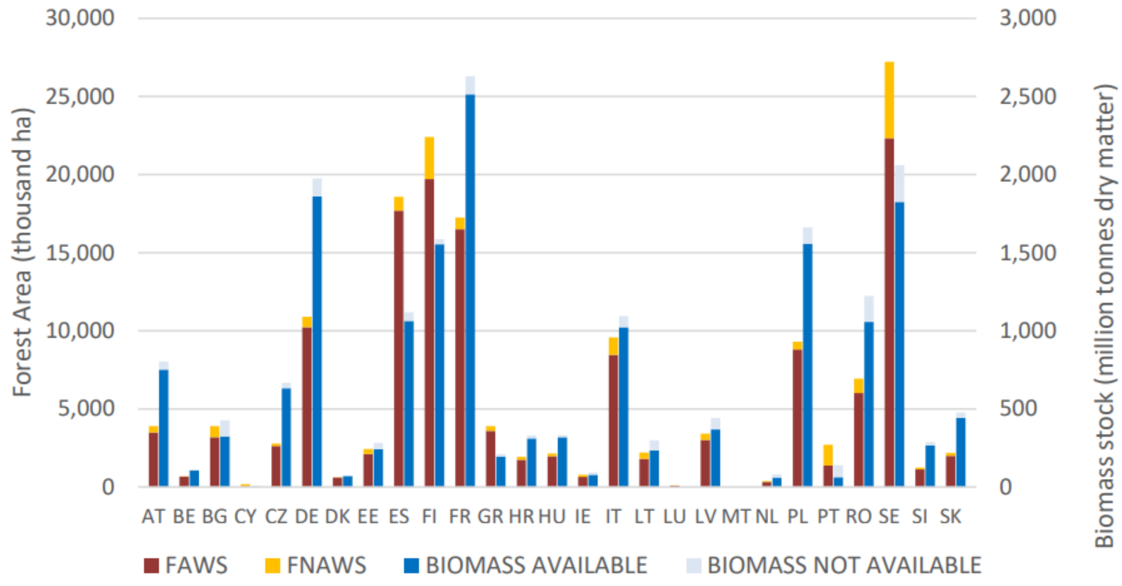
<u>Figure 8</u>: The share of renewable energy of EU's final energy consumption with the bioenergy contribution. (European Commissions, Bioenergy 2023;7)

Regarding to the EU climate target in 2035 where 32% of energy consumption will be from bioenergy where biomass's main type is solid biomass that plays 70% of total primary energy production. Biogas shares 12%, liquid biofuels share 11% and another bioenergy from waste takes 7% as shown in figure 9 below:

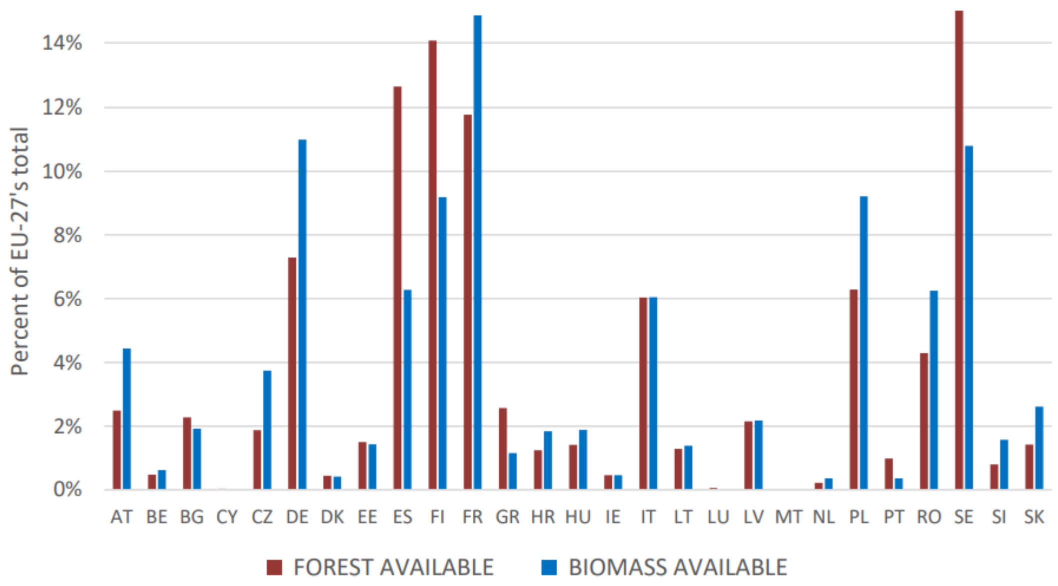


<u>Figure 9</u>: Bioenergy production in Europe from 2004 -2017. (European Technology and Innovation Flatform 2023;8)

Most of EU bioenergy supplied from biomass sources does not need to import outside of Europe due to the amount of forestry and agricultures plays 60% in EU domestic biomass supplied (figure 10-11). Direct and indirect wood supply (figure 12) are the main sources from forestry where wood is the most important renewable source in many European countries such as Latvia 29%, Finland 24%.



<u>Figure 10</u>: EU -Forest area and biomass available in wood supply in 2020. (Fuel Europe, 2023;9).



<u>Figure 11</u>: EU -Forest area and biomass available in wood supply in 2020. (Fuel Europe, 2023;9).

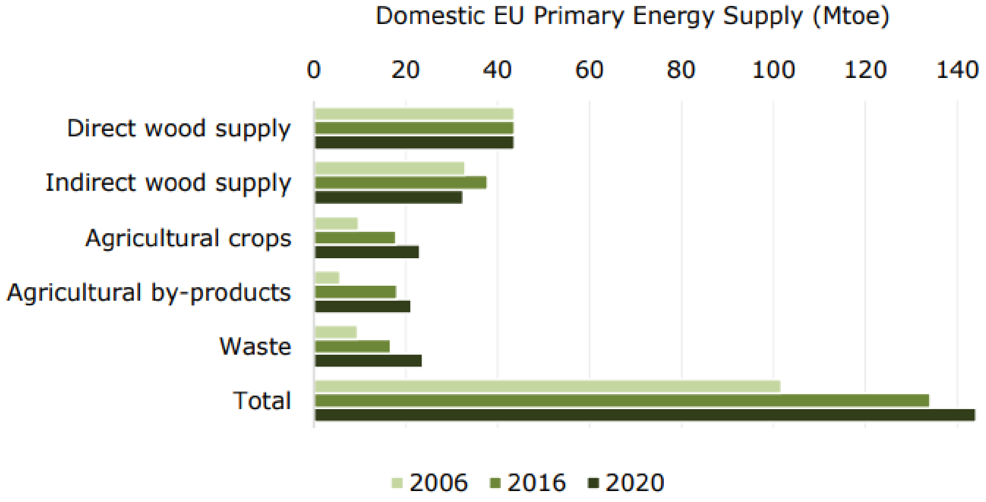


Figure 12: EU Biomass sources and Biomass supply from 2006-2020.((European Commissions, Bioenergy 2023;7)

Due to the huge amount of biomass potential in EU, the estimation of biomass used for bioenergy in future will be predicted as showed in figure 13.

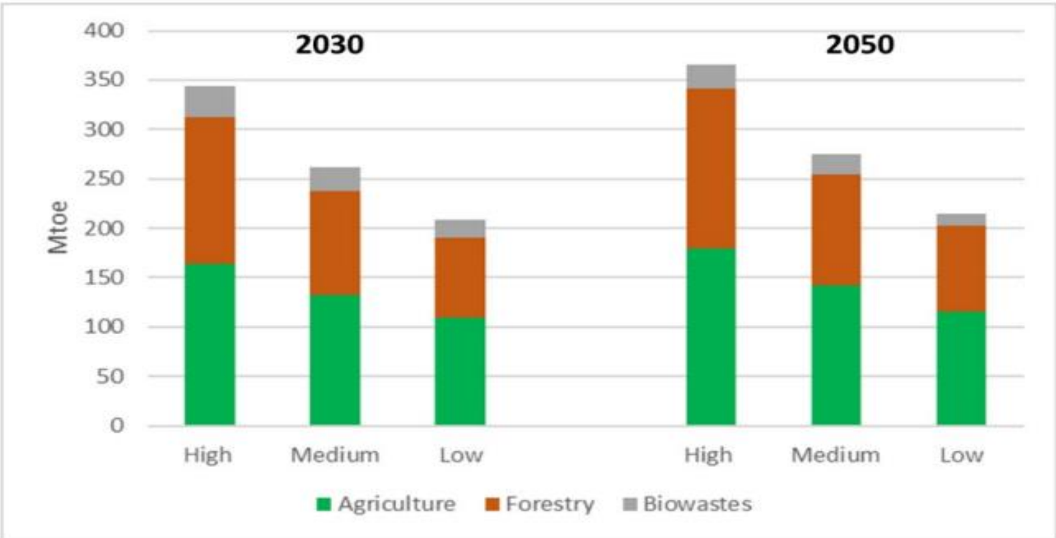


Figure 13: EU Sustainable biomass for bioenergy in 2030 and 2050. (European Commissions, Bioenergy 2023;7).

The estimated amount of EU bioenergy in all markets will be in between 208-344 Mtoe in 2030 and this amount can still be increased if all of EU member states can work together to improve the forest management and set the common regulations for sustainable use of land, water, and forest in the future. Besides that, the continuous of doing research and innovation for biomass and biofuels must be made to be able to extend the amount the biomass sources and to increase the efficiency at the same time. This will require the strong policy makers for all of EU members.

Figure 14 below is an example of how important biomass act in German's energy production in the past 20 years. In 2023, German's gross energy production from biomass reached to 44.6 Terawatt hours with more than 14.922 biomass power plants across Germany.

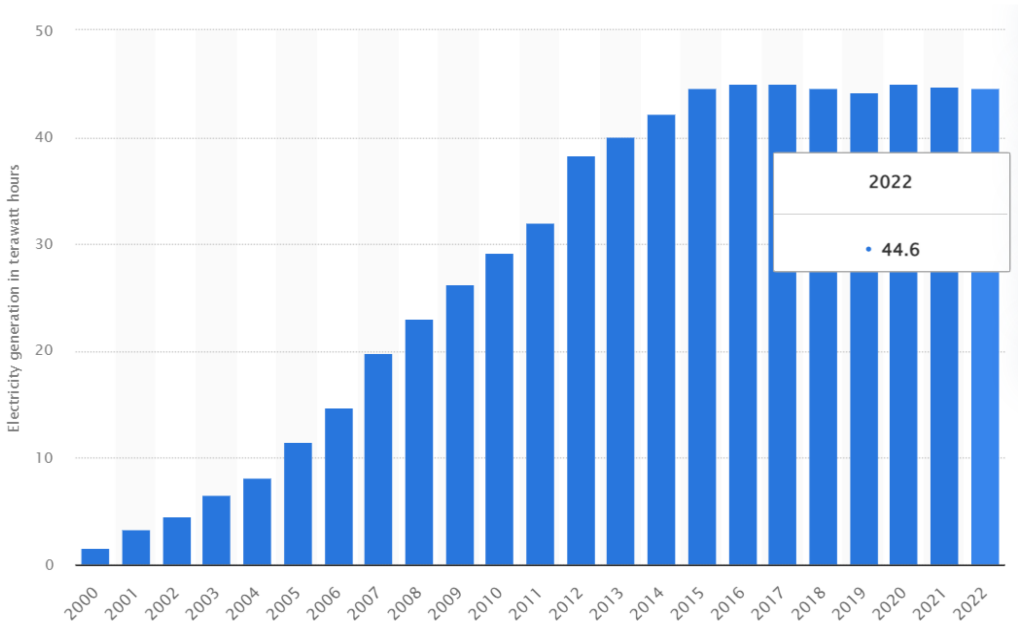


Figure 14: German's gross electricity generation from biomass in [terawatt hours] between 2000-2022 (Lucia Fernandez, 2023;10)

2.1.1 Bioenergy and Biofuel Technologies for EU's energy future

Beside the traditional way of producing bioenergy from biomass such as combusting woods products, animal wastes, there are also modern way of producing bioenergy which is included also biofuels from biogas. These technologies (figure 15) are bio-refineries, wood pellet heating systems. Liquid biofuels technologies will be main target for EU's transportation and energy production in 2030 till 2050 due to the capacity of replacement for gasoline.

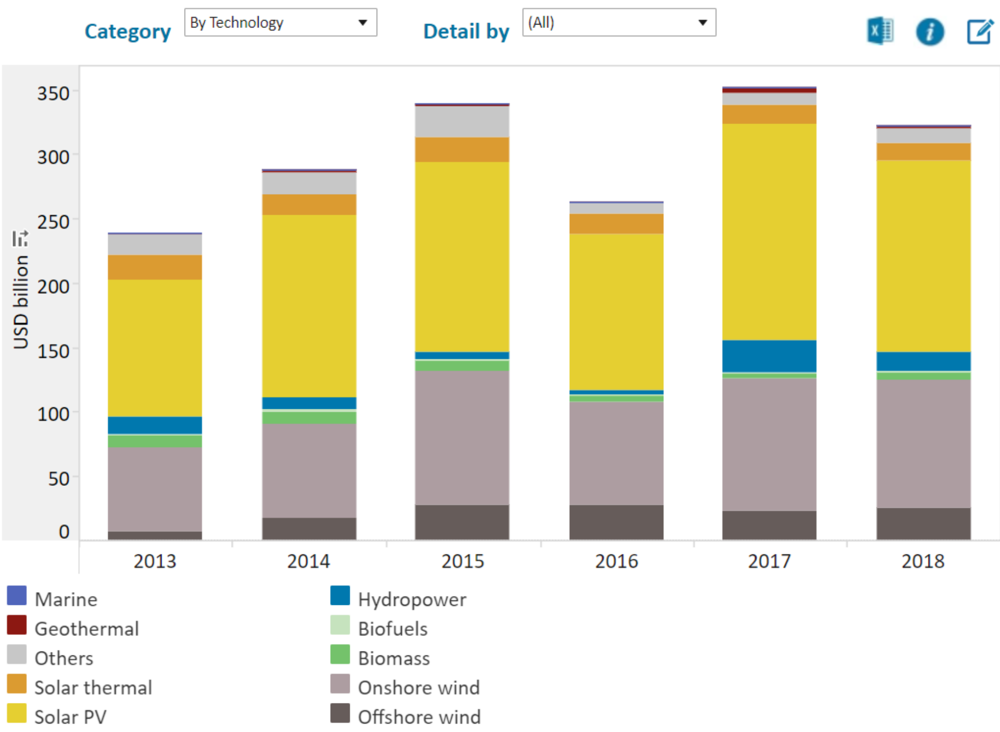


Figure 15: EU's commitment of financial technologies of RES from 2013-2018. (IREA 2023;11)

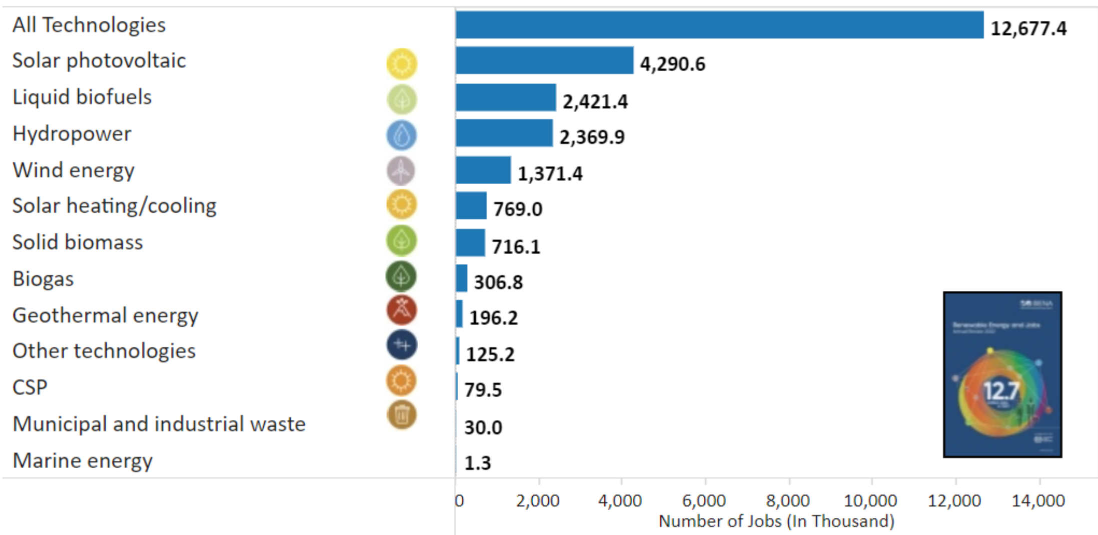


Figure 16: Number of jobs needed for RES by technology in EU's 2021. ((IREA 2023;11)

The description of how to convert biomass and waste steams to advanced biofuels are introduced in figure 17-19. These conversion technologies are based on known processes and therefore, they can be developed further to archive that biofuel targets. In this pathway technology, there are 6 main key biomass groups as presented which two of them are biomethane and hydrotreatment of lipids are commercial. The rest of them which are still under development.

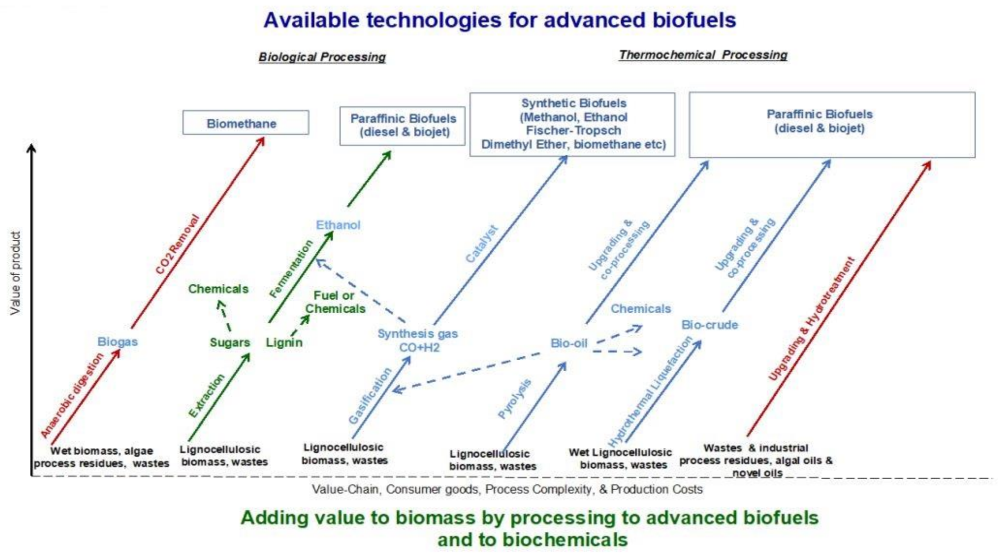


Figure 17: Overview of advanced biofuels technologies roadmap. (Dr.Maniatis; Imperial College London,2016;12)

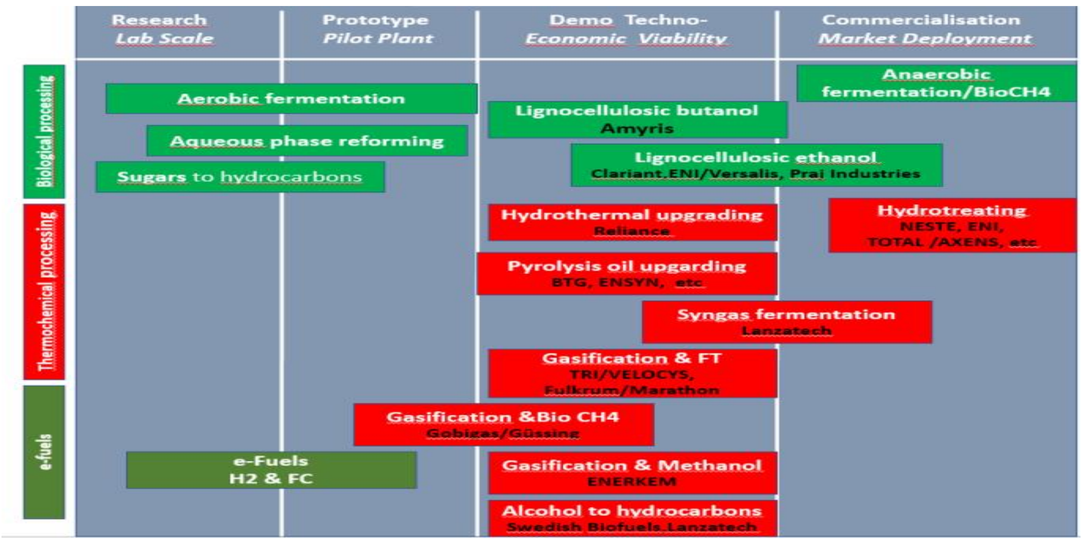


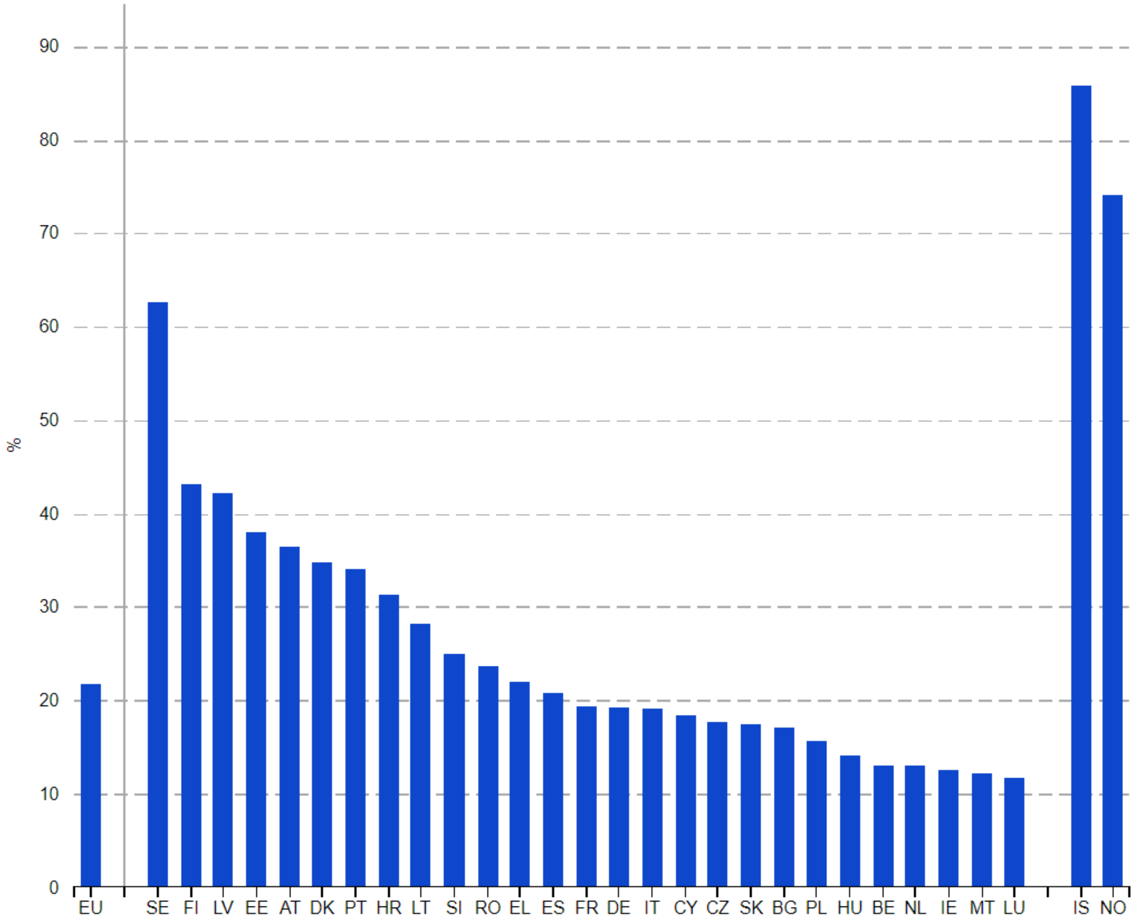
Figure 18: Advanced biofuel technology pathways in 2030. (Dr.Maniatis; Imperial College London,2016;12)

Table 1: Suggestion for advanced biofuel technologies

Material	Conversion technology type	Biofuel type
Waste oils and fats, cooking or used oil,	Hydrotreatment included co-processing	Hydrotreated vegetarian oil and renewable diesel, used for Sustainable Aviation Fuels.
Sewage sludge, agriculture resides, energy crops,	Biogas; landfill production	Biomethane
Lignocellulosic, solid waste	Enzymatic hydrolysis; fermentation Gasification + fertilization	Ethanol
Lignocellulosic solid agriculture residues, liquid industrial waste, torrefied woods	Gasification +catalytic synthesis Pyrolysis + Hydrotreatment	Synthesis fuel Biocrude
CO2 from RES and Air	Reaction with RES hydro	e-fuel

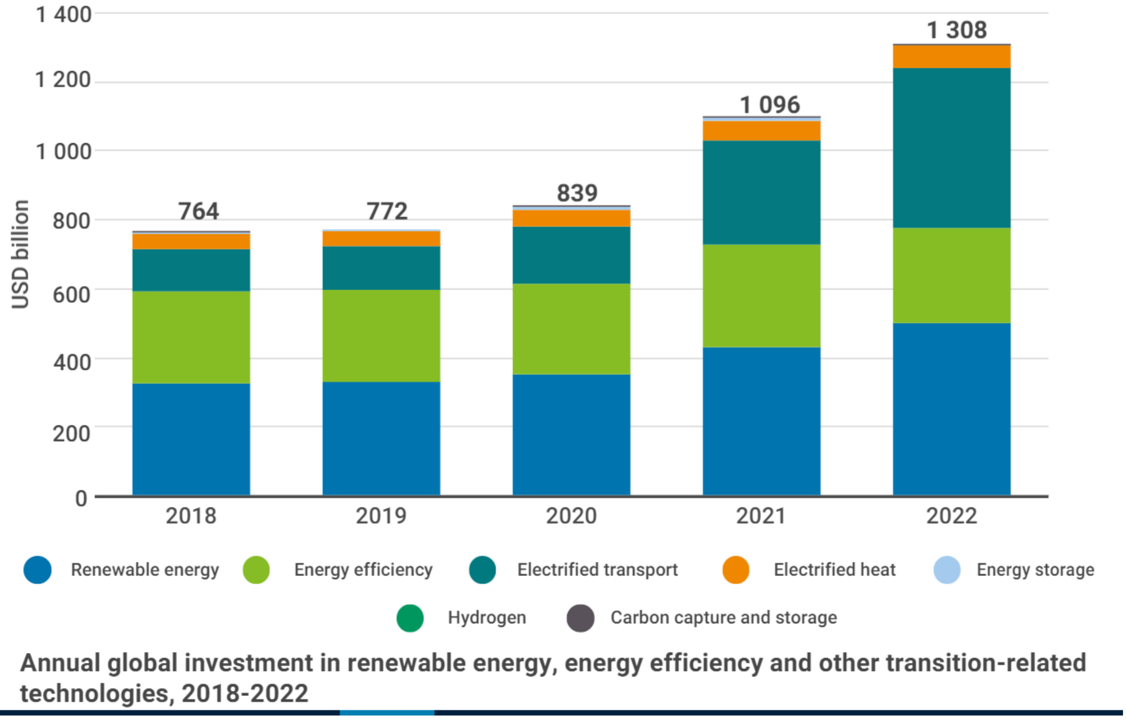
2.1.3 Renewable Energy's production and consumption in 2021

According to European Commission, Eurostat, the share of RES's consumption for EU is 21,8% in 2021 and they target to achieve 30% by 2030 which Sweden is the leading country of RES consumption up top more than 60% (figure19).



<u>Figure 19</u>: The share of EU's RES consumption in 2021 (in %). (Eurostat 2023;3)

According to International Renewable Energy Agency (IRENA), in 2022 the global investment in renewable energy, energy efficient and technologies have reached to high record of 1.3 trillion USD which has risen about 70% investment cost of the year 2019 and 19& of the year 2021 which shown in the figure 20 below:



<u>Figure 20</u>: Record of global investment in Renewable energy and technologies. (Eurostat 2023;2)

3 Strategic plans and actions for Renewable Energy Transition

This part is about the ideas of how renewable energy transition will be accelerated based on actual situation in whole Europe, regional reviews, infrastructures, technologies, climate conditions or available energy sources to come up with specific plans and steps in sustainable energy transformation up to 2035. This plan still must focus also on the problem of reducing CO2 emission, scaling up energy transition to meet the 1.5oC goal. Table 2 below is the summary of whole chapter 3 in term of strategical plans and actions for EU's Renewable Transition. Each of actions and strategic plans will be explained in the sub-chapter.

Table 2: Summary of strategic plans and actions for Renewable Energy Transition in Europe

Strategic Plans	Actions (see detail in written by each of statement)
European Union level	Policy Support, Rules, and Regulations
	Decision Making &Effort Sharing Regulations (ESR)
	Massive investment in Technology and Infrastructure
	Integrated modelling for economic
	Modernization and Digitalization in cross border power grids
	Energy Efficiency Directive
Government Level	National policy frames
	Decision making (Tax reduction, permits)
	Long-Term energy scenarios tool (LTES)
	Power modelling and optimization
	Investment on local resources & technology

3.1 European Union Member State level

The countdown for the global energy transition in on every continent, country and city is unique. Therefore, European Union needs to model countries and regionals based on the energy available sources. Flexible power generation system can adjust the weather conditions and store excess power. Reliability and cost of 100% renewable energy.

To define the clear Green Transition Pathways for European countries, it is important to build up the regional modelling to find out the best suitable energy resources to develop and innovate energy technologies on it.

European countries are divided in 4 big areas which are Nordic, West, Central and Southwest. Wind power, hydro power potentially will be developed in northern and western region due to the wind and hydro capacities (figure 21) as the potential natural resources based on climate regions while solar potential will be developed more in southern of Europe included Turkey where sun shines all the time of the year. Since Europe has a very good interconnection between country to country about energy infrastructure, it brings a positive point to get quickly common share about the energy transition network, markets and easily to share the common of other local renewable resources to each other. If European Union focus on the higher share of PV solar energy 54% from southern regions and higher share of wind power and hydro power (43%) from northern regions, together with the plan of doing the interconnection pools with each of country in the member states, the electricity generation will meet the demand for all of EU countries by 2030-2040. This scenario is possible to become really based on the actual results of current electricity production in all Europe and in each of regions. This positive side will be developed more about the energy efficiency and technologies as well as the need to have the one common network for the distribution.

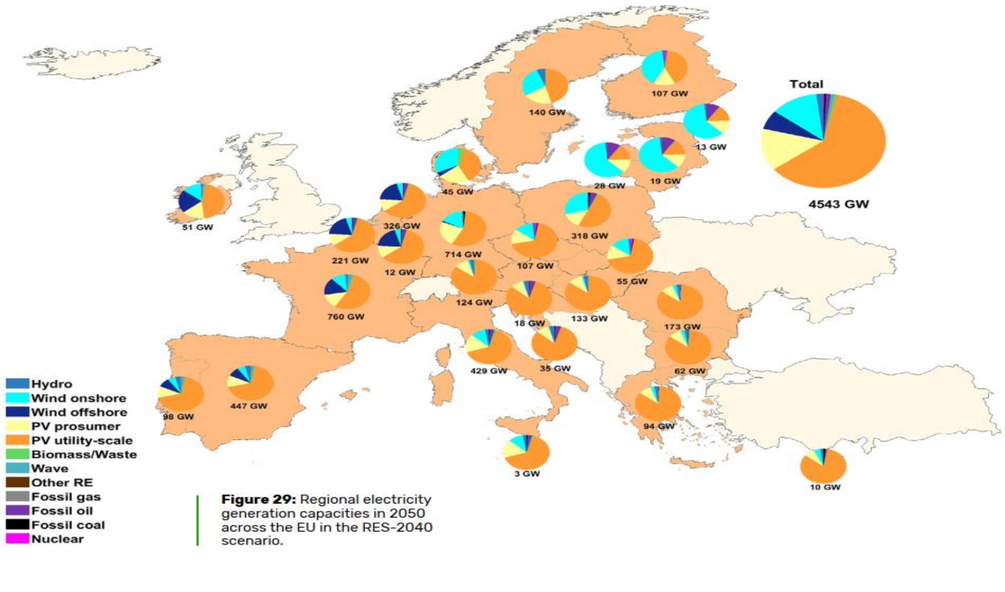


Figure 21: Regional electricity production based on potential resources in Europe. ((Manish Ram and others, LUT, 2023, 4)

According to European Commission, the Renewable Energy Directive (2009/28/ES), the development of renewable energy has growth by 21.8% in 2021 which Sweden has had the highest share of RES consumption up to 60% in 2021, Finland ups to 43% and Latvia 42% [5].

3.1.1 Policy support and decision making

The EU policies aim to balance and stay united for the needs of energy transition by taking decision together with the purpose of increasing the share of hydrogen and renewable energy to decarbonate for the common goal. The EU policies should have climate neutral by 2050 or so called European Green Deal which ‘’Fit For 55 packages’’ is a legislative proposal made by European Commission to get all European countries to reach the common goal of reduce emissions at least 55% in 2030 and will become neutral in 2050. The target of ‘’Fit for 55’’ is the current effort of European Commission to turn the climate goals into the law to all of member states. The figure 22 below will present the overview of this ‘’Fit For 55 packages’’:

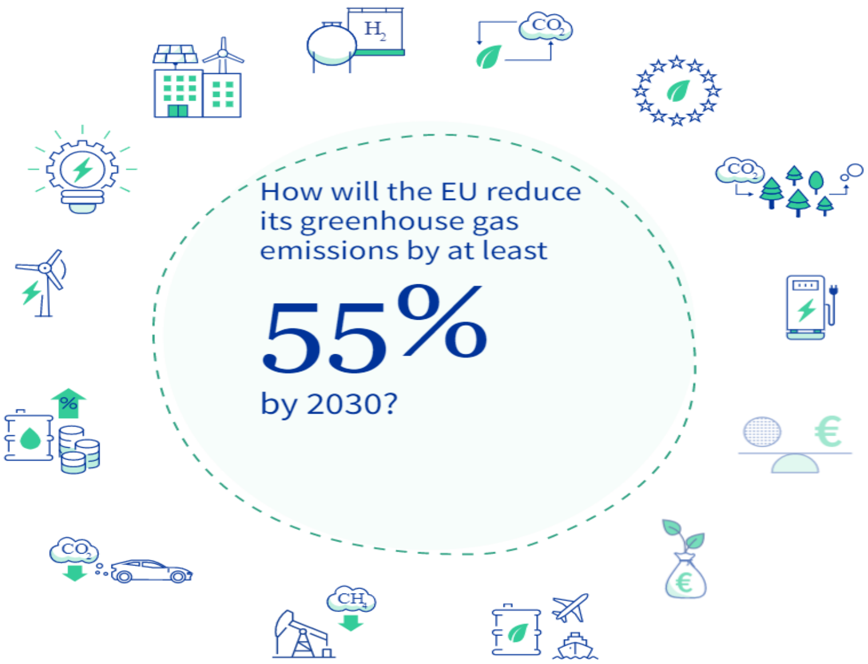


Figure 22: What are included in the ‘’Fit For 55’’ package. (European Council, 2023;13)

On March 28th, 2023, European Council has formed the first part of the ''Fit For 55'' package by setting rules to reduce net greenhouse gas emissions by 2055 which apply for all cars and vans; set rules as the effort sharing regulation to all of Member States; setting rules for land use and forest regulation and market stability reserve decision making (figure 23).

On March 30th, 2023, the provisional deal on the renewable energy directive was made between European Council and European Parliament negotiators to reach the political agreement to increase the share of renewable energy of EU's consumption to 42.5% by 2030 with additionally 2.5% would achieve 45% in total. This deal is targeted for transportation, industry, buildings, district heating and cooling which are applied to all European countries.

The target of EU's Green Deal requests every statement working together to reduce the fossil fuel and increase the using of renewable and low carbon fuels. This target will require a transformation of EU energy system, not only for company but also for each of individual consumer. Furthermore, European Union should build up the framework for the green energy transition based on the regional outlook. This mean, beside the common agreement about the CO2 emission by 2050 applied to all of member states, it is also important to encourage each of European Union to work on their local resources for driven energy system.

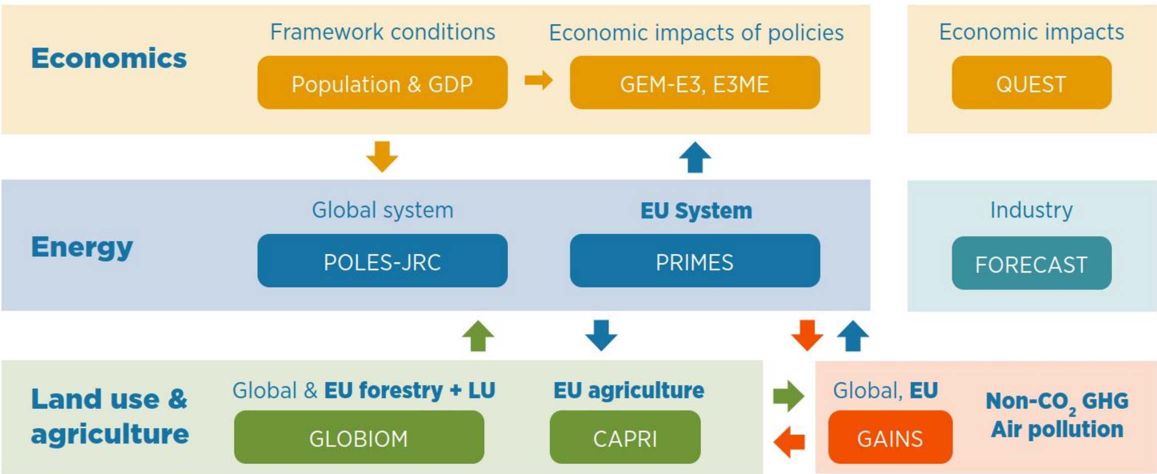


Figure 23: Integrated modelling of economics, energy, and land use for European Commission. (IRENA 2020;14)

3.1.2 Current technologies and investment and cost

For heat and electricity generation: European Union to increase the amount of having CHP plants (Heat combined Power Plant) with high technologies applied in all of member state to solve both problem of heat and electricity issues. With the modern of CHP plants which Nordic countries are having at this moment for example Finland, Denmark to run high technologies CHP plant with biomass, the electricity production is sustainable and renewable. Norway is also a good example of having quite large potential of hydro power plants to adapt the energy demand in their country and possible to trade energy to another member state via Nord-pool exchange trade network. These are one of good example models to apply for the rest of another member state where their local resources are considered as priority and then technologies to make the transition happened (figure 24-25). At the same time with transition from fossil fuels to biomass (bioenergy) fuels, it is important to consider also about the energy efficiency, energy storage and emission issues.

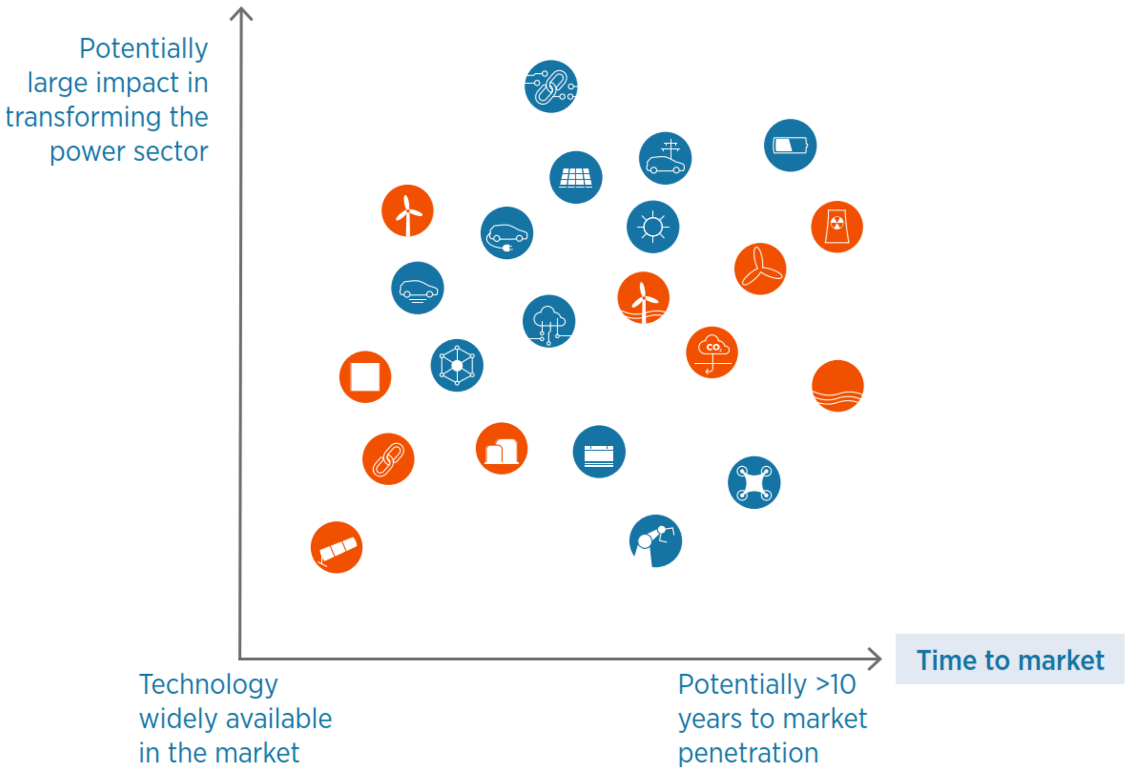


Figure 24: Potential Impact for Power Transition. ((IRENA 2020;14)

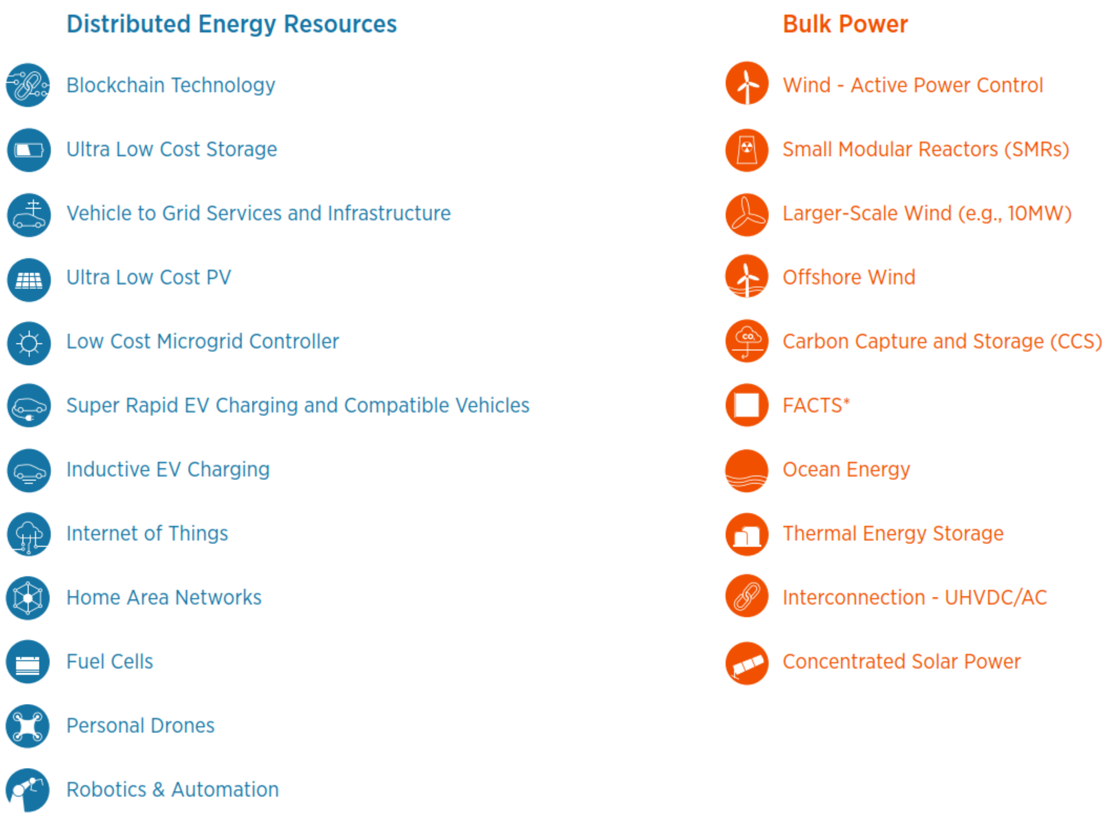


Figure 25: Technologies in relation with energy resources and power transition. (Håkan Agnevall, Wärtsilä 2023;2).

Carbon capture and storage (CCS) are common technologies to reduce emissions, but direct air capture (DAC) technology is being seen as the future target for all of Europe members due to it benefits of achieving zero CO2 in the first phase and negative CO2 in the second phase. Additionally, DAC plays an important role in the synthetic fuel production process as well matched perfectly to Solar PV and Wind power energy system.

For transport sectors which consume huge amount of energy and create also massive amount of emission, it is necessary to make them into next level of electrification.

Therefore, the policy for DAC technology will need to be applied to all of EU members in the production processes of synthetics and chemical fuels.

For investment by IRENA, European Union needs about 35 trillion USD for the Success of Renewable energy transition by 2030. (IRENA, Investment 2023;14)

By 2030, European energy companies will invest up to one trillion euros in renewable energy sector which wind and solar energy will be around 650 million euros investment where

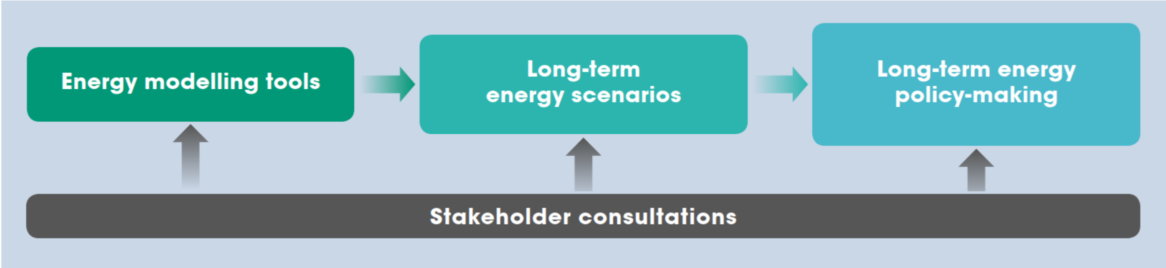
German is one of the European countries who will invest most due to the capacity and energy demand. Spain is the second country that will invest around 34 billion euros also in wind and solar energy by 2025 and up to 76 billion euros by 2030 according to clean energy wire magazine. (Reporter Charlotte Nijihuis, 2021; 15)

For cost saving, if European Union set the ambitious scenario to reach 61% renewable energy by 2030 with 80GW new capacity while the current baseline scenarios of RES provide 50% power for the same period for 40GW, then Europe's energy would save 50bn Euro per year by 2030. (Håkan Agnevall, Wärtsilä 2023;2).

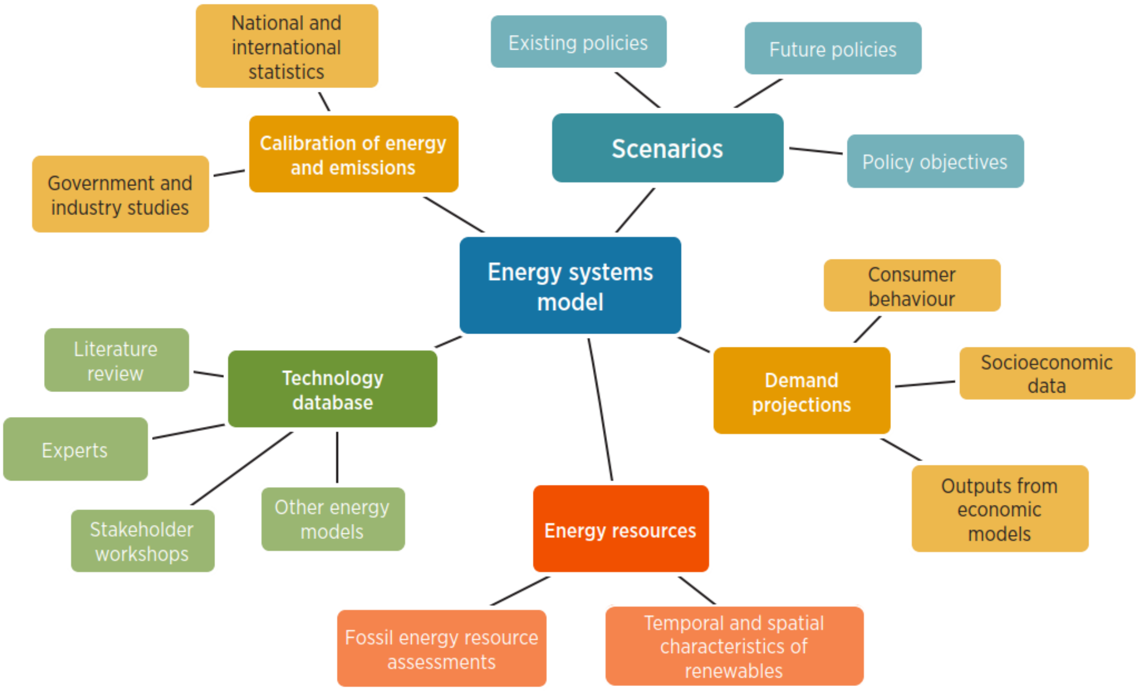
3.2 Government Level

3.2.1 Policy level, taxes, decision making:

The green transition at government level requires a strong governance structure where the investigation of policy maker's questions and answers in relation to the impacts of renewable transition to economic growth, welfare, and society. Policy makers and investors must have own strategic and plan to be ready to adapt to new technologies, new trends or even uncertain technologies, market might be happened during the transition. For this reason, it is important and necessary to have the long -term energy scenarios (LTES) for each of government (figure 26) which allow them to follow up their national and international policy debates as well as short -term and long-term energy strategies and policies visions (figure 27).

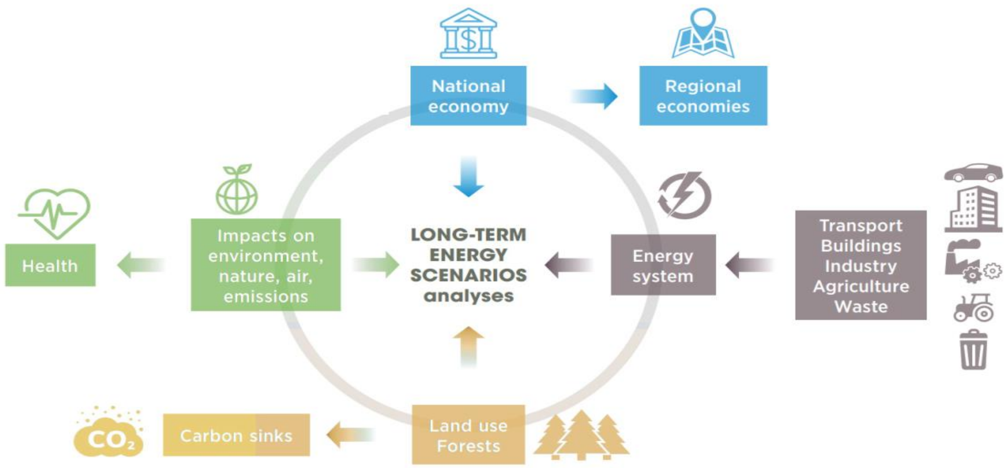


<u>Figure 26</u>: Main idea of LTES tool at Government level. (IRENA, LTES 2020; 16)



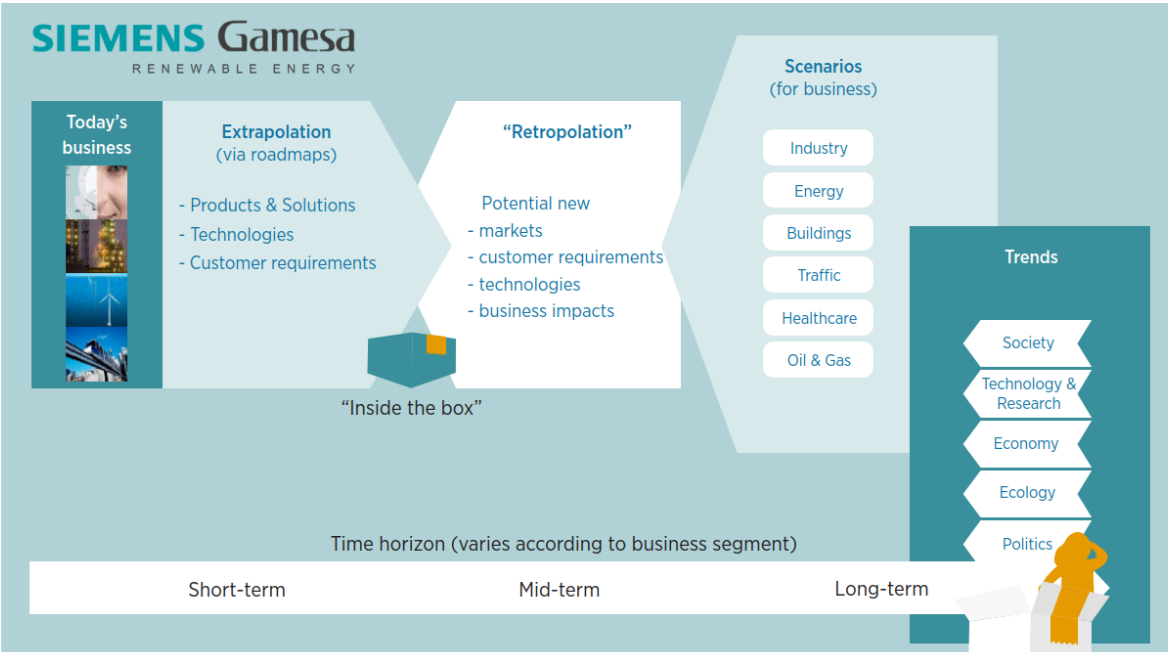
<u>Figure 27:</u> Input requirements for LTES. (IRENA, LTES 2020; 16)

In Finland, LTES is a significant assessment tool in relation to impact of climate changes and energy policy which are handled by national research organization VTT where the new climate strategy for 2035 has been made. The figure 28 below will show Finnish government used LTES provided by VTT to build up framework of climate impacts and policies.



<u>Figure 28</u>: LTES for climate impacts and policies from Finnish government. (IRENA, 2020; 17)

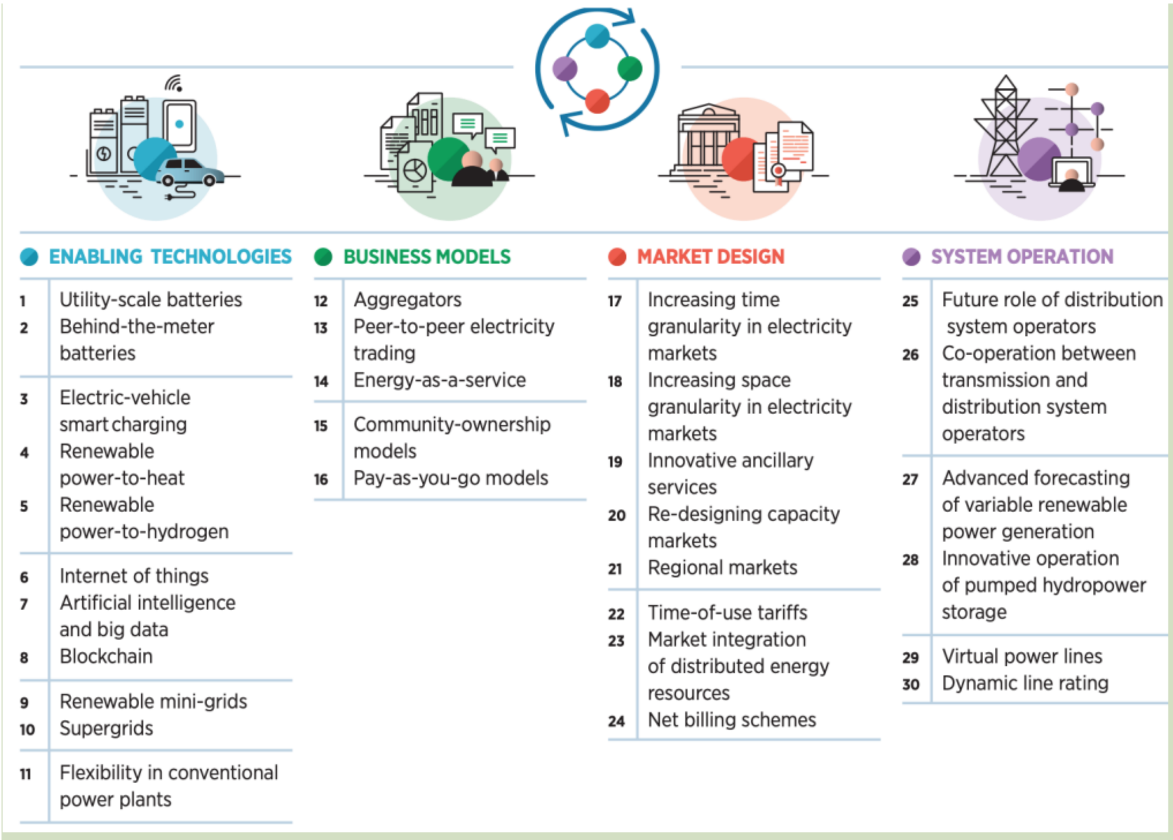
Among those countries in Europe which has dependency on gas supply from Russia, the Germany government has committed to develop 100% renewable energy by 2035 by building up to 20GW of renewable energy sources per year, this means, the clear direction of reduce or even cut down gas as 60% of German gas consumption imported from Russia which leads to the difficulty to cut down immediately the gas supply. The German policy should focus on lower demand of gas as much as possible. Since the Russian invasion of Ukraine began, German government has launched the plans of reducing rapidly the import of gas from 60% to 30% to end of 2030. Figure 29 below is the introduction of how Siemens in Germany pointed out the relationship between policy maker and their business under German energy regulation.



<u>Figure 29</u>: Siemens Gamesa's visions in relation with policy makers and their business. (Siemens Gamesa, Policy 2023; 18)

3.2.2 Current technologies, innovations, and investments.

Focus on the power modelling and optimisation, the landscape of EU's integrated technologies and innovations in RES are presented in figure 30. Each of country must turn all sectors of industries into electrification by 100 % RES in 2035. This must be the primary driver for the energy strategy in short or long term. Besides, the definition of using e-fuels and e-chemicals will be more commonly used. These are synthetic fuels and chemical products from renewable electricity.



<u>Figure 30</u>: The landscape of EU innovation to integrate RES. (IRENA, Scenarios for energy transition 2023;19)

Finland to build up the model of integrated European energy system transition as a great example of how European energy system transition will be applied which is presented from figure 31 below:

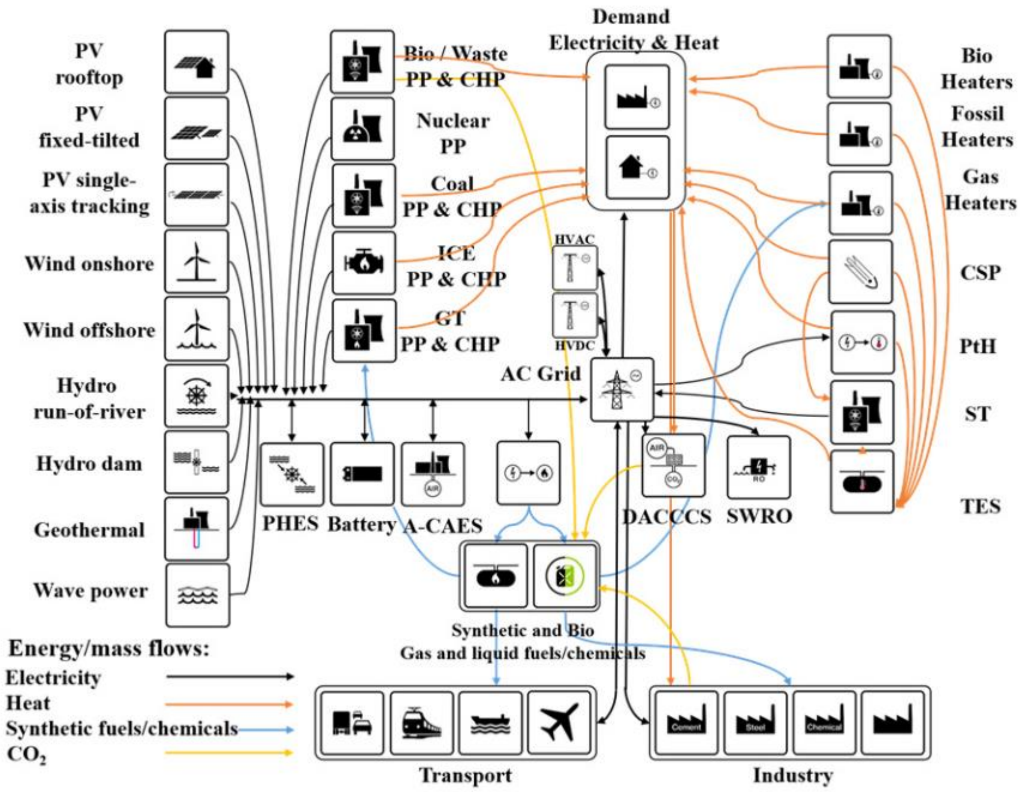


Figure 31: LUT-Energy System Transition Model (LUT_ETSM). ((Manish Ram and others, LUT, 2023, 4)

This model is applied to all cross-energy demand sectors in Finland which are included power, heat, transport, agriculture (Manish Ram and others, LUT, 2023, 4) and all industry sectors. The model is evaluated as one of the most optimal costs saving and energy efficiency for Energy System Transition in future. Technologies which are applied for this model are:

- Heat and electricity generation technologies from renewable
- Energy Storage Technologies: heat, electricity, gas, CO2
- Vehicle to grid technologies with smart EC charging
- Power to fuels and power to chemical (Power to X) technologies

3.3 Cost and benefits of integrated European Energy System Transition

3.3.1 Cost of Integrated European Energy System Transition

According to the European Commission and the World Bank evaluation, the investment of **379 billion Euros** would be needed annually for Energy Transition from 2020-2030 which mostly will be invested in renewable energy sources and building new infrastructures cross over all member states.

Despite of having current challenges with the financial environment and others related to this target, from government level to European Union, it is important to have clear policy frameworks and agreements of what are investment for costs and needs to proceed the energy sector transition success.

As it came to the green energy transition, unlike fossil fuel sources, with renewable energy source requires high capital cost and low operation cost, this meaning capital expenditure (CAPEX) and operation expenditure (OPEX), together with fuel costs will be changed and affected massively into the investment framework/plan. The below figure 34 below presented the 3 different scenarios of energy system costs in 2030, 2040 and 2050. Energy system costs are included for power, heat, transport and industry sectors all together. In general, the total annual energy system cost will be decreased from 2030 to 2040 and 2050 due to the affected of the high required capital cost to invest but operation cost will be reduced by time. This proved that 100% green transition (RES) will have long term cost benefits in the future for all European countries.

Beside the trend of annual investment cost for all of energy system, the trend for each of individual cost such as investment cost for installed technologies are also decreasing from scenarios 2030 to 2050 as shown in figure 32-33 below.

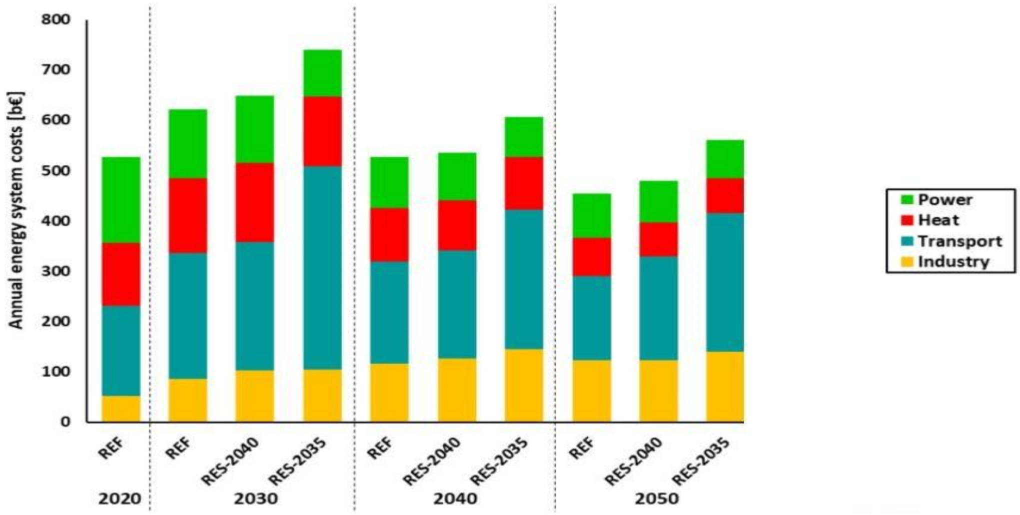


Figure 32: Annual energy system costs during 3 scenarios from 2020 to 2050 (Manish Ram and others, LUT, 2023, 4)

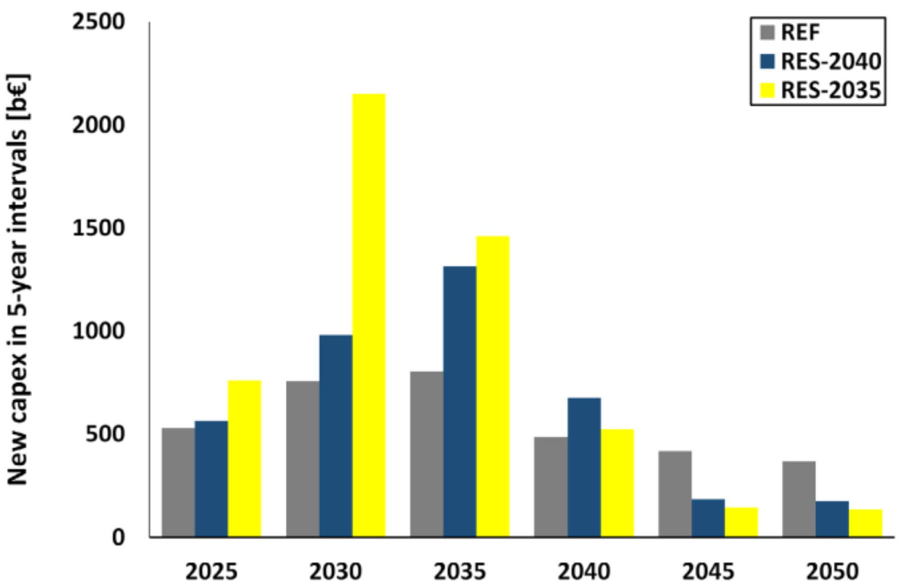


Figure 33: Capital expenditure (CAPEX) in 5 years internal of for different scenarios. (Manish Ram and others, LUT, 2023, 4)

Both above figures have clearly proved that longer time investment is important for the sustainable profits to the green transition investment plan.

In the term of RES transition, there will be more investment on the infrastructure where new wind and solar power plants will be built as part of the RES pathway to achieve 100% RES plan. Together with new bult wind and solar power plants, the projects of upgrading existed ones also need to do and this requires more investment on solar and wind sector in about 300 -700 billion Euros in between 2030 and 2050 (Amber, 61). The summary of Energy System Transition cost will be presented in the table 3 where Stated Policy, Technology Driven and System Change are 3 modelled pathways for European Energy System. Stated Policy Pathways cost is related to National pathways cost by 2035 while Technology Driven Pathways Cost and System Change Cost are formed to minimise the cost in both term of climate change target and economical target.

Table 3: Overview of clean energy transition pathway cost in 2035 in [€/bn]. (Dr Chris Rosslowe, New Energy Generation, 2023; 20)

Pathway costs for:	**Stated Policy**	**Technology Driven**	**System Change**
Power system cost until 2035	4.660	4.610	4.569
Energy system cost until 2035	8.150	7.620	7.140
Energy system cost savings by 2035		530	1010
Investment requirement before 2035	1.330	1.630	2.080
Additional investment by 2035		300	750

With the above estimation of investment cost for RES transition, Europe could have the success in the Clean Energy System by 2035 with very low cost due to the bigger investment from beginning but the number of new jobs will be increased, that means to increase the GDP and employment for the country , additionally the cost is reduced by every years and the benefit of having clean energy system will bring back in the future.

3.3.2 Benefits of European Energy System Transition

The most benefits of having Integrated Energy System Transition for Europe are to secure energy supply, meaning there is no need to export energy source from outside, shifting to

100% renewable and clean energy, avoid using fossil fuel and protect the environment by net zero ambition target.

3.4 Modernization and Digitalization of Europe's Power Grids

The target of new modernization of EU's power grids is to combine renewable energy sector, energy efficiency, energy storage, energy network and transition to carbon-dependent regions. This target has been funded officially from European Union and be part of European Green Deal Investment Plan. Interconnection power grid is very important for European Countries for security seasons to secure power supply, energy independence and lower energy bills to every citizen of each country. The connection network across European countries will enable the possibilities and choices to choose the most available and type of energy as well as the price options to end user. This also increase the way of using green energy at the same time. Modernization for the cross-border electricity grids would cost European around 584 billion euros according to News about securing the EU's electricity supply. (Frank Urbach, Securing EU's electricity supply;2023 21)

The main cores of electric grid are consisted of Transmission System; Distribution System; Generation System which aimed to be modernized by grid digitalization. This is the new process to make electricity usage easier and more efficiently. In this modernization, the power transparency in low-voltage grids will be digitised via digitalized transformer stations and Advanced Intelligent Transformers (AIT) will be more innovated in the future to capture the whole system's grids and database to improve the efficiency of the transmission. The new modernization also applied in the Advanced Digital Twins (Virtual Models) for operation points simulation and predication of load profiles based on current loads. This is a great opportunity for grid operators to make decision via data base for future forecast. Furthermore, for the Smart Grids at medium and low voltages, there is a need to moderate also the Digital Secondary Substation (DSS) beside AIT. This modernization should be applied in all renewable power plants and 5G should be able to adapt for future energy of Europe via the modernization and digitalization solutions as presented in figure34 below.

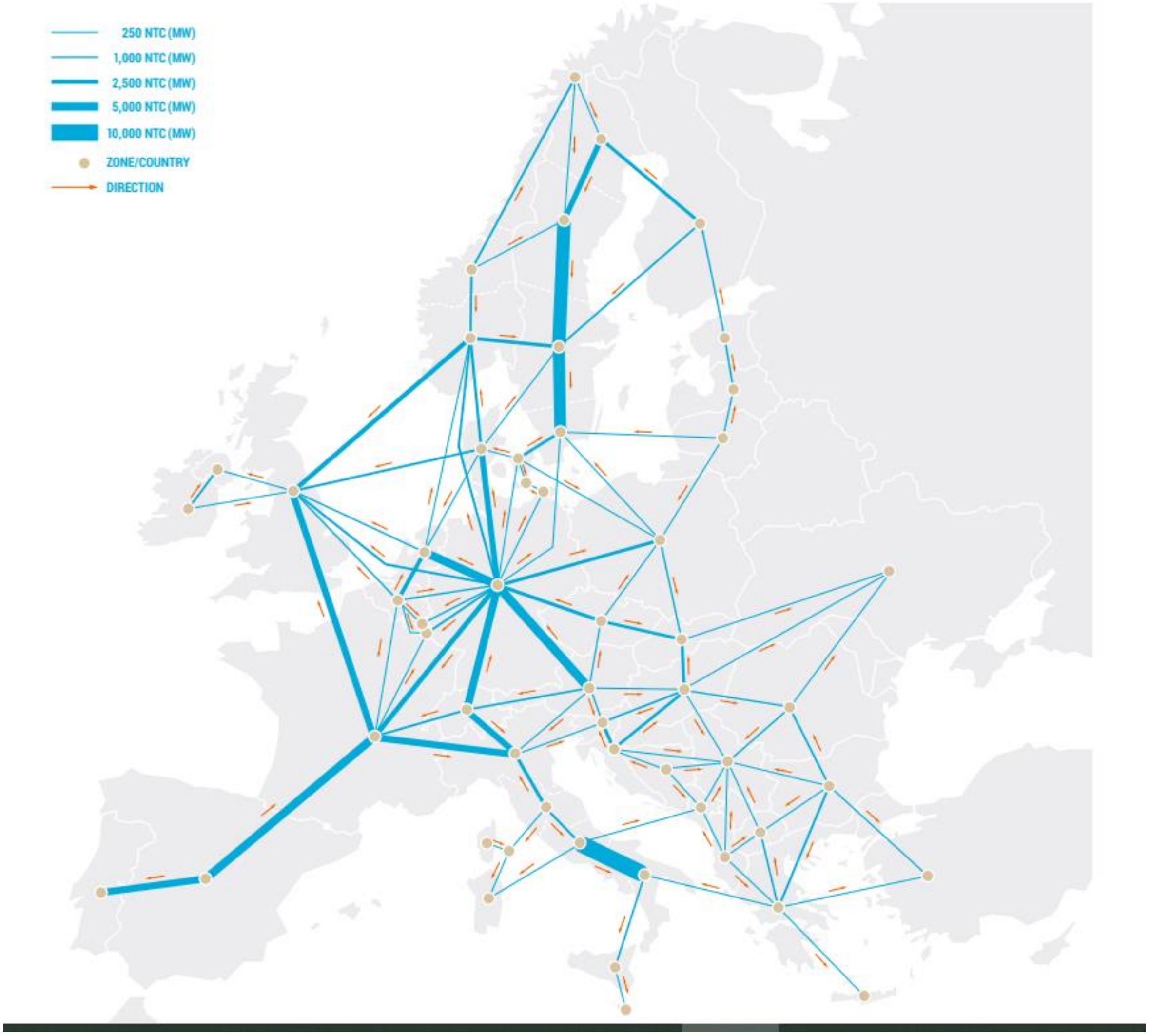


Figure 34: Network Transfer Capacity (NTC) Model in 2030. (ENTSO-E,2023;22)

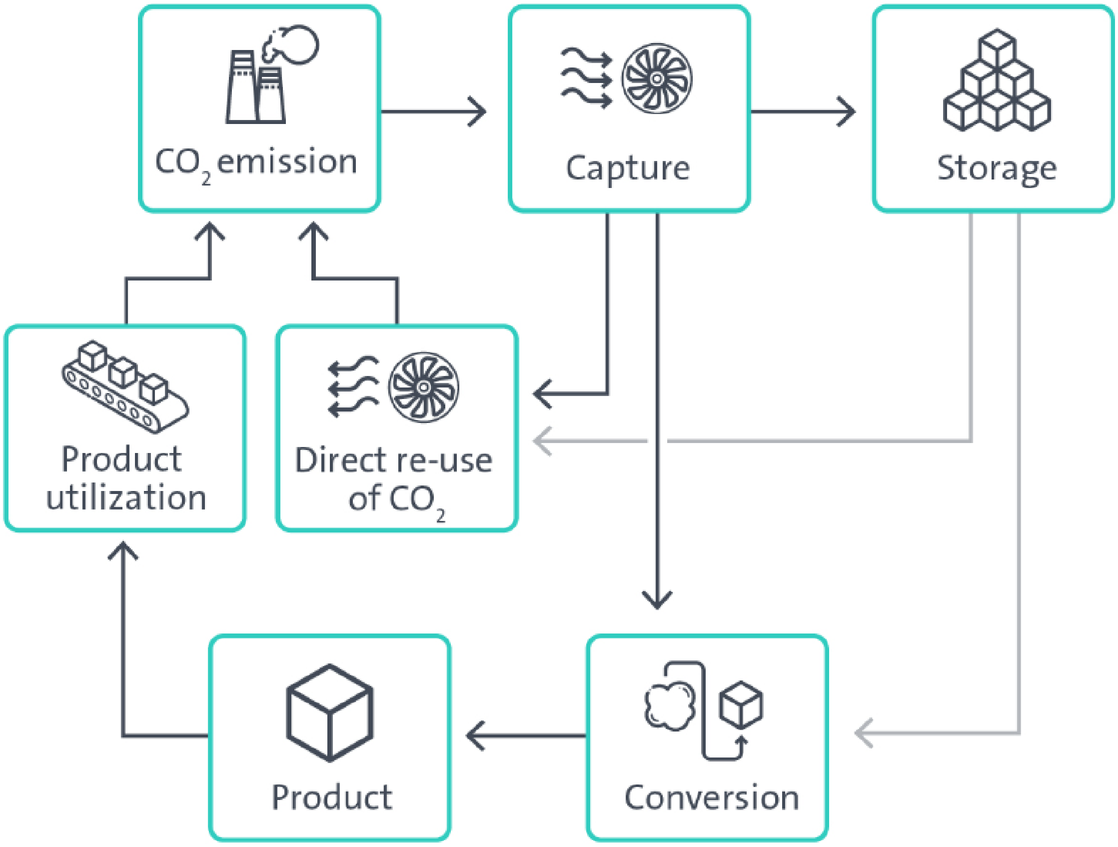
Among those European countries, Denmark has the most advanced power grid with the high energy security and delivery.

3.5 Technologies needed for RES Transition in Europe

To enable renewable energy system transition in Europe, together with massive investment costs, technologies are back-bond of the whole green transition pathway and is the main key to open the success of RES transition plan in Europe for the energy future. The below are main technologies which need to be applied and improved more in the EU's future energy (figure 35).

3.5.1 Technologies in Carbon capture utilisation and storage CCUS

- **Negative emissions Technologies**
- a) Direct Air Capture (DAC) technology to capture air directly CO_2 from air. This is one of the methods to achieve net zero emission, CCUS technologies needs to be developed more sustainably in both small- and large-scale industries especially in the retrofit for existing CCUS facilities. To prevent emissions fossil fuels used in power plants, capturing direct CO_2 (DCCUS) from atmosphere is predicted as new technology.
- b) Bioenergy with carbon capture and storage technology (BECCS): this is the method to capture CO_2 from the combustion of biofuels power plants.
- **Re-using Co2 Technologies**
- a) Directly: Captured Co2 can be re-used in greenhouse or another application such as in drying cleaning process.
- b) As new element for new product such as transforming to new fuels, chemical materials
- Storage Technology: CO_2 after captured, if it cannot be use directly, it can be stored to ensure the EU’s energy security and energy efficiency target. **Renewable hydrogen storage** for power grids is important as it keeps the balance of energy’s demand and supply for short or long time periods. This helps to improve the flexibility of energy system and increase the energy efficiency.



<u>Figure 35</u>: Overview of whole CCUS technologies (European Patent Office, 2022;23)

3.5.2 Technologies of Renewable Hydrogen

Renewable hydrogen storage for power grids is important as it keeps the balance of energy's demand and supply for short or long time periods. This helps to improve the flexibility of energy system and increase the energy efficiency. Unlike fossil fuels, when hydrogen is used as direct fuel in heating and energy, it will be converted into water and electricity. Green hydrogen will be replaced fossil fuels in future. Beside green hydrogen, there are also blue and green hydrogen which produced by natural gas which blue hydrogen can capture over 80% of CO2 emissions to be stored directly. Innovated technology of production hydrogen with electrolysers is developing and expanding as example shown in figure 36. Some of the conversion technologies for green production to end user is also introduced in figure 37 as well. According to Renewable Energy Industry Group in Linked in (Barilam Dandge, Energy Engineer; RES group ;24) a group of energy engineers have estimated that it will take less than 5 years for green hydrogen to achieve cost parity with fossil fuels.

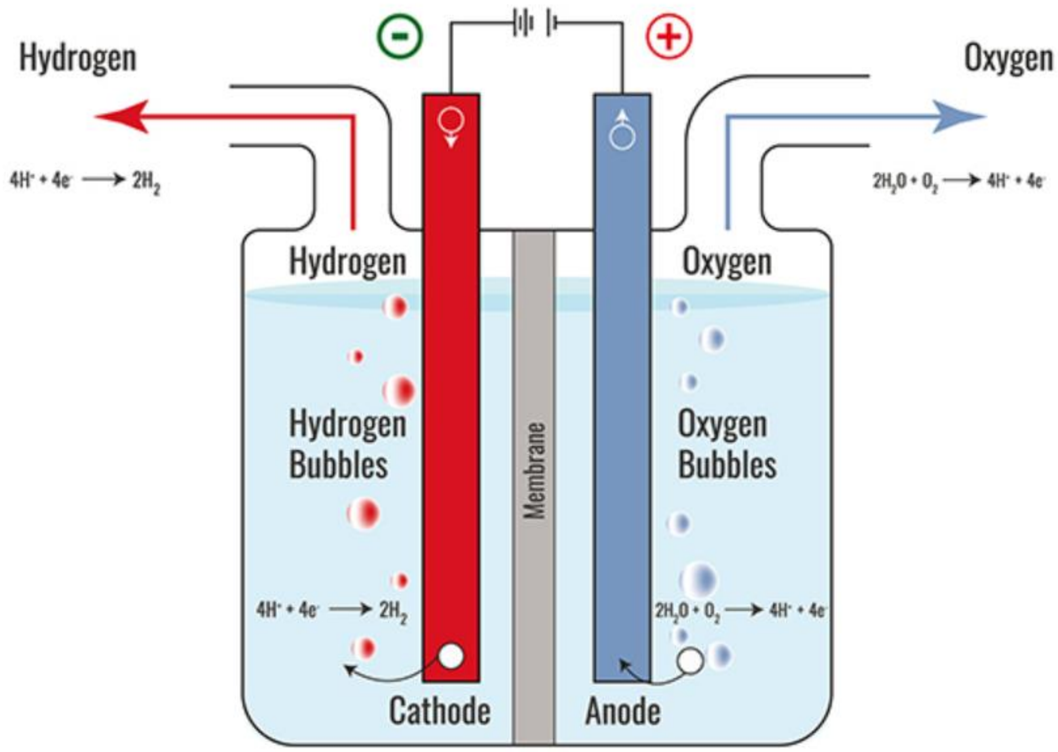


Figure 36: Innovation technology on production hydrogen from electrolysis of water (European Patent Office, Clean Energy Technologies, 2023; 25)

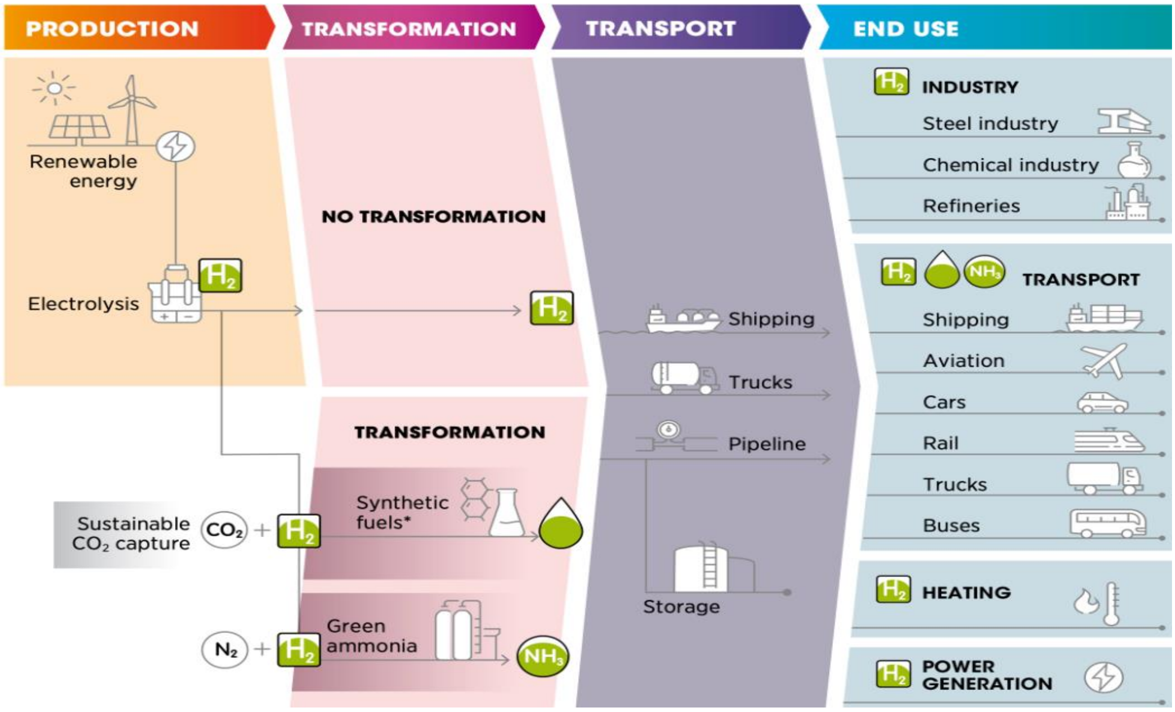


Figure 37: Conversion of green hydrogen production to end users. (World Economic Forum, Hydrogen, 2023; 26).

According to the World Economic Forum published in 2021, June (World Economic Forum, Hydrogen, 2023; 26), Green Hydrogen Production Technologies which have been innovated in green hydrogen transition are for example advanced technology of Digital Twins in digital technology sector, artificial intelligence of things (AIoT) with data management and analysis showed in figure 38.

According to Custom Market Insights CMI (Trisha Jadha, Research Analysis at Custom Market Insight 2023; 28), the Global Green Hydrogen Market size will be increased about 55% from 2022 to 2030 with the estimation from 1.8 billion USD in 2022 to 90 billion USD in 2030 which covers for power generation, transportation, and others (figure 39).

In Europe, according to Energy Connection Research (Energy Connects 2022;29), more than 40 green hydrogen projects will be started up in 2030 which bring Finland, Denmark, Sweden around 18% of Europe's green hydro production capacity via Electrolysers.

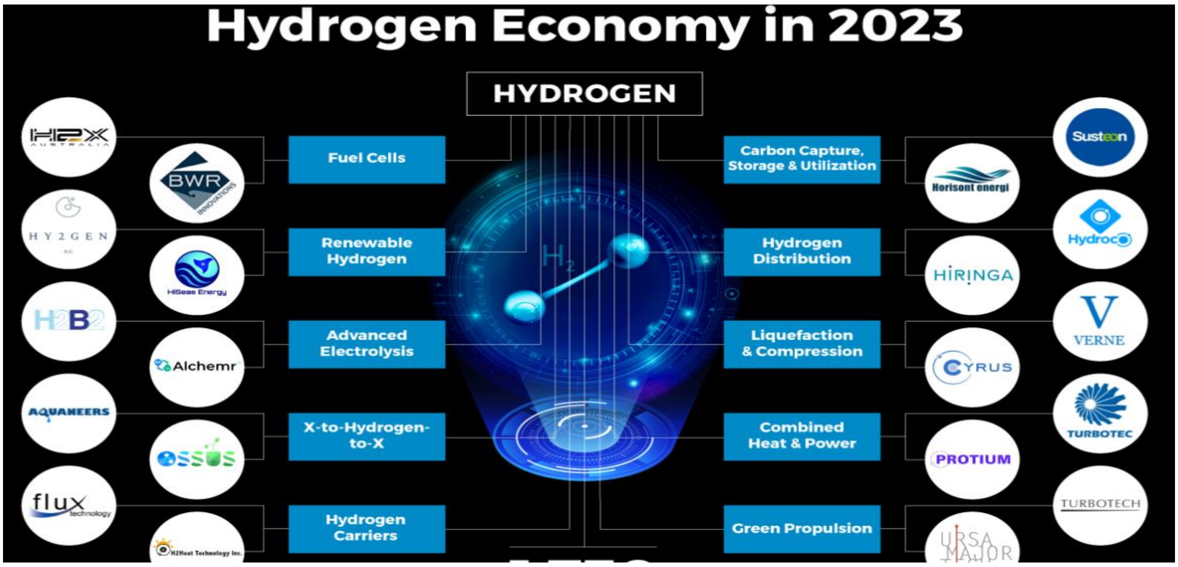


Figure 38: Top 10 Trends and Innovation Technologies Impact the Hydrogen Economy in 2023. (Research Insight 2023; 27).

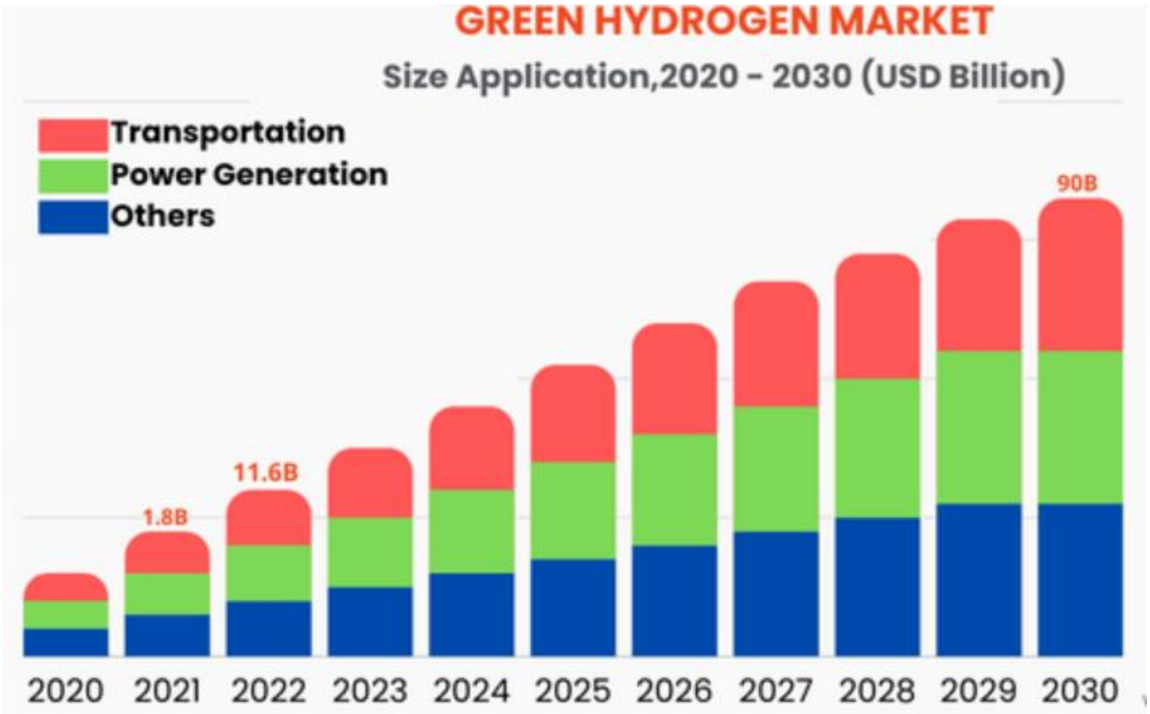


Figure 39: Global Green Hydrogen Market 2020-2030 by CMI. (Trisha Jadha, Research Analysis at Custom Market Insight 2023; 28).

3.5.3 RES Transmission Network

Energy The vision of future Smart Grid is to fulfil the end user energy's need with the flexibility and an easy access to connect to common network, especially to renewable power networks with reliable energy security. The European Smart Electricity network is the combination of stakeholders. The figure 40 and 41 below will present how does the future Smart Grid and Network will be seen:

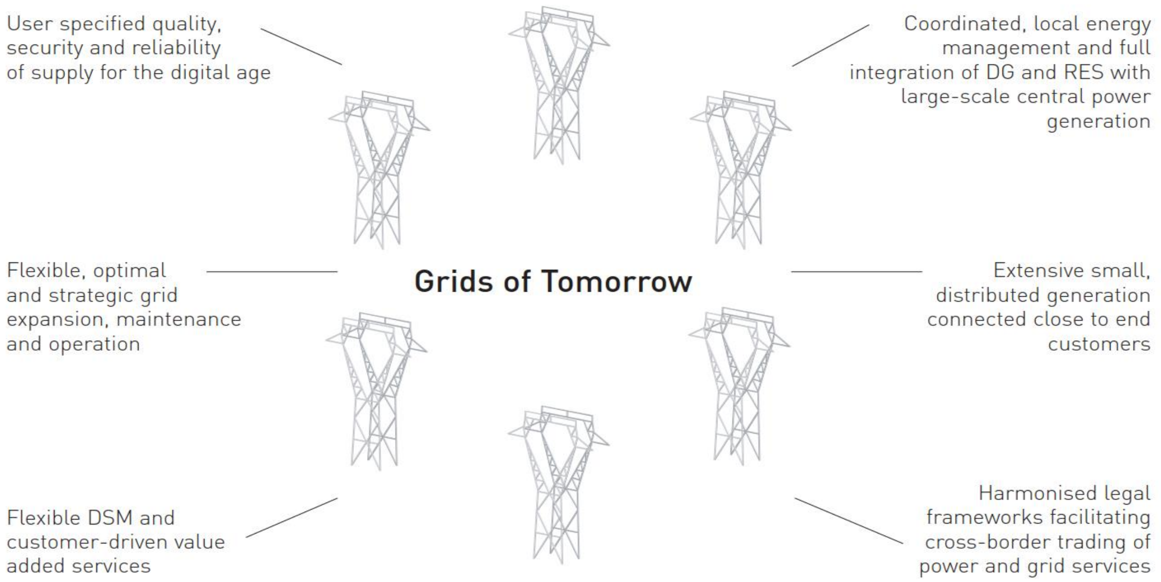
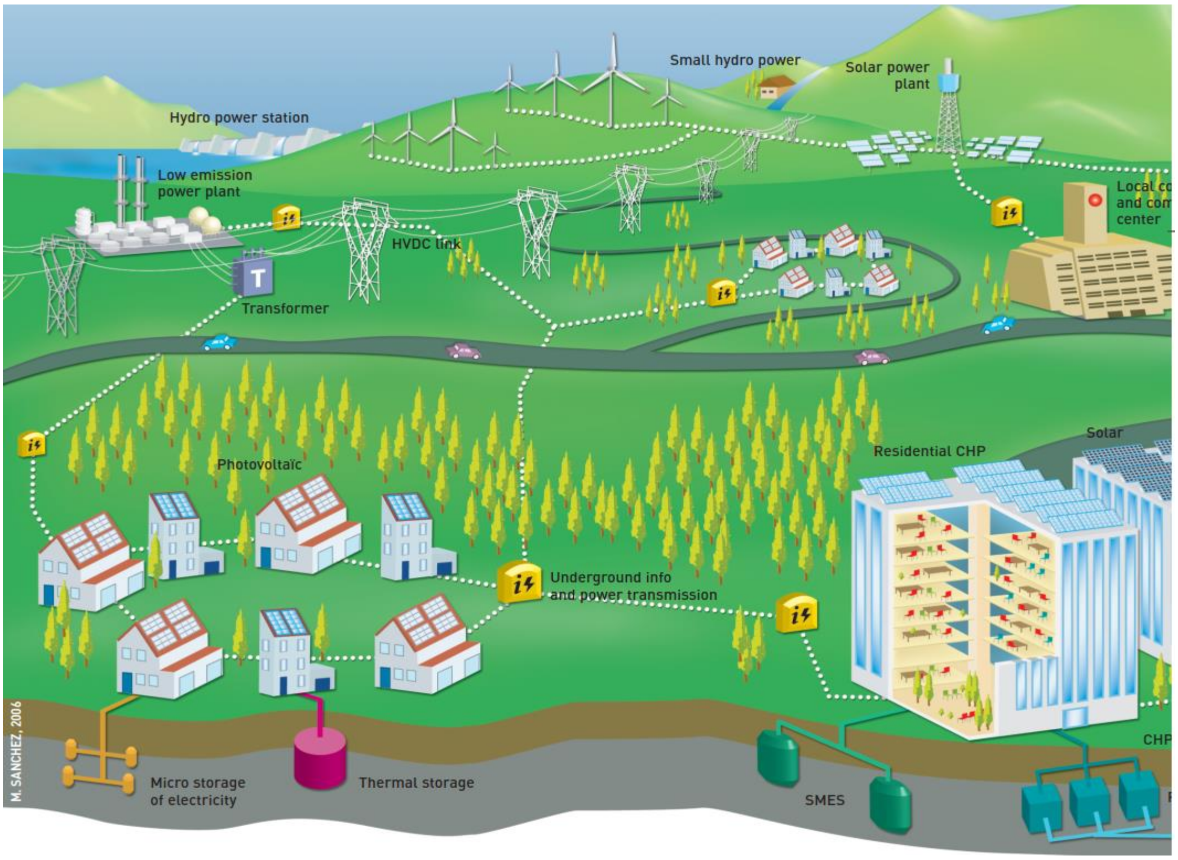
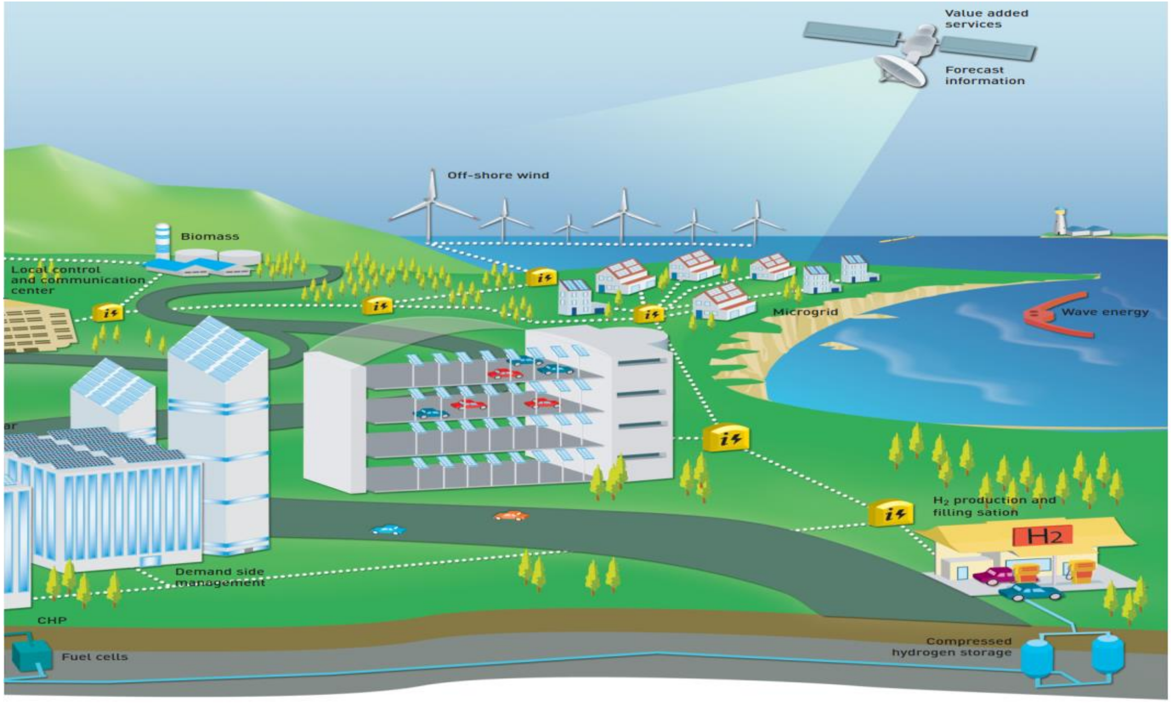
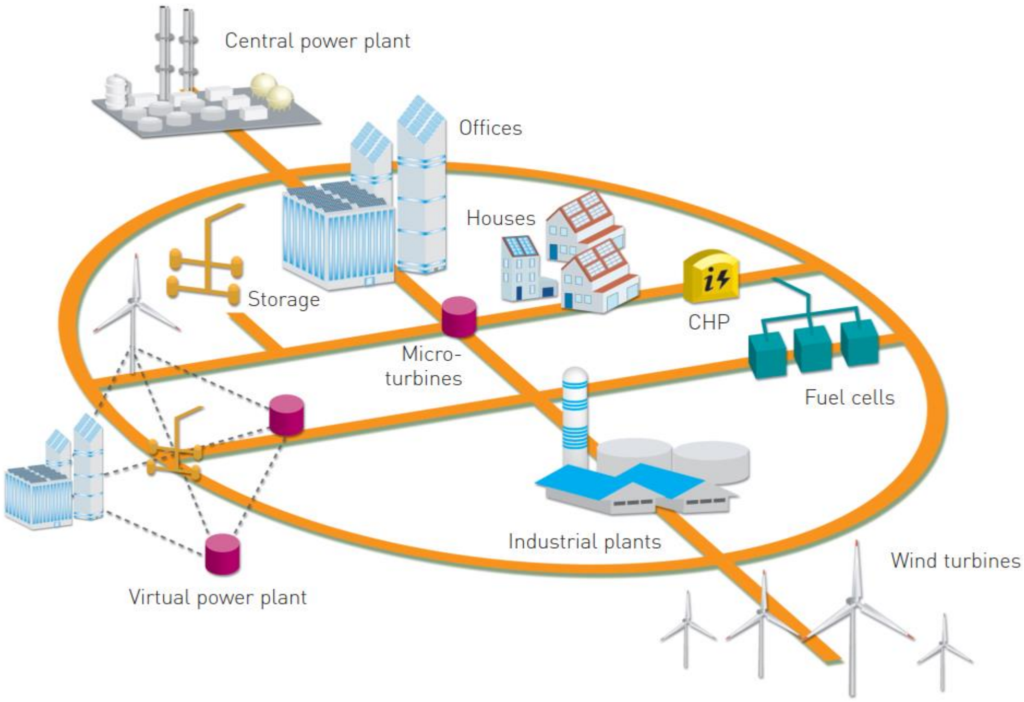


Figure 40: Overview of Future Grid. (European Commission, EUR 2040; European Technology Platforms Smart Grids;30).





<u>Figure 41</u>: European Future Network Vision. (European Commission, EUR 2040; European Technology Platforms Smart Grids;30).



<u>Figure 42:</u> The share of central and distributed generators in Operation system. (European Commission, EUR 2040; European Technology Platforms Smart Grids;30).

For future network, more integrated secure network in combination between central and distributed generators.

In the interconnected electricity and power network (cross-border network), exchange capacity network is very important as it allows countries to help to each other’s during the peak load times and the weather conditions. Examples below (figure 43) are about the illustration of Net Transfer Capacity in Nordic country & Baltic Sea region in regard of power balance in winter from FINGRID and another example (figure 44) of electricity exchange network vs prices cross border of Europe.

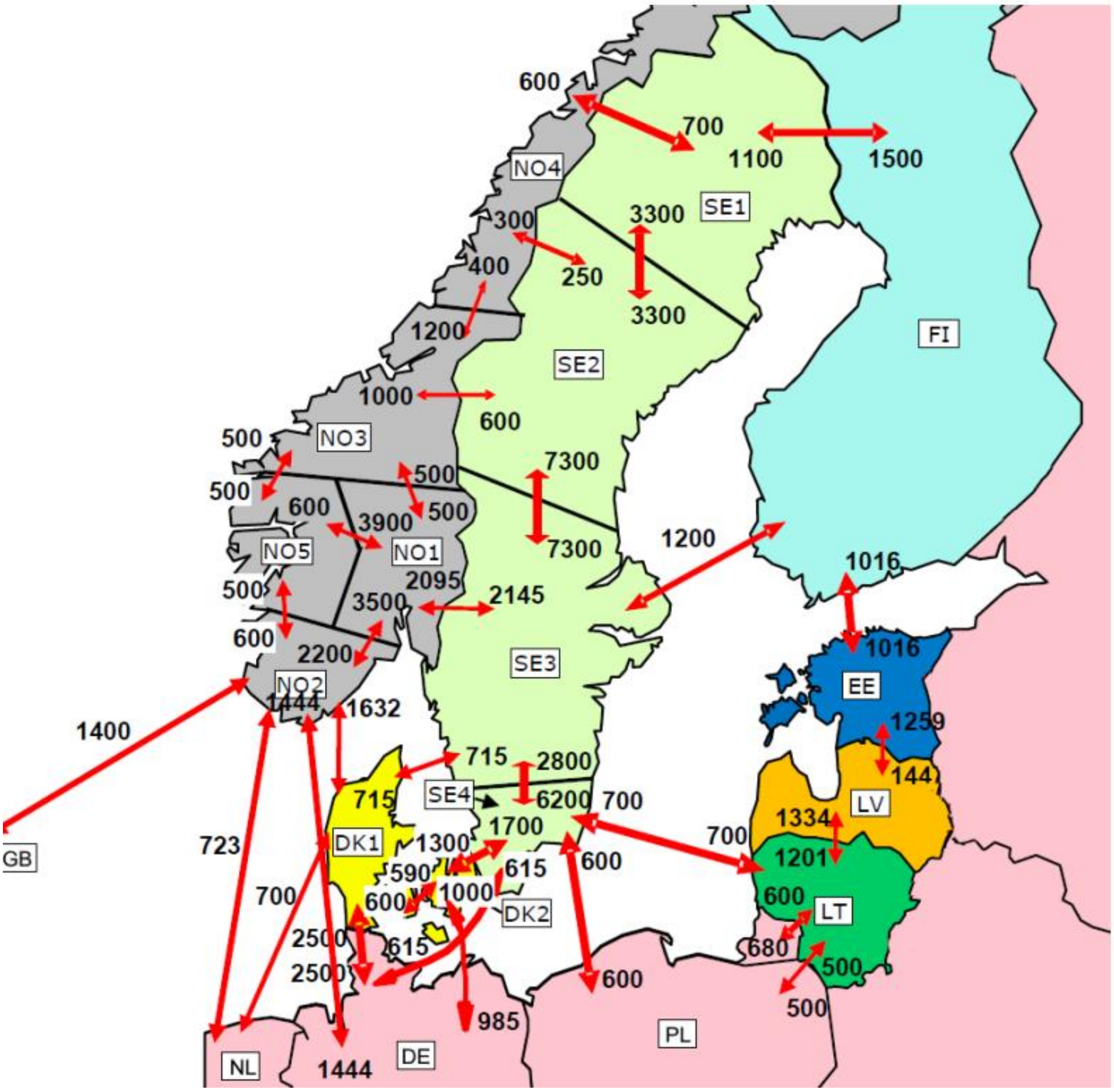


Figure 43: Illustrated of Net Transfer Capacity (NTC) in 2030. (FINGRID, Nordic and Baltic Sea Winter Power Balance 2022-2023; 31)

<u>Figure 44</u>: Higher electricity exchange network vs. Prices between country by ENTSO-E 2023; 22)

3.5.4 Technologies in Batteries (Energy Storage)

a) **Advanced rechargeable lithium-ion (Li-ion) batteries** in electronic devices: Together with integrated renewable energy networks such as solar panel and wind power into electricity network; batteries play 90% of electricity storage's patenting activities. Therefore, innovation on the advanced rechargeable lithium -ion batteries used in electric devices will be increased, especially in electric mobile sector where lithium-ion batteries can be improved for extending life cycle, recyclability, and power output. Furthermore, batteries which have no longer to charge, it can be re-used in second life applications in different ways, such as in power electric cars or in power energy storage. Beside lithium-ion batteries (33%), there are also **sodium ion batteries** (33%) and **solid-state batteries** (33%) which holds the greatest potential for future market.

b) **Redox-flow** batteries (RFBs): used for long storage times and long discharges which is a good solution for integrated renewable energy and energy storage due to the benefit of cost-effective and flexibility.

c) **Liquid Metal Batteries (LMB):** The most advantages of LMB is the ability to suffer the structure damages. During peak load times in solar or wind power, a larger power is consumed. LMB is a good solution to reduce cost to store solar or wind power on electricity grid by using LMB which has ability to retain 90% capacity over 5000 charging devices.

Figure 45 below is the summary of batteries technologies in Europe from 2030-2050 by EUROBAT 2023.

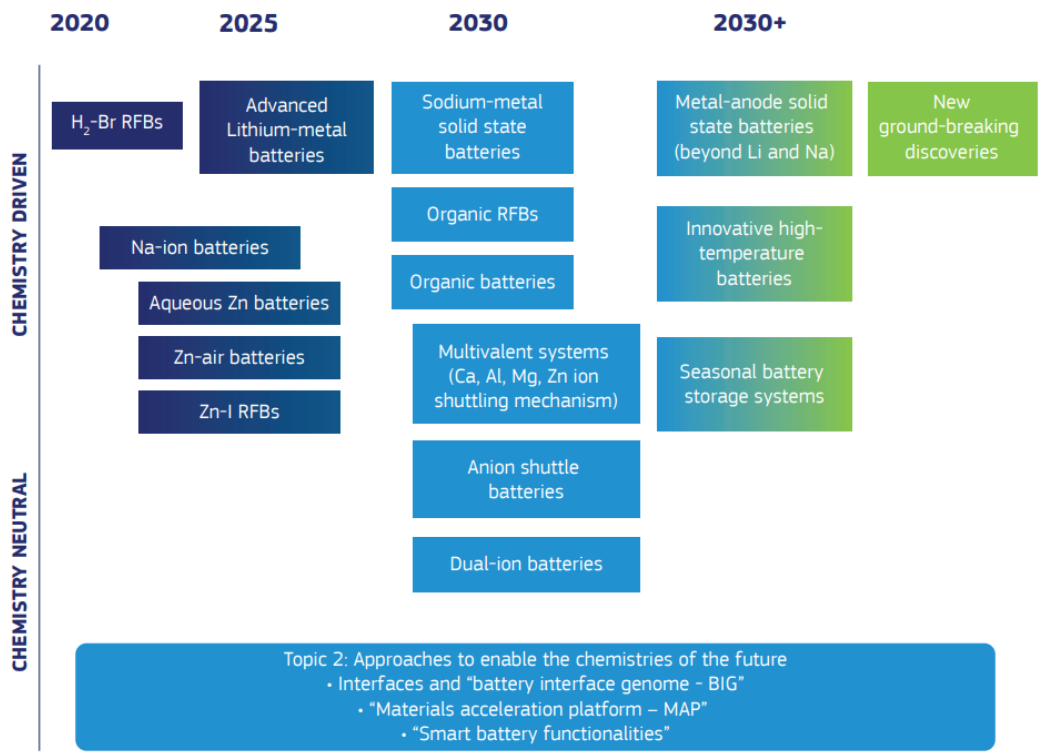


Figure 45: The roadmap of batteries technologies in Europe from 2020-2030. (EUROBAT 2023; 32)

4 Collection of Technologies in Renewable Energy Industry

4.1 Collection of current developed technologies in Renewable Energy Industry

In the table 4 below are example of some additional collections for the most updated innovation and technologies in Renewable Energy Industry in over the world. The information was collected via Renewable Energy Industry Group in Linked In were gathered more than 1000 energy engineers, expertise, professors, and researchers on the matters of the renewable energy. The group has been very active in discussing and sharing a lot of experiences on the world's current situation of energy crisis and solutions where to make it better. Many of members in this group are scientist who designed new technologies which adapted to the current energy crisis as well as proposed new solutions for renewables energy and transition in Europe and in over the world. Furthermore, the innovation and technologies trends come along with the major key parts who are energy companies that are doing the development works currently in practical world. One of the most major key partners are

Siemens, ABB, General Electric; Wartsila, Schneider Electric Ltd companies which play an important key factor to accelerate green transition in Europe and in over the world.

Table 4: Current innovation and technologies in different sector of RES Industry in 2023

Innovation &Technology	**RES sector**	**Majors Key Partners**
Advanced Energy Storage System (Thermal Storage)	Energy Storage	Siemens Gamesa; Samsung SDI; Hitachi; GE; ABB; Wartsila ; LG C
Advanced Agrivoltaics	Solar Energy	SOLAR Technology Co
Advanced Turbine Structure	Wind Power	Siemens Gamesa, G&E
Artificial PhotoSynthesis	Sun power	Siemens Energy; Panasonic North America; Toshiba Cooperation; Fujitsu; Toyota Central Europe.
Advanced Sun Sensor	Solar Energy	ABB ltd; Sumitomo Cooperation; Hydro-X group
Submarine Power Cable	Offshore Wind Generation	Siemens AG, General Electric Company
Micro Grid Control System	Energy Distribution Grid	Siemen Gamesa, ABB
Turbine Control System	Power Generation	Siemens ; ABB; GE
Microwave Power Transition	Power Transition	Huawei, LM Wind Power; NEC Corporation
Advanced Biomass boiler	Biomass- power generation	GE; Amec Foster Wheeler
Biogas Upgrading	Biomass- power generation	Biogas-E; Carbo Tech Gas System GmbH; Bright Bio Tech.
Solar Updraft Tower	Solar Power	Hyperion Solar Energy
Advanced Distribution Management System (ADMS)	Distribution	ABB; Schneider Electric; GE; Siemens; Oracle.
Blue Hydrogen Revolution	Hydrogen	Siemens; ATCO; Linde

Boiler Innovation	Advanced Energy Generation Technology	Foster Wheeler; General Electric (GE), Siemens AG,
Wind powered water Pump	Sustainable Agriculture	Grundfos
Smart Grid Driving Building to Grid Technology	Energy Grid System	Siemens; ABB; Schneider Electrics; GE, Honeywell International Incorporated

These above updated technologies and innovation which reflected how quickly the big companies have turned to renewable energy application such as in solar energy sectors, carbon capture sectors or bio-generation sectors which are focus trends that will develop more in the future.

4.2 Nordic's Green Revolution- A successful study case to possible use

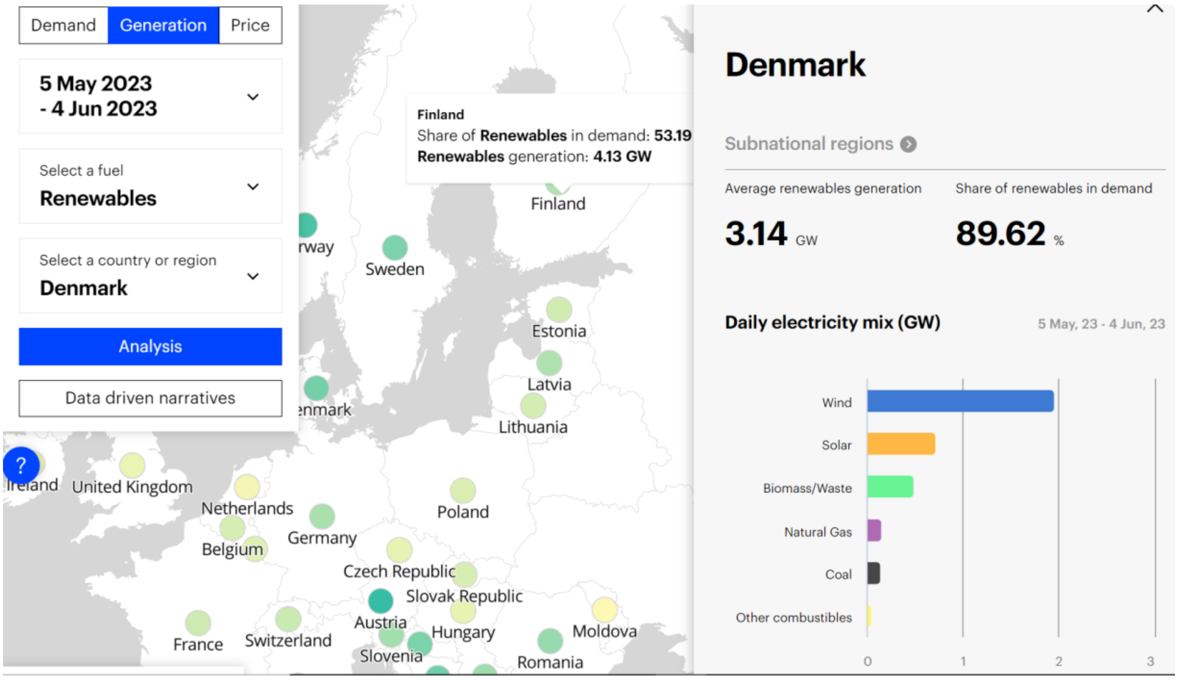
In this part, the focus will be on the roles of renewable energy and technologies from Nordic countries to the rest of European countries to foreseen and predict whenever Nordic Energy System's Model, Technology and Framework would be a practical example/model to apply to another countries for boosting Green Energy Transition goes faster and more flexible. These analytical with statistic updated report will explain how Nordic countries have committed the green transition's target and why they have done it so well. The report also identified that, the Model of Nordic 's Green Energy Transition and Technology will entirely possibly become common model and framework for Europe in term of successful RES Transition in the future. Therefore, the voice of Nordic countries should be risen, and their Energy System Framework and Policy must be the good practise to use for the rest of other countries in Europe. In the end of this chapter, examples of how Danish Government handled for Climate Targets in 2030 via Carbon Capture & Energy Storage System Technology will be look like and the other example of Combined Heat and Power Plant from Finland would be the potential trend for Europe's Future Energy.

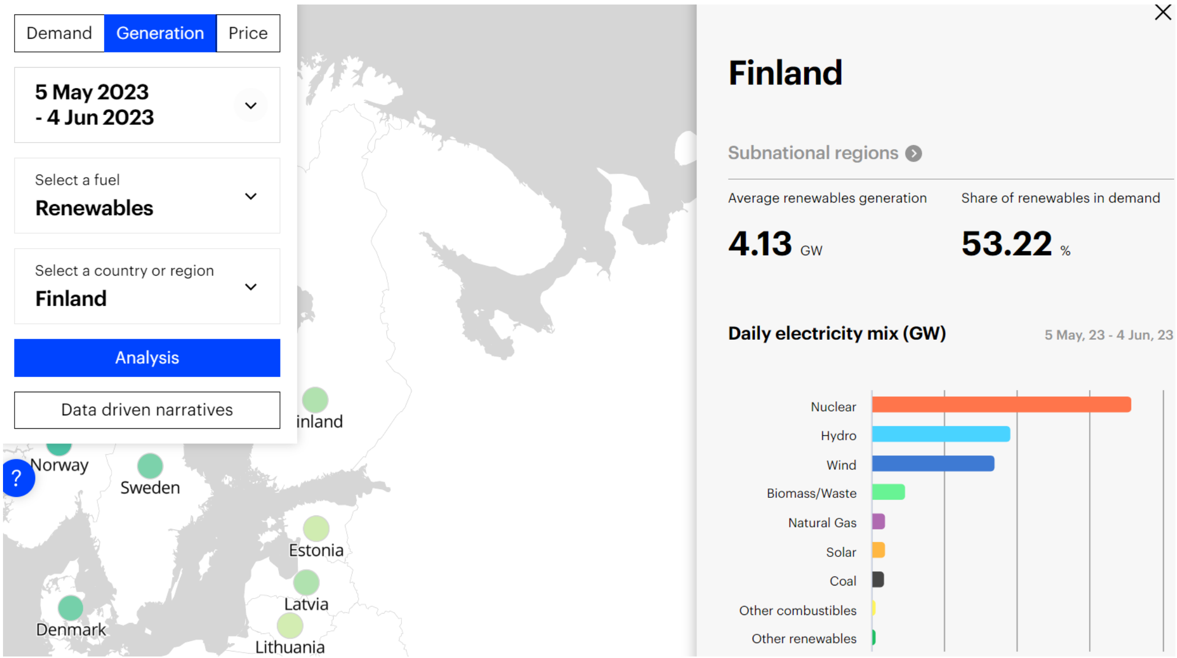
Besides that, not only having the clear policy, best technologies, large investment, the behaviour of Nordic citizens for changes are also important in the Green Energy Transition Pathways.

In early spring 2023, VTT, Technical Research Centre of Finland has reported that Nordic countries have solved European Energy crisis (VTT updated by 2023;33). Thanks to the forward-thinking manners, Nordic countries has invested a lot in the energy transition where their tends were investment in natural local resources such as waterways, wind, offshore, onshore as well as the electrification of society. These were made before Energy crisis started and it has been successfully covered well Europe's Energy Issues during the crisis.

Updated by Nordic Energy Research on 12th May 2023, Nordic countries allowed the first submission of Nordic Energy Challenges 2023 for Energy solutions and projects to meet the first deadline of requirement to solve the problems of Energy and Security sectors on the matters of Energy Efficiency, Hydrogen Microgrid, North Sea Power and clear framework for Nordic co-operation. This even has made Nordic to become one of the most sustainable and renewable regions in the world (figure 49). (Nordic Renewable Research 2023; 34).

Figure 46 below is the updated real time electricity tracker from International Energy Agency (IEA) in 1 month period from 05th May 2023 to 04th June 2023 (IEA, 2023;35) in Nordic countries where most of natural resources such as hydro power from Norway, wind power from Denmark or biofuels from Sweden are the critical key resources which have lead Nordic countries to become of the most leader in the world in renewable energy production and consumption.


Demand
Generation
Price
5 May 2023
- 4 Jun 2023
Select a fuel
Renewables
Select a country or region
Denmark
Analysis
Data driven narratives
Finland
Share of Renewables in demand: 53.19
Renewables generation: 4.13 GW
Finland
Sweden
Estonia
Latvia
Lithuania
United Kingdom
Netherlands
Belgium
Germany
Poland
Czech Republic
Slovak Republic
Austria
Hungary
Slovenia
France
Switzerland
Moldova
Romania
Denmark
Subnational regions
Average renewables generation
3.14 GW
Share of renewables in demand
89.62 %
Daily electricity mix (GW)
5 May, 23 - 4 Jun, 23
Wind
Solar
Biomass/Waste
Natural Gas
Coal
Other combustibles
0
1
2
3


Demand
Generation
Price
5 May 2023
- 4 Jun 2023
Select a fuel
Renewables
Select a country or region
Finland
Analysis
Data driven narratives
Norway
Sweden
Estonia
Latvia
Lithuania
Denmark
Finland
Subnational regions
Average renewables generation
4.13 GW
Share of renewables in demand
53.22 %
Daily electricity mix (GW)
5 May, 23 - 4 Jun, 23
Nuclear
Hydro
Wind
Biomass/Waste
Natural Gas
Solar
Coal
Other combustibles
Other renewables

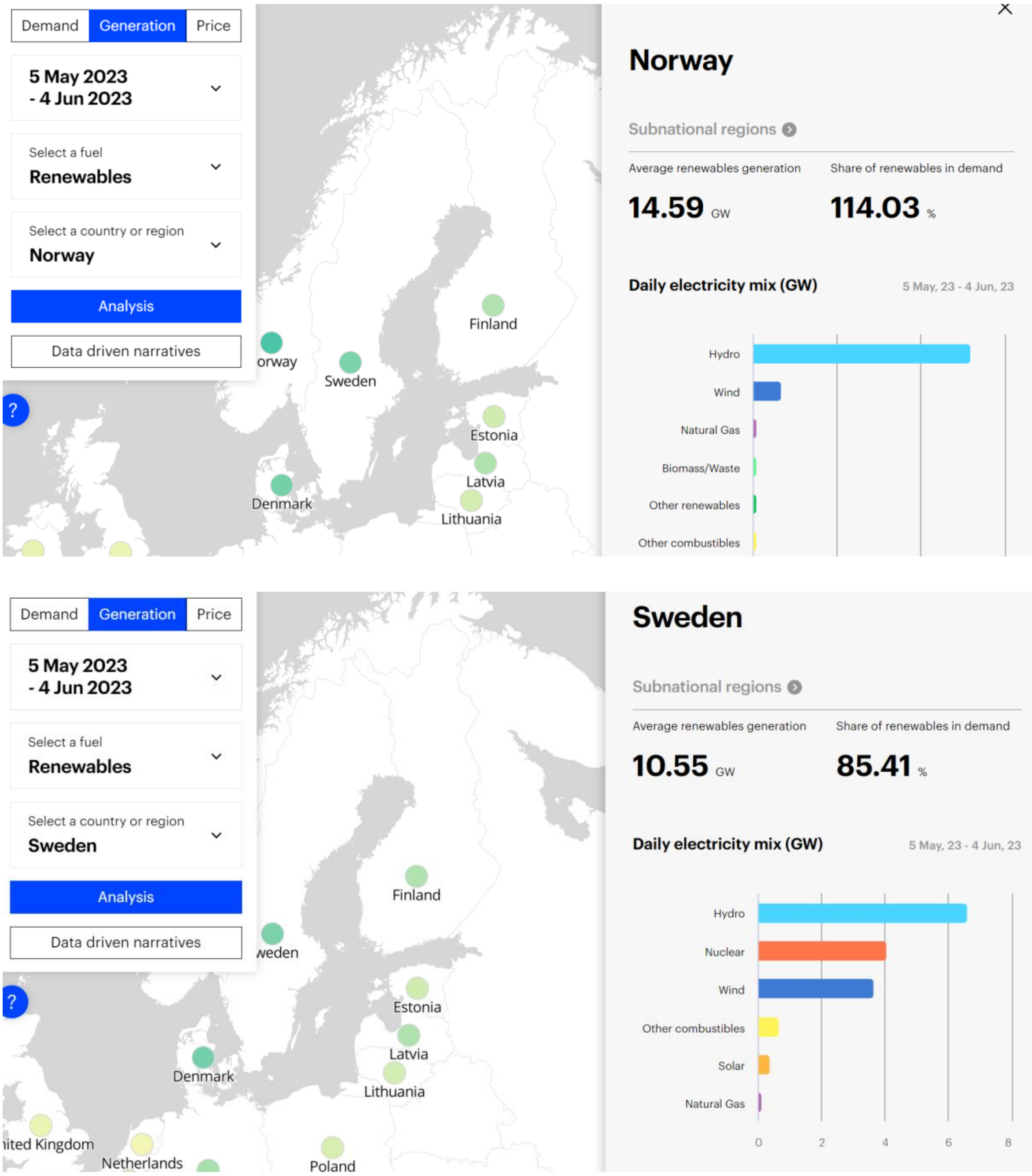


Figure 46: Real Time Electricity Tracker of Denmark, Norway, Sweden, Finland from 05th May -04th June 2023. (IEA, 2023;35)

According to Nordic Energy Research, Nordic, or Scandinavian countries which are Norway, Denmark, Sweden, Iceland, and Finland have completed 2 years ahead of schedule which European Commission's target has set in 2020 for Renewable Energy Transition while the rest of another European countries are still going on with the target as shown in figure 47.

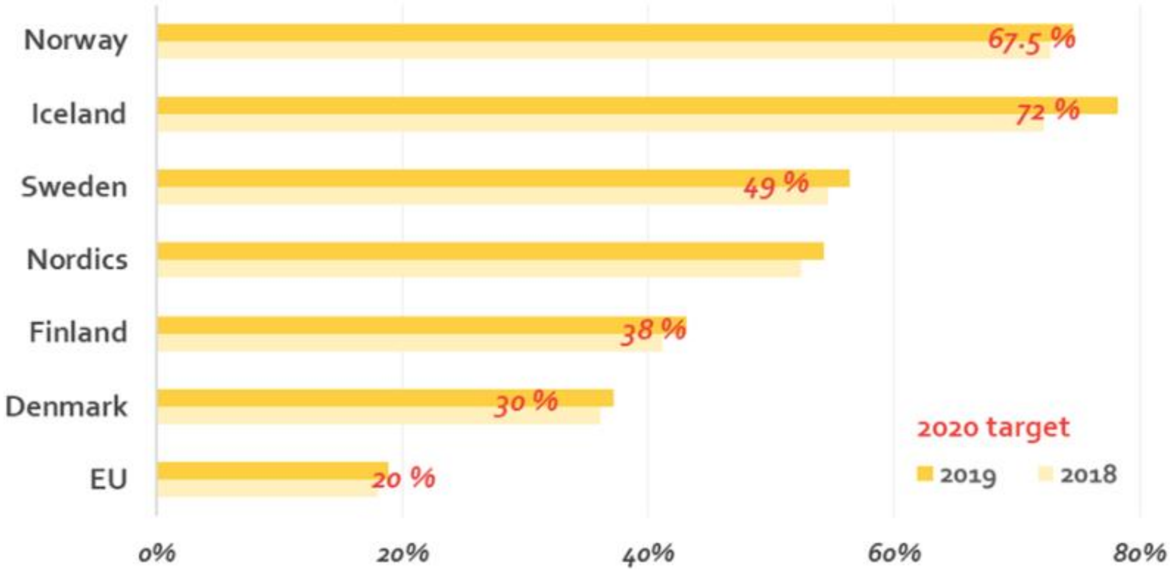


Figure 47: Share of Renewable Energy between Nordic countries and EU in target year 2020. (Nordic Energy Research 2023;36)

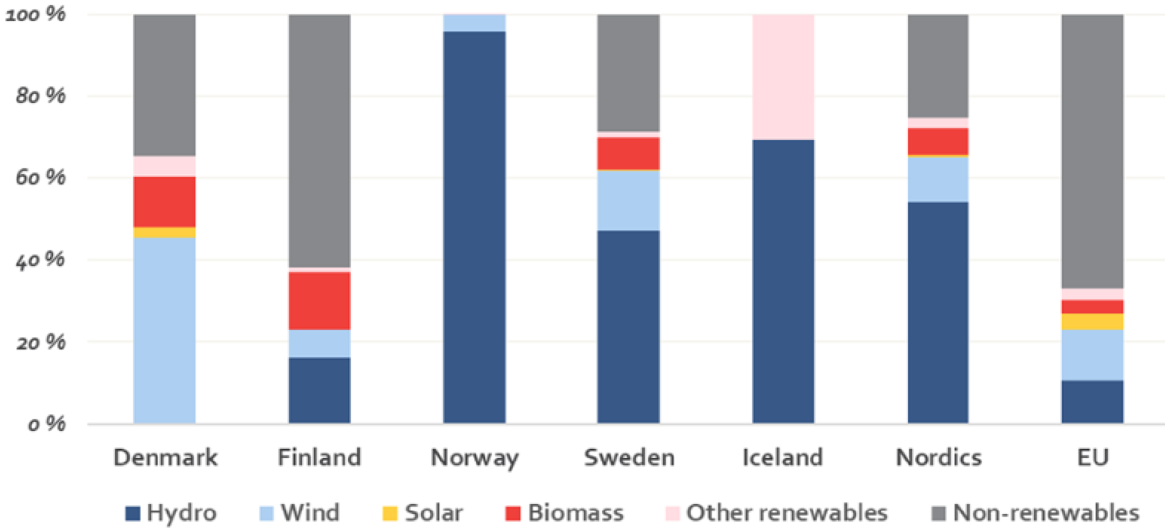


Figure 48: Renewables in Electricity mix (%) in Nordic countries and EU. (Nordic Energy Research 2023;36)

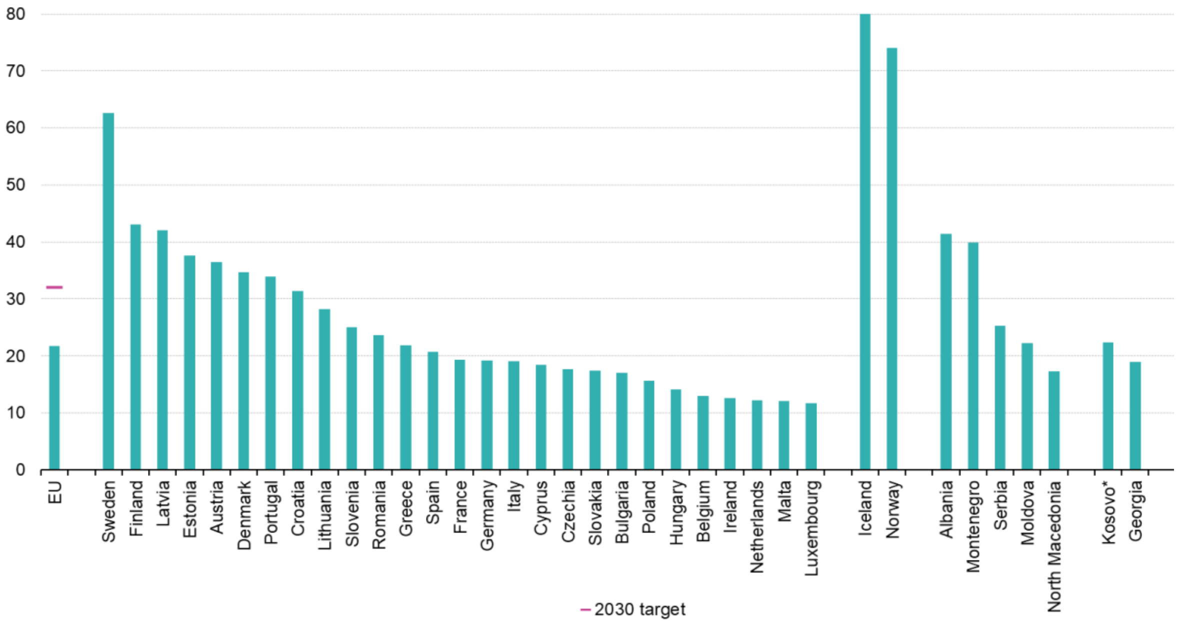


Figure 49: The share of energy from renewable sources in 2021 by 2030 target (Eurostat 2021;37)

Not only to be as the leader in green energy transition by taking advantage of strong existed natural resources, but Nordic countries are also the greatest leader in cutting down CO2 emission by strong government's policy frameworks; clear development plans as well as having forward- thinking manners to help them to be success in carbon neutrality in Europe.

Figure 50 and 51 below have demonstrated the commitment of Nordic country on the decarbonisation target already in 2019

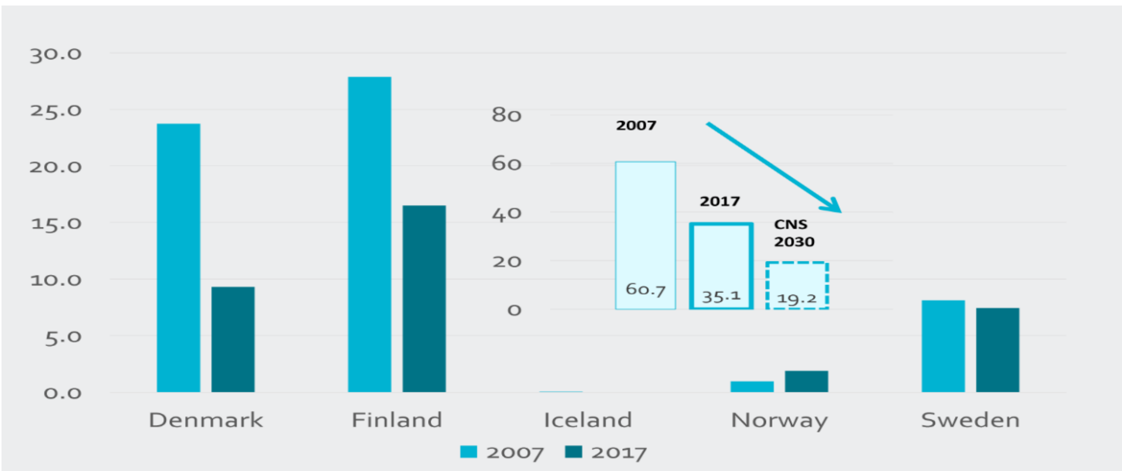


Figure 50: Nordic countries' power and district heating emission CO2 (Mt) progress. (Nordic Renewable Research 2023;38).

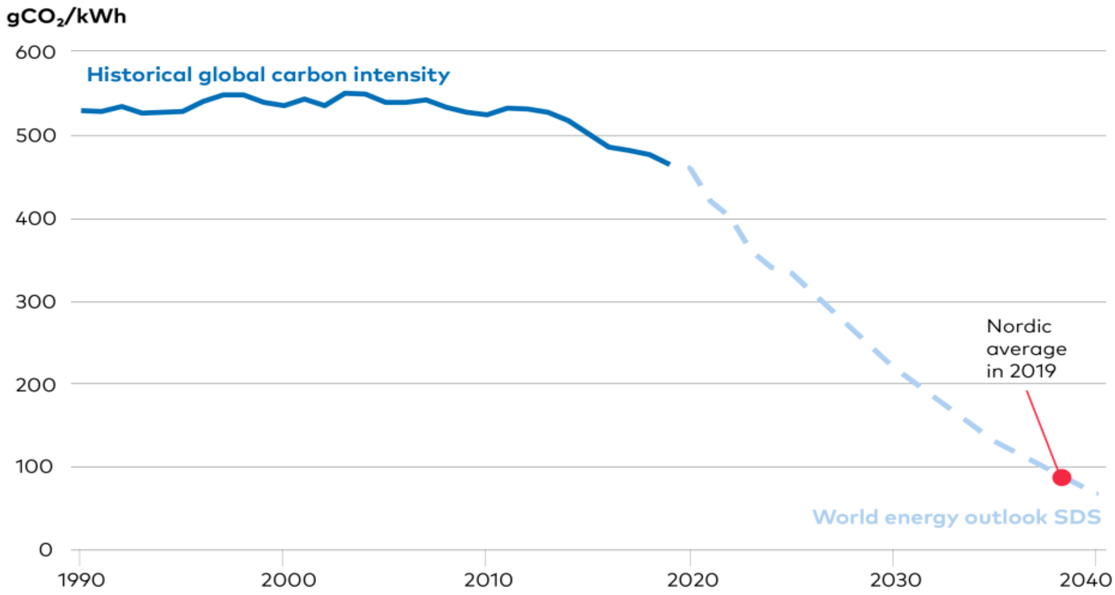


Figure 51: Historical global carbon intensity and Nordic decarbonisation from 1990-2040 (Nordic Renewable Research 2023;38).

Here are keys of success from Nordic Green Energy which are possible to become a standard model/method for another rest of European countries to learn.

- **Success key 1**: Nordic countries, included Baltic Sea and North Sea regions have the adequate infrastructure, equal system; interconnected power plant system which can achieve the optimisation of energy.
- **Success key 2**: Nordic countries have been successful in streamlined process for grid connection and capacity available in time demands where Nordic already has a good starting point for the transformation. Thanks to the system adequacy in Nordic countries, the transmission grid can exchange resources between regions and cross borders.
- **Success key 3**: Nordic countries have easy and equal market access with integrated secured market. Together with providing financial incentives, their targets are providing the flexibility, equality, and system security.
- **Success key 4**: Well balancing and management of all flexible energy sources in both energy consumption and production where natural resources (waterways, wind, offshore) are well equipped to Nordic countries.

- **Success key 5**: Well -maintained and developed Nordic Electricity Transmission System Operators (TSOs) to all equal infrastructures to cross borders for renewable energy sources since Nordic countries have had a long traditional cooperation to each other, even before Nordic Energy Market created.
- **Success key 6**: All energy sectors and stakeholders are considered vitally (figure 52).

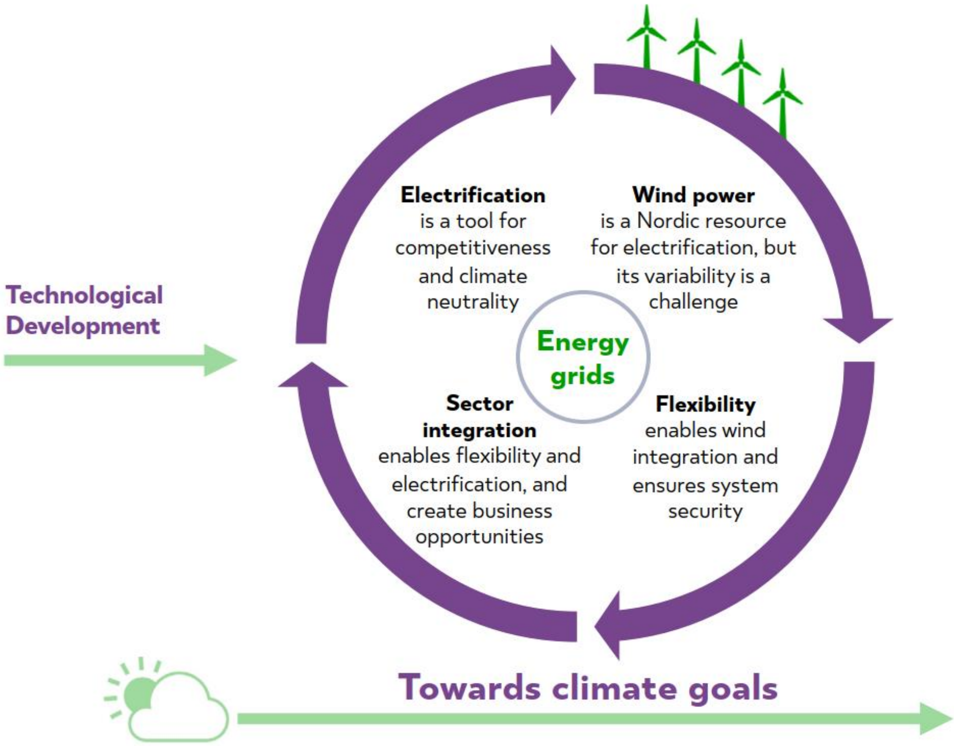


Figure 52: The elements of success in Nordic Green Energy System. (FINGRID 2022;39).

Below are example of **Nordic Carbon Capture and Energy Storage (NCES)** Model , Structure and Application from Danish Government for the Climate Target in 2035 (figure 53-54)

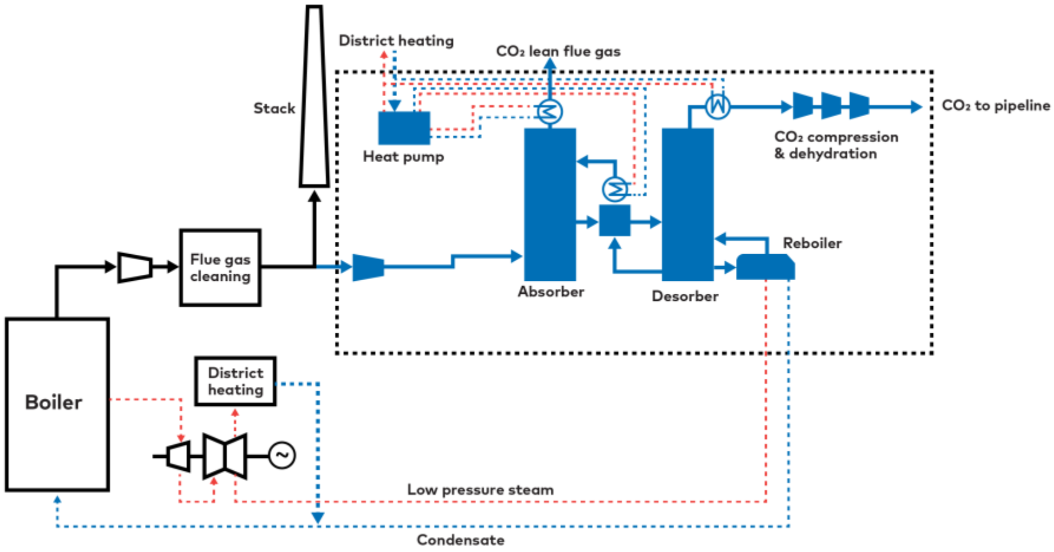


Figure 53: NCES application to power plant from Danish Energy Agency (Nordic Renewable Research 2023,40)

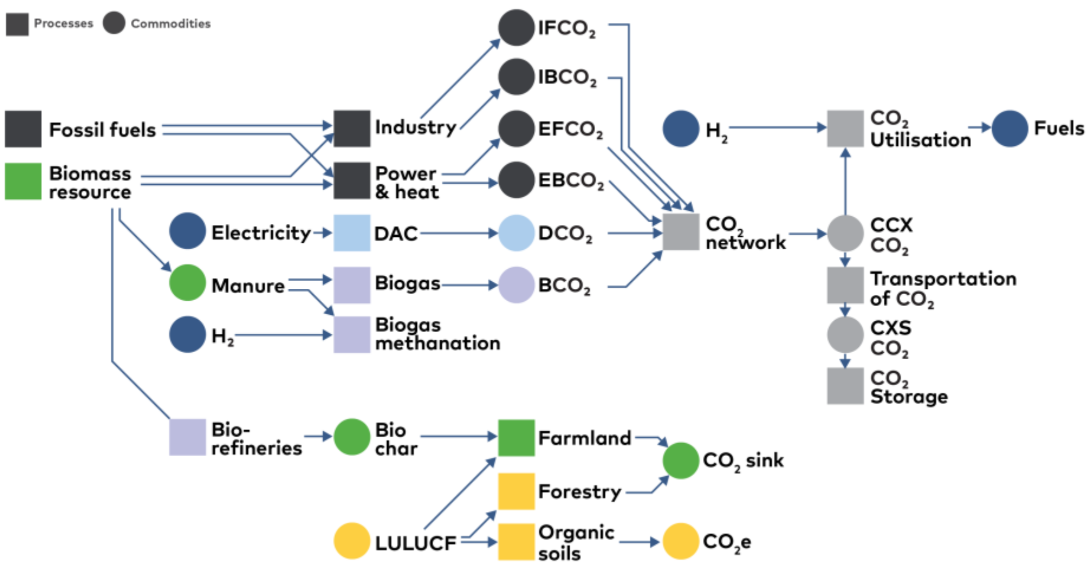


Figure 54: Model structure of NCES. (Nordic Renewable Research 2023,40)

For Europe's Future Energy (2022-2050), Biomass based Combined Heat and Power (Co-generation) will be increased significantly with 20% electricity and 25% heat for Europe in 2030 and by 2050, these amount would be up to 40-50% in both heat and electricity, and bring biomass CHP to become the potential trend in the Europe's Future Energy where Nordic countries are currently leading in the combined heat and power generation (CHP) with the high energy efficiency and low carbon emission. Some of key companies in Europe are leading in CHP technologies are: Siemens AG; UPM; GE; Wartsila; Valmet. One of the countries which has the best practices in CHP (Combined Heat and Power) is Finland where biomass is used as the main fuel in CHP power plants and this trend should be encouraged to be applied to another countries where bioenergy (woods, forest industry) are potential resources: The figure 55 is an example of Biomass power plant designed by (Siemens energy 2023;41). Figure 56 is example of advanced CFB boiler design from Valmet where is can be applied to Bio-CHP model and figure 57 is good example of how smart city in Europe should be looked like.

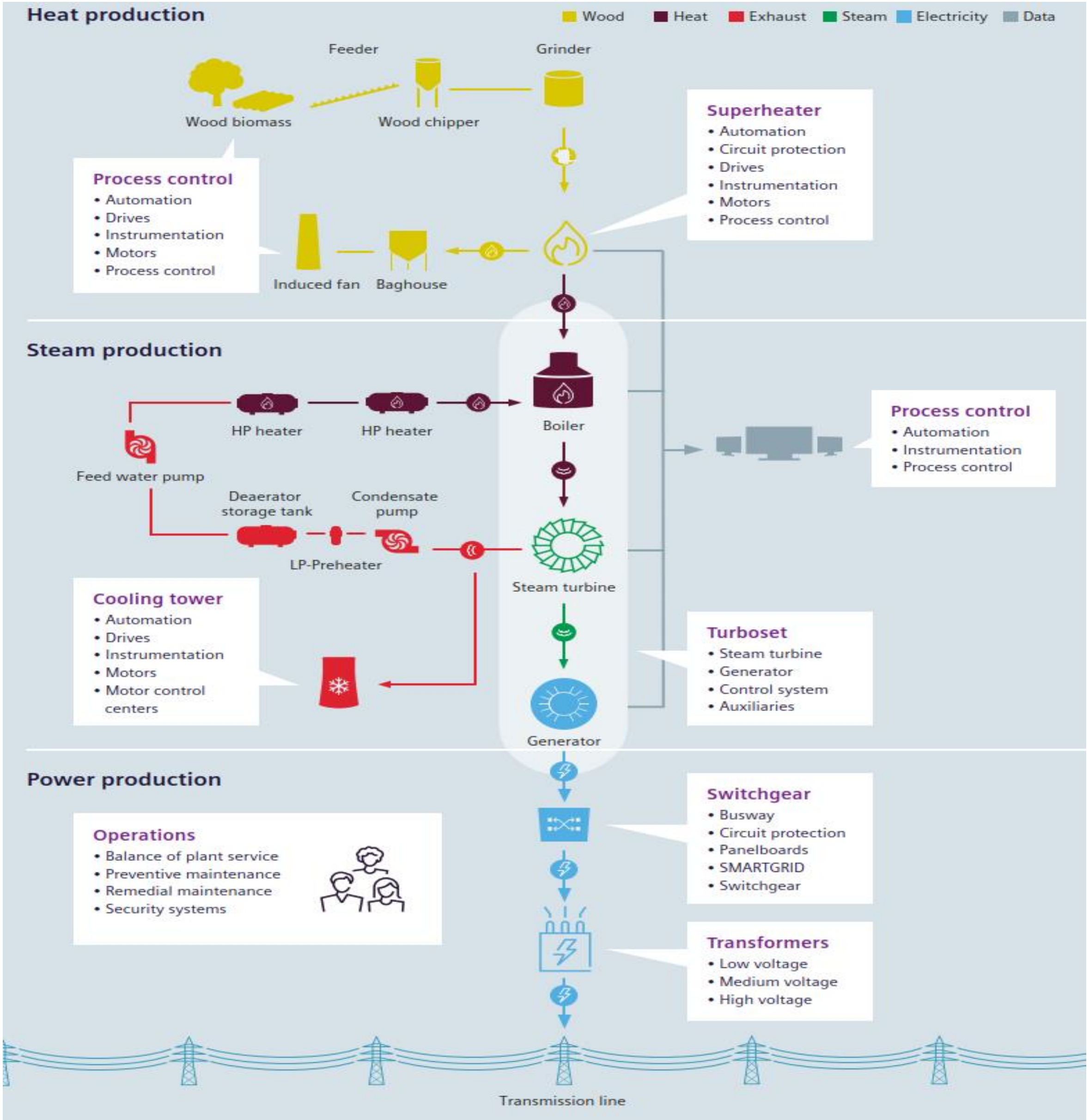


Figure 55: Biomass power plant by Siemen (Siemens energy 2023;41)

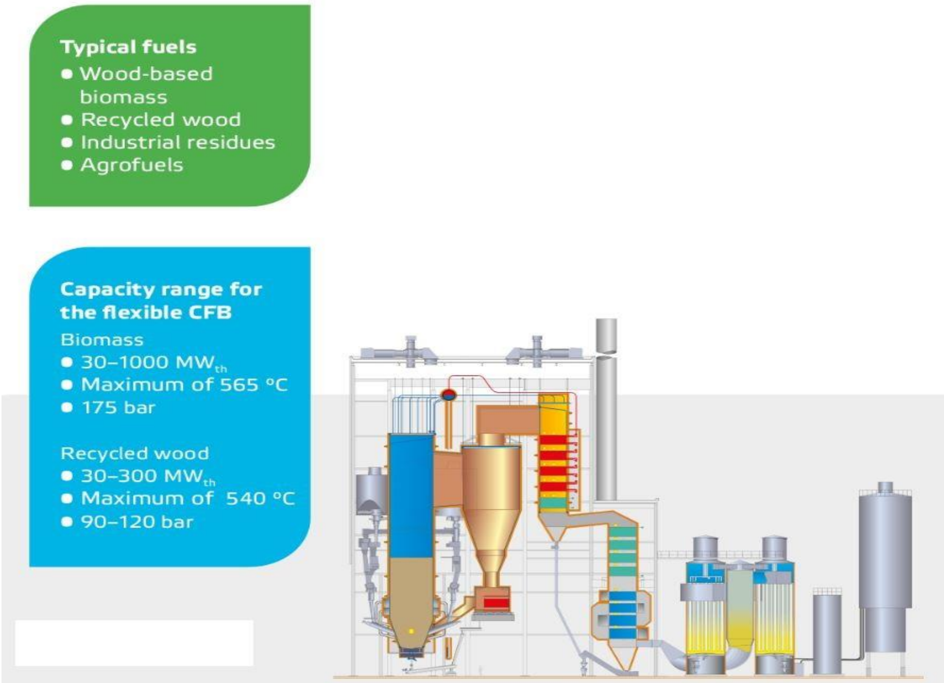


Figure 56: Advanced CFB technology from Valmet, Finland. (Valmet Boiler 2023, 42)

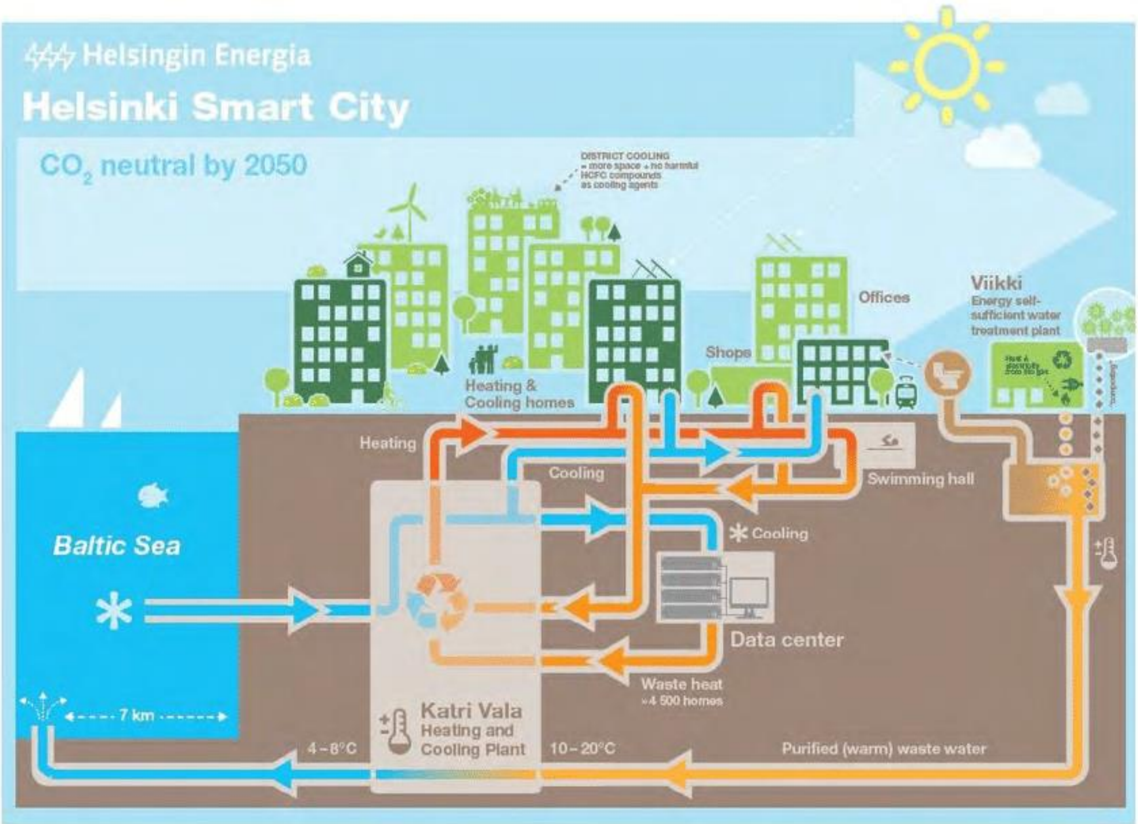


Figure 57: Helsinki Smart City with district heating and cooling (Theresa Kirschner, Research Gate 2023,43)

5 Conclusions

The researched has pointed out clearly that it is time now to stop using fossil fuels to produce electricity in Europe and it is critical to replace it with renewable energy for powering a green future where **solar power, hydro power, and ocean power; wind energy and biofuels** much be accelerated into the RES transition. To achieve RES target, EU needs to have the clear **strategic policy actions**, detail on technologies choices, finance support and plan permission which decision makers in all European countries must work and support together for the same goals. Therefore, the following **found out recommendations for EU's energy policy** are:

- Increasing economics of scale and providing flexibly the incentives for investment by co-operation together to cross border.
- Encouraging all of RES projects with fast decision making and permission as priority.
- Encouraging investments in flexible energy storage by creation market frameworks to enable RES and base power.
- Encouraging public investment to secure private capital by using credit taxes.
- Promote energy security, energy efficiency, lowering cost by encouraging interconnected infrastructure projects which can link all renewable energy system in European countries together.
- Planning in detail the pathways of renewable system using Power to X technologies and fuel productions from hydrogen.
- Using renewable system in power sector to shift to electrifying for transport, industry, heating, and cooling sectors.
- Digitalisation of European Energy System where system integration is the closed loop and combination of Renewable Energy, Design Principal for Data Spaces; Smart home and Buildings; Bi-directional EV charging; IOT to optimise renewable energy production and usage.

Beside creating clear processes for policies, European Union needs to **improve technologies based on current region outlook**, combined with innovations to optimise energy transition system over the Europe. These technologies are applied from both current energy system and sources which are existed in each of countries as well as **integrated** one such as:

- Critical materials
- Energy storage
- Hydrogen
- Infrastructure
- Carbon capture

Via the study case of Green Revolution for Nordic Countries- the successful example of how Heat and Combined Power Plants (CHP) model should be applied to other area of European countries where similar natural resources existed. Together with this, the Nordic Strategy concepts could be studied and learn by the rest of another European countries. With this application model and concept, renewable energy capacity of whole EU will be increased, number of fossil fuels will be reduced rapidly, net zero emission will achieve, and the energy security will be protected. Regional outlook and natural resources analytics are methods to define which area in Europe where could develop more energy system based on their climate changes impacts. The below are **the found out for summary and suggestion for different regions of Europe to develop their energy system in term of renewable and sustainable:**

- **Northern Europe**: Hydro power, Offshore wind power, biomass energy; oil and gas extraction; Offshore energy production infrastructure (wind, oil, gas); coastal energy infrastructure (power plants and refineries); Oil and gas transport by biofuels; Transmission and Distribution Grid; Heating and Cooling Demand (Bioenergy CHP)
- **Central Eastern Europe**: Thermal power plant (Biomass); Transmission and Distribution Grids; Electricity Substations; Heating and Cooling Demand (Bioenergy CHP)
- **Central Western Europe**: Offshore energy production infrastructure (wind); Thermal power plants (Biomass); Transmission and Distribution Grids; Electricity Substations; Heating and Cooling Demand (Bioenergy CHP)
- **British Isles**: Offshore energy production infrastructure (wind); Coastal energy production (power plants and refineries); Transmission and Distribution Grids; Heating and Cooling Demand; Electrical Substations; Heating and Cooling Demands
- **Iberian Peninsula, Apennine Peninsula and South-Eastern Europe**: Hydropower; Solar power; Biomass Energy; Thermal Power Plans (Biomass);

Transmission and Distribution Grids; Pumped Hydro Storage; Peak Electricity Demand; Energy demand for desalinations.

Being success **of taking advantages of natural domestic resource** to build up own type of energy and power generation for each of national will play an important key of success for whole Europe on the Green Transition Pathways.

Hence, **renewable energy needs a stronger grid to deliver decarbonisation in future**. **The grids must be updated seriously, more investment and work for new infrastructures** such as more 250.000km submarine cables and 20 million km underground cables, about 300,000km HDVC transmission to have total electrical grid reach to 150 million km which is twice enough compared today grid.

The result of making renewable energy system (RES) transition in Europe will have clear impacts on **EU's long term energy demand and supply**, especially in power and electricity sectors as well as transport and industry. Additionally, RES or green transition also has significantly impact on the **fossilization on energy supply** which fossil fuels will be shifted to green renewable fuels thanks to the technology's conversion of e-fuels; e-chemicals; biomass fuels. Furthermore, EU's RES transmission will bring a **massive growth of electrification** on the heat, transport, and all other industries area where electricity storage technologies play an important role in enable transition running towards. The role of energy storage is to avoid the interruption of providing power or electricity from network so therefore, **PV solar batteries; vehicle to grid; hydrogen storage; methane storage or pumped hydro energy storage; heat storage are great options to develop more from now to future.**

In the term of success in renewable energy system transition for European countries, it is **critical to work together, nation by nation, co-operation by big companies such as ABB, Siemens Energy, Wartsila, GE and another energy companies worldwide** to have the best and updated innovation, technologies, and solutions in energy industries. These companies have involved globally to many projects in power and energy generation such as Wärtsilä for Intelligent Software GEMS (Energy Management Platform) that delivery 100% renewable energy sources as based load and supporting existed grid infrastructure for Energy Storage and Optimisation. With Siemen Energy who has tested the raging winds with new grid technology in North Sea could bring North Sea to become the Europe's largest climate-neutral energy system by 2050.Another updated technology from Siemens also in Green Hydrogen production where Integrated Electrolyser heat pump solution was innovated for combined production in heat and hydrogen should be taken in advantage for energy future energy as well. Additionally, Biomass power plant model from Siemens (Figure 55) is a great example model and design for every countries in Europe to study and apply since the trend of increasing Bio-CHP plants will play an important role in RES pathways for EU in 2030 to the future.

Finally, beside on the actions and plans for accelerate renewables such as actions on policy, more investment on technologies; strengthen the cross-border grid, expanding cross border infrastructures, improve energy efficiency, and secure supply chain & resources which are key success factors for Europe's Future Energy, there are also importance of European citizen's behaviours to adapt to changes which are also the remain topics where each part of Europe is not the same based on the cultural and regions. Europe still needs to work more closely and tightly to these matters via rules; regulations and supporting to each other for the common goal in energy sector.

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