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Analysis of the key features of the future EU energy market and associated regional/ national landscapes

Authors : Mr. Andrei GOICEA (FORATOM)

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Project officer: Angelgiorgio IORIZZO

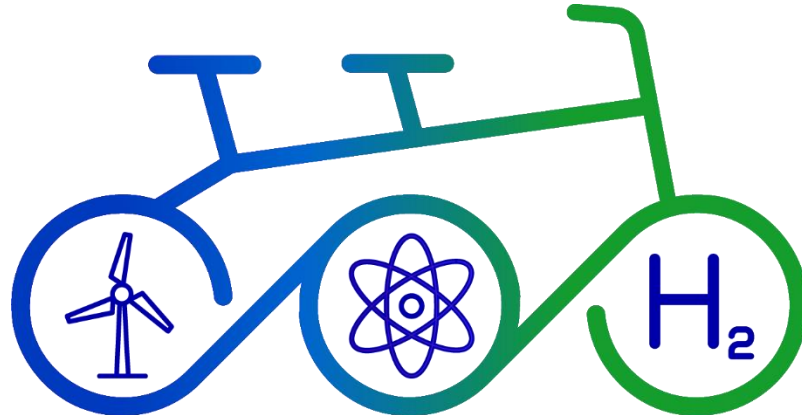
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Summary

In this task, nucleareurope (FORATOM) will coordinate the analysis of the future European energy scenarios which will characterize the EU energy landscape in the next decades. Partners will bring their expertise in their respective areas of experience in order to build a global picture covering key regional trends and needs: General knowledge of EU energy and climate context nucleareurope (FORATOM) with support of the other participants from their own analyses of energy scenarios and potentials for SMR deployment; Some regional considerations will be given for Eastern Europe and Ukraine as an example of the EU neighborhood region (ENERGORISK), for Central Europe from the Czech Republic energy policy/energy scenarios analysis for possible heat market for SMR in the Czech Republic (UJV), and for Nordic region heat and electricity market by VTT and FORTUM.

Approval

Date	By
2023-02-01 15:45:10	Dr. Christophe SCHNEIDESCH (ENGIE)
2023-02-01 15:49:29	Dr. Claire VAGLIO-GAUDARD (CEA)



TANDEM

D1.1 – Analysis of the key features of the future European energy market and associated regional/ national landscapes

WP1 - Task 1.1

February 1st 2023 [M6]

Andrei Goicea (Nucleareurope)
with the contribution of Task 1.1 partners



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Abbreviations and Acronyms

Acronym	Description
CHP	Combined Heat and Power
EC	European Commission
EED	Energy Efficiency Directive
GHG	GreenHouse Gas
H&C	Heating & Cooling
HSS	Heat Supply System
LTO	Long-Term Operation
NECP	National Energy and Climate Plan
PINC	Nuclear Illustrative Programme
SMR	Small Modular Reactor
EERA	European Energy Research Alliance
ETS	Emissions Trading System
RED	Renewable Energy Directive



Executive Summary

This document provides an analysis of the nuclear capacities, SMR deployment, and trends of evolution in energy production and consumption for the next decades. This analysis enables to emphasize the role of SMRs to deal with these trends and to propose energy scenarios including SMRs providing power, heat and hydrogen, at two time frames, 2035 and 2050. The main approaches that underpin these scenarios aim to set the techno-economical frameworks for the analysis of the selected hybrid energy system configurations for a 2035 and 2050 energy mix perspective aligned with the relevant EU and member states policies.

Keywords

Energy scenarios, energy decarbonisation, SMR, nuclear energy usage, energy markets, energy needs



1. Introduction

The European Commission (EC) confirmed in November 2018 that nuclear will form the backbone of a carbon-free European power system, together with renewables. However, transitioning just the power sector to clean energy would get the world only one-third of the way to net-zero emissions (IEA, 2020). Nuclear power plants have been historically designed and well optimized for the generation of electricity that is one of the most universal vector for energy worldwide but may provide other products and services in the next decades. The idea of using nuclear energy for non-power applications is not new (IAEA, 2020); since the 1950's, nuclear power has been used as a heat source for seawater desalination (e.g. in Kazakhstan, Japan, India, Pakistan and USA) (IAEA, 2017A), district heating (e.g. in Switzerland and Russia) and steam supply to industrial users (e.g. in Canada, Switzerland, Norway and Germany) (IAEA, 2017B).

The energy decarbonization relies on the deep transformation of the energy production and consumption, facilitated by European and national policies for energy, transport, economics and climate, and induced by new energy market development and new energy usage; it leads to envisage several realistic energy scenarios to deploy in the next decades. Energy scenarios including nuclear are briefly reviewed in this document, in light of existing studies, with the following considerations:

- priorities set by the European Commission,
- priorities set by European country policies thanks to the knowledge of the consortium partners,
- spatial scale,
- energy market development and growth,
- new energy usage.

The analysis of energy scenarios is focused on 2035's horizon and 2050's horizon. *Chapter 2* provides an analysis of the energy needs in Europe to suggest trends on the evolution of energy production and consumption in the next decades. The European nuclear capacity development and Small Modular Reactor (SMR) deployment, based on the European Commission (EC) vision and Nucleareurope reports, are presented in *Chapter 3*. *Chapter 4* emphasizes the role of SMRs to deal with these trends and *Chapter 5* proposes energy scenarios including SMRs providing power, heat and hydrogen. These scenarios will be derived in the next WP1 tasks into hybrid energy system configurations to study in the TANDEM project. The main approaches that underpin these scenarios aim to set the techno-economical frameworks for the analysis of the selected hybrid energy system configurations for a 2035 and 2050 energy mix perspective aligned with the relevant EU and member states policies.



2. Analysis of the energy needs and the different European markets

The European Union has very ambitious targets in achieving the decarbonisation of the economy for both 2030 (-55% GHG emission reduction) and 2050 (net zero emissions). As shown in Figure 1, the power sector is one of the first to be decarbonized by 2040. That would require huge efforts to overcome all the challenges that are coming with the ambitions, keeping in mind the trilemma that should be solved: decarbonisation, affordability and security of energy supply.

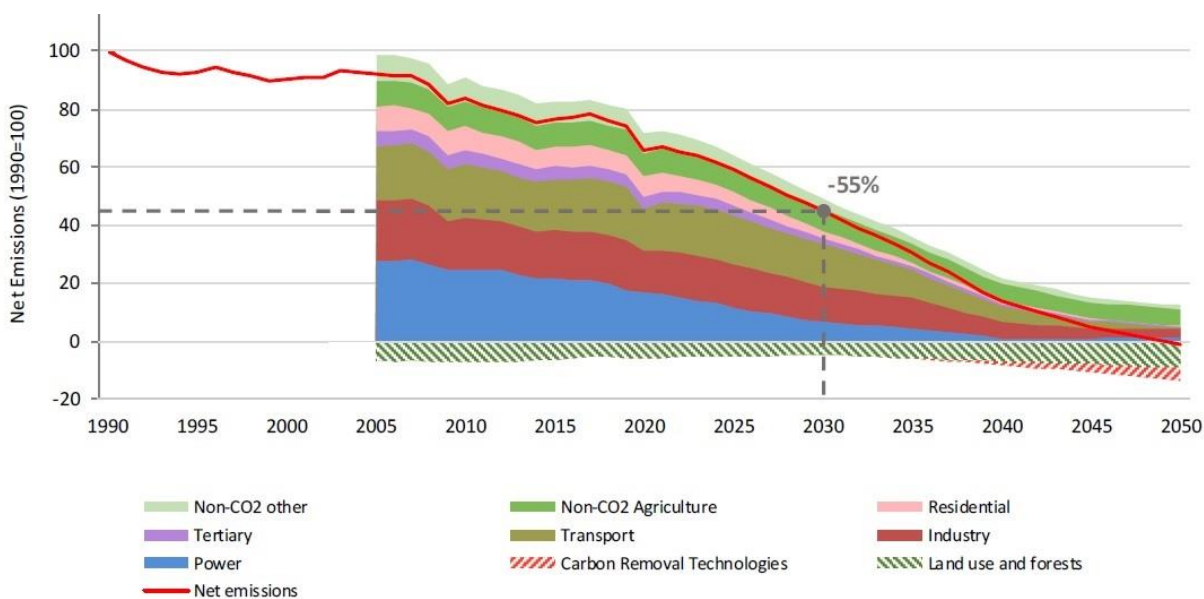


Figure 1: The EU's pathway to climate neutrality, 1990-2050¹

When we are talking about energy, we should not limit only to the power sector; in the European Commission's vision, other energy carriers having an important role to play in the medium and long term.

¹ Stepping up Europe's 2030 climate ambition - [COM\(2020\) 562 final](#)

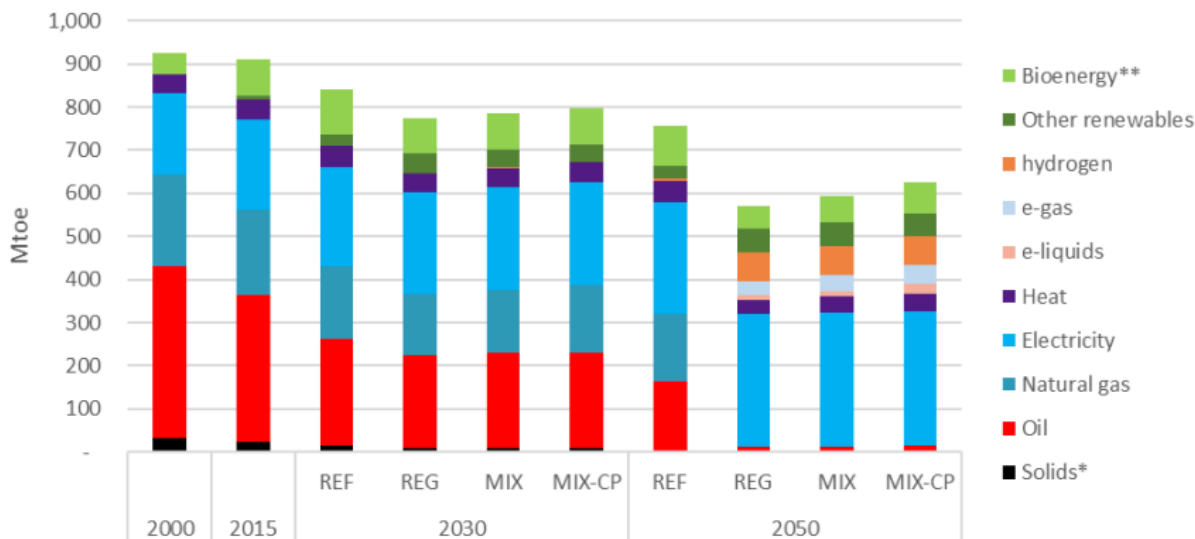


Figure 2: Share of energy carriers in final energy consumption - Source ESTAT, PRIMES²

Box.1 Explanations on the 3 core policy scenarios produced to serve as common tools for analysis across the impact assessments of various initiatives of the [European Green Deal policy package](#), presented in July 2021.

- **REG:** relying on very strong intensification of energy and transport policies in absence of carbon pricing in road transport and buildings. In REG, maritime transport sector is included in the EU Emissions Trading System (ETS).
- **MIX:** relying on both carbon price signal extension to road transport and buildings and strong intensification of energy and transport policies. With its uniform carbon price, it reflects either an extended and fully integrated EU ETS or an existing EU ETS and a new ETS established for road transport and buildings with emission caps set in line with cost-effective contributions of the respective sectors. Maritime transport sector is assumed to be included in the existing EU ETS in MIX.
- **MIX-CP:** representing a more carbon price driven policy mix that illustrates a revision of the Energy Efficiency Directive (EED) and Renewable Energy Directives (RED) but limited to a lower intensification of current policies in addition to the carbon price signal applied to new sectors. Unlike MIX, this scenario allows to separate carbon price signals of “current” and “new” ETS. The relative split of ambition in GHG reductions between “current” ETS and “new ETS” remains,

According to Figure 2, while in 2030 we still heavily rely on oil and gas, the share of the fossil fuels will be very much reduced in 2050. In the long term, we are facing a deep electrification in all scenarios; electricity will represent more than half of the energy consumed in EU.

For the scope of this report, we consider mainly the power market, but we also take into consideration the heat and hydrogen markets, as SMR technologies can have an impact on it as

² Impact Assessment for the Renewable Energy Directive - [SWD\(2021\) 621 final](#)

well. Below can be found the potential of the different markets, as identified by one of the partners of the TANDEM project, ENGIE Tractebel.

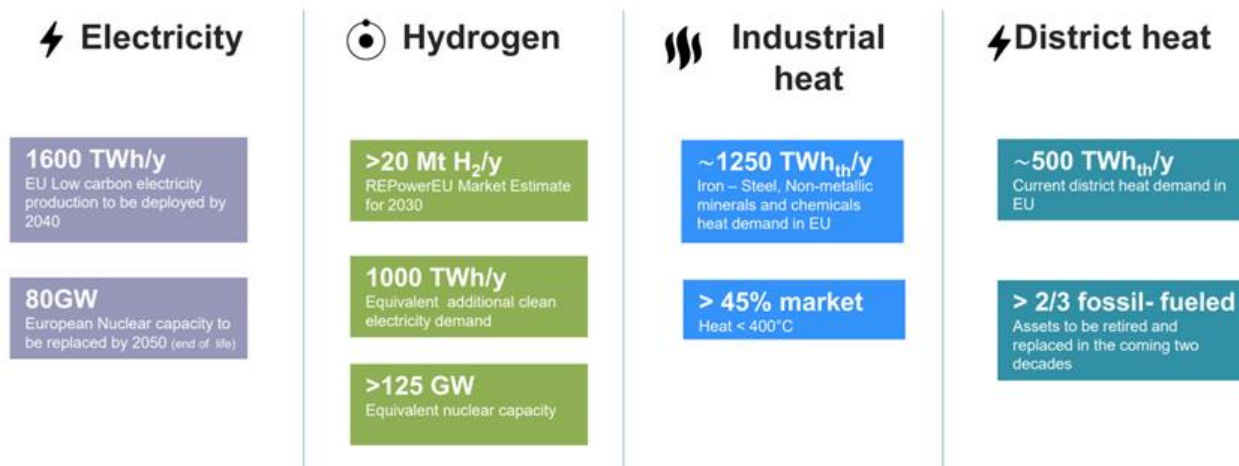


Figure 3: The EU energy market need

2.1 Power market

The information on the power market developments and forecasts can be found in Chapter 3 where the perspective of the nuclear power contribution is analysed in detail. Nevertheless, Figure 4 presents the overview of how the EU’s gross electricity generation might develop in the long term: the first conclusion is that the electricity supply will double by 2050 in all the scenarios analysed.

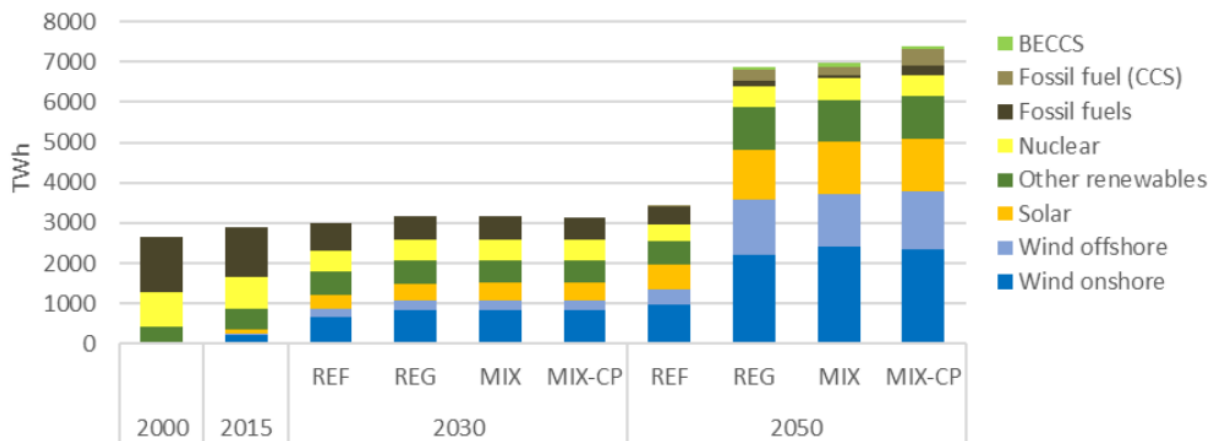


Figure 4: Gross electricity generation in the EU - Source EUROSTAT, PRIMES³

³ Impact Assessment for the Renewable Energy Directive [SWD\(2021\) 621 final](#)

2.2 EERA analysis of the REPowerEU plan

The REPowerEU plan was set up by the EC in the context of the energy crisis after the Russian invasion in Ukraine. Building on the Fit for 55 package of proposals and complementing the actions on energy security of supply and storage, the REPowerEU plan put forward a set of actions. EERA points out some improvement axis to development in addition to REPowerEU, with the objective to reduce the European dependency on Russian fossil fuels and to accelerate the energy transition. Some interesting considerations of (EERA, 2022) are recalled hereafter regarding:

- *heat decarbonization*: « despite the strong electrification trend, the REPowerEU Plan should have a stronger focus on measures related to heating and cooling. » « Heating and cooling constitute about 50% of the final energy demand in Europe and represent by far the most significant energy sector to be decarbonised. » One EERA recommendation is to « foster research into SMRs for producing heat in addition to electricity in cogeneration mode, effectively contributing to the decarbonisation of heat production »;
- *the study of the energy system integration*: « an energy system integration perspective is fundamental for achieving the goals of the clean energy transition in Europe, including those dictated by the REPowerEU Plan. Insufficient consideration of such a perspective leads to a fragmented, silo-based approach to the transition, which affects its speed, cost and effectiveness. An energy system integration approach should be at the core of the REPowerEU strategy » ;
- *the use of energy storage*: « energy storage, a key component for achieving the clean energy transition, is also a prerequisite for implementing REPowerEU. [...] However, energy storage is not presented as an integral part of the REPowerEU Plan and is mentioned only in the specific context of natural gas storage » ;
- *the hydrogen usage*: « the ambitious hydrogen goals set out in REPowerEU also require a strong systems integration perspective. Hydrogen is a highly versatile energy vector and is therefore expected to play several distinctive roles in the clean energy transition, particularly as fuel, energy storage system, industrial feedstock and also as an enabling technology for sector coupling. Distinguishing between these different roles is essential for designing optimal sourcing scenarios, relating to both EU domestic production and imports. »

The TANDEM project is fully aligned with these different considerations. The project will implement them as much as possible in its proposals and studies.



2.3 Heat market

The energy transition with a reduction of CO₂ emissions requires to consider sectors beyond the electricity sector. Heating and Cooling (H&C) is the largest sector in the European energy system, consuming about half of its total final energy needs (Figure 5). While the information on the heat market provided below are mainly for the H&C, as presented in Figure 3, there is also a potential market for industrial heat. Chapter 3 will be developed some points regarding the nuclear prospects for it.

Heating and cooling roadmaps developed by Heat Roadmap Europe⁴ constitute valuable resources for better addressing heating and cooling challenges, regardless of the fact that they summarize a 2015-based overview. Most of the thermal energy is used in buildings (space segment including private, commercial and public) and industry (process segment). Without a decarbonisation of this sector, it will not be possible to achieve the reductions in CO₂ emissions needed to prevent global temperature rises.

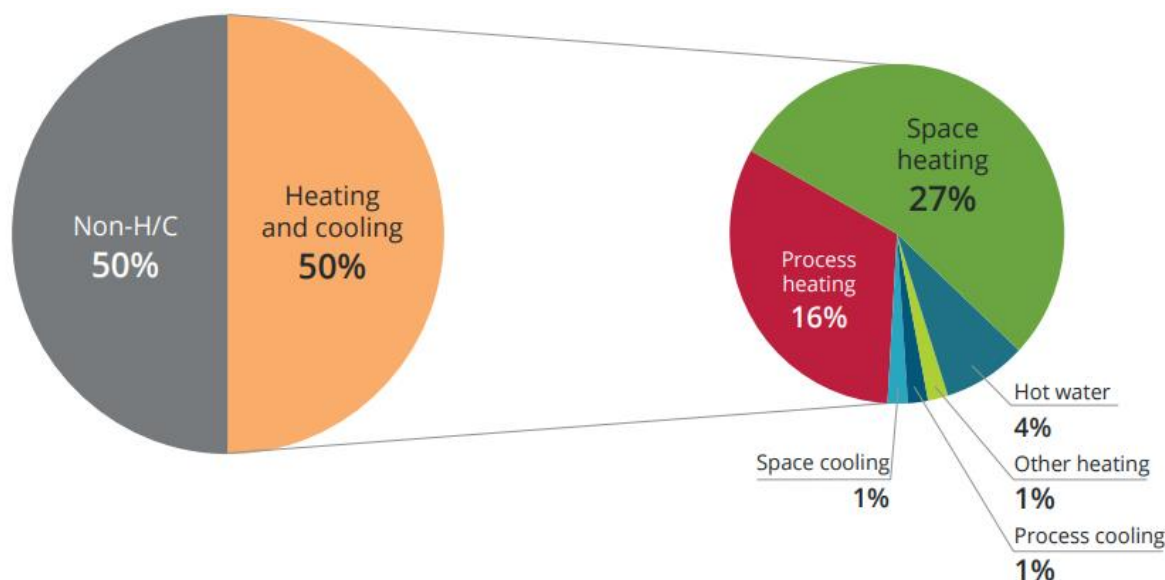


Figure 5: Heating and cooling demand in 2015 in the EU28 by end-use compared to total final energy demand (Heat Roadmap Europe, 2017)

Most of the thermal energy is produced from fossil fuels (66%, where gas reaches a 42% share) and only 12% comes directly from renewable energies (solar thermal and biomass). Electricity

⁴ <https://heatroadmap.eu/>

(including heat pumps) and district heat together supply 22% of heat (Figure 6), which may or may not be renewable, depending on local circumstances.

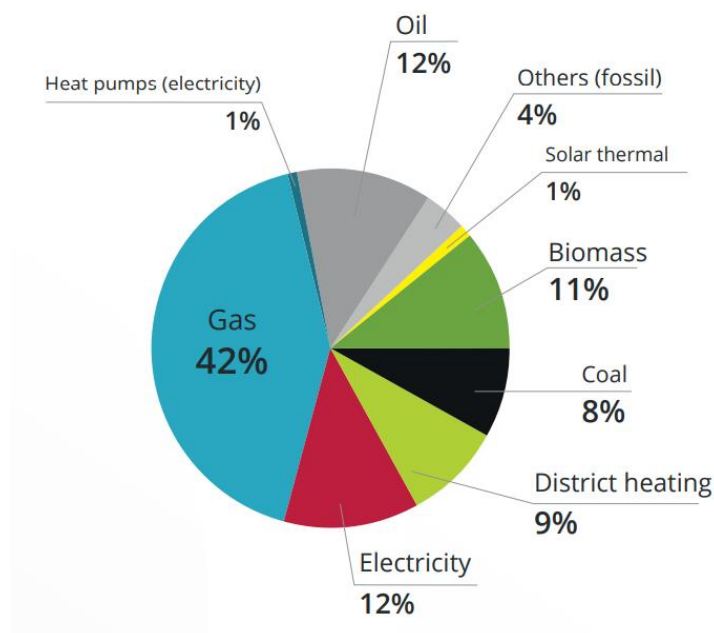


Figure 6: H&C final energy by energy carrier in 2015 (EU28) (Heat Roadmap Europe, 2017)

In addition, heating and cooling have a local nature and their implementation implies to take into account the related infrastructure developments. This is especially important when considering district energy, since the cost of infrastructure represents a significant share comparing with the cost of supplying the energy.

Within the industry sector, process heating is most relevant with a 81% share of the final energy demand, with different end-uses covering specific ranges of process temperatures (9% below 100°C, 21% within 100-200°C, 9% within 200-500°C and the largest share of 42% above 500°C). The different ranges of temperatures needs are matched by specific energy carriers. Coal and gas tend to be utilised for high-temperature process heating, while biomass is most used for steam, and district heating for low temperature processes. Cooling comes exclusively from electricity. The decarbonization of the process heating will therefore ask for tailored approaches adapted to the processes requirements.

Within the services and residential sector, the energy demand is largely dominated by space heating.

Scenarios and strategies have been developed which largely hinge on energy savings through better energy performance of buildings and reductions in energy demands in industry; the use of thermal networks in urban areas which integrate new efficient and renewable energy sources to the system, and highly efficient and flexible use of individual heating technologies in rural areas.



The heating and cooling sector can be fully decarbonised based on technologies and approaches which already exist, are market-ready and have successfully been implemented in Europe. Energy efficiency on both the demand and the supply side are necessary to cost-effectively reach the decarbonisation goals.

Sector coupling, especially a progressive electrification of heat and mobility energy demands, will have a significant impact on the assumed generation technologies. New technologies are emerging as power-to-gas, power-to-heat and mobility applications.

2.4 Hydrogen market

Figure 7 gives an overview of the hydrogen production capacity in 2020 spread across different production technologies. The conventional production methods of reforming, partial oxidation, gasification, by-product production from refining operations, and by-product production from ethylene and styrene, represent 95.7% of total capacity. By-product electrolysis (i.e., capacity from chlorine and sodium chlorate production) accounts for 3.7%. Reforming with carbon capture contributes 0.5% of total hydrogen production capacity. Power-to-hydrogen accounted for only 0.1% of total hydrogen production capacity in 2020.

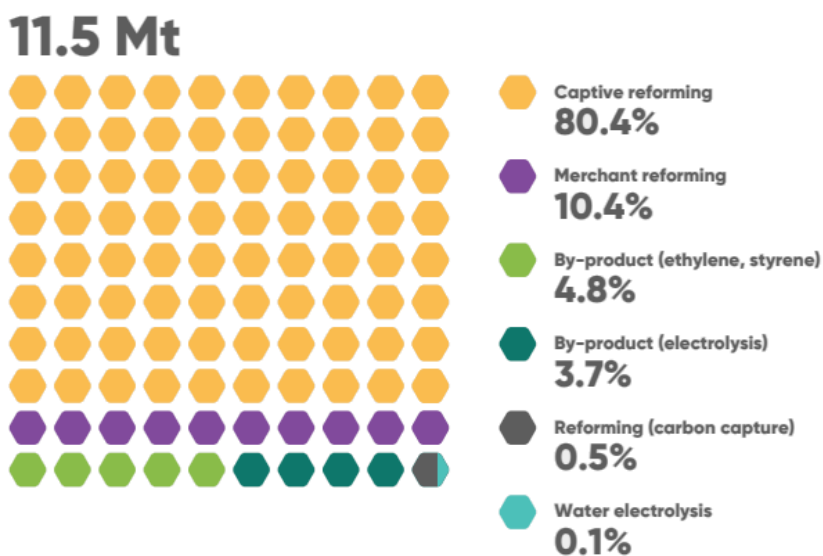


Figure 7: Hydrogen generation capacity by the production process in 2020 (Hydrogen Europe, 2022)

Regarding hydrogen demand, in 2020 it was estimated at around 8.7Mt. The biggest share of hydrogen demand comes from refineries (Figure 8), which were responsible for 50% of total hydrogen use (~4.4 Mt), followed by the ammonia industry with 29% (~2.5 Mt). Emerging “decarbonisation” applications, like transport, account for less than 0.1% of the market.

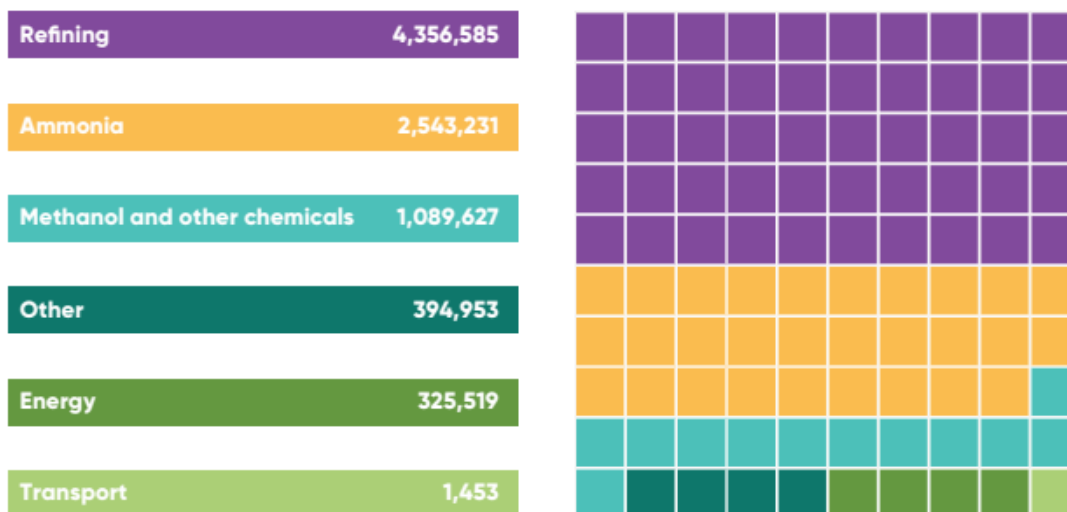


Figure 8: Total hydrogen demand in 2020 by application (t) (Hydrogen Europe, 2022)

The REPowerEU plan recently introduced by the Commission sets a target of 20Mt of renewable hydrogen use by 2030, a 3-fold increase when compared with the Fit for 55 program. Refining and ammonia are still predicted to take a big share of the hydrogen demand but other uses are now also considered, as depicted in the chart below.

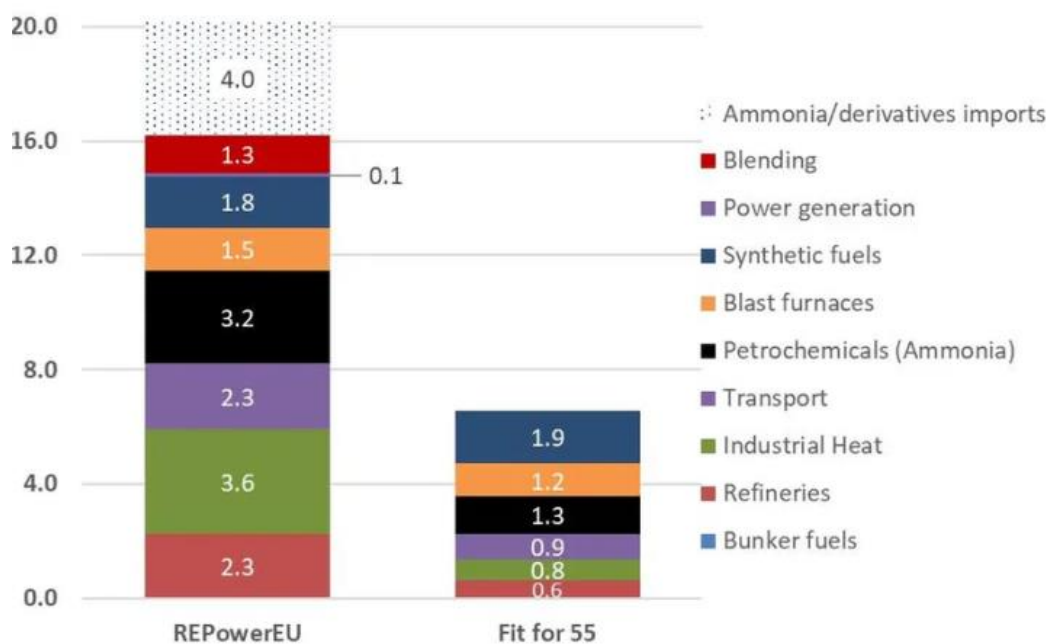


Figure 9: Hydrogen use by sector in 2030 (Mt H2) ⁵

⁵ REPowerEU Plan - [SWD\(2022\) 230 final](#)



Most of these activities, such as ammonia production, refining and power generation, will be able to benefit not only from direct hydrogen production from SMRs but also from electricity and heat production.

There are attempts to classify the future uses of hydrogen. M. Liebreich classifies different uses from uncompetitive to unavoidable in Figure 10. Current uses of the hydrogen are in the unavoidable section with some new use-cases, but some use-cases often referred in public discussion, e.g. hydrogen personal vehicles, are deeply embedded in the uncompetitive section.

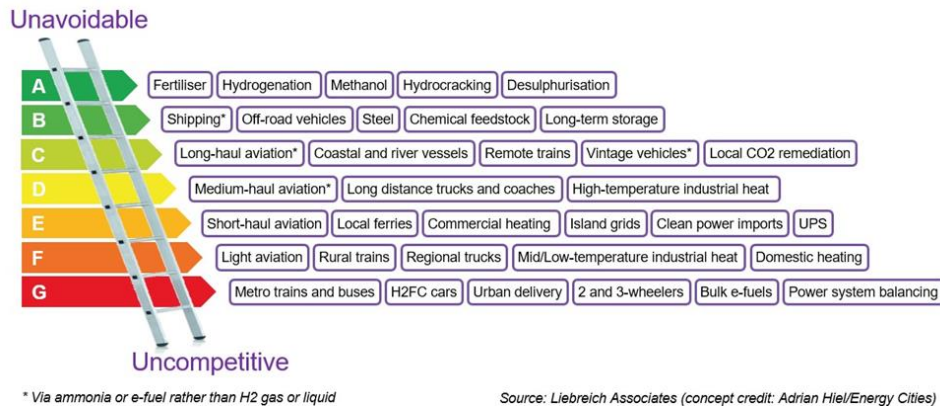


Figure 10: Uses classified from uncompetitive to unavoidable⁶

3. Forecasts on the European nuclear capacity development (including SMR technologies)

The analysis will start from the existing energy scenarios at EU level with details on nuclear sector forecasting. The EU energy scenarios for medium term (2030) are based on the [National Energy and Climate Plans](#) (NECPs) submitted by each member state for the period 2021-2030. In the NECPs, nuclear new build is not really considered as the existing plans for new projects are implemented mostly after 2030. Therefore, when EC had to propose scenarios for long term – up to 2050 – for nuclear, they extrapolated the information available in NECPs, which led to a relative low share/installed nuclear capacity.

That is why, for building the long term scenario for nuclear for the TANDEM project, it will be used also other sources than EC, including the vision for 2050 report of Nucleareurope (Compass Lexecon, 2021). When we are discussing in particular about forecasts on the SMR deployment, the above mentioned report is also containing some figures for medium to long term (2030-

⁶ <https://www.linkedin.com/pulse/clean-hydrogen-ladder-v40-michael-liebreich/>

2050)⁷ gathered from the Nucleareurope members in January 2021 but a new scenario might worth to be taken into account, to include the latest developments.

3.1 EC vision on nuclear in the latest energy scenarios

3.1.1 Nuclear Illustrative Programme (PINC)⁸

*“The Commission predicts a decline in nuclear generation capacity at EU level up to 2025, taking into account the decisions of some Member States to phase out nuclear energy or to reduce its share in their energy mix. This trend would be reversed by 2030 as new reactors are predicted to be connected to the grid and the lifetime of others will be extended. Nuclear capacity would increase slightly and remain stable at **between 95 and 105 GWe by 2050.**”*

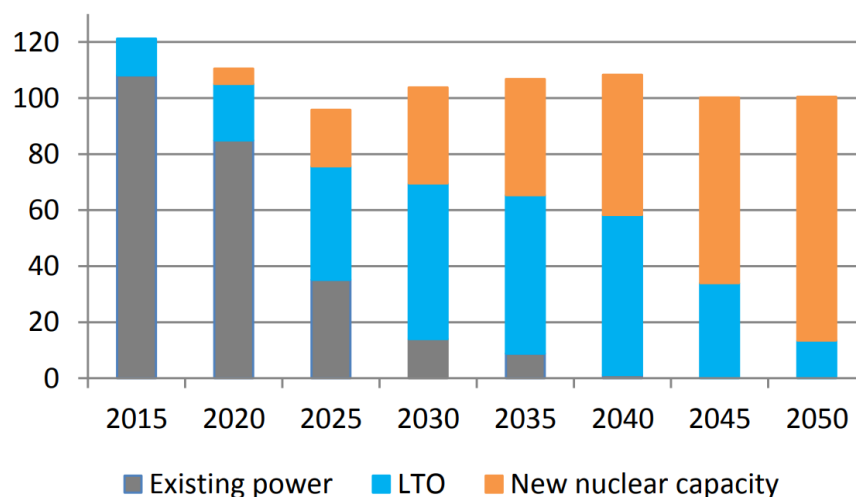


Figure 11: European nuclear capacity in the next decades (in GWe), on the basis of the Nuclear Illustrative Programme

The figures are for EU28 (EU27+UK) and do not mention the SMR capacity in the document.

3.1.2 EU’s long-term vision⁹

Renewables together with nuclear energy will be the backbone of a carbon-free European power system.

Installed capacity:

⁷ The SMR assumption figures from the report were resulting from a survey among the members of Nucleareurope’s SMR Task Force run in January 2021

⁸ EC communication on the Nuclear Illustrative Programme [COM\(2017\) 237 final](#)

⁹ A Clean Planet for all - A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy - [COM\(2018\) 773 final](#)

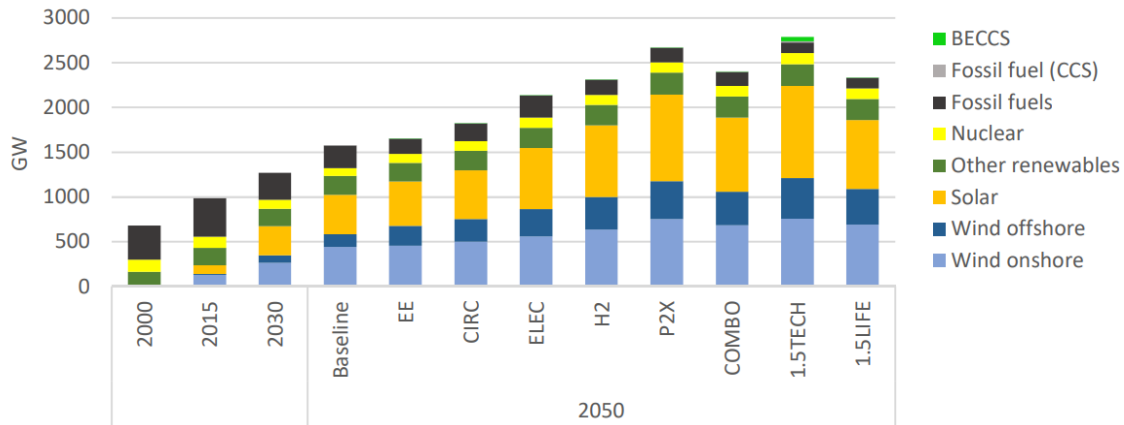


Figure 12: European energy installed capacity in the next decades (in GWe), on the basis of the EU’s long term vision

Nuclear installed capacity for 2050 is somewhere between 99 and 121 GWe.

2050 Scenario	GWe
Baseline	86.8
EE	99.3
CIRC	106.7
ELEC	112.9
H2	114.1
P2X	116.9
COMBO	116.9
1.5TECH	121.3
1.5LIFE	114.8

Table 1: European nuclear energy installed capacity in the 2050 scenario, on the basis of the EU’s long term vision

Like for PINC presented in section 3.1.1, the figures are for EU28 (EU27+UK).

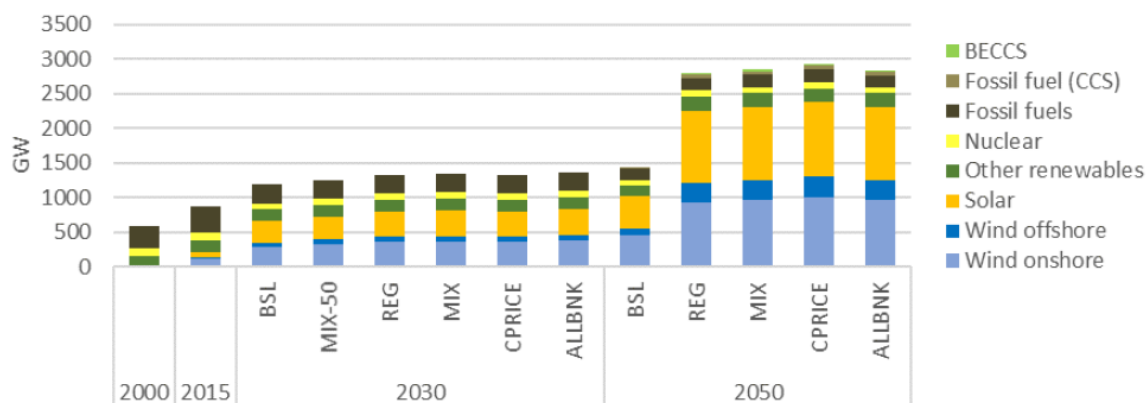
The forecasted share of nuclear in the electricity mix in 2050 would be around 15%, currently being around 25%.



3.1.3 European Green Deal/ Fit for 55/REPowerEU

- European Green Deal

All the figures for this section are referring to EU27.



Source: 2000, 2015: Eurostat, 2030-2050: PRIMES model

Figure 13: Installed power production capacities¹⁰ (European Green Deal)

	2030	2050
Nuclear installed capacity (GWe)	92	81 - 86*
Share of nuclear electricity production	15% - 19%*	9%-10%*

*the baseline scenarios are not taken into consideration as it cannot reach the decarbonisation ambitions

Table 2: European nuclear energy installed capacity in 2030 and 2050 (European Green Deal)

¹⁰ Stepping up Europe’s 2030 climate ambition - [COM\(2020\) 562 final](#)



- Fit for 55 package (based on the National Energy and Climate Plans)

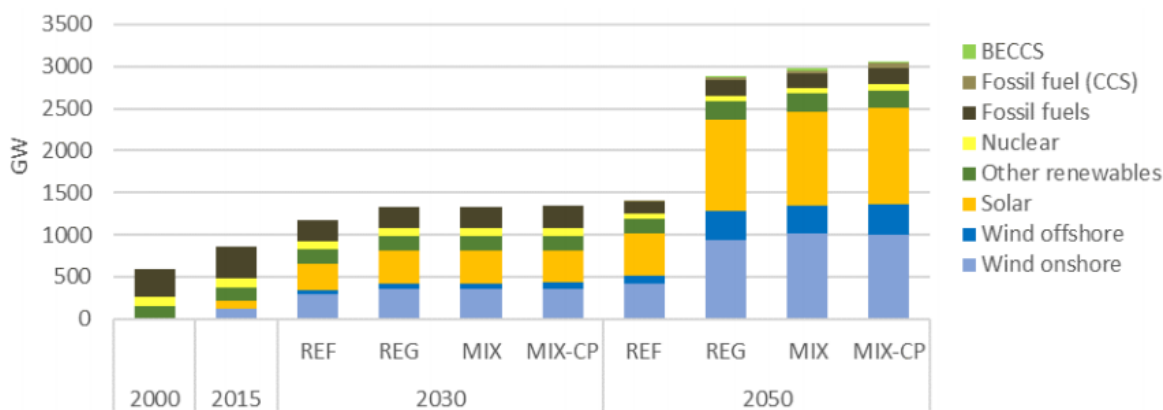


Figure 14: Installed power production capacities¹¹ (Fit for 55 package)

Scenario	2030				2050			
	REF	REG	MIX	MIX-CP	REF	REG	MIX	MIX-CP
Nuclear installed capacity (GWe)	93.9				55	50	62	70
Share of nuclear electricity production	17.3%	16.2%	16.3%	16.3%	11.8%	7.7%	7.8%	6.9%

Table 3: European nuclear energy installed capacity in 2030 and 2050 (Fit for 55 package)

As a result of high uptake of renewables, the installed fossil-fuel capacity will decrease both in reference (REF) and policy scenarios compared to 2015. By 2030, the combined installed capacity of the EU’s nuclear power plants is also projected to decline as result of planned phase-outs in several Member States.

- REPowerEU plan

There are no specific information from REPowerEU plan regarding the forecast of the installed capacity for 2030. However, from the gross inland consumption by source, it can be seen that

¹¹ Impact Assessment for the Renewable Energy Directive [SWD\(2021\) 621 final](#)



nuclear is expected to deliver a larger contribution comparing with the forecast from Fit for 55 package.

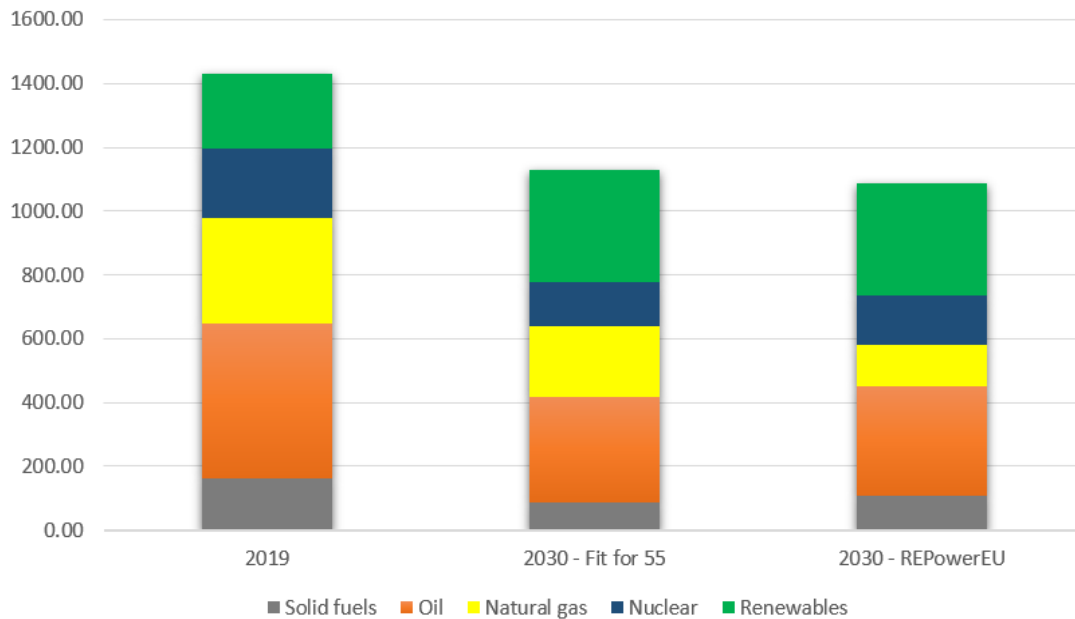


Figure 15: Gross inland consumption by fuel (Mtoe)¹²

3.1.4 Preliminary conclusions

The forecast for the nuclear installed capacity in EC's long term scenarios in the last 5 years is decreasing. It can be explained by more ambitious targets for renewable deployment but also by the extrapolation of the feedback from the member states that was provided for the 2030 perspective.

Another reason for the level of nuclear is also due to the economic assumptions taken into consideration in building the scenarios ([technology assumptions](#) for the "EU reference scenario 2020" or the [ones from 2018](#)). For both Nucleareurope raised concerns regarding:

- The missing information for the **SMRs and Gen IV technologies**,
- **Overnight Investments Costs** too high,
- Nuclear capacity **construction costs** that show little or no learning curves in the assumptions,
- The figures for **fixed O&M costs** that are too high,
- The **thermal efficiency** that can be higher for the reactors performing co-generation,
- No hypothesis regarding the **cost of fuel**,
- **Capacity factor** that is at least 90%.

¹² REPowerEU Plan - [SWD\(2022\) 230 final](#)

In this context, Nucleareurope considered necessary to provide a vision for the power system at the 2050 time frame, taking into consideration the economic or security of supply aspects as well as the energy sector integration (mainly hydrogen).

3.2 European nuclear long term scenarios

As seen from the previous point, nuclear is seen in the different scenarios proposed by EC as decreasing in long term as both installed capacity and share in the electricity mix.

3.2.1 Nucleareurope's Vision 2050

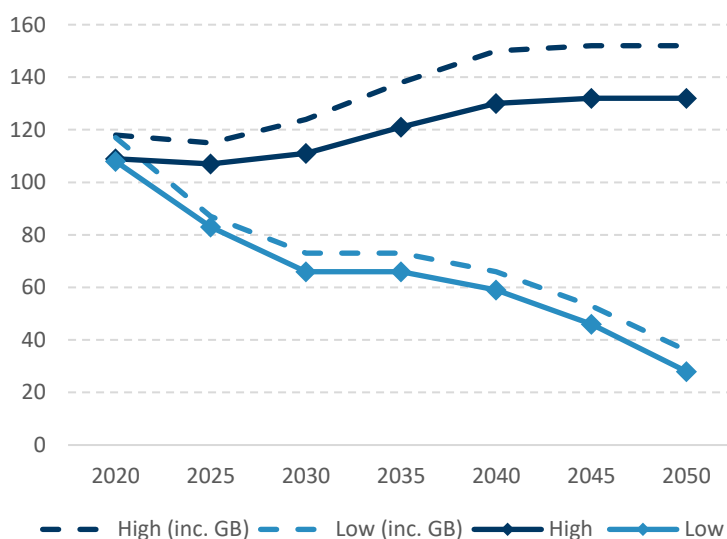


Figure 16: EU-27+UK Nucleareurope's nuclear installed capacity outlooks (GWe) (Compass Lexecon, 2021)

For the sake of comparison with the previous analysis were considered only the **figures for EU27**. Besides, the report is taking into consideration the following scenarios:

- In the **low nuclear scenario**, most existing plants close without further life-time extension and new plants projects fail to conclude. The nuclear capacity decreases to **28 GWe by 2050**;
- In the **high nuclear scenario**, several long-term operation (LTO) extensions are awarded and a number of additional new plants (including 25 GWe of SMR and <1 GWe of Gen-IV) are commissioned replacing thermal baseload and contributing to decarbonisation of the power sector and wider European economy. The nuclear capacity reaches **132 GWe by 2050**.

In terms of distribution for the 3 main geographical areas (EU-27+UK) we have:



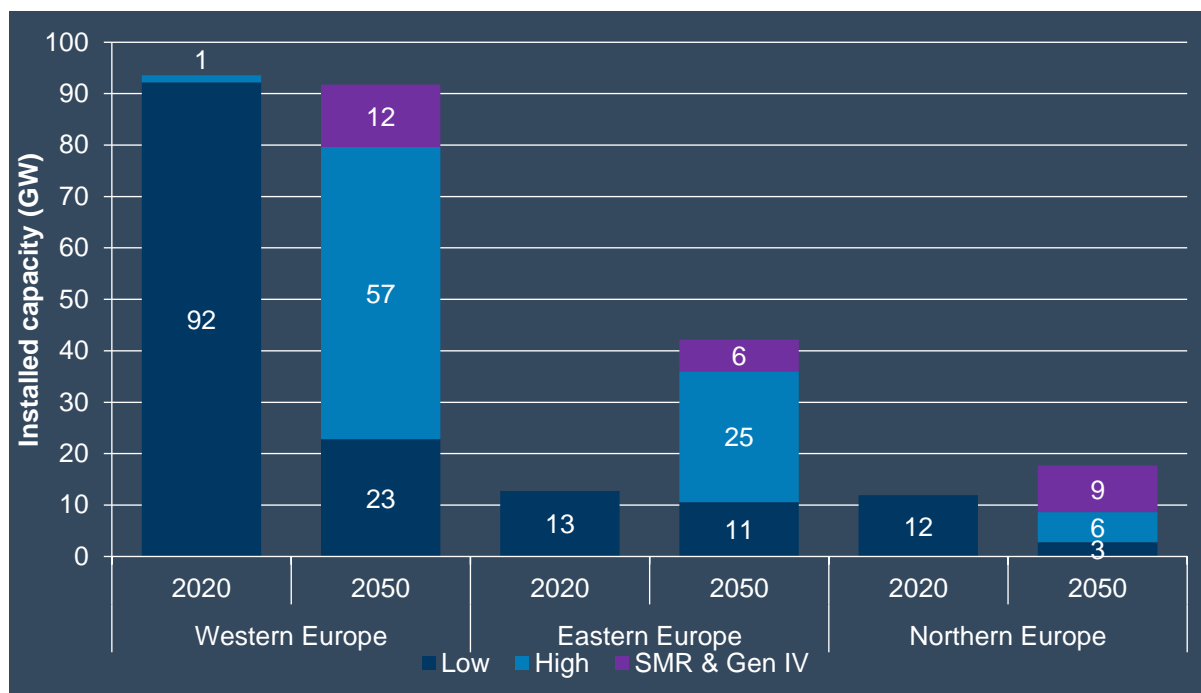


Figure 17: Installed nuclear capacity by European region and scenario (GWe) in Nucleareurope's vision

Regarding SMRs, the figures are based on the results of a survey among the members of Nucleareurope's SMR Task Force in January 2021.

3.2.2 Other scenarios relevant for this analysis

- National scenarios:

- Netherlands (<https://hcss.nl/report/scenario-study-nuclear-energy-conclusions-summary/> - October 2022)
- Finland (<https://www.nucnet.org/news/fortum-begins-two-year-feasibility-study-into-new-nuclear-10-1-2022-see-also-annex>)
- Sweden (<https://www.nucnet.org/news/new-government-announces-plans-to-build-nuclear-power-plants-10-5-2022>)
- Romania (<https://www.nucnet.org/news/ustda-grants-usd14m-to-ropower-for-smr-engineering-study-11-2-2022>)
- Czech Republic (see Annex)
- Ukraine (see Annex)
- Estonia (<https://www.nucnet.org/news/country-could-have-first-nuclear-reactor-by-2035-says-working-group-10-3-2022>)
- Poland (<https://www.nucnet.org/news/very-good-chance-us-will-supply-reactors-for-first-nuclear-station-10-2-2022>)



- Global scenarios regarding the SMR perspectives:

- IAEA (IAEA, 2022)

It offers a good overview on the different SMR designs deployment timeline and the understanding on how they fit in our proposed scenario.

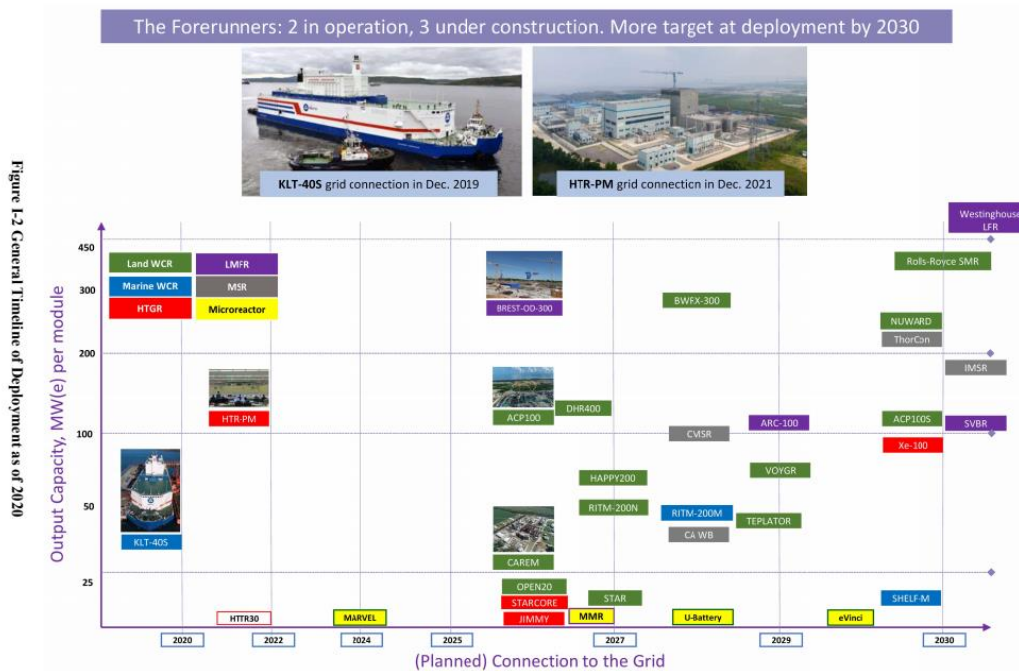


Figure 18: General Timeline of SMR Deployment as of 2020

- OECD/NEA (OECD/NEA, 2021)

4. SMRs in an energy integrated systems

4.2.2 Overview on the potential of SMRs in an energy integrated systems

As seen in Chapter 3, SMRs are seen mainly as source of electricity. However the developers of SMR technologies are taking into consideration also other energy products such as heat or hydrogen carrier (both through electrolysis but also thermochemical water splitting using high temperature heat or a combination of the two processes).

Figure 19 below illustrates the potential of an SMR to deliver power together with renewables to decarbonise the power system but also for hydrogen production and in the same time can also deliver heat for district heating, industrial heating / processes and hydrogen production.



Figure 19: SMRs in an energy integrated system - Source: Tractebel

4.2.3 SMR capabilities for the heat production

The capabilities to deliver heat (on a given temperature range) depending on the reactor technology is illustrated in Figure 20.

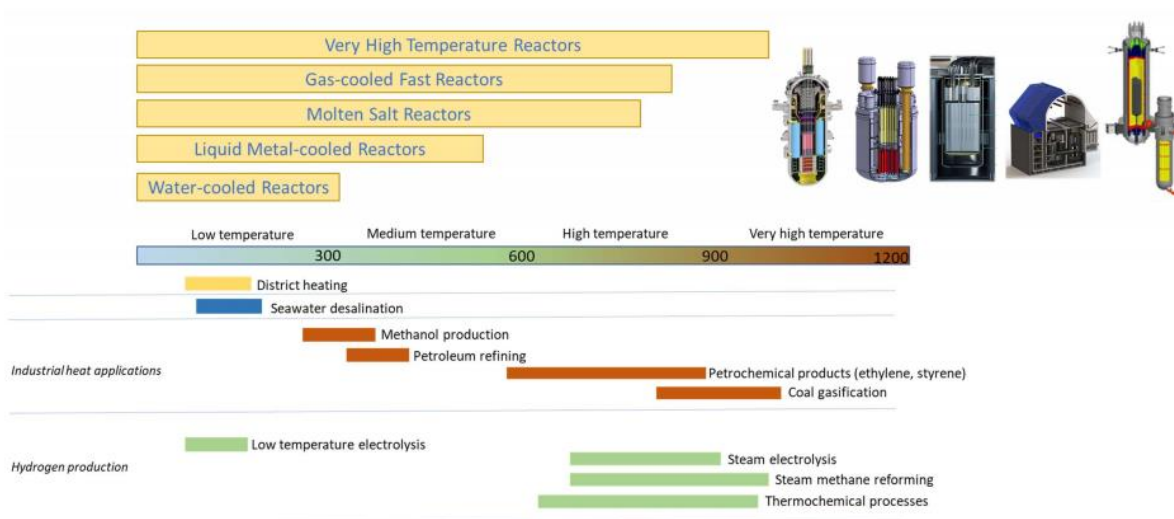


Figure 20: Exit working temperature of SMR technologies and corresponding non-electric applications (IAEA, 2022)

The heat production can have a broad range of usages, depending on the type of chosen technology. For the TANDEM project time frame considerations (2035) we consider that the SMR technology available for commercial deployment will be based on light-water reactors, nevertheless, some high-temperature reactors and metal-cooled reactors may be available at this time.

5. Proposal of the energy scenarios to derive TANDEM hybrid energy systems

The TANDEM project aims at supporting the safe and cost-effective integration of SMR technology (in general) in a climate neutral and sustainable energy mix.

The energy scenarios are to set the techno-economical frameworks for the analysis of the selected hybrid energy systems, in a commonly accepted approach towards a 2035 and 2050 energy mix perspective aligned with the relevant EU and member states policies.

Consequently, it is proposed to consider two distinct scenarios - a base line scenario and a demonstration scenario -, each one of those being defined at the same two time frames, 2035 and 2050. In this two by two matrix structure, the outcomes could be considered on two complementary dimensions.

Based on the conclusions from Chapter 2 and 3 (mainly section 3.2.1) and considering the contributions of the project partners by providing some national perspectives regarding the SMR technology deployment, it has been decided the following: two scenarios will be considered, with emphasis on the SMR technologies. Both scenarios will have fixed figures for the large reactors installed capacity, the only variable being the SMRs installed capacity.

The expected capacity of large reactors in the EU can be found in Table 4 below.

	2020	2025	2030	2035	2040	2045	2050
Large reactors and Gen IV installed capacity	109	107	111	119	123	121	107

Table 4: Installed capacity of large reactors (Compass Lexecon, 2021) for TANDEM energy scenarios

The two proposed scenarios for the SMRs are the following:

	Production	2020	2025	2030	2035	2040	2045	2050
Low SMR deployment scenario (GWe) Note for heat production the capacity is in GWe equivalent	Power					2.7	4.4	10
	Heat						0.5	2
High SMR deployment scenario (GWe) Note for heat production the capacity is in GWe equivalent	Power				2.6	9	14.5	33
	Heat					0.5	2	6

Table 5: SMR installed capacity for both power and heat production for TANDEM energy scenarios

A summary of the proposed scenarios can be found in Figure 21.

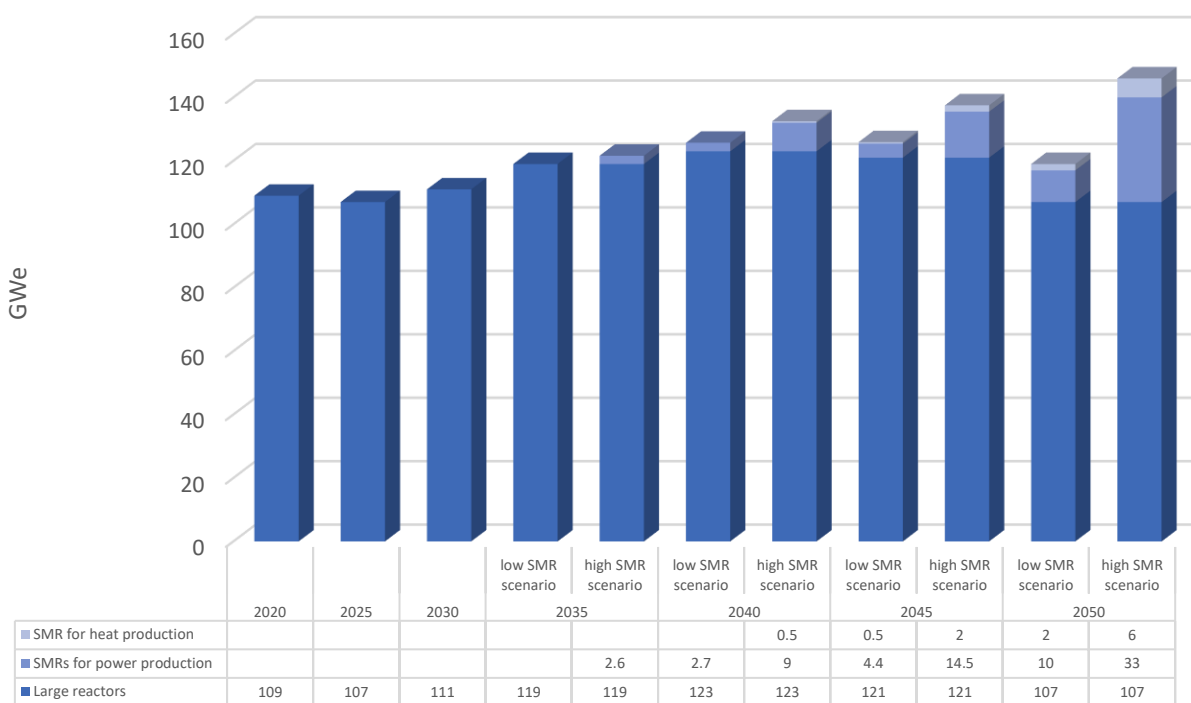


Figure 21: Nuclear installed capacity by 2050 in EU27 for TANDEM energy scenarios



6. Conclusion

The TANDEM project proposes to address most of the potential challenges of the SMR integration into hybrid energy systems. Considering as 2035 the time perspective when the first SMRs will be implemented in Europe, it can be seen that only the proposed scenario with a high SMR deployment is taking into consideration the potential of both power and heat production.

And even if by 2050 the biggest share of nuclear installed capacity is represented by large nuclear reactors, SMRs will still have a strong influence at regional level, where local industries or population can benefit from direct connection for power production but also heat for industrial processes or district heating.

References

Compass Lexecon, 2021. Pathways to 2050: Role of nuclear in a low-carbon Europe - 2021 updated results. Available at <https://www.nucleareurope.eu/publications/>

EERA, 2022. EERA REPowerEU Manifesto. European Energy Research Alliance, Brussels. URL: https://www.eera-set.eu/component/attachments/?task=download&id=928:EERA_REPowerEU_Manifesto_Final

Heat Roadmap Europe, 2017. Heating and Cooling – facts and figures – The transformation towards a low-carbon Heating & Cooling sector. June 2017. URL: https://heatroadmap.eu/wp-content/uploads/2019/03/Brochure_Heating-and-Cooling_web.pdf

Hydrogen Europe, 2022. Clean Hydrogen Monitor 2022. URL: <https://hydrogeneurope.eu/clean-hydrogen-monitor-2022/>

IAEA, 2017A. Opportunities for Cogeneration with Nuclear, IAEA Nuclear Energy Series - NP-T-4.1 – 2017. URL: <https://www.iaea.org/publications/10877/opportunities-for-cogeneration-with-nuclear-energy>

IAEA, 2017B. Industrial applications of nuclear energy, IAEA Nuclear Energy Series - NP-T-4.3 – 2017. URL: https://www-pub.iaea.org/MTCD/Publications/PDF/P1772_web.pdf

IAEA, 2020. Climate change and nuclear power. Edition 2020. URL: <https://www.iaea.org/sites/default/files/iaea-ccnp2022-body-web.pdf>

IAEA, 2022. Advances in Small Modular Reactor – Technology developments – A Supplement to: IAEA Advanced Reactors Information System (ARIS) -2022 Edition. URL: https://nucleus.iaea.org/sites/smr/Shared%20Documents/2022%20IAEA%20SMR%20ARIS%20Booklet_rev11_with%20cover.pdf

IEA, 2020. Energy technology perspectives.
URL:https://iea.blob.core.windows.net/assets/7f8aed40-89af-4348-be19-c8a67df0b9ea/Energy_Technology_Perspectives_2020_PDF.pdf

Lindroos et al, 2021. Replacing fossil fuels with bioenergy in district heating – Comparison of technology options, Energy, Volume 231, 2021, 120799, ISSN 0360-5442, <https://doi.org/10.1016/j.energy.2021.120799>

OECD/NEA, 2021. Small Modular Reactors: Challenges and Opportunities. Available at https://www.oecd-nea.org/icms/pl_57979/small-modular-reactors-challenges-and-opportunities?details=true



Annex - SMR deployment forecast provided by TANDEM partners

Czech Republic

Heat market in Czech Republic

Status

The report “YEARLY REPORT ON THE OPERATION OF CZECH HEAT SUPPLY SYSTEMS FOR 2021” [source: Energy Regulation Office of Czech Republic] covers all heat produced in licensed activities, including CHP, and also statistics on heat balance, supply and consumption by category. The report also contains an overview of the installed capacities in the Czech heat producing plants. The yearly report for 2021 is based on the data in the report for 4Q 2021 and contains some data that is more accurate.

The gross heat production totalled 161,657.4 TJ in 2021. A month-to-month comparison indicates quite significant variations in gross production, caused by the weather. Most of the heat was produced from brown coal (38%), followed by natural gas (21%) and biomass (15%). The structure of heat production by fuel differs in each of the Regions depending on fuel availability.

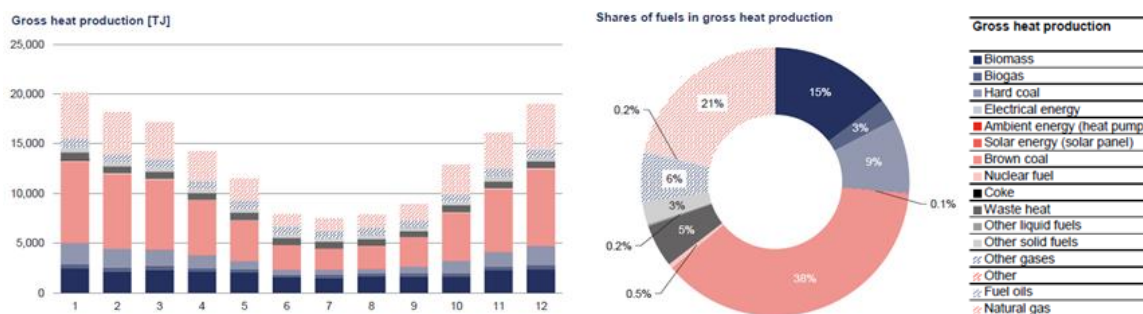


Figure 22: Gross heat production by fuel [TJ]

Approximately 29% of gross production was consumed in the entity’s own enterprise or facility. Heat supply accounted for approximately 57%, own use for process purposes accounted for 6%, and losses accounted for 8% of gross heat production.

The heat supply production itself shows a similar share of production means. Most of the heat was produced from brown coal (43%), followed by natural gas (28%) hard coal (11%) and biomass (9%).

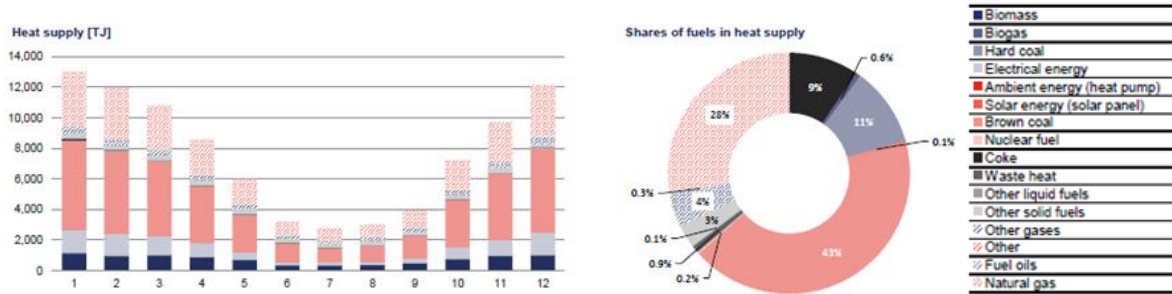


Figure 23: Heat supply by fuel [TJ]

District heating, or heat supply systems (HSS), is traditionally well developed in the Czech Republic. Approximately 1.7 million households, which is more than 4 million inhabitants or 40% of the population, are connected to HSS systems. Almost half of the heat supplies from HSS go to the housing sector (44%), 28% to industry and the rest is supplied to the tertiary sector (services, health care and education).

Evolution

The fuel mix scenario within the heat supply system up to 2050 has been determined in “Assessment of the decarbonisation of district heating in the Czech Republic - June 2022” report [Source: Ministry of Industry and Trade pf Czech Republic]. It is evident that the share of fossil fuels (especially coal) will gradually decrease, which should also lead to a related decrease in greenhouse gas emissions. However, this scenario has a number of uncertainties, which are currently compounded by developments in the geopolitical situation. In particular, the role of natural gas, which was to play the role of a transition fuel and allow partial substitution of coal, requires to find alternative energy sources.

Before the outbreak of the war in Ukraine, a strategy for the transformation of the Czech heating industry was planned, which was based on the decarbonization of the Czech heating industry, i.e. the fastest possible exit from coal and the transition to other low-emission energy sources, where natural gas played a primary role in this transformation. All measures were prepared and set up for this.

In the light of the current military conflict, the question of the level of gas use in the energy transition has arisen, which is in fact the main topic of all discussions, where a common approach throughout the European Union aims to ensure sufficient quantities of gas and adequate prices.

The strategy has been adapted as follows

- In the future period, in the development of gas sources, limit the development of new heat production plants from gas to the level of "covering" of natural gas outside Russia with the possibility of subsequent substitutes of alternative fuels (LNG, biomethane, hydrogen...)

- in the case of current natural gas heat production plants – gradual integration of natural gas substitution through newly installed facilities for the production of hydrogen from RES, biomethane.

In order to maintain energy security, the issue of a slower exit from coal and the extension of the use of existing coal sources is also considered.

The next table (see Table 3.2.1) presents the proposed evolution of the future energy mix in the Czech heating industry, based on data from 2019 and the related expected transformation of this sector in 2030, 2040 and 2050. There is a strong focus on the use of renewable energy sources and their integration into the heating industry, although there are limited possibilities in the Czech Republic. In the field of district heating, it is the use of sustainable biomass, but also the integration of heat pumps and solar collectors for hot water into heat supply systems.

Fuel	2019 Heat (TJ)	2030 Heat (TJ)	2040 Heat (TJ)	2050 Heat (TJ)
Coal and coal products	52 178	4 696	0	0
Oil and oil products	186	0	0	0
Natural gas	22 155	27 214	13 629	0
Peat	0	0	0	0
Solid biomass	4 601	15 178	16 778	17 832
Biogas	538	667	1 333	2 000
Geothermal	0	1 500	8 500	11 000
Solar thermal	1	200	1 300	3 500
Waste (renewable part)	1 890	5 556	4 167	2 778
Nuclear power (large NPP only)	234	2 499	3 000	3 500
Waste (non-renewable part)	1 260	3 704	2 778	1 852
Electric boilers	13	1 296	2 592	2 592
Heat pumps	87	90	1 590	2 500
Industrial waste heat	978	970	1 500	2 000
Tertiary waste heat	0	300	1 500	3 000
Waste water	0	0	2 500	3 626
Hydrogen	0	200	2 604	6 273
Other fossil gases	3 423	3 423	0	0
Biomethane	0	10 019	12 960	14 000
DHS supply total	87 543	77 510	76 731	76 453
New customers	0	3 098	6 697	10 795
Connected customers	87 543	74 412	70 034	65 657

Table 6: Fuel mix based on supplied heat from CHS (basic, 2030, 2040 and 2050)

Therefore, the final share at 2050 horizon has a strong contribution from RES like solid biomass (23%), biomethane (18%), geothermal (14%), solar thermal (5%) and a combination of other sources including hydrogen (8%) and nuclear contribution of 3%.

However, those trends do not reflect the most recent adjustments to the real situation :

- Gas sources need to be replaced on a faster rate
- Biomass and Biomethane figures are optimistic in their growth

Considering the latest trends regarding the SMR technologies, it could be considered to have one or two SMR units with thermal installed capacity 170-340 by 2035.

The Czech Resource adequacy assessment (ČEPS, 2021) identifies three national energy scenarios:

	Progressive	Conservative	Reference
Attenuation of coal resources	until 2033	until 2038	According to operators
Heating industry	Transformation to gas until 2030 (including)	Transformation to gas until 2030 (including)	By operators (partial transformation to gas)
Nuclear	Expected commissioning of new nuclear source (NNS) in 2036		
RES	Progressive prediction	Realistic prediction	Realistic prediction
Consumption	Progressive scenario (higher electrification)	Conservative scenario (medium electrification)	Same as in the Conservative scenario (medium electrification)

Table 7: National energy scenarios in Czech Republic

The electricity production in nuclear power plants and heating plants and industry power plants is indicated by these scenarios for years of 2025, 2035 and 2040 as follows:

Installed power	Progressive 2025	Progressive 2030	Progressive 2035	Progressive 2040
Heating plants and industry power plants	2 086 MW	1 943 MW	1 659 MW	1 373 MW
Nuclear power plants	4 047 MW	4 047 MW	4 047 MW	5 187 MW

Table 8: Installed power and electricity production in progressive scenario in 2025, 2035 and 2040

Installed power	Conservative 2025	Conservative 2030	Conservative 2035	Conservative 2040
Heating plants and industry power plants	2 086 MW	1 943 MW	1 675 MW	1 373 MW
Nuclear power plants	4 047 MW	4 047 MW	4 047 MW	5 187 MW

Table 9: Installed power and electricity production in conservative scenario in 2025, 2035 and 2040



Finland

Heat market in Finland

District heat production covers heat supplied to district heat grid and losses in the grid. Own heat consumption of generating public/private producers is not included. However, industrial consumption is included when industry is buying district heat from the grid.

District heat production in Finland is a common and efficient way of providing heating for buildings. Building heat refers to any building connected to district heating: residential, commercial, public or industrial with a end-use of delivered energy for heating and hot water.

District heat is produced in central heating plants, where heat is generated from a variety of sources including wood chips, peat, and waste heat from industrial processes. The heat is then distributed through a network of underground pipes to buildings and homes in the surrounding area.

Finland has a well-developed district heat industry with approximately 200 district heating grids, 3 million customers, and over 80% of the building heat supplied in the largest cities. The total share of the building heating was 46 % in Finland in 2021. The district heating market is well established, but still growing slowly. A heating degree corrected use of district heating has grown from 33.5 TWh at 2010 to 36 TWh at 2020. The future trend might see a slight decrease in the use of district heating due to energy efficiency renovations and reducing number of heating degree-days due to warming climate.

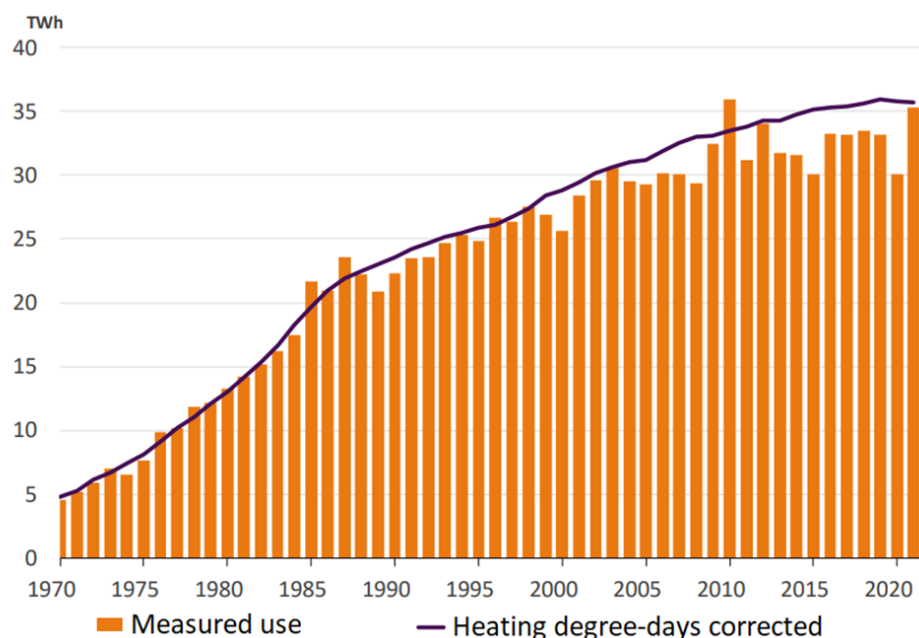


Figure 24: Measured and heating degree-days corrected use of district heat in Finland.

Source: Finnish Energy



Heating Degree Days (HDD) are used to measure the heating needs of different months and years. Eurostat has defined that “Heating degree days and cooling degree days are weather-based technical indexes designed to describe the energy requirements of buildings in terms of heating or cooling” and provide long term statistics on both [Eurostat]. As the temperatures vary between different years, the energy demand of different years can be normalized and compared using HDD. Long term statistics show a decreasing trend in HDD and increasing trend in CDD due to climate change.

Eurostat, <https://ec.europa.eu/eurostat/web/products-eurostat-news/-/ddn-20220531-1>

Finnish district heating sector was using mainly oil up to oil crisis in 70’s and replaced the oil with coal, natural gas, and peat. Since 2000, the share of biomass has increased rapidly. In 2010’s the use of waste heat, including large heat pumps and direct waste heat, has grown rapidly. It is a continuing trend that biomass and waste heats are replacing fossil fuels in the Finnish district heating grid.

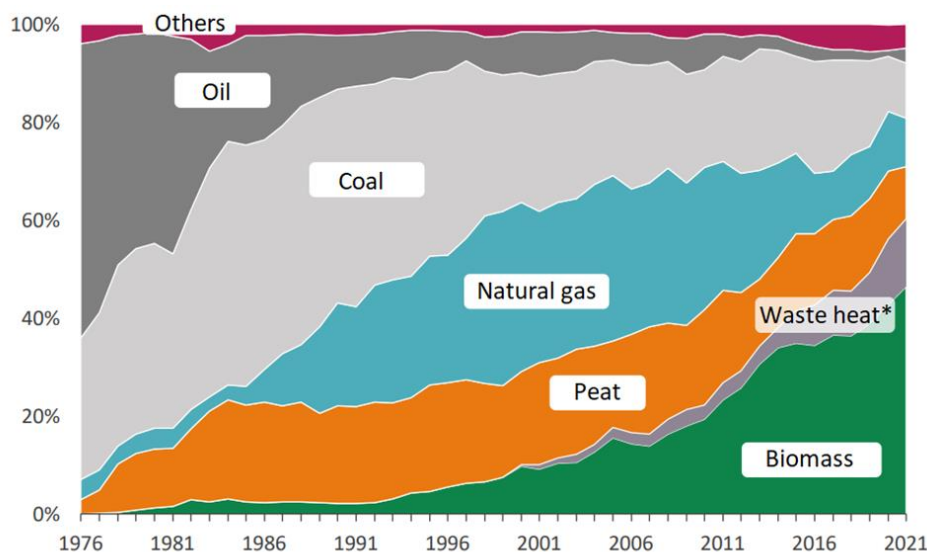


Figure 25: Fuels used in generating the Finnish district heating. Source: Finnish Energy

Investments to new energy sources, increasing energy prices, and CO₂ emission costs can be seen in the the average price of Finnish district heating for customers, which has increased from less than 40 €/MWh in 2000 to above 80 €/MWh in 2020. Some smaller grids are using mainly local biomass and can have significantly smaller production costs than district heating grids with CO₂ intensive generation. The range of average customer prices were from 50 to 120 €/MWh in 2020.

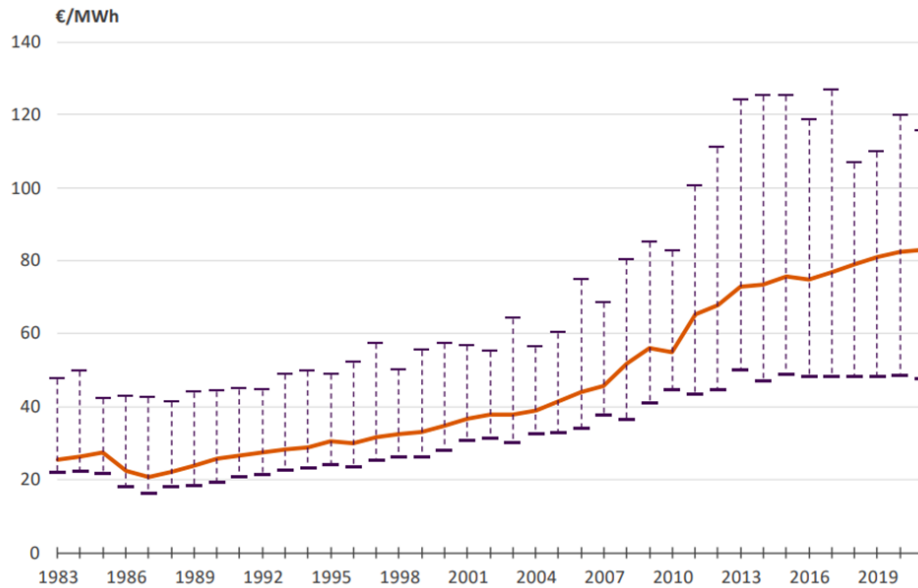


Figure 26: Average, minimum, and maximum prices of Finnish district heating. Source: Finnish Energy

Finland is targeting to be carbon neutral by 2035. Many cities have adopted their own carbon neutrality target for the same year. There are no similar nationwide scenarios for district heating development as in the Czech case, but the current trends shown in previous figures are likely to continue. This is further supported by the decision to ban coal use in 2029, but this will mostly affect the district heating generation in the capital region. Oil and gas will remain in the mix primarily for peak load hour use. Growth in biomass could be presumed to primarily replace peat, but otherwise significant further growth for biomass is less likely due to resource limits. Several studies show that Southern Finland does not have enough biomass to replace fossil fuels and expansions on biomass capacity would have to be based on imported fuel (Lindroos et al, 2021). . All of this primarily points to a significant increase in the use of heat pumps utilising waste heat with room for support from nuclear.

Ukraine

Ukraine national energy scenarios

The structure of electricity production by Ukraine's energy sector consist of 54% of nuclear power, 36% of thermal power plants, 4% of RES, and 6% of other sources /SSSU 2020/. According to Ukraine's Energy Strategy until 2035 /UES 2017/, three scenarios are considered: inertial (life extension of operating NPP and replacement of decommissioned NPPs by others sources); stabilizing (keeping nuclear part of electricity production at 53-55%) and extensive (increase nuclear part of electricity production to 56-60%).

Forecast of energy production (in billion kWh) until 2035 by base-case scenario is presented below.

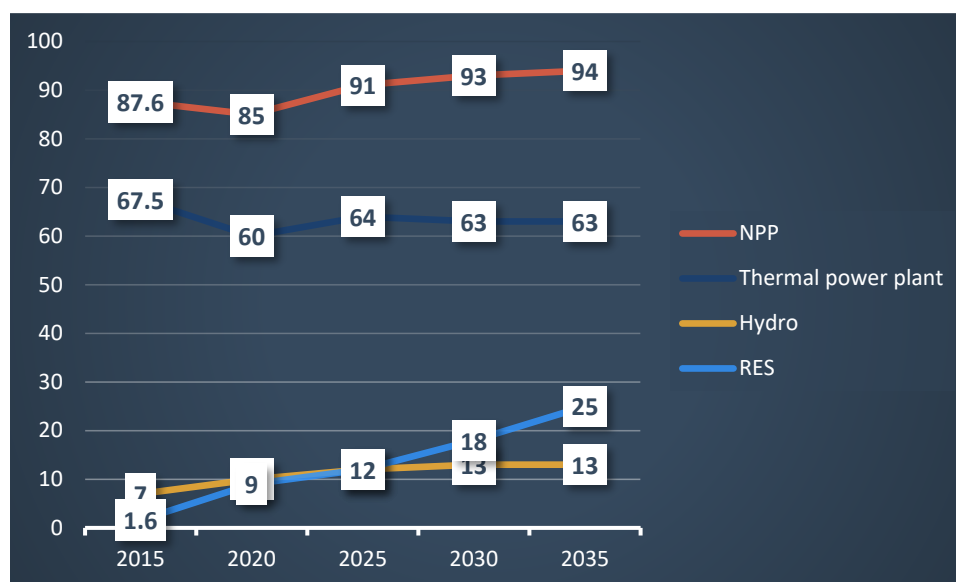


Figure 27: Forecast of energy production (in billion kWh) in Ukraine

Regarding implementation of SMRs in Ukraine, several activities have been launched during past 5 years.

Holtec considered the possibility of building a plant for the manufacturing of SMRs-160 in Ukraine. It includes the licensing and construction of reactors in Ukraine, as well as the partial localisation of SMR-160 components. The Ukrainian manufacturing hub is to mirror the capabilities of Holtec's Advanced Manufacturing Plant in Camden, and will be one of four manufacturing plants Holtec plans to build at distributed sites around the world by the mid-2020s. This consortium will give fresh impetus to realise the objectives of the MoU signed by Energoatom and Holtec last year that envisages building of six SMR-160s with total capacity of 960 MW at the Rivne NPP /WNN 2021/.



The recent project funded by the Rivne NPP on selection of reactor technology for the Rivne NPP unit 5 (to replace Rivne NPP units 1 and 2 with total capacity 880 MWh) suggested for further detailed evaluations several options, including construction of 12 or 24 NuScale modules with total capacity 600-1200 MW /ARB 2021/.

In 2021 NuScale Power and Energoatom signed memorandum of understanding to explore SMR deployment in Ukraine. Under this MoU Energoatom will explore the possible deployment of NuScale reactors to replace fossil fuel plants as well provide technical assistance for gap analysis in supporting the licensing and deployment of SMR technology in Ukraine /NUS 2021/.

It should be emphasized that the war of the Russian Federation against Ukraine, which is currently ongoing, will have long-term negative consequences for the Ukrainian energy sector. The Russian forces, shelling the entire territory of Ukraine, deliberately targeted substations connected by high-voltage communication lines to Ukrainian NPPs. In November 2022 all power units of all NPPs in Ukraine were automatically disconnected from the power grid. The temporarily occupied Zaporizhzhya NPP, which has been out of operation since September of this year, went into the total blackout mode with the start-up of all diesel generators. Thus, for the first time in the 40-year history of the Ukrainian nuclear power industry, all NPP power units were shut down /UEA 2022/. Moreover, the Russian military has already damaged about half of Ukraine's energy infrastructure /BBC 2022/, /BBC 2022a/. With each subsequent attack, the system becomes less reliable, which is why reducing power consumption has been needed to control the situation. Definitely, it will necessitate long-term recovery in all spheres without exception including energy strategy and plans on scope of the SMR implementation into energy sector.

In 2022, as part of the UN's COP27 Climate Conference, U.S. and Ukraine announced cooperation on a Ukraine Clean Fuels from SMR pilot project, that will demonstrate production of clean hydrogen and ammonia using secure and safe SMR and cutting-edge electrolysis technologies in Ukraine. The project aims to carry out a first-of-a-kind pilot of commercial-scale production of clean fuels from SMRs using solid oxide electrolysis. In addition, it should contribute to the decarbonisation of hard-to-decarbonize energy sectors through the production of clean hydrogen, and improve long-term food security through the production of clean ammonia fertilizers. Also a new initiative has been launched aimed at accelerating Europe's transition from coal-fired power to SMR while preserving local jobs through workforce retraining. The Phoenix project announced at November 2022 will provide direct US support for coal-to-SMR feasibility studies and related activities in support of energy security goals for countries in central and eastern Europe /ANS 2022/.

References:

/ANS 2022/ U.S., Ukraine launch SMR project for clean hydrogen production. <https://www.ans.org/news/article-4511/us-ukraine-launch-smr-project-for-clean-hydrogen-production/> [Accessed: 2022-11-21] (2022)).

- /ARB 2021/ Construction of Rivne NPP unit 5. Selection of recommended type of nuclear power unit using IAEA methodology. (Будівництво енергоблоку №5 Рівненської АЕС. Рекомендації щодо вибору типу енергоблоку за методикою МАГАТЕ. Етап 3. Вибір рекомендованого типу енергоблоку за методологією МАГАТЕ. in Ukrainian). Analytical Research Bureau for NPP Safety. 20ARB-06.300.ОД.1 (2021).
- /BBC 2022/ Ukrainians told to 'charge everything' as power grid hit by Russia. <https://www.bbc.com/news/world-europe-63323263>. [Accessed: 2022-10-20] (2022)
- /BBC 2022a/ Ukraine conflict: How much damage has Russia done to power supplies? <https://www.bbc.com/news/world-europe-63721069>. [Accessed: 2022-11-28] (2022)
- /NUS 2021/ NuScale Power Signs Memorandum of Understanding with Energoatom to Explore SMR Deployment in Ukraine. <https://newsroom.nuscalepower.com/> [Accessed: 2021-09-01] (2021).
- /SSSU 2020/ State Statistics Service of Ukraine (Derzhavna sluzhba statystyky Ukrayiny). [Online] <http://www.ukrstat.gov.ua> [Accessed: 2022-11-25] (in Ukrainian))
- /UES 2017 Ukraine's Energy Strategy Until 2035 "Security, Energy Efficiency, Competitiveness". Approved by order of the Cabinet of Ministers of Ukraine. № 605-p 1 (2017)
- /UEA 2022/ On November 23, 2022, due to a decrease in frequency in the power system of Ukraine, emergency protection was activated at the Rivne, South Ukraine and Khmelnytskyi NPPs, as a result of which all power units were automatically disconnected. <https://www.energoatom.com.ua/app-eng/eng-2311222.html> [Accessed: 2022-11-23] (2022).
- /WNN 2021/ Consortium established for SMR-160 deployment in Ukraine. <https://world-nuclear-news.org/Articles/Consortium-established-for-SMR-160-deployment-in-U> (2021).

