European Commission, Unit ENER.D2

Nuclear Energy Generation Sensitivity Analysis: Impact of Long Term Operations (LTOs)

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Contents

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Executive Summary

The average operating age of the nuclear fleet in Europe is about 30 years. The operational life of a nuclear reactor is set in some Member States at 40 years, whereas in others the operating licence is granted for an unlimited period, subject to regular safety reviews. However, for most reactor types it is admitted that 40 years is an important point in time where specific issues need to be considered. Taking into consideration that the share of nuclear power in gross electricity generation in the EU is about 27%[1], decisions about long term operations (LTOs) of existing nuclear power plants represent an important factor in the definition of the energy mix in Europe.

This "*Nuclear Energy Generation Sensitivity Analysis*" is based on the EUCO30 scenario developed using the PRIMES model. The model considers the achievement of EU climate and energy targets as constraints (including efficiency levels and percentages of renewables in energy generation). Investments levels in the different sources of energy resulting from the model are endogenous and market-based (that is, investments are profitable). In order to consider possible policy developments in the nuclear sector with respect to LTOs decisions, this "*Nuclear Energy Generation Sensitivity Analysis*" is based on five different policy options. These options differ with respect to *i*) the number of reactors entering LTOs and *ii*) the duration of LTOs for each reactor. One of the options used in the analysis closely replicate the information contained in the PINC[2]. Known policy decisions (e.g. no nuclear countries and phase-out from nuclear of Germany) have been considered and set as constant in all the options.

<u>Main results as concerns the impact of LTOs on the EU nuclear energy sector</u>

In the medium term, LTOs decisions have a significant incidence in the overall installed nuclear capacity in the EU. On the horizon 2030, installed nuclear capacity varies from 110.9 GWe in the option with more LTOs to 89.7 GWe in the option with less LTOs (from a level of 120.8 GWe in 2015). This is the consequence of a faster substitution of nuclear energy with renewables in the case of a larger number of nuclear power plant entering in shutdown mode by 2030.

On the contrary, little incidence of LTOs decisions in the overall installed nuclear capacity can be expected in the longer term. On the horizon 2050, installed nuclear capacity varies from 106.2 GWe in the option with less LTOs to 112.3 GWe in the option with more LTOs. The expected increase in electricity demand (due in particular to the very high level of electrification in stationary and mobile applications) and lower levels of substitution of nuclear energy with renewables in the long term (due to decreasing economies of scale for these latter) contribute to sustain the demand for nuclear energy as a part of the energy mix. In 2050, the share of nuclear power in gross electricity generation in the EU should stabilise at around 19%.

[1] Data concerning 2015.

[2] Communication on a Nuclear Illustrative Programme, COM(2017) 237 final.

Linked to the previous point, in the long term LTOs decisions will have little impact on the overall investment expenditures levels in new builds. In the period up to 2050, cumulative investment expenditure in new builds varies from EUR 358.7 billion[3] in the option with more LTOs to EUR 332.2 billion in the option with less LTOs.

Nevertheless, LTOs decisions play a significant role as concerns the moment in which a new significant wave of investment expenditures in nuclear is expected to take place. More LTOs determine a shift in the period in which a large part of the nuclear fleet in Europe will end operations and would need to be replaced, at least in part, by new nuclear capacity. Higher investment expenditures for new power plants of around EUR 56 billion can be expected in the decade 2031-2040 in the option with less LTOs compared to the option with more LTOs. Such a trend is hence reversed in the decade 2041-2050, where higher investment expenditures for new builds are required in the option with more LTOs compared to the option with less LTOs.

Main results as concerns the impact of LTOs on the EU energy sector as a whole

The overall system costs of the EU energy sector will be lower as the prolongations of the lifetime of existing nuclear reactors become larger (more reactors in LTOs) and longer in duration (more years in LTOs). Cumulative monetary savings of EUR 88 billion up to 2050 emerge comparing the least costly option (more LTOs) and the most costly option (less LTOs).

As concerns greenhouse gas emission levels, only a small decrease of 50 Mt CO2-eq can be observed during the period 2021-2050 in the option with more LTOs compared with the option with less LTOs. This is because nuclear capacity not entering LTOs is primarily replaced by low-carbon variable renewables, which become more competitive in the medium term (in the model, ETS prices also readjust in order for all options to respect the carbon budget).

In the case of a larger number of reactors entering LTOs, a limited but positive impact can be expected for final consumers in the mid-term, as the average pre-tax electricity price is kept at lower levels (in 2030, EUR 137.8/MWh in the option with more LTOs versus EUR 139.2/MWh in the option with less LTOs).

Comparison with the PINC

The results obtained in the modelling exercise for the option that mainly replicate the information contained in the PINC are generally close to the ones of the option with less LTOs.

[3] Values as for 2013.

1. Introduction

The average operating age of the nuclear fleet in Europe is 30 years. The operational life of a nuclear reactor is set in some Member States at 40 years, whereas in others the operating licence is granted for an unlimited period of time subject to periodic safety reviews. However, for most reactor types it is admitted that 40 years is an important point in time when specific issues need to be considered (in particular ageing survey and feed-back).

In 2015, the share of nuclear power in the gross electricity generation in the EU was 27%. The replacement of the existing nuclear capacity following the end of its operational life needs to be adequately planned ahead of time. Otherwise, there is the possibility that security of supply concerns will put some pressure on the work of safety regulators and operators when deciding whether or not to extend the useful life of a reactor.

The evolution of nuclear power in the EU, following the expiration of the operating licences of the 127 reactors currently in operation, will depend upon a combination of the following options:

- Long term operations[4] (LTOs);
- Shut-down and replacement by new nuclear capacity;
- Shut-down and replacement by other generation technologies.

Building on the EUCO30 scenario[5], this "*Nuclear energy generation sensitivity analysis*" has been constructed by identifying five different options to emulate possible policy developments.

Each option considers as stable known policy decisions, such as the phasing out from nuclear in Germany and Belgium and some reactor-based measures (e.g. planned shutdown of Ringhals 1 and 2 in Sweden and final shutdown of Santa Maria de Garona in Spain).

A separate simulation has been run for each of the following options:

- Option A: PINC as a base case[6];
- Option B: includes known policy decisions and LTOs assumptions for existing remaining reactors as follows: 25% shut down at 40 years, 37,5% LTOs 10 years, 37,5% LTOs 20 years[7];

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[4] The IAEA defines long-term operations of a nuclear power plant, or LTOs, as the operation "beyond an established time frame set forth by, for example, licence term, design, standards, licence and/or regulations, which has been justified by safety assessment, with consideration given to life limiting processes and features of systems, structures and components".

[5] EUCO30 scenario models the achievement of climate and energy targets as agreed by the European Council in 2014 (scenario with 30% efficiency target). In this exercise, the benchmark has been a revised version of the scenario, which incorporates improved techno-economic characteristics for various RES technologies, mainly wind and solar power, following recent developments in these markets.

[6] This option includes known policy decisions and LTOs assumptions for remaining reactors as follows: 31% shut down at 40 years, 18% LTOs 10 years, 51% LTOs 20 years. By taking into account all the existing reactors (including those affected by known policy decisions), the composition of the simulation would be: 38% shut down at 40 years or before, 18% LTOs 10 years, 44% LTOs 20 years. Such a scenario is compatible with the possibility of shutting down 17 reactors in France by 2025.

- Option C: includes known policy decisions and LTOs assumptions for existing remaining reactors as follows: no shut down at 40 years, 50% LTOs 10 years, 50% LTOs 20 years[8];
- Option D: includes known policy decisions and LTOs assumptions for existing remaining reactors as follows: no shut down at 40 years, 30% LTOs 10 years, 70% LTOs 20 years[9];
- Option E: includes known policy decisions and LTOs assumptions for existing remaining reactors as follows: no shut down at 40 years, 10% LTOs 10 years, 90% LTOs 20 years[10].

All the different options have been modelled using the PRIMES energy systems model. Although the different assumptions among the various options concern mainly the power module of PRIMES, the PRIMES model has been used as a whole so as to capture the effects of the different LTOs schedules among nuclear reactors on energy prices and consequently, on the end-use consumers. Decisions regarding new nuclear investments are endogenous, i.e. the model can decide freely the generation sources that will replace the nuclear capacity not entering LTOs.

2. Scenarios

This "*Nuclear energy generation sensitivity analysis*" consists of five (5) scenarios in total, as part of the quantitative work for the current exercise, which are developed in this report. All scenarios extend the projections to 2050. The key differentiating element among them is the assumptions regarding the long-term operation of nuclear power plants. A table summarising all scenarios is displayed below, and a more detailed presentation of the lifetime extensions schedule is annexed to this report. The assumptions can be differentiated among scenarios in two ways:

- Number of reactors entering LTOs;
- Duration of LTOs for each reactor.

The different assumptions used among the scenarios lead to a different time profile for the power capacity of the existing nuclear plants, as shown in Figure 1. The EUCO30 scenario is mentioned in most tables and figures contained in this report for comparison purposes of the nuclear, and can be used as a reference point. ***Option A*** (which contains information that broad replicate the assumptions made in the PINC[11]) assumes that less nuclear reactors will enter LTOs in the mid-term, and more will see their lifetime getting extended post-2035, compared to EUCO30. In general, ***Option B*** includes lifetime

[7] By taking into account all the existing reactors (including those affected by known policy decisions), the composition of the simulation would be: 33% shut down at 40 years or before, 35% LTOs 10 years, 32% LTOs 20 years. Such a scenario is compatible with the possibility of shutting down 17 reactors in France by 2025.

[8] By taking into account all the existing reactors (including those affected by known policy decisions), the composition of the simulation would be: 11% shut down at 40 years or before, 46% LTOs 10 years, 43% LTOs 20 years.

[9] By taking into account all the existing reactors (including those affected by known policy decisions), the composition of the simulation would be: 11% shut down at 40 years or before, 28% LTOs 10 years, 61% LTOs 20 years.

[10] By taking into account all the existing reactors (including those affected by known policy decisions), the composition of the simulation would be: 11% shut down at 40 years or before, 11% LTOs 10 years, 78% LTOs 20 years.

[11] Communication on a Nuclear Illustrative Programme, COM(2017) 237 final.

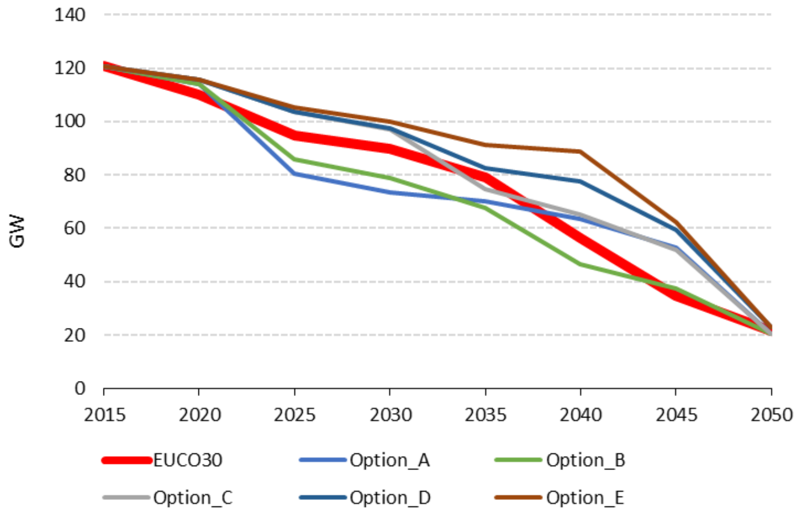
extensions for a lower number of reactors and for less years. The remaining options include in general, more and longer lifetime extensions, although the assumptions for the ***Options C and D*** bring the capacity of the existing reactor levels close or below to the case of EUCO30 by 2035. Towards the long-term, both options involve more capacity operating in LTOs.

Table 1. Summary of all scenarios developed and presented in the current study

Scenario name	Shut down at 40 years	LTOs 10 years	LTOs 20 years
Option A	31%	18%	51%
Option B	25%	37.5%	37.5%
Option C	No	50%	50%
Option D	No	30%	70%
Option E	No	10%	90%

Note: The figures appearing on the table include only assumptions for nuclear power plants for countries for which shutdown policies and LTOs assumptions are not known.

Figure 1. Total electrical capacity of nuclear reactors operating in 2015 for EU28.



As mentioned before, the new nuclear investments are endogenous decisions of the model. However, the construction and beginning of operation of the following nuclear reactors that are currently under construction, is exogenous for all the scenarios in this exercise and is presented in Table.

Table 2. Exogenous investments in new constructions (MW)

Nuclear power plant	Member State	Net Capacity	Commissioning year (rounded to 5-years period)
Flamanville 3	France	1680	2020
Hinkley Point C (new)	United Kingdom	3168	2025
Olkiluoto 3	Finland	1651	2020
Mochovce 3,4	Slovakia	880	2020
Paks 5	Hungary	1261	2025

Paks 6	Hungary	1261	2030

The investment costs for greenfield and brownfield investments, as well as for refurbishment[12] of nuclear plants, are shown in Table 3[13].

Table 3. Range of investment costs for refurbishments, and greenfield and brownfield investments for nuclear power plants.

(EUR '13 / kW net)	Min	Max
Refurbishment for extension of lifetime	850	1500
EPR brownfield investment	4850	5500
EPR greenfield investment	6000	6500
future EPR brownfield	4000	4500
future EPR greenfield	4850	5250

Note: The costs for refurbishment correspond to the needed investment costs for a plant to enter LTOs operation for 10 years.

The implications of each policy option have been assessed in terms of **security of supply**, measured as the impact of energy dependence (i.e. the extent to which the EU relies upon imports in order to meet its energy needs) and **cost-effectiveness**, defined as variation in overall energy system costs compared to the EUCO30 scenario.

3. Results

This section presents the key outcomes from the modelling exercise.

Nuclear capacity and investments

Table 4 presents the installed nuclear capacity for EU28 across all scenarios. The assumptions regarding the number of reactors entering LTOs in each scenario are the main drivers of the differences in capacity between the scenarios (see Annex A), but these are complemented with the endogenous decisions of the model on capacity expansion.

Table 4. Net installed nuclear capacity in (GWe)

	2015	2020	2025	2030	2035	2040	2045	2050
EUCO30	120.8	114.2	105.1	109.9	112.6	117.8	116.7	109.2
Option A	120.8	118.2	89.1	84.6	98.0	125.3	129.8	106.2
Option B	120.8	118.2	94.6	89.7	95.4	109.8	114.7	106.2

[12] Refurbishment refers to undertaking the necessary technical works in order to extend the lifetime of power plants or improve their technical characteristics and may include environmental upgrading. Capital costs of refurbishment are lower than cost of new investment, but the lifetime extension is limited. For nuclear power plants, the refurbishment works are mainly associated with ensuring that the appropriate security conditions are met for reactors to continue operating beyond their initial operational lifetime.

[13] The figures shown on the table are the ones used in the power module of PRIMES and have been used in all modelling exercises for the Commission, since (and including) the elaboration of the EU Reference scenario 2016, i.e. the scenarios that have provided input to the Impact Assessment accompanying the Clean Energy for All Europeans package of proposals, released in November 2016.

Option C	120.8	120.0	112.3	108.0	102.4	126.8	133.4	110.6
Option D	120.8	120.0	112.3	108.5	110.2	136.5	136.4	108.5
Option E	120.8	120.0	114.2	110.9	117.2	141.3	138.0	112.3

In the long term (2050), EU nuclear capacity stabilises close to 110 GWe in all scenarios, down from 121GW in 2015. However, in the mid-term, significant differences are observed among scenarios, based on the number of nuclear reactors that enter LTOs in each case. The ***Option A*** and ***Option B*** options generally assume that a lower number of nuclear reactors (compared to EUCO30) will get permission to operate beyond the originally foreseen lifetime of 40 years. The ***Option A*** scenario is the case where the nuclear capacity is the lowest among all scenarios in 2030 (85 GWe). The opposite is true for scenario ***Option E***, which assumes that 90% of the reactors will enter LTOs for 20 years. In the latter, the capacity of nuclear stations is 112 GWe in 2030.

In the period post-2030, investments in new nuclear power plants are needed in order to support the significant increase observed in electicity demand (Figure 2). Up to 2030, the strong energy efficiency policies hinder any growth in electricity demand, as the overall final energy consumption decreases, and the switch to electricity is not enough to compensate it. Beyond 2030, though, as the electrification of final consumption[14] continues and starts to include also the transport sector, a significant increase in electricty demand is projected. The latter leads to increased investment needs for new power plants, including nuclear stations, in particular in East European countries which retire significant amounts of coal-fired capacity that was serving as baseload capacity in their energy system. In these cases, nuclear presents an attactive alternative to replace bulk amounts of power supplied to their grids.

The following tables present the nuclear investments in new plants and the investments in the refurbishment of old plants. Cumulatively the investments in new nuclear plants over the period 2021-2050, attain maximum levels in ***Option C*** and ***Option E*** (around 85GWe), while in the other options they are close to 81GWe. As anticipated, the capacity of nuclear plants entering LTOs is maximized in the ***Option E*** (94 GWe) and minimized in the ***Option A*** (66GWe), cumulatively in the period 2021-2050. Investments in the refurbishment of all plants are maximized in the period 2026-‘30 in all options, as during this period most European reactors complete 40 years of operation and LTOs begin.

Table 5. Investment in new nuclear plants per 5-year periods (GWe)

	2016-‘20	2021-‘25	2026-‘30	2031-‘35	2036-‘40	2041-‘45	2046-‘50
EUCO30	4.5	5.8	9.9	13.4	28.0	20.4	5.7
Option A	4.5	4.4	2.4	16.7	34.1	15.1	8.6
Option B	4.5	4.4	2.4	16.7	35.7	13.5	8.6

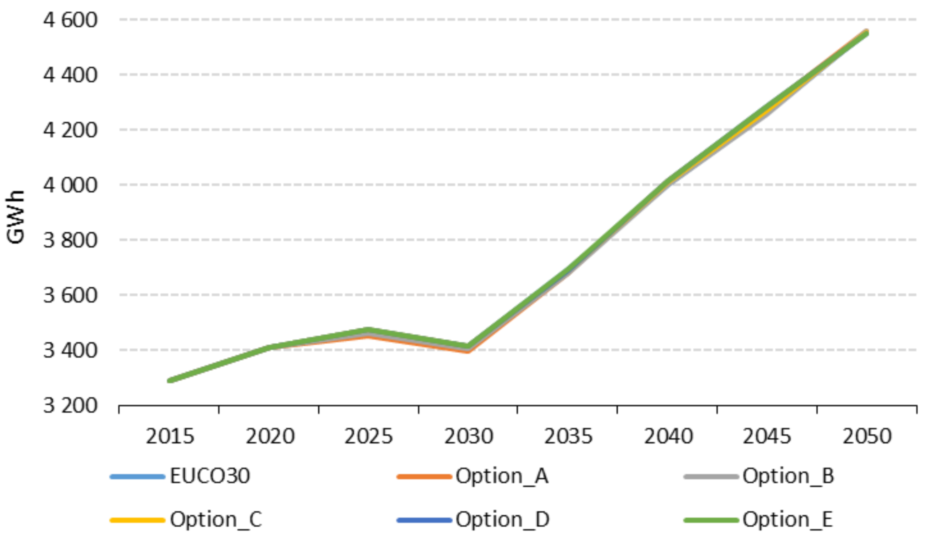
[14] The electrification of final demand is a main pillar of the decarbonisation of the EU energy sector. It mainly refers to fuel switching for mobility and heating purposes, away from fossil-fuels and towards electricity in all demand segments. In transportation, this is implemented via the introduction and wide penetration of electric vehicles. In the heating sectors (including buildings and industry) via the replacement of fossil-fuel powered boilers by heat pumps for the production of low-enthalpy heat. Replacement of certain applications in industry with alternative processes also amplify the electrification of certain industrial sectors.

Option C	4.5	4.4	2.4	16.7	34.1	19.5	8.6
Option D	4.5	4.4	2.4	16.7	31.2	17.9	8.6
Option E	4.5	4.4	2.4	15.1	26.5	22.8	13.8

Table 6. Investment in the refurbishment of old nuclear plants per 5-year periods (GWe)

	2016-'20	2021-'25	2026-'30	2031-'35	2036-'40	2041-'45	2046-'50
EUCO30	11.0	29.7	25.7	3.9	8.8	2.1	4.0
Option A	2.0	11.6	37.3	6.5	4.2	6.3	0.0
Option B	2.0	17.1	36.0	7.8	4.2	6.3	0.0
Option C	3.7	33.0	38.3	9.8	4.2	6.3	0.0
Option D	3.7	31.2	40.2	10.2	4.2	6.3	0.0
Option E	3.7	32.2	42.9	8.9	4.2	6.3	0.0

Figure 2. Gross electricity demand for EU28 in selected scenarios



Evolution of RES

The outlook for power generation from RES is closely related to the developments of the nuclear power industry. The high prices of ETS allowances post 2030 make investments in fossil-fuelled power plants scarce, with limited investments in gas-fired generation (usually equipped with CCS technologies) taking place in order to provide flexibility and act as reserve capacity for the stability of the electricity system.

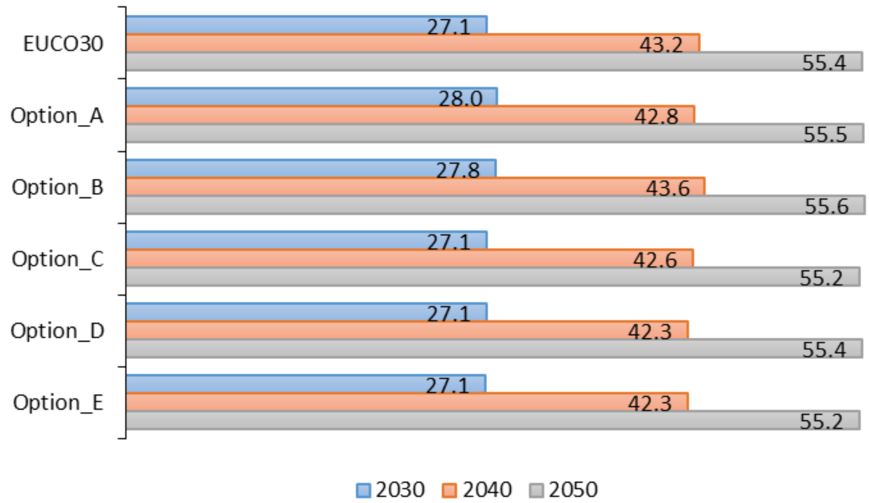
Given the above, the share of variable RES generation picks up fast and reaches 52.1% for ***Option A*** scenario by 2030, whereas the share for ***Option E*** scenario is 48.7%. The driver of this difference is the higher refurbishment percentage of nuclear power plants in ***Option E*** which leads to lower participation of RES in the generation mix. By 2050, where the total capacity of nuclear is almost 110 GWe in all scenarios, the percentage of RES generation reaches 74%.

Table 7. Renewable share for electricity (RES-E) (%)

	2015	2020	2025	2030	2035	2040	2045	2050
EUCO30	28.2	35.6	42.9	48.9	55.9	62.9	66.8	74.0
Option A	28.2	35.6	44.5	52.1	58.0	61.7	65.0	74.3
Option B	28.2	35.6	43.9	51.4	58.5	64.1	67.1	74.4
Option C	28.2	35.6	42.1	49.0	57.5	61.3	64.2	73.5
Option D	28.2	35.6	42.2	48.9	56.5	60.3	64.3	73.9
Option E	28.2	35.6	42.0	48.7	55.7	60.2	64.0	73.4

The aforementioned developments also affect the total RES share for EU28 as expected and observed in Figure 3.

Figure 3. Overall RES share (%)



Power generation mix

The evolution of the European power generation mix in the horizon up to 2050 is obviously affected by the lifetime extensions of the nuclear reactors currently in operation. A relatively low number of reactors entering LTOs leaves space for other electricity sources to enter the power mix at a faster pace (Figure 6). For example, RES generation is sensibly higher in ***Option A*** and ***Option B*** than in ***Option D*** and ***Option E***, which favor the lifetime extension of the nuclear reactors.

In all scenarios, generation from wind presents the largest growth during the projection period. The wind participation in the generation mix attains maximum levels in case of ***Option B***, where the total electricity generation from wind reaches 1 835 TWh by 2050.

Power generation from solar also presents significant growth, the amplitude of which for 2030 depends again on the assumptions regarding the evolution of the existing nuclear power plants. In the long term (2050), power generation from solar is in the order of 670 TWh across all scenarios.

The role of power generation using gaseous fuels dwindles in the long term, however, considerable installed capacity is required as it provides flexibility and ancillary services for the stability of the power system. The characteristics of plants running on gaseous fuels with relatively fast ramping times and emergence of synthetic methane provide an opportunity for gaseous generation to have a role in the future power mix, unlike generation from solids that is almost eliminated from the power mix. The power generation from gas follows a descending trajectory post 2035 and ends up being almost 410 TWh in all scenarios for 2050, whereas generation from solids is less than 60 TWh in all scenarios at the same point in time.

Power generation from biomass increases to almost 320 TWh by 2050. Generation from hydro also increases but to a far lesser extent, as the available sites are limited.

As shown in Figure 4, power generation from nuclear has large deviations between the scenarios during the period 2020-2050. Generation from nuclear power plants reaches maximum levels in the ***Option E*** scenario, as it was expected from the LTOs assumptions used in each scenario, and generates cumulatively almost 769 TWh (or 14%) more than in the ***Option B*** during this period.

Figure 4. Nuclear power plants generation

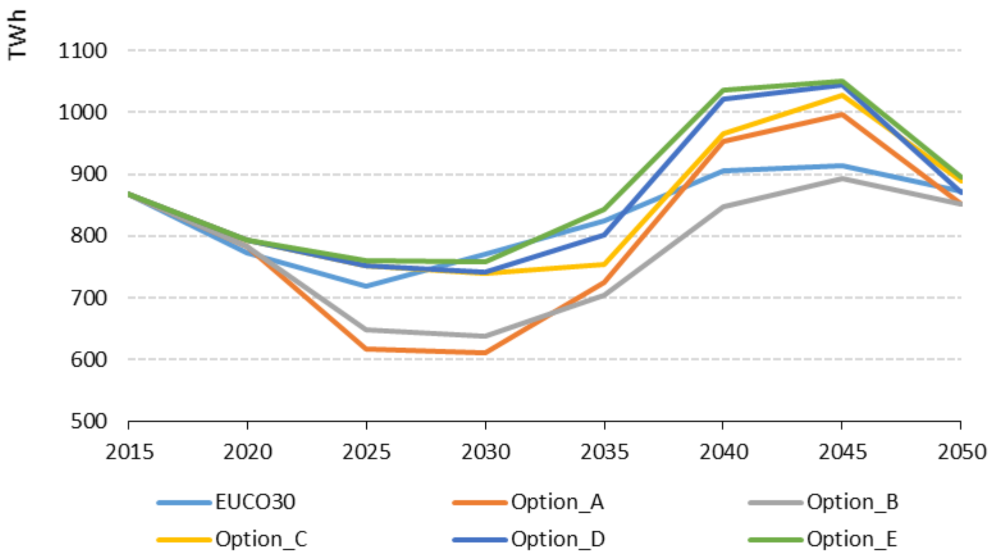
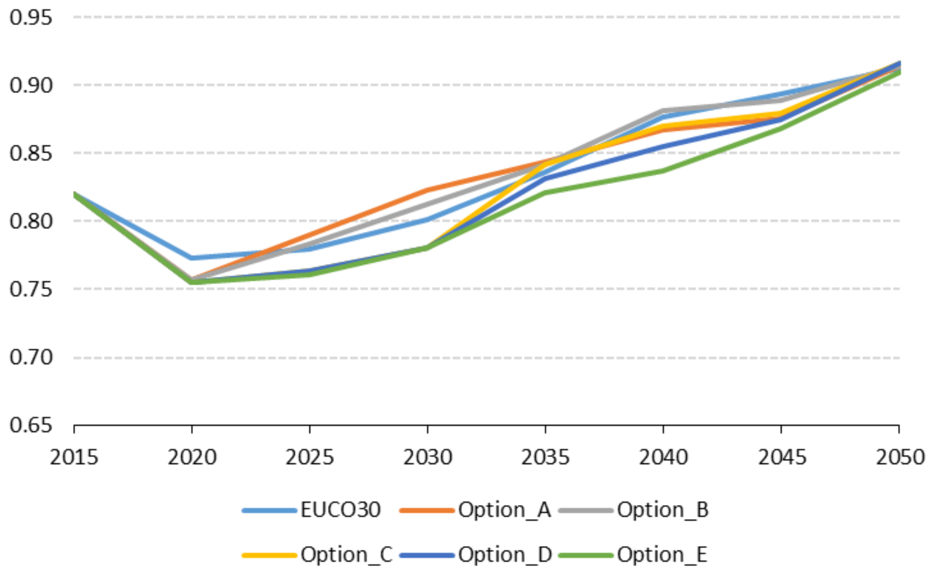


Figure 5. Average load factor for EU28 nuclear reactors



An increase in time for load factors of nuclear power plants is observed for all scenarios (Figure 5). In general, the scenarios that include assumptions with a larger number of reactors entering LTOs exhibit lower capacity factors, especially in the medium term. However, the average load factor for nuclear plants remains above 70% for all Member States[15] throughout the projection period. The increasing load factors over time are an outcome of the smoothening of the electricity load duration curve in future years, within a decarbonisation context - mainly due to smart charging of electric vehicles and demand response in the building sector. Such assumptions are consistent with the scenarios developed for the Impact Assessments accompanying the Clean Energy for All Europeans proposal (e.g. the EUCO30 scenario).

The electricity system under this context is assumed to have achieved a sufficient level of digitalization and have become more intelligent in order to allow better coordination between consumers and suppliers for electricity. More specifically, the emergence of EVs, the charging of which can take place during periods of low power demand, plus demand response, the penetration of smart grids, etc., lead to a load curve that is much smoother than today. For instance, this allows for more French nuclear reactors to operate at base load operation, in contrast to the current situation in the country, where many of them operate as load followers. In other words, the smoothened load curve leads to increasing capacity factors for French nuclear power plants over time.

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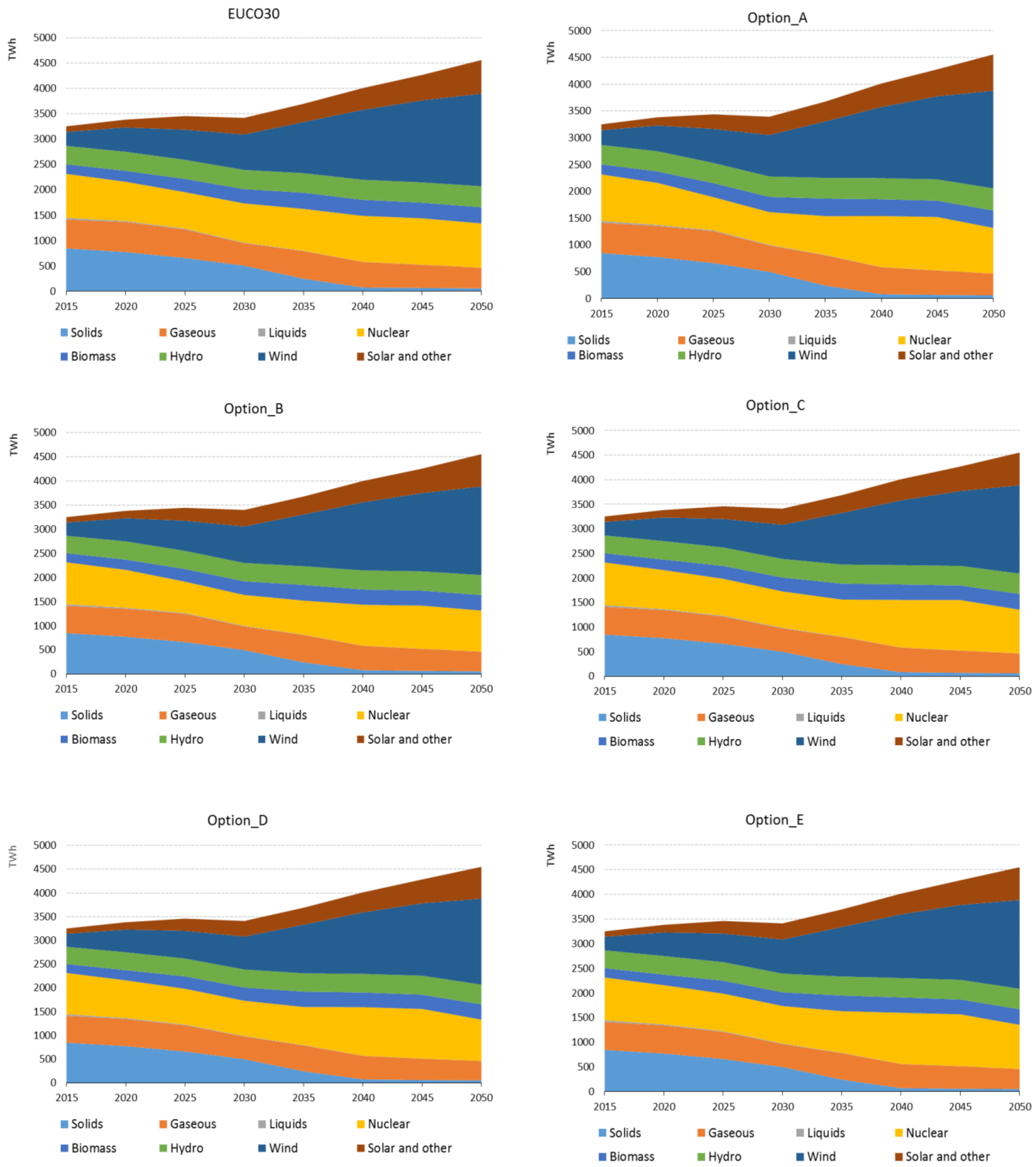
[15] Excluding Member States with announcements regarding the phase-out of nuclear energy.

Figure 6. Power generation mix



GHG emissions

Total GHG emissions in Europe present a continuous declining trend in all scenarios (Table 8). In all scenarios, the decline is similar, regardless of the pace of the retirements of nuclear plants. The reasoning behind this trend is that by 2030, variable RES become competitive with other carbon-intensive means of power generation, due to:

- Reductions in the capital costs of RES and improvements of their techno-economic characteristics;
- Increasing ETS prices that reduce the competitiveness of fossil-fueled generation (coal and gas).

Consequently, any loss in nuclear capacity is to a significant extent replaced by RES. In all scenarios, the EU emits 1158 Mt of CO_2-eq per year, 80% less than the respective emissions in 1990 (Figure 7), in line with its long-term decarbonisation objectives.

Table 8. Total GHG emissions (Mt of CO_2-eq)

	2015	2020	2025	2030	2035	2040	2045	2050
EUCO30	4583.4	4277.5	3903.0	3406.5	2674.8	1924.1	1493.9	1158.0
Option A	4583.7	4273.1	3918.6	3408.8	2665.9	1917.8	1492.6	1157.9
Option B	4583.4	4273.2	3918.2	3408.9	2669.8	1920.5	1494.4	1157.6
Option C	4583.4	4269.7	3906.9	3409.4	2673.9	1926.9	1492.3	1158.6
Option D	4583.7	4269.7	3906.7	3410.4	2669.0	1926.1	1492.0	1158.5
Option E	4583.7	4269.6	3907.5	3408.3	2668.2	1926.1	1492.5	1158.4

As shown in Table 8, there is no significant change in the total GHG emissions amongst the scenarios. The same is true for ETS emissions that are presented in Figure 8. The growth in electricity demand post 2030 does not result in significantly higher emissions from power generation, as the incremental demand is covered mostly by investments either in new nuclear power plants or in RES.

Figure 7. Total GHG emissions (% change to 1990)

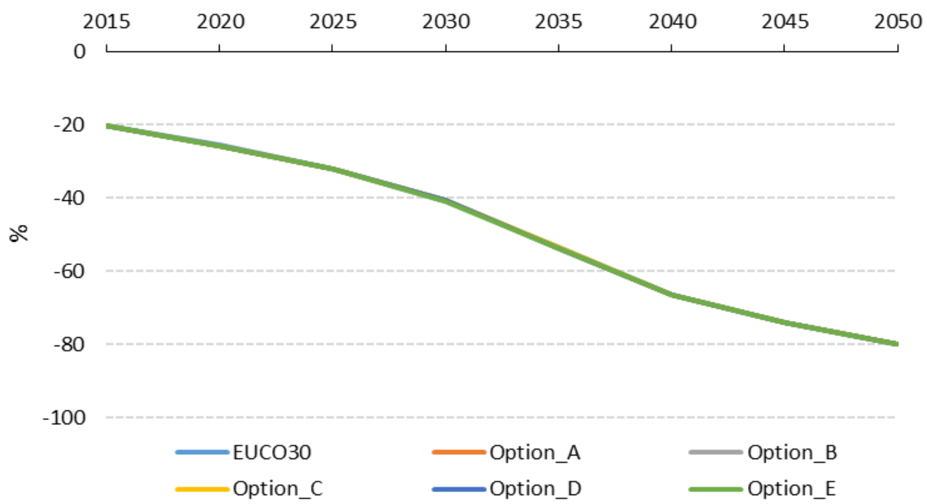
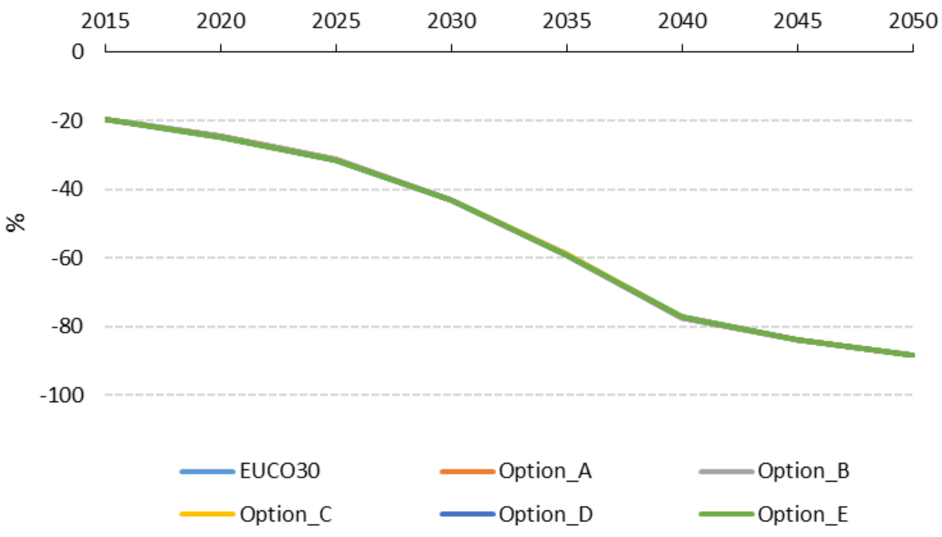


Figure 8. ETS sector's emissions (% change to 2005)



Import dependency

Improvements in EU import dependency are observed especially in the mid-term, as the number of reactors entering LTOs increases, however, the relative improvement is small. For instance, by 2030, the EU imports 54.9% of its energy needs in ***Option A***, whereas this drops only by one percentage point in the case of ***Option E*** (Table 9).

Table 9. Import dependency for EU28 (%)

	2015	2020	2025	2030	2035	2040	2045	2050
EUCO30	55.9	55.3	54.9	53.5	51.4	45.7	40.9	35.4
Option A	55.9	55.2	55.8	54.9	52.1	45.5	40.4	35.6
Option B	55.9	55.2	55.5	54.7	52.2	46.1	41.0	35.6
Option C	55.9	55.1	54.7	53.9	51.8	45.4	40.3	35.4
Option D	55.9	55.1	54.7	53.9	51.5	45.1	40.1	35.5
Option E	55.9	55.1	54.6	53.8	51.2	44.9	40.1	35.4

Electricity prices

The power & heat supply module of the PRIMES model endogenously projects the prices of electricity and steam that are used by the demand modules. The prices are calculated so as to fully recover all production costs including capital costs, fuel costs, monetary and carbon-related taxes, and other fixed and variable costs.

The prices in a given year take into consideration the investments occurring at the specific period, via transforming the corresponding overnight cost into a series of equivalent annuity cash payments.

The average pre-tax electricity prices[16] for all scenarios modelled in the current study are presented in Table 10. Electricity prices for 2030 in the main scenarios are increasing as

[16] Average price of electricity for each consumers sub-sector (industry subsectors, households, market services, non-market services etc.) weighted by their consumption levels.

the number of nuclear reactors that see their operation getting permission to extend decreases. This is true also in scenarios where less nuclear reactors enter LTOs and additional new investments need to be built to compensate for the retired capacity. The investment costs to extend the lifetime of nuclear reactors are generally lower than the investment costs for most new power plants. In 2030, the highest prices are observed in ***Option A***, whereas the lowest in ***Option E***.

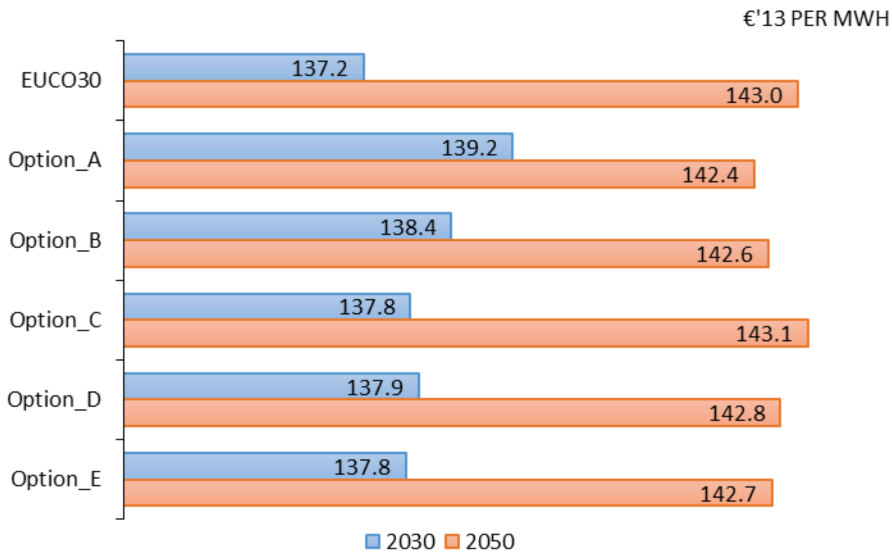
Box 1. Assumptions regarding the function of power markets in PRIMES.

The scenario setup used in PRIMES assumes that perfect financing conditions and a well-functioning market will prevail in the future. This is expected for scenarios which aim at assessing which are the best policies as otherwise, in distorted market conditions, the best policy may not be delivering as expected (second best theory in public economics). A well-functioning power market occurs when the prices in the wholesale and in the retail markets converge. In addition, they need to reflect scarcities, thus providing the accurate price signal to investments (adequate signal means that the prevailing prices provide security that capital costs will be recouped, as prices are above variable costs). Without price convergence between retail and wholesale markets, arbitrage will be possible acting to the detriment of those entities which are not vertically integrated (i.e. if they are long in the generation side they expect revenues from wholesale, but those who are long in the sales in retail have the interest to squeeze wholesale prices, and vice-versa). Over-capacity in the generation (as it is the case today in the EU) is a distortion qualifying the market as a non-well-functioning one. Asymmetry of prices between wholesale and retail is another symptom of a non-well-functioning market. Therefore, the assumption of PRIMES concerning a total cost recovery without specifying the origin of revenues explicitly is correct for long-term policy assessment. Power economics has a formal proof that the adequate price signal for investment is the long-term marginal cost of the system, which comprises the variable cost and the capital cost of the peak load unit. Over-capacity is not compatible with this condition and for this reason the model performs optimal capacity expansion exactly as needed by demand. In these conditions, a perfect bilateral contracting market (at a retail level directly) leads to exactly the same result, which is the long-term marginal cost of the system. This is possible even without a wholesale market, as it has been the case of Western Europe for a long period. Therefore, the wholesale and the bilateral contacts are equivalent ways of recovering costs in a well-functioning market, only one of them suffice or they may coexist.

Table 10. Average pre-tax electricity prices (in €'13/MWh)

	2015	2020	2025	2030	2035	2040	2045	2050
EUCO30	123.1	129.7	133.5	137.2	146.0	146.7	144.8	143.0
Option A	123.1	130.1	134.8	139.2	148.0	147.0	144.0	142.4
Option B	123.1	130.0	133.9	138.4	147.8	147.4	144.6	142.6
Option C	123.1	130.0	132.9	137.8	146.7	146.4	143.9	143.1
Option D	123.1	130.0	132.8	137.9	146.4	145.8	143.3	142.8
Option E	123.1	130.0	132.6	137.8	145.9	145.4	143.3	142.7

Figure 9. Average price of electricity (pre-tax) for selected years



Energy system costs

The cumulative total energy system costs are shown in Figure 10.The ***Option E*** scenario appears to be the least costly option during 2021-2050, as it takes advantage of more nuclear plants entering LTOs, with related lower investment costs. On the other hand, the scenario ***Option B*** appears to be the most costly.

Figure 10. Total energy system costs - including auction payments and excluding disutility costs- cumulatively

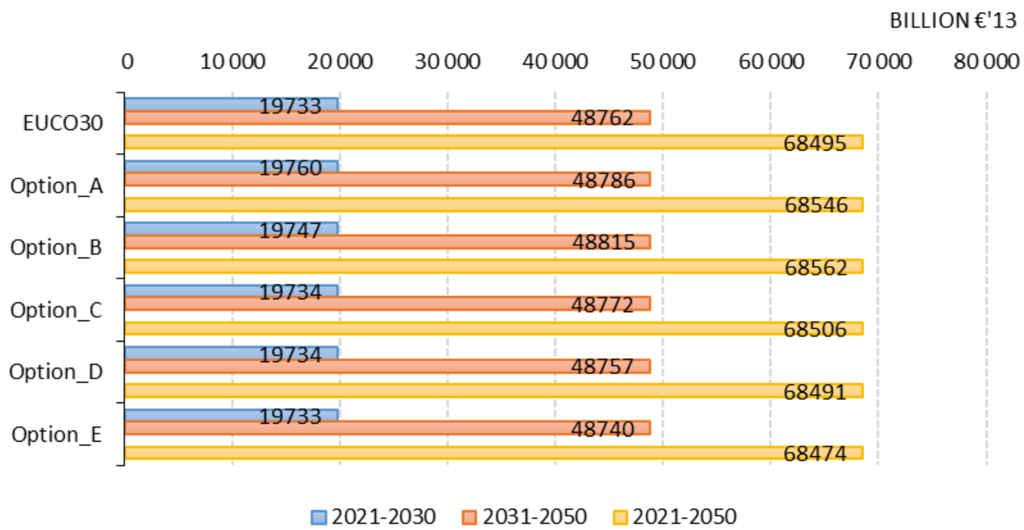
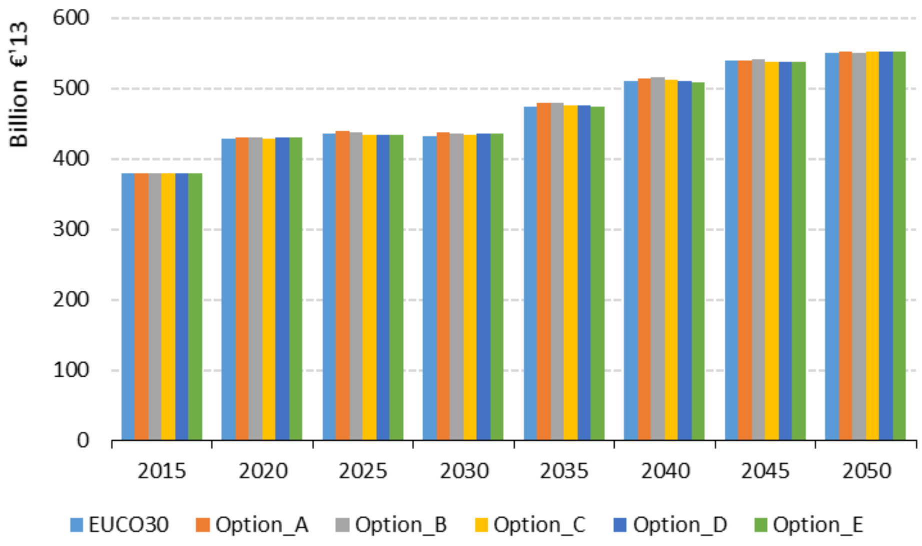


Figure 11. Total Cost of Electricity and Steam supply annually



The costs related to the European electricity and steam supply are presented in Figure 11. As a general remark, the costs follow the trends observed in the total costs of the energy system, as it is mainly the evolution in the power system that are differentiated in most scenarios.

Investment expenditures required by the power system are presented in Table 11. During the projection period 2021-'50, ***Option E*** presents the largest investments costs cumulatively across all scenarios (and overall).

The same applies to investment costs of new nuclear power plants which reach their maximum levels in ***Option E*** during 2021-2050 (Table 12). Investment expenditures for the refurbishment of old nuclear plants, which are shown in Table 13, present a larger variation across the scenarios. In ***Option E*** costs are EUR 133 billion (2013 levels) during the projection period 2021-2050, while in ***Option B*** the costs are around EUR 80 billion.

Table 11. Investment expenditure for the power system (in billion Euro'13 cumulatively)

	Power plants			Power grids			Total power system		
	'21-'30	'31-'50	'21-'50	'21-'30	'31-'50	'21-'50	'21-'30	'31-'50	'21-'50
EUCO30	380	1197	1577	364	1159	1523	744	2356	3100
Option A	401	1197	1598	383	1155	1537	784	2352	3135
Option B	386	1208	1594	380	1158	1538	766	2366	3132
Option C	374	1248	1622	365	1152	1517	739	2400	3139
Option D	378	1240	1618	364	1160	1524	742	2400	3142
Option E	386	1248	1634	363	1155	1519	750	2403	3152

Table 12. Investment expenditure in new builds (billion Euro'13)

	2015	2020	2025	2030	2035	2040	2045	2050	'15-'50
EUCO30	0.0	21.9	28.2	48.8	57.2	102.9	70.9	19.2	349.1
Option A	0.0	21.9	22.4	11.1	71.6	121.9	57.5	29.1	335.4
Option B	0.0	21.9	22.4	11.1	68.2	128.2	51.2	29.1	332.0
Option C	0.0	21.9	22.4	11.1	71.6	125.4	75.9	29.1	357.3
Option D	0.0	21.9	22.4	11.1	71.6	118.0	68.7	27.7	341.4
Option E	0.0	21.9	22.4	11.1	66.4	106.7	84.3	45.9	358.7

Table 13. Investment expenditure in the refurbishment of old plants (billion Euro'13)

	2015	2020	2025	2030	2035	2040	2045	2050	'15-'50
EUCO30	1.4	9.6	26.8	22.8	3.2	7.9	1.7	3.2	76.5
Option A	1.5	2.3	18.9	43.5	8.6	4.2	4.8	0.0	83.8
Option B	1.4	2.3	20.8	36.9	9.7	4.2	4.8	0.0	80.0
Option C	1.5	3.7	43.4	45.3	13.5	4.2	4.8	0.0	116.4
Option D	1.7	3.9	45.2	49.3	15.1	4.4	4.8	0.0	124.4
Option E	1.9	4.1	51.4	54.2	13.4	4.5	4.8	0.0	134.4

Figure 12. Investment expenditure in new nuclear power plants

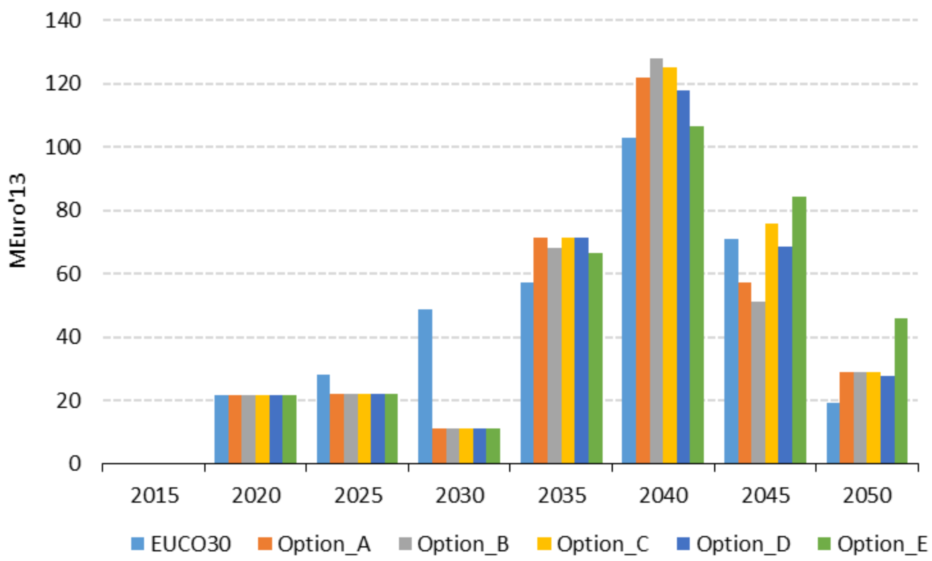
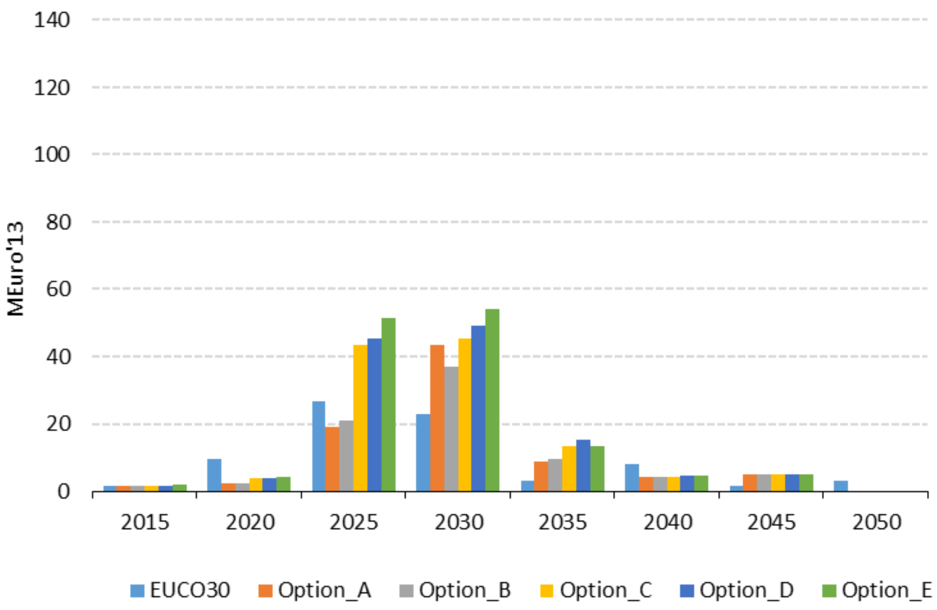


Figure 13. Investment expenditure in the refurbishment of existing nuclear power plants



Analysis per Member State

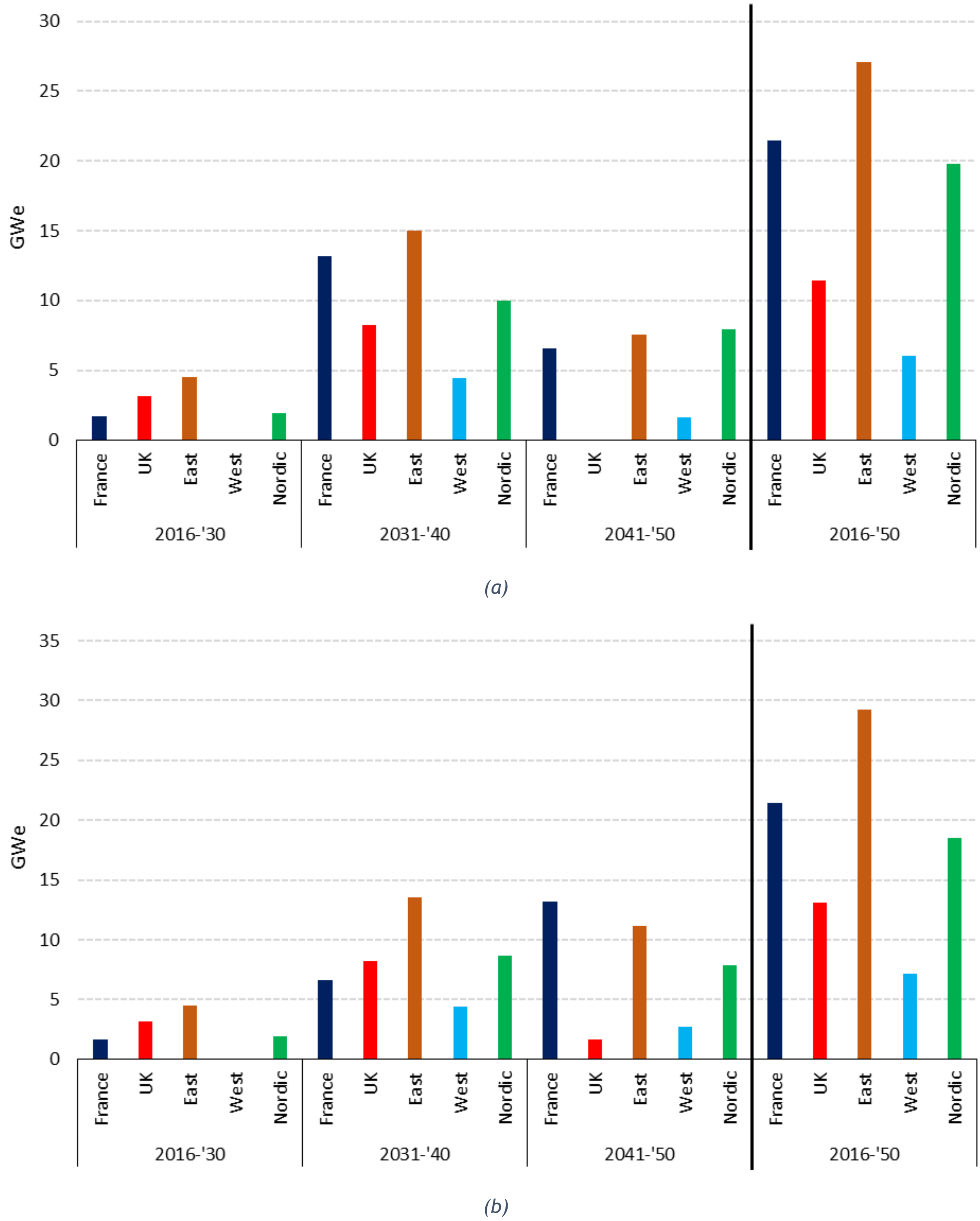
Detailed results regarding the developments in nuclear capacity per Member State are given in analytical tables presented in Annex A. In order to provide more insights on a regional basis in the current section, EU Members States have been grouped according to convention presented in Table 14.

Table 14. Grouping of EU Member States in regions

Regions	***Member States included***
France	France
UK	United Kingdom
Rest of western MS (West)	Austria, Belgium, Germany, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain
East	Bulgaria, Croatia, Cyprus, Czech Republic, Estonia, Greece, Hungary, Latvia, Lithuania, Poland, Romania, Slovak Republic, Slovenia
Nordic	Denmark, Finland, Sweden

Out of the 28 EU Member States, 12 had never and do not have any plans to build nuclear capacity for power generation (denoted in red in the Table 14). Two Member States (Germany and Belgium) have existing plans to phase out nuclear capacity within in the next decade (denoted in blue). Lithuania is expected to resume its nuclear program in the future (yellow), while Poland is expected to engage in building nuclear plants for the first time, towards the long term (green). The remaining 12 Member States are expected to continue relying, to different extents, on nuclear power for electricity generation (black).

Figure 14.Investments in nuclear new builds in Option A (a) and Option E (b)



The investments in new nuclear capacity for the options A and E, grouped in the regions presented in Table 14, are shown in Figure 14. The cumulative investments throughout the entire projection period (2016-2050) are similar across the two scenarios (and in general among all options examined). What differs among scenarios, is the timing of the construction of new plants. For instance in ***Option A***, which assumes that less nuclear reactors will enter in LTOs, more investments in new power plants are required in the decade 2031-'40 compared to ***Option E***, in order to replace retiring capacity. In the latter, the high number of reactors entering LTOs, allows for investments in nuclear plants to be deferred to the decade 2041-'50.

Besides France and the United Kingdom, who are expecting to continue making significant investments in new nuclear capacity, the majority of new capacity is built in Eastern European States, as the prevailing high ETS prices in the long-term, make the operations of their solid-fired capacity uneconomic. Therefore, an opportunity for nuclear energy to replace amounts of retired sold-fired is presented. Nordic countries (Finland and Sweden) also make significant investments in new power plants in the long term.

The investments in new plants in the Eastern Member States, lead to a continuous increase in nuclear capacity in this region, which surpasses 30 GW by the end of the projection period. Despite, the large amount of investments in France, the additional investments do not fully compensate the retirement of old plants (regardless of whether they have entered LTOs or not), a fact that results to nuclear capacity in France standing at 35 GW in 2050 in ***Option A*** as shown in Figure 15, but also in all other options examined. The main reasoning behind this partial only replacement of nuclear capacity is that other sources of power generation (solar and wind) are becoming more competitive, especially after the long term, thus fully replacing retiting plants with new ones is a most costly option than a combination of replacing the retired fleet partially and building new RES capacity. The two Nordic States with nuclear probles, continue to expand their nuclear capacity. The United Kindom expands its nuclear capacity towards the long-term. The capacity of the remaining western Member States drops importantly in the mid-term due to the phase-out of nuclear power in Germany and Belgium, thus the share of nuclear power in total generation drops to very low levels (Figure 16).

Figure 15. Total electrical capacity of nuclear reactors per region in Option A

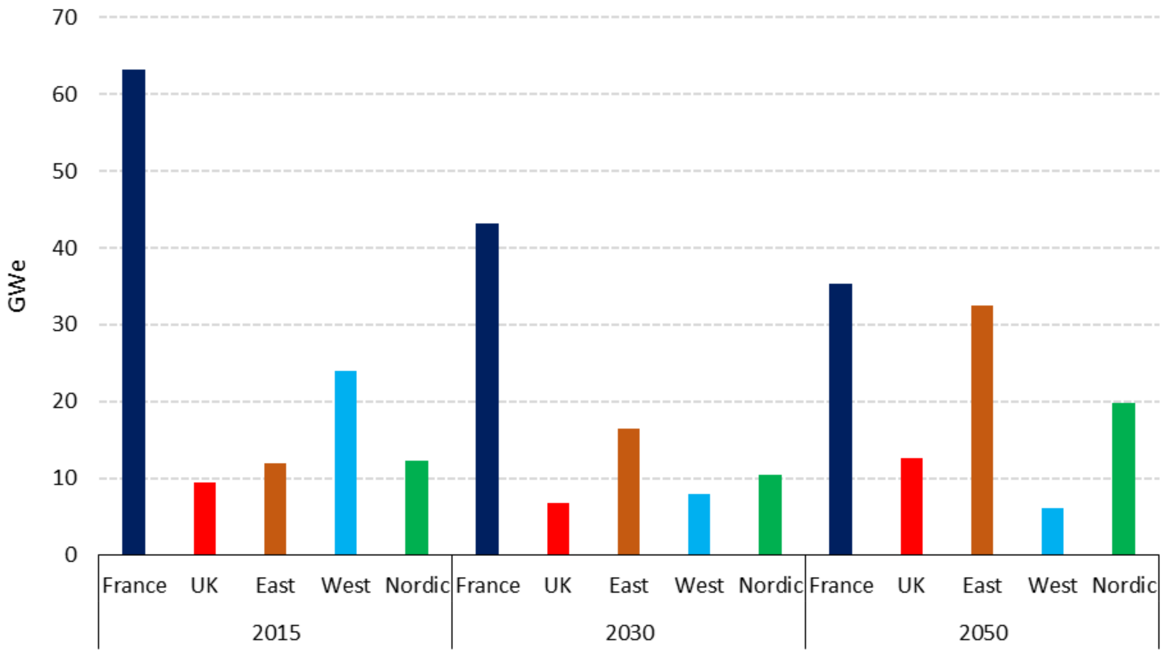
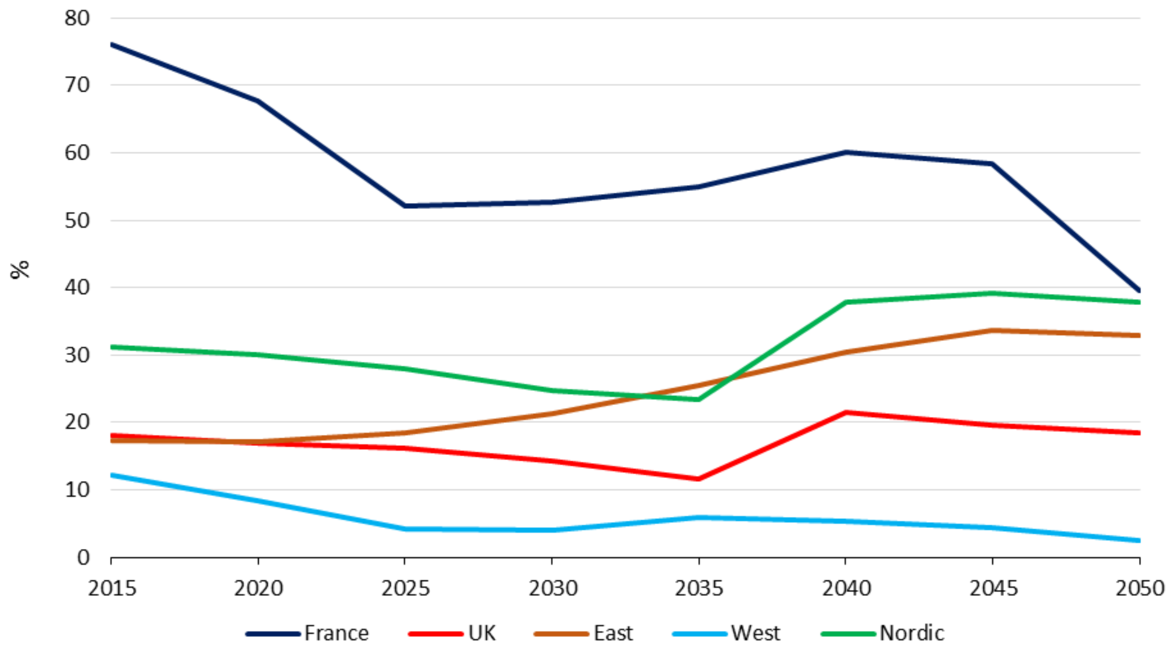


Figure 16.Share of nuclear power generation in total gross supply of electricity in Option A



4. Discussion and concluding remarks

This "*Nuclear Energy Generation Sensitivity Analysis*" presents the results of a quantitative modelling exercise on different pathways of the European power system in a policy context that aims at the deep decarbonisation of the European economy in the long-term. Emphasis was given to the technical and economic challenges Europe will face as a significant part of its nuclear fleet is aging and decision of long term operations (LTOs) need to be taken. The analysis draws conclusions from the elaboration of a total of five scenarios that have been constructed using the PRIMES energy systems model, an analytical modelling tool that has been used extensively during the past three decades in policy analysis and impact assessments related to the EU energy sector.

The modelling exercise shows that the overall system cost of the EU energy sector decreases with more and larger prolongations of the lifetime of existing nuclear reactors. For instance comparing the option containing the assumptions with the largest part of the fleet entering LTOs (***Option E***), with the one where only a small part of the nuclear reactors enters LTOs (***Option B***), cumulative monetary savings of 88 billion Euros'13 are achieved with the former. The extension of the lifetime of nuclear reactors in ***Option E*** implies lower investments expenditures for power plants in the decade 2031-'40 of around EUR 56 billion cumulatively (compared to ***Option B***), as the refurbished nuclear plants still operating in LTOs reduce the need for investments in new power capacity. This is not still the case in the next decade (2041-'50) as investment expenditures attain maximum levels in case of ***Option E*** (EUR 95 billion additionally on top of the requirements for ***Option B***). This happens as this is the period where most reactors end their LTOs and they need to be finally replaced via building new power capacity. This replacement has taken place in the previous decade in ***Option B***.

As expected, the investments expenditures for the refurbishment of old plants during the projection period (2021-2050) are highest in ***Option E*** due to the higher percentage of nuclear power whose life is extended. The investment costs in this scenario reach EUR 128 billion, whereas in ***Option B*** they are around EUR 76 billion.

Moreover, also for final consumers the expenditures are lower as the average pre-tax electricity price is kept at low levels in the mid-term (EUR 137.8/MWh in 2030 in ***Option E*** in contrast with EUR 139.2/MWh in ***Option A*** and EUR 138.4/MWh in ***Option B***).

As far as GHG emissions are concerned, only a small improvement is noticed in ***Option E*** and ***Option D***. Only a small decrease of 50 Mt CO2-eq is observed in ***Option E*** compared to the ***Option B*** scenario cumulatively during 2021-2050. This is due to the fact that the nuclear capacity not entering LTOs is primarily replaced by low-carbon sources of electricity (variable RES), which become more and more competitive towards the medium term. The 2030 RES target (27%) is overshot in some scenarios for the same reason. Nuclear reactors retiring without the prolongation of their lifetime leave more space for additional investments in RES as the latter become more and more competitive. Towards the end of the projection period, the competiveness of RES allows the decarbonisation target of the EU (-80% GHG emission reductions compared to 1990 levels) to be met by expanding mainly the capacity of RES, therefore, limited new investments in nuclear energy are needed, throughout the scenarios.

Even though nuclear power generation might lose the relative competitive advantage against RES in the medium term, its importance as a carbon-free source of electricity remains. Especially in the long term, the full decarbonisation of the EU power system will require significant growth in electricity demand due to the very high degree of electrification in stationary and mobile applications and potentially the introduction of synthetic fuels as a means abate the remaining GHG emissions. Although the majority of such demand will be covered by RES, if demand increases beyond certain levels, low cost installation sites for RES will be saturated and therefore in economic terms RES and nuclear will continue to be economically competitive options.

The construction of nuclear capacity required human capacity and high level of expertise, which may not be available if nuclear is abandoned in the midterm. Reviving the nuclear industry towards the middle of the century, after a period of hibernation in the medium term, is a task highly questionable regarding its successful outcome.

The sensitivities find that the extension of nuclear power leads to lower economic costs, and provides a lifeline for nuclear industry in case nuclear remains an option for deep decarbonisation. The cumulative difference in total energy system costs in the period 2021-2050 between a scenario with relatively high lifetime extensions (***Option E***) and one with relatively low (***Option B***), is however only EUR 88 billion (or 0.1%). From an emissions point of view in a 2050 perspective the differences are minimal.

Annex A - Operating and extended nuclear capacity (MW) in each Member State for all scenarios

The following table presents the assumptions and results in terms of nuclear power capacity for all EU Member States that currently have, or aim to (re-)launch in the future nuclear programs for power generation. For each country, the following details are given:

- Operating: Refers to the evolution of capacity of existing reactors, without LTOs;
- Extended: Refers to the capacity of reactors operating in LTOs;
- New plants: Evolution of capacity of new greenfield, or brownfield investments;
- Total: Sum of all of the above.

Table 15. Operating and extended nuclear capacity, new investments and total capacity (MW) in the Option A scenario

Country	Capacity	2015	2020	2025	2030	2035	2040	2045	2050
Germany	Operating	12188	8197						
	Extended								
	New plants								
	Total	12188	8197						
Netherlands	Operating								
	Extended	485	485	485	485	485			
	New plants					1117	1117	1117	1117
	Total	485	485	485	485	1602	1117	1117	1117
Belgium	Operating	3907	5921	3907					
	Extended								
	New plants								
	Total	3907	5921	3907					
France	Operating	63247	61480	37929	12570	5992	5992		
	Extended			4485	28931	35509	35509	39669	13870
	New plants		1680	1680	1680	6630	14880	16530	21480
	Total	63247	63160	44094	43181	48131	56381	56199	35350
Spain	Operating	7399	7399	4273					
	Extended			3126	7399	7399	7399	4273	
	New plants					3300	3300	4950	4950
	Total	7399	7399	7399	7399	10699	10699	9223	4950
United Kingdom	Operating	9374	8884	4643	3603	1198			
	Extended						1198	1198	1198
	New plants			3168	3168	4818	11418	11418	11418
	Total	9374	8884	7811	6771	6016	12616	12616	12616
Sweden	Operating	9532	6949	5965					
	Extended			984	6949	6949	5550	1190	
	New plants						5000	10273	11523
	Total	9532	6949	6949	6949	6949	10550	11463	11523
Finland	Operating	2726	2726	1853					

	Extended			874	1747	1747	874		
	New plants		1651	1651	1651	1651	6601	8251	8251
	Total	2726	4378	4378	3398	3398	7475	8251	8251
Czech Republic	Operating	4006	4006	3516	2048	2048	2048	2048	2048
	Extended			490	1958	1958			
	New plants					2400	4800	6000	7200
	Total	4006	4006	4006	4006	6406	6848	8048	9248
Slovakia	Operating	1940	1940	1940	940	940			
	Extended				1000	1000	940	940	940
	New plants		880	880	880	880	3280	3280	3280
	Total	1940	2820	2820	2820	2820	4220	4220	4220
Hungary	Operating	1000							
	Extended	960	1960	1960	1960	1000			
	New plants			1261	2522	2522	3692	3692	3692
	Total	1960	1960	3221	4482	3522	3692	3692	3692
Slovenia	Operating	700	700						
	Extended			700	700	700	700		
	New plants							1117	1117
	Total	700	700	700	700	700	700	1117	1117
Romania	Operating	1414	1414	1414	707	707			
	Extended				707	707	1414	1414	1414
	New plants								
	Total	1414	1414	1414	1414	1414	1414	1414	1414
Bulgaria	Operating	1920							
	Extended		1920	1920	1920	1920	1920	1920	960
	New plants							1200	2400
	Total	1920	1920	1920	1920	1920	1920	3120	3360
Poland	Operating								
	Extended								
	New plants	0	0	0	0	3300	6600	8250	8250
	Total	0	0	0	0	3300	6600	8250	8250
Lithuania	Operating								
	Extended								
	New plants	0	0	0	1117	1117	1117	1117	1117
	Total	0	0	0	1117	1117	1117	1117	1117
EU28	Operating	119353	109617	65441	19868	10885	8040	2048	2048
	Extended	1445	4365	15023	53756	59374	55503	50605	18382
	New plants	0	4211	8640	11018	27735	61805	77195	85795
	Total	120798	118194	89104	84643	97995	125348	129847	106225

Table 16. Operating and extended nuclear capacity, new investments and total capacity (MW) in the Option B scenario

Country	Capacity	2015	2020	2025	2030	2035	2040	2045	2050
Germany	Operating	12188	8197						
	Extended								
	New plants								
	Total	12188	8197						
Netherlands	Operating								
	Extended	485	485	485					
	New plants					1117	1117	1117	1117
	Total	485	485	485	0	1117	1117	1117	1117
Belgium	Operating	3907	5921	3907					
	Extended								
	New plants								
	Total	3907	5921	3907					
France	Operating	63247	61480	37929	12570	5992	5992		
	Extended			9988	34433	35509	23623	27783	13870
	New plants		1680	1680	1680	6630	14880	16530	21480
	Total	63247	63160	49596	48684	48131	44495	44313	35350
Spain	Operating	7399	7399	4273					
	Extended			3126	7399	5306	2060	1027	
	New plants					3300	4950	4950	4950
	Total	7399	7399	7399	7399	8606	7010	5977	4950
United Kingdom	Operating	9374	8884	4643	3603	1198			
	Extended						1198	1198	1198
	New plants			3168	3168	4818	11418	11418	11418
	Total	9374	8884	7811	6771	6016	12616	12616	12616
Sweden	Operating	9532	6949	5965	273	273	273		
	Extended			984	6677	6677	5277	1190	
	New plants						5000	10273	11523
	Total	9532	6949	6949	6949	6949	10550	11463	11523
Finland	Operating	2726	2726	1853					
	Extended			874	1747	1747	874		
	New plants		1651	1651	1651	1651	6601	8251	8251
	Total	2726	4378	4378	3398	3398	7475	8251	8251
Czech Republic	Operating	4006	4006	3516	2048	2048	2048	2048	2048
	Extended			490	1958	1958			
	New plants					2400	4800	6000	7200
	Total	4006	4006	4006	4006	6406	6848	8048	9248
Slovakia	Operating	1940	1940	1940	940	940			
	Extended				1000	1000	940	940	940
	New plants		880	880	880	880	3280	3280	3280
	Total	1940	2820	2820	2820	2820	4220	4220	4220
Hungary	Operating	1000							

	Extended	960	1960	1960	1960	1000			
	New plants			1261	2522	2522	3692	3692	3692
	Total	1960	1960	3221	4482	3522	3692	3692	3692
Slovenia	Operating	700	700						
	Extended			700	700	700	700		
	New plants							1117	1117
	Total	700	700	700	700	700	700	1117	1117
Romania	Operating	1414	1414	1414	707	707			
	Extended				707	707	1414	1414	1414
	New plants								
	Total	1414	1414	1414	1414	1414	1414	1414	1414
Bulgaria	Operating	1920							
	Extended		1920	1920	1920	1920	1920	1920	960
	New plants							1200	2400
	Total	1920	1920	1920	1920	1920	1920	3120	3360
Poland	Operating								
	Extended								
	New plants	0	0	0	0	3300	6600	8250	8250
	Total	0	0	0	0	3300	6600	8250	8250
Lithuania	Operating								
	Extended								
	New plants	0	0	0	1117	1117	1117	1117	1117
	Total	0	0	0	1117	1117	1117	1117	1117
EU28	Operating	119353	109617	65441	20141	11158	8313	2048	2048
	Extended	1445	4365	20526	58502	56524	38005	35473	18382
	New plants	0	4211	8640	11018	27735	63455	77195	85795
	Total	120798	118194	94606	89660	95417	109773	114715	106225

Table 17.Operating and extended nuclear capacity, new investments and total capacity (MW) in the Option C scenario

Country	Capacity	2015	2020	2025	2030	2035	2040	2045	2050
Germany	Operating	12188	8197						
	Extended								
	New plants								
	Total	12188	8197						
Netherlands	Operating								
	Extended	485	485	485	485	485			
	New plants					1117	1117	2234	2234
	Total	485	485	485	485	1602	1117	2234	2234
Belgium	Operating	3907	5921	3907					
	Extended								
	New plants								
	Total	3907	5921	3907					
France	Operating	63247	61480	37929	12570	5992	5992		
	Extended		1766	25318	48910	36421	34596	38756	13870
	New plants		1680	1680	1680	6630	14880	16530	21480
	Total	63247	64927	64927	63160	49044	55468	55286	35350
Spain	Operating	7399	7399	4273					
	Extended			3126	7399	7399	7399	4273	
	New plants					3300	3300	4950	4950
	Total	7399	7399	7399	7399	10699	10699	9223	4950
United Kingdom	Operating	9374	8884	4643	3603	1198			
	Extended			2335	3375	3445	3603	1198	1198
	New plants			3168	3168	4818	11418	14718	14718
	Total	9374	8884	10146	10146	9461	15021	15916	15916
Sweden	Operating	9531	6949	5965	273	273	273		
	Extended			984	6677	6677	5277	1190	
	New plants						5000	10273	11523
	Total	9532	6949	6949	6949	6949	10550	11463	11523
Finland	Operating	2726	2726	1853					
	Extended			874	1747	1747	874		
	New plants		1651	1651	1651	1651	6601	8251	8251
	Total	2726	4378	4378	3398	3398	7475	8251	8251
Czech Republic	Operating	4006	4006	3516	2048	2048	2048	2048	2048
	Extended			490	1958	1958			
	New plants					2400	4800	6000	7200
	Total	4006	4006	4006	4006	6406	6848	8048	9248
Slovakia	Operating	1940	1940	1940	940	940			
	Extended				1000	1000	940	940	940
	New plants		880	880	880	880	3280	3280	3280
	Total	1940	2820	2820	2820	2820	4220	4220	4220
Hungary	Operating	1000							

	Extended	960	1960	1960	1960	1000			
	New plants			1261	2522	2522	3692	3692	3692
	Total	1960	1960	3221	4482	3522	3692	3692	3692
Slovenia	Operating	700	700						
	Extended			700	700	700	700		
	New plants							1117	1117
	Total	700	700	700	700	700	700	1117	1117
Romania	Operating	1414	1414	1414	707	707			
	Extended				707	707	1414	1414	1414
	New plants								
	Total	1414	1414	1414	1414	1414	1414	1414	1414
Bulgaria	Operating	1920							
	Extended		1920	1920	1920	1920	1920	1920	960
	New plants							1200	2400
	Total	1920	1920	1920	1920	1920	1920	3120	3360
Poland	Operating								
	Extended								
	New plants	0	0	0	0	3300	6600	8250	8250
	Total	0	0	0	0	3300	6600	8250	8250
Lithuania	Operating								
	Extended								
	New plants	0	0	0	1117	1117	1117	1117	1117
	Total	0	0	0	1117	1117	1117	1117	1117
EU28	Operating	119353	109617	65441	20141	11158	8313	2048	2048
	Extended	1445	6131	38191	76838	63460	56722	49691	18382
	New plants	0	4211	8640	11018	27735	61805	81612	90212
	Total	120798	119960	112272	107997	102352	126840	133351	110642

Table 18.Operating and extended nuclear capacity, new investments and total capacity (MW) in the Option D scenario

Country	Capacity	2015	2020	2025	2030	2035	2040	2045	2050
Germany	Operating	12188	8197						
	Extended								
	New plants								
	Total	12188	8197						
Netherlands	Operating								
	Extended	485	485	485	485	485			
	New plants					1117	1117	2234	2234
	Total	485	485	485	485	1602	1117	2234	2234
Belgium	Operating	3907	5921	3907					
	Extended								
	New plants								
	Total	3907	5921	3907					
France	Operating	63247	61480	37929	12570	5992	5992		
	Extended		1766	25318	48910	43746	43746	40582	13870
	New plants		1680	1680	1680	6630	13230	16530	21480
	Total	63247	64927	64927	63160	56369	62969	57112	35350
Spain	Operating	7399	7399	4273					
	Extended			3126	7399	7399	7399	4273	
	New plants					3300	3300	4950	4950
	Total	7399	7399	7399	7399	10699	10699	9223	4950
United Kingdom	Operating	9374	8884	4643	3603	1198			
	Extended			2335	3375	3445	3603	3603	3603
	New plants			3168	3168	4818	11418	11418	11418
	Total	9374	8884	10146	10146	9461	15021	15021	15021
Sweden	Operating	9532	6949	5965	273	273	273		
	Extended			984	6677	6677	6677	2590	
	New plants						3750	9023	10273
	Total	9532	6949	6949	6949	6949	10699	11612	10273
Finland	Operating	2726	2726	1853					
	Extended			874	2237	2237	874		
	New plants		1651	1651	1651	1651	6601	8251	8251
	Total	2726	4378	4378	3888	3888	7475	8251	8251
Czech Republic	Operating	4006	4006	3516	2048	2048	2048	2048	2048
	Extended			490	1958	1958	963	963	
	New plants					2400	4800	6000	7200
	Total	4006	4006	4006	4006	6406	7810	9010	9248
Slovakia	Operating	1940	1940	1940	940	940			
	Extended				1000	1000	940	940	940
	New plants		880	880	880	880	3280	3280	3280
	Total	1940	2820	2820	2820	2820	4220	4220	4220
Hungary	Operating	1000							

	Extended	960	1960	1960	1960	1000	1000	1000	
	New plants			1261	2522	2522	3692	3692	3692
	Total	1960	1960	3221	4482	3522	4692	4692	3692
Slovenia	Operating	700	700						
	Extended			700	700	700	700		
	New plants							1117	1117
	Total	700	700	700	700	700	700	1117	1117
Romania	Operating	1414	1414	1414	707	707			
	Extended				707	707	1414	1414	1414
	New plants								
	Total	1414	1414	1414	1414	1414	1414	1414	1414
Bulgaria	Operating	1920							
	Extended		1920	1920	1920	1920	1920	1920	960
	New plants							1200	2400
	Total	1920	1920	1920	1920	1920	1920	3120	3360
Poland	Operating								
	Extended								
	New plants					3300	6600	8250	8250
	Total					3300	6600	8250	8250
Lithuania	Operating								
	Extended								
	New plants				1117	1117	1117	1117	1117
	Total				1117	1117	1117	1117	1117
EU28	Operating	119353	109617	65441	20141	11158	8313	2048	2048
	Extended	1445	6131	38191	77328	71274	69235	57285	20787
	New plants		4211	8640	11018	27735	58905	77062	85662
	Total	120798	119960	112272	108487	110167	136453	136394	108497

Table 19.Operating and extended nuclear capacity, new investments and total capacity (MW) in the Option E scenario

Country	Capacity	2015	2020	2025	2030	2035	2040	2045	2050
Germany	Operating	12188	8197						
	Extended								
	New plants								
	Total	12188	8197						
Netherlands	Operating								
	Extended	485	485	485	485	485			
	New plants					1117	1117	2234	2234
	Total	485	485	485	485	1602	1117	2234	2234
Belgium	Operating	3907	5921	3907					
	Extended								
	New plants								
	Total	3907	5921	3907					
France	Operating	63247	61480	37929	12570	5992	5992		
	Extended		1766	25318	48910	50981	50981	40582	13870
	New plants		1680	1680	1680	4980	8280	16530	21480
	Total	63247	64927	64927	63160	61953	65253	57112	35350
Spain	Operating	7399	7399	4273					
	Extended			3126	7399	7399	7399	4273	
	New plants					3300	3300	4950	4950
	Total	7399	7399	7399	7399	10699	10699	9223	4950
United Kingdom	Operating	9374	8884	4643	3603	1198			
	Extended			4241	5281	3445	4643	4643	3603
	New plants			3168	3168	4818	11418	11418	13068
	Total	9374	8884	12052	12052	9461	16061	16061	16671
Sweden	Operating	9532	6949	5965	273	273	273		
	Extended			984	6677	6677	6677	2590	
	New plants						3750	9023	10273
	Total	9532	6949	6949	6949	6949	10699	11612	10273
Finland	Operating	2726	2726	1853					
	Extended			874	2726	2726	874		
	New plants		1651	1651	1651	1651	6601	8251	8251
	Total	2726	4378	4378	4378	4378	7475	8251	8251
Czech Republic	Operating	4006	4006	3516	2048	2048	2048	2048	2048
	Extended			490	1958	1958	1958	1958	
	New plants					2400	3600	4800	7200
	Total	4006	4006	4006	4006	6406	7606	8806	9248
Slovakia	Operating	1940	1940	1940	940	940			
	Extended				1000	1000	1940	1940	940
	New plants		880	880	880	880	3280	3280	4480
	Total	1940	2820	2820	2820	2820	5220	5220	5420
Hungary	Operating	1000							

	Extended	960	1960	1960	1960	1960	1960	1000	
	New plants	0	0	1261	2522	2522	3472	3472	4642
	Total	1960	1960	3221	4482	4482	5432	4472	4642
Slovenia	Operating	700	700						
	Extended			700	700	700	700		
	New plants							1117	1117
	Total	700	700	700	700	700	700	1117	1117
Romania	Operating	1414	1414	1414	707	707			
	Extended				707	707	1414	1414	1414
	New plants								
	Total	1414	1414	1414	1414	1414	1414	1414	1414
Bulgaria	Operating	1920							
	Extended		1920	1920	1920	1920	1920	1920	960
	New plants							1200	2400
	Total	1920	1920	1920	1920	1920	1920	3120	3360
Poland	Operating								
	Extended								
	New plants					3300	6600	8250	8250
	Total					3300	6600	8250	8250
Lithuania	Operating								
	Extended								
	New plants				1117	1117	1117	1117	1117
	Total				1117	1117	1117	1117	1117
EU28	Operating	119353	109617	65441	20141	11158	8313	2048	2048
	Extended	1445	6131	40097	79723	79958	80465	60320	20787
	New plants		4211	8640	11018	26085	52535	75642	89462
	Total	120798	119960	114178	110882	117201	141313	138010	112297