Road to EU Climate Neutrality by 2050

Spatial Requirements of Wind/Solar and Nuclear Energy and Their Respective Costs

A Peer-Reviewed Publication for ECR Group and Renew Europe, European Parliament, Brussels, Belgium

Katinka M. Brouwer, LL.M., dr. Lucas Bergkamp (editor)

Brussels, January 2021

Road to EU Climate Neutrality by 2050

Spatial Requirements of Wind/Solar and Nuclear Energy and Their Respective Costs

A Peer-Reviewed Publication for ECR Group and Renew Europe, European Parliament, Brussels, Belgium

Katinka M. Brouwer, LL.M., dr. Lucas Bergkamp (editor)

Brussels, January 2021

This publication has been prepared for ECR Group and Renew Europe.

- The ECR Group: “If the EU and its global partners really want to tackle issues such as climate change, recycling, waste, emissions and pollution, food quality and food security, then the EU needs to adopt sensible and sustainable measures which do not place unnecessary and costly burdens on businesses and Member States. Rather than unrealistic targets which will never be fulfilled or properly implemented, the ECR Group supports an ambitious, incremental, and sensible approach that all Member States can support.” For further information, see https://ecrgroup.eu/

- Renew Europe: “We will invest in a sustainable continent. We do not have a Planet B, so we must make sure that we preserve the one we have for future generations. The Paris climate agreement of 2015 set out the roadmap, now it is time to deliver on the promises made and even go beyond them.” For further information, see https://reneweuropegroup.eu/en/

Table of Contents (Abbreviated)

Table of Contents

Foreword

The EU has endorsed the ambitious objective of achieving climate neutrality (i.e. net zero greenhouse gas carbon emissions) by 2050. An energy transition is necessary to achieve this objective. This report presents the results of a study that examines three issues that are key to the EU climate neutrality's ambition:

i. The effect of EU climate neutrality on the average global atmospheric temperature by 2050 and 2100;
ii. The spatial (land and sea) requirements for wind and solar energy versus nuclear energy in the Czech Republic and The Netherlands; and
iii. The cost of wind/solar energy and of nuclear energy for these two countries.

Summaries

Following this foreword, we have included two summaries, a brief Executive Summary, and a much longer Extensive Summary. While the Executive Summary gives the reader our answers to the main questions posed in this study, the illustrated Extensive Summary follows each main step in our analysis, so that the reader can discern the structure of our reasoning.

These summaries have been written in plain English, so that they are accessible to policy makers and interested citizens alike. The report itself uses also technical terms and abbreviations – a glossary and list of abbreviations have been added as annexes to this report to assist the reader.

Authors and Contributors

The authors of this study have been assisted by an interdisciplinary team of experts with academic qualifications and professional experience in a number of disciplines, including energy economics, modelling, engineering, business administration, natural sciences, climate science, and law and policy-making. Each of the key chapters has been reviewed by at least two peer reviewers with relevant academic qualifications and professional backgrounds. A list of these peer reviewers is attached to this report as Annex XIV.

Through a collaborative effort, the team has succeeded in bringing their extensive expertise to bear on the issues discussed in this report. The authors hope that this report will be judged on its merits, as they believe that it should play a key role in policy-making in connection with the EU's 2050 climate neutrality program. All professionals that have contributed to the completion of this report champion the cause of evidence-based energy- and climate policy-making. The authors are thankful to all of them for their indispensable contributions, scrutiny, comments, feedback, criticism, and guidance.

Evidence-Based Analysis: "Do the Numbers"

The EU is committed to evidence-based policy-making, also in the areas of energy and climate policies.[1] In this spirit, Commissioner Frans Timmermans has repeatedly emphasized that facts, science, and evidence-based analysis should inform policy-making, and encouraged interested parties to "do the numbers"[2] on nuclear energy.

The authors share Commissioner Timmermans 's views on the role of evidence in policy making. The research and analysis conducted in connection with this study have therefore been based on 'state-of-the-art' professional standards, academic literature, prior analyses, such as those conducted for the Dutch government and electricity network operators, and other relevant, reliable information. References to sources are provided throughout this report.

Of course, it would have been preferable had the European Commission itself done a comprehensive cost/benefit analysis of alternative policy options available to pursue the EU's climate neutrality objective. The fact that no such analysis has been conducted, despite the European Commission's '*Better Regulation,*' highlights the strong political forces and sense of urgency behind EU climate policy-making.[3]

This is not to say that the European Commission has not conducted any analysis relevant to the issues discussed in this report; it most definitely has. While Commissioner Timmermans appears to be focused very much on perceived disadvantages of nuclear energy, a 2016 Commission report succinctly sums up its advantages:

"Nuclear energy is a source of low-carbon electricity. The International Energy Agency (IEA) estimated for example that limiting temperature rise below 2 °C would require a sustained reduction in global energy CO_2 emissions (measured as energy-related CO_2/GDP), averaging 5.5 % per year between 2030 and 2050. A reduction of this magnitude is ambitious, but has already been achieved in the past in Member States such as France and Sweden thanks to the development of nuclear build programmes.

1 European Commission, Evidence-based policy making in the European Commission, available at https://ec.europa.eu/jrc/en/publication/evidence-based-policy-making-european-commission

2 "Timmermans acknowledged the benefits nuclear power can bring in the transition to a zero-carbon economy but pointed to "serious disadvantages," such as uranium imports and treatment of radioactive waste. "The second disadvantage I need to mention is that it's very expensive," Timmermans said. "It's very, very expensive." … "Do the numbers and then draw your own conclusions, that's my only plea," he said." Frédéric Simon, Brussels 'won't stand in the way' of new nuclear plants, says EU climate chief, EURACTIV, 26 okt. 2020 (updated: 27 okt. 2020), available at https://www.euractiv.com/section/energy/news/brussels-wont-stand-in-the-way-of-new-nuclear-plants-says-eu-climate-chief/ Cf. Interview with Frans Timmermans on the EU Green Deal, New Mobility News, 3 Feb 2020, available at https://newmobility.news/2020/02/03/interview-frans-timmermans-on-the-eu-green-deal/

3 European Commission, Better regulation: why and how, available at https://ec.europa.eu/info/law/law-making-process/planning-and-proposing-law/better-regulation-why-and-how_en

Nuclear energy also contributes to improving the dimension of energy security (i.e. to ensure that energy, including electricity, is available to all when needed), since:

a. fuel and operating costs are relatively low and stable;

b. it can generate electricity continuously for extended periods; and

c. it can make a positive contribution to the stable functioning of electricity systems (e.g. maintaining grid frequency).

Finally, nuclear can play an important role in reducing the dependence on fossil fuel energy imports in Europe."[4]

Since this data is from before 2016, Commissioner Timmermans may be right, and the cost of nuclear energy may be higher than the cost of other electricity-generating technologies. With this study, we intend to find out.

Holistic, Constructive and Innovative Approach

Analysis for purposes of policy-making is typically limited to specific aspects relevant to a policy issue. Such specialized analysis often is useful to address an issue in depth from the perspective of a particular discipline, be it economics, energy transition science, climate science, political science, or law. At the level of policy-making, however, all such disciplines have to be integrated into a holistic whole. Unfortunately, there is a lack of integrated, holistic analysis useful to policy makers; specifically, the Summaries for Policy Makers (SPMs) prepared by the IPCC do not provide it, and are silent on such critical issues as spatial requirements and costs of power generation technologies. The issues addressed in this report lend themselves very well to an integrated assessment, which is what the authors have aimed to provide.

Further, analysis and advice for policy makers is often colored by a selective or subjective perspective on the relevant issues. Further, much analysis and tools for policy makers incorporate value or normative judgments that remain hidden in the technical details. As discussed in this report, the analyses done for the Dutch government are examples. This applies also to tools, such as the *Energy Transition Model* (ETM).[5] By generating nuclear variants on the scenarios for the Dutch government in the ETM, however, this study demonstrates that even in a model that is not designed to treat nuclear on equal footing with renewable energy, nuclear energy is not necessarily inferior to wind and solar.

The authors of this report have attempted to clarify the key issues for policy makers, without making subjective or value judgments or at least making any such judgments explicit. Many issues arose that required thinking 'outside the box.'

4 European Commission, STAFF WORKING DOCUMENT Accompanying the Communication from the Commission: Nuclear Illustrative Programme presented under Article 40 of the Euratom Treaty for the opinion of the European Economic and Social Committee, Brussels, 4.4.2016, SWD(2016) 102 final, available at https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_autre_document_travail_service_part1_v10.pdf

5 Energy Transition Model, available at https://energytransitionmodel.com/

For instance, the team identified the limitations of the so-called 'levelized cost of electricity' methodology as applied to nuclear and renewable energy for purposes of policy-making. In addition, it has unraveled the complexities around the market-based weighted cost of capital or 'WACC.' The WACC, as typically used in energy studies, reflects government-related risk in addition to commercial risk. For purposes of this study, the team developed a method to extract the government-related portion to arrive at a realistic WACCs reflective of only commercial risk. Team members have also pioneered a novel way to avoid the common, but controversial, practice of discounting the electricity output of alternative generation technologies for purposes of policy advice. This 'synchronized lifetime analysis' is described further in this report; the authors believe that it may become the standard for comparing electricity-generating technologies.

To Conclude for Now

As this study demonstrates, the argument that "nuclear energy is extremely expensive," which Commissioner Timmermans has entertained, requires qualification. Likewise, his concerns about uranium imports and nuclear waste management need to be weighed against not only the advantages of nuclear energy, but also the disadvantages of renewable energy.

In light of the spatial and economic consequences of renewable energy relative to nuclear energy, the EU is well advised to consider a "*Nuclear Renaissance*" program. Under this program, the EU would create a level playing field for all electricity generation technologies.

The authors hope that this study will be widely distributed and read. The people of Europe deserve it and the energy transition needs it.

Brussels, December 2020

Executive Summary

The EU is committed to achieving **climate neutrality** (i.e. net zero greenhouse gas emissions) by 2050. Electrification of the energy system is a key component of this strategy. This implies that the electricity (or power) system must be completely 'decarbonized' over the next three decades.

This study analyses and compares **two climate-neutral power-generating technologies** that can result in decarbonization of the electricity system[6] -- **wind/ solar** and **nuclear**. We assess the amount of **space** necessary for each technology to deliver the power required, and the **costs** of the power thus generated. This analysis has been done for two EU member states: **The Netherlands**, a country along the North Sea with abundant wind, and the **Czech Republic**, a landlocked country with no access to sea and less wind. This study also assesses the **effectiveness of EU climate neutrality**.

Space demand

We found that amount of space required to provide annually 3000 PJ of power in The Netherlands by wind and solar power[7] in 2050 would range from 24,538 to 68,482 km². To put this in perspective:

- 24,538 km² is roughly the size of the **five largest provinces** of The Netherlands combined (Friesland, Gelderland, Noord-Brabant, Noord-Holland, and Overijssel); and
- 68,482 km² corresponds to about **1.8 times the entire land territory** of The Netherlands.

To generate the same amount of energy, **nuclear power** would require, on average, no more than 120 km², which is **less than half the size of the city of Rotterdam**. Thus, due to their low power density, **wind energy requires at least 266 (offshore) to 534 (onshore) times more land and space than nuclear** to generate an equal amount of electricity; for solar on land, at least **148 times more land** is required (disregarding, in all cases, the additional land required for the necessary network expansion and energy storage or conversion solutions).

For the Czech Republic, the amount of space required to generate 1,800 PJ by **wind and solar**[8] would range from 14,630 km² to 43,758 km². To put that into perspective, that covers **19 % and 55 % of the Czech Republic's available land**. Achieving the same level of electricity output with nuclear power would require no more than **269km²**.

6 These technologies only result in decarbonization if fossil fuel power generation infrastructure is effectively replaced and decommissioned in parallel.

7 Based on 1/3 of each of onshore wind, offshore wind, and solar on land, and 100 % electrification.

8 Based on ½ onshore wind and ½ solar on land with 100 % electrification.

> **//** While nuclear requires a tiny bit of land to provide a whole lot of power at a low cost, wind and solar require a whole lot of land to provide a tiny bit of power at a high cost. **//** **From: 'Road to EU Climate Neutrality'**

Costs

The **cost of nuclear is generally lower** than the cost of wind/solar, in most scenarios by a significant margin. In the best-case scenario for wind/solar, the cost of nuclear is still slightly lower. In the worst-case scenario for wind/solar, **nuclear cost only one fourth as much as wind/solar, i.e. wind/solar cost four times as much**. For an average Czech household,[9] this means an annual electricity bill of that is at least €50 more expensive for wind/solar compared to nuclear; for the Dutch,[10] it implies an **annual electricity bill that is at least €165 more expensive for wind/solar compared to nuclear**. In reality, the **cost of wind/solar is even higher** because these technologies require other expenses to bring the power where it is needed and to maintain the integrity of the electricity system (so-called integration- and system-related costs).

Based on ETM modelling for The Netherlands, we found **additional integration cost for wind/solar at levels of up to 18 %**, further deteriorating the economic case for wind/solar.

Effectiveness of EU Climate Neutrality

EU 2050 climate neutrality, if achieved, will likely cause only a very small decrease in the global average atmospheric temperature increase. Relative to current policies, **2050 EU carbon neutrality will add no more than between 0.02 and 0.06 °C average temperature reduction in 2050** and between 0.05 and 0.15 °C in 2100, **if no carbon leakage occurs**, which the EU cannot prevent. For the EU to achieve carbon neutrality in 2050, it must begin now deploying **renewable energy at a rate at least 4 – 7 times higher than the average rate** over the last 12 years. Even if the EU can do so

> **//** EU climate neutrality is an ideal that may never become reality in our interdependent world. The reality is that the EU cannot limit emissions in the whole world, and that the proposed solution, renewable energy, is an ideal with serious side effects. **//** **From: 'Road to EU Climate Neutrality'**

9 Based on average per capita electricity usage of 5,800 kWh per annum, or 32,200 kWh per household.

10 Based on household of 4, https://www.engie-energie.nl/energieadvies/gemiddeld-energieverbruik.

> **//** The EU needs a realistic 'no regrets' solution to the climate problem. The nuclear solution is as climate-effective as the renewable solution, but is much less space-demanding, significantly cheaper, and has fewer, lesser side effects. **//** **From: 'Road to EU Climate Neutrality'**

over three decades, there still is a very high likelihood that other countries will not limit their emissions, thus frustrating the EU's efforts.

To exclude this unfortunate outcome, the EU would have to curb also carbon emissions from outside EU territory. A relatively certain way for the EU to prevent carbon dioxide emissions in the rest of the world would be acquiring the current estimated reserves of fossil fuels.[11] Such a purchasing program would impose a **minimum cost of €560,000.00 per household, or a total expense of €109,200,000,000,000**, which is approximately 7 times the entire EU's annual GDP and thus would be **prohibitively expensive**. This number not only gives us an idea of the economic value of fossil fuels, but also shows that a sure way to prevent the EU's climate neutrality efforts from being futile, is unrealistic. Put differently, the enormous cost of buying up all fossil fuels casts **doubt over the practicality of EU climate neutrality policy**.

'No regrets' solutions

The ineffectiveness of the EU climate neutrality program gives policy makers a good reason to consider space- and cost-effective '***no regrets***' **solutions**, such as nuclear power. Nuclear power can also play a role in the evolving **hydrogen technology**, which is another part of the EU's climate neutrality strategy. At the same time, an **unambiguous choice for the nuclear** power option would meet the EU policy objectives of ***energy security, affordability***, and ***social acceptability***.[12] EU energy policy-making, however, should also consider impacts of various power generation technologies on other EU policies and interests, such as **environmental and health policies**. In many areas, nuclear energy would appear to perform well relative to renewable energy.

Policy Recommendations

Thus, to realize its climate neutrality ambition, the EU needs to end the unjustified discrimination of power generation technologies and create a technology-neutral[13] level playing field for decarbonized power generation technologies. To this end, the EU can adopt a '**Nuclear Renaissance**' program that places nuclear energy on equal footing with renewable energy. The study report provides **12 policy recommendations** for such a program.

---

11 Adverse substitution effects may occur, if, instead of fossil fuels, wood and other biomass are combusted for energy. If this results in deforestation, carbon dioxide will be added to the atmosphere, but not subsequently removed.

12 Social acceptability of nuclear energy is an issue, as is social acceptability of renewable energy. As discussed in this report, while nuclear energy's social acceptability appears to be growing, that of renewable energy appears to be on the decline.

13 As discussed in this report, current EU climate policy is not technology-neutral, because it favors renewable energy. There is nothing inherent to climate policy, however, that requires any such technology bias; policy could merely stipulate performance requirements.

Extensive Summary

The EU is committed to achieving climate neutrality (i.e. net zero greenhouse gas emissions) by 2050. Electrification of the energy system is a key component of this strategy. This implies that the electricity (or power) system must be completely 'decarbonized' over the next three decades.

This study assesses the effectiveness of EU climate neutrality, and analyses and compares two climate-neutral power-generating technologies that, if they effectively replace fossil fuel infrastructure, can result in decarbonization of the electricity system -- wind/solar and nuclear. We determine the amount of space necessary for each technology to deliver the power required, and the costs of the power thus generated. This analysis has been done for two EU member states: The Netherlands, a country along the North Sea with abundant wind, and the Czech Republic, a landlocked country with no access to sea and less suitable land.

Key Takeaways

The EU's 2050 climate neutrality strategy involves a high risk of ineffectiveness. The anticipated energy transition, however, can hedge against this risk by deploying 'no regrets' solutions that are resistant to climate-related ineffectiveness. Nuclear power is such a solution.

In addition, with respect to both spatial requirements (area of land required) and costs of electricity, nuclear power offers substantial advantages over renewable power (any combination of wind and solar). The cost advantage of nuclear power increases once system costs are added to the equation, and increases further with higher penetration rates of wind and solar.

These advantages have been recognized in the Czech Republic, but not (yet) by policy makers at the EU level and in The Netherlands.

Part I. Effect of EU Climate Neutrality

EU 2050 climate neutrality, if achieved, will likely cause only a very small decrease in the average global atmospheric temperature increase, estimated at between 0.05 °C and 0.15 °C in 2100, and no more than between 0.02 °C and 0.06 °C in 2050, assuming no carbon leakage occurs.

- Even if this can be achieved, this would mean that the average global temperature would still increase by some 3 °C[14] (assuming estimates are accurate).
- Electricity-generating technologies therefore should be evaluated for the degree to which they constitute 'no regrets' solutions.

a. The EU's plan to become the first climate-neutral continent in 2050 is merely aspirational; there is **no proven pathway** that will lead to this result.[15] Much depends on factors that the EU does not control, such as technological breakthroughs, demand for energy, the cost of moving towards climate neutrality, the general state of the economy (GDP), population growth, etc.

b. The **EU's share of global carbon emissions** has been **below 10 % for several years**. In 2050, the EU's share of global emissions will have declined further, due to strong emission growth in the rest of the world, which, in turn, is caused by economic growth in those countries (as mandated by the UN SDGs) and '**outsourcing**' of emissions from developed nations to developing nations.

Study	Temperature reduction due to 2050 EU CN in 2050	Temperature reduction due to 2050 EU CN in 2100
Lomborg (2016) [6] – number derived from author's numbers; for methodology see Annex VII	0.02 °C	0.05 °C
Rogelj (2016) [7] -- number derived from author's numbers; for methodology see Annex VII	0.06 °C	0.15 °C

Table 1.1

14 Note that this estimate is based on an assumption about climate sensitivity that was made at the time the research on which we rely was conducted (i.e. 2016).

15 While this is an issue with respect to many polices adopted by governments, it is a particular troublesome issue in relation to climate policy because of its scale, lack of diversification, extent of central planning, and the many problems caused by it that are ignored.

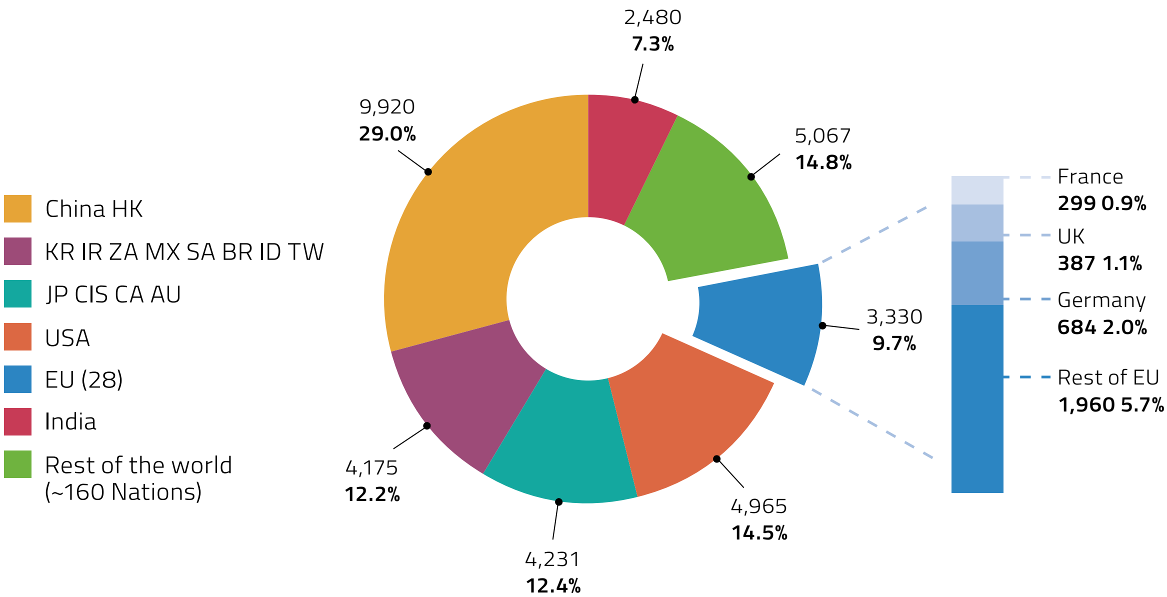


Figure 1.1. Annual CO_2 emissions 2019: in million tonnes - % global output *BP data 2020.*

Annual CO_2 emissions [1]

c. **CO_2 is only one of the greenhouse gases**, although it is the main one at approx. 75 % of the total. The GHGs covered by the EU climate legislation are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulphur hexafluoride (SF_6), nitrogen trifluoride (NF_3), hydrofluorocarbons (HFCs), and perfluorocarbons (PFCs) (Regulation 2018/1999, Annex V, Part 2). The potency, or **global warming potential (GWP), of GHGs differs**, however, and most GHGs have a GWP that (far) exceeds CO_2's GWP, which, by definition, is set at 1. **CO_2 equivalent** of a GHG is used to convert its GWP to that of CO_2 – the amount of CO_2 that causes the same warming as this GHG.

Global greenhouse gas emissions by gas [15]

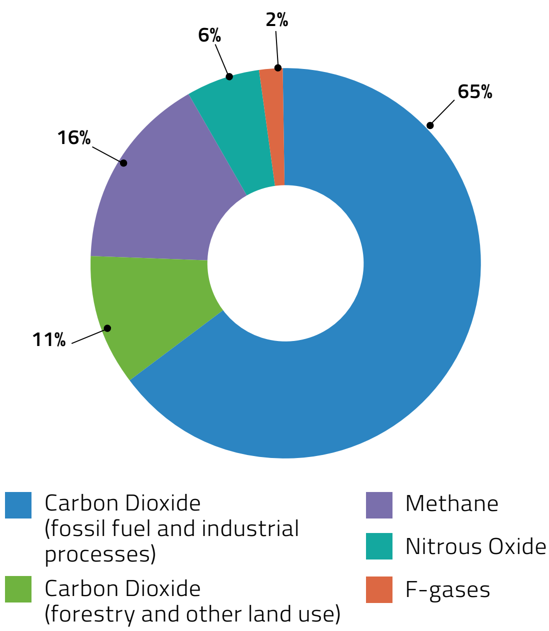


Figure 1.2. Global Greenhouse Gas Emissions by Gas.

Global greenhouse gas emissions by gas and source [14]

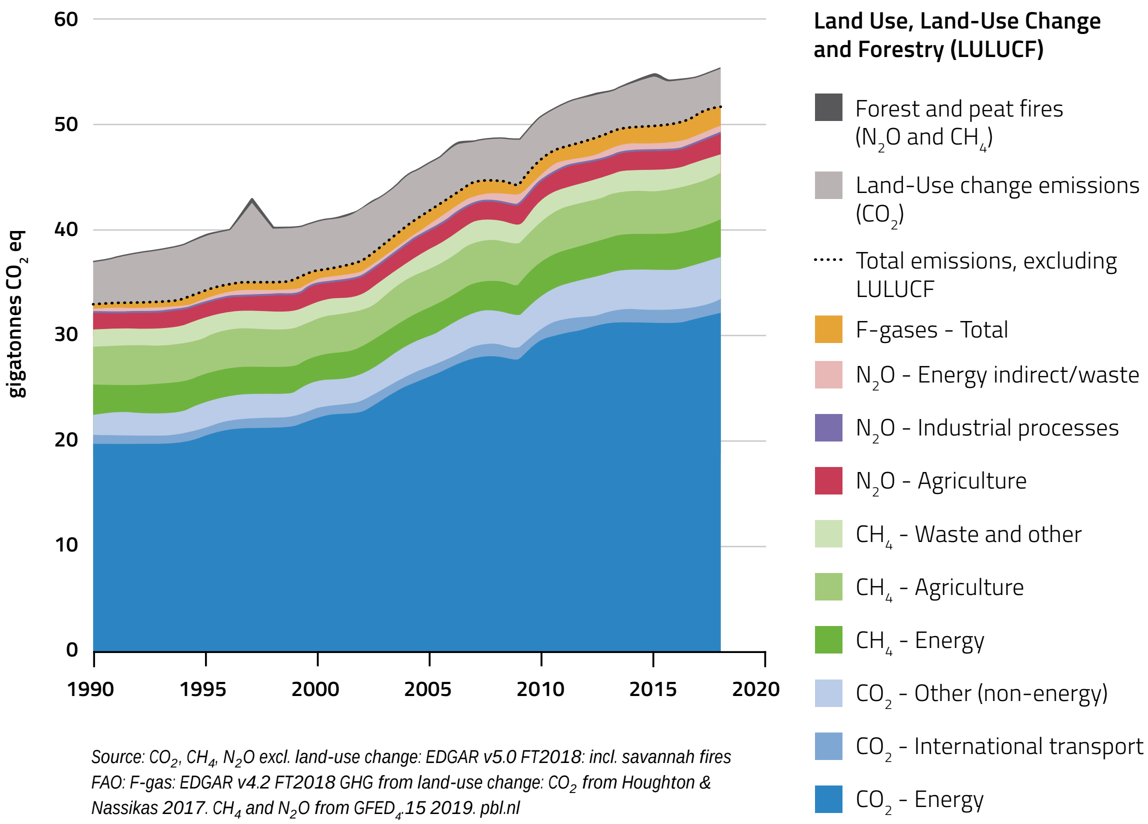
d. Growth in global GHG emissions (excluding those from land use change) in 2018 was the **highest since 2011**, **increasing at a rate of 2.0 %**, reaching 51.8 gigatonnes of CO_2 equivalent (GTCO_2 eq), with the developing world **steadily increasing**. [14]

i. In 2018, the 2.0 % (1.0 GTCO_2 eq) increase in global GHG emissions was mainly due to a **2.0 % increase in global fossil CO_2 emissions** from fossil fuel combustion and those from industrial non-combustion processes including cement production.

ii. Global emissions of **methane (CH_4)** and **nitrous oxide (N_2O)** increased by **1.8 %** and **0.8 %**, respectively. Global emissions of **fluorinated gases (F-gases)** continued to grow by an estimated 6 % in 2018, thereby also contributing to the 2.0 % growth in total GHG emissions.

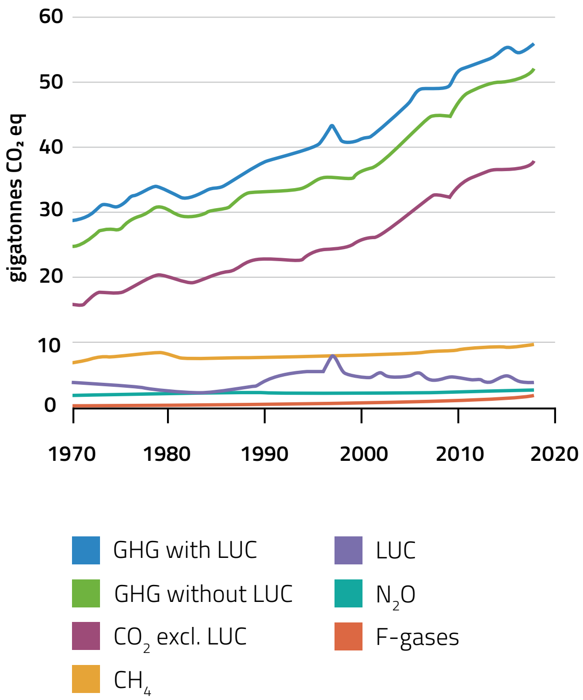
iii. **Global consumption of oil products and natural gas continued to increase, by 1.2 % and 5.3 % in 2018**, led by increased consumption in China, the US, and Russia.

iv. The 2018 increase in global emissions followed **trends in primary energy demand and in the energy mix**. In 2018, energy demand increased by 22 EJ, which was met for 50 % by fossil fuels and 50 % by nuclear and renewable power.



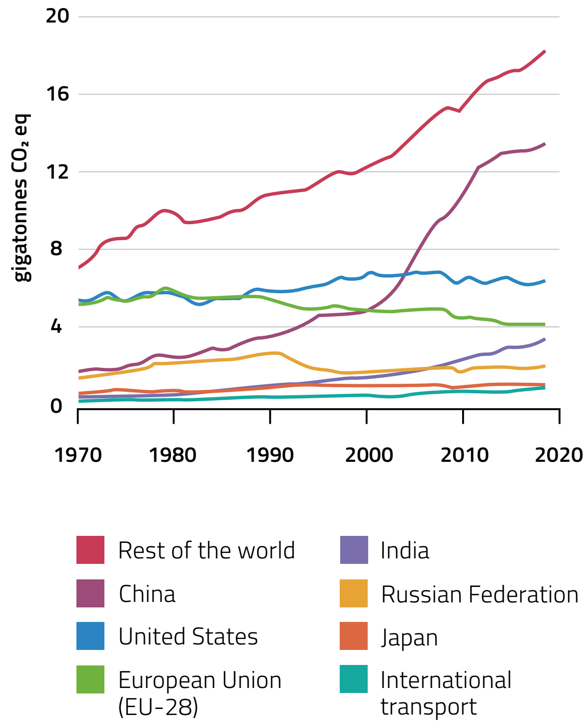
Source: CO_2, CH_4, N_2O excl. land-use change: EDGAR v5.0 FT2018: incl. savannah fires FAO: F-gas: EDGAR v4.2 FT2018 GHG from land-use change: CO_2 from Houghton & Nassikas 2017. CH_4 and N_2O from GFED$_4$.15 2019. pbl.nl

Figure 1.3. Global greenhouse gas emissions, per type of gas and source, including LULUCF.



LUC = Land-use change, GHG = greenhouse gas
Source: GHG excl. LUC EDGAR v5.0 FT2018
LUC: Houghton and Nassikas 2017
pbl.nl

Figure 1.4. Global greenhouse gas emissions: per type of gas.



Source: EDGAR v5.0 FT2018 (without land-use change). pbl.nl
both: F-gas: EDGAR v4.2 FT2018: incl. savanna fires.

Figure 1.5. Global greenhouse gas emissions: top emitting countries and the EU.

Global GHG emissions by type of gas and country [14]

e. In the period 1990-2019, the ***EU has reduced emissions from fossil fuels by about 25 %***. In fact, the EU and Russia are the only industrialized economies that have significantly reduced their fossil CO_2 emissions relative to their 1990 levels. The US and Japan show increased CO_2 emissions since 1990 by 0.8 and 0.4 %, respectively. The ***emerging economies of China and India show strong emission growth*** with 2019 CO_2 emissions levels, respectively, 3.8 and 3.3 times higher than in 1990, due to rapid industrialization and 'outsourcing' effects. Power generation is the largest source of emissions.

Fossil CO_2 emissions from major emitting economies and by sector [13]

f. The '**outsourcing**' effect of European climate policies (also known as '**carbon leakage**') can be demonstrated by accounting for both territorial emissions and the emissions associated with domestic consumption of imports.

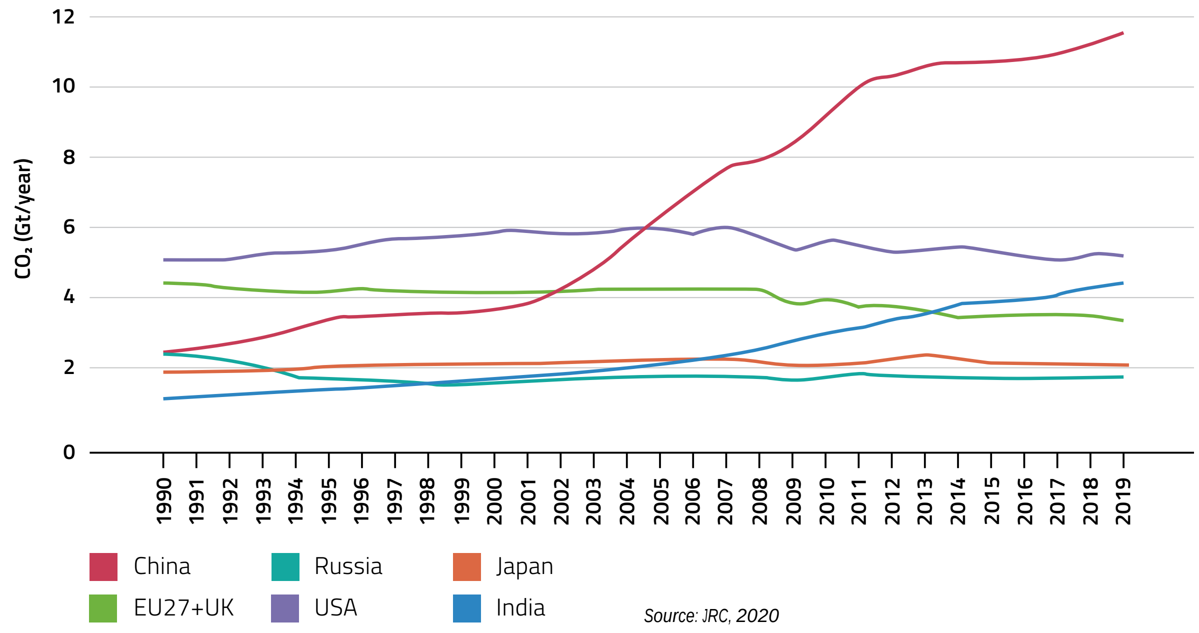
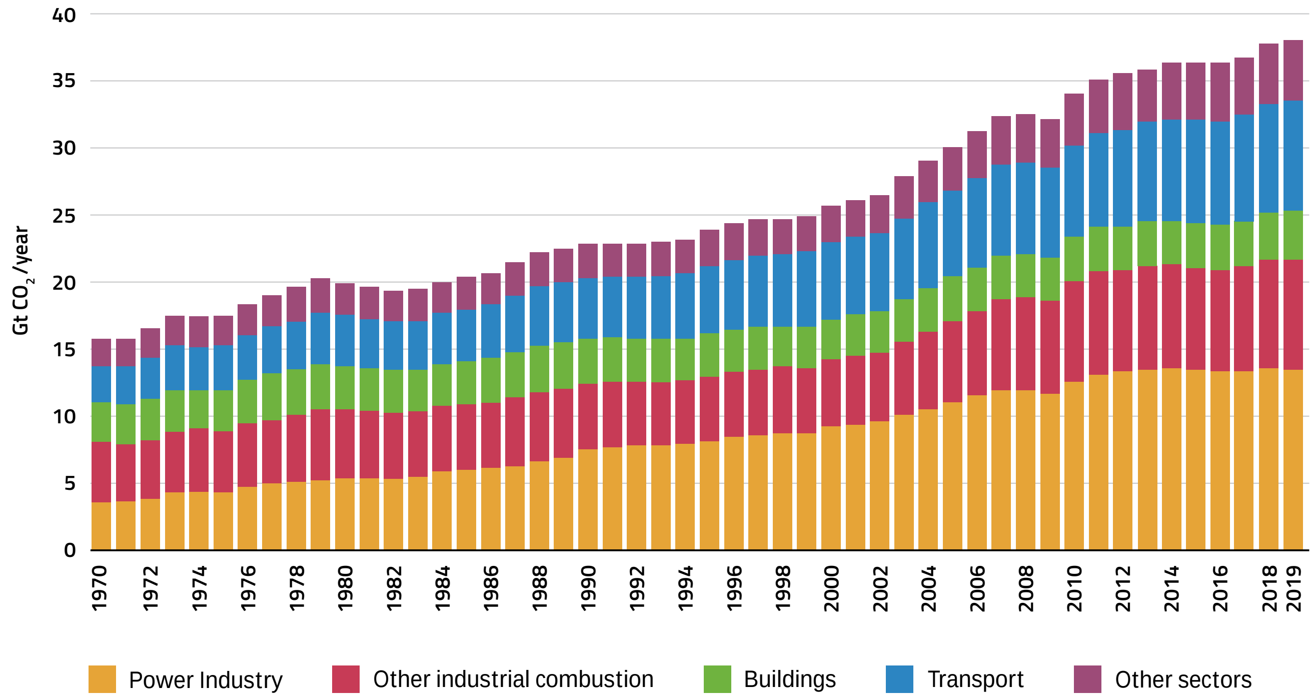


Figure 1.6. Fossil CO_2 emissions of the major emitting economies.



Source: JRC, 2020.

Figure 1.7. Total global annual emissions of fossil CO_2 in Gt CO_2/yr by sector. Fossil CO_2 emissions include sources from fossil fuel use, industrial processes and product use (combustion, flaring, cement, steel, chemicals and urea).

Decoupling of GDP per head from CO_2 emissions seems to have happened at the expense of outsourcing manufacturing [2]

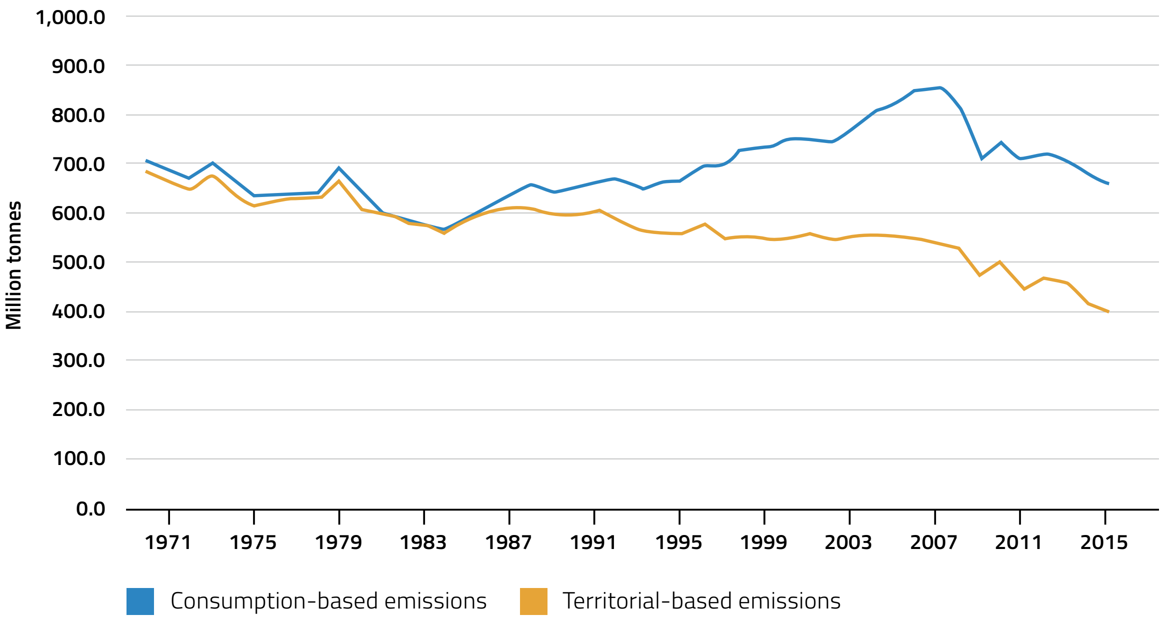


Figure 1.8. Different measures of CO_2 emissions, 1970 to 2015, UK.

Total GHG emissions associated with UK consumption [3]

g. In 2019, **global carbon emissions** from energy use **increased by at least 0.5 %, despite a decrease in the EU**.[16] According to JRC, the global emissions growth continued in 2019 with ***global anthropogenic fossil CO_2 emissions increasing by 0.9 %*** compared to 2018, reaching 38.0 Gt CO_2. [13] The increase was fueled by strong emission increases in China (2.6 %) and, to a lesser extent, India (1.8 %); JRC reports an even higher growth rate for China at 3.4 %. [13]

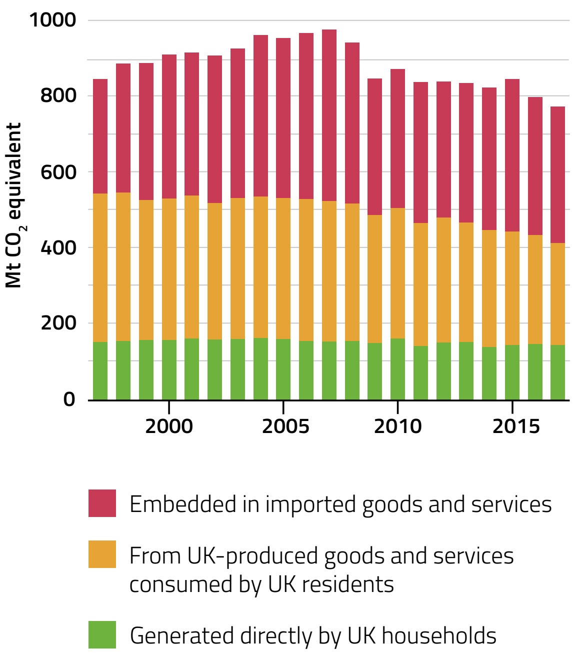


Figure 1.9. Total greenhouse gas emissions associated with UK consumption (DEFRA).

16 We do not discuss 2020 and the COVID-19, which has created an exceptional situation.

Annual Fossil CO_2 emissions 2019 [4]

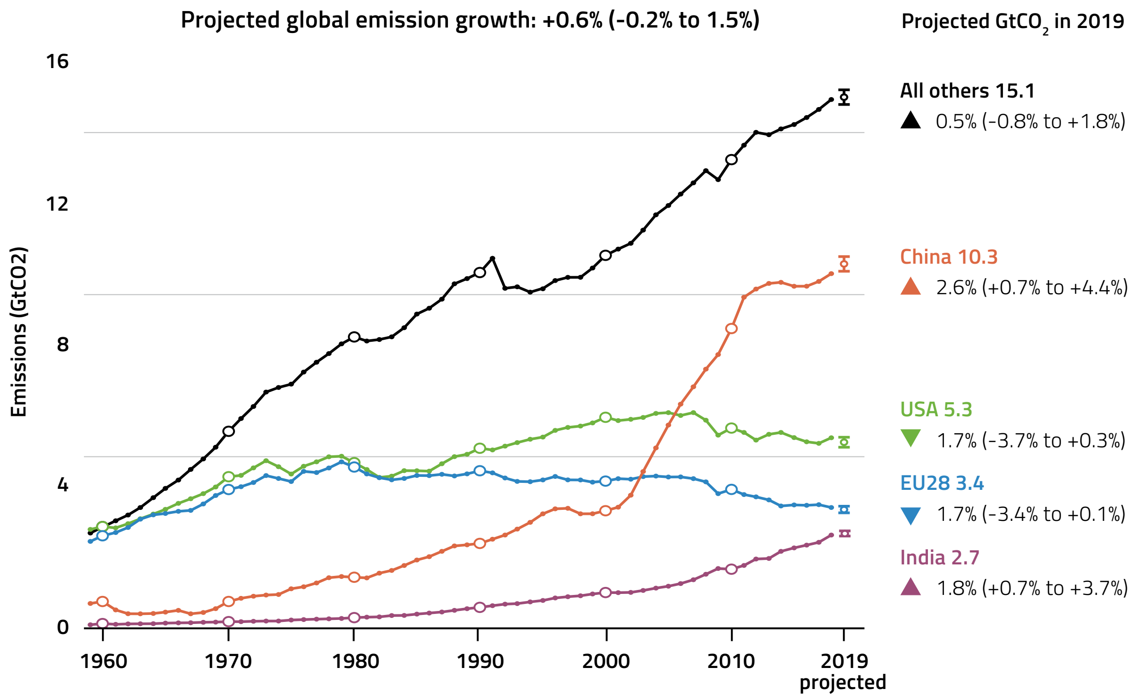


Figure 1.10. Annual fossil CO_2 emissions and 2019 projections

Annual Total CO_2 Emissions [8]

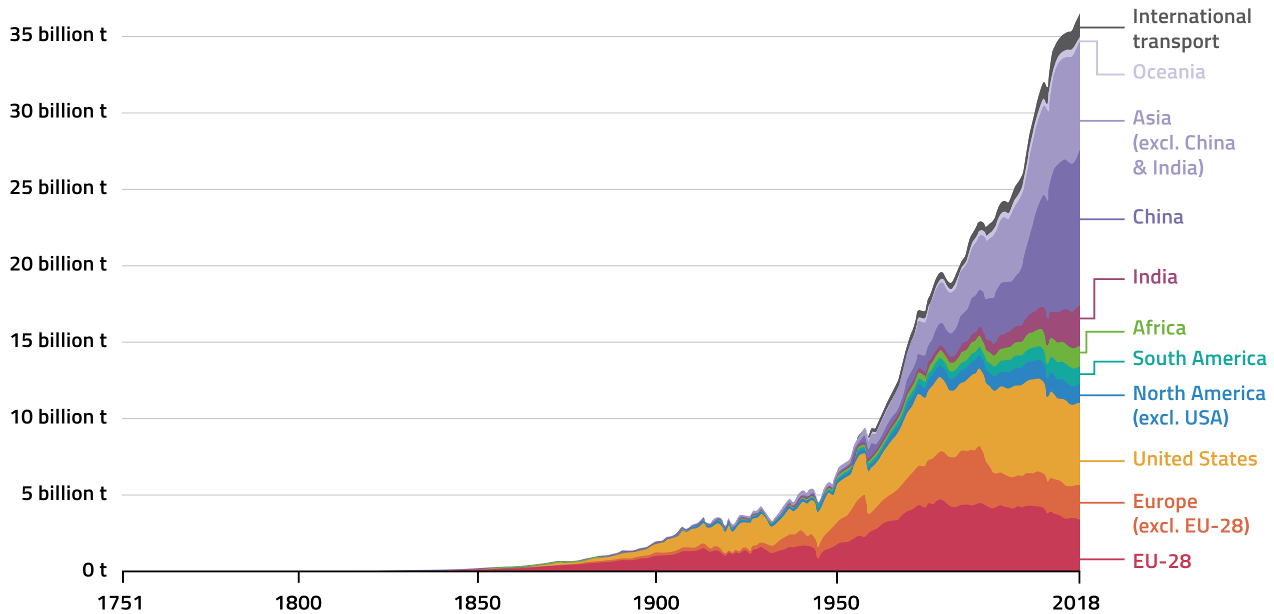


Figure 1.11. Annual total CO_2 emissions, by world region

Source: Carbon Dioxide Information Analysis Center (CDIAC); Global Carbon Project (GCP)
Note: 'Statistical differences' included in the GCP dataset is not included here.
OurWorldInData.org/co2-and-other-greenhouse-gas-emissions - CC BY

h. The **atmospheric concentration of carbon dioxide continues to increase**. No peak concentration has been reached, and the CO_2 level shows no signs of peaking. This is **critically important**, because, according to conventional climate science, it is the atmospheric concentration of carbon dioxide that drives global warming and climate change, which is the problem the EU hopes to remedy through its climate neutrality policy.[17]

Atmospheric carbon dioxide concentration [5]

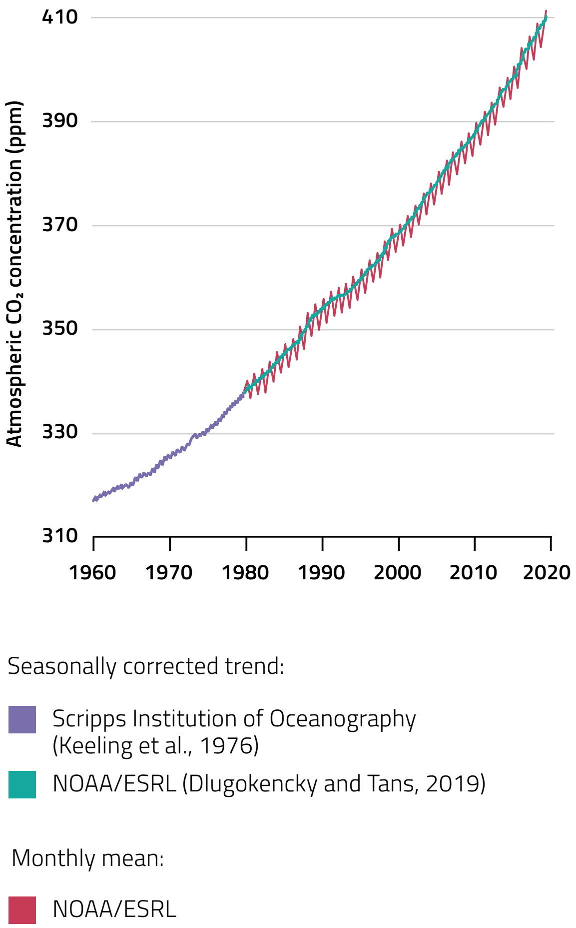


Figure 1.12.

i. EU climate neutrality will only have its intended favorable effect on reducing the average global atmospheric temperature increase, ***if and only if no 'carbon leakage' (or outsourcing) occurs, which thus far has occurred consistently***. Indeed, carbon leakage explains why global emissions continue to rise despite the significant (and costly) reductions in the EU.

ii. Even if the EU is able to prevent carbon leakage and outsourcing, when it achieves carbon neutrality in 2050, it may still find that its efforts were in vain, because emissions from other countries increased. As discussed below, an effective way to prevent this unfortunate outcome (i.e. buying up all fossil fuels), is beyond the EU's reach. This state of affairs requires that ***the EU hedge against the risk of its efforts not achieving the desired effect*** by ***giving priority to 'no regret' solutions***.

i. This suggests that ***EU climate neutrality***, even if achieved, may have ***very little effect on the average global temperature increase***. Other, non-EU nations, including developing nations, have no obligation to reduce their emissions, and the EU has no way to force them to do so. Thus, the EU's efforts are vulnerable to potential failure.

i. Given that the EU has very little or no control over non-EU nations' emissions, it can only use **diplomacy** and **economic incentives** to get them to change their policies; e.g. the EU can offer to pay for non-EU countries' reduction efforts, or impose carbon taxes on imports into the EU. Given the value of the world's fossil fuel reserves (see further below), there is no way that strong diplomacy and economic incentives created by the EU can have more than a **negligible influence**.

17 It is true that countries representing a substantial portion of global emissions are committed to a climate neutrality policy, but the question is how strong these commitments are. If the past is representative of the future, the expectations should be tempered. International climate policy since 1990 has not had the effect of reducing global emissions or the atmospheric carbon dioxide concentration.

ii. The EU and national policies have produced modest reductions in carbon emissions thus far, and emissions from the rest of the world continue to increase, with **no sustained evidence of a peak, let alone of the necessary decrease**.[18] Thus, there is a substantial risk that the EU's efforts, even if successful, will not have the desired effect.

iii. International climate policy has a **poor track record**. Since the adoption of the UNFCCC in 1992, global carbon emissions have steadily increased, despite the Kyoto Protocol and the Paris Agreement. In fact, the international mitigation efforts have **not produced a drop** in global emissions. ***On what principle is it that, when we look we see nothing but failure behind us, we are to expect nothing but improvement before us?***

Global carbon emissions and international climate policy [10]

j. Another way to assess the EU climate neutrality ambition is to ask: what is the **necessary rate of deployment of renewable energy** to arrive at zero emissions in 2050 in the EU and worldwide? Taking the average rate of addition of renewable energy over the last 12 years, assuming a linear trajectory, the following requirements would have to be met:

i. For the world to achieve a **45 % reduction in 2030**, it needs to increase the rate of annual addition of renewables by a **factor of 16**;

ii. For the world to achieve a 45 % reduction in 2050, it needs to increase the annual addition of renewables by a factor of 10;

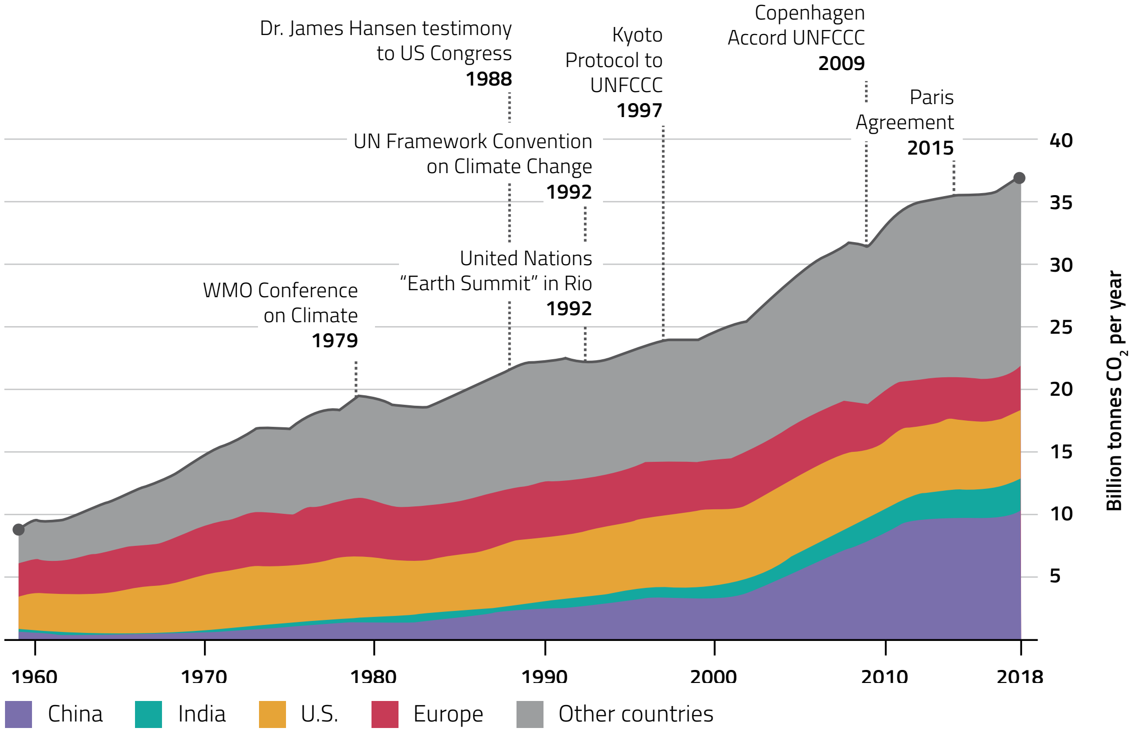


Figure 1.13. Global Carbon Emissions

Source: Global Carbon Budget 2018 • Get the data

18 Research by Burgess et al. suggest that 2019 was a peak, but it is too early to treat it as such. Cf. Burgess, Matthew G., Justin Ritchie, John Shapland, and Roger Pielke Jr., IPCC baseline scenarios have over-projected CO_2 emissions and economic growth, Environmental Research Letters (ERL, forthcoming), available at https://osf.io/preprints/socarxiv/ahsxw/

EU climate neutrality, even if achieved, may have very little effect on the average global temperature increase. Other, non-EU nations have no obligation to reduce their emissions, and the EU has no way to force them to do so. Developing nations have a right to develop their economies. Thus, the EU's efforts run a substantial risk of not achieving their objective.

iii. For the EU to achieve zero emissions by 2050, it needs to increase the annual addition of renewables by a factor of 4, assuming the energy demand drops by 0.7 % annually.

iv. For the **EU to achieve zero emissions by 2050**, it needs to **increase the annual addition of renewables by a factor of 7**, assuming the energy demand increases by 1.2 % annually.

k. Even though this is a huge mountain to climb, the biggest problem may not even be the expansion of the renewable energy system. The biggest problem probably will be **retiring fossil fuels within the same time frame, including in the EU itself,** in particular if intermittent renewable energy continues to expand and nuclear energy declines. The humungous cost associated with buying up the global fossil fuel reserves demonstrates that EU climate neutrality is unlikely to be effective.

i. Thus far, the EU's emissions reduction efforts have not caused a corresponding drop in global emissions, because the **use of fossil fuels continues unhindered in large parts of the world** (and, to a lesser extent, within the EU). In the EU, the necessity of back-up for intermittent renewable electricity generation, combined with an averseness to nuclear energy, prevents the rapid phase-out of fossil fuel power generation.

ii. With the demand for fossil fuel in the Western world declining, prices on the world markets are likely to drop (all else equal) and fossil fuels will become more affordable for developing countries. This will allow them to consume more fossil fuels, and grow their economies as mandated by the UN SDGs, which, in turn, will further fuel the demand for fossil fuels.[19]

iii. To prevent carbon emissions in the rest of the world with a high degree of certainty,[20] over the period from now to 2050, the EU could **buy up all fossil fuels (oil, gas, coal/lignite) and retire them definitively**.

iv. If there are no fossil fuels other than the currently known reserves, at current market price levels, the total cost of this purchasing program will be **at least €109,000,000,000,000**, which is

19 Cf. Sinn, Hans-Werner, The Green Paradox: A Supply-Side Approach to Global Warming, MIT Press, 2012.

20 Adverse substitution effects may occur, if, instead of fossil fuels, wood and other biomass are combusted for energy. If this results in deforestation, carbon dioxide will be added to the atmosphere, but not subsequently removed.

approximately **7 times the entire EU's annual GDP** and equal to €560,000 per EU household.[21]

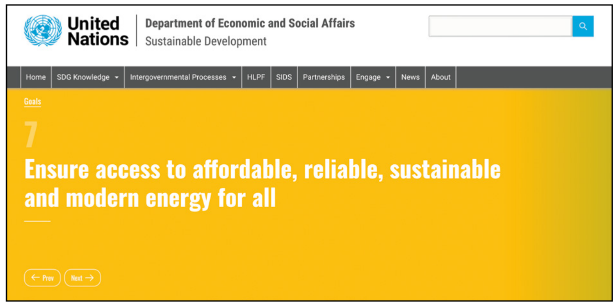
v. Assuming the buying will be linear over 30 years, the **EU would have to spent approximately a quarter of its GDP on fossil fuel purchasing** every year, which is **more than 20 times the 2019 EU budget (of €165 billion), every year, starting in 2021 up to and including 2050**.

vi. These numbers not only give us an idea of the **economic value of fossil fuels**, but also show that a known certain way to prevent the EU's climate neutrality efforts from being futile, is unrealistic. Put differently, the enormous cost of buying up all fossil fuels casts doubt over the practicality of EU climate neutrality policy. Thus, there is a high probability that **EU climate neutrality will not have the desired effect**.

vii. But even if such a program were feasible, it would raise serious concerns from **developing nations**. Under the United Nations Sustainable Development Goals, developing nations have been promised an **end to poverty and hunger**, "**access to affordable, reliable, sustainable and modern energy for all**"[22] and **industrialization**.[23] All of these goals are ranked higher than the fight against climate change.[24]

viii. The international law framework (UNFCCC, Paris Agreement) recognizes the **rights of nations, in particular developing economies, to exploit their own resources and develop their economies**, and does not require that they pursue emissions reductions (also referred to as 'differentiated responsibilities').

ix. Given developing nations' right to develop and the immense opportunity cost of foregoing development, it is unlikely that they will refrain from doing so, or that the developed nations can persuade them otherwise or prevent them from doing so.



---

21 There are approx. 195 million households in the EU. Eurostat, Household composition statistics, available at https://ec.europa.eu/eurostat/statistics-explained/index.php/Household_composition_statistics. On a per capita basis, given that the EU has approximately 450 million citizens, this represents an expense of roughly €250,000 per citizen. World Bank, https://data.worldbank.org/region/european-union, population statistics as of 2019.

22 United Nations, SDG number 7, available at https://sdgs.un.org/goals/goal7 UN SDG number 1 is 'end poverty' and number 2 is 'end hunger.'

23 United Nations, SDG number 9, available at https://sdgs.un.org/goals/goal9 ("Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.)

24 United Nations, SDG number 13, available at https://sdgs.un.org/goals/goal13

UN Framework Convention on Climate Change [9]

Recalling also that States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction,

x. Thus, even if the EU member states can achieve zero emissions by 2050, there is a **substantial risk that emissions from other nations more than compensate for the EU's reductions** and **no positive effect on the global climate will materialize**.

From Nature Climate Change, January 2020 [4]

Carbon dioxide emissions continue to grow amidst slowly emerging climate policies

A failure to recognize the factors behind continued emissions growth could limit the world's ability to shift to a pathway consistent with 1.5 °C or 2 °C of global warming. Continued support for low-carbon technologies needs to be combined with policies directed at phasing out the use of fossil fuels.

G. P. Peters, R. M. Andrew, J. G. Canadell, P. Friedlingstein, R. B. Jackson, J. I. Korsbakken, C. Le Quéré and A. Peregon

Global fossil CO_2 emissions grew at 0.9% per year in the 1990s and accelerated to 3.0% per year in the 2000s, but have returned to a slower growth rate of 0.9% per year since 2010, with a more pronounced slowdown from 2014 to 2016. Despite modest declines in emissions in the United States and the European Union (EU) over the past decade, the growth in emissions in China, India and most developing countries has dominated global emission trends over the past 20 years. The Global Carbon Budget projection[1] suggests that global fossil CO_2 emissions will grow by 0.6% (range –0.2% to 1.5%) in 2019, with emissions projected to decline in the United States and the EU28, but projected to increase in China, India and the rest of the world (Fig. 1a).

NATURE CLIMATE CHANGE | VOL 10 | JANUARY 2020 | 2-10 | www.nature.com/natureclimatechange 3

xi. In a 2018 interim special report pursuant to the Paris Agreement on Climate Change, the IPCC has mapped out a pathway to limiting the temperature increase in 2100 to 1.5 °C. [17]
   - This pathway, which explicitly includes nuclear energy as an option, requires that the **entire world reaches climate neutrality around 2050**.
   - Limiting warming to 1.5 °C requires **drastic emission reductions** by 2030 and **carbon neutrality** by around 2050. This would entail **unprecedented transformations of energy, land, urban, and industrial systems**, including measures to achieve "negative emissions" by removing carbon from the atmosphere.
   - There is **no plausible, feasible plan or pathway** to achieve global climate neutrality by 2050, however. It is merely an aspiration.

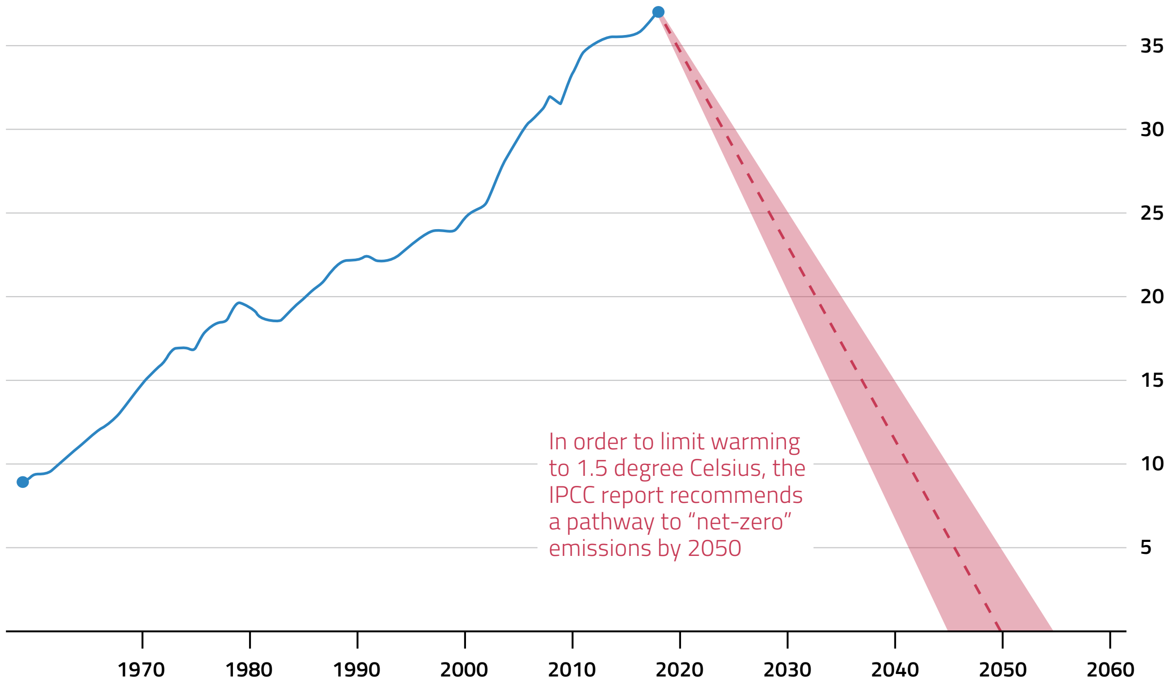


Figure 1.14. IPCC carbon emission pathway to limit warming to 1.5 degrees

Billion tonnes CO_2 per year
Source: Global Carbon Budget 2018 • Get the data

IPCC Special Report -- Limiting warming to 1.5 °C requires drastic emission reductions by 2030 and carbon neutrality by around 2050. This would entail unprecedented transformations of energy, land, urban, and industrial systems, including measures to achieve "negative emissions" by removing carbon from the atmosphere.

IPCC carbon emission pathway to limit warming to 1.5 degrees

xii. Compared to where policies are now, the **changes would have to be unrealistically radical**. Even for the more modest target of 2 °C the required policy changes do **not appear realistic**.

Global greenhouse gas emissions as implied by INDCs compared to no-policy baseline, current-policy and 2 °C scenarios [7]

xiii. If we look at all emissions from energy use (not only electricity), it becomes clear that achieving net zero in a few decades by deploying currently

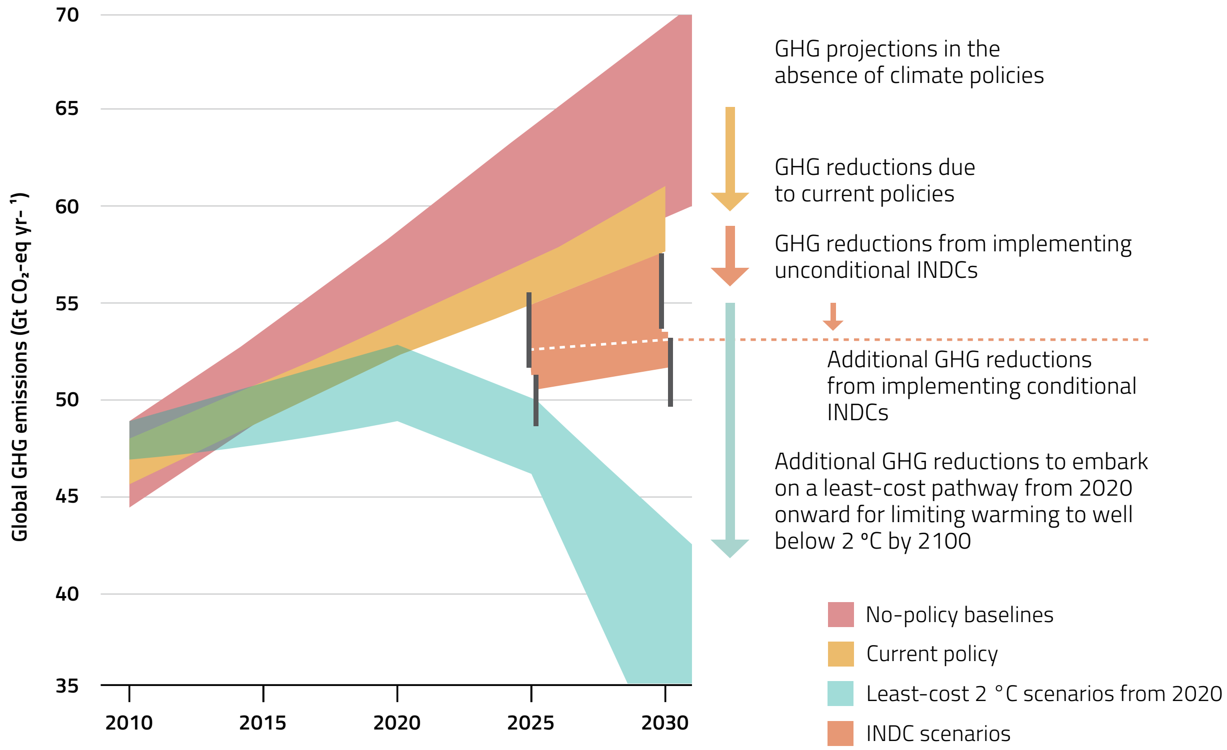


Figure 1.15.

Source: Joeri Rogelj et al., Paris Agreement climate proposals need a boost to keep warming well below 2 °C, Nature, volume 534, pp. 631–639 (2016).

available technologies is impracticable. It has been calculated that getting to net zero in 2035 requires **replacing approximately 0.1 EJ (exajoules) of fossil energy with renewable energy every day starting now.** [16] This is equivalent to approximately **2 nuclear plants or 3,000 wind turbines of 2.5 MW**. A corresponding amount of fossil fuel would have to be retired every day. **All new, additional energy use would have to be carbon-free**. Reality is entirely at odds with these requirements.

xiv. Thus, the **EU is not likely to achieve climate neutrality by 2050. There is no well-defined plan to get there**. No cost/benefit-analysis has been done on alternative policy options; not all policy options have been carefully considered, some viable options, most notably, nuclear power, are even virtually off the table, and the EU cannot afford to buy up all fossil fuel reserves in the world or any significant portion thereof, or otherwise prevent global emissions increases.
EU climate policy-making is led by **a desire to become climate neutral without a rational strategy and roadmap** that can lead the member states to this result. The EU's aspirational strategies and plans all pursue **derivative objectives**, such as renewable energy targets, and are **neither sufficient nor necessary** to achieving climate neutrality. The Green Deal contemplates that the EU will continue to strengthen pre-existing policies, such as energy efficiency and renewable energy, while **betting on technological breakthroughs** in areas such as hydrogen, energy storage, and system integration. Meanwhile, the chief drivers of EU climate policy are targets set by the policy makers for

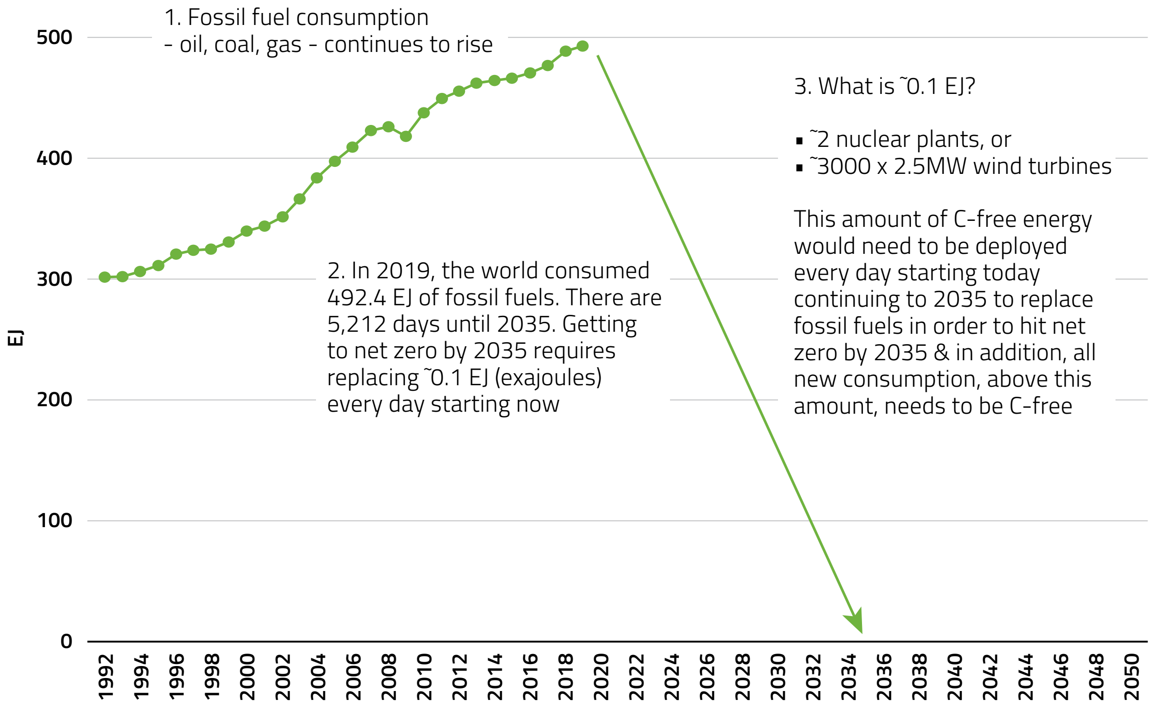


Figure 1.16. Global Fossil Fuel Consumtion

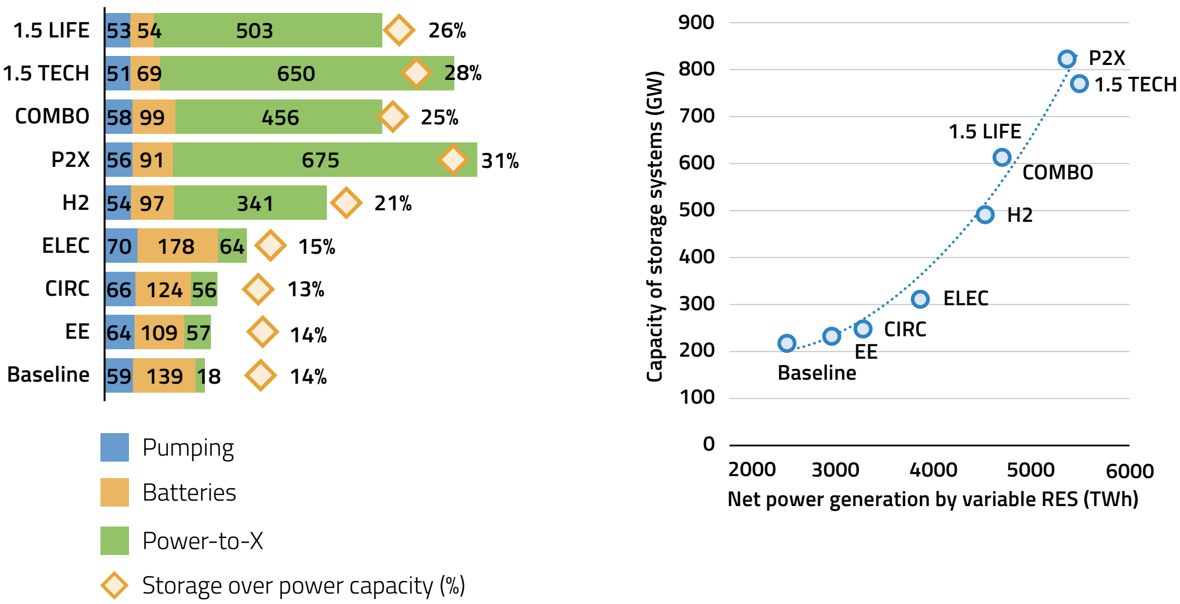
Source: BP 2020, R. Pielke Jr. , 24 Sept 2020

renewable energy and emissions reductions, and financial incentives for research and development, which **do nothing to address the root cause of the global emissions increase.**

xv. In short, there is a **high probability of failure** in that either (i) the EU will not achieve climate neutrality, because the necessary technologies are not ready for wide scale deployment or the costs turn out to be too high (note that the system-related cost of renewable energy increases with its penetration rate), or (ii) the rest of the world will not limit their emissions so that the EU's sacrifices are in vain.

Is climate-neutrality by 2050 in the EU viable and sustainable in the long run? [11]

Developing a power system with a high share of variable RES requires the development of storage technologies., demand response, mesh grids and an efficient multi-country integrated system and market, to share the resources that would enable the cost-effective balancing of variable RES generation. Large-scale storage of electricity (**Fig. 6**) with versatile features and seasonal cycles such as large-scale batteries, power-to-H_2 for chemical storage and compressed air electricity storage, depends on the technology readiness levels (TRL) of those technologies that currently remain at a demonstration stage. Without the synergy between chemical storage



Source: PRIMES model.

Figure 1.17 . EU storage systems capacity (GW), share of total power capacity and correlation of power storage with variable RES generation. In these graphs, the abbreviations 'P2X', '1.5TECH', '1.5LIFE', 'COMBO, etc. refer to scenarios of energy mixes with a decreasing percentage of variable renewable energy.

and the production of hydrogen and synthetic fuels, the huge increase of the power system size, projected in the climate-neutral scenarios, would have been unmanageable. The non-linear increase of storage as a function of the volume of total generation can be depicted in the right-hand side chart shown in figure 1.17.

xvi. This reinforces the need for ***'no regrets'*** **solutions,** i.e. ***policies that confer benefits, and do not cause adverse impacts and negative externalities, irrespective of any positive effects they may have on the problem of climate change***.

xvii. **Power-generating technologies should be evaluated in terms of the extent to which they are '*no regrets*' solutions,** which is currently not done by the EU. Despite the obvious need, the EU has not conducted a cost/benefit analysis of the alternative electricity-generating technologies and electricity systems. This analysis, which should include 'no regrets' assessment, akin to application of the precautionary principle, should address **all benefits and costs of alternative power generation technologies**, such as those listed in Annex IX attached to the report.

xviii. **Two important features of power-generating technologies** that have not received much attention in EU and national policy-making are (i) **the land and space a technology requires**, and (ii) **its costs**. As this study has demonstrated, once these features are accurately reflected in policy-making, **nuclear energy appears to be an attractive, space-and cost-efficient option**.

Part II. Spatial Requirements of Power Generating Technologies

1. If electricity in The Netherlands and the Czech Republic is solely or chiefly provided by wind turbines and solar panels, these renewable energy technologies will take up very significant portions of the available land. This is due to the **low power density of wind and solar**, which is approximately **150 to 500 times lower** than the power density of nuclear power, on average (see further, below).

    a. Depending on variables such as electricity demand and capacity factors, in realistic scenarios, there is **not enough land to meet all power demand** if the Czech Republic and The Netherlands were to rely solely or predominantly on wind and solar power. In the Czech case, it is even **out of the question that the available land will be sufficient to cover all electricity demand**.

    b. In any event, the **spatial impact of high penetration of wind and solar** in the electricity system will be **very substantial** and will increase as a function of the percentage of wind and solar in the power mix.

        i. In The Netherlands, **offshore wind may alleviate the pressure on land somewhat**, but creates its own issues in terms of marine impacts, costs (see below), etc.

        ii. As the penetration of wind and solar increases, **competing land uses, landscape protection, and nature protection** will increasingly come under pressure, resulting in land price increases and deterioration of the living environment.

        iii. In the Czech Republic, if **only 30 % of the power is generated by renewables, all available land is occupied with wind and solar** at a power demand of only 1,000 PJ.

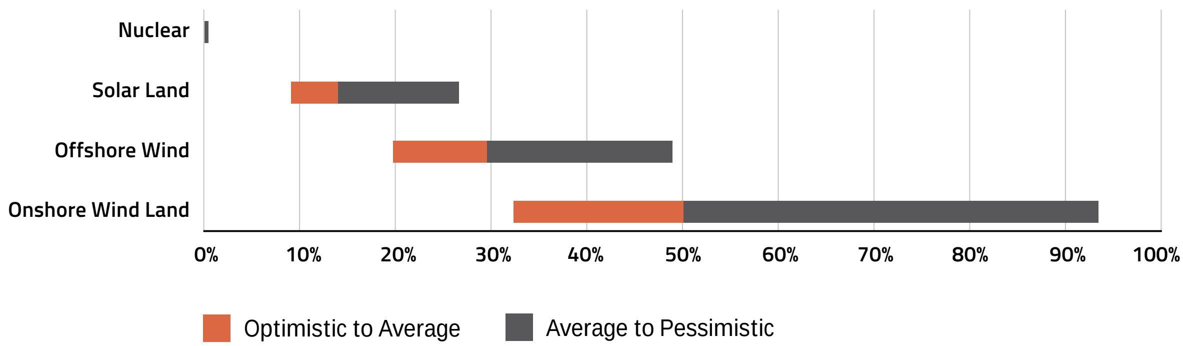


Figure 1.18. The Netherlands - Area Required if Each Source Provides 500 PJ in Energy Annually

% of Energy Demand Supplied by Renewables

Energy Demand (PJ)	10%	15%	25%	35%	45%	50%	55%	75%	100%
1,500	10.8%	16.2%	27.0%	37.7%	48.5%	53.9%	59.3%	80.9%	107.8%
1,750	12.6%	18.9%	31.4%	44.0%	56.6%	62.9%	69.2%	94.3%	125.8%
2,000	14.4%	21.6%	35.9%	50.3%	64.7%	71.9%	79.1%	107.8%	143.8%
2,250	16.2%	24.3%	40.4%	56.6%	72.8%	80.9%	88.9%	121.3%	161.7%
2,500	18.0%	27.0%	44.9%	62.9%	80.9%	89.8%	98.8%	134.8%	179.7%
2,750	19.8%	29.6%	49.4%	69.2%	88.9%	98.8%	108.7%	148.2%	197.7%
3,000	21.6%	32.3%	53.9%	75.5%	97.0%	107.8%	118.6%	161.7%	215.6%
3,250	23.4%	35.0%	58.4%	81.8%	105.1%	116.8%	128.5%	175.2%	233.6%
3,500	25.2%	37.7%	62.9%	88.1%	113.2%	125.8%	138.4%	188.7%	251.6%
3,750	27.0%	40.4%	67.4%	94.3%	121.3%	134.8%	148.2%	202.2%	269.5%
4,000	28.8%	43.1%	71.9%	100.6%	129.4%	143.8%	158.1%	215.6%	287.5%

Figure 1.19. The Netherlands - % of Available Land Occupied in 100% Renewables Scenario (electricity only). Current annual energy use in The Netherlands is approximately 3100 PJ (see https://www.clo.nl/indicatoren/nl0052-energieverbruik-per-sector).

% of Energy Demand Supplied by Renewables

Energy Demand (PJ)	10%	15%	20%	25%	30%	40%	60%	75%	100%
1,000	29.0%	43.5%	58.0%	72.5%	87.0%	116.0%	174.1%	217.6%	290.1%
1,200	34.8%	52.2%	69.6%	87.0%	104.4%	139.3%	208.9%	261.1%	348.1%
1,400	40.6%	60.9%	81.2%	101.5%	121.8%	162.5%	243.7%	304.6%	406.2%
1,600	46.4%	69.6%	92.8%	116.0%	139.3%	185.7%	278.5%	348.1%	464.2%
1,800	52.2%	78.3%	104.4%	130.5%	156.7%	208.9%	313.3%	391.6%	522.2%
2,000	58.0%	87.0%	116.0%	145.1%	174.1%	232.1%	348.1%	435.2%	580.2%
2,200	63.8%	95.7%	127.6%	159.6%	191.5%	255.3%	382.9%	478.7%	638.2%
2,400	69.6%	104.4%	139.3%	174.1%	208.9%	278.5%	417.8%	522.2%	696.3%
2,600	75.4%	113.1%	150.9%	188.6%	226.3%	301.7%	452.6%	565.7%	754.3%
2,800	81.2%	121.8%	162.5%	203.1%	243.7%	324.9%	487.4%	609.2%	812.3%
3,000	87.0%	130.5%	174.1%	217.6%	261.1%	348.1%	522.2%	652.7%	870.3%

Figure 1.20. Czech Republic - % of Available Land Occupied in 100% Renewables Scenario (electricity only). Current annual energy use in the Czech Republic is approximately 1800 PJ.

2. If electricity in The Netherlands and the Czech Republic is solely or chiefly provided by nuclear power, **nuclear power plants will take up only a minute fraction of the land and space necessary for wind and solar**. This is due to the very high **power density** of nuclear, which is **at least 150 up to over 500 times higher** than the power density of wind and solar.
   a. Nuclear power plants can be sited at the same sites where fossil fuel-fired power plants are located, and require approximately the same area as such plants, which implies **savings on infrastructure** to connect to the network.
   b. These features **greatly reduce pressures on land availability, landscape protection and nature protection**, which is a significant advantage, in particular when competition for land increases.

	Average GWh / km^2		Indexed to Nuclear (i.e. nuclear produces x times more electricity per km^2)	
	NL	CZ	NL	CZ
Onshore Wind Land	13	13	534	534
Onshore Wind Water	14	n/a	506	n/a
Offshore Wind	26	n/a	266	n/a
Solar Roof	136	163	51	43
Solar Land	47	65	148	108
Nuclear	6,982	6,982	1	1

Table 1.2.

3. Compared to wind and solar, **nuclear power produces approx. 500 and 150 times more electricity per square kilometer**.

4. These numbers **exclude the additional land and space demand imposed by renewable energy**, which increases exponentially as renewable energy expands and makes up a larger share of the power mix. This additional land is required for the **additional infrastructure** necessary for the integration of renewable energy into the electricity system, such as **energy storage and conversion facilities**.

Part III. Cost of Power Generating Technologies and System Cost

1. In virtually **all realistic scenarios, nuclear** power **is cheaper than wind and solar** power in terms of € per MWh in both the Czech Republic and The Netherlands, both at market-based interest rates and at a zero interest rate.[25] These estimates are based on realized costs for each technology and do not factor in any future cost decreases.

€ / MWh	Nuclear	Solar	Onshore Wind	Offshore Wind
0 % WACC	35	72	47	59
3 % WACC	19	65	41	49

Table 1.3. The Netherlands

€ / MWh	Nuclear	Solar	Onshore Wind	Offshore Wind
0 % WACC	30	43	31	N.A.
4.2 % WACC	16	41	29	N.A.

Table 1.5. The Czech Republic

a. While tables 1.4. and 1.5. only lists the **costs of generating the electricity**, the costs of the electricity system include both the (i) cost of electricity-generation (LCOE), and (ii) the cost of transmission, distribution, storage and conversion (integration and system-related cost). The integration- and system-related cost of nuclear energy is much lower than that of intermittent renewable energy, which, moreover, increases exponentially as the penetration rate of renewable increases.

b. Each electricity-generating technology (wind, solar, nuclear) produces **both types of cost**, which, to a significant extent, are a function of (i) the extent to which a technology is deployed in a system (the power mix), and (ii) the pre-existing infrastructure.

2. The **main drivers of the LCOE for both wind/solar and nuclear** are, in order of importance:
   i. weighted average cost of capital (WACC)
   ii. capacity factor
   iii. capital cost
   iv. fixed O&M cost

The **WACC is the most influential**, but also the most controversial factor. Based on thorough analysis of this debate, our approach estimates the WACC for policy makers by **separating government risk** (which policy makers control) from **project risk** (which operators control to a great extent). In standard LCOE calculations, non-intermittent nuclear electricity is discounted more heavily than intermittent renewable

25 These estimates do not discount the energy produced to reflect intermittency or the time of generation. This is the default throughout the extensive summary, unless otherwise noted.

electricity, even though electricity is fungible and the economic value of intermittent energy is lower. Our method avoids this practice, but does not discount intermittent renewable electricity to account for its lesser economic value.

3. In part because the WACC is also used as discount rate, the WACC to be applied in planning decisions is not a given for policy makers. The choice of a WACC/discount rate is a value-laden decision, not a technical matter to be decided by experts. Deciding the appropriate discount rate for policy purposes involves political and moral debates as much as economic and technical issues. Given that policy making can influence WACCs directly, policy makers should scrutinize the WACCs used in any LCOE. Using a **policy-neutral WACC of 3 % for The Netherlands and 4.2 % for the Czech Republic,** we find that **in most plausible scenarios nuclear power is cheaper than all types of renewable energy (offshore wind, onshore wind, solar)** or any combinations thereof in both the Czech Republic and The Netherlands.

a. Only if all or most variables turn out to be in favor of renewable and to the detriment of nuclear, some renewable power might have a lower LCOE, although not necessarily a lower total cost.
b. Note that this cost comparison is based merely on LCOE and, thus, does not take into account **integration and system-related costs**, which are much **higher for renewable power** than for nuclear (see further below).
c. **In most plausible scenarios nuclear power is cheaper than all types of renewable energy (offshore wind, onshore wind, solar) in both**

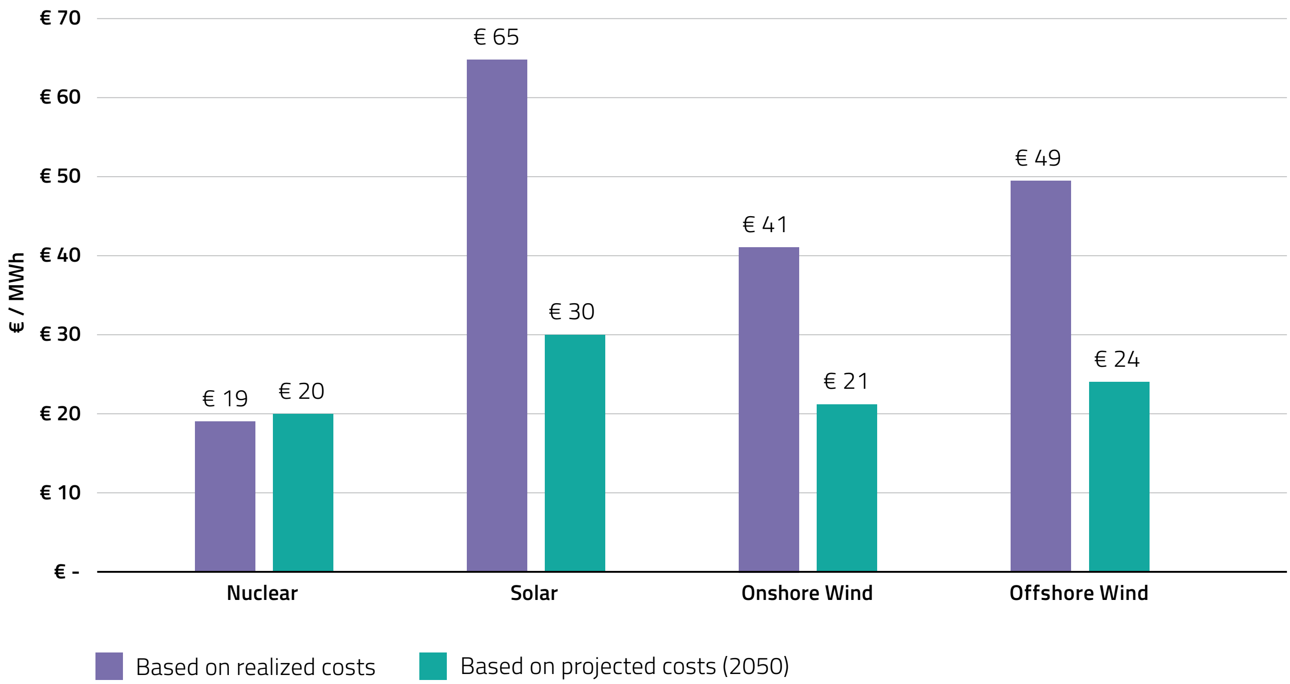


Figure 1.21. The Netherlands: LCOE Analysis

In most plausible scenarios nuclear power is cheaper than all types of renewable energy (offshore wind, onshore wind, solar) in both the Czech Republic and The Netherlands, even before integration- and system-related cost is added, which is much higher for renewables.

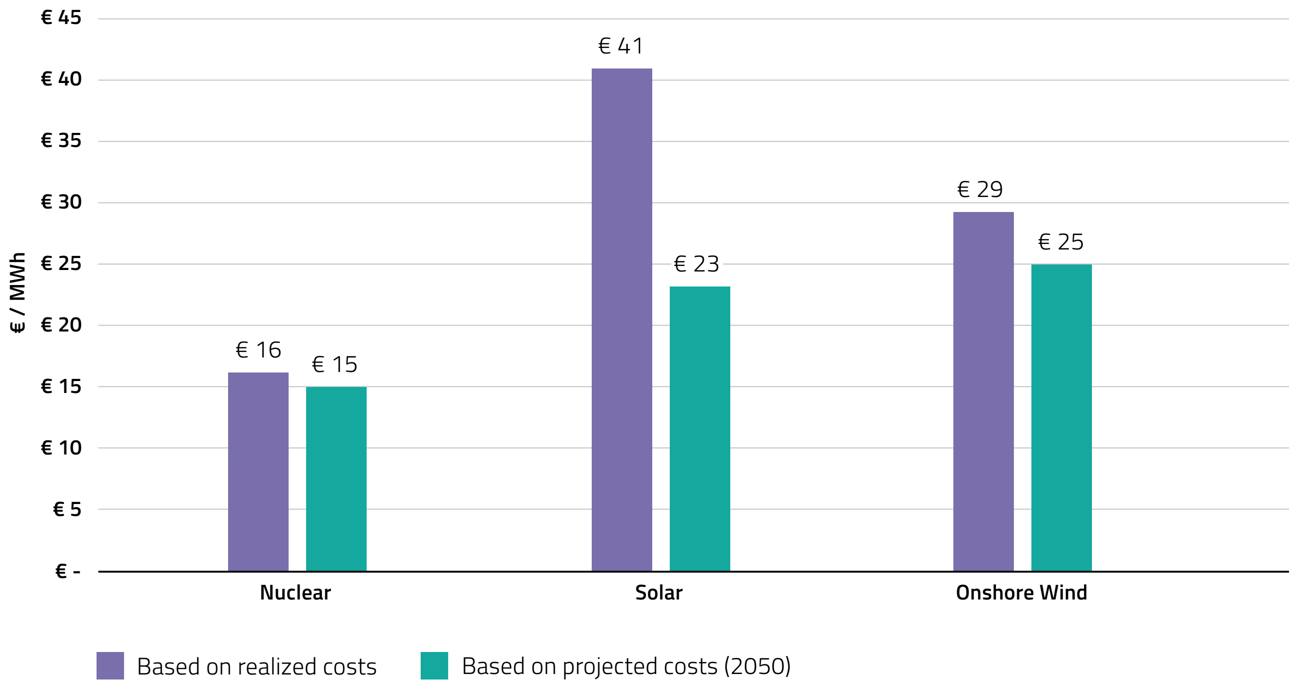


Figure 1.22. The Czech Republic: LCOE Analysis

the Czech Republic and The Netherlands, even before integration- and system-related cost is added, which is much higher for renewables (see further below).

d. Likewise, spatial requirements are not taken into account in this analysis (refer to the discussion above).

4. We further **adapted the LCOE method** by developing a **synchronized lifetime analysis** as an additional point of reference. A synchronized lifetime analysis is the preferred method for comparing various power generating technologies, because it avoids the distorting effects of discounting projects with different lifetimes and different production schedules.

This method confirms that **nuclear power is a more cost-efficient solution to meet chosen levels of electricity production over a given period of time, even before integration- and system-related costs are added.**

a. As expected, the cost advantage of nuclear decreases as the WACC increases.

b. This result is independent of the level of power output required. It is also independent of the time period over which the analysis is conducted, assuming the lifetime of the technology is exhausted.

Note: The time periods under consideration for The Netherlands and the Czech Republic are different due to different technical lifetimes of the renewable power technologies.

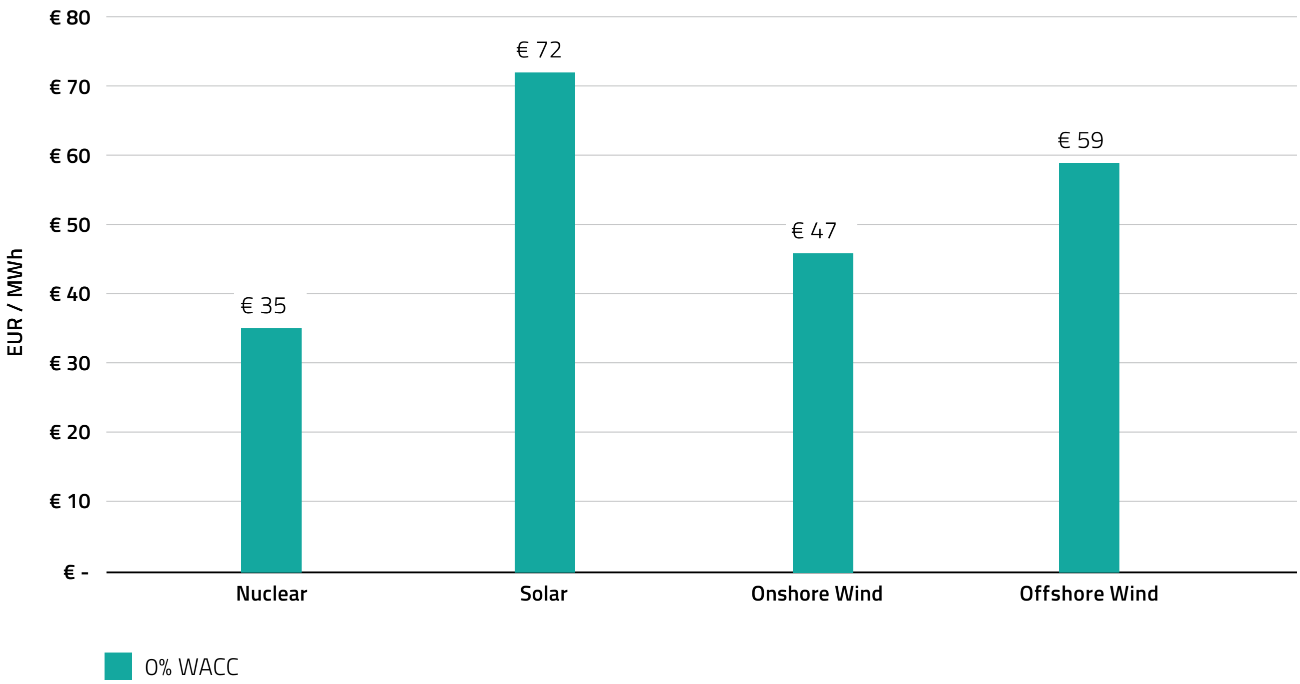


Figure 1.22. The Netherlands - Synchronized Lifetime Analysis (based on realized cost of levelized output and no discounting).

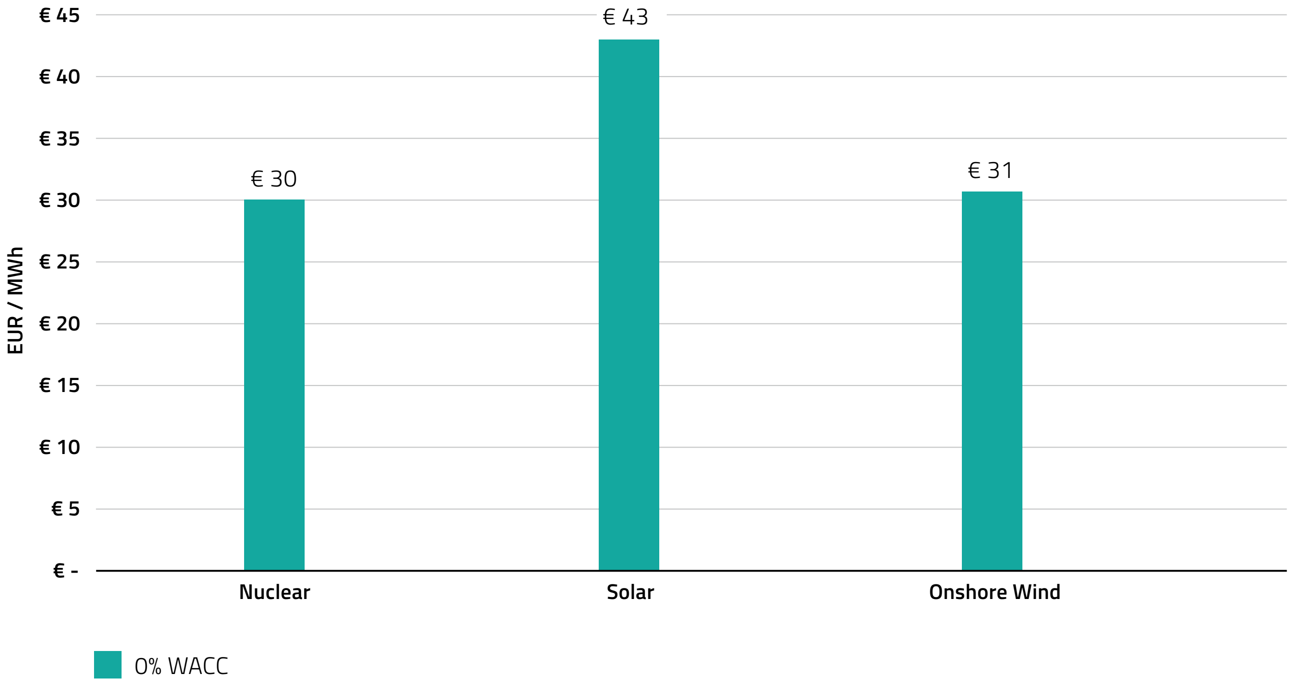


Figure 1.23. The Czech Republic - Synchronized Lifetime Analysis (based on realized cost of levelized output and no discounting).

	Nuclear	Solar	Onshore Wind	Offshore Wind
Present Value of Generation Costs at 0 % WACC, *Relative to nuclear*	1.0x	2.0x	1.3x	1.7x
Present Value of Generation Costs at 3 % WACC, *Relative to nuclear*	1.0x	1.9x	1.2x	1.5x

Table 1.6. The Netherlands - Synchronized Lifetime Analysis

	Nuclear	Solar	Onshore Wind
Present Value of Generation Costs at 0 % WACC, *Relative to nuclear*	1.0x	1.4x	1.0x
Present Value of Generation Costs at 4.2 % WACC, *Relative to nuclear*	1.0x	1.0x	0.7x

Table 1.7. The Czech Republic - Synchronized Lifetime Analysis

5. If the **integration and system-related costs** (profile cost, connection cost, balancing cost, grid cost) are included in the analysis, the **cost advantage of nuclear power over wind and solar power increases further**. This is true especially when wind and solar power achieve high penetration rates.

   a. **Integration- and system-related costs are low for nuclear power, because nuclear power plants provide a constant output (no intermittency) and, to some extent, can adjust power production to fit demand (flexibility)**. Moreover, they can be located at the current sites of fossil fuel-powered electricity plants or similar, relatively small sites, close to the power infrastructure and close to where electricity is most needed.

b. **Integration- and system-related costs are high for wind and solar power, because this technology is intermittent (no constant output) and it is incapable of producing power on demand (stochastic, no flexibility)**. As renewable energy displaces conventional energy sources, integration- and system-related cost increases exponentially because the problem of intermittency increases, requiring more backup-, storage- and conversion facilities. Moreover, the sites for wind and solar facilities are often located at relatively remote areas, far away from the power infrastructure and from where electricity is most needed. This contributes further to higher integration costs as infrastructure needs to be built to connect these facilities to the existing grid and wind/solar are unable to replace conventional power generation facilities at a 1:1 ratio.

c. Based on modelling with the ETM, for The Netherlands, **total energy system costs could be reduced by as much as 18% by replacing renewable generation with nuclear generation,** with more cost savings for those scenarios that initially had more renewables in the energy mix. Importantly, **grid connection costs, only one part of the integration costs, were reduced by over 60 % in one scenario**, which would save the Dutch government almost EUR 10 billion per year.

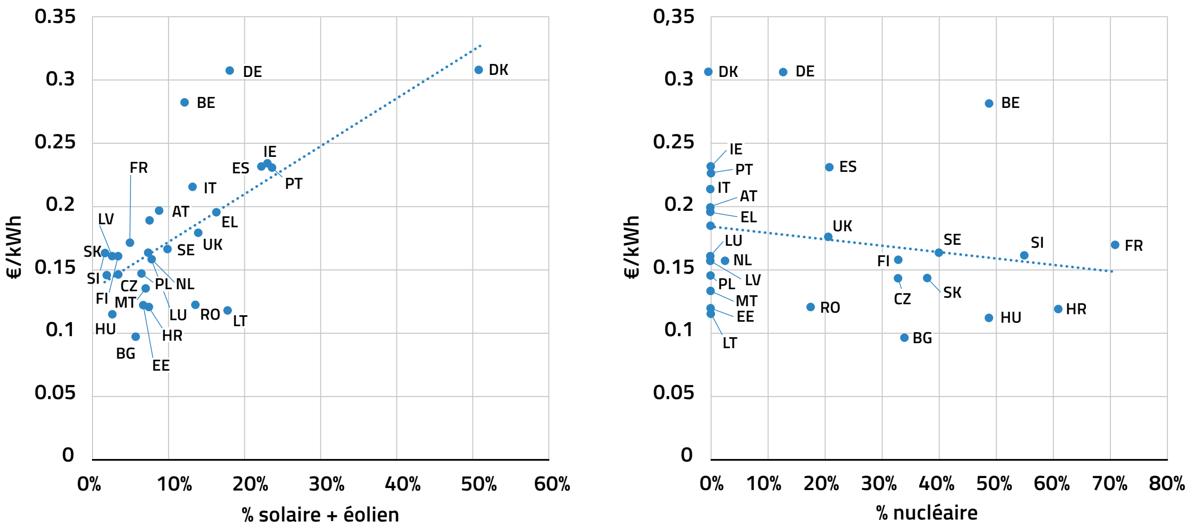
d. Further evidence for the **price-inflating effect of renewable energy** is derived from Germany, where household electricity prices broke the **30 cents per kWh** barrier in recent years. These high prices have been contrasted with those in France, which relies much more on nuclear power, where in 2019, the average household electricity prices in France were **18 cents per kWh**. Interestingly, in scenario analysis for France, the scenarios with **60 % renewables** were **55 billion euros more expensive** than the scenario that kept nuclear power capacity constant and renewables at 35 %.

24 Jan 2020, 14:00 | Ellen Thalman, Benjamin Wehrmann

What German households pay for power

#Cost & Prices

Power prices in Germany are among the highest in Europe, not least due to the costs arising from the launch of renewable energy sources – but many customers continue to support the country's energy transition regardless. While wholesale electricity prices on average have been in decline in recent years, surcharges, taxes, and grid fees raise the bill for Germany's private households and small businesses. However, market observers say that power costs are often not even high enough for customers to look for cheaper alternatives. [UPDATES lates 2019 BDEW figures; 2020 renewables surcharge]



1.24. Price of electricity (household)

From: Prof. Samuel Furfari, Uinversite Libre de Bruxelles, 2019.

Source: Eurostat (Dec 2018)

e. Importantly, as the **rate of penetration of wind and solar power increases**, the **integration and system-related cost increase exponentially**, further widening the gap between the low cost of nuclear power and the high cost of renewable power.

f. As the figure 1.24. suggests, **higher renewable energy penetration rates are positively correlated to higher household electricity prices**, while **higher nuclear energy shares are positively correlated with lower electricity prices**.

Part IV. Policy Recommendations

Because current EU policies **favour renewable energy over nuclear energy**, assessment of the relative cost of both technologies can easily be led astray and reflect the **policy status quo**, rather than anything inherent to these technologies. Massive funding found its way into the development and deployment of wind and solar energy solutions. This had the effect of reducing the price of renewable energy, but it has also had a relative **inflating effect on the cost of nuclear power** and of the deployment thereof in the EU.

Given the advantages of nuclear power from spatial and economic viewpoints, however, Member State governments will likely **need to add nuclear power to their energy mixes** to stay on track in their attempts to meet the EU climate neutrality's objective.

1. Under the current EU and member state policies, the following **benefits are extended to renewable energy**, which are **not (or only to a much more limited extent) available to nuclear power**:

   a. **Direct subsidies (grants) for research and development** of renewable power technologies, including wind and solar technologies;
   b. **Direct subsidies (investments grants, loan guarantees, soft loans) for actual renewable power projects,** including wind and solar projects;
   c. **Indirect subsidies by paying for infrastructure** required specifically by renewable power projects out of general budget, tax revenues, or levies;
   d. **Mandatory, guaranteed minimum shares for renewable energy** in the energy mix imposed through minimum targets for renewable energy, with renewable energy defined to exclude a competing decarbonized technology;
   e. **Priority and privileged access to the energy market** through priority dispatch, feed-in tariffs (FiT), feed-in premiums (FiP), to the detriment of competing power generators, including decarbonized power producers;

f. **Quota obligations with tradable green certificates**, and similar minimum purchase requirements for renewable electricity;
g. **Tax incentives** available only to renewable power generation, not to other decarbonized power generation technologies;
h. **Tendering schemes** that favor renewable power generators over other decarbonized power generators;
i. **Expedient permitting and regulatory procedures** that reduce the risks for renewable power projects, but are not available to other decarbonized power projects;
j. **Procedures and rules relating to grid access and operation** that favor renewable generators or disadvantage other power producers;
k. **Other features of power market design, structure, and functioning** that favor renewable power projects;
l. **Land-related policies that keep the price of land use for renewable power projects low**, including, but not limited to, agricultural policies;
m. **Lack of obligation for renewable power generators to compensate property owners that suffer damage** (e.g. reduced property value) as a result of location of renewable power plants;
n. **No internalization of negative externalities** (e.g. adverse environmental impacts) into the price of renewable power generation; and
o. **Free riding on other technologies that keep the power system stable and flexible**, such as base load generators and flexibility providers.

2. To meet the public demand for nuclear power, the EU should place renewable and nuclear on equal footing and endorse a '***Nuclear Renaissance***' program. This program would comprise twelve key elements:

a. **Equal treatment**: All decarbonized power generation technologies (wind, solar, nuclear) receive equal treatment by the EU and member state governments.
b. **Generator pays principle**: Based on the principles of cost internalization and "polluter pays," all EU policies ensure that the fully loaded costs, including integration- and system-related costs as well as relevant externalities, are taken into account in policy making with respect to both renewable and nuclear power.
c. **No discriminatory subsidies**: All open and hidden subsidies, direct and indirect, in cash or in kind, and other advantages for renewable energy (e.g. targets, priority rules, higher or guaranteed feed-in tariffs, subsidized infrastructure necessary for wind on sea, deflated land use prices, etc.) are eliminated, so that nuclear can compete on a level playing field. Other EU policies are not skewed to provide benefits to renewable energy.
d. **Total system cost rules**: The electricity market is redesigned so that total system costs, rather than marginal cost of subsidized power generation technology, drives carbon-neutral investments.
e. **Differentiated electricity products**: Based on the idea that unequal cases are not treated the same way, the concept of 'energy only' is no longer construed in a way that favors the marginal cost of stochastic, demand-unresponsive electricity generation, but recognizes the fundamentally different nature of constant, on demand electricity supply, and demand-unresponsive electricity supply.
f. **Holistic assessment**: The extent to which power generation technology, whether wind, solar, or nuclear, has favorable or adverse effects on other EU interests and policies (such as habitat and species protection, toxic-free environment, agricultural policy, energy policy, etc.) and causes other externalities, is identified and objectively assessed in connection with policy making at EU and member state levels.

g. **Expedient regulatory procedures**: Like renewable energy, nuclear power equally benefits from expedited, efficient permitting and regulatory procedures, and the EU requires that the Member States eliminate privileged treatment of any power generation technology in their administrative procedures.
h. **Legal and policy certainty**: To encourage investment in the best power generation technology and keep the finance cost down, legal and policy certainty is guaranteed to both renewable and nuclear power.
i. **Adequate compensation of damage**: The EU requires that Member States provide for reasonable compensation for EU persons that suffer damage or harm, or are otherwise disadvantaged, by siting decisions in relation to power generation facilities and transmission lines.
j. **Access to finance on the merits**: Access to private and public finance is a function of the merits of power generation technologies. Privileges and discrimination in this area are eliminated.
k. **EU nuclear energy regulation for the new era**: EU nuclear energy regulations are reviewed and updated, as necessary, to ensure that they are fit for purpose and for the new era in power generation. Nuclear regulation is effective and efficient.
l. **EU nuclear liability and compensation program**: The EU enacts EU regulation on nuclear liability to ensure that there are additional incentives for prevention and that compensation is available if a nuclear accident were to happen.

Conclusions

1. The EU's 2050 climate neutrality strategy involves a high risk of policy failure. The anticipated energy transition, however, can hedge against this risk by deploying 'no regrets' solutions that are good investments, bring down emissions, and have little adverse impact. Nuclear power is such a solution.

2. With respect to both spatial requirements and costs, nuclear power offers substantial advantages over renewable power (wind, solar). These advantages have been recognized in the Czech Republic, but not (yet) by policy makers at the EU level and in The Netherlands.

References

1. BP Statistical Review of World Energy 2019, https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html
2. UK Office for National Statistics, The decoupling of economic growth from carbon emissions: UK evidence, https://www.ons.gov.uk/economy/nationalaccounts/uksectoraccounts/compendium/economicreview/october2019/thedecouplingofeconomicgrowth fromcarbonemissionsukevidence
3. UK Defra, UK's Carbon Footprint 1997-2017, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/918325/Consumption_emissions_March_20_fullycompatible.pdf
4. G.P. Peters et al., Carbon dioxide emissions continue to grow amidst slowly emerging climate policies, Nature Climate Change, Vol. 10, January 2020, pp. 2–10.
5. Pierre Friedlingstein et al., Global Carbon Budget 2019, Earth Syst. Sci. Data, 11, 2019, pp. 1783–1838.
6. Bjorn Lomborg, Impact of Current Climate Proposals, Global Policy, Volume 7, Issue 1, February 2016, pp. 109-116.
7. Joeri Rogelj, Michel den Elzen, Niklas Höhne, Taryn Fransen, Hanna Fekete, Harald Winkler, Roberto Schaeffer, Fu Sha, Keywan Riahi & Malte Meinshausen, Paris Agreement climate proposals need a boost to keep warming well below 2 °C, Nature, volume 534, pp. 631–639 (2016).
8. Global emissions have not yet peaked, Our World in Data, https://ourworldindata.org/co2-and-other-greenhouse-gas-emissions
9. United Nations Framework Convention on Climate Change, https://unfccc.int/resource/docs/convkp/conveng.pdf
10. Corinne Le Quéré et al., Global Carbon Budget 2018, Earth Syst. Sci. Data, 10, 2141–2194, 2018, https://doi.org/10.5194/essd-10-2141-2018
11. Pantelis Capros, Georgios Zazias, Stavroula Evangelopoulou, Maria Kannavou, Theofano Fotiou, Pelopidas Siskos, Alessia De Vita, Konstantinos Sakellaris, Energy-system modelling of the EU strategy towards climate-neutrality, Energy Policy 134 (2019) 110960.
12. Sepulveda, N.A. (2016), Decarbonization of Power Systems: Analyzing Different technological Pathways, Master Degree Thesis, Massachusetts, Institute of Technology (MIT).
13. Crippa, M., Guizzardi, D., Muntean, M., Schaaf, E., Solazzo, E., Monforti-Ferrario, F., Olivier, J.G.J., Vignati, E., Fossil CO_2 emissions of all world countries - 2020 Report, EUR 30358 EN, Publications Office of the European Union, Luxembourg, 2020, ISBN 978-92-76-21515-8, doi:10.2760/143674, JRC121460.
14. J.G.J. Olivier and J.A.H.W. Peters, TRENDS IN GLOBAL CO_2 AND TOTAL GREENHOUSE GAS EMISSIONS -- 2019 Report, PBL, May 2020.
15. IPCC (2014) (based on global emissions from 2010), Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
16. Pielke, R. (2019) "The World Is Not Going To Halve Carbon Emissions By 2030, So Now What?" https://www.forbes.com/sites/rogerpielke/2019/10/27/the-world-is-not-going-to-reduce-carbon-dioxide-emissions-by-50-by-2030-now-what/#5679ccc33794
17. IPCC, Special Report 1.5, 2019, available at https://www.ipcc.ch/site/assets/uploads/sites/2/2019/06/SR15_Full_Report_High_Res.pdf

1

Introduction

Introduction

The EU is committed to achieving climate neutrality (i.e. net zero greenhouse gas emissions[26]) by 2050. Electrification of the energy system is a key component of this strategy. This implies that the electricity (or power) system must be completely 'decarbonized' over the next three decades.

The European Commission did not indicate, however, what effect the EU's climate ambition would have on the problem of climate change, specifically, the average global atmospheric temperature increase caused by human greenhouse gas emissions, nor did it attempt to assess the land use and space demands and total cost of the contemplated energy transition.

Study Subject

This study assesses the effectiveness of EU climate neutrality, and analyses and compares two climate-neutral power-generating technologies that can result in decarbonization of the electricity system (assuming effective replacement of fossil fuel power generation) – renewable energy (wind/solar) and nuclear energy. Geographically, the study focuses on two Member States on opposite side of the spectrum for wind energy potential: The Netherlands, a country along the North Sea with abundant wind, and the Czech Republic, a landlocked country with no access to sea and less suitable land.

In these countries, we are assessing the power generation technologies concerned, renewable (wind/solar) and nuclear, with respect to their demand for land/space to generate a specified amount of electricity. In addition, we determine their costs, both

26 Note that net zero greenhouse gas emissions require net negative CO_2 emissions to compensate for on-going emissions of other GHGs.

the cost of power generation and, to a more limited extent, the integration- and system-related cost.

Study Relevance

The contemplated energy transition is not without risks in terms of both climate effectiveness and economic effects. In this study, we engage several key questions relevant to ensuring a successful and affordable energy transition within the EU. Since achieving climate neutrality will require unprecedented investments and expenses, it is essential that the EU pursue the 2050 climate neutrality mission in a cost-effective and efficient manner.

If there is significant uncertainty about the effect on the climate problem, and the response by non-EU countries is not a given, '*no regret*' solutions become more appealing. These kinds of solutions serve as a hedge against the risks associated with these uncertainties, since they remain good investments, irrespective of any positive effect they may have on the problem of climate change, thus, also in case the effect of the EU's transition on climate change appears to be negligible, or the 2050 zero GHG target would need to be abandoned or postponed during the transition period.

Structure of Report

Following this introduction, Part 2 of this report discusses the EU policy background against which the issues discussed here arise. Through this background analysis, we attempt to place the key questions addressed in this study firmly in the context of EU policies and policy-making. This part reviews the overarching policy principles relevant to policymaking in the climate area, the EU climate and energy policies. In addition, we focus specifically on the renewable energy policy, the sustainable finance initiatives, and nuclear power regulation, which are all directly relevant to the issues discussed in this report.

Subsequently, the research questions and their background are reviewed (Part 3). In this part, we also describe the objectives of our research, as well as the methodologies and data we have used to answer the research questions. The scope and limitations of this study are briefly reviewed too.

Part 4 covers the topic of EU climate neutrality's effect on the average temperature. We assume that there is a relation between greenhouse gas emissions and global warming. By way of introduction, we begin by discussing scientific uncertainty and policy uncertainty in the context of climate change. The objective is not to engage the science or policies as such, but rather to lay the groundwork for understanding the challenges the EU faces in this area. We then proceed to review the existing literature relevant to greenhouse gas (GHG) emissions, the EU's current and projected contributions to global GHG emissions, and the effect thereof on the average global atmospheric temperature.[27] The analysis of the expected effect of EU climate neutrality on the temperature can inform the policy choices facing the EU. We assess also the rate of renewable energy dispersion necessary to achieve climate neutrality in 2050, and an alternative to the current policy, called 'taking climate neutrality seriously,' which does not hinge on the mitigation efforts of other countries. To complete this section, we discuss the international context and the limiting conditions and restrictions it imposes on the EU.

In the subsequent parts of the report, the focus shifts to the comparison of wind/solar power and nuclear

27 This part does not address the relation between the average temperature and other possible changes in the climate system, such as sea level rise, ocean acidification, and extreme weather.

power with respect to, first, spatial requirements (i.e. the surface areas required by these technologies to produce a given amount of electricity) and then the cost of electricity (i.e. the cost of generating a given amount of electricity produced by a particular technology). We developed models to compute spatial requirements and costs; note that our cost model estimates only the cost of electricity generation, not the system-related costs associated with power generation technologies. These models are fully transparent and allow for reproducibility of the results. The model inputs can be varied to reflect a range of possible scenarios, and thus accommodate uncertainties. We provide explanations and justifications for the inputs used for the model, and contrast our model with other existing models. Sensitivity analysis is also presented.

In Part 5, we present the results of our modelling of spatial requirements for the Czech Republic and The Netherlands for wind/solar and nuclear power. These two countries differ substantially in their potential for renewable power -- The Netherlands is a country at the North Sea with abundant wind, both on land and on the North Sea off shore area that is part of Dutch territory, while the Czech Republic is a landlocked country with no access to sea and less suitable land for wind power. Before the model outputs are presented, a brief introduction and description of the policy background are provided to give the reader additional context. In the case of The Netherlands, we also discuss recent studies done for the Dutch government on spatial requirements of various renewable technologies. We present conclusions and further reflections at the end of this part.

We then turn to the cost of wind/solar and nuclear power (Part 6). Following an introduction and description of our cost model, we first discuss the costs of renewable and nuclear power in the Czech Republic and then turn to The Netherlands. For each country and each type of technology, the discussion covers the levelized cost of electricity (LCOE) model outputs. Subsequently, we identify the main drivers of LCOE, and any uncertainties and model limits. A discussion of our findings concludes each section. To be able to make accurate comparisons of the cost of electricity across the spectrum of different technologies, we use a novel method that we call "synchronized lifetime analysis." This method involves a conventional levelized cost of electricity (LCOE) calculation, modified by replacing power discounting by synchronizing power delivery in equal quantities across technologies. This part of the report discusses also the synchronized lifetime analysis model outputs.

In Part 7, the analysis focuses on the relations between electricity generation technologies, the electricity system as a whole, and the economy and society. The LCOE is not the only cost associated with the electricity system; in addition, there is significant cost associated with integrating power generation technology and its output into the power system, and this integration cost differs between various power technologies. There are also differences in terms of the broader effects of power generation technologies on the economy and society. This part presents a qualitative and limited quantitative discussion of these issues for wind/solar and nuclear power. We estimate integration costs of wind/solar and nuclear for The Netherlands, and present a case study of integration costs based on electricity prices. The discussion of other system-related cost focuses on land use-related issues and is qualitative. In an annex, an overview is presented of a wide range of impacts and externalities associated with wind, solar, and nuclear energy. This overview is intended to complete the range of considerations relevant to policy makers.

Part 8 presents a series of policy recommendations based on the findings of the study, as presented in previous parts. Before laying out these recommendations, we first provide brief explanations of the basics of the electricity system, power generation technologies, power delivery through the electricity network, load dispatch and merit order, the electricity market and the so-called 'merit order effect', the electricity bill for consumers, investing in private electricity generation markets, and subsidies, free-riding, and externalities in power markets. In these reviews, we zoom in on aspects of renewable and nuclear energy that are salient to energy policy-makers. Our policy recommendations are aimed at establishing a technology-neutral, non-discriminatory framework for electricity generation.

The conclusions are set forth in the Part 9. We wish to point out here that the analysis of the relative spatial and cost requirements of wind/solar and nuclear energy does not depend on the merits of the EU climate neutrality policy; these parts of the study can be read as stand-alone assessments. Thus, the conclusions on the relative spatial and cost requirements of wind/solar and nuclear energy do not hinge or build on the conclusions on the effect of EU climate neutrality.

We have added a list of references as Part 10 and over a dozen annexes that provide further details and back-up relevant to the models utilized for this analysis and other topics. For the reader's convenience, a glossary and list of abbreviations are included, alongside a table that links the research questions to specific sections of this report.

This report is intended to assist the reader in understanding the key issues associated with wind, solar and nuclear energy. To achieve this objective, we had to cover a lot of ground. Not all readers will read it cover to back without putting it down. A detailed table of contents, a brief executive summary, and an extensive summary can help them to identify those parts in which they take specific interest.

Before getting into the substance, we wish to assure the reader that we, unlike some of the authors we criticize, have attempted consistently to avoid hidden value judgments and prejudging. This report lets facts and numbers speak without trying to massage and bend them to fit preconceived policy preferences. As such, it offers another perspective on the cost of nuclear power that is more realistic and respectful of the choices that policy makers face.

The report was finalized on 30 November 2020.

2

Relevant EU Policies

Relevant EU Policies

As discussed in the introduction, this study examines (i) the effect of EU climate neutrality on the average global atmospheric temperature by 2050, (ii) analyzes the land and space requirements for wind and solar electricity in the Czech Republic and The Netherlands, relative to the land required for the same amount of nuclear power, and (iii) compares the cost of wind/solar power to the cost of nuclear power for these two countries.

EU laws and policies are relevant to these issues in several ways, both directly and indirectly. In this section, we provide an introduction to these EU laws and policies. The objective of this analysis is to place the topics of this study in their policy context, which has a bearing on both answering the question posed and interpreting the answers to these questions.

The first section briefly discusses some overarching policy principles that have helped to shape the specific policy areas. The EU climate policy, including the Green Deal and EU Climate Law are reviewed in the second section. In the third section, we turn to the EU energy policy, including the EU Energy Union. The fourth part deals specifically with the EU laws and policy regarding renewable energy. Section five reviews the EU sustainable finance initiatives, which are also relevant to the financing of energy projects. In the sixth part, we discuss the EU regulatory framework for nuclear electricity. The final part presents some conclusions on these policies.

a. Overarching Policy Principles

Many of the EU's climate and energy policies, directly or indirectly, in one way or another, can be traced back to an undefined principle set out in the EU Treaty. The pertinent provision stipulates as follows:

*"The Union shall establish an internal market. It shall work for the **sustainable development** of Europe based on balanced economic growth and price stability, a highly competitive social market economy, aiming at full employment and social progress, and a high level of protection and improvement of the quality of the environment."* [28] *(emphasis supplied).*

The Treaty on the Functioning of the European Union works this out further by requiring that sustainable development be promoted by integrating environmental protection requirements into "the definition and implementation of the Union's policies and activities."[29]

In addition, the EU has adopted several generic policy principles that apply to all EU policies or, by their terms, only to environmental policies, although their scope of application may be broader. The former includes principles such as **proportionality, equality before the law, legal certainty, and subsidiarity**. Although these principles are relevant to the subject of this study, they are not further discussed here.

The EU's principles for environmental policy-making apply to all environmental, many health and safety, and most climate-related policies. They are intended to inform legislation and policy-making relating to environmental protection and sustainable development. There are five such principles:

- The ***precautionary principle***, which allows regulatory action to be taken even if a risk has not been established with full certainty, and is applied to manage risk in cases of scientific uncertainty.
- The ***prevention principle***, which aims to prevent environmental and climate-related damage, including harm to protected species, natural habitats, water and soil, or harm due to climate change.
- The ***rectification at source principle***, which seeks to prevent pollution at its source, rather than address it at the 'end-of-pipe' or remedy its effects.
- The ***polluter pays principle***, which implements the concept of 'internalizing negative externalities,' and requires that polluters pay for the costs of the pollution they cause.[30]
- The ***integration principle***, which requires that environmental protection requirements be integrated into other EU policies, in particular with a view to promoting sustainable development.[31]

Much can be said about each of these principles, but for purposes of this study a few comments suffice. The precautionary, prevention, and polluter pays principles have shaped the EU's climate policies in important ways. There is scientific uncertainty about the magnitude and seriousness of the impact of human activities on climate change, but the precautionary principle allowed the EU to move ahead with its ambitious programs despite the causal uncertainties. Obviously, some of the EU's climate-related policies are underpinned by the prevention principle, such as those relating to fluorinated gases. In relation to the polluter pays principle, it has been argued by a former top climate official of the European Commission that the theory of cost internalization has been the main instrument of EU climate policy.[32]

28 Article 3(3), Treaty on European Union.

29 Article 11, Treaty on the Functioning of the European Union (TFEU).

30 Article 191(2) of TFEU.

31 Article 11, TFEU.

32 "In the 1990s, economists were actively looking at how to improve environmental policymaking, and made a strong case for putting a price on the impacts of pollution that are not otherwise paid for by the polluter ("pricing environmental externalities")." Jos Delbeke and Peter Vis (editors), EU Climate Policy Explained, European Union, Brussel, 2016, available at https://ec.europa.eu/clima/sites/clima/files/eu_climate_policy_explained_en.pdf

The integration principle is perhaps the least visible in the EU policies at issue here. As discussed in the conclusions of this part and throughout this report, there appear to be tensions, if not conflicts, between the objectives and requirements of climate and environmental policies and those of other policies, but, remarkably, it is not necessarily so that the former always do a better job of promoting sustainable development.

b. EU Climate Policy

Climate change is believed by EU policy makers to pose serious risks to humanity and the survival of the plant, but is also viewed as an opportunity. At the presentation of the EU Green Deal, echoing the European Parliament's resolution,[33] Climate Commissioner Frans Timmermans even stated: *"We are in a climate and environmental emergency. The European Green Deal is an opportunity to improve the health and well-being of our people by **transforming our economic model**"*[34]. *(emphasis supplied)* The EU intends to "move fast and move first" in addressing climate change and becoming the world's first climate neutral continent.

Instruments

The EU's climate strategy has several main prongs: emissions trading under the '*cap and trade*' program established by the Emissions Trading System[35] (which covers power plants), energy and resource efficiency, renewable energy, energy saving (demand reduction), industry decarbonization, other mitigation strategies, and adaptation.[36] Other instruments to fight climate change include national targets for sectors outside emissions trading (such as transport, buildings and agriculture), forest and land policies, CO_2 emission standards for vehicles, increasing energy efficiency of buildings and products, promoting innovative low-carbon technologies, phasing down climate-warming fluorinated greenhouse gases and protecting the ozone layer, adapting to the impacts of climate change, and funding climate action.[37]

In its communication on *The European Green Deal*, the Commission envisions that the electricity sector in 2050 will be "*largely based on renewable sources.*"[38] More specifically, in 2018, the Commission predicted that "[b]y 2050, more than 80 % of electricity will be coming from renewable energy sources (increasingly located off-shore), … with a nuclear electricity share

33 European Parliament resolution of 28 November 2019 on the climate and environment emergency (2019/2930(RSP), available at https://www.europarl.europa.eu/doceo/document/TA-9-2019-0078_EN.pdf

34 The European Green Deal sets out how to make Europe the first climate-neutral continent by 2050, boosting the economy, improving people's health and quality of life, caring for nature, and leaving no one behind, Press Release, 11 December 2019, available at https://ec.europa.eu/commission/presscorner/detail/e%20n/ip_19_6691

35 Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a system for greenhouse gas emission allowance trading within the Union and amending Council Directive 96/61/EC, OJ L 275, 25.10.2003, pp. 32–46, as amended. The ETS applies to emissions from approximately 11,000 heavy energy-using installations, including power stations & industrial plants, covering around 45% of the EU's greenhouse gas emissions.

36 European Commission, Climate strategies & targets, available at: https://ec.europa.eu/clima/policies/strategies_en

37 EU climate action and the European Green Deal, available at https://ec.europa.eu/clima/policies/eu-climate-action_en

38 "A power sector must be developed that is based largely on renewable sources, complemented by the rapid phasing out of coal and decarbonising gas. At the same time, the EU's energy supply needs to be secure and affordable for consumers and businesses. For this to happen, it is essential to ensure that the European energy market is fully integrated, interconnected and digitalised, while respecting technological neutrality." European Commission, The European Green Deal, 2019, COM(2019) 640 final

In 2018, the Commission predicted that "by 2050, more than 80 % of electricity will be coming from renewable energy sources (increasingly located off-shore), ... with a nuclear power share of circa 15 %.

of circ. 15 %."[39] While emphasizing technological neutrality, the Commission did not analyze, however, how much land and space would be required for that much renewable energy production, how much these energy options could contribute towards achieving carbon neutrality, and how electricity prices would be affected. This study attempts to begin to fill these gaps.

A first of its kind, the proposed EU Climate Law,[40] would make the climate neutrality objective of the European Green Deal binding. Under this draft law, the EU member states jointly would have to achieve net zero greenhouse gas emissions by 2050. The law attempts to coordinate other relevant EU policies so that they contribute to this goal, and "to move in a fair and ***cost-effective*** manner towards the temperature goal of the 2015 Paris Agreement on Climate Change" ensuring "a socially-fair and ***cost-efficient*** transition"[41]. *(emphasis supplied).* Importantly, the proposed Climate Law requires that the EU and Member States, in taking measures to achieve the climate-neutrality goal, take into account:

*"the contribution of the transition to climate neutrality to the **well-being of citizens**, the **prosperity of society** and the **competitiveness of the economy; energy security** and **affordability**; ... **cost-effectiveness and technological neutrality** in achieving greenhouse gas emissions reductions and removals and increasing resilience."*[42] *(emphasis supplied).*

The European Commission uses the term "climate neutrality" because it will likely be impossible to eliminate 100 % of fossil fuels; to achieve climate neutrality the CO_2 emitted by the remaining fossil fuel use must be "neutralised" either by storing it (so-called "carbon capture and storage" or CCS technology) or reuse it in a non-emitting application. Both of these solutions have not yet been demonstrated to be economically feasible at reasonable cost.

39 "The global expansion of renewable energy, instigated by EU leadership, led to massive cost decreases in the last 10 years, in particular in solar and on- and off-shore wind. Today, more than half of Europe's electricity supply is free from greenhouse gas emissions. By 2050, more than 80 % of electricity will be coming from renewable energy sources (increasingly located off-shore). Together with a nuclear power share of ca. 15 %, this will be the backbone of a carbon-free European power system." European Commission, A Clean Planet for All, 2018, COM(2018) 773 final

40 Proposal for a REGULATION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL establishing the framework for achieving climate neutrality and amending Regulation (EU) 2018/1999 (European Climate Law), COM/2020/80 final (the "EU Climate Law"), available at https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1588581905912&uri=CELEX:52020PC0080 Note that the term "Law" is strange, as the EU Treaty does not contemplate any "Law." Article 288 of the Treaty on European Union provides that "[t]o exercise the Union's competences, the institutions shall adopt regulations, directives, decisions, recommendations and opinions." There is no reference to a "Law.".

41 Recitals 3 and 8, EU Climate Law.

42 Recital 15, EU Climate Law. Cf. Article 3(3), which requires that the Commission, when setting a trajectory to transition towards climate neutrality, must consider "(a) cost-effectiveness and economic efficiency; (b) competitiveness of the Union's economy; (c) best available technology; (d) energy efficiency, energy affordability and security of supply; (h) the need to ensure a just and socially fair transition; [and] (i)international developments and efforts undertaken to achieve the long-term objectives of the Paris Agreement and the ultimate objective of the United Nations Framework Convention on Climate Change."

The proposed EU Climate Law requires that the transition to climate neutrality be fair and cost-effective, as well as cost-efficient, and contributes to prosperity, competitiveness, energy security, energy affordability, and technological neutrality. How the Climate Law would ensure that these conditions are met, is unclear.

Progress towards climate neutrality would be assessed every five years, in line with the 'global stocktake' exercise under the Paris Agreement. The proposed Climate Law, which references the EU's renewable energy initiatives,[43] is pending before the EU legislature under the ordinary legislative procedure.[44]

The Electricity Mix

Indeed, renewable energy has been a key element of the EU's climate policy, but it is not entirely uncontroversial. Renewable energy sources include wind electricity, solar electricity and biomass.[45] All three of these sources of energy utilize natural phenomena as energy, and two of them do not emit CO_2 during operation, but all three have drawbacks that affect their cost/benefit-ratio and, in some cases, limit their deployment.[46]

Although the Commission foresaw a 15 % nuclear electricity share in the total energy mix in its 2018 "A Clean Planet for All" communication, it did not address nuclear electricity in *The Green Deal*. Due to its high power density, nuclear power may offer advantages over renewable electricity as far as land usage requirements are concerned. The cost of electricity production, however, is also a main concern and "energy poverty" has become a concern of European policy makers (see further below). An evidence-based comparison of the land/space demand and cost of wind/solar and nuclear, which, as noted, has not yet been released by the EU, would aid policy makers.

c. EU Energy Policy

In addition to the EU climate policy, its energy policy shapes the transition to a carbon-neutral economy by 2050.

43 "The Union has, through the 'Clean Energy for All Europeans' package been pursuing an ambitious decarbonisation agenda notably by constructing a robust Energy Union, which includes 2030 goals for energy efficiency and deployment of renewable energy in Directives 2012/27/EU 30 and (EU) 2018/2001 31 of the European Parliament and of the Council, and by reinforcing relevant legislation, including Directive 2010/31/EU of the European Parliament and of the Council." Recital 9, EU Climate Law.

44 The European Parliament's legal service has opined that the proposed delegation of powers to the European Commission under the Climate Law would be unlawful under the Treaty. See Non-paper on the choice of delegated acts to set out the trajectory for achieving climate neutrality in the proposal for a European Climate Law [2020/0036(COD)], 31 March 2020, available at https://www.politico.eu/wp-content/uploads/2020/04/Climate-law-paper-NON_PAPER.pdf?utm_source=POLITICO.EU&utm The Council's legal service has taken the same position.

45 The official definition set forth in Article 2(1) of Directive 2018/2001 defines renewable energy as "energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas."

46 Part 8 discusses the impacts of the various power generation technologies at issue in this study.

The Treaty on the Functioning of the EU defines the powers of the EU in relation to energy policy.[47] It also defines the powers that are reserved to the Member States, where it states that measures adopted by the EU legislature "shall not affect a Member State's right to determine the conditions for exploiting its energy resources, its choice between different energy sources and the general structure of its energy supply,"[48] except if measures are adopted unanimously, in which case they may "significantly affect a Member State's choice between different energy sources and the general structure of its energy supply."[49] Thus, EU measures that restrict the Member States' right to choose between energy sources and to structure the energy supply require unanimity.[50]

Under the heading of the 'Energy Union,' the EU is pursuing integration of the member states' energy markets, and policies to ensure energy security of supply, improve energy efficiency, and decarbonise the economy.[51] Through the Energy Union program, the EU attempts to ensure greater coherence in all policy areas to achieve a "***reliable, affordable and sustainable*** energy system"[52] *(emphasis supplied).*

Objectives

More specifically, the Energy Union is aimed at five objectives:

i. *integration of the EU internal energy market* (i.e. enabling energy to be transmitted throughout the EU through transmission and other infrastructure and without technical or regulatory barriers);

ii. *diversification of sources of energy* and ensuring *energy security*;

iii. *improving energy efficiency* to reduce energy consumption and lower emissions;

The Energy Union is aimed at diversification of sources of energy, ensuring energy security, improving energy efficiency, and ensuring energy affordability.

---

47 Article 194(1) TFEU provides as follows: "In the context of the establishment and functioning of the internal market and with regard for the need to preserve and improve the environment, Union policy on energy shall aim, in a spirit of solidarity between Member States, to: (a) ensure the functioning of the energy market; (b) ensure security of energy supply in the Union; (c) promote energy efficiency and energy saving and the development of new and renewable forms of energy; and (d) promote the interconnection of energy networks.

48 Article 194(2), TFEU.

49 Article 192(2)(c), TFEU.

50 There is a legal issue as to whether all EU energy legislation meets this Treaty requirement, which is not further discussed here.

51 "The energy union strategy ..., a key priority of the Juncker Commission (2014-2019), aims at building an energy union that gives EU consumers - households and businesses - secure, sustainable, competitive and affordable energy." COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE, THE COMMITTEE OF THE REGIONS AND THE EUROPEAN INVESTMENT BANK A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy, Brussels, 25.2.2015, COM/2015/080 final, available at https://eur-lex.europa.eu/resource.html?uri=cellar:1bd46c90-bdd4-11e4-bbe1-01aa75ed71a1.0001.03/DOC_1&format=PDF European Commission, ENERGY UNION PACKAGE: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL, The Paris Protocol – A blueprint for tackling global climate change beyond 2020, Brussels, 25.2.2015, COM(2015) 81 final, SWD(2015) 17 final.

52 European Union, Energy, available at https://europa.eu/european-union/topics/energy_en

iv. *decarbonization* of the energy system and broader economy; and

v. financial support for R&D into *low-carbon and clean energy* technologies to drive the energy transition.[53]

By its own terms, the 2019 EU Electricity Regulation, sets "the basis for an efficient achievement of the objectives of the Energy Union and in particular the climate and energy framework for 2030 by enabling market signals to be delivered for increased efficiency, higher share of renewable energy sources, security of supply, flexibility, sustainability, decarbonisation and innovation."

To ensure policy coherence, the EU attempts to coordinate energy policy also with other policies. Climate policy, of course, is an area that closely relates to energy policy. As noted above, one of the objectives of the EU's energy policy is to decarbonize the energy system. The EU electricity market legislation is also aimed at facilitating the objectives of the Green Deal by enabling further electrification of the energy system.[54] Conversely, the EU climate policy also refers back to the EU energy policy. In the 'Green Deal' Communication, for instance, the European Commission recognizes the importance of energy security and competitiveness.[55]

Energy security

Energy security, i.e. security of energy supply and delivery, is a key element of the EU energy policy. The shift toward renewable energy creates additional challenges for energy security, however. As the European Commission explains, "[a] key role is to encourage cross-border cooperation and interconnections to make energy flow more smoothly across the whole of the EU. When there is no sun or wind to produce electricity, it is key for an EU country to be able to rely on imports of electricity produced in a neighbouring EU country."[56] Of course, if there is significant statistical dependence between wind and solar strength in two neighboring countries, import will not be of much help in securing adequate supply.

In any event, expansion of cross-border transmission is a key element of the EU's electricity market policy. In order for that to work, the neighbouring EU Members States to which the Commission refers, should be able to deliver electricity to its neighbour at that time, which may be challenging if that country also overrelies on variable renewable electricity.[57] Needless to say, the expansion of the transeuropean transport infrastructure will involve substantial costs.[58]

Capacity mechanisms

In addition to increased cross-border transmission, to address the issue of the electricity supply becoming unreliable with the advance of renewable electricity,

---

53 European Commission, Energy union, available at https://ec.europa.eu/energy/topics/energy-strategy/energy-union_en?redir=1

54 As the European Commission puts it, the EU electricity legislation contributes to "the EU's goal of being the world leader in energy production from renewable energy sources by allowing more flexibility to accommodate an increasing share of renewable energy in the grid. The shift to renewables and increased electrification is crucial to achieve carbon neutrality by 2050." European Commission, Electricity market design, https://ec.europa.eu/energy/topics/markets-and-consumers/market-legislation/electricity-market-design_ro#the-electricity-directive-and-electricity-regulation

55 European Commission, COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE EUROPEAN COUNCIL, THE COUNCIL, THE EUROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS, The European Green Deal, Brussels, 11.12.2019, COM/2019/640 final ("[The EU] recognizes the need to maintain its security of supply and competitiveness …"

56 European Commission, In focus: Energy Security in the EU, https://ec.europa.eu/info/news/focus-energy-security-eu-2020-avr-27_en

57 The European Commission does not address this issue explicitly, but seems to suggest that energy storage could be a solution too.

58 In addition to costs, there will be delays. This study does not address these issues.

Capacity payments distort markets and price signals, and add to the total costs of the power system. These payments help to alleviate the risks posed by an electricity market characterized by increasing penetration levels of variable renewable energy.

the EU uses several policy instruments aimed at maintaining a functioning electricity market with high penetration of variable renewable energy. An important instrument is the system of so-called '***capacity mechanisms***,' i.e., payments made to power plants to be available for generating electricity when needed, not for electricity generated. These mechanisms are highly relevant to an electricity system dominated by renewable energy. Recent EU electricity legislation[59] revised the eligibility criteria for power plants in order to be eligible for subsidies[60] for capacity mechanisms by imposing a maximum CO_2 emission limit.

Capacity payments can help to alleviate the risks posed by an electricity market characterized by increasing penetration levels of variable renewable energy.[61] These kinds of payments, however, are also bound to create inefficiencies by distorting markets and price signals,[62] and add to the total cost of the electricity system. To limit these adverse effects, the EU has put in place an EU-wide assessment process for such mechanisms.[63]

Demand response

To facilitate the transition to renewable electricity, member states may also use "demand response" measures, defined as "the change of electricity load by final customers from their normal or current consumption patterns in response to market signals, including in response to time-variable electricity prices or incentive payments."[64] For instance, to accommodate the intermittency of renewable electricity, member states may use financial incentives

59 Directive 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, OJ L 158, 14.6.2019, pp. 125–199. Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity, OJ L 158, 14.6.2019, pp. 54–124.

60 Subsidies to generation capacity emitting 550gr CO_2/kWh or more are to be phased out.

61 Bhagwat, Pradyumna C ; Marcheselli, Anna ; Richstein, Jörn C ; Chappin, Emile J.L ; De Vries, Laurens J, An analysis of a forward capacity market with long-term contracts, Energy policy, 2017, Vol. 111, pp. 255-267 ("Capacity markets can compensate for the deteriorating incentive to invest in controllable power plants when the share of variable renewable energy sources grows.")

62 Article 3 of the Electricity Regulation provides that "prices shall be formed on the basis of demand and supply; market rules shall encourage free price formation and shall avoid actions which prevent price formation on the basis of demand and supply; [and] market rules shall facilitate the development of more flexible generation, sustainable low carbon generation, and more flexible demand." Article 3, Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity, OJ L 158, 14.6.2019, p. 54–124

63 This assessment should be based on the latest calculation of future supply-demand scenarios, and take into account the availability of renewable energy sources, demand side flexibility and cross-border infrastructure in times of system stress. Regulation (EU) 2019/943 of the European Parliament and of the Council of 5 June 2019 on the internal market for electricity, OJ L 158, 14.6.2019, pp. 54–124.

64 Article 2, under 20, Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU, OJ L 158, 14.6.2019, p. 125–199.

(including selling electricity at a negative price) for consumers to use electricity when the sun shines or the wind blows, or disincentives (higher prices) when there is not enough electricity to meet all demand. These price fluctuations may pose challenges for some consumers, and adversely affect energy affordability.

In addition, demand response, in a broad sense, can also be utilized to help ***balance the grid***. For instance, when there is excessive production of wind and solar electricity, this electricity could be stored in the batteries of electric cars; consumers could be given incentives to permit this or even be required by law to permit it. Conversely, as a last resort, in times of low electricity production, consumers could be subject to power rationing or be cut off from the grid, with or without their permission.[65]

To fully implement these policies, the existing electricity grid will have to be reshaped. Although such a new "smart grid" is technically feasible, it will probably entail very substantial cost, which will have to be borne by consumers or tax payers. If governments choose to spare industrial consumers so as to maintain their competitiveness on global markets, the cost burden will have to be carried by households and other small consumers. As a result, the issue of energy poverty may become more acute and necessitate other support measures.

Energy independence

Energy dependence is viewed as a threat to the security of the energy supply. One author has called it "the biggest threat" and "the toughest challenge of all."[66] During the last couple of decades, energy dependence has typically been debated as an issue of dependence on Russian gas imports. The main sources of gas for the EU as a whole are imported LNG and Russian pipeline gas; these two will remain the two main sources of gas up to 2030. There will only be limited quantities of non-Russian pipeline available for the EU before 2025.[67] Nevertheless, the European Union has worked to expand gas interconnections to enable a more fluid and dynamic gas market.

EU energy independence can be enhanced by moving away from imports of fossil fuels, and increasing domestic production of fuels and electricity. The latter can be achieved by adding wind, solar, and nuclear capacity. Domestically produced biofuels can help to reduce the dependence on fossil fuels in transportation. In theory, nuclear electricity can also be used to produce hydrogen, when the demand for electricity is low (e.g. during night time).[68]
The EU's energy independence ambition, however, needs to be balanced against other objectives, such as diversification, affordability, and security.

65 In the UK, the concern is that consumers could be cut off without their consent: "The revelation that smart meters could allow energy networks to switch off central heating systems has sparked a debate on whether Britain's use of the appliances should be reviewed." 'They're a scam, we should follow the Swiss model', Telegraph, 21 September 2020, available at https://www.telegraph.co.uk/news/2020/09/21/scam-should-follow-swiss-model-telegraph-readers-smart-meters/

66 Vladimir Urutchev, Energy Dependence: The EU's Greatest Energy Security Challenge?, European View (2014) 13:287–294, available at https://doi.org/10.1007/s12290-014-0319-1

67 European Parliament, Policy Department A for the Committee on Industry, Research and Energy (ITRE), EU Energy Independence, Security of Supply and Diversification of Sources, Proceedings of a workshop, Brussels, 6 February 2017, IP/A/ITRE/2016-07, available at https://www.europarl.europa.eu/RegData/etudes/STUD/2017/595367/IPOL_STU(2017)595367_EN.pdf#:~:

68 See, however, Samuel Furfari, The Hydrogen Illusion, September 2020 (arguing that "the use of hydrogen to store and then produce electricity, but also as a fuel, will not happen for obvious economic and safety reasons" and that "this illusion is, above all, a mistake used to cover up a previous mistake on intermittent renewable energies").

Technology neutrality

Although it has not been articulated as an overarching principle, technology neutrality has also shaped EU energy policy. This concept allowed EU member states to pursue different energy technologies within their territories, with countries such as France investing in nuclear power, and Eastern European countries investing in coal-fired power plants.[69]

With the drive towards decarbonization of the energy system, fossil fuel-fired power plants (without carbon capture, removal, or storage facilities) will have to be phased out in the EU. All carbon-neutral energy options, however, are open to the EU member states, although, as discussed below, renewable energy receives preferential treatment. Nevertheless, technology neutrality is still an important element of EU policies. As the Commission's Green Deal communication puts it:

"At the same time, the EU's energy supply needs to be secure and affordable for consumers and businesses. For this to happen, it is essential to ensure that the European energy market is fully integrated, interconnected and digitalised, while ***respecting technological neutrality****."*

Indeed, technological neutrality is critically important to ensure that all carbon neutral technologies can compete on their own merits. In this respect, the Renewable Energy Directive, which excludes nuclear energy, raises questions.[70]

Reliability and risk

Reliability and resilience, of course, are also important objectives of the European electricity system. Reliability is essential for the entire system, from electricity generation and the transmission system to cross-border interconnections and the local grid.

Reliability requires, among other things, that operators are ready to address risks when they arise. The EU has realized that risk preparedness has become essential in an electricity market dominated by renewable electricity. In 2019, the Regulation on risk preparedness in the electricity sector was adopted.71 Under the Regulation, Member States are required to prepare plans for how to deal with potential future electricity crises, and put the appropriate tools in place to prevent, prepare for and manage these situations.72 These assessments must address seasonal and short-term adequacy, and cover, inter alia, "*variability of production of energy from renewable sources*" and "*the probability of the occurrence of an electricity crisis*."

Energy Poverty

Energy poverty, of course, is closely related to energy affordability.[73] The EU made the ***prevention of energy***

69 As the Australian government stated in 2015 Energy White Paper, a 'technology-neutral policy and regulatory framework support[s] new energy sources and enable change, innovation and transformative technologies." Energy White Paper maps Australia's powerful future, 8 April 2015, available at https://www.minister.industry.gov.au/ministers/macfarlane/media-releases/energy-white-paper-maps-australias-powerful-future

70 Current EU climate policy is not technology-neutral, because it favors renewable energy. There is nothing inherent to climate policy, however, that requires any such technology bias; policy could merely stipulate performance requirements.

71 Regulation (EU) 2019/941 of the European Parliament and of the Council of 5 June 2019 on risk-preparedness in the electricity sector and repealing Directive 2005/89/EC, OJ L 158, 14.6.2019, pp. 1–21.

72 Article 8 of Regulation 2019/941 requires that a methodology for short-term and seasonal adequacy assessments be adopted.

73 A 2019 poll shows that 89 % of EU citizens agree that the EU must ensure access to affordable energy, such as ensuring competitive market prices, in particular to reduce the number of people unable to pay their energy bills. Special Eurobarometer 492 2019, available at https://op.europa.eu/en/publication-detail/-/publication/b891cfb7-d50f-11e9-b4bf-01aa75ed71a1/language-en?WT.mc_id=Searchresult&WT.ria_c=37085&WT.ria_f=3608&WT.ria_ev=search

poverty a policy priority in the 2019 'Clean Energy for all Europeans' package.[74] Energy poverty is defined with reference to adequate warmth, cooling, lighting and the energy to electricity appliances, which are regarded as essential services. The EU established an Energy Poverty Observatory to alleviate this issue.[75]

Pursuant to the Regulation on the governance of the energy union and climate action (EU/2018/1999), the Member States were required to submit National Energy and Climate Plans (NECPs) to the European Commission by the end of 2019. In addition to topics such as policies regarding energy efficiency, renewables, greenhouse gas emissions reductions, interconnections, and research and innovation, these plans are also to address energy poverty, including specific national objectives on energy poverty. The Czech NECP notes that energy poverty has been decreasing since 2005, and is lower than the EU average.[76] According to the Dutch NECP, "[a]lthough there is no specific policy in the field of energy poverty, there is a scheme that prevents people who cannot pay their energy bill (or pay it on time) from being disconnected."[77] These NECPs do not discuss whether, and, if so, to what extent, increasing the share of renewable energy sources in the electricity mix affects energy poverty.

Nuclear energy

Despite the fact that nuclear energy can be traced back to the origins of the EU,[78] the EU legislation on the electricity markets tolerates nuclear energy, but does not deal with it specifically. It only refers to nuclear in passing and in connection with fossil fuel power plant, where it refers to the past:

"Historically, the electricity system was dominated by vertically integrated, often publicly owned, monopolies with ***large centralised nuclear or fossil fuel power plants****. The internal market for electricity, which has been progressively implemented since 1999, aims to deliver a real choice for all consumers in the Union new business opportunities and more cross-border trade, so as to achieve efficiency gains, competitive prices and higher standards of service, and to contribute to security of supply and sustainability."*[79]

d. EU Renewable Energy Policy

In the context of this study, an important piece of EU legislation is the 2009 Renewable Energy Directive (RED-I).[80] RED-I sets rules for the EU to achieve 20 % renewable energy by 2020 – by the end of this year, the EU as a whole must meet at least 20 % of its total energy needs with renewable energy by 2020. This EU-wide target has been achieved through the

---

74 European Commission, Clean Energy for all Europeans package, March 2019, available at https://op.europa.eu/en/publication-detail/-/publication/b4e46873-7528-11e9-9f05-01aa75ed71a1/language-en/format-PDF/source-164711015

75 European Energy Poverty Observatory, available at https://www.energypoverty.eu/about/what-energy-poverty

76 "The share of households that could not maintain sufficient thermal comfort decreased from 11 % in 2005 to 5 % in 2016 and the number of households with energy bill arrears fell from 5 % in 2005 to 2 % in 2016." Czech Republic, National Energy and Climate Plan 2021-2030, Nov. 2019, available at https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en#final-necps

77 The Netherlands, National Energy and Climate Plan 2021-2030, Nov. 2019, available at https://ec.europa.eu/energy/topics/energy-strategy/national-energy-climate-plans_en#final-necps

78 Euratom is the European Atomic Energy Community. It was established in 1958 by the Treaty establishing the European Atomic Energy Community, which was one of the Treaties of Rome. Euratom was intended to create a common market for the development of the peaceful uses of atomic energy. Initially, this common market was limited to Belgium, France, West Germany, Italy, Luxembourg, and The Netherlands. Afterwards, Euratom was expanded to include all EU Member States; its powers have also been expanded over time. As with the other treaties, the European Commission is the guardian of the Euratom Treaty.

79 Recital 2, Electricity Regulation.

80 Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, OJ L 140, 5.6.2009, p. 16–62.

The Renewable Energy Directive is intended to (i) provide long-term certainty for investors, (ii) speed up permitting procedures for renewable energy projects, (iii) increase market integration of renewable electricity, and (iv) accelerate the uptake of renewables in the heating/cooling and transport sectors.

attainment of individual national targets, which vary between member states as a function of their economic capabilities and their renewable energy potential. EU member states are also required to ensure that at least 10 % of their transport fuels come from renewable sources by 2020.

Following the Paris Agreement on Climate Change and as part of the 'Clean Energy for All Europeans' package, in December 2018, a revised Renewable Energy Directive (RED-II) entered into force.[81] RED-II sets a new binding renewable energy target for the EU for 2030 of at least 32 %, with a clause for a possible upwards revision by 2023.[82] It also imposes an increased 14 % target for the share of renewable fuels in transport by 2030, while amending the criteria for bioenergy sustainability so as to limit in particular the use of first generation biofuels. Pursuant to the Regulation on the Governance of the Energy Union and Climate Action,[83] the member states must submit a 10-year integrated national energy and climate plan (NECP) for 2021-2030 demonstrating how they will meet the new 2030 targets for renewable energy and for energy efficiency. The member states must transpose RED-II into national law by 30 June 2021.

Under RED-II, the EU framework for renewable energy pursues economic and financial policy objectives aimed at promoting renewable energy. The new framework is intended to (i) provide long-term certainty for investors, (ii) speed up permitting procedures for renewable energy projects, (iii) increase market integration of renewable electricity, and (iv) accelerate the uptake of renewables in the heating/cooling and transport sectors, and (v) encourage consumers to produce and consume their own renewable energy ("self-consumption") and to act jointly through "renewable energy communities."[84]

81 Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources, OJ L 328, 21.12.2018, p. 82–209 ("RED-II").

82 The Commission has initiated the revision process. EU renewable energy rules – review, https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/12553-Revision-of-the-Renewable-Energy-Directive-EU-2018-2001

83 Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council, OJ L 328, 21.12.2018, p. 1–77.

84 RED-II. See also European Commission, Fact sheet The Revised Renewable Energy Directive, available at https://ec.europa.eu/energy/sites/ener/files/documents/directive_renewable_factsheet.pdf

By way of example, RED-II promotes renewable energy in the following ways:

- *Renewable support schemes* – To reach or exceed the renewable target, a member state may apply support schemes. Support schemes for electricity from renewable sources must provide incentives for and maximize the integration of electricity from renewable sources in the electricity market. Direct price support is to be granted in the form of a market premium.[85] The level of, and the conditions attached to, the support granted to renewable energy projects may not be revised in a way that negatively affects the rights conferred thereunder and undermines the economic viability of projects that already benefit from support; the level of support may be adjusted only in accordance with objective criteria set forth in the original design of the support scheme.[86]

- *Administrative procedures* – National rules regarding the authorization, certification and licensing procedures that are applied to renewable energy projects must be objective, transparent, proportionate and necessary. Administrative procedures are to be streamlined and expedited; predictable timeframes must be established. The particularities of individual renewable energy technologies are to be taken into account.[87] At the volition of applicants, a dedicated national contact person must provide guidance and facilitate the entire administrative permit application and granting process.[88]

It should be noted that RED-II defines "energy from renewable sources" as ''energy from renewable sources' or 'renewable energy', which means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas.[89] This definition, of course, does not cover nuclear electricity. Consequently, nuclear electricity projects do not benefit from the national support schemes and simplified and expedited administrative procedures.

While RED-I imposed an obligation on each Member State to reach an individualized target, RED-II works differently. RED-II imposes only an EU-wide obligation. Under other EU legislation, Member States are required to submit national energy and climate plans (NECPs) for 2021-2030, outlining how they will meet the new 2030 targets for renewable energy and for energy efficiency.[90]

e. EU Sustainable Finance Initiatives

Since financing plays a pivotal role in energy markets, the EU's initiatives on sustainable finance deserve attention. In March 2018, the European Commission adopted an Action Plan on financing sustainable growth.[91] This Action Plan is aimed at (i) reorienting capital flows towards sustainable investment in order to achieve sustainable and inclusive growth; (ii) manage financial risks stemming from climate change, resource depletion, environmental degradation and

85 Articles 4(1), 4(2) and 4(3), RED-II.

86 Articles 6(1) and 6(2), RED-II.

87 Article 15(1), RED-II.

88 Article 16(1), RED-II.

89 Article 2(1), RED-II.

90 Regulation on the Governance of the Energy Union and Climate Action (EU) 2018/1999, OJ L 328, 21.12.2018, p. 1–77.

91 COMMUNICATION FROM THE COMMISSION, Action Plan: Financing Sustainable Growth, COM/2018/097 final.

The Renewable Energy Directive defines “energy from renewable sources” as energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas.”

This definition does not cover nuclear power, although nuclear energy is also decarbonized.

social issues; and (iii) foster transparency and long-termism in financial and economic activity.

In these three areas, the Action Plan sets out ten key actions, such as an EU taxonomy, i.e. a classification system for sustainable activities, creating an EU Green Bond Standard and labels for green financial products. In June 2020, the Taxonomy Regulation was published.[92] An economic activity qualifies as environmentally sustainable if it:

a. contributes substantially to one or more of the environmental objectives (climate change mitigation, climate change adaptation, the sustainable use and protection of water and marine resources, the transition to a circular economy, pollution prevention and control, the protection and restoration of biodiversity and ecosystems[93]);
b. does not significantly harm any of the environmental objectives;
c. is carried out in compliance with the minimum safeguards; and
d. complies with technical screening criteria established by the Commission.[94]

Under the Taxonomy Regulation, an economic activity qualifies as “contributing substantially to climate change mitigation where that activity contributes substantially to the stabilisation of greenhouse gas concentrations in the atmosphere at a level which prevents dangerous anthropogenic interference with the climate system consistent with the long-term temperature goal of the Paris Agreement through the avoidance or reduction of greenhouse gas emissions or the increase of greenhouse gas removals, including through process innovations or product innovations, by: (a) generating, transmitting,

92 Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088, OJ L 198, 22.6.2020, p. 13–43. As the Commission explains, “the EU sustainable finance taxonomy will guide investment in these activities to ensure they are in line with our long-term ambitions.” European Commission, Communication, “Powering a climate-neutral economy: An EU Strategy for Energy System Integration”, COM(2020) 299 final, Brussels, 8.7.2020, available at https://ec.europa.eu/energy/sites/ener/files/energy_system_integration_strategy_.pdf

93 Article 9, Taxonomy Regulation.

94 Article 3, Taxonomy Regulation.

storing, distributing or using renewable energy in line with Directive (EU) 2018/2001, including through using innovative technology with a potential for significant future savings or through necessary reinforcement or extension of the grid; … [or] (h) producing clean and efficient fuels from renewable or carbon-neutral sources."[95]

In the legislative process leading to the adoption of the Taxonomy Regulation, there has been much debate about nuclear electricity. The EU Technical Expert Group on Sustainable Finance addressed nuclear electricity in the Technical Annex[96] to its report.[97] Based on the '*do no harm*' requirement, nuclear opponents argued that it should not be included in the EU's sustainable finance program.[98] The regulation as adopted, however, leaves open whether nuclear electricity could qualify.[99] In this debate, the key issue appears to be whether nuclear waste can be managed without significant impact to the environment. According to the EU Technical Expert Group (TEG), "nuclear energy generation has near to zero greenhouse gas emissions in the energy generation phase and can be a contributor to climate mitigation objectives."[100] As the TEG found that "the evidence about nuclear energy is complex and more difficult to evaluate in a taxonomy context, … it was not possible for TEG, nor its members, to conclude that the nuclear energy value chain does not cause significant harm to other environmental objectives on the time scales in question. The TEG has therefore not recommended the inclusion of nuclear energy in the Taxonomy at this stage."

In a June 2020 FAQs document, the European Commission states that "[w]hile nuclear energy is generally acknowledged as a low-carbon energy source, opinions differ notably on the potential environmental impacts of nuclear waste."[101] To reach a decision on this issue, the Commission wants a "scientifically rigorous, transparent" assessment, based on a "balanced set of views" and reflecting "the principle of technological neutrality." The Commission has decided to request the Joint Research Centre for a technical report on the 'no significant harm' aspects of nuclear energy. This report will be the basis for further review and decision-making.[102] The JRC is expected to submit its opinion in the course of 2021.[103]

In the context of sustainable finance, attention should also be paid to the European Commission's Guidelines

---

95 Article 10(1), Taxonomy Regulation.

96 Technical Annex: Taxonomy, Final report of the Technical Expert Group on Sustainable Finance, March 2020, available at https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy-annexes_en.pdf

97 Taxonomy: Final report of the Technical Expert Group on Sustainable Finance, March 2020, available at https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/200309-sustainable-finance-teg-final-report-taxonomy_en.pdf

98 Frédéric Simon, 'Do no harm': Nuclear squeezed out of EU green finance scheme, EURACTIV, 06-12-2019, available at https://www.euractiv.com/section/energy-environment/news/do-no-harm-nuclear-squeezed-out-of-eu-green-finance-scheme/

99 EU Taxonomy leaves low-carbon nuclear 'in limbo', admits climate adviser, World Nuclear News, 03 August 2020, available at https://www.world-nuclear-news.org/Articles/EU-Taxonomy-leaves-low-carbon-nuclear-in-limbo-adm

100 Technical Annex: Taxonomy, pp. 210-211.

101 European Commission, FREQUENTLY ASKED QUESTIONS about the work of the European Commission and the Technical Expert Group on Sustainable Finance on EU TAXONOMY & EU GREEN BOND STANDARD, June 2020, available at https://ec.europa.eu/info/sites/info/files/business_economy_euro/banking_and_finance/documents/200610-sustainable-finance-teg-taxonomy-green-bond-standard-faq_en.pdf

102 "The JRC's report will be reviewed by experts on radiation protection and waste management under Article 31 of the Euratom Treaty, as well as by experts on environmental impacts from an equivalent Commission environmental group or committee." FAQs Taxonomy, p. 13.

103 JRC to assess nuclear's inclusion in EU Taxonomy, World Nuclear News, 06 July 2020, available at https://www.world-nuclear-news.org/Articles/JRC-to-assess-nuclears-inclusion-in-EU-Taxonomy

The European Commission states that "while nuclear energy is generally acknowledged as a low-carbon energy source, opinions differ notably on the potential environmental impacts of nuclear waste."

The Joint Research Centre is preparing a technical report on the 'no significant harm' aspects of nuclear energy.

on State aid for environmental protection and energy 2014-2020.[104] These guidelines will soon have to be reissued, as they expire. Various types of aid relevant to the subject matter of this study are covered by the Guidelines, including (1) aid for energy from renewable sources; (ii) aid for energy efficiency measures, including cogeneration and district heating and district cooling; (iii) aid in the form of reductions in funding support for electricity from renewable sources; (iv) aid for energy infrastructure; and (v) aid for generation adequacy measures. There is no reference to nuclear energy.

The objective of environmental aid is stated to be "to increase the level of environmental protection compared to the level that would be achieved in the absence of the aid." The Guidelines note that "[a] low carbon economy with a significant share of variable energy from renewable sources requires an adjustment of the energy system and in particular considerable investments in energy networks." The primary objective of aid in the energy sector, therefore, is "to ensure a competitive, sustainable and secure energy system in a well-functioning Union energy market." Given the different stage of technological development of renewable energy technologies, the Guidelines permit technology specific tenders "on the basis of the longe term potential of a given new and innovative technology, the need to achieve diversification; network constraints and grid stability and system (integration) costs."

Because the full cost of carbon may not yet be internalized, the Commission assumes that a market failure persists and will permit state aid for renewable energy that contributes to "the achievement of the related, but distinct, Union objectives for renewable energy." The Guidelines define 'renewable energy sources' as "renewable non-fossil energy sources: wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases." Nuclear energy does not fall under this definition.

Under the Guidelines, for instance, state aid in the form of operating aid for the production of renewable electricity and/or combined production of renewable heat, is permissible under conditions. Tax

104 COMMUNICATION FROM THE COMMISSION, Guidelines on State aid for environmental protection and energy 2014-2020, 2014/C 200/01, 28.6.2014, OJ C 200/1.

The Commission will permit state aid for renewable energy that contributes to the achievement of the EU objectives for renewable energy. Under the Guidelines, state aid in the form of operating aid for the production of renewable electricity, is permissible under conditions. Tax exemptions, reductions from environmental taxes and exemptions from charges for the financing of energy from renewable sources do not have to be notified individually.

Thus, while the Guidelines clear the way for renewable support programs, the situation for nuclear energy remains opaque.

exemptions, reductions from environmental taxes and exemptions from charges for the financing of energy from renewable sources do not have to be notified individually. Thus, while the Guidelines clear the way for renewable support programs, the situation for nuclear energy remains opaque.

f. EU Nuclear Electricity Regulation

The EU, more specifically, ***Euratom***,[105] ***has extensively regulated nuclear electricity***. These regulations address (i) ***nuclear safety***, (ii) ***nuclear waste management***, (iii) ***radiation protection***, (iv) decommissioning of nuclear facilities, and (v) misuse protection. In addition, nuclear-related activities are covered by general regulations aimed at protecting the environment, public safety, occupational health, etc. There are also international treaties that impose ***strict liability on operators of nuclear facilities*** for damages resulting from nuclear accidents.[106] These treaties require that nuclear operators contract insurance (or present other financial security) to cover these liabilities.[107]

---

105 Euratom, or the European Atomic Energy Community, "regulates the European civil nuclear industry, which produces almost 30 % of energy in the EU. Euratom's work safeguards nuclear materials and technology, facilitates investment, research and development, and ensures equal access to nuclear supplies, as well as the correct disposal of nuclear waste and the safety of operations. Its main instruments are the Euratom Supply Agency, and its research and nuclear safeguard activities. Notably, Euratom is involved in developing atomic fusion technology which has the potential of delivering abundant sustainable energy in the future." European Parliament, European Atomic Energy Community (Euratom) – Structures and tools, Briefing, September 2017, available at https://www.europarl.europa.eu/RegData/etudes/BRIE/2017/608665/EPRS_BRI(2017)608665_EN.pdf

106 Convention on Third Party Liability in the Field of Nuclear Energy of 29th July 1960, as amended by the Additional Protocol of 28th January 1964 and by the Protocol of 16th November 1982, available at https://www.oecd-nea.org/law/nlparis_conv.html

107 Nuclear Energy Agency, Paris Convention on Nuclear Third Party Liability, available at https://www.oecd-nea.org/law/paris-convention.html

The ***EU Nuclear Safety Directive***[108] imposes "the highest standards of nuclear safety."[109] Nuclear safety involves both compliance with design and technical standards and management procedures. The directive requires that EU member states give the highest priority to nuclear safety at all stages of the lifecycle of a nuclear power plant, and that national regulatory authorities be independent and have sufficient staff and resources. ***Safety assessments*** are mandatory before the construction of new nuclear power plants; existing nuclear power plants must implement significant safety enhancements. A system of safety peer review has been established. At least once every 10 years, a ***safety re-evaluation*** of a nuclear power plant must be conducted.

Radioactive waste and spent fuel are also subject to regulation by the EU (Euratom). The management of any radioactive waste generated from the production of electricity in nuclear power plants is subject to the ***Radioactive Waste and Spent Fuel Management Directive***,[110] which requires that member states draw up and implement national programs for the safe management of these materials, including in the long-term. Responsible and safe management of spent fuel and radioactive waste is required to avoid imposing undue burdens on future generations. A ***high level of safety*** in spent fuel and radioactive waste management must be achieved to protect workers and the general public against the dangers arising from ionising radiation. A comprehensive and robust legal framework and a competent, independent regulatory body with sufficient resources, must be established. Every three years, member states are to submit to the Commission national reports on the implementation of the directive, and they must conduct self-assessments of their programs and invite international peer reviews of their national regulatory programs at least every ten years. Low level nuclear waste is managed safely is the EU.

Radiation protection regulation is intended to protect people from the dangers of ionising radiation. The EU regulatory framework establishes basic safety standards,[111] a prior authorization scheme for

Euratom has extensively regulated nuclear power.

These regulations address (i) nuclear safety, (ii) nuclear waste management, (iii) radiation protection, (iv) decommissioning of nuclear facilities, and (v) misuse protection.

108 Council Directive 2014/87/Euratom of 8 July 2014 amending Directive 2009/71/Euratom establishing a Community framework for the nuclear safety of nuclear installations, OJ L 219, 25.7.2014, p. 42–52.

109 Recital 5, Nuclear Safety Directive.

110 Council Directive 2011/70/Euratom of 19 July 2011 establishing a Community framework for the responsible and safe management of spent fuel and radioactive waste, OJ L 199, 2.8.2011, p. 48–56.

111 Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom, OJ L 13, 17.1.2014, p. 1–73.

The financial and regulatory incentives that the EU has created for renewable energy are withheld from nuclear power, while nuclear energy is subject to demanding EU and international regulations applying to the full life cycle of the plant, the fuel, and the spent fuel, from cradle to grave, and beyond.

The concept of technological neutrality, which the EU has endorsed, would appear to be inconsistent with prioritizing one carbon-neutral power generation technology over another one.

transport of radioactive waste,[112] and includes an emergency preparedness and response program. Before a member state permits the operation of a new nuclear plant, the Commission is to evaluate the potential health impact from the plant on the population of neighboring member states.[113]

Under the EU Directives on nuclear safety and on management of spent fuel and radioactive waste the ***decommissioning of nuclear power plants*** is a responsibility of member states. Each Member State must deal internally with its spent fuels. Finland, France and Sweden have selected sites for the deep geological disposal of intermediate and high level waste, which are due to open between 2024 and 2035.[114]

The decommissioning of a nuclear power plant must meet the ***highest safety standards***. It starts with the shutdown process, followed by the removal of nuclear material from the site, and the environmental restoration of the site. This process is complex and may take up to up to 30 years. The EU assists the Member States in addressing issues related to funding of nuclear decommissioning through a group of experts known as the Decommissioning Funding Group (DFG).[115]

g. Conclusions on Relevant EU Policies

This brief review of EU policies and regulations applying to renewable energy and nuclear energy suggests that this legislation is likely to have significant impacts on the ***relative competitiveness***

112 Council Directive 2006/117/Euratom of 20 November 2006 on the supervision and control of shipments of radioactive waste and spent fuel, OJ L 337, 5.12.2006, p. 21–32.

113 COMMISSION RECOMMENDATION of 11 October 2010 on the application of Article 37 of the Euratom Treaty, OJ L 279/36, 23.10.2010.

114 European Commission, Radioactive waste and spent fuel, https://ec.europa.eu/energy/topics/nuclear-energy/radioactive-waste-and-spent-fuel_en

115 Commission Recommendation of 24 October 2006 on the management of financial resources for the decommissioning of nuclear installations, spent fuel and radioactive waste, OJ L 330, 28.11.2006, p. 31–35.

of these two electricity sources. The ***financial and regulatory incentives that the EU has created for renewable energy are withheld from nuclear power, while nuclear energy is subject to demanding EU and international regulations*** applying to the full life cycle of the plant, the fuel, and the spent fuel, from cradle to grave, and beyond.

In addition, the EU has set itself objectives to which nuclear electricity can contribute in significant ways. For instance, the EU fosters ***security of energy supply and energy affordability***, including the prevention of energy poverty. Nuclear energy is a source of abundant and secure energy, it is non-intermittent, and able to provide electricity when demanded. Energy independence, for one, may be greatly enhanced by nuclear energy. And, of course, nuclear energy can contribute to the EU's climate neutrality mission. The concept of ***technology neutrality***, which the EU has endorsed, would appear to be inconsistent with prioritizing one carbon-neutral electricity generation technology over another one.

Because the EU often omits to spell out in any detail how its specific initiatives contribute to the various objectives it has set for its climate, environmental and energy policies, it may not consistently make balanced policy decisions. The recent ***omission to include nuclear energy in the sustainable finance taxonomy*** illustrates this point – while renewable energy was deemed to qualify automatically without any meaningful assessment, nuclear energy was excluded without any sound, reliable assessment of its sustainability.

In the context of this study we merely note these ***discrepancies in policy and legislative treatment***. We have not attempted to detail and quantify the effects thereof on the competitiveness of the two technologies. On the basis of reports from the field, however, we believe that this is an issue that merits further analysis if the EU is serious about meeting the objectives of its climate, energy, environmental, and economic policies. It is in this space that this study can contribute to improving EU policy making going forward.

As noted above, the EU has paid surprisingly little attention to the issues of spatial requirements of electricity generation technologies and of the relative costs of such technologies.[116] The reason for this lack of attention is that the ***EU made a policy decision in favor of renewable energy without considering the relative pros and cons of all technologies***; once renewable electricity became a legal mandate, cost-benefit analysis of alternative options no longer was perceived as providing pertinent information. Likewise, although the EU pays ***lip service to cost-effectiveness, efficiency, and affordability***, it has not even attempted to come up with estimates of the cost of the energy transition necessary to achieve climate neutrality in 2050.

There is reason to believe that these issues (spatial requirements and relative costs) will feature more prominently on the EU agenda in the next decade. In this regard, it is interesting to note that citizens of The Netherlands believe that renewable electricity (wind turbines, solar) has a larger share than it actually has,[117] apparently because they either perceive the country to be already full of wind turbines or they

116 See, for instance, European Commission, IN-DEPTH ANALYSIS IN SUPPORT OF THE COMMISSION COMMUNICATION COM(2018) 773, A Clean Planet for all -- A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy, Brussels, 28 November 2018, available at https://ec.europa.eu/knowledge4policy/publication/depth-analysis-support-com2018-773-clean-planet-all-european-strategic-long-term-vision_en

117 Respondents thought that the share of wind energy was 16 % (actually, 2 %), of solar energy 17 % (actually, 1 %), and of bio-energy 12 % (actually, 5 %). NEDERLANDSE VERENIGING DUURZAME ENERGIE, NEDERLANDERS OVERSCHATTEN AANDEEL DUURZAME ENERGIE, 19 juli 2020, available at https://www.nvde.nl/nvdeblogs/nederlanders-overschatten-aandeel-duurzame-energie/

The number of social conflicts related to wind power plants or solar energy plants is on an all-time high, but decarbonization of the power sector remains critical to achieving carbon neutrality. Energy affordability and the cost of electricity are more important than ever.

The EU therefore cannot afford to continue to treat an important decarbonized power generation technology as a pariah.

expect renewable electricity to have greater efficiency than it actually has. Once people begin to understand the ***relative spatial requirements and efficiencies of alternative electricity generating technologies*** better, these issues are likely to become politically more salient. Clearly, both wind/solar and nuclear power are able to contribute towards the 2050 climate neutrality objective; ***the choice between the two therefore hinges on other factors***.

The two aspects of electricity generation covered by this study, spatial requirements and cost, are highly relevant to current policy debates for three reasons. First, in light of the conflicting demands made on land and space for a variety of purposes (residential use, industrial use, nature protection areas, recreational areas, sports, agriculture, forestry, fishery, transportation, infrastructure, etc.[118]), the ***issue of land use is regarded as increasingly critical*** by national and local governments;[119] and ***"the number of social conflicts related to wind power plants or solar energy plants is on an all-time high"***[120]. *(emphasis supplied)*. Second, since the electricity sector makes a substantial contribution to total EU carbon emissions, and the demand for electricity is bound to increase due to further electrification,[121] ***decarbonization of the electricity sector is critical to achieving carbon neutrality***;[122] not all technologies can contribute to this

118 Cf. Eurostat, Land use statistics, available at https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Land_use_statistics

119 "About 80 % of Europe's surface area is shaped by land use in cities, agriculture and forestry." European Environment Agency, Land use, available at https://www.eea.europa.eu/themes/landuse Siting of power plants is a particular sensitive issue.

120 Bosch, Stephan ; Rathmann, Joachim ; Schwarz, Lucas, The Energy Transition between profitability, participation and acceptance – considering the interests of project developers, residents, and environmentalists, Advances in geosciences, 2019, Vol.49, pp. 19-29 ("In planning processes for Renewable Energy Technologies mostly economic approaches are chosen, but simultaneously the number of social conflicts related to wind power plants or solar energy plants is on an all-time high.")

121 Electrification Strategy EU, available at https://electrificationstrategy.eu/#:~:text=The%20EU%20Electrification%20Strategy%20will%20be%20the%20key,decarbonise%20the%20transport%20and%20heating%20%26%20cooling%20sectors.

122 European Environment Agency (EEA), CO_2 Intensity of Electricity Generation, available at https://www.eea.europa.eu/data-and-maps/data/co2-intensity-of-electricity-generation ("To date, power generation remains the largest GHG-emitting sector in Europe. Carbon dioxide (CO_2) is by far the most commonly-emitted GHG across the sector, being a product of combustion processes. An almost complete decarbonisation of the EU's electricity sector is needed in order to meet the EU's objective of becoming the first carbon-neutral continent by 2050. Electricity can play an increasing role in decarbonising energy use across a number of sectors, such as transport, industry and households.")

objective to the same extent.[123] Third, in light of the enormous cost incurred due to COVID-19 crisis and the electrification trend, ***energy affordability and the cost of electricity are more important than ever***.[124]

The importance of this study for EU policy making therefore can hardly be overstated. With the ambitious programs mapped out by the EU, spatial requirements and costs will become dominant considerations in the area of energy policy making at the European and national levels.

Given the findings presented in this report, the EU should redesign its policies so that the worst consequences of the current mandates are avoided. The EU must put climate and energy policy on a sustainable, 'no regrets' trajectory that does not cause massive adverse spatial and related impacts, respects Europe's landscapes and nature, and meets the people's need for secure, affordable electricity without attempting to change their lifestyle.

---

123 To determine the CO_2-emissions associated with a particular power generation technology, full life cycle analysis needs to be undertaken (from cradle to grave). See, e.g., Wolfram, Paul, Wiedmann, Thomas, Diesendorf, Mark, Carbon footprint scenarios for renewable electricity in Australia, Journal of Cleaner Production, 2016-06-15, Vol.124, pp. 236-245. ("In this paper, scenario-based hybrid Life-Cycle Assessment is applied to calculate the economy-wide carbon footprints of seven electricity generation technologies in scenarios with differing renewable electricity penetration. This work is the first to apply a full life-cycle approach to scenario analysis of electricity generation in Australia. The findings are at the higher end of previously reported carbon footprint intensity ranges and above median values.")

124 Thomson, Harriet, Bouzarovski, Stefan, Snell, Carolyn, Rethinking the measurement of energy poverty in Europe: A critical analysis of indicators and data, London, England: SAGE Publications, Indoor + built environment, 2017, Vol.26 (7), pp. 879-901.