EUI FLORENCE SCHOOL OF REGULATION

ROBERT SCHUMAN CENTRE

POLICY BRIEF

Electrification and sustainable fuels: Competing for wind and sun[1]

Highlights

- This study seeks to answer a simple question: will we have enough renewable electricity to meet all of the EU's decarbonisation objectives, and, if not, what should be the priorities?
- We assess through a "conservative" approach how much renewable electricity will be needed to electrify future energy demand, while taking into account 2019 energy use and flow data, improvements in energy efficiency from electrification and policies set forward by the EU and other reference modelling works (IEA, IRENA, EU EC …). Energy services that cannot be electrified need to be fueled by sustainable fuels or provided through other solutions.
- It would be technically feasible to supply around 65% of current electricity demand with renewable electricity on the basis of the NECPs. But there is little room by 2030 for supplying the additional renewable electricity demand due to the electrification of road transport, and of the heating of buildings, not even including electrification of industry and electricity demand for producing synthetic fuels – including hydrogen.
- Five main policy actions are suggested by 2030 and 2050.

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Authors

Ronnie Belmans, KU Leuven- EnergyVille; Piero Carlo dos Reis, Florence School of Regulation; Pieter Vingerhoets, VITO- EnergyVille

Introduction

As part of the Green Deal [2], the EU wishes to reach full climate neutrality by 2050. As an intermediate step, a reduction in greenhouse gases of 55% by 2030 has been put forward as a target. The basis of the overall approach for climate neutral energy system is found in the COM(2020) 299 “Energy system integration strategy”, a coherent approach, based on engineering fundamentals[3]:

1. Energy efficiency first, including the circular economy and the use of waste heat.
2. Then the electrification of those applications where this is credible in terms of cost-efficiency and technology.
3. If the first and the second approach prove not feasible, sustainable fuels will have to be used (amongst them hydrogen).

This approach leads to a sustainable energy system based on renewable resources that predominantly deliver electric energy as output: wind, solar and the more traditional hydro and some geothermal generation. The basic laws of thermodynamics, the physical laws that rule energy systems, are clear: every time the energy is changed from one vector into another (electricity into hydrogen, for example) a significant amount of the original energy is lost. Therefore, as (renewable) electricity may be considered to be the 'highest quality of energy', wherever possible it should not be changed “on route” towards the final use. In other words: if the energy service can be delivered electrically, it should be done in that way. Applications that can not be addressed by electricity, are called “hard to abate” applications as they require alternative solutions.

Therefore, a smart transition, that is cost effective, should try to deliver the energy for the services needed using a minimum amount of energy, which is guaranteed by electrifying as much as possible the energy supplied. Where this is not possible, the most efficient and effective sustainable fuel must be used. There are a number of options here, both low carbon (decarbonising industry using CCS/CCU based on fossil fuels and low-carbon hydrogen during the transition) and zero-carbon hydrogen produced using electrolysis and potentially pyrolysis using renewable electricity. Given the basic laws of thermodynamics, using sustainable fuels based on green electricity for applications that can be supplied directly by electricity is always inefficient and leads to higher investments in required wind and PV resources and conversion systems (electricity to sustainable fuels and to final energy service).

This study seeks to answer a simple question: will we have enough renewable electricity to meet all of the EU's decarbonisation objectives, and, if not, what should be the priorities?

A simple three steps methodology is followed. The starting point is the energy use and flow data as provided by Eurostat for EU-27 in 2019[4]. Then we try to estimate the share of the future energy services that can be supplied by electrification, taking due account of the improvement in energy efficiency that results from using electricity for transport and heating compared to using fossil fuels. We assess how much renewable electricity will be needed to do so, accounting for the policies set forward by the EU and other reference modelling works (IEA, IRENA, EU EC …).

In preparing this analysis, at every point where the option presented itself, we have taken a 'conservative' approach to demand and supply. We therefore assume that ambitious predictions/estimates regarding renewable electricity production will be met, and that energy demand will be reduced or constrained based on the achievement of even more ambitious energy efficiency objectives (that would require a step-change compared to current success in this area).

Energy services that cannot be electrified need to be fueled by sustainable fuels. Sustainable fuels may be biofuels, low carbon hydrogen (blue or turquoise hydrogen based on natural gas, or green hydrogen from electrolysis) as well as e-fuels based on green hydrogen. The production of the green and to a lesser extent turquoise hydrogen adds to the electricity needs. When looking at sustainable fuels, methane – and its potential leakages – have to be carefully considered.

2 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM:2019:640:FIN
3 https://ec.europa.eu/energy/sites/ener/files/energy_system_integration_strategy_.pdf
4 https://ec.europa.eu/eurostat/cache/sankey/energy/sankey.html?geos=EU27_2020&year=2019&unit=KTOE&fuels=TOTAL&highlight=_&nodeDisagg=0101000000000&flowDisagg=false&translateX=0&translateY=0&scale=1&language turquoise) or carbon =EN

1. Role of electricity in current energy supply & demand

An overview is given of the 2019 demand for energy carriers and industrial feedstock in the different sectors, and of the relative shares of electricity generation by energy source according to Eurostat[5]. Final energy and feedstock consumption is roughly 12.000 TWh, of which electricity is only 21 % (2485 TWh). 37 % of the electricity is supplied from renewable resources (953 TWh: wind 367 TWh, hydro 293 TWh, solar 126 TWh, geothermal 7 TWh, bioenergy 160 TWh). In our analysis of future demand and supply, the two "classical" resources (hydro and geothermal) are assumed to remain constant in the decades to come as most of the potential in EU 27 is already in use. Biofuels probably will be diverted to "hard to abate" demand (sustainable molecules) or biobased chemistry, where they have a higher value.

Electrifying many applications will reduce the overall energy consumption to a large extent at the one hand, and increase the electricity input at the other, bringing electric energy more and more to the forefront of the overall energy system.

2. Towards 2030: Trends in renewable electricity supply

One of the first steps towards carbon neutrality is to cover existing electricity demand by carbon neutral resources. To decarbonise around 65% of the present EU-27 electricity use by 2030 – an estimated, reasonable contribution to reach the -55% GHG emissions reduction target of the EU Green Deal[6] -, 1615 TWh of green electricity supply will be needed.[7] On the basis of existing EU Member States targets/commitments, and assuming that they are met, we estimate the EU-27 output of wind and PV by 2030 at around

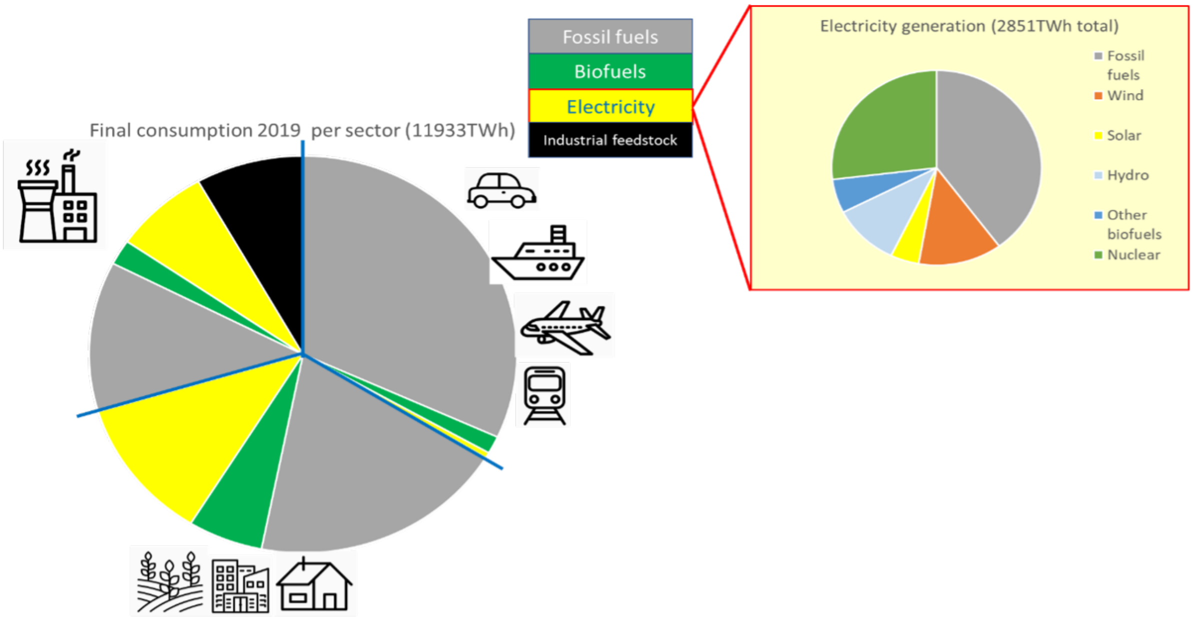

Figure 1: Overview of the final consumption (energy and non-energy) per sector, and details on the electricity generation according to Eurostat. Marine bunkers 507 TWh and international aviation 485 TWh were included for sake of completeness.

5 Source:https://ec.europa.eu/eurostat/cache/sankey/energy/sankey.html?geos=EU27_2020&year=2019&unit=KTOE&fuels=TOTAL&highlight=_&nodeDisagg=0101000000000&flowDisagg=true&translateX=0&translateY=0&scale=1&language=EN

6 This estimate is also in agreement with the EU-27 ambition levels set for the renewable share in the supply-side towards the achievement of the EU Green Deal targets. COM(2020)562: "By 2030, the share of EU renewable electricity production is set to at least double from today's levels of 32% of renewable electricity to around 65% or more."

7 COM(2020)562: "By 2030, the share of EU renewable electricity production is set to at least double from today's levels of 32% of renewable electricity to around 65% or more."

1,150 TWh per year compared to the present 487 TWh: an addition of 663 TWh. If we add hydro and geothermal, we get 1477 TWh.[8] This estimate may be viewed as reasonable in the light of comparative studies. A study by FSR on the costs of decarbonization[9] estimates a potential, by 2030, of 1361-1367 TWh for solar and off/onshore wind summed together. The EU EC SWD(176) MIX scenario reports the potential of 1505 TWh for the same technologies by 2030.[10]

Based on the NECPs, and assuming that Member States meet their objectives, supplying 65% of current electricity demand (1615 TWh) with renewable electricity by 2030 may be considered to be ambitious, but technically feasible.

This does not, however, take into account the additional expected demand for renewable electricity from electrification in other sectors. Equally, we will need to factor in the electricity system changes that will result from such rapid renewable electricity growth, notably given the intermittent nature of the power sources. Additional investments in grid and storage will be required to enable these levels of renewable electricity to be achieved.

3. Towards 2050: Trends for renewable electricity supply

Inevitably, predicting potential or economically efficient electricity demand and the ability of renewable electricity supply to meet it is more difficult with greater levels of uncertainty. This is the case, for example, by 2050. However, we have reviewed available estimations for solar PV, onshore wind and offshore wind on the basis of models from IEA, IRENA, EU EC, and the aforementioned FSR study[11], and of other relevant sources. Overall, we see the potential for a three to four times increase in renewable electricity generation compared to 2030 within the EU. While the renewable electricity capacity of onshore wind and solar PV are assumed to increase by a factor of between two and three, the renewable electricity capacity of offshore wind is assumed to grow from 88.4 GW to either 290 GW or to 300 GW (by a factor of almost four). Again, this is ambitious, will require huge investment and continued (or even increased) public acceptance on funding and planning, but is technically possible.

4. Electrification of energy demand by 2030 & 2050

The next step of this 'availability analysis' is to consider the questions: how much renewable electricity will the EU need, for which uses, and by when to meet its GHG objectives and associated targets?

Again, for 2050, such an analysis is of course difficult; it depends on may factors including technological development and policy choices. However, we have undertaken a high-level sector-based analysis of expected additional electricity demand, based on -55 % carbon reduction by 2030 and carbon neutrality by 2050. In particular we have assessed the electricity needed to decarbonize the transport, buildings and service sectors, and finally for industry, on the basis of the end-uses that can be technically and cost-effectively electrified (if a service is provided, for example, using green hydrogen whenever electrification would be possible instead, the total electricity necessary from renewable resources will be higher).

We assume that the demand for energy services - i.e. the amount of km that people will wish to travel or industrial products required) does not change[12], but have factored in energy efficiency improvements that result from changes in energy sources (electric cars and heat pumps are far more efficient, for example, than combustion engines and oil/gas boilers). This (largely reasonable) assumption reflects that this is not a detailed energy modelling exercise, but rather a trend analysis.

4.1. Transport

The EU put forward a “sustainable and Smart Mobility Strategy – putting Europe on track for

8 Details on the derivation of the precise numbers are disclosed in the accompanying policy paper with the same title.

9 Piebalgs, A.; Jones, C.; Dos Reis, P.C.; Soroush, G.; Glachant, J.M.; FSR Technical Report *Cost-effective decarbonisation study* URL: https://fsr.eui.eu/publications/?handle=1814/68977

10 Details on the derivation of the precise numbers are disclosed in the accompanying policy paper with the same title.

11 As of the moment of drafting this policy brief (April 2021), the data relative to EU renewable electricity deployment by 2050 according to the latest IRENA 1.5°C scenario (IRENA “World Energy Transitions Outlook 1.5°C Pathway - Preview“, 2021) has not been made public yet. Therefore, we will use the numbers disclosed in the IRENA 2020 TES scenario.

12 Mobility in persons.km or ton.km remain the same as are the transport modi. The temperature and comfort in the houses remain the same.

the future", 9 December 2020[13]. The only concrete number given is the estimate/aim that by 2030 at least 30 million zero-emission vehicles will be in operation on European roads. This number is extremely low as the number of passenger cars on European roads is some 243 million,[14] This number is totally incompatible with the 55% greenhouse gas reduction by 2030 put forward in the Green Deal.

Let us assume, for the purpose of this exercise, that all applications of road and rail internal combustion engines can eventually be electrified and that there is constant mobility demand. In that case, the extra renewable electricity to be supplied, taking account of ICE vehicle efficiency assumptions, amounts to 1053 TWh to 1263 TWh from the almost 3300 TWh of fuel used today. The electrification of road transport implies an enormous gain in energy efficiency.

The potential for direct electrification for aviation and shipping (passenger and freight transport, including marine bunkers and international aviation) is limited and hydrogen or synthetic fuels/ biofuels will be required. Therefore, we estimate the renewable electricity demand by 2050 for decarbonizing aviation and shipping at 1490 TWh. In order to do so, we assumed that aviation and navigation can be performed using hydrogen - and not other hydrogen-derived fuels - and that the efficiency of electrolysers will improve to around 75%.[15] If more appropriate fuels (ammonia, methanol, methane, e-diesel, e-kerosine) are used, the overall conversion efficiency will be lower and the amount of renewable electricity required will be higher.

4.2. Buildings and services sector

On 14 October 2020, the European Commission published its "Renovation Wave Strategy". This strategy aims to at least double the renovation rates in the next ten years and to make sure that these renovations lead to higher energy and resource efficiency. The Commission foresees that by 2030 up to 35 million buildings will have been renovated.[16] Based on existing experience, this is extremely ambitious, but nonetheless we base our calculations on the assumption that it will be achieved. Buildings are responsible for 40% of the EU's energy consumption and 36% of its greenhouse gas emissions, so this is an important assumption.

In order to stay in line with EU ambitions[17], roughly three quarters of the energy demand should be saved through renovation (2196 TWh). Part of the remaining energy demand might continue to be supplied through the present sources (heat networks, renewables). The fossil-based portion which will remain after deep renovation (1887 TWh)[18] should be decarbonised using heat pumps, requiring 755 TWh of heat. The amount of electricity to be supplied depends on the COP (coefficient of performance) of the heat pump leading to an electricity demand of 216 TWh[19]

The above-mentioned 75% energy efficiency assumption is highly ambitious given existing renovation rates and levels (few renovations today provide the savings needed to meet these objectives). Nonetheless, in line with the conservative approach taken in this analysis, we have calculated expected future renewable electricity demand for 2050 assuming they are met.

In theory hydrogen and synthetic fuels should not be used: though it is possible that these fuels will be used, say, in rural applications with weak electric grids, or where customers prefer to heat using molecules (and regulation currently permits this).

4.3. Industry

To a significant extent, regarding heating applications within industrial processes, fossil fuels could theoretically be substituted by direct electrification.

- For temperatures of up to around 1000°C, direct electrification technologies are available[20]. Especially for low-temperature processes, (<100-2000C) heat pumps often prove an efficient solution.
- For very high temperature heating and feedstock industrial processes electrification is

13 https://ec.europa.eu/transport/sites/transport/files/legislation/com20200789.pdf
14 https://www.acea.be/press-releases/article/zero-emission-vehicles-european-commission-ambitions-far-removed-from-toda
15 This latter assumption means that at least 33% more of renewable electricity will be required in order to consume 1 kWh of hydrogen, compared to using directly 1 kWh of electricity.
16 https://ec.europa.eu/energy/sites/ener/files/eu_renovation_wave_strategy.pdf
17 https://ec.europa.eu/commission/presscorner/detail/en/IP_20_1835
18 natural gas (1345 TWh) and petroleum/solid fuels (542 TWh)
19 https://ec.europa.eu/environment/emas/takeagreenstep/pdf/BEMP-7.4-FINAL.pdf
20 https://www.mckinsey.com/industries/electric-power-and-natural-gas/our-insights/plugging-in-what-electrification-can-do-for-industry

currently not an option, and sustainable fuels - molecules, will be necessary. However, the introduction of new technologies based entirely on electrification or hydrogen is going to be limited within the next ten years, and may expect to be concentrated between 2040 and 2050. It remains to be seen how this will develop, and one constraining factor may indeed be the physical unavailability of renewable electricity in the EU for all potential uses, and notably industry for direct and indirect (hydrogen) uses. In such circumstances CCS can be added to existing installations - we have 30 years of technological development to possibly bring CCUS and other low-carbon technologies to very close to zero, if not zero, carbon.

- If we focus on the industrial processes where fossil fuel input is both part of the material and the energy flow (iron and steel, chemical and petrochemical, non-metallic minerals), fossil fuel consumption for these applications is currently 912 TWh. By 2050, if we assume – as a minimum – that half of it will be replaced by electricity, an additional 456 TWh of annual electricity consumption will be created by 2050. Overall, industrial electricity demand is therefore going to increase substantially between 2020 and 2050, with a minimum of 500 TWh, but most probably double that.

Conclusion - green electrons will be scarce and should be considered valuable - policy recommendations

Seen in this light, and again on the basis of a conservative analysis whose conclusions do not change if we substitute the numbers for future renewable electricity supply with those of other scenarios we analysed (e.g., IEA), and an achievement of current targets set towards carbon neutrality, it becomes clear that there is little room by 2030 for supplying the additional renewable electricity demand due to the electrification of road transport (458 TWh for 40% electric vehicles and 20% trucks), the heating of buildings (108 TWh for 50% renovation and heating by heat pumps), not even including the electrification of industry and the electricity demand for producing synthetic fuels – including hydrogen.

Given the fact that green electrons will be scarce, they should therefore be considered to be valuable. Five main actions need to be considered by 2030 and 2050:

- A significant increase in ambition for renewable electricity supply is required. However, producing all of the above with electric energy in the EU-27 will be hard, and close cooperation with neighboring countries will be needed.

- The use of renewable electricity has to be targeted following the energy system integration strategy. Applications where electrification brings an enormous gain in efficiency such as passenger transport or low-temperature heating both in building and industry should be prioritized.

- In terms of producing hydrogen, there is strong GHG value in achieving the Commission's target of substituting 'grey' hydrogen demand used as feedstock by 2030. Using renewable electricity to do so would add around 400 TWh p.a. to produce the 8 MT of grey hydrogen currently consumed in the EU. Using precious renewable electricity over the next decade to do so when the hydrogen can be very largely decarbonised using SMR/CCS, and almost certainly at far lower cost, appears illogical unless considerable very cheap renewable electricity can be produced in addition to needs for electricity supply, transport building and industry, which appears unlikely. Pyrolysis, producing potentially zero-carbon hydrogen using a fraction of the renewable electricity compared to electrolysis is a promising technology, that needs maturing.

- For the hard-to-abate sectors where sustainable fuels are likely needed as feedstock and/or energy source in high temperature applications in industry or for long-distance transport applications (aviation and navigation) or as green energy strategic reserves for periods with low wind and sun (including the shorter Dunkelflaute), the focus might usefully be put, in the next years, on technology development and demonstration.

- In addition to carbon neutral technologies, the import of both renewable electricity (requiring major new power lines to be constructed) and renewable energy based molecules from outside Europe should be assessed or rolled out.

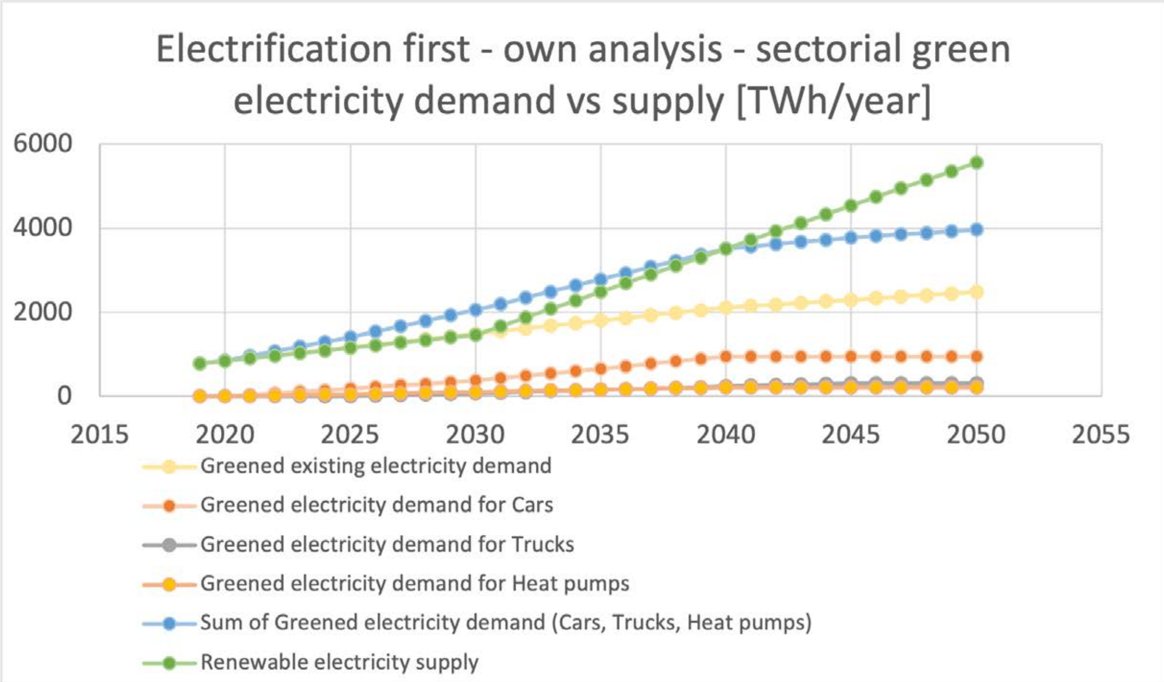
Electrification first - own analysis - sectorial green electricity demand vs supply [TWh/year]
6000
4000
2000
0
2015
2020
2025
2030
2035
2040
2045
2050
2055
Greened existing electricity demand
Greened electricity demand for Cars
Greened electricity demand for Trucks
Greened electricity demand for Heat pumps
Sum of Greened electricity demand (Cars, Trucks, Heat pumps)
Renewable electricity supply

Figure 2

The Florence School of Regulation

The Florence School of Regulation (FSR) was founded in 2004 as a partnership between the Council of the European Energy Regulators (CEER) and the European University Institute (EUI), and it works closely with the European Commission. The Florence School of Regulation, dealing with the main network industries, has developed a strong core of general regulatory topics and concepts as well as inter-sectoral discussion of regulatory practices and policies.
Complete information on our activities can be found online at: fsr.eui.eu

Robert Schuman Centre for Advanced Studies

The Robert Schuman Centre for Advanced Studies (RSCAS), created in 1992 and directed by Professor Brigid Laffan, aims to develop inter-disciplinary and comparative research on the major issues facing the process of European integration, European societies and Europe's place in 21st century global politics. The Centre is home to a large post-doctoral programme and hosts major research programmes, projects and data sets, in addition to a range of working groups and ad hoc initiatives. The research agenda is organised around a set of core themes and is continuously evolving, reflecting the changing agenda of European integration, the expanding membership of the European Union, developments in Europe's neighbourhood and the wider world.

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