Comparing the cost of solar, wind and biomethane on a dispatchable basis

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Introduction

In the European Climate Law, the EU has agreed to reach net-zero emissions by 2050. The largest share of greenhouse gas emissions comes from energy production for heating, industry, transport and power production. Emission reduction in all of these sectors relies to some extent on gaseous energy carriers, which means that capacity to produce renewable gases needs to increase rapidly to comply with the Climate Law target. Electrification of processes in all sectors and a rapid scale-up of renewable power will play a major role as well, with a large contribution from solar and wind energy. As emission reduction in power generation is relatively straightforward, the power industry can and must be climate neutral well before 2050. For this report, Common Futures considers 2040 as an achievable date for this ambition for the EU-27.

In this report, Common Futures compares the costs of power in €/MWh for the dispatchable electricity[1] demand in 2040, produced by either combustion of biomethane or combustion of hydrogen from wind and solar electricity. This is complemented by an assessment to indicate the potential of dispatchable power from batteries charged with wind and solar electricity for flexible power supply in 2040.

The levelized cost of electricity (LCOE)[2] of wind and solar power has come down to attractive levels: they can supply electricity whenever there's sufficient demand at costs as low as 20 (solar) or 40 (wind) €/MWh. In an electricity system with a high share of solar and wind, there will be a high need for flexibility options to match supply and demand. For short-term balancing, options available are demand response, batteries, and stronger interconnection. However, in the European climate, longer periods of days and weeks with either too little or too much supply of wind and solar electricity will occur, for which a form of dispatchable generation is needed.

One of the main questions that is still highly debated, is what the preferred power generation method for dispatchable power in such a climate-neutral power system should be. This is where biomethane is one of the main candidates, as it is storable in any natural gas storage, and it can be used in any gas-fired power plant.

To estimate the dispatchable power demand in EU-27 countries in 2040, the electricity demand and supply prognoses of the TYNDP 2022 scenario report in the distributed energy scenario[3] is considered, as it is a very recent and widely accepted 2040 energy scenario. Its estimate is a final electricity demand in 2040 of around 3,500 TWh in all sectors[4]. In this scenario, it is assumed that dispatchable renewables, excluding hydropower, supply a joint generation of approximately 410 TWh[5] before transmission and distribution, or 11% of the final electricity consumption.

[1] Electricity that can be generated on-demand, contrary intermittent power sources like solar and wind which are dependent on the weather for power generation.

[2] The net present costs of electricity generation from a certain power source.

[3] A COP 21 compliant scenario for installed capacities of power generation from 2020 – 2050 in steps of 10 years, simulating a pathway achieving EU-27 carbon neutrality by 2050 and at least 55 % emission reduction in 2030. This scenario is developed in the ENTSOG and ENTSO-E models.

[4] TYNDP, draft scenario report 2022, October 2021, page 17

[5] TYNDP page 30 & 31, combining figure 23 & 25

In this report, Common Futures compares the costs of power in €/MWh for that final 410 TWh, when fully producing it from hydrogen from wind and solar electricity, biomethane or dispatch from batteries charged with wind and solar electricity.

Comparison of dispatchable power sources

Three pathways for dispatchable power supply in Europe for 2040 are compared based on their average costs per MWh. Costs for power per MWh from these dispatchable power sources can become very expensive compared to power directly delivered by solar or wind. It should therefore be considered that power from these sources is only used during limited periods of the year, i.e. when power from intermittent sources is insufficient. Dispatchable and intermittent power sources are therefore not competing power sources, but they complement each other. In the average electricity cost, relatively high prices for dispatchable power sources will be compensated by relatively low prices from intermittent power sources.

For all dispatchable options only, feedstock, production, grid injection, storage and conversion technologies are included. Transmission and distribution beyond grid injection are excluded because the infrastructure needed is highly dependent on the final set-up; whether gas production, storage and power generation are clustered or not. That discussion is outside the scope of this assessment. Next to that, it is also difficult to determine the fraction of T&D used for power production and the fraction used for other purposes like industry or transport.
Utility-scale installations are considered for this analysis: gas production is clustered in large electrolyser facilities (100 MW) close to wind and/or solar farms or digesters linked to methanisers (5MWth), and storage takes place in large salt caverns, natural gas caverns or battery parks.
Figure 1 shows the scope of included capacities and infrastructure for the pathways (A) dispatchable biomethane, (B) dispatchable solar and wind through hydrogen and (C) dispatchable solar and wind through batteries.

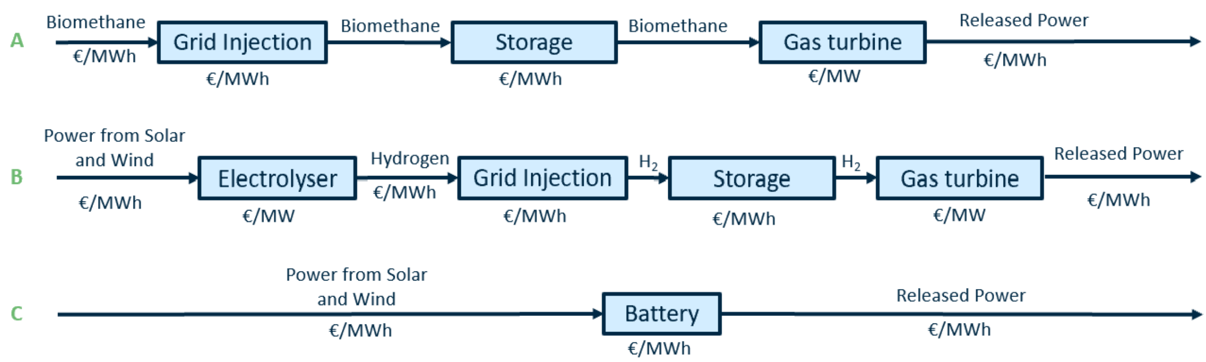

Figure 1: Scope of the assessment

To estimate the costs of released power for each pathway, estimations are made on the installed capacity of the included technologies for secure power supply and the costs of the included technologies. To do so, the findings in the report are based on reports written or commissioned by renowned organisations in the energy sector.

Pathway A: dispatchable biomethane

This chapter analyses the costs of dispatchable power from biomethane, leading to an overall cost of 149 €/MWh. Figure 2 shows the prices used to get to this estimation. This chapter further elaborates on the prices and the efficiencies of included technologies.

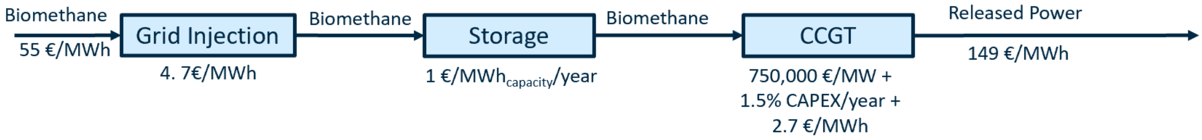

Figure 2: prices included for Pathway A

Biomethane feedstock and production

Today, the typical production costs of biomethane in an Anaerobic Digester with a methanation unit are 70–90 €/MWh[6]. Based on information from suppliers, large digesters today can already reach < 55 €/MWh. Common Futures believes that these costs can be lower by 2040, assuming that biomethane production happens mainly at large facilities. Also, gasification becomes an ever more interesting biomethane production technology, with projections of 47 €/MWh by 2050[7]. It is therefore expected that costs for biomethane production in 2040 can be reduced to 50 €/MWh.

Transport

Transport of biomethane can be divided into production facility-to-grid, grid-to-storage, and storage-to-power-plant. For this analysis, only the former is considered. It is assumed that biogas pipelines from a limited number of production facilities to a regional methanation unit and a biomethane pipeline from this unit to the existing methane (natural gas) grid.

The total biomethane network costs in 2050 are estimated to be 9.7 €/MWh of which biogas pipes cover 5.0 €/MWh and grid injection and connection costs add 4.7 €/MWh per year[8]. Common Futures assumes these indications to be the same in 2040, as this technology is already developed and we expect no innovative updates from 2040 to 2050 that would significantly reduce the costs of this technology.
Because the biogas pipelines link the anaerobic digester to the methanation unit, these costs are included in Figure 2 as costs of biomethane ready for grid injection

Storage

Biomethane can be stored in natural gas storages since it has the same composition as natural gas. For the inflow of biomethane a constant inflow from anaerobic digesters with upgrading stations is considered, making the inflow predictable and to a large extent comparable to natural gas inflow with constant reservoir extraction plus imports.

[6] Gas for Climate, The optimal role for gas in a net-zero emissions energy system, March 2019, page 14
[7] Gas for Climate, page 15
[8] Gas for Climate, page 84

Gas is routinely and cheaply stored in large volumes. Investment costs for creating underground gas storage are around €25 per MWh of storage capacity[9]. Although the technical lifetime could be very high (>50 years), the depreciation period will likely not exceed 30 years. As many storage facilities are already likely in use, OPEX costs are low, and the total cost is a modest fraction of the total cost for dispatchable power from biomethane, storage costs are simplified to fixed annual costs of 1 € per MWh of storage capacity per year.

For storage capacity, the working gas capacity is considered; the gas that can be extracted. The current ratio of yearly natural gas consumption to storage is used as a proxy for the needed gas storage. This is not a perfect proxy for the needed gas storage capacity, as it also includes strategic reserves, and natural gas for other purposes than power production, for which different levels of flexibility are desired. The proxy excludes gas extracted from natural gas reserves, line packing, and imports. Whereas line packing[10] is important for intra-day storage of gasses, it has limited impact on the need for seasonal storage and is therefore excluded from this assessment. Considering the proxy for 2040 also ignores efficiency improvements in generation technologies: with higher efficiencies, a lower storage capacity is needed.

This methodology to estimate the need for gas storage was considered by Guidehouse in a study commissioned by GIE[11], in co-operation with some of its members operating gas storages, which is why consider it an appropriate estimation method.

In EU-27 + UK, there was an average yearly natural gas consumption of 5,724 TWh from 2014-2019, and a working gas storage capacity of 1,168 TWh in 2021. Therefore the desired ratio of consumption-to-storage is 4.9 : 1[12] is used for this report.

Transport and storage combined, are assumed to have methane losses of 0.18%[13]. However, even if losses were assumed in the order of 1%, which would have a considerable climate impact, the impact on the economics of dispatchable power generation would be very small.

Gas-fired power plants

It is assumed that the necessary turbine capacity equals the peak load minus nuclear baseload and dispatchable hydropower load. This is for hours during winter with almost no sun and wind. Because this assumption is relevant for all three pathways, it has little implications for the outcome of the comparative assessment.

Considering the Distributed Energy scenario for 2040 from the TYNDP scenario report for 2022, the average peak demand (the highest single hourly power demand (GW) within a year) will reach approximately 610 GW in 2040[14]. This scenario assumes a hydropower capacity of 174 GW in 2040 and a nuclear capacity of approximately 103 GW[15], which would mean a turbine capacity of 333 GW.

[9] Gas for Climate, page 218

[10] Increasing the pressure in the gas grid to store more gas, such that the gas grid functions as storage.

[11] Guidehouse for Gas Infrastructure Europe, Picturing the value of underground gas storage to the European hydrogen system, June 2021, page 24.

[12] Guidehouse, page 23.

[13] Marcogaz, Methane emissions in the European Natural Gas midstream sectors, November 2017, page 2.

[14] TYNDP, page 18.

[15] Linearly interpolated from 139GW capacity in 2018, shrunk to 86GW in 2050.

For power production from biomethane, combustion through a combined cycle gas turbine (CCGT) is considered. The CCGT has an efficiency of 60%, Capital expenditure (CAPEX) costs of 750,000 €/MW, variable operational expenditure (OPEX) costs of 2.7 €/MWh and fixed OPEX of 1.5% CAPEX/year[16]. This indication is based on the estimated costs for 2050, but Common Futures believes these indications to be compatible with the 2040 scenario, as this technology is already developed and no innovative updates from 2040 to 2050 are expected that would significantly reduce the costs of this technology.

Pathway B: dispatchable power from hydrogen produced by solar and wind

This chapter analyses the costs of dispatchable power from hydrogen produced by solar and wind, leading to an overall cost of 143 €/MWh. Figure 3 shows the prices used to get to this estimation. This chapter further elaborates on the prices and efficiencies of included technologies.

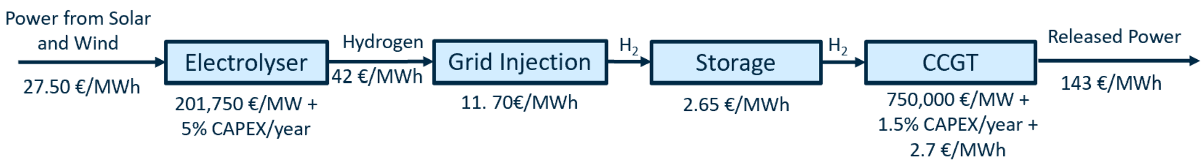

Figure 3: prices included for pathway B

Electrolysers

There lies an optimisation challenge behind the desired installed capacity of electrolysers for green hydrogen production, used for power generation: power from green hydrogen is only generated when power generation from solar and wind cannot match supply. If more solar and wind power is installed, there are more hours of overproduction from solar and wind and electrolysers can be run more hours to produce green hydrogen. However, increased shares of wind and solar penetration also reduce the demand for dispatchable power generation. Therefore, for the cost-optimum production of hydrogen, the capacity of electrolysers, solar panels and wind turbines are communicating vessels.

For this analysis, hybrid hydrogen production (from solar and wind) with dedicated power for hydrogen production is considered, with a capacity factor of 0.43 and electricity feedstock of 27.50 €/MWh[17].

The lifetime of electrolysers in 2040 is set at 30 years, the efficiency at 76%, the CAPEX at 201,750 €/MW, and the fixed OPEX at 5% of the CAPEX per year[18]. Nowadays, costs are still higher than 1 million €/MW.

Based on these inputs, the costs of hydrogen production are 42.35 €/MWh. This is in line, though on the progressive side, with the estimation from the European Hydrogen Backbone 2021 study, which estimates that by 2040 “up to 1,600 TWh of green hydrogen can be produced at 60 €/MWh or less of which up to 500 TWh around 45 €/MWh”.[19]

[16] Gas for Climate, page 217.
[17] Gas for Climate, page 24
[18] EHB with Gas for Climate, “Analysing future demand, supply, and transport of hydrogen”, June 2021, page 104
[19] EHB, page 60

Transport

For this analysis, it is assumed that the hydrogen storage and power generation take place at the same location. The electrolysers are linked to the solar and wind parks, thus the hydrogen has to be transported from these parks to a hydrogen grid (assumed to be in place by 2040), then to the storage and finally, from storage to the power plant. For the scope of this analysis, only the hydrogen transport from the production facilities to the hydrogen grid is included, including compression.

The distance from electrolyser to hydrogen grid is considered to be in the order of 1-10 kilometres and the highest costs are compression and connection costs. Roland Berger estimates that costs for grid injection of hydrogen from a 5 MW electrolyser, including 250 meters of pipeline and compression, are €0.39/kg[20]. As hydrogen has an energy density (at Lower Heating Value) of 33.33 MWh/tonneH_2, this corresponds to 11.70 €/MWh.
The size of electrolysers considered in this study is considerably larger (100 MW), which brings cost advantages, and should allow for a longer pipeline (1-10 kilometres) at a similar cost.

Storage

When wind and/or solar electricity are considered for hydrogen production, the inflow of hydrogen will be intermittent, making its supply more volatile than natural gas supply.
For storage of hydrogen, salt caverns are considered, at which hydrogen can be stored for 2.65 €/MWh[21] by 2050, which Common Futures thinks can already be achieved by 2040; this corresponds to 2.65 €/MWh.

Hydrogen losses in transport and storage are similar to methane losses[22] and are thus set at 0.18%. Even assuming losses on the order of 1% would have made little difference in the final economic assessment.

Turbine

The turbine capacity is assumed to be the same as in the biomethane pathway because the same peak capacity is needed. Also the same turbine efficiency and costs are considered for a fair comparison. It is already possible to retrofit existing natural gas turbines to hydrogen turbines[23], and investment and maintenance costs for these two are expected to be very similar. Assuming that more efficient turbines are also more expensive, turbines with a higher efficiency become more interesting for more expensive feedstock costs. Because feedstock costs of hydrogen and biomethane are fairly similar, it is also reasonable to assume the same turbine type from a cost-optimisation perspective.

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[20] Roland Berger commissioned by the Fuel Cells and Hydrogen 2 Joint Undertaking, Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities, Fall 2017, slide 13
[21] ETC, Making the Hydrogen Economy Possible, expressed as 0.10 $/kg, April 2021, page 42
[22] Gas for Climate, page 179
[23] ETC, page 78

Pathway C: dispatchable power from batteries produced by solar and wind

This chapter analyses the costs of dispatchable power from batteries produced by solar and wind. The costs of released power are dictated by the number of times the battery can be unloaded. For a year-round flexible power supply, overall costs would be approximately 758 €/MWh. Batteries become competitive when they can be unloaded more than 40 times per year, for approximately 15% of flexible power demand. Figure 4 shows the prices used to get to this estimation. This chapter further elaborates on the prices and the capacities and efficiencies of the battery.

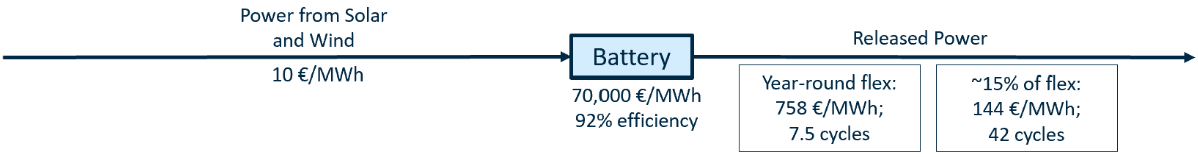

Figure 4: prices included for Pathway C

When considering batteries for year-round peak-capacity purposes, not so much the peak release capacity, but the storage capacity becomes a limiting factor. The most critical assumption for batteries is the capacity needed for sufficient electricity supply in extended periods of limited wind and sun hours. To the best of our knowledge, there are no studies for Europe that rely on batteries for 100% of their dispatchable capacity, equal to approximately 10 – 15% of the total electricity supply. The PAC scenario used by EEB and CAN Europe[24] presents modelling results for 2030, still relying on flexible operation of natural gas-fired power plants, does not provide details of flexibility thereafter; 'flexible biogas cogeneration' is mentioned as one of the possible options.
Studies for which batteries are considered for flexible power generation consider them for short-term intraday flexibility, but not for seasonal flexibility. The power released from batteries can however significantly contribute to the flexible power demand: for example, TYNDP[25] estimates that nearly 60TWh of electricity is released from batteries by 2040, or 15% of flexible power demand, and the rest is generated by hydrogen or biomethane fired power plants.

Any estimation on the average price per MWh for electricity released from batteries for year-round flexibility supply will exceed the estimation for dispatchable biomethane or dispatchable solar and wind through hydrogen. The investment costs of batteries are mainly determined by the needed storage capacity, which is very large in a system fully dependent on one source for its dispatchable power, as seen in the biomethane pathway. The marginal capacity[26] has a low utilisation rate (<1 cycle per year) and thus makes no sense to install from an economic perspective if also dispatchable green gas is available for power generation.

Costs and efficiencies

For year-round dispatchable power supply, high ratios of storage capacity to release capacity are preferred, as it slightly reduces the costs of the battery per MWh capacity. Predicting the price development for batteries can be tricky, as it is one of the fastest developing technologies: lithium-

[24] CAN Europe and EEB, Building a Paris Agreement Compatible (PAC) energy scenario, June 2020, page 38
[25] TYNDP, page 31
[26] The Last installed battery

ion battery pack prices dropped from around $1,200 $/kWh in 2010 to 132 $/kWh in 2021 with even lower prices for battery electric vehicle packages[27]. Large car manufacturers like Renault and Ford have already publicly announced targets of 80 $/kWh in 2030[28], equivalent to 71 €/kWh. This is in line with estimations from the European technology and innovation platform, which estimates 70 €/kWh in 2030, which is used for the 2040 estimation. They estimate that the lifetime of batteries will be 20 years by 2030, with a roundtrip efficiency of >93% and a self-discharge rate of 0.5% per month. Considering seasonal storage, 92% discharge roundtrip efficiency seems a reasonable estimation. Although these numbers relate to 2030, they are considered for this study because technology improvements curves flatten over time and the estimations seem optimistic compared to estimates in other studies, such as by Gas for Climate[29] or IEA[30].

The batteries for electricity storage are standalone batteries, without the integration of batteries from electric vehicles. Even if batteries from electric vehicles were included, still a large number of incremental batteries with few cycles per year would need to be installed, which are the largest determinant for the price of power dispatched by batteries.
The electricity used for filling the batteries is assumed to be mainly curtailed electricity, for an average price of 10 €/MWh.

Capacity

Due to the absence of studies estimating the needed battery capacity for covering the entire power flexibility demand, the proxy for the necessary storage capacity needed for biomethane, corrected for the battery efficiency (0.92 compared to 0.6 of the CCGT) is also used to estimate the needed battery capacity for year-round flexibility. Considering the more intermittent inflow of electricity from solar than the production of biomethane – both with a curtailed as well as dedicated power scenario for batteries, this proxy is probably on the lower end of the uncertainty spectrum.

Results

With the assumptions mentioned above, and considering an interest rate of 5%, the average costs per MWh to produce or release dispatchable power for the EU-27 countries in 2040 by either biomethane or solar and wind through hydrogen is shown in Table 1.

Table 1: costs per MWh for dispatchable electricity for year-round flexibility supply from biomethane or solar and wind through hydrogen in 2040 for EU-27

Dispatchable Power Pathways	€/MWh
Biomethane to power	149
Solar and wind to power through hydrogen	143

[27] Bloomberg NEF, Battery Pack Prices Fall to an Average of $132/kWh, But Rising Commodity Prices Start to Bite, November 2021. Retrieved from https://about.bnef.com/blog/battery-pack-prices-fall-to-an-average-of-132-kwh-but-rising-commodity-prices-start-to-bite/?utm_medium=Twitter_BNEF&utm_campaign=BNEF&utm_source=Social-o&utm_content=organic&tactic=431831

[28] Bloomberg NEF

[29] Gas for Climate, page 217

[30] https://www.iea.org/commentaries/battery-storage-is-almost-ready-to-play-the-flexibility-game ; 186 USD/kWh (2017) translates to 186 €/kWh in 2021.

Figure 5 then shows the costs of components. The price for each component in the power generation mix is multiplied by the efficiencies later in the chain, and can thus be larger than the standalone component. For example, the feedstock electricity for electrolysers costs 27.5 €/MWh but constitutes to 60.4 €/MWh of the electricity due to the efficiencies of the electrolyser (0.76), storage and transport (0.998), and power generation (0.6).

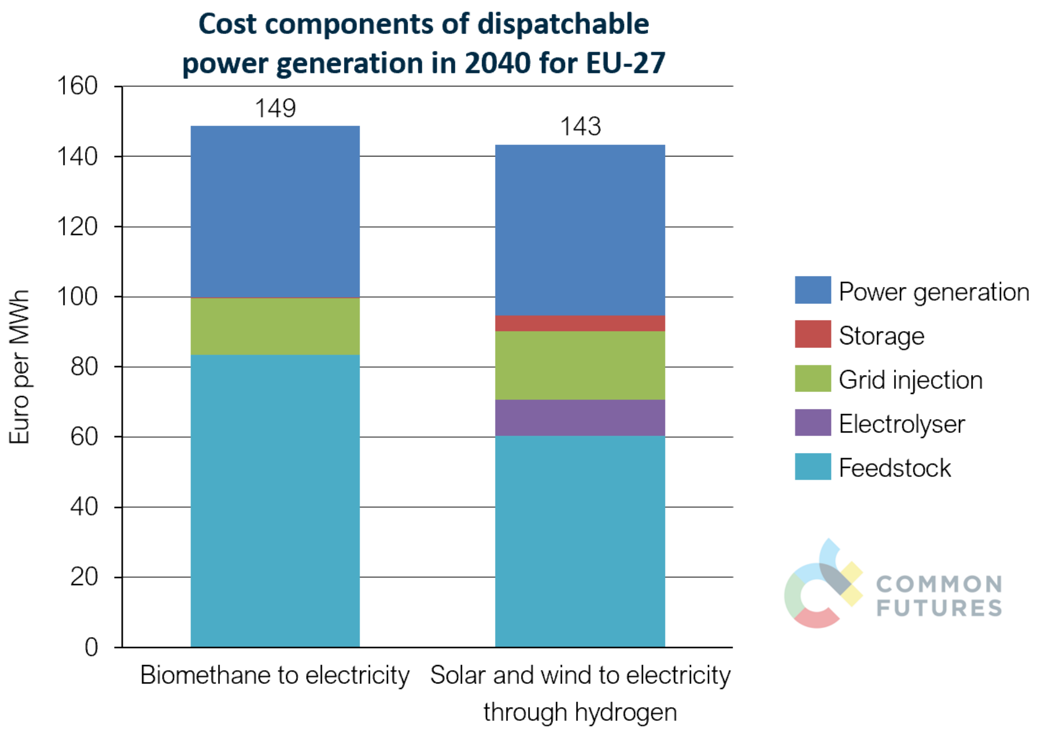

Figure 5: Cost components of dispatchable power in Pathway A and B in 2040 for EU-27

Figure 5 shows that power from biomethane and dispatchable solar and wind through hydrogen can be produced for very similar average costs per MWh. Based on the results and uncertainties in price developments, one cannot indicate whether one of these technologies would be a preferred technology for dispatchable power generation from a cost perspective. For both pathways, the production price of the gas is the most critical assumption, as the price multiplies for the final power generation due to efficiency losses in the turbine. Price developments of digesters, solar panels, wind turbines and electrolysers will largely determine the real 2040 prices of dispatchable power in these pathways. However, as they are comparable in a price comparison, they can also complement each other in a European energy system:

- First, a system with access to a variety of energy sources becomes more resilient.
- Second, marginal costs for incremental hydrogen and biomethane production increase when it is assumed that cost-optimal production locations are utilized first: depending on both can reduce the average feedstock production costs.
- Third, there is a potential scarcity of available feedstock for biomethane production or locations for solar- and wind parks. Having access to two energy carriers can reduce scarcity risks in renewable gas transition years.

- Fourth, considering two domestic dispatchable energy carriers reduces import dependence, as their combined contribution can be larger than that of either of the two on its own.
- Last, no geographical distinction was made in this study. Throughout Europe, there may be regions or countries for which one of the two energy carriers is the preferred solution.

Dispatchable power from batteries produced by solar and wind

Considering the estimation of needed storage capacity where the current storage capacity needed for biomethane is used as a proxy, the average costs for power released from batteries would be 758 €/MWh. Dispatchable power from solar and wind to power through batteries becomes unreasonably expensive as a year-round flexibility solution due to the low number of average annual cycles of the batteries that need to be installed: batteries considered in this scenario had an average of 7,5 cycles per year. However, if batteries can be installed under the condition that they can be unloaded > 42 times per year, batteries can become part of the solution in the flexibility challenge:

- At 42 cycles per year, costs from dispatchable power from solar and wind to power through batteries are approximately 144 €/MWh, which makes this solution cost-comparable to the other two pathways.[31]
- When used for peak shaving, average power costs from gaseous energy carriers can be reduced due to smaller installed turbine capacity.

The desired capacity for batteries would result from an optimisation study.

Conclusions

In this study, Common Futures analysed the costs of released power for three dispatchable power pathways for EU-27 in 2040. Each pathway can be part of the electricity mix, but pathways depending on renewable gasses are cheaper per MWh for year-round flexibility than a pathway depending on batteries. Both dispatchable power from biomethane and from sun and wind through hydrogen can be generated for similar costs of approximately 150 €/MWh. They can complement each other in a renewable energy system: their joint production potentials are higher improving the feasibility of meeting the full demand for dispatchable power, and there is a lower risk of feedstock scarcity. Power from sun and wind through batteries is insufficient for year-round flexibility: high storage capacity is needed for secure power supply, which reduces the annual number of cycles of battery operation to a minimum. However, batteries used for intra-day flexibility can be cost-competitive for dispatchable power supply at short time scales.

Based on these findings, Common Futures concludes that there is a relevant role for both renewable biomethane as well as green hydrogen in the future energy system, complemented by a small share of batteries.

[31] If this were to correspond to 60 TWh of electricity supply, as assumed in the TYNDP report, this indicates a €100 billion investment: 60/42 = 1.43 TWh installed battery capacity, or 1.43 * 10^9 kWh. 1.43 *10^9 * 70 €/kWh = €100 billion.

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