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# The Energy Situation in the Federal Republic of Germany: Analysis of the Current Situation and Perspectives for a Non-Fossil Energy Supply

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**Abstract:** Formulating energy policies at national, European, and global levels is extremely challenging. The move away from fossil fuels is associated with a variety of technological, economic, and social implications, each of which is subject to dynamic changes and societal scrutiny and can hardly be predicted with certainty. Therefore, a fact-based assessment for the path to a sustainable green energy future is sought out in this paper, using the road-based mobility sector of the Federal Republic of Germany as an example. The analysis performed in this paper is built on publicly accessible, reputable sources like DESTATIS and EUROSTAT. In addition, some very simple calculations were made, e.g., on the potential for wind and photovoltaic energy within Germany. Such an analysis needs to start with the overall energy consumption of any one country. A basic assumption of the paper is that the energy system of the future will be based to a large extent on electricity and its storage in chemical energy. It is assumed that, in addition to hydrogen, liquid energy sources will play a significant role due to the simplicity of their logistics and the subsequent implications on cost. Examples of green, electricity-based fuels with great potential are methanol, methane, and ammonia. Additionally, biomass plays an important role, either for direct use as a fuel or as a source of non-fossil carbon. Today, biofuels, i.e., biodiesel and bioethanol, deliver the largest contribution to climate protection in the EU transport sector. The main goal—the reduction of greenhouse gas emissions—often collides with geopolitical circumstances or national political necessities. This includes, for example, the current world market situation and its national impacts caused by the Russian attack on Ukraine. The prospect for a green, sustainable, and defossilized energy supply are discussed in this context. The paper concludes that a defossilized world energy supply and trade based on renewable electricity and its derivatives, eHydrogen and refuels, and on biomass, is feasible.

**Keywords:** eFuels; biomass; bioFuels; energy transition; energy supply; defossilation; mobility; energy storage; energy transport; regenerative energy

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## 1. The Current Energy Landscape of Germany

Energy is essential to ensure the prosperity of any industrialized country. Therefore, such countries face a predicament with respect to global warming and the Paris Climate Agreement. This demands a reduction of 55% of greenhouse gas emissions with respect to the level of 1990 [1] by 2030.

The number against which all effort needs to be compared is the total demand of primary energy. For Germany this was 3560 TWh in 2019 and approximately 4100 TWh in 1990, which includes all consumers, i.e., industry, trade, households, transport, heating, lighting, etc. A reduction of 55% for 2030 would result in some 2300 TWh. The share of renewable energy sources in this was only 14.8% [2] in 2019 and increased only slightly to 16.1% in 2021 [3]. Photovoltaics and wind turbines covered about one third, whereas approximately half of the renewables are for heating purposes. Plausible simulations show that a reduction of the primary energy demand to approximately 2000 TWh by 2050 [4] would be possible. Large savings would originate from the direct local generation of electricity in Germany (wind and PV), from heating with (electric) heat pumps and massive improvements in building insulation as well as essential improvements in power train efficiencies (e.g., electric driving and sophisticated hybrid concepts). However, for all of these forecast improvements to take effect, the simulated system architecture needs to be realized corresponding to concepts and not to political whims and dogmata. The quoted simulation sees approximately 1000 TWh/a in electricity from wind and photovoltaics in 2050, i.e., 50% of the primary energy demand. Compared to this, in 2019 this was 5%, i.e., only about 180 TWh/a in 3559 TWh/a. For the current situation this means for the transport sector that electric vehicles are fed with energy from coal power plants. It is important to note that the calculation with the "German energy mix" in this context is wrong, since the additional electricity will purely be supplied by switching to coal power plants (this is called "marginal current", although it is not marginal at all).

## 2. Energy Imports into EU Countries; Current Situation

One absolutely essential consideration in this context is the importation of energy in any industrialized country. Most European nations do not have enough fossil resources of their own, nor enough land surface to satisfy their energy needs from photovoltaics and wind energy. Germany in the last 20 years on average imported some 60% of its primary energy demand, with a peak of 67% in 2019 [5]. From this it is obvious that the importation of energy cannot be omitted and simulations of future green energy systems [6] confirm this, even for the year 2050.

## 3. Energy Imports into Industrialized Countries; Future Prospects

Energy imports in the shape of electricity or hydrogen are extremely costly, geopolitically difficult, or, in many cases, not possible at all. Here, liquid, storable, and renewable fuels will be a viable solution [7]. In addition, the use of biomass will contribute to relieve this situation to some degree. It is clear that the reconversion into electricity of imported energy carriers (hydrogen, methanol, or others) to power the grid during Dunkelflaute cannot be avoided. However, the reconversion for the purpose of charging battery electric vehicles aggravates the $CO_2$ emissions, if there is not enough locally produced electricity, since then the so-called "marginal" electricity (from fossil sources) needs to fill in the gap. In terms of vehicle efficiency, this would not make any sense, since the resulting efficiencies well-to-wheel would be more or less equal for all types of vehicles, including those with internal combustion engines (ICE), albeit at a much higher cost for the battery or fuel cell vehicles. Therefore, for transport, it would be favorable to use these bio- or reFuels directly in highly efficient hybrid powertrains with ICE. Well-to-wheel efficiencies take into account the complete chain of energy/fuel production, distribution, storage, and end use. In contrast, tank-to-wheel considerations only regard the efficiency of converting energy from the vehicle tank/battery (storage) to vehicle movement.

Storage and transport of energy pose the same challenges in many cases (e.g., tanks, batteries), i.e., in terms of weight, volume, handling, (volumetric) energy density, and travel range. However, mobile storage is much more challenging than stationary storage and distribution. This distinguishes transport from other sectors and is another important argument for using liquid green fuels in mobile applications. Additionally, a national strategic energy reserve is absolutely imperative, which, for 6 months from today requires some 1800 TWh of storage. This must be low cost, robust, and with easy handling and logistics, resulting in liquid fuels, which, in an emergency, can be distributed by tanker.

In the transport sector, alternative technologies, such as battery-powered and hydrogen fuel cell vehicles are supposed to play a large role in the future. These will save greenhouse gas emissions in the medium term, when the electricity markets have been transformed to supply an abundance of green energy. However, until such scenarios become reality, $CO_2$-neutral transport can already be achieved today, with an immediate reduction in $CO_2$ emissions, through the use of re- and bioFuels in the well-established, robust, and cost-effective internal combustion engine. One example for this is second-generation biodiesel produced from waste, e.g., cooking oils, with a $CO_2$ savings potential of up to 80% compared to fossil diesel fuel [8].

## 4. Replacing Fossil Supplies through National Biomass? Geopolitical Considerations

Independently of the technological development of the new low-emission mobility, the geopolitical situation in the world very essentially governs the transition in the energy and mobility sectors, in particular in two respects. One is the availability of raw materials needed for this transition, the other is the availability of energy carriers. The latter was seriously disturbed by the Russian aggression against Ukraine and the side effects of the western embargo against Russia, i.e., the Russian retaliation in terms of stopping energy supplies to the West. This had dramatic effects on the German energy policy, because a large part of the German energy imports originated from Russia. Russia supplied mainly crude oil and natural gas, but also secondary energy carriers like refined diesel fuel (DF) (and also Uranium for nuclear power plants.). The Russian share of the crude oil supply was about 34% [9], that of the German diesel fuel demand about 15% [10]. By November 2022, the Russian share of crude oil imports dropped to 17% [11], with severe effects on the oil price and, hence, the economy and inflation rate. Since, currently, as pointed out in the energy analysis, Germany and Europe do not dispose of enough green energy, this gap needed to be closed by other sources, and bioFuels can relieve this problem to some extent (see below).

Another extremely important energy source for Europe was natural gas, Russia being one of the main suppliers. In 2021, the total consumption of natural gas in Germany was 1012 TWh, up by 14% from 2019. Approximately half of this was imported from Russia, i.e., 500 TWh. In the first quarter of 2022, the amount of natural gas imported from Russia was reduced to about 40% [12], or around 200 TWh. To facilitate this, the subsequent gap had to be closed otherwise. Such a situation should have accelerated the build-up of renewable energies. However, progress hitherto was far too slow (see above), and more fossil fuel had to be bought elsewhere on the world market (e.g., LNG). This again led to massive energy price increases. One solution would have been the use of biobased energies, e.g., biodiesel, Ethanol, HVO, BioCrude, etc. The usage of biobased fuels in Germany was 34.5 TWh in 2021 [13]. The overall unused theoretical quantity of energy in 2015 was up to 124 TWh [14]. This could be used as heating oil and gas in households and industry. However, ideally it would replace fossil fuels for transport purposes, since stationary applications can easily be fed by pipelines ($H_2$) and cables directly with the new green (unfortunately not yet abundant) energies, whereas the mobile storage of these energy carriers presents an expensive challenge.

The Russian aggression not only left a gap in crude oil but also in diesel fuel supplies. Germany consumed roughly 32 million t of diesel fuel, equal to approximately 350 TWh in 2021 [15]. Before the war 4.8 million t were imported from Russia [16]. Today it is estimated that about half of this is left, approximately 2.6 million t [17]. This remaining import could completely be replaced by established biodiesel. The total consumption of fuels in Germany in 2021 was approximately 52.1 million t, with an energetic biofuel share of 5.7% [17]. The largest share of biofuels was biodiesel and hydrogenated vegetable oils (approximately 28 TWh) blended with fossil diesel fuel at a rate of 4.2%. This is still less than the up to 7%, stipulated by the EU, which would obviously offset some of the gap from the Russian embargo. The 28 TWh share corresponds to about 2.5 million tons. The production capacity of biodiesel of approximately 3.9 million t and the actual production of approximately 3.45 million t allowed Germany to export approximately 2.2 million t of biodiesel [18]. The conclusion is that a complete replacement of Russian diesel fuel would be possible and largely $CO_2$ free at that, saving between 2 and 3 t of $CO_2$ per t of fuel, depending on the origin of the raw material.

## 5. Replacing Fossil Supplies by Electro-Based Energy Carriers

With the use of electricity as one prime energy source, a number of problems have to be solved in terms of transport and storage.

### 5.1. World Wide and National Energy Logistics

In order for electricity to be used efficiently, it is necessary to keep transport distances short. In contradiction to this, electricity should be harvested where it is most economic, i.e., where the wind blows, or where the sun shines intensively. Therefore, an economic and ecologic compromise between the location of electricity production and its transport to the (industrial) centers of consumption needs to be found. For the transport of electricity within Germany, from the northern parts of the country, including offshore facilities, where the wind intensity is considerably higher than in the south, a suitable grid needs to be installed. The same goes for the transport of PV electricity from south to north. The corresponding grid losses are inevitable.

### 5.2. Worldwide and National Energy Storage

With respect to stored energy, today, we draw on tanks of fossil fuel, which are simple, robust, and cost efficient, with very simple logistics and an enormous storage capacity. In the "electric age" this is not quite as simple. One approach is storage in batteries. These however have an extremely low storage density of less than 1/40th of diesel fuel (coarse estimate: diesel fuel at 12,000 Wh per kg vs. Li-ion cells at a very optimistic 300 Wh/kg). The incorporation of vehicle batteries and future household storage batteries as well as public facilities in a "Smart Grid" appears to be the most complex and costly approach for a national economy. A simpler and less costly approach would be chemical storage.

### 5.3. Chemical Storage and Its Challenges

Electricity can be used to electrolyze eHydrogen at an efficiency of roughly 70%. However, hydrogen has a very low volumetric energy density, even under high pressure (350/700 bar systems) or cryogenic liquid states at −253 °C. Both of these methods consume large amounts of energy: compression approximately 12%, supercooling a minimum of 28% of the gravimetric energy content of hydrogen, and the resulting logistics are complex and expensive. Its diffusion through many materials (it is, after all, the smallest molecule) poses an additional problem that increases cost. The direct use of hydrogen is favorable in stationary applications, where a pipeline can circumvent the problem of the expensive storage tank to some extent.

Since hydrogen does not appear to be an optimal solution, neither for long term storage nor for temporary storage in long distance transport, the hydrogen derivatives come into the focus, in particular methanol, which is liquid at ambient conditions and, hence, allows for very cheap and efficient logistics. Methanol already has a large global market [19]. The production of eMethanol has an energetic efficiency of 52%. The production of $eH_2$ plus its liquefaction has a combined efficiency of at best 50% that of eH2 and with compression to 700 bar an efficiency of just over 60%, albeit with a high reduction in energy density (1.4 $kWh/Liter_{700bar}$ instead of 2.34 $Wh/Liter_{liquid}$). Liquid transport entails only minimal losses, i.e., the energy to drive the overseas tanker, which is particularly attractive for extremely long distances, very much like the transport of crude oil around the world today. This means that the green electricity needs to be converted directly on site into a transportable and storable medium. With this simplification of energy logistics, a promising concept is the erection of solar and wind farms in places where there is an abundance of sun and/or wind. Examples are the regions of Patagonia, Greenland, or Australia and Africa/Arabia in the "earth's sunbelt". Europe also offers suitable places in Greece, southern Italy, Spain, or Portugal.

Methanol has only about half the volumetric energy density of diesel fuel, but approximately twice the that of liquid hydrogen at −253 °C. A conventional overseas tanker with a capacity of 250,000 $m^3$ can ship just over 1,100,000 MWh of methanol, whereas the currently largest $LH_2$ carrier only holds 293 MWh [20]. A comparison of various energy carriers is given in the following table (Table 1).

**Table 1.** Properties of energy carriers, in particular volumetric energy density (bold font column). methanol and ethanol are favorable from a logistical point of view (orange and turquoise lines). For comparison the numbers for a typical battery are given. methane and hydrogen are grouped in grey and blue, respectively.

| Fuel, State of Matter | Energy [kWh/L] | Volumetric Factors with Ref. to Diesel | Remark | Energy [kWh/kg] |
|---|---|---|---|---|
| Diesel, liquid at 20 °C, 1013 mbar | 9.74 | 1/1 | For comparison: $Li^+$-Battery: 0.7–0.9 kWh/L | 11.7 |
| Gasoline, liquid at 20 °C, 1013 mbar | 9.25 | 0.95/1.05 | / | 11.1 |
| Methanol, liquid at 20 °C, 1013 mbar | 4.43 | 0.45/2.2 | Production efficiency 52% (from electricity via $H_2$ electrolysis to MeOH (Boiling point 65 °C) | 5.6 |
| Ethanol, liquid at 20 °C, 1013 mbar | 5.8 | 0.59/1.68 | Widely used bio component (Boiling point 78 °C) | 7.9 |
| Ammonia, liquid at 20 °C, 8.6 bar | 3.17 | 0.33/3 | Best production efficiency 59% → Future process, not industrialized yet. | 4.9 |
| Methane, liquid at −162 °C, 1013 mbar | 5.9 | 0.61/1.65 | / | 13.9 |
| Methane, gaseous at 20 °C, 200 bar | 2.25 | 0.23/3.92 | / | 13.9 |
| Hydrogen, liquid at −253 °C, 1013 mbar | 2.34 | 0.24/4.16 | Production + liquefaction: $0.7 \times 0.72 = 0.50$ (compared to methanol) | 33 |
| Hydrogen, gaseous at 20 °C, 700 bar | 1.42 | 0.15/6.86 | Production + compression efficiencies: $0.7 \times 0.88 = 0.62$ (compared to methanol) | 33 |
| Hydrogen, gaseous at 20 °C, 350 bar | 0.85 | 0.09/11.45 | / | 33 |

## 6. The Cost of Electro-Based Energy Carriers

Machhammer [21] calculated for the Haru Oni project in Chile that methanol and even green eGasoline and eDiesel could be produced at roughly 18 €c/kWh, including 14,000 km tanker transport to, e.g., Rotterdam, 500 km inland water transport and 200 km road tanker. He assumed 3.8 €c/kWh electricity cost. In the earth's sunbelt, electricity can currently be produced for under 1 €c/kWh (in Saudi Arabia the current minimum is 0.88 €c/kWh incl. CAPEX + OPEX). Adding the cost for electrolysis, as forecast in approximately 5 years, the synthesis cost for $H_2$ and DAC $CO_2$ to methanol and the transport cost as described above, methanol, available in Germany, would cost 10 €c/kWh or less, which amounts to approximately 40 €c/L of eMethanol without tax and profit (current price 1 February 2023 of mainly fossil sources is 38 €c/L (478 €/t) [22]) and less than 1€ for the equivalent energy of 1 L of petrol [23]. Methanol can be converted to conventional fuels either in a Fischer–Tropsch process (eKerosene and eDiesel EN590) or though polymerization in "Methanol-to-Gasoline" (MtG) to eGasoline EN228. The C3 Mobility project has demonstrated that petrol from MtG can be produced for 0.89 € per litre [24]. One possible region of the world is MENA (Middle East North Africa). Currently MENA is geopolitically difficult. The risks and opportunities were calculated by DLR in the MENA-Fuels project [25].

## 7. eMethane and bioMethane

Another attractive eFuel is Methane. eMethane can substitute natural gas, with the advantage of $eCH_4$ being close to 100% pure. A second already established route to green Methane is biogas. This is today mainly used in decentralized, small, combined heat and power plants (CHP) for on-site electricity and heat generation. The volume of this heat was 13 TWh (2021), which corresponded to about 2% of the overall heat from natural gas. Total electricity generation from biogas in 2021 was 28 TWh, compared to that of natural gas 2021 at 60 TWh (equal to 10% of the total electricity generation of ~600 TWh) [13.2]. Direct substitution and feeding into the gas grid amounted to approximately 11 TWh/a, which corresponds to roughly 1% of the current natural gas consumption. An increase in biogas capacities was hindered by the food vs. tank discussion. This needs to be overcome. For bioMethane, there is potential of 26–76 TWh/a [13.3]. The overall capacity of 100–125 TWh of bioMethane [26] is another 3.6% of 3500 TWh.

In summary, there were 256 TWh of biomass energy utilized in 2021 [13], which is 7–8% with respect to 3500–3000 TWh/a primary energy demand. This is divided in 172 TWh for heating, 50 TWh for power generation and 34.5 TWh for bioFuels (approximately 4% of transport demand). The DBFZ Report No. 41 [26] states that up to 15% of the primary energy demand could be covered by biomass in the future. This would be approximately 500 TWh. Other authors also found approximately 500 TWh of technical potential of various biomass fractions for 2020 (in DBFZ Report No. 8) [27]. WECOM [1] quotes 400 TWh of biomass energy for 2050, then equal to approximately 20% of the primary energy demand. This confirms that today biomass can potentially contribute approximately 15% to the transition of the energy system, including the transition of transport.

## 8. Summary and Conclusions

For a non-fossil green future, a mix of established and new technologies is necessary. For the necessary energy imports, liquid reFuels (renewable electro-based fuels) are a favorable option, which at the same time facilitates a national strategic energy reserve as well as a $CO_2$-neutral, robust, and cost-effective transport sector. This system should be augmented by bioFuels and fuels from (plastic) waste, which already today offer a low $CO_2$ energy source. For this, both first- and second-generation biofuels should be considered since both have their characteristic advantages. The short-term deprivation of Russian energy imports can unfortunately not be fully mitigated through renewable fuels. However, the Russian aggression will hopefully accelerate the process to a larger energy independence in Europe. For this, renewable methanol could potentially be drawn from a variety of geographical and politically acceptable locations. New regenerative fuel components from biomass will help to reduce the share of fossil fuels, already in the run up to 2030. The demand of crude oil will obviously become less with the progress in the transition to electricity, hydrogen, and renewable fuels. However, the build-up of the green energy capacities will probably take 20 to 30 years [28], well beyond the timeframe set for the 1.5 °C target. This process could massively be accelerated if the EU provided the legal framework for reFuels in combustion engines to be acknowledged as $CO_2$-neutral. In the medium and long term, direct electricity as well as the green derivatives methanol, eGasoline, and eDiesel will facilitate the transition of the energy and mobility systems.

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## Nomenclature

In this paper, the following nomenclature is used: The prefixes denote the origin or classification of the energy sources.

Bio- (biomass) is self-explanatory. reFuels are fuels produced from renewable electricity sources. From these, hydrogen, and subsequently synthetic fuels are produced. The next category are sustainable biofuels (advanced biofuels), which fall under Renewable Energy Directive II (REDII) [29]. In contrast to reFuels, eFuels can be produced from electricity and carbon sources of fossil origin. However, since eFuels should also aim for a high regenerative share, there is no fundamental contradiction between re- and eFuels. $CO_2$ can come from industrial processes, from direct air capture, or from biomass. The term green describes the basic use of non-fossil energy sources.

## References

1. Available online: https://www.bundesregierung.de/breg-de/aktuelles/co2-kohlenstoffdioxid-oder-kohlendioxid-emission-614692 (accessed on 18 May 2023).
2. Available online: https://ag-energiebilanzen.de/arbeitsgemeinschaft-energiebilanzen-legt-bericht-zum-energieverbrauch-2019-vor/ (accessed on 25 March 2020).
3. Available online: https://ag-energiebilanzen.de/energieverbrauch-zieht-wieder-an/ (accessed on 21 December 2021).
4. Wagner, Elbling, and Company, Commit to Connect 2050. Available online: https://www.ontras.com/sites/default/files/2021-11/2020_04_21_CTC2050_Abschlussbericht.pdf (accessed on 30 April 2020).
5. Available online: https://ec.europa.eu/eurostat/databrowser/view/NRG_IND_ID__custom_4741275/bookmark/table?lang=de&bookmarkId=4fd882e6-e52b-4a4a-97e6-8a3dae3e9cb6 (accessed on 28 April 2023).
6. Wagner, Elbling, and Company, Simulation 2050. Available online: https://www.mobility-impacts.de/new-power/detail/news/unterschaetztes-biomethan-fuer-ein-dekarbonisiertes-verkehrssystem.html (accessed on 26 August 2022).
7. Machhammer, O. Renewable Electricity from Germany or e-Fuels from Chile: What Should Future Mobility be Based on? *Chem. Ing. Tech.* **2021**, *93*, 641–654. [CrossRef]
8. Available online: https://tecosol.de/de/ (accessed on 18 May 2023).
9. BAFA. Amtliche Mineralöldaten Februar 2022. Available online: https://www.bafa.de/SharedDocs/Downloads/DE/Energie/Mineraloel/moel_amtliche_daten_2022_02.html (accessed on 18 May 2023).
10. Available online: https://www.iwd.de/artikel/deutschland-bezieht-viel-diesel-aus-russland-539711/ (accessed on 1 April 2022).
11. Available online: https://de.statista.com/statistik/daten/studie/1315009/umfrage/russischer-anteil-an-deutschen-erdoelimporten/ (accessed on 16 March 2023).
12. DBFZ. Die Rolle von Biogas für Eine Sichere Gasversorgung in Deutschland. (13.1: p. 3, 13.2: p. 4, 13.3: p. 7). Available online: https://www.dbfz.de/fileadmin/user_upload/Referenzen/Statements/Positionspapier_Biogas_Ukraine.pdf (accessed on 30 May 2022).
13. Available online: https://www.umweltbundesamt.de/themen/klima-energie/erneuerbare-energien/erneuerbare-energien-in-zahlen#ueberblick (accessed on 17 March 2023).
14. FNR. Biomassepotenziale von Rest- und Abfallstoffen-Status Quo in Deutschland. 2015, p. 13. Available online: https://mediathek.fnr.de/broschuren/bioenergie/band-36-biomassepotenziale-von-rest-und-abfallstoffen-status-quo-in-deutschland.html (accessed on 18 May 2023).
15. FNR. Basisdaten Bioenergie 2022. p. 34. Available online: https://www.nq-anlagentechnik.de/basisdaten-bioenergie-2022/ (accessed on 30 July 2022).
16. IW. Kurzbericht 21/2022, Russland Bedeutung als Kraftstofflieferant. Available online: https://www.iwkoeln.de/fileadmin/user_upload/Studien/Kurzberichte/PDF/2022/IW-Kurzbericht_2022-Diesel-aus-Russland.pdf (accessed on 9 March 2022).
17. FJRG. Biokraftstoffe zur Versorgungssicherheit in Deutschland mit Dieselkraftstoff und leichtem Heizöl. 2022, pp. 1–2. Available online: https://sf8b4942a8784a38f.jimcontent.com/download/version/1678878431/module/9925446169/name/Pressemitteilung%20September2022.pdf (accessed on 17 September 2022).
18. UFOP. Biodiesel & CO 2021/2022. p. 35. Available online: https://www.ufop.de/files/4816/6860/5256/WEB_ProgressReport_Biodiesel_English_2022.pdf (accessed on 30 September 2022).
19. Available online: https://www.methanol.org/the-methanol-industry/ (accessed on 18 May 2023).
20. Available online: https://www.uniti.de/fileadmin/user_upload/energie_Mittelstand_02_2021_final_4_low_1.pdf (accessed on 20 February 2021).
21. Available online: https://www.haruoni.com/#/en (accessed on 18 May 2023).
22. Available online: https://de.statista.com/statistik/daten/studie/730823/umfrage/durchschnittlicher-preis-fuer-methanol-auf-dem-europaeischen-markt/ (accessed on 16 May 2023).
23. Atzler, F.; Sitnik, L.; Garcia-Lopez, I.; Werner, R.; Roß, T. Ecological and Economical considerations on the Energy and Mobility Transition; FAD Konferenz. Available online: https://tu-dresden.de/ing/maschinenwesen/iet/boysen/ressourcen/dateien/2022-1117-Energiewende-und-Transportsektor-BOY-H2-COL-Paper.pdf?lang=de (accessed on 24 November 2022).
24. Graebner, M.; Kuschel, M. C3 Mobility Project, Freiberg. Available online: http://www.c3-mobility.de/ (accessed on 18 May 2023).
25. DLR. MENA-Fuels. Available online: https://www.izes.de/en/projekte/mena-fuels (accessed on 30 December 2018).
26. Brosowski, D.G.A. *DBFZ Report 41: National Resource Monitoring for Biogenic Residues, By-products and Wastes*; Deutsches Biomasseforschungszentrum Gemeinnützige GmbH: Leipzig, Germany, 2021; p. 33.
27. DBFZ; Seyfert, U.; Bunzel, K. Report Nr. 8, Biomassepotenziale in Deutschland 2008 bis 2020. 2011, p. 28. Available online: https://www.dbfz.de/fileadmin/user_upload/Referenzen/DBFZ_Reports/DBFZ_Report_8.pdf (accessed on 30 December 2011).

28. FVV. Fuel Study 4b. Available online: https://www.fvv-net.de/fileadmin/Storys/Wie_schnell_geht_nachhaltig/PR_1452_FVV_Fuels_Study_IVb_2022-10-06.pdf (accessed on 6 October 2022).
29. Available online: https://vm.baden-wuerttemberg.de/de/politik-zukunft/refuels/wissenswertes-rund-um-refuels#:~:text=reFuels%20ist%20ein%20%C3%BCbergeordneter%20Begriff (accessed on 24 June 2020).