Ecological and Economical considerations on the Energy and Mobility Transition

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Abstract

The transition from fossil to renewable energies is possible! The basis of any new green world wide energy system will be renewable electricity from photovoltaics and wind as well as waste material. In this paper the considerations are based on **electricity** and **electrolysed hydrogen** as well as its derivatives. Waste material as well as solar heat were not included, although these sources will be important parts of the transition. Nevertheless the basic messages of this paper are unaffected, since the assessments herein are based on magnitudes rather than exact decimal point numbers. The results are strikingly obvious and thus convey a clear message how the transition can be achieved.

For the new energy order a number of fundamental questions on **ecology** as well as **economy** need to be answered:

1) What is the most **sustainable and affordable system of storing and transporting energy**, to overcome daily and seasonal fluctuations in renewable energy generation? The answer to this question inherently linked to transport / mobility, in the sense of mobile energy storage for land, air and watercraft as well as for energy logistics. Essential prerequisites lie with the terms "**energy density**" and "**logistics/handling**".

2) The new world wide energy system needs to be **affordable** for the **individual** as well as for **trade** and **industry**, i.e. for whole societies, and not only in industrial but much more importantly also in developing countries. **Without this precondition, the transition will not happen**. An overwhelming resistance from populations as well as whole nations then can be expected, who see their livelihood and/or competitiveness endangered.

4) The revolution from the old to the new energy system will have winners and loosers. The latter will impede and prolongate this transition as much as possible, if no solution is offered. Although this is not a scientific question, it nonetheless needs to be addressed. The success of the transition to a large part is not a question of technical solutions but of political, in particular geopolitical considerations.

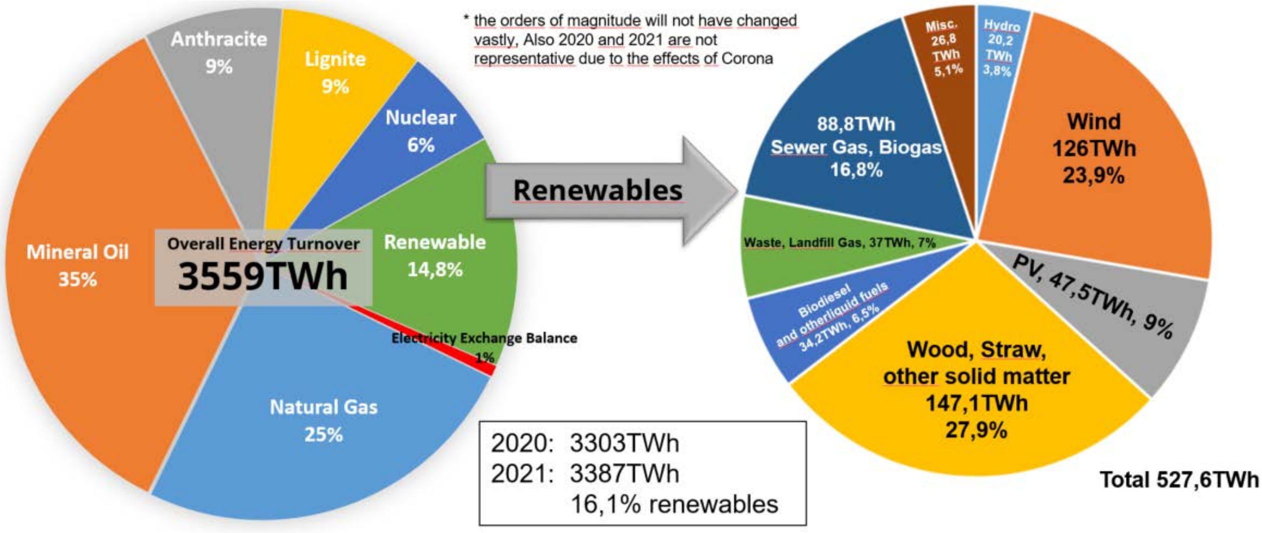
5) A transition of this scale is only possible according to the "**rules of industrialisation**". Otherwise, the transition cannot be implemented at all.

There are numerous books and papers available on the energy transition, in various degrees of detail. In this paper it will be tried to simplify this complexity and to break it down to the most important boundary conditions by means of simple but obvious assessments. Approaches will be suggested, which at least for the short and midterm can successfully be implemented. The derivation of these approaches will draw on the review of literature as well as on credible public statistics. By no means it is intended to present these suggestions as "one and only solutions", but such that help to facilitate the energy transition in a wider context with practical, sound and effective measures.

1 Introduction: The overall energy situation in industrialised countries

To understand the implications of the energy transition – and hence of the mobility transition – a number of boundary conditions need to be made clear. The example of the German energy economy here is only a placeholder for the situation in many industrialised countries, at least for many of the EU member states.

Figure 1 shows on the left the breakdown of energy carriers in the overall energy turnover of Germany in 2019 [1]. This includes all consumers (industry, households, trade, transport, etc.) in Germany. The most important number here is the fraction of renewables, where app. 15% is far too low to achieve a significant effect on climate change. The numbers for 2021 have only changed very little, with 16,1% renewables, and a minute shift from oil to gas. The overall primary energy demand increased to 3387TWh, after 3303TWh in the first year of the pandemic 2020. An often publically quoted number is that of renewable electricity. This is shown in Figure 2 and displays a fraction of 40% of renewable electricity. **However, electric energy only accounts for 1/6th of the total energy turnover!**



* the orders of magnitude will not have changed vastly, Also 2020 and 2021 are not representative due to the effects of Corona

2020: 3303TWh
2021: 3387TWh
16,1% renewables

Figure 1: Breakdown of energy carriers in the overall energy turnover in 2019 of Germany (left) and breakdown of renewables (right) [1]

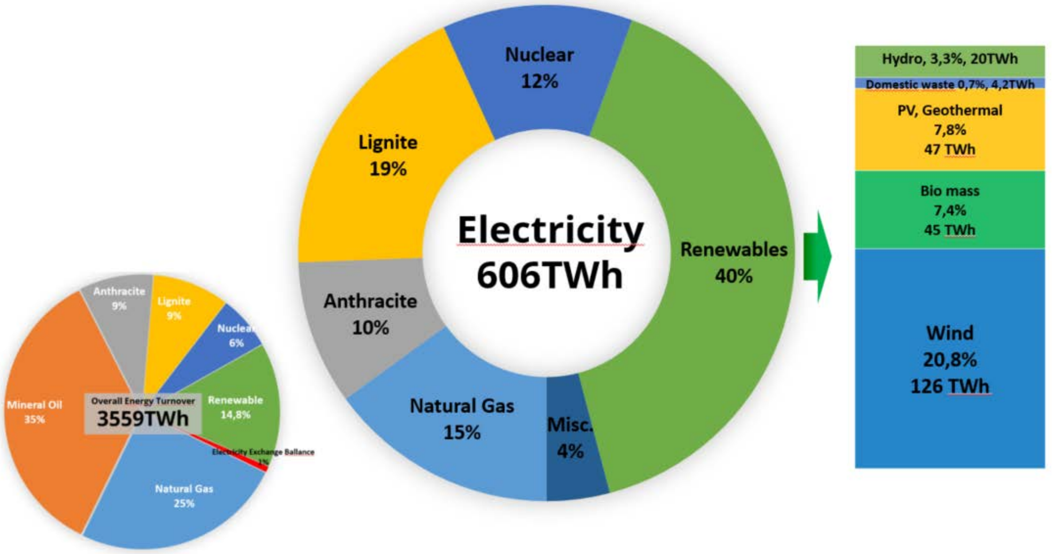


Figure 2: Breakdown of sources for electricity in Germany 2019 and breakdown of renewable electricity (right) [1]

These Figures also exemplary show, that Germany, as most industrialised countries, rely on the import of energy. Germany in 2019 imported 68% of its energy turnover [2]. The development of import quotas from 1990 to 2014 for Germany and the average of 28 EU member states are shown in Figure 3. The need of industrialised countries to import energy will be discussed further below.

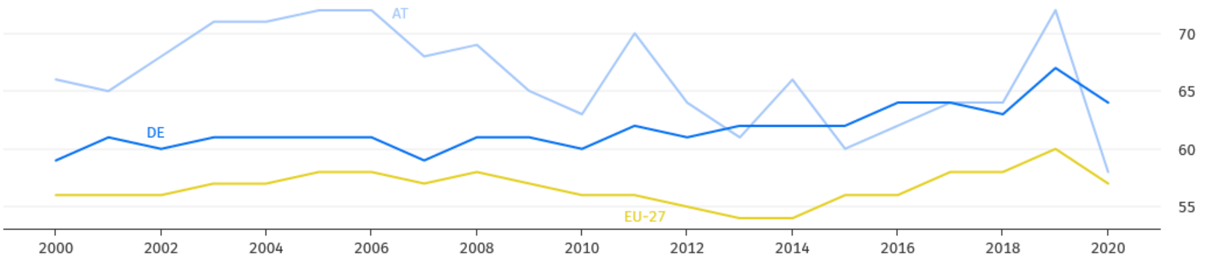


Figure 3: Energy imports for Germany, Austria and the average of 27EU member states [3]

Figure 4 shows the forecast of primary and final energy demand in Germany for 2050 of Wagner, Elbling and Company, WECOM [4]. The overall primary energy demand agrees well with the data of the FNR forecast 2018 and the “Energiekonzept 2050” of the German Federal Government from 2019, both shown in [5]. WECOM attributes the huge savings amongst others to the direct generation of electricity (without the detour via steam generation), the massively improved insulation of buildings and the use of heat pumps as well as the high efficiency of electric vehicles. Irrespective of whether these scenarios are realistic, they still predict remaining imports of 20 to 30%! **This means that the pathways and technologies for energy logistics remain important, both in terms of ecology and cost. Here not only the cost of production of future energy carriers is important, but also that of their long distance transport, handling and distribution.**

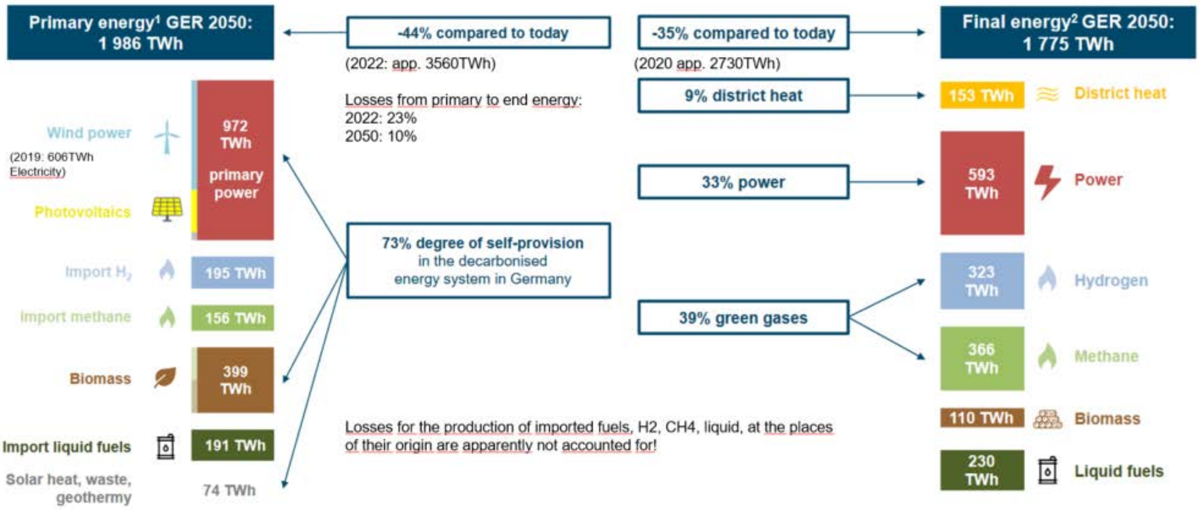


Figure 4: Forecast of primary and final energy demand in Germany for 2050 [4]. Excl. ambient heat and decentral solar heat (230 prim./186 final TWh)) and grid connection losses.

It is also vital to understand, that these simulations are all based on the supposition, that the results and measures would be implemented in time without political, dogmatic and regulative delays and restraints.

If energy imports can be reduced greatly, as assumed in the above quoted studies, the question arises, whether it would be possible for a country to become completely independent, and this will be discussed in the next Chapter.

2 Energy self sufficiency?

The evaluation on a potentially possible self-sufficiency of one country will concentrate on **electricity** from photovoltaics, PV, and wind power as the basis of the green energy system. The production of energy from waste, (waste) biomass and solar heat was not considered here, although these can offset a significant fraction of the overall energy demand, in particular biomass (see Figure 4). Nevertheless the orders of magnitude demonstrated here will convey a clear message. In the following calculations it is evaluated for Germany, whether it would be possible to supply all of the needed green energy from own land resources.

Table 1 shows an assessment where the number of wind turbines was doubled from app. 30000 (status 2019) to 60000 in a fictious scenario. Also all devices were modernised from some 3MW to 6MW power (state of technology 2022). The load factor was taken from [6] to be on average for on and off shore app. 23% of 8760h/year operation. This yields the amount of 725TWh, which is roughly 20% of the annual energy turnover as shown in Figure 1, respectively one third of the demand forecast for 2050 [4, 5]. If these 60000 wind turbines were clustered in wind parks with 10 turbines each, this would result in 6000 windparks. The surface of Germany of 357000km divided by the number of 6000 windparks yields a surface square of app. 60km^2, meaning that one windpark would be needed on average every 7 to 8 kilometres north-south and east-west.

Basis: Primary Energy Consumption in Germany 2021, estimate app. 3500TWh					
No of plants	Full Load Power	Overall Power	Load Factor	Energy harvest	Fraction of 3500TWh
n	MW	MW		TWh/a	%
60000	6	360000	0,23	725	20,7%
	Turbines per Windpark	Surface of Gemany	Surface Square per Park	Distance between Windparks	
	-	km2	km2	km	
60000	10	357000	59,5	**7 to 8km**	

Table 1: Energy harvest from wind turbines in a fictious scenario of 60000 turbines on shore in Germany with 6MW each

The situation improves, if off shore facilities are included. The order of magnitude of 725TWh agrees well with the forecast of WECOM [4]. Although such a large contingent seems generally possible, it appears unlikely that this will be realised in the short term, in particular with respect current regulations and a growing public rejection of infrastructure projects.

A huge advantage of windpower versus PV is, that wind potentially can blow all year round, whereas PV only will work during daylight, i.e. roughly 4000h/a (on average 12h/d) anywhere in the world. This will be discussed further in Chapter 4.

Photovoltaics installations are the second essential measure for future electricity generation. In Germany an average solar irradiation of 1100kWh/m^2/year can be assumed [7], which includes long term average weather as well as daily and seasonal sun hours, i.e. the load factor is already incorporated in the data. An efficiency of PV of app. 20% was supposed, which may improve in the future to 25 or more. However for the general statement this assumption is sufficient.

The solar irradiation in Germany varies from app. 1300 kWh/m^2/a to 950 in the North [7]. Using the above stated efficiency for PV conversion of 20% this gives an electric yield of

220kWh/m^2/a. From this it follows, that 5% of Germany's surface, 17850 km^2 (17850 x 10^6 m^2) covered by PV would supply a total of 3927TWh, which for the purpose of the argument is close enough to the 3600TWh/a total current energy consumption of Germany quoted above. This would be sufficient to cover the total energy needs of the country, alas if a lossless energy supply is assumed, without regarding transport and storage as well as the conversion of electricity to mechanical movement or heat. 5% of surface can graphically be represented by one square kilometre out of 20km^2, i.e. a square of 1 by 1 km length within a square of 4,5 by 4,5km (see Figure 5). This comparison goes to show, that even in a lossless scenario the magnitude of the necessary PV surface is considerable. If a surface fill factor of app. 0,7 for field installations is assumed, as well as a flat rate efficiency of 70% for grid and conversion losses, this surface increases to 2km^2, i.e. a square of 1,4 x 1,4km, equal to 10% of the land surface.

An additional challenge is the storage of energy for times of darkness / cloudiness and lack of wind. As pointed out above, PV runs on average half a day, excluding times of cloudiness. This means, that at least half of the energy would need to be stored to cover the dark calm periods. The production efficiency of Hydrogen through electrolysis can optimistically be assumed to be 70%. If it is assumed, that the production facilities always are placed close to the PV or windpark, then grid losses can be neglected. Extending the PV area to cover for H_2 production would lead to a square of 2km^2 (1,7 x1,7km). Adding the losses for compression or liquefaction or the production of e.g. Methanol (production efficiency ~50%), Ammonia, or higher Hydrocarbons (production efficiency MtG ~42% [8]) for storage or particular applications (e.g. Kerosene for aviation), the necessary surface area may well increase to 3…..4km^2 or more. The orders of magnitude are shown to scale in Figure 5. If the same calculation is performed with an overall energy demand of ~2000TWh (forecast 2050) instead of roughly 3600TWh for 2022, then instead of 4km^2 the smaller blue box of 2km^2 in the depiction in Figure 5 applies.

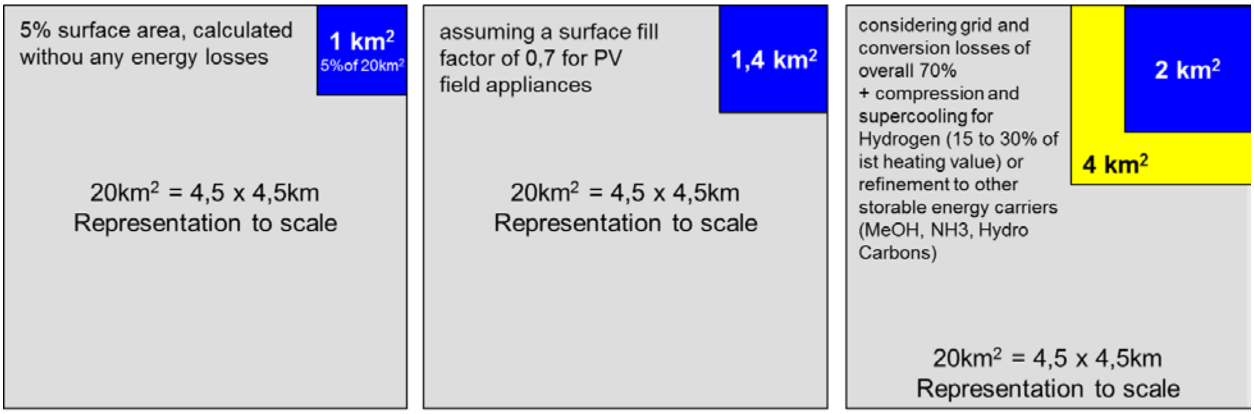


Figure 5: Surface of PV for the energy supply of Germany as explained in the text and normalised to 20km^2 for a graphic representation. Reference energy demand is 3600TWh. For the simulation with 2000TWh, the PV surface can roughly be halved in surface area (see text explanation).

These rough estimates on windpower and PV show that in Germany it will be extremely difficult to allocate sufficiently large portions of the land surface, to cover for the national overall energy demand.

Conclusion: These above derived numbers for wind and PV as well as hydrogen production and storage suggest, that Germany will not be self-sufficient in renewable energies, at least not in a useful timeframe. It also shows quite clearly, that for the **energy transition land surface is the most important resource**, apart from solar irradiation and wind itself. Therefore it must be stated that countries with little land resource and dense population will not be able to provide their energy from their own land, even less so if they are industrialised.

However, the conclusion should by no means be to do nothing. On the contrary: any nation should invest as much as reasonably possibly to support the transition to CO_2-neutral or –free technologies. The emphasis here is on “reasonable” in the sense of ecologically and economically viable and affordable, i.e. not at any cost! If the EU countries want to export these new technologies/systems into the world, they must demonstrate the working system at least on a national scale rather than in pilot projects.

3 Energy Import

The calculations in the previous Chapter demonstrate that the energy self-sufficiency is a question of available surface and the intensity of solar irradiation and wind.

Regarding the distribution of solar irradiation onto the world, the “sun belt” of the earth receives by a factor of up to 2,3 more energy than Germany, i.e. up to 2500kWh/m^2/year. Also, there is usually no competition between agriculture and energy harvesting in the deserts of the world. This offers the respective countries the perspective to rise to “energy suppliers of the world”. Figure 6 shows the Annual solar irradiation across the world [9]. For the European Union it would be one perspective to make those countries of the EU, which are economically not as well off, the energy producers of Europe, namely Portugal, Spain, the South of Italy and Greece. Although these countries may not be able to supply all of the needed energy, this would still be a great step forward. Also, these countries are likely to grant geopolitically stable conditions. This topic will be discussed further in Chapter 6.

Figure 7 shows the wind map of the world [10]. Greenland and Patagonia appear to be extremely suitable for energy harvesting, but also Scotland, Ireland, Denmark and Norway. Also, the Horn of Africa, one of the poorest regions of the world, and West Africa apparently could make a viable business out of wind farming. Germany again is not a top notch area for this.

In Chapter 2 it was established, that countries like Germany are unlikely to become self-sufficient in their energy supply. As laid out in Chapter 3, if energy needs to be imported, the next question is how this should best be done. Intrinsically linked to the transport question is that of storage. Unless electricity can be transported directly and be produced “just in time” to demand, a storage is imperative. These topics will be discussed in Chapter 4.

A central question is whether PV and wind would be sufficient to satisfy the words energy demand. Again a very simple approach is used for an estimate: If it is assumed that Germany contributes app. 2% of the world CO_2 emissions and that these are all related to energy consumption, then the world consumes in turn 50 times the energy of Germany. If instead of the average solar irradiation of 1100kWh/m^2/a for Germany the best value in the “sunbelt” of 2500kWh/m^2/a is used, then using the same PV efficiency of 20% as in the above example, the PV yield rises from 220 to 500kWh/m^2/a. With a fill factor of 0,7 this reduces to 350 kWh/m^2/a. For 3600TWh an area of 10286km^2 would be necessary, e.g. in the Sahara, to provide the German energy demand. This is only 2,9% of Germany´s surface neglecting any losses, analogous to the example in the previous Chapter. f an overall efficiency of 33% is assumed (this will be derived in the next Chapter) this surface increases to 30858km^2. For the world energy demand subsequently a surface of 30858km^2 x 50 = 1.542.900km^2 would be necessary. Comparing this to the areas of deserts and high intensity sunshine in the world one finds in Wikipedia [11] the following numbers in Mio km^2: Sahara ~9; Australian deserts ~1,3; Tharr and Colistan (India and Pakistan) ~0,27; Gobi ~2,35; New Mexico USA ~0,3.

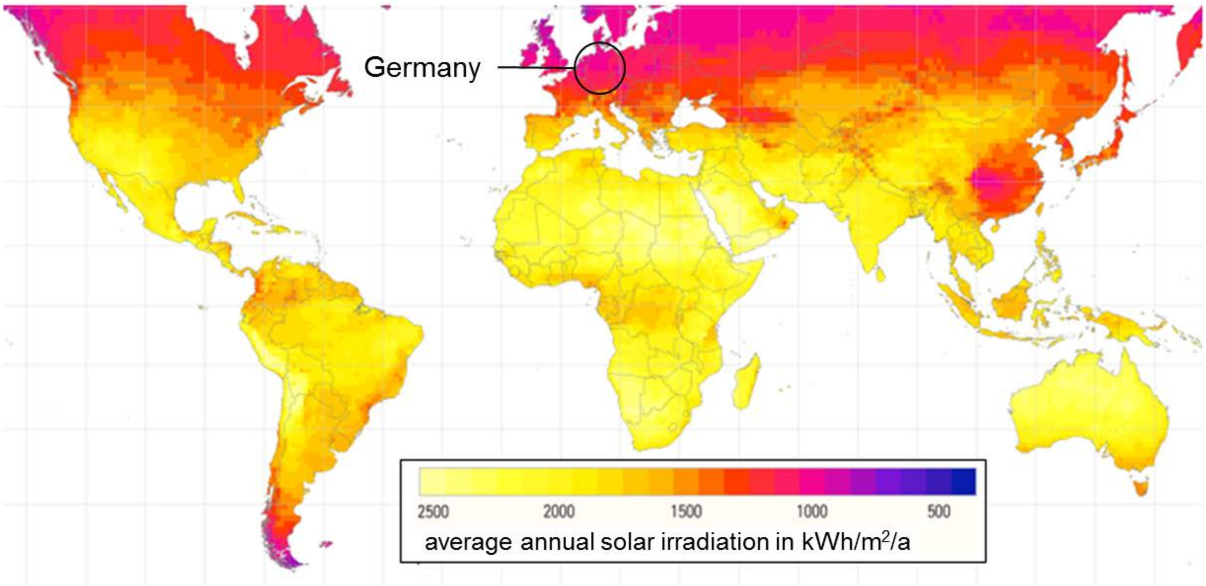


Figure 6: Annual solar irradiation [9]

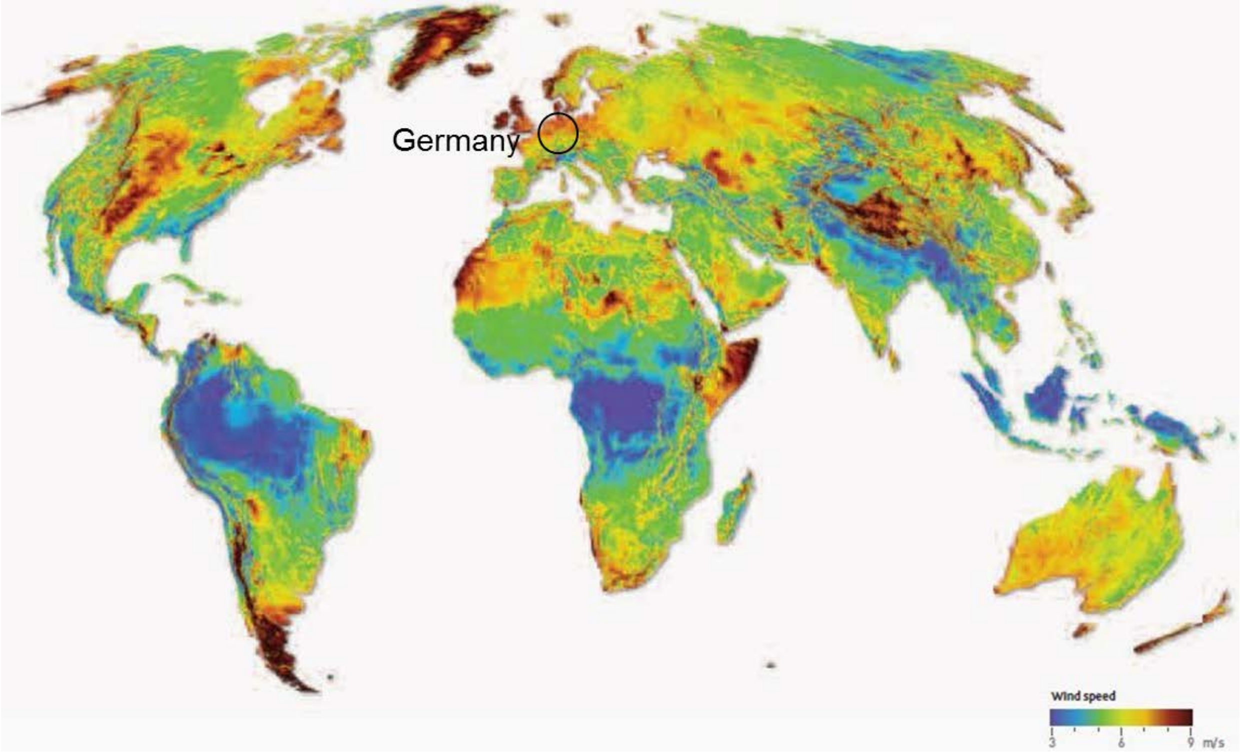


Figure 7: Wind map of the world, wind speed 80m above ground [10]

Additionally there are regions for wind farming, the use of solar heat and biomass. The very obvious conclusion is, that **there is enough renewable energy for the whole world**. However, the existing energy system was developed in over 100years, whereas the renewable system would need to be in place until 2050. The effort and investments will be humongous!

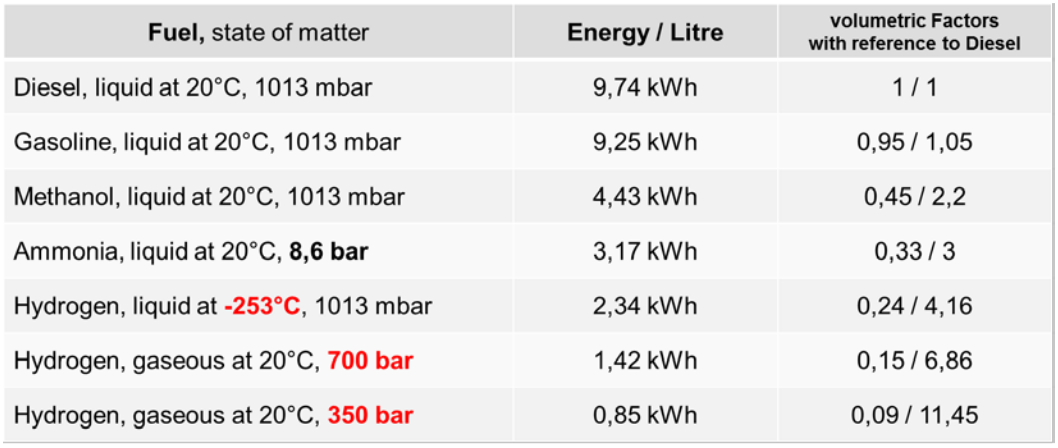
4 Energy and Logistics

In the context of energy provision it does not make sense to limit the discussion to the potentially highest efficiency of any application with the respective forms of energy. Rather a systemic approach is needed, which includes energy consumption for the production of energy, energy carriers, logistics and storage. For this one imperative is the 100% reliable energy supply, with extremely high resilience against technical failures, geopolitical uncertainties or terrorism etc.. **The energy system must not fail, Blackouts are not an option!**

The undisputed supposition of this paper is that electricity and electrolysed hydrogen are the (main) basis of the new world energy system.

Electricity is easily and best transported via cable. Long distance battery transport is completely out of the question due to the low energy density and charging / decharging losses. Even if the energy density of lithium ion batteries is assumed to be 300Wh/kg, this is minute compared to beyond 11000Wh/kg for hydro carbon fuels. 37 ships would be needed instead of 1 to transport the same energy content. With an optimistic charging respectively decharging efficiency of 95% (at slow charging rates), 10% of the energy would be lost only for the direct transport. Nevertheless, the efficiency of transporting energy overall still would be good compared to many other methods of storage and transport (e.g. the production of Methanol from electricity, hydrogen and CO_2 is only 52%) . Cost and availability of resources are other strong arguments against battery transport storage. Electricity transport via cable will be discussed below, in the context of global use of wind and sun energy.

The assessment of the transport of Hydrogen is more complex. It is generally speaking more sensible than the example of batteries logistics, yet still largely unrealistic. For comparison the specific volumetric energy content of various reFuels (renewable electricity based synthetic fuels) is given in Table 3. Hydrogen clearly is not a trivial substance in terms of logistics. Liquefaction consumes between 28 and 46% of its heating value, compression to 700 bar app. 12% [12, 13], depending on the method employed. At 350bar pressure Hydrogen requires over 11 times the space of Diesel fuel for the same amount of energy transported! To stay with the above example of battery transport: at 350bar storage pressure 11 ships would be needed instead of 1.



Fuel, state of matter	**Energy / Litre**	**volumetric Factors with reference to Diesel**
Diesel, liquid at 20°C, 1013 mbar	9,74 kWh	1 / 1
Gasoline, liquid at 20°C, 1013 mbar	9,25 kWh	0,95 / 1,05
Methanol, liquid at 20°C, 1013 mbar	4,43 kWh	0,45 / 2,2
Ammonia, liquid at 20°C, **8,6 bar**	3,17 kWh	0,33 / 3
Hydrogen, liquid at **-253°C**, 1013 mbar	2,34 kWh	0,24 / 4,16
Hydrogen, gaseous at 20°C, **700 bar**	1,42 kWh	0,15 / 6,86
Hydrogen, gaseous at 20°C, **350 bar**	0,85 kWh	0,09 / 11,45

Table 3: Volumetric energy densities of various renewable energy carriers

Electricity transport via cable is only sensible up to several thousand kilometres without too many losses. A method for this, albeit currently still extremely expensive, is the high voltage direct current transmission, HVDC. Machhammer [14] used for his economic comparison of eFuels from Chile to electricity generation in Germany a technically useful distance of about 6000km. In his analysis he counted out the use of H_2 in long distance energy logistics with ships due to the low volumetric energy density.

With respect to cost, Machhammer compared in a further investigation [15] the combinations “wind electricity in Patagonia + refuels transport to Europe” to “wind electricity + BEV” in Germany. He assumed a production of at least 1GW, which is a low value for industrialised energy production. 1GW x 8670h/a yields 8,67TWh (with a load factor of 100%!) compared to

2000 or 3600TWh annual demand for Germany (see Figure 1 and Figure 4). He found, that above a distance of 3000km, the price for the unit energy including transport was more expensive for H_2 transported in a pipeline or HVDC transmission than for liquid fuels production and shipping.

Therefore, for the long distance transport, he compared the transport and distribution cost for three liquids: Hydrogen bound in an LOHC process (liquid organic hydrogen carrier), Methanol and synthetic petrol or Diesel. The comparison was based mainly on specific invest (CAPEX), in order to avoid the difficulties to compare literature values for the single process steps. The cost for these is often derived with different methods and thus often not suitable for comparisons. He assumed a transport distance of 14000km from Patagonia to Rotterdam, 500km inland water transport to a distribution hub and 200km road tanker transport. With these prerequisites he compared the combinations “LOHC + tanker + fuel cell” to “eFuel + tanker + internal combustion engine, ICE” to “battery vehicle + electricity generated in Germany”. The result is shown in Figure 8: Specific energy cost in €ct/kWh for different liqid fuels, Methanol, petrol, Diesel, LOHC-H2 compared to electricity generated in Germany by PV and wind.. Not considered in this calculation is the cost and efficiency per kilometre of moving a vehicle. This will be discussed below (see Figure 10).

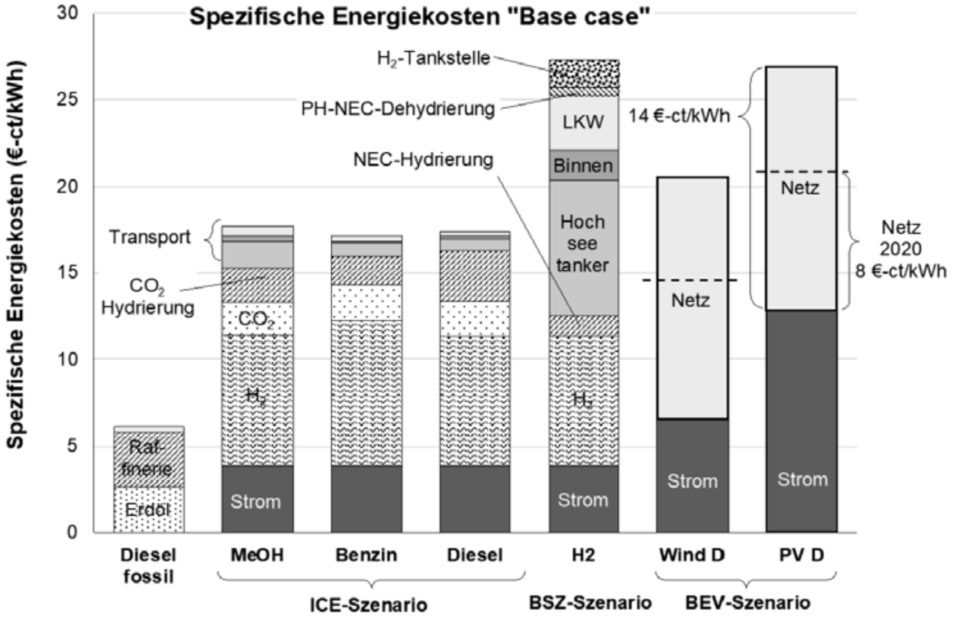
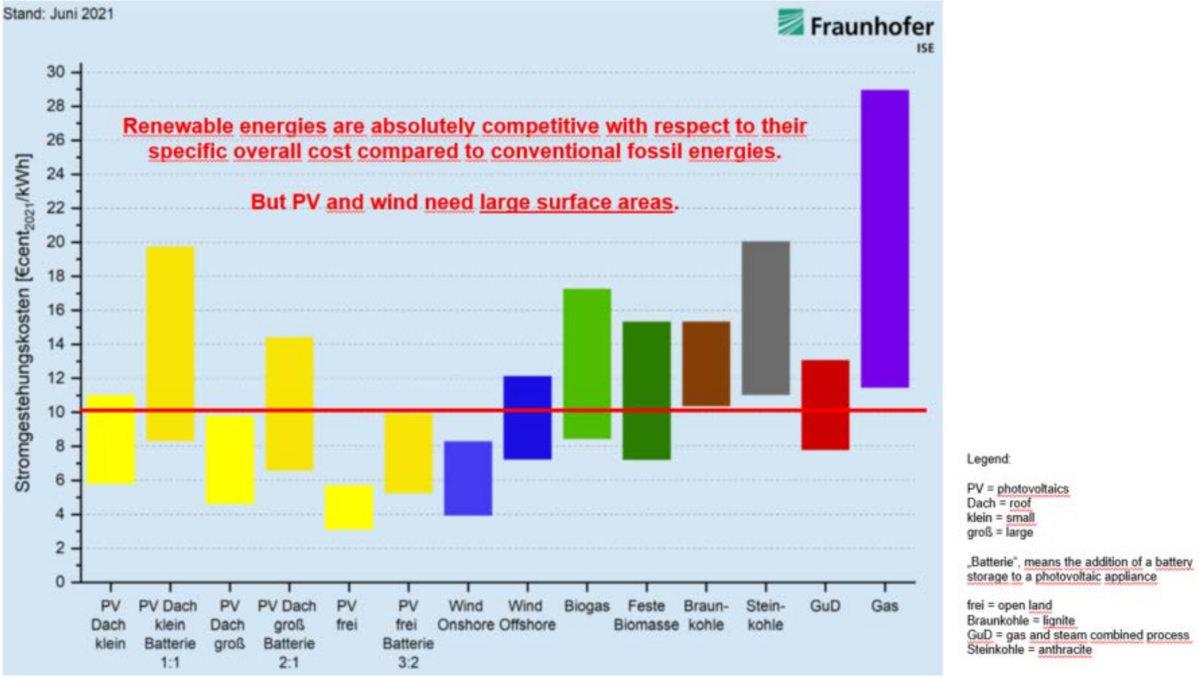


Figure 8: Specific energy cost in €ct/kWh for different liqid fuels, Methanol, petrol, Diesel, LOHC-H_2 compared to electricity generated in Germany by PV and wind.

In the cost comparison the grid stabilising measures as well as the build-up of the charging grid were not included, due to the difficulties to collect reliable figures. This gives the BEV-scenario in Figure 8 an additional advantage.

Machhammer based his simulation on 3,8€c/kWh for wind farming in Patagonia. This agrees qualitatively with the findings of Fraunhofer on “Total Electricity Cost” of 2021 [7] shown in Figure 9. However, it is probably to assume, that building such a facility in Patagonia should be somewhat cheaper than in Germany. If the very low prices currently quoted for PV electricity from Saudi Arabia of around 1€c/kWh are applied, the unit energy from reFuels should develop very favourably.

The quoted price for reFuels from Figure 8 of app. 18€c/kWh agrees well with a simplified plausibility check: for this the price for PV electricity in Saudi Arabia was assumed to be 1€c/kWh. One litre of Methanol, contains 4,4kWh, the efficiency of production is app. 50% and the energy content is half that of one litre of petrol. Therefore, for the energy equivalent of 1 litre of petrol the production cost would amount to roughly 20€c (~5€c x 2 (production efficiency) x 2 (heating value)). To cater for the electrolysis and the MeOH production the price was simply doubled to 40€c/kWh (which indeed is a very crude guess). Divided by the energy content of gasoline of roughly 10kWh/l gives 4 to 5€c per kWh. Increasing the electricity price from 1€c/kWh in Arabia to 3,8 ≈ 4€c in Patagonia, as set in Machhammer´s paper, we arrive at 16 to 18€c/kWh of MeOH. Although this may be a very coarse check, it still confirms the plausibility of Machhammer´s numbers.



Renewable energies are absolutely competitive with respect to their specific overall cost compared to conventional fossil energies.

But PV and wind need large surface areas.

Figure 9: Total electricity cost including CAPEX and OPEX in 2021 [7].

The specific fuel / energy cost per kilometre for German renewable electricity as well as LOHC-H_2 and reFuels imported from Patagonia are depicted in Figure 10. Here obviously the BEV has the efficiency advantage (tank-to-wheel). On the other hand, the spread of cost is relatively low, at 3 to 8€c/km, i.e. 3 to 8€/100km.

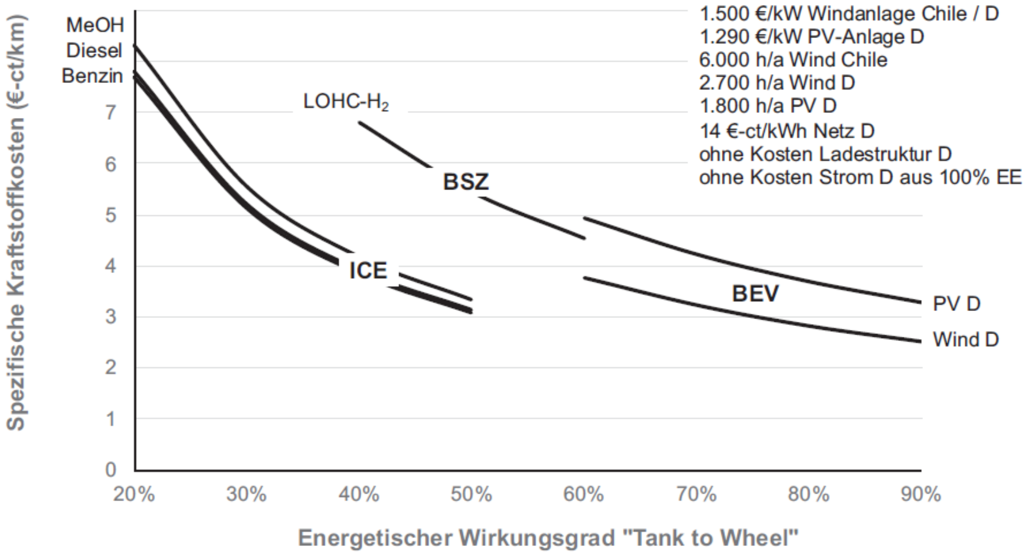


Figure 10: Specific fuel cost as function of tank-to-wheel efficiency for various powertrain technologies. This does not include the cost for production and recycling of the vehicles! A load collective efficiency of 20% was assumed for the ICE powertrain. [14]

In contrary to specific fuel cost, sales prices are **dominantly determined by the profit margin and the taxation** The current sales prices of fossil fuels result in at least 10€/100km for an ICE vehicle, assuming a fuel consumption of 5 to 6 l/100km and a sales price of 2€/l for Diesel and 1,80€/l for petrol. This is also valid for a BEV, assuming 20kWh/100km and 50€c/kWh sales price at a charging station. **These numbers very clearly show that green liquid fuels in ICE costwise are a viable alternative to BEV.**

5 Industrialisation as key to affordability

To supply goods in high quality and at a low price, an industrialised process with large quantities (volume or mass) or pieces produced is necessary. Energy generation or production of powertrains are examples for such processes. The cost for the unit produced consist of the production cost itself, the cost for product development and the production facilities, as well as the desired profit. The total costs are divided by the number of pieces, the volume or mass of produce sold (also units of energy). This means, that a higher output yields lower cost per unit (or a higher profit). Energy and energy carrier production falls in these categories of huge volumes at a low price. An industrial process should have the following attributes:

5.1 Robustness

A production site must not fail, i.e. production should be available 24 hours 7 days a week on 365 days a year, minus some days for maintenance or yearly closures. The number of faulty units should at worst be in the low ppm region, i.e. preferably less than 100 out of 1mio units. This is a coarse rule of thumb for mass production of consumer goods, which will obviously vary for different products, markets and price ranges.

Example: The electrolysis of Hydrogen and the production of Methanol by catalytic synthesis from H_2 and recycled CO_2 may not be sensitive to contamination, poisoning, clogging or other functional failures and must work beyond app. 8500h/year for many years without too much wear and maintenance.

5.2 Cost

For the example of electrolyser: materials, e.g. the PEM-membrane must not be expensive, neither in base material nor in production. Here the use of precious metals is one of the challenges to be solved. This also goes for the catalytic Methanol synthesis: the catalyst must be cheap and robust, i.e. without precious metals, but consisting of cheap common materials like e.g. Iron, Copper and Zinc. Otherwise the product, Hydrogen or Methanol, may not be competitive.

5.3 Scalability

The above sketched robust and cheap process must deliver not only 1000 tons a year, but 100 million tons, in order to supply the energy for a whole nation or the world.

5.4 Efficiency

The efficiency does not play an excessive role in industrial processes (obviously within certain limits). If the process delivers produce reliably for a low price and for this (some) more (green) energy is required, then this is much preferred to a sophisticated, high-efficiency process, which is less reliable, with frequent downtimes, high cost and complexity and possibly lacking the ability to produce the required large quantities. The invest (more windmills) will in fact increase with lower efficiency, but this is outweighed by far by a cheap and reliable production, generating a continuous profit!

5.5 Ecology

An industrial process should satisfy the requirements of ecology, i.e. the product as well as the production facility should not contain (too many) materials, which need to be mined or produced with big environmental impact or ethical issues anywhere in the world. But this unfortunately in different part of the world is often is a matter of discretion, which may be difficult to influence.

6 Infrastructure

It does not afford a scientific investigation to conclude from Figure 1: Breakdown of energy carriers in the overall energy turnover in 2019 of Germany (left) and breakdown of renewables (right) [1] and the everyday press releases, that neither Germany nor Europe currently have the infrastructure to produce and distribute electricity or hydrogen in sufficient amounts for CO_2 reduction. This is also true for those regions of the earth where wind and sun can be harvested very economically. Windparks and PV fields, electrolysis capacity and Methanol works, Fischer-Tropsch and Methanol-to-Gasoline compounds need to be erected. Additionally distribution infrastructure, cables, pipelines and port facilities need to be built. This is an enormous task, requiring huge investments. Considering the extremely close timeline for the remaining CO_2 budget, **we cannot afford to reject any of the technological options**. However, also a focus on affordable, yet ecological technologies and on the best case application of each energy carrier is needed. **Therefore the political and legal basis need to be set now, to enable huge and fast progress, and this definitely includes the introduction of reFuels.**

7 (Geo)political Implication (non-scientific)

This paragraph represents the opinion of the author. It is meant to clarify the non-triviality of the challenge. Although, there is plenty of energy from wind and sun, not all areas / countries in the world are suitable to contribute to the solution, and as stated in the abstract there will not only be winners, but also loosers when the world swings round to an ecological energy system. This causes repercussions, which are briefly touched upon in this Chapter.

In many parts of the world where sun and wind energy are plenty, political systems are unfavourable for the massive investments needed to stem the overwhelming task to tap these energies. This will limit the efforts of those who want and need the new green energy to “friendly” or at least “reliable” partners, e.g. to areas like Patagonia, Australia, maybe Greenland and unfortunately leaves many African States yet again excluded from a bright future in wealth. Also Russia would have many opportunities to develop this industry, but can currently not be assessed as friendly of only reliable or prepared to do so. China will use their wealth in surface area and energy opportunities for themselves.

But there is another challenge that massively impedes the efforts to move toward a solution of Green House Problem. In democratic systems in recent years, we have seen a strong influence of “foreign powers” and “interest groups” on elections, referenda and various important, less publicised governmental or industrial decisions. Good examples are the Brexit, the US election 2020, and the current Russian war against Ukraine. In those circumstances populations are flooded with “information” from various groups, well known or obscure (e.g. Cambridge Analytica), in order to swing decisions or sentiments to the by whomever preferred result. Even the political exchange between trustworthy groups, like established political parties, is often tainted by ideological rather than objective arguments. The truth in these “informations” is at least in part doubtful and it is a complex matter, unfortunately not feasible for everyone and everytime, to filter well researched, scientifically sound facts from hear say, half knowledge, superstition and white or outright lies. Today the internet offers a wealth of possibilities to distribute fake news. For the theme of this paper this concerns the "dangers" of wind mills, PV, the use of eFuels, the enlagement of the electric grid, BEVs, ICEs, etc., etc.. Open democratic countries are particularly vulnerable to this. They are also assailable to attacks from authoritarian states or groups, including international companies.

It is easy to conclude, and far from any conspiracy theory, that those nations and international enterprises, whose business it at risk, will use their money and power to prevent any change for as long as possible. Pleas to moral and social responsibility have shown to be utterly useless. With respect to the energy topic, these groups are likely to be the producers and vendors of oil, coal and gas, who will go to great lengths to impede and prolongate the transition process. Some of them may however invest their wealth in the new green sector!

Also, the dependency of industrialised countries on energy imports is a very effective means of exerting pressure on decisions within these countries. Their potential ability to supply themselves with energy from their own land, or at least to resort to new energy sources from other parts of the world, certainly is not in the interest of the "old fossil powers" or those countries who want to exercise political influence. This means that these groups will not only fight the loss of income but even more so the loss of political power.

It needs to be emphasised, that some of aforementioned "interest groups", to very large parts through their income from the sale of fossil energy carriers, would have the money, the time and the resource in terms of land, sun and wind, to invest in new energies and keep up respectively develop their business in the energy sector.

Another geopolitical aspect is the access to of raw materials. As quoted in the Industrialisation Chapter, the raw materials for industrial processes should be plenty and cheap. The Deutsche Rohstoffagentur DERA [16] monitors a large number of raw materials and trade products. However, the information on availability of materials and the markets are extremely divers and difficult to cluster for an overview. Of particular interest in the DERA analysis is "Risk group RG3, high risk", being defined as follows: "raw materials and intermediate products with a high country concentration and a medium to high weighted country risk. The likelihood of supply shortages or constraints and high price volatilities or price spikes is particularly high." The country risk assesses the political, social, legal and economic stability of supplying countries. The country concentration evaluates, in how many countries the material in question is being mined and/or processed. Currently 45% (133 out of 297) monitored trade products were in RG3, amongst these are the precious metal group, PGM, Cobalt, rare earth metals, but also Copper, Aluminium and Tin, to name but a few. However, the risk is also on "bread and butter" materials as raw iron, raw steel and coking coal as well as Magnesium.

China, Russia and the US generally play very important roles in the materials market, for particular materials also Australia, Chile, Kongo and Indonesia. China is seen as most important mining country, most important producer of refinement products and most important exporter of interstage products. It continues to hold a dominant position with respect to most of the examined raw materials and accounts for an even higher share of the examined intermediate products.

Example: Vehicle batteries need Nickel, Lithium, Manganese, Graphite and Cobalt in various chemical alloys. While Lithium and Manganese currently are positioned in RG2, Cobalt and Graphite are in RG3. Nickel is still in RG1. **Cobalt has a particularly high country and concentration risk, with Kongo being the most important mining country (72%).** For Platinum and Rhodium South Africa hold app. 70% of the mining capacities and app. 80% of the processing to intermediate materials. 50%of the world´s Silicon in mined in China, 60% is processed there. Over 70% of Rare Earth Metals are mined in China 70%+.

There are estimates of DERA, that the current run on BEVs will lead to a shortfall in Lithium production of at least 90000t, in the worst case 300000t, in the ramp up towards 2030 . For comparison: the annual production 2020 was 82000t. [17]

This means, that for Germany and many other EU countries there is a high risk of not being able to access these materials, either for reasons of real shortages, export restrictions or for political reasons. This may endanger the progress in the energy and mobility transition and the potentially resulting business cases.

There is no obvious conclusion or recommendation from this Chapter. The increasing world demand for “new” raw materials requires research, discovery and exploitation of reserves. This happens in time frames of 10s of years. **Diversification, cooperation, joint ventures, share holding and global trade as well as the search for other technical solutions have been the tools for any industry to avoid or at least moderate volatility and shortage.** This is equally true today, however with the added aspiration on ecology and human rights.

With respect to the battery example, this may be a pledge for the Sodium-Ion-Battery. In the long run the extremely good availability of its core materials will be a striking argument, in particular with respect to low production cost. In a press release [18] CATL advertise their latest achievements. They claim additional advantages compared to the Lithium-Ion technology like very short charging times, a high capacity of 90% at -20°C and a massively improved safety against thermal runaways!

8 Affordability

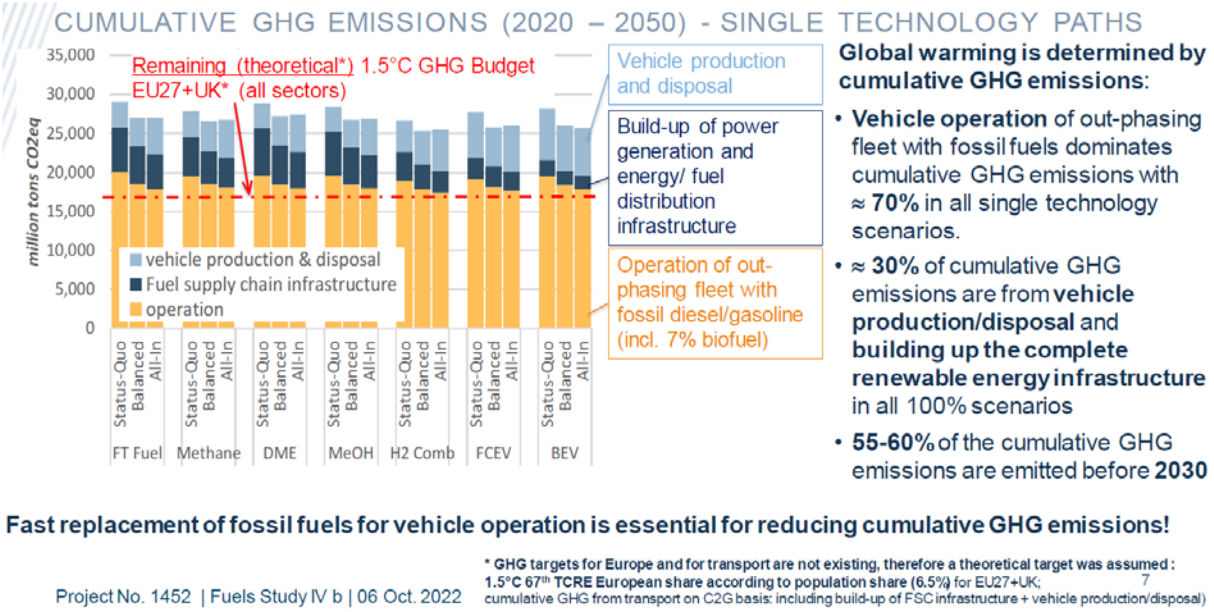
Currently fuel cell and battery electric vehicles are still expensive. In the future price reduction due to the growing industrial production of fuel and battery cells are forecast. This is important in order not to leave large parts of the population behind. A future energy economy can only be realized if it remains affordable for the whole population!

A compilation of www.gehalt.de [19] shows, that out of 15Mio **full time employees** 9% earn up to 1500€ before taxes, 27% earn up to 2000€ and 64% up to 3000€ before taxes. This agrees with another statistic by the Statistische Bundesamt (destatis.net) which puts 43% of all german **households** below a net income of 2600€ [20] which was corrected with a numbers of factors for comparability of various life situations (“net equivalence income”). The average income in Poland is app. 1200€, that in Ukraine ~290€ [21]. **This means, that there are large parts of the world, the EU and the german population for whom high tech transport will not be accessible.**

A cheap alternative to e.g. the BEV for lower income groups could be a **CO_2 neutral ICE** vehicle, with simple 1,5 litre 3 cylinder engine, naturally aspirated, high efficiency concept **running on green Methanol**, 40 to 50kW, with no or simple 48V electrification. Remember: Each kW power from an ICE costs only about 10 to 20€. This is usually the range calculated with in the automotive and commercial vehicle industry for series production [22].

9 The Future Energy System, Outlook and Conclusions

In order to properly conclude the “Ecological and Economical considerations”, it is instructive to feed back to the 1,5°C climate target. The Fuel Studies IV and IVb study, carried out by Frontier Economics and the ifeu Institute [23], commissioned by the FVV, shows clearly, that **without the defossilisation of the existing vehicle fleet the 1,5°C scenario cannot be reached at all**, Figure 11, The yellow columns show the GHG emission from the vehicle fleet as function of the each alternative powertrain technology introduced. Irrespective of which new technology was considered, the by far dominant GHG emission came from the existing fleet before the introduction of the any new technology.


CUMULATIVE GHG EMISSIONS (2020 – 2050) - SINGLE TECHNOLOGY PATHS

Global warming is determined by cumulative GHG emissions:

- **Vehicle operation** of out-phasing fleet with fossil fuels dominates cumulative GHG emissions with ≈ **70%** in all single technology scenarios.
- ≈ **30%** of cumulative GHG emissions are from **vehicle production/disposal** and **building up the complete renewable energy infrastructure** in all 100% scenarios
- **55-60%** of the cumulative GHG emissions are emitted before **2030**

Fast replacement of fossil fuels for vehicle operation is essential for reducing cumulative GHG emissions!

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* **GHG targets for Europe and for transport are not existing, therefore a theoretical target was assumed : 1.5°C 67th TCRE European share according to population share (6.5%)** for EU27+UK; cumulative GHG from transport on C2G basis: including build-up of FSC infrastructure + vehicle production/disposal)

7

Figure 11: Fuel Study VIb, commissioned by FVV, carried out by Frontier Economics and ifeu Institute. Comparison of the Green House Gas emissions of various powertrain technologies in seven 100% scenarios.

Conclusion of this paper in brief:

- There is enough renewable energy for the whole world. Electricity, Hydrogen and Methanol are the “new oil“.
- Surface area is the most important resource for PV and windpower (apart from suitable solar irradiation and wind intensity)
- As long as **green electricity and Hydrogen are not available in abundance** in Europe, it would be sensible to use imported eFuels in mobile applications and locally produced electricity and H_2 economically in stationary applications. However, BEVs are very suitable for short distances of up to app. 100….200km and facilitate local emission free transport.
- Methanol is a very suitable base substance for transport fuels, but can also be used directly as fuel, e.g. in high efficiency ICE concepts.
- The Methanol-to-Gasoline process allows for the efficient defossilisation of 2/3 of the existing vehicle fleet, i.e. of SI-ICE passenger cars. The production of Diesel and Kerosene through Fischer-Tropsch-Synthesis requires a higher technical effort.
- Although the investments into the “new green world energy system” are humongous, they are very likely to **pay back in the mid term**. Politics need to set a reliable framework to enable these industrial engagements.
- On the basis of the actual electricity production cost for wind and PV it appears realistic, that the future energy cost in a renewable energy system **not necessarily need to be higher than today**. Pricing is dominantly a matter of desired profits and taxation, not of the product cost!
- All of the population(s) need to be included, needs to have the liberty to travel!

- Geopolitical implications and their repercussions on raw materials may obstruct progress. Smart industrial policy is needed to circumvent these challenges.
- **For the reduction of Green House Gas emissions the defossilisation of the existing fleet is imperative**. For this, the introduction of refuels is imperative.

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