SYNTHETIC ENERGY SOURCES – PERSPECTIVES FOR THE GERMAN ECONOMY AND INTERNATIONAL TRADE

An analysis of market potentials, investment and employment effects

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SUMMARY

Synthetic fuels

Electricity generated from renewable energies such as solar or wind energy (RES-E) is converted by chemical processes into liquid or gaseous synthetic fuels and combustibles and thus made storable.

Chemical energy sources

include both fossil and synthetic fuels.

In this study, commissioned by IWO, MEW and UNITI, we examine the relevant aspects of the import and worldwide trade in synthetic fuels produced from renewable energies.

The results can be summarised as follows:

Synthetic fuels will be indispensable for a CO2-neutral energy supply

- The high energy density of chemical energy sources, produced from renewable energies, renders them indispensable in various sectors such as air and sea transport, while other sectors will see competition between CO2-reduced options.
- In addition, the seasonal storage of energy required in an energy system dominated by renewable energies and ongoing peak load coverage may necessitate the use of chemical energy sources.
- Furthermore, using synthetic fuels paves the way to use existing infrastructures and technologies, which helps overcome acceptance disputes concerning the transformation of the energy system as well as cutting costs.

Meeting the targets set for the energy system transformation in Germany and Europe makes the import of synthetic fuels inevitable

- A self-sufficient energy supply for Germany is unrealistic even after implementing the energy transition – as the limited availability of sites for renewable power generation plants already reflects.
- As a general rule therefore, Germany will have to keep importing energy sources.
- Chemical energy sources based on renewable energies outperform electricity when imported in terms of transportability and integration with existing infrastructure – particularly supplies imported from more distant regions.
- Importing synthetic fuels also lets us benefit from the advantages of larger renewable electricity generation potentials as well as cost reduction potentials entailing PtX production abroad.

PtX

„Power-to-X“ refers to various technologies for storing or otherwise using what is normally renewable electricity – PtX therefore refers also to synthetic fuels („power-to-liquids“ and „power-to-gas“).

A world market for PtX will reach considerable dimensions and trigger corresponding investments in plants

- Global demand for PtX could easily reach around 20,000 TWh by 2050 – the equivalent of half the current global crude oil market.
- The global demand for electrolysers and other conversion capacities (methanisation plants and plants producing synthetic liquid fuels) would then be in the order of 8,000 GW.
- This would then trigger an estimated average investment of 215 billion euros per year in PtX plants (electrolysers, other conversion plants, plants to capture CO2 from the air). For comparison: Global investments in the oil and gas sector currently amount to approx. 746 billion euros per year.

Germany already leads the way in the relevant key technologies

- Germany currently exports 19% of the global electrolyser supply, which are the most cost-intensive components of PtX production plants, which makes it currently the world’s largest exporter of electrolysis plants.
- Germany also has a considerable 16% global market share of capital goods produced in the plant engineering sector, a figure that can also be applied roughly to chemical plant components.

Multiplier effects

are defined as indirect effects on an economy, triggered by the direct value chain –for example, an increase in employment numbers.

As a technology supplier, Germany can realise opportunities given in a growing world market for PtX in terms of added value and employment.

- This is illustrated by macroeconomic calculations based on current market conditions: For the German economy, this would result in additional value-added effects totalling around 36.4 billion euros per year. A share of 15.4 billion euros would be attributable to direct demand for PtX technologies and the remainder to multiplier effects, i.e. triggered indirect demand effects.
- This would correspond to an increase in the expected gross domestic product amounting to around 1.1 percentage points in 2020.
- At the current employment intensity, this approach would see up to 470,800 vacancies filled for the German economy. Of these, around 175,000 jobs would result from direct employment and the remainder from indirect effects.

PtX creates an international win-win situation

Developing the PtX market helps boost added value and employment effects – in Germany as well as in the countries of origin.

Also for PtX export countries, the emerging industry and the export offer opportunities

- Investments in plants producing synthetic fuels and their export potential can spawn key development impulses at production sites, with future markets driven by global demand in mind. Stronger trade links, emerging industries and exports can boost local economies and employment.
- Extrapolated to the estimated realistic market volume of 20,000 TWh PtX per year, this would elicit total added value of around 2,000 billion euros per year, which roughly equates to the collective GDP of the 120 poorest countries worldwide.
- Objective location advantages, strong renewable energy potentials and high land availability above all, mean such development impulses may offer great opportunities, particularly for deprived regions.
- Moreover, in a „post-fossil“ future, exporting synthetic fuels offers a long-term growth perspective for countries currently exporting fossil fuels in bulk.

1. WE EXAMINE THE ECONOMIC EFFECTS OF A GLOBAL PTX ECONOMY

An **80-95%** reduction of greenhouse gas emissions

has been set as an ambitious energy and climate target for Germany by 2050 – compared with 1990.

Sector coupling

is regarded as an essential building block for achieving these medium- to long-term climate protection goals.

Climate targets are driving the energy transition in Germany and Europe

In the Paris Climate Protection Agreement, Germany and the European Union have set themselves ambitious targets for reducing greenhouse gas emissions („GHG"). By 2050, GHG emissions are to be reduced by at least 80%, but if possible by 95% compared with 1990 levels. This makes it necessary to reduce GHG emissions in the energy system itself as well.

Under the headline „integrated energy" the German government is considering the use of electricity in sectors where fossil fuels currently still prevail (above all in heating/cooling, transport and industrial processes) as an essential building block for achieving medium- and long-term climate protection goals. However, some policy areas are currently overwhelmingly focused on the direct use of electricity in the context of sector coupling. Synthetic energy sources from renewable electricity – „power-to-liquids", „power-to-gas" – are currently only seen as a fallback solution due to the additional conversion processes needed and reduced efficiencies they entail.

Conversely – and from a technical perspective – liquid synthetic fuels from renewable energies lend themselves to many areas of the transport sector; virtually irreplaceable in aviation, shipping and heavy load traffic, for mobile processing machines, e.g. in agriculture, construction and forestry, or vehicles with internal combustion engines in general; almost all of which are now powered by chemical energy sources.[1]

Given that demand for renewable energy as a primary energy source in the context of sector coupling is expected to rocket and the limited long-term surface resources for photovoltaics/wind power in Germany and foreseeable acceptance problems (partly regarding the facilities themselves, partly because of the grid expansion required), there is a risk that long term, demand for renewable energy produced in Germany will outstrip supply.

One alternative would be to import renewably generated synthetic gases and liquid fuels. This could initially involve blending a certain

[1] Around 98% of the operating energy in the transport sector currently originates from liquid energy sources (Prognos et al., 2018).

proportion of synthetic fuels produced from (renewable) electricity with fossil fuels („blending"), until the energy needs of the relevant sectors are met in full down the line.

Survey of the economic effects of a worldwide PtX market

In this study, commissioned by IWO, MEW and UNITI, we examine relevant aspects of the import and worldwide trade of synthetic fuels produced from renewable energies. The following questions are addressed as a priority:

- What is the extent of the global market potential for synthetic fuels?
- Which macroeconomic and industrial policy effects can be expected in Germany by the establishment of an international PtX economy? In this context, opportunities for German plant engineering are particularly relevant when developing new economic sectors that enable the production of synthetic fuels from renewable energy sources (e.g. export of electrolysis plants).
- In principle, which regions are suitable for producing electricity-based synthetic fuels?
- What benefits does foreign direct investment elicit in countries , e.g. in terms of economic growth and employment?
- What other opportunities arise from the international trade in synthetic fuels, e.g. with regard to site availability for renewable energies, energy supply costs in Germany and the security of supply?

2. LONG TERM, SYNTHETIC FUELS WILL UNDERPIN THE TRANSITION TO A CO2-NEUTRAL ENERGY SUPPLY

International trade in and procurement of synthetic fuels presupposes that the use of these chemical energy sources is expedient in the context of the energy transition. Below, we will set out the main reasons why.

The energy transition requires the energy systems to be „de-fossilised“

Synthetic fuels – i.e. gases produced synthetically from renewable sources („Power-to-gas”) or liquid fuels produced synthetically („Power-to-liquid”) – can play key roles in helping meet the ambitious climate protection goals set by the Federal Government of Germany.

”De-fossilisation” including the use of synthetic fuels

Whether or not the end customer has access to renewable energy in the form of electricity or CO2-neutral synthetic fuels is irrelevant as far as the climate balance is concerned!

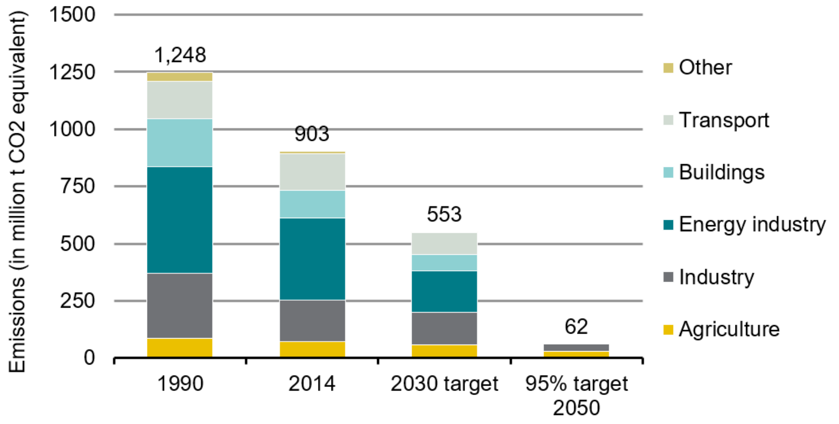
Synthetic fuels can be produced with a neutral climate footprint and subsequently reburned: Even though CO2 emissions are being generated during end use, this CO2 had already been removed from the environment during production. Accordingly, its carbon footprint is neutral, and climate-damaging effects are almost completely mitigated.

Figure 1 shows that the ambitious climate targets require almost a complete neutral carbon footprint in the energy, heat and transport sectors – which is why the energy system must be „de-fossilised”. Accordingly, energy must be provided from climate-neutral sources in the long term, i.e. renewable energies above all. A number of countries also use nuclear energy and fossil fuels with CO2 capture and storage as CO2-neutral energy sources.

However, the question remains as to how these renewable energies, which will remain the key long-term cornerstone of the energy supply, should be supplied:

- directly as biogenic fuels and combustibles (e.g. biomass),
- as electricity, or
- as synthetically produced chemical energy sources (e.g. hydrogen, methane, ammonia, petrol, diesel, kerosene or methanol). In addition, chemical substances such as ammonium can be produced on the basis of renewable energies and used in industry and agriculture.

Figure 1. Climate and decarbonisation objectives for the individual sectors



Source: Frontier Economics

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Renewable electricity and synthetic fuels will play key roles in the energy transition.

The direct use of renewable energies, such as solar thermal or geothermal energy, is limited to certain applications, especially when it comes to providing heat. It should be noted that technical and economic limitations also apply to these sector-specific applications. Other capacities, such as hydro power or biogenic energy sources, have largely been exhausted in Germany, with only limited growth potential remaining.

In this respect, renewable electricity and its direct use, as well as synthetic fuels, will be key when it comes to the transition of the German energy system. Previously, the climate policy argument has often revolved exclusively around direct use and only marginally addressed the potential of synthetic fuels – which, as we will explain below, is mistaken.

Certain energy applications require a high energy density such as in chemical energy sources

Around 70%

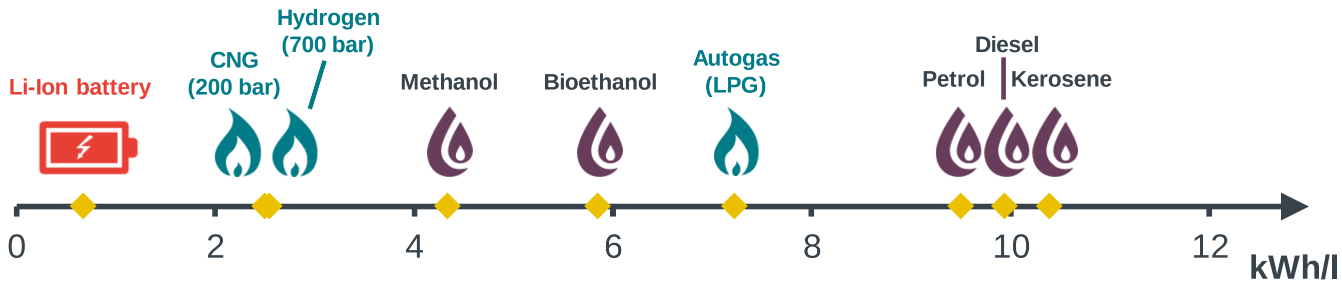
of the final energy consumption in Germany is based on chemical energy sources – not least due to their good transportability and storage capacity.

An essential characteristic of chemical energy sources is their high energy density (Figure 2). This applies to liquid fuels in particular, but also to gases such as methane and hydrogen. Consequently, whenever transporting or storing energy in bulk, chemical energy sources offer significant advantages over electrical energy. Not least because of these basic chemical-physical properties, around 70% of the final energy consumption in Germany is based on chemical energy sources.

In some sectors – fractions of the transport sector (e.g. air transport, shipping, long-distance road haulage) and in the chemical industry

– liquid energy sources in particular will become difficult or impossible to replace in the foreseeable future.[2]

Figure 2. Energy densities of chemical energy sources vs. batteries



Source: Summarised representation based on multiple sources[3]

Energy storage is an essential factor for the energy transition – and it requires chemical energy sources

The increasing generation of energy from renewable sources, in Germany in particular wind and solar power, makes energy storage an essential factor, because wind and sun are only available intermittently. This applies both short-term, i.e. fluctuations within or between individual days and continuing over weeks and seasonally, i.e. stretching over several months.

[2] I.a. Prognos et al (2018): Status and Perspectives of Liquid Energy Sources in the Energy Transition.

[3] See, i.a. (i) http://www.fnr.de/fileadmin/allgemein/pdf/broschueren/broschuere_basisdaten_bioenergie_2017_2.pdf; (ii) https://www.dke.de/resource/blob/933404/fa7a24099c84ef613d8e7afd2c860a39/kompendium-li-ionen-batterien-data.pdf; (iii) https://www.elgas.com.au/blog/1698-cng-vs-lpg-comparing-properties-sources-uses-homes-cars-vehicles; http://www.fz-juelich.de/SharedDocs/Downloads/IEK/IEK-3/Flyer/Info_Direktmethanol-Brennstoffzellen%20(D).pdf?__blob=publicationFile; (iv) http://www.fz-juelich.de/SharedDocs/Downloads/IEK/IEK-3/Flyer/Info_Direktmethanol-Brennstoffzellen%20(D).pdf?__blob=publicationFile; (v) https://www.bmvi.de/SharedDocs/DE/Anlage/MKS/mks-kurzstudie-cng-lpg.pdf?__blob=publicationFile; (vi) http://www.dglr.de/publikationen/2012/281188.pdf; (vii) https://www.bmvi.de/SharedDocs/DE/Anlage/VerkehrUndMobilitaet/wasserstoff-bewegt-minifolder.pdf?__blob=publicationFile

Around 62%

of annual demand for liquid fuels is currently met by existing storage capacities for such sources.

To date, the long-term seasonal storage of electricity has remained infeasible. The gas and oil infrastructure in Germany, in turn, has been developed so that the volatile nationwide demand for energy in various sectors can be reliably met around the clock. This also applies to seasonal fluctuations in demand.

To achieve such a degree of technical supply, safeguarding storable energy sources while maximising possible energy density and having the necessary infrastructure are both crucial. Storable energy sources decouple demand from supply. This enables maximum flexibility in energy supply and distribution.

Existing storage facilities for liquid energy sources can already accommodate more than 535 TWh (corresponding to around 42% of the annual demand for mineral oil or 62% of the annual demand for liquid fuels in Germany[4]) (Figure 3). In addition, existing gas storage facilities in Germany provide for a capacity of around 260 TWh (meeting more than 33% of annual gas demand).[5] In comparison, the capacity of all German storage systems[6] in the electricity system is only about 0.04 TWh.[7]

The storage capacity of German electricity storage power plants currently suffices to meet average electricity demand for 41 minutes.

4 The reference figure for the 62% storage coverage percentage reflects total domestic sales of the main petroleum products: petrol, diesel fuel and extra-light heating oil. (Federal Office of Economics and Export Control: Mineral oil data for the Federal Republic of Germany, December 2017).

5 Primary energy consumption gas 2016: 2.804 PJ (according to https://www.bmwi.de/Redaktion/DE/Infografiken/Energie/energie-primaerverbrauch.html).

6 The capacities indicated are provided almost exclusively by pumped storage power plants. Despite the lack of systematic statistics on battery storage capacity provision, even the most optimistic of estimates shows battery storage capacity remains in the negligible single-digit GWh range.

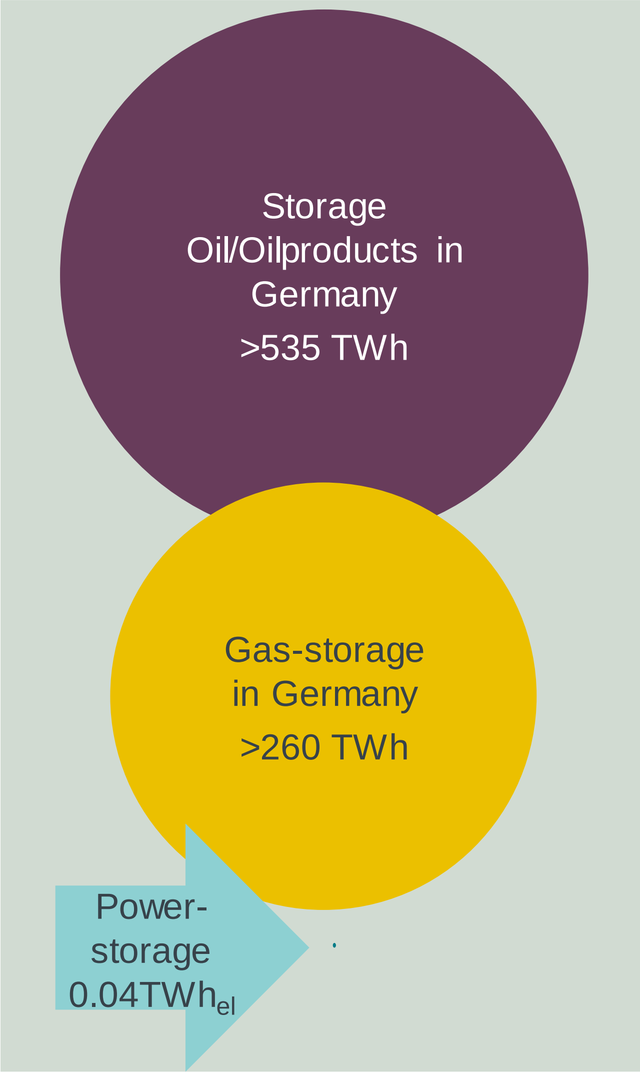
7 Gas storage volume according to Gas Infrastructure Europe, storage capacities for liquid energy sources according to ETR Report (2018) and storage capacity of electricity storage facilities according to German Bundestag (2017), p. 8.

Only approx.

41 minutes

of the average electricity demand can currently be met by German electricity storage facilities.

Figure 3. Storage capacities in Germany



Source: Gas storage volume according to Gas Infrastructure Europe, storage capacities for liquid energy sources according to ETR Report and storage capacity of electricity storage facilities according to the German Bundestag[8] (Federal Parliament)

Note: Proportional representation of the storage volume as a point at the arrowhead.

Both the reliability of chemical energy sources and their importance in terms of storage capability are also reflected by their intended roles as primary energy sources in disaster control and emergency power supply, particularly for critical infrastructures. For example, a high proportion of emergency power generators in Germany are based on liquid fuels.[9]

[8] Deutscher Bundestag (2017): Development of electricity storage capacities in Germany from 2010 to 2016; ETR report -Bräuninger (2018): The role of mineral oil as an energy storage facility in the energy transition debate.

[9] Federal Office for Civil Protection and Disaster Relief: Fuel supply in case of power failure - Recommendations for civil protection and disaster control authorities (Volume 18).

System costs are the relevant parameter, rather than any conversion losses

Thanks to these qualities, the use of synthetic fuels – alongside electrification – is helping slash costs within the energy system. Here, cost savings can be realized addressing certain additional cost drivers:

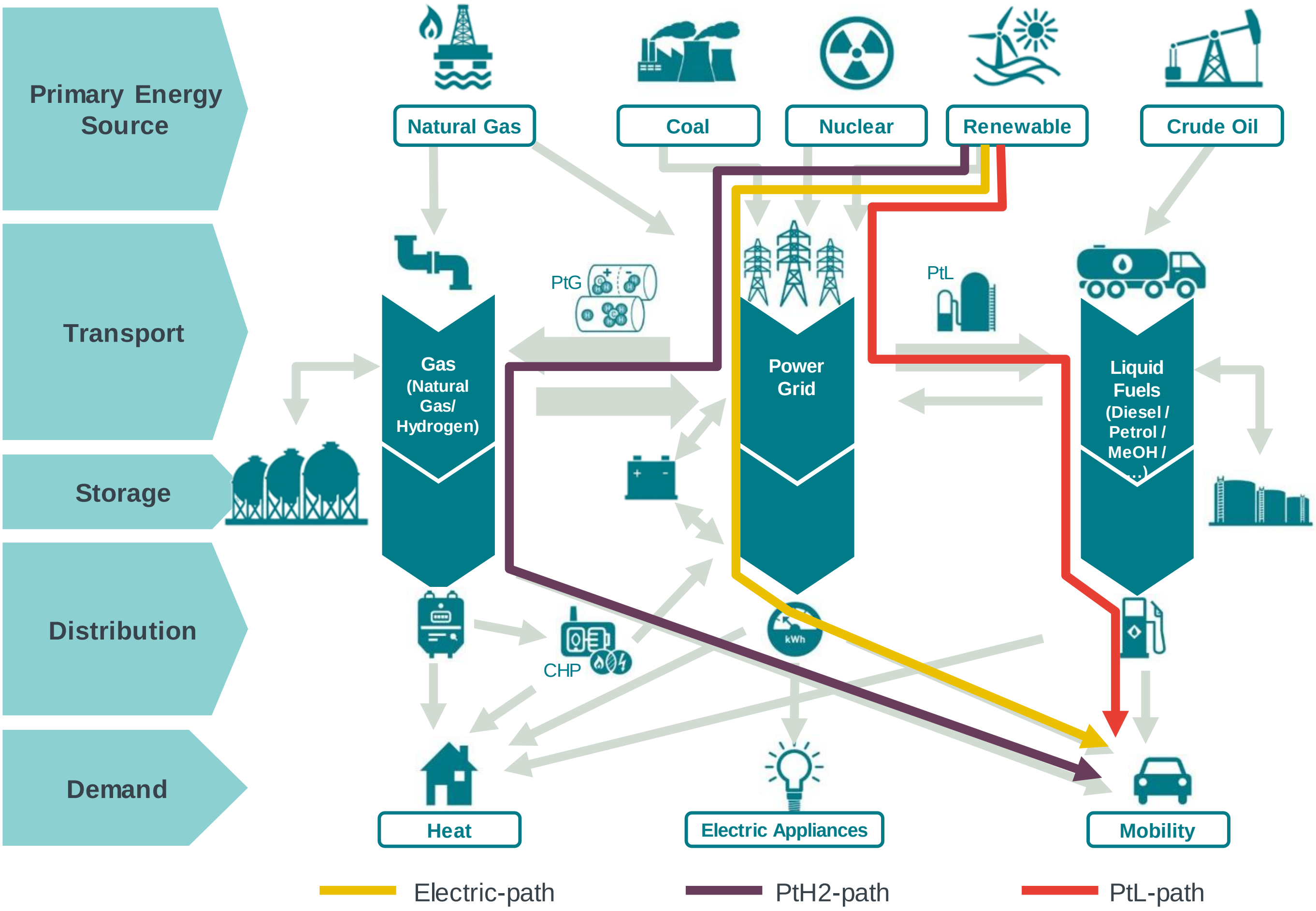
- Cost savings, for example
  - by using existing infrastructure such as gas pipelines, filling stations, storage facilities, etc. and
  - using existing and less costly application technologies such as condensing boilers vs. expensive heat pumps for heating purposes.
- Additional investment costs for systems, e.g.:
  - electrolysers to produce hydrogen, synthesis plants to produce synthetic liquid fuels or methane and plants to produce CO2 (e.g. direct air capture) as well as
  - renewable energy facilities that also have to be built due to conversion losses when producing synthetic fuels.

When assessing the economic viability of synthetic fuels, the decisive factor is not only conversion losses – which are often the focus of public debate – but also the respective effects on investments and expansion requirements regarding generation, conversion, storage and electricity grids. Figure 4 shows a stylised overview of the German energy system featuring three different energy source groups – electricity grid, gas grid and infrastructure for liquid fuels – all of which are essentially usable for connecting the primary energy sources and the final energy consumption entities.

Leveraging the example of the transport sector, three possible approaches for using renewable energy in the transport sector in future emerge:

- Directly via electrification and corresponding provision via the power grid;
- Indirectly by conversion into synthetic liquid fuels (e.g. synthetic diesel); or
- Indirectly by conversion into synthetic gases (hydrogen or methane).

Figure 4. Energy supply chains in the transport sector of Germany



Source: *Frontier Economics*

Note: *Illustration of the energy supply chain in the mobility sector, applicable to different sectors.*

This kind of systemic approach shows how conversion losses of synthetic fuels are often more than offset by the advantages chemical energy sources offer in terms of energy supply. Various studies[10] have recently addressed the question of which energy system is suitable and at what cost to achieve a long-term energy shift towards exclusively renewable energy sources.

Although the results differ in detail depending on assumptions and study set-up, the basic message is that an energy system using chemical energy sources has clear cost advantages over a predominantly direct electrification.

[10] I.a. Frontier Economics et al. (2017): The value of gas infrastructure for the energy transition in Germany; Dena (2018): dena lead study Integrated Energy Transition.

Up to
600
billion euros

can be saved in investments in the long term in Germany by using PtX, among others.

In a study for the German Gas Transmission System Operators (FNB Gas Study), Frontier Economics has shown that an energy mix using PtX (in gaseous and liquid form) can avoid investments of EUR 250 billion until 2050 compared to comprehensive electrification.[11] A recently published dena study even predicts savings of up to 600 billion euros with PtX, if optional importing possibilities were also used.[12]

Changing cost structures leads to cheaper energy – but costlier capacity!

The cost advantages that synthetic fuels elicit compared to extensive electrification are also directly attributable to wholesale cost structure changes in an energy system with increasingly renewable energy resources:

While the use of fossil energy sources directly involves the „consumption" of raw materials, thus incurring direct costs, this association no longer applies to renewable energy sources: The provision is primarily associated with fixed capacity costs, i.e. despite the high investment required to construct wind and solar power plants, once done, the generation itself incurs minimal direct costs. Similar relationships also apply to the grids, which is why the overall system characterised by higher proportions of supply-dependent renewable energies (e.g. wind and solar in particular) tend to spawn:

- **Energy becoming cheaper** – pure energy consumption (in kWh) drops in price provided the entire system does not reach its capacity limit;
- **Costlier capacity and peak outputs** – providing power (in KW) however becomes far more expensive.

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Electrification often solves „the wrong problem"!

However, the advantage of solutions that involve electrifying end applications, such as heat pumps or electric mobility, lies precisely in the efficient use of energy. Put simply it can be said that from this perspective, electrification „is solving the wrong problem": The electrification of end applications saves precisely where costs will fall in the future (namely, for each kWh of energy provided), however it imposes large demands in terms of capacity provision (e.g. for fast-charging processes or heat provision under extreme weather conditions with consumption peaks). In particular providing capacity and peak power supply entail significantly higher costs within an electrical system than via chemical energy sources.

This can be clearly seen when replacing combustion engine with electric vehicles (see „reality check").

[11] Frontier Economics et al. (2017): The importance of the gas infrastructure for Germany's energy transition.

[12] Dena (2018): dena pilot study „Integrated Energy Transition".

REALITY CHECK OF THE „ELECTRICITY ONLY“ SCENARIO: CASE STUDY ON ELECTRO MOBILITY

Applications such as electromobility essentially address the „wrong problem“: Although the element energy is becoming cheaper, it is optimised, which means that complex (and increasingly expensive, see above) charging capacities and peak capacities are required.

A prerequisite for the extensive use of electromobility is the comprehensive roll-out of charging infrastructure. Here, rather than the charging infrastructure itself, the system-wide provision of the corresponding capacities is the significant cost driver – both in terms of the electricity grid and available generation capacity.

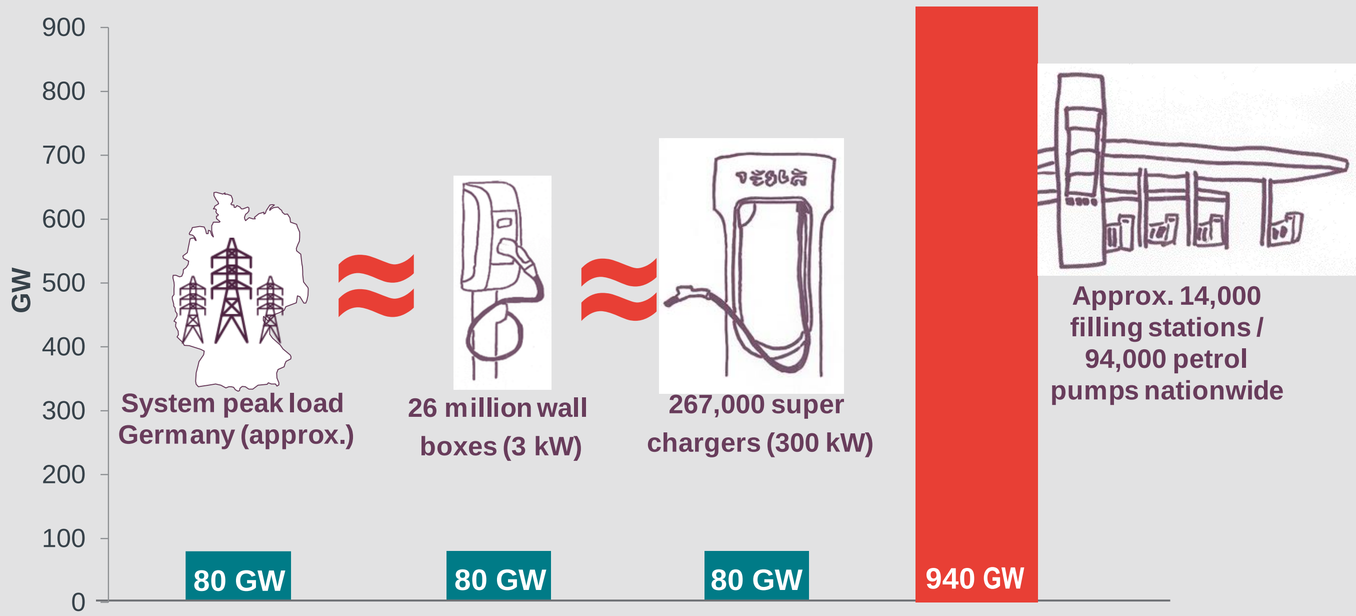
It needs to be taken into account that charging and refuelling infrastructure entails an optionality value: The core characteristic of mobility is that traffic flows in terms of space and time cannot be precisely predicted. This applies all the more to Germany, given its central European location and the resulting volume of transit traffic. Accordingly, the tank and refuelling infrastructure should not be tailored for optimal utilisation, but for regional peak situations – which inevitably results in significant portions of infrastructure being used only temporarily, resulting in a significant under-utilisation on average.

A simple and rough calculation demonstrates the (high) level of the current vehicle supply infrastructure and the scope to which the electricity charging infrastructure would need to be expanded, which is illustrated by Figure 5:

- Germany has around 94,000 petrol pumps available at petrol stations. Taking into account the average duration of a refuelling process, the flow rates achieved and the energy density, the average „output“, by which energy is transferred to a vehicle during a refuelling process, amounts to around 10 MW, i.e. 10,000 kW. This means that the current filling station infrastructure in Germany is equivalent to a (secured) total capacity of **940 GW**.
- For comparison: The electrical charging capacity of a conventional „wallbox“ is only around 2-3 kW and even „super chargers“ achieve only around 300 kW. The current peak load in the electricity grid (for all electricity consumers in Germany) is still only around **80 GW**.

Such figures bring home the fact that even if taking the higher efficiency of electromobility into account, using electric mobility nationwide will require a multiple of the currently available power in the electricity system, and this presumes only the supply level currently given at filling stations.

Figure 5. Output of the current filling station network compared to the provision of electricity in the mobility sector



Source: Frontier Economics

Note: 940 GW thermal; estimated total installed capacity of current service station infrastructure.
80 GW electric; current power grid peak load (for all electricity consumers in Germany).
Orders of magnitude remain relatively robust over time, with marginal changes in recent years.

Utilising existing infrastructures helps overcome acceptance limits of the energy transition

Apart from economic and technical aspects, what people often forget is that the energy transition project depends on having the broad support of society. To accommodate this aspect, various technologies must be evaluated. In this context, synthetic energy sources offer further advantages over comprehensive electrification, given their scope to allow ongoing use of existing infrastructure for gas and liquid fuels and cushioning the often controversial electricity sector expansion.

More than

double

the current circuit length in the high-voltage grid would be necessary for a comprehensive electrification!

Comprehensive electrification will require considerable grid expansion: Computations by RWTH Aachen University show[13] that comprehensive electrification would mean more than doubling the length of electric circuits in the high-voltage grid, equating, for example, to around 30-35 additional electricity pylon links from north to south throughout Germany. For comparison: Estimates suggest 15 years would be needed to expand those north-south lines which are already required today.

[13] Frontier Economics et al. (2017): The importance of the gas infrastructure for Germany's energy revolution.

Figure 6. The effects of the required extension of the high-voltage network in Germany

Source: Frontier Economics et al. (2017): The importance of the gas infrastructure for Germany's energy transition

Note: Scenario selection „Predominantly electrification".

Accordingly, politicians and network operators both now agree that expanding on a far larger scale – such as comprehensive direct electrification would require – presents a huge challenge. Distribution grids also face similar challenges when rolling out a comprehensive charging infrastructure for electromobility or installing heat pumps nationwide.

3. SYNTHETIC FUELS HAVE TO BE IMPORTED TO REACH THE ENERGY SYSTEM TRANSITION TARGETS SET IN GERMANY AND EUROPE

In the previous section, we showed how the future use of synthetic fuels in the context of energy system transition is indispensable and sensible.

In this section, we argue that it is neither efficient nor realistic to foresee a purely national provision of the energy required in future from renewable sources. In this respect, the international trade and purchase of gaseous and liquid synthetic fuels from renewable energies will be key when it comes to the future energy strategy.

> Energy demand in Germany in 2050 will still be at least 75% of its current needs– despite all efforts to improve efficiency!

German independence from energy imports unrealistic even after the energy transition

Germany currently covers about 2/3 of its primary energy supply through imports.[14] Since Germany's demand is expected to comprise at least 75% of its current needs in 2050,[15] even if the highest energy efficiency targets are achieved, the question remains as to how such quantities of energy can be supplied. Germany's long-term climate protection goals, its non-use of nuclear energy and (as things stand) the non-use of fossil fuels in connection with CO2 capture mean that come what may, the long term will inevitably involve covering most energy needs by renewable energies.

Is it really feasible to consider such quantities being provided independently within Germany in future?

It seems rather unlikely: Electricity (used either as-is, directly, or indirectly via synthetic fuels) will be key to the energy transition. Estimates assume that electricity demand per year could end up exceeding 3,000 TWh long term, compared to around 540 TWh today.[16]

[14] AG Energiebilanzen.

[15] Frontier Economics et al. (2017): The importance of the gas infrastructure for Germany's energy transition.

[16] Agentur für Erneuerbare Energien (Agency for Renewable Energies) (AEE) (2016): Meta-analysis – flexibility by coupling electricity, heat and traffic. Most of the studies presented here forecast German gross electricity consumption ranging from around 600 to 1,200 TWh/a by 2050.

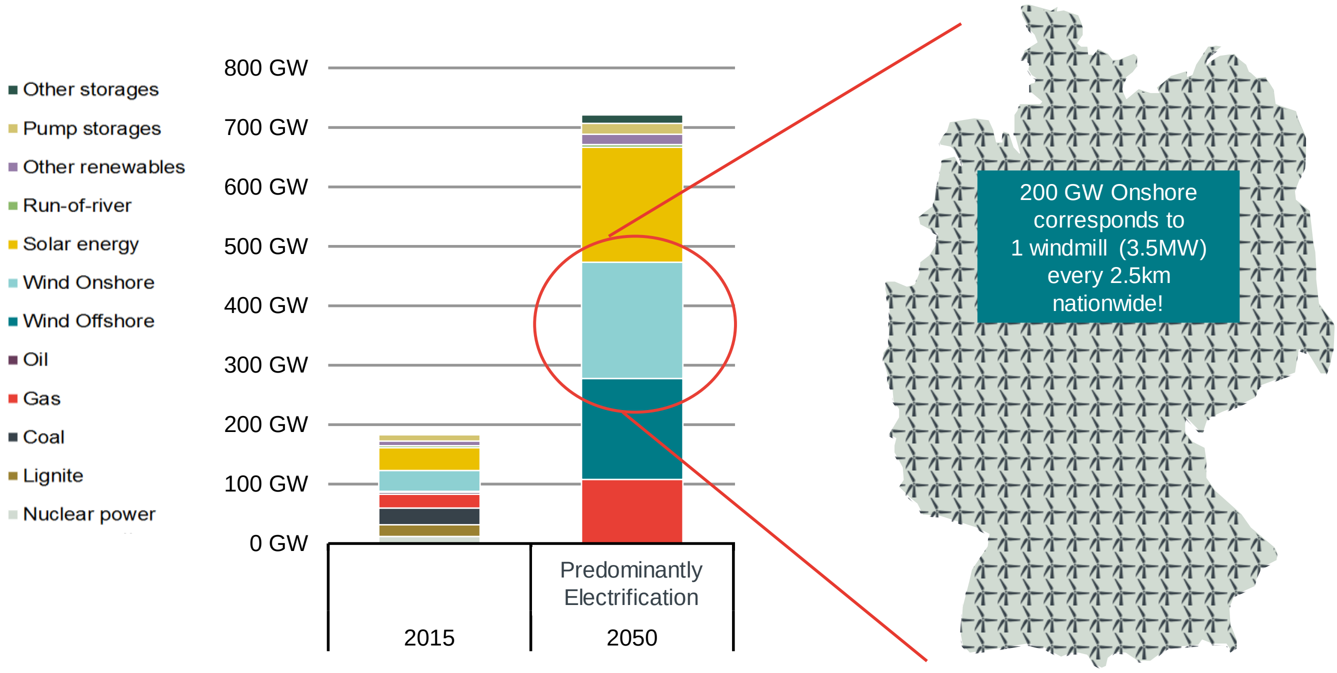
Every
2.5 km

a wind turbine would have to be installed, to ensure uniform nationwide deployment of a wind-based electricity generation capacity with approx. 200 GW onshore.

Even if the electricity demand does not increase beyond 1,000 TWh, up to 600 GW of the electric energy capacities – roughly one-third of which from offshore wind, onshore wind and photovoltaic sources – would have to be installed in Germany by 2050[17] if the energy demand shall be met by domestic generation. In comparison: Today, plants of approx. 57 GW (combined on- and offshore wind power) and 44 GW (solar) are installed – this scenario would require a multiple of present-day capacities.

These necessary expansions of renewable plants and the required accompanying infrastructure (electricity grid, and storages if we refrain from PtX) are likely to encounter increasing resistance within Germany. The resistance is reflected by the number of available renewable energy sites: Even if from a technical perspective, sufficient sites capable of accommodating renewable energy installations exist in Germany, it is doubtful whether they can be used to potential, given potential opposition from nearby residents. This ties in directly to the widespread disputes that arise when wind turbines are installed on land. For comparison: 200 GW of installed wind-based electricity generation capacity on land would equate to installing wind turbines every 2.5 km nationwide!

Figure 7. Consequences of the electricity generation capacities required in Germany



Source: Frontier Economics et al. (2017): The importance of the gas infrastructure for Germany's energy transition
Note: Scenario selection „Predominantly electrification".

[17] Frontier Economics et al. (2017): The importance of the gas infrastructure for Germany's energy transition.

In this respect, it can be assumed that making the energy transition project work will require importing (renewable) energy due to a decline in public acceptance.

Boosting the scale of renewable energy imports requires chemical energy carriers

> Chemical energy sources have a clear advantage over electricity when importing renewable energy due to the existing infrastructure.

If it proves impossible – as seems certain – to meet the renewable energy demand within Germany, these quantities of energy will have to be imported on a larger scale in future. Although scope remains to import biomass, biogas and other direct biogenic fuels, the volume is limited. In addition, transport of electricity from renewable energies, especially over long distances, is only possible to a limited extent: This is mainly because transporting electricity per unit of energy is relatively costly, especially when having to bridge long transport distances and handle transport losses.

When it comes to importing energy in bulk and over long distances chemical energy carriers clearly outperform electricity (likewise for storage facilities). Transport costs are less important with chemical energy sources – distances have significantly less influence here.[18]

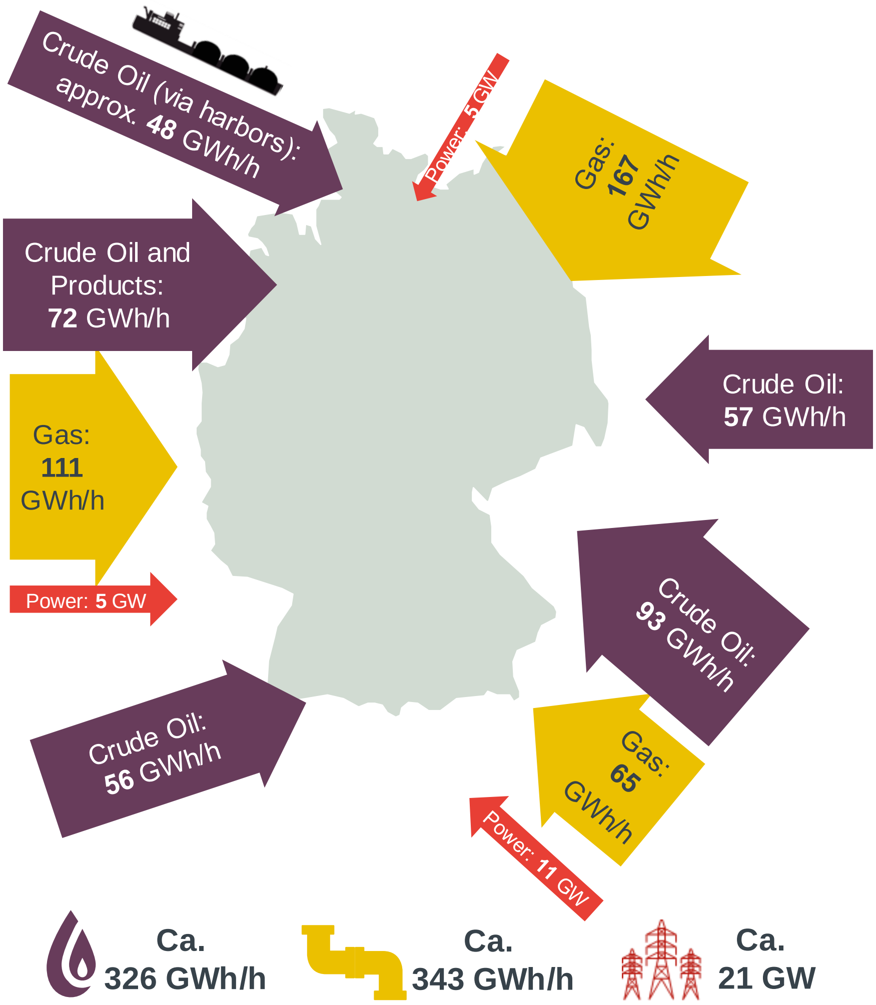
In addition, existing transport infrastructure can be used for imports

Even better, having already fully developed import infrastructure to hand facilitates the import of synthetic fuels: In energy transport terms, Germany's gas and oil infrastructure is very strong and outperforms, for example, the infrastructure for importing and transporting electricity many times over. Accordingly, the combined installed capacities of pipelines used to import oil and gas amount to almost 696 GWh/h as opposed to electricity with only 21 GW – constituting just 3% of the capacities of the former.

Imported synthetic fuels from renewable energies can also be fed directly into the existing infrastructure (transport, distribution and storages) within Germany. This helps mitigate the grid expansion restrictions outlined in section 2 and boosts acceptance of the energy transition.

[18] Overall, transport costs are negligible, while liquefaction and regasification are the main cost drivers for PtG transport costs, rather than distance (Agora Verkehrswende, Agora Energiewende and Frontier Economics (2018): Future costs of electricity-based synthetic fuels).

Figure 8. Comparison of current transport capacities of chemical energy sources vs. electricity



Source: *Frontier Economics*

Note: *Transport capacities for gases/liquids are given as GWh/h equivalent to volume sizes (e.g. m³/h), but are comparable to the usual GW for electricity.*

More than **40%**

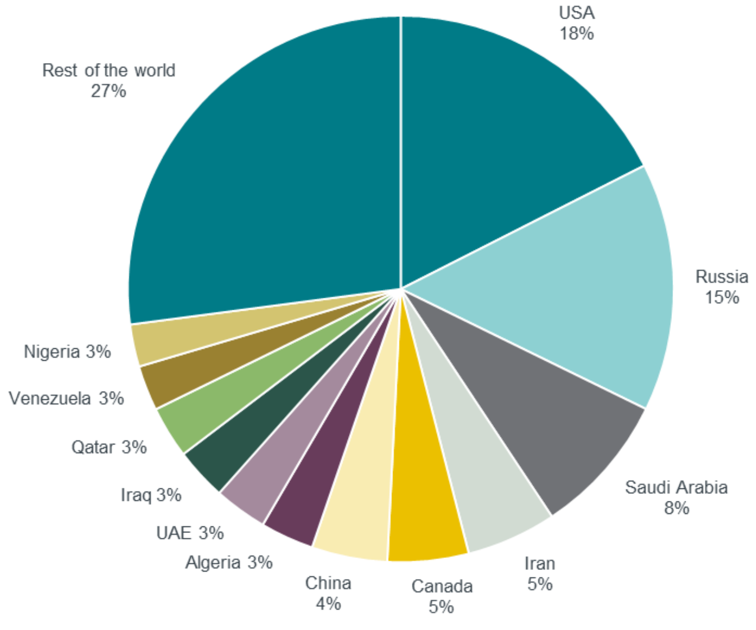
of the world market for gas and crude oil production is dominated by three countries on the supply side – PtX products can create new diversified supplier structures.

International trade in chemical energy carriers from renewables contributes to diversification

Germany has one of the highest raw material import percentages of any industrial nation, since almost all its petroleum products and natural gas, among others, are imported. Today, imports come from a limited number of countries of origin, which concentrates the supply. More than 40% of the global market for gas and crude oil production in 2014 was dominated by only three countries of origin – the USA, Saudi Arabia and Russia (Figure 9).

The bulk of the overall world market, comprising almost three-quarters of gas and crude oil production, is made up of only 12 countries, with the rest of the world collectively providing only 27%, spread over many countries with comparatively negligible supply capacities.

Figure 9. World market shares in gas and crude oil production



Source: https://www.eia.gov/beta/international

In contrast, synthetic fuels, as a general rule, can be imported from many countries worldwide with favourable site conditions for renewable energies and appropriate expanses. This means new players may emerge, which could contribute to further risk diversification.

High yields from renewable energy plants

require a high level of full load hours and are a decisive cost factor in PtX production.

Wind energy potential and incident solar radiation are key drivers when it comes to capability for and costs of renewable energies (wind and photovoltaics) in various countries: The higher the hours of use of renewable energy plants, the cheaper the resulting electricity is to produce. In addition, the time availability of electricity from renewable energies determines the utilization of the conversion plants – this is a fundamental cost factor in PtX production due to the high capital intensity of the plants.

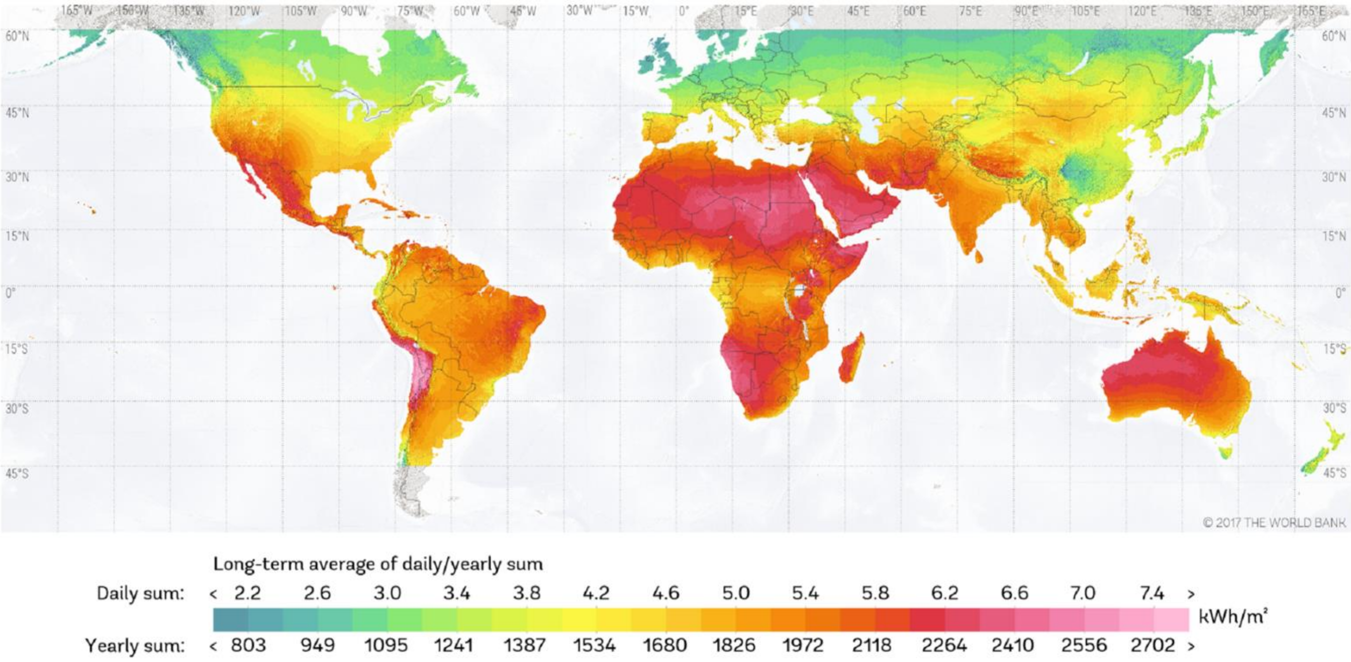
The world maps shown in Figure 10 and Figure 11 can be used to identify numerous countries or even entire regions with strong PtX potentials and potential export countries. Almost the entire African continent is a potential PtX exporter – primarily based on PV – likewise all Middle East nations. Many Central and South American nations, as well as those in Asia, also show strong photovoltaic potentials, which are also combinable with wind energy in certain cases. Canada, Kazakhstan, Russia, Norway or Iceland are further examples of possible PtX exporters, especially based on wind energy. In principle, many coastal regions worldwide can also be considered to play a role.

Diversification of the world market is possible through PtX!

There are many potential future PtX suppliers worldwide, which would also support Germany’s security of supply.

Consequently, a number of options exist for diversifying energy imports of renewable energies using PtX compared to today’s trading with fossil fuels. This would help widen the scope of global energy trade, while simultaneously boosting the security of supply for purchasers such as Germany and Europe.

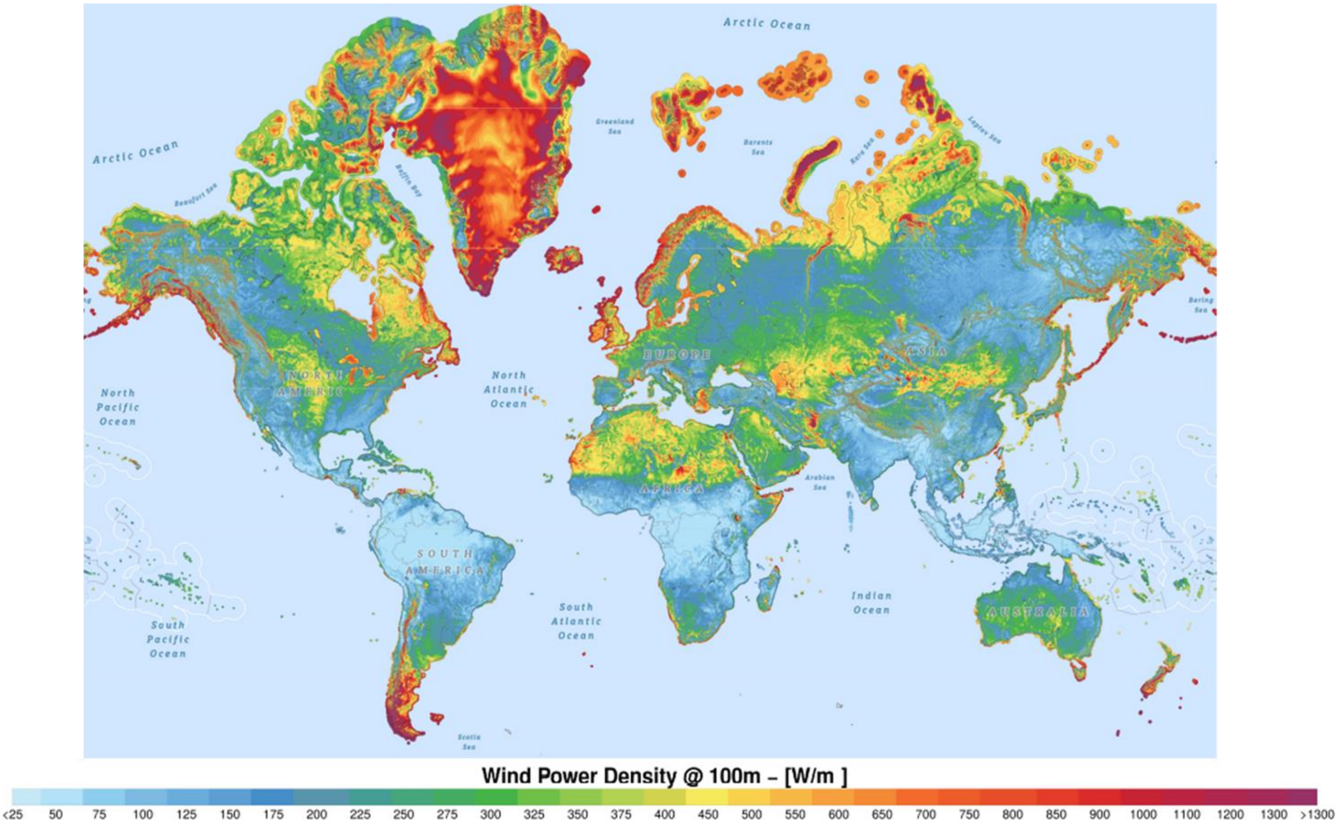
Figure 10. World map solar radiation



Source: World Bank Group, http://globalsolaratlas.info/

Note: Global horizon irradiation (GHI) - [kWh/m2]; annual scale from green (803 kWh/m2) to pink (≥ 2,700 W/m2).

Figure 11. World map wind energy



Source: World Bank Group, http://globalsolaratlas.info/

Note: Wind Power Density Potential @100m - [W/m]; scale from light blue (25 W/m) to dark red (≥ 1,300 W/m).

Many of these possible PtX production countries also have the necessary surface at their disposal, as shown by the following example:

EXAMPLE: VERY STRONG PTX POTENTIALS AVAILABLE ABROAD

Many of the contingent PtX-producing countries not only possess enormous renewable energy potential but also have huge expanses available, which are ideal for deploying the systems required. The North African country of Algeria is one example: A surface area of almost 2.4 million square kilometres makes it approx. seven times the size of Germany, but with only 17 inhabitants per square kilometre, Algeria has a very low population density and a corresponding surfeit in terms of constructible surface (compared to 237 inhabitants per square kilometre in Germany).[19] Algeria is also one of the top 20 global oil and gas producers, which gives it scope to build on existing infrastructures to produce and distribute synthetic fuels, including for transport to Europe (see Section 5).[20]

Countries elsewhere show comparably strong area potentials, such as Saudi Arabia, Kazakhstan or – with a slightly smaller area – Namibia and Angola in Africa. Although Namibia and Angola are smaller compared to very big countries like Saudi Arabia or Kazakhstan, Namibia is still twice the size of Germany and Angola is even four times as big. Leading the way in this respect are countries like Brazil or Australia, which are almost 23 times the size of Germany and also thinly populated.

As well as population density, other factors exist which must be taken into account and which could, if necessary, limit the entire usable area, such as avoiding competition for use (e.g. preservation of rainforest areas in Brazil).

[19] World Bank 2017.

[20] World Bank 2014. Harvard Pipeline World Map.

An affordable energy transition should exploit the potential to cut costs through imports

Mid to long term, the energy transition will depend on providing renewable energies at the lowest possible cost. However, many global regions pave the way to tap into renewable energies as sun, wind, water and biomass far more cost effectively than in Central Europe. Converted into fuels and combustibles, these can be transported at proportionally low cost[21] in liquid and gaseous form, then used in Europe, capitalizing on the existing pipeline, transshipment, interim storage and tanker infrastructure.

With a study commissioned by Agora Energie- und Verkehrswende[22] we have shown that synthetic fuels can be supplied much more efficiently from distant overseas locations such as North Africa, the Middle East or Iceland, than via domestic production (Figure 12). The analyses show that synthetic fuels (PtL) can be provided 30% cheaper via PV in North Africa than when offshore wind generation in the North and Baltic seas is used.

Cost savings like this, which imports allow, would benefit German industry and German consumers and help consolidate acceptance of German climate protection efforts: Firstly, by limiting the overall burden and secondly in the transition process, where at a given cost far more climate-neutral fuels could be made available due to the cheaper PtX production abroad.

An illustrative calculation shows the magnitude of the potential savings: If the above-mentioned savings potentials for imports of around 8 ct/kWh are taken as a base, this would result in annual savings potentials exceeding 200 billion euros, based on Germany's current total import volume of energy sources of around 2,600 TWh.[23]

Renewable energies are significantly cheaper abroad!

In many global regions, renewable energies can be generated much more cost-effectively than in Central Europe – and imported with the help of PtX in future.

PtL can be

30% cheaper

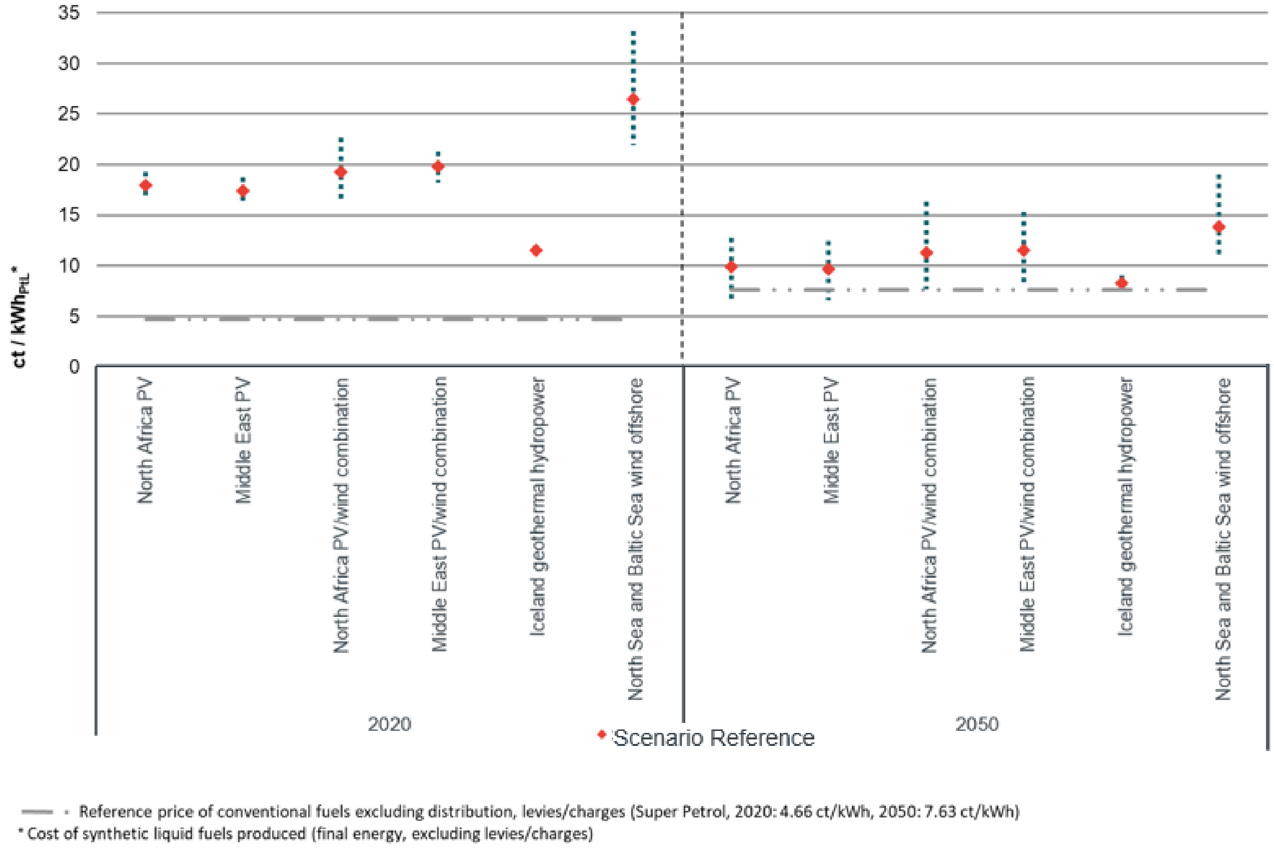
if supplied via PV in North Africa rather than offshore wind power in the North and Baltic seas – even until 2050.

21 Our analyses for Agora Energie- und Verkehrswende (2018) show that transport costs comprise around 0.5% of the total PtL production costs. Assuming that gases are transported by tankers (and must therefore be liquefied and regasified), the transport cost share of PtG production is somewhat higher at 7% of the total costs, albeit still low on a pro-rata basis and many countries still allow the use of existing pipeline infrastructure, which is linked to lower costs.

22 Agora Verkehrswende, Agora Energiewende and Frontier Economics (2018): Future costs of electricity-based synthetic fuels.

23 AG Energiebilanzen.

Figure 12. Cost comparison of PtX production abroad vs. Germany using the example of synthetic liquid fuels



Source: Agora Verkehrswende, Agora Energiewende and Frontier Economics (2018): Future costs of electricity-based synthetic fuels

Note: The cost results of the study are presented using the example of PtL (synthetic liquid fuel), but comparable with the results for PtG (methane).

4. THE GLOBAL USE OF SYNTHETIC FUELS GENERATES GREAT OPPORTUNITIES FOR GERMANY AS A TECHNOLOGY SUPPLIER

“

In terms of industrial policy and economics, globally expanding the PtX market can clearly benefit Germany.

In the preceding sections, we have outlined how using synthetic fuels from renewable energies makes sense, or is even a must in the context of the energy transition. In addition, importing and trading overseas in synthetic fuels has major advantages compared to a predominantly domestic energy generation, including in terms of location availability, diversity and security of supply.

In the following section, we will show that Germany can participate in the global expansion of the synthetic fuels market, based on Power-to-X technologies, in terms of both the industrial policy and the national economy. To this end, we first set up an estimate of the potential scale of a future world market for synthetic fuels, to then determine the economic effects of the investments required in must-have facilities and infrastructures. It turns out that Germany can gain considerable benefits in terms of growth and employment in the plant engineering sector.

50% of the current oil market share

could easily be taken and covered by a future world market for synthetic fuels by 2050.

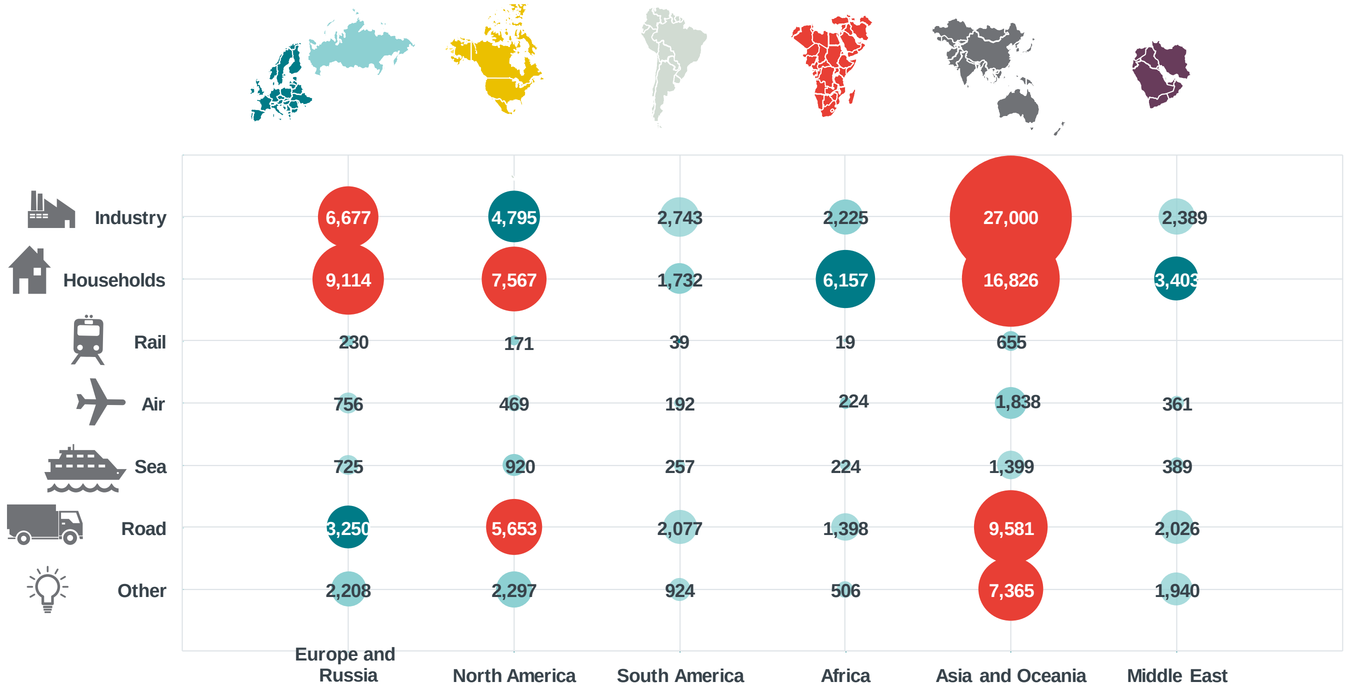
Meanwhile, global demand for synthetic fuels could easily reach 20,000 TWh per year by 2050

Even rough calculations and cautious assumptions show that the worldwide demand for synthetic fuels could easily be in the range of 20,000 TWh or more per year by 2050.[24] This would correspond to about half the current global demand for crude oil or eight times the current final energy demand in Germany.

This order of magnitude can be derived, for example, from a rough calculation: This is based on energy industry forecasts for the global long-term energy demand throughout all sectors and various regions; prepared by OECD and IEA in the World Energy Outlook 2016 up to 2040 (Figure 13).

[24] These rough estimates are to be understood as a first approximation and orientation to possible dimensions of a worldwide PtX market and could be iteratively corrected in future. Any influencing factors and sensitivities are not yet entirely transparent.

Figure 13. Worldwide future energy demand



Source: *Calculations by Frontier Economics based on OECD/IEA „World Energy Outlook 2016" (New Policies Scenario); U.S. Energy Information Administration (2015): Passenger travel accounts for the majority of energy used in world transportation*

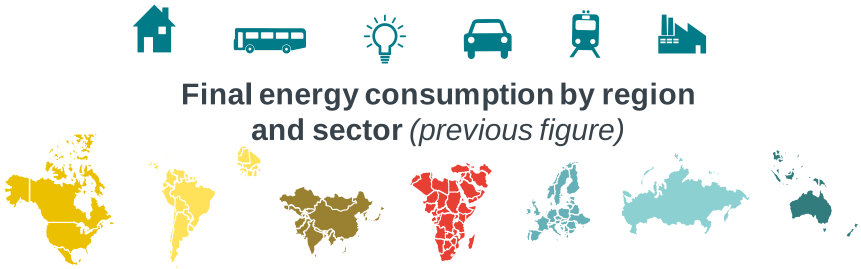
Note: Final energy consumption in TWh in 2040.

To simplify matters, we use this energy demand (differentiated by sector and region) to underpin our calculation of the possible magnitudes for a PtX market in 2050.

For the various energy-consuming sectors we use indications to determine potential shares of future PtX energy sources to cover long-term energy forecasts, e.g. for 2050 (Figure 14). The benchmark case features shares ranging from a relatively moderate 10 to 20% in those sectors in which electrification with renewable electricity as an alternative to PtX is comparatively easy to use on a larger scale (e.g. industry, individual road traffic, households, etc.), up to a maximum of 70% in the aviation sector, where, apart from synthetic fuels from renewable sources (and biofuels, with limited potential), it is difficult in the long term to use alternative climate-neutral energy sources (because of the low energy density of storage, limiting the feasibility of using electricity to shorter distances and smaller aircraft).

Since the PtX shares to cover energy demand in the long term (i.e. around 2050) are unknown today and speculative, we calculate the possible ranges for PtX use in the context of low and high cases, in addition to the reference case (Figure 14).

Figure 14. Possible fluctuations in future world market demand for Power-to-X



TtX share of energy consumption

	Road – Passengers	Road – Freight	Sea	Air	Rail	HH	TCS	Industry	Other
Low Case	0%	10%	40%	40%	0%	0%	0%	8%	0%
Reference Case	10%	20%	50%	70%	10%	10%	10%	10%	0%
High Case	30%	30%	70%	90%	10%	20%	20%	30%	0%

	Low Case	Reference Case	High Case
PtX-Markt	Ca. 10.300 TWh	Ca. 20.600 TWh	Ca. 41.175 TWh

Source: *Calculations by Frontier Economics based on the final energy forecasts in Figure 13*

Note: *PtX shares of final energy consumption are plausibly estimated for 2040 and have been discussed and agreed in several expert panels.*

Approx.

20,000

TWh

synthetic fuels could be in demand worldwide by 2050.

It becomes clear that, even with relatively moderate assumptions for future PtX shares, long term quantities on a scale of between 10,000 and 40,000 TWh will easily spawn a future market for synthetic fuels. In the average reference case, a market volume of approx. 20,000 TWh is achieved – which could save up to 4,500 million tonnes of CO_2.[25] The following analyses are based on this scenario.

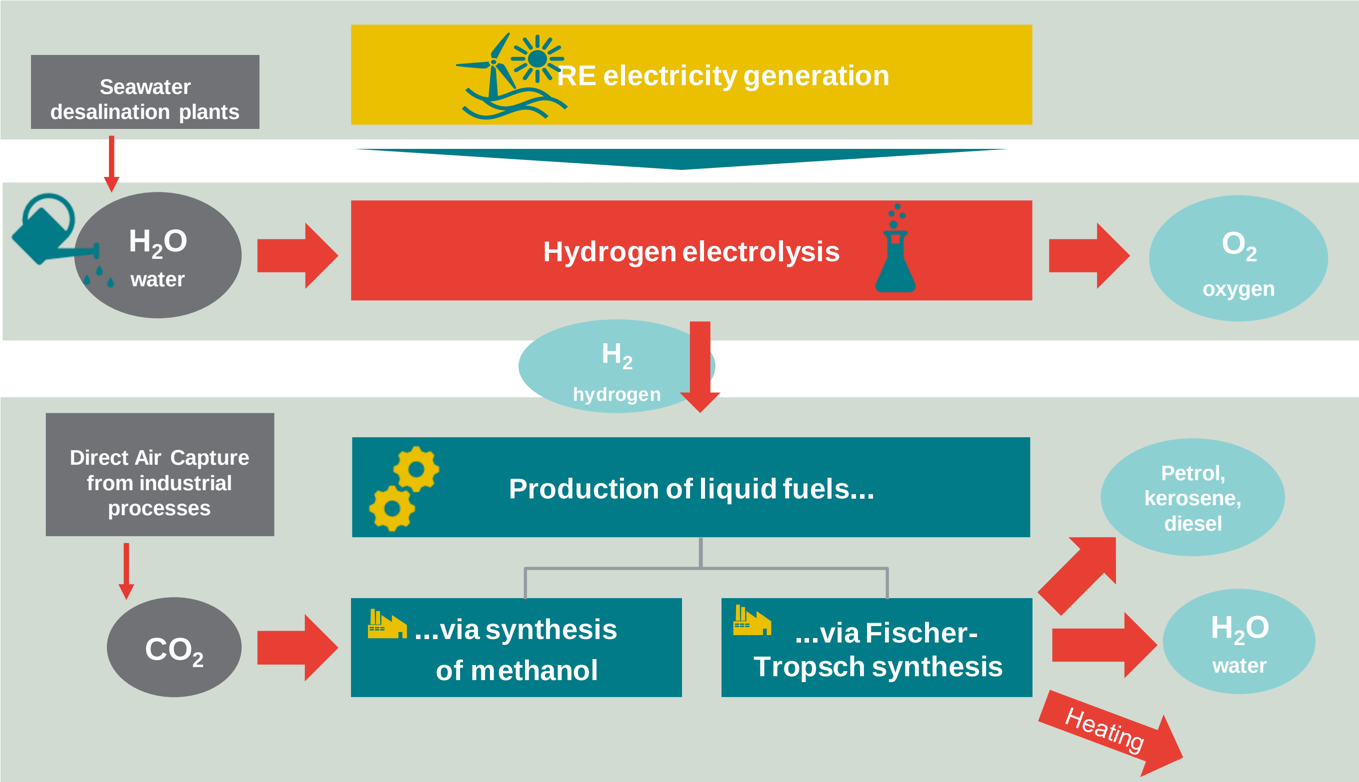
Investing in plant capacities for PtX production will be crucial

Producing PtX in such quantities requires appropriate conversion facilities and infrastructure. These comprise mainly electrolysers and synthesis plants for methanisation or producing liquid fuels from hydrogen (e.g. via methanol or Fischer-Tropsch processes), but

[25] The results of CO_2 avoidance assume that PtX replaces half each of the fossil fuels - in this case diesel and natural gas. The 20,000 TWh are converted using direct emission factors from the Federal Environment Agency.

also plants that provide the CO_2 (e.g. by capture from the air or from industrial plants) (Figure 15). These plants are described in the following as „PtX technologies“ (excluding renewable electricity generation plants).

Figure 15. Schematic view of the PtL production process



Source: Frontier Economics

Note: Schematic view of the PtL production typical of other processes for PtX production.

The capacity requirements of electrolysis and PtX conversion plants can be roughly derived from the worldwide PtX demand:[26] Producing about 20,000 TWh of PtX would require about 8,000 GW of conversion plants by 2050 (Figure 16). The majority (approx. 6,000 GW) would be accounted for by electrolysers for producing hydrogen[27] and approx. 2,000 GW by plants for downstream processes such as methanisation, methanol production or Fischer-Tropsch synthesis.[28]

26 In this simplified calculation, we assume half the PtX volumes produced will be marketed as liquid fuels and the remainder as synthetic gases. The flat-rate 50/50 allocation reflects the assumption that a technological mix of both options will ultimately emerge; taking the respective conversion costs into account. Ultimately, the costs between synthetic liquid fuels and synthetic methane differ only slightly (Agora and Frontier Economics (2018)), meaning that assumption of cost allocation has relatively little impact on costs. Furthermore, we assume that half the green gas is directly transported and used as hydrogen (PtH2; especially in industry and transport), while the remainder is additionally methanised (PtCH4; especially in the heat sector). This assumption corresponds to the approach taken in the Frontier Study for FNB Gas (Frontier Economics et al (2017): The importance of the gas infrastructure for Germany’s energy transition).

27 An exemplary total for usage hours of approx. 4,200 h/a is assumed.

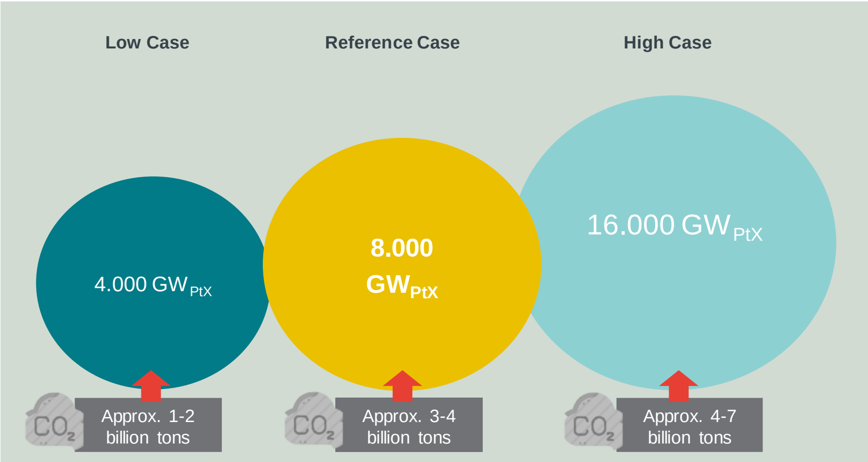
28 More or less ongoing operation is assumed here.

To convert to methane or synthetic liquid fuels as in our calculation, approx. 3-4 billion tons of CO_2 would be needed (producing H_2 requires no CO_2). To simplify matters, we assume the CO_2 is obtained from the air via Direct Air Capture (DAC) (see Figure 16).[29]

8,000 GW

PtX plant capacity could be required worldwide to meet a demand of around 20,000 TWh.

Figure 16. Required PtX plant capacities and tons of CO_2 by 2050



Source: *Frontier Economics*

Note: *The capacity calculations are based on the full-load hour assumption for photovoltaic and wind combinations in North Africa.*

Around **215** billion euros

per year could need to be invested in PtX equipment – almost 30% of today's investment in the entire oil and gas sector.

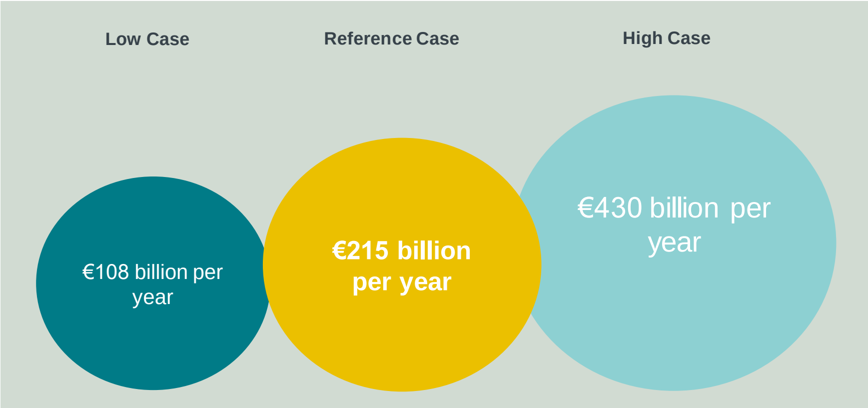
Using simplified assumptions on investment costs for the PtX plants, a further step could involve extrapolating the capacity requirement back into the relative investment requirements.[30] According to this calculation, an average annual investment volume of around 215 billion euros per year could be generated worldwide by 2050 (Figure 16). For comparison: Worldwide annual investments in the oil and gas sector currently total approx. 746 billion euros.[31] Even with relatively conservative assumptions, the required investment volume in PtX plants alone would comprise almost 30% of today's investments in the oil and gas sector.

[29] Our long-term calculations assume that CO_2 is obtained from the air. However, as long as significant quantities of CO_2 are emitted, e.g. from industrial plants, the CO_2 can be provided by these processes far more cheaply.

[30] Assumptions as average values for 2030: Electrolysers: 625 EUR/GW_{el}, further conversion 675 EUR/GW.

[31] International Energy Agency, 2016. Investments in the oil and gas sector are reported by the IEA as $873 USD and were converted at the current EUR/USD exchange rate of 18 July 2018. See https://www.iea.org/publications/wei2017/

Figure 17. Annual investments in PtX plant capacities until 2050



Source: Frontier Economics

In addition, further investments must be made in the expansion of renewable energies, since the electricity for Power-to-X should come from renewable energy sources to achieve the targeted CO_2 neutrality. For the scenario under consideration the required investment volume could amount to a further 450-500 billion euros per year.[32] These investments are not included in the following analysis.[33]

73%

of the investment volume in PtX technologies is accounted for by the electrolyser as the central element.

Germany spearheads the relevant key technologies

Based on the previously indicative average investment volume in PtX technologies of 215 billion euros per year, we estimate in the following possible positive effects for the German economy in terms of value added and employment. To this end, we start by determining Germany's global market share for the respective plant types, then calculate the economic effects from this demand in terms of added value and employment. In our calculations we assume for the sake of simplification that Germany's current global market shares, economic multipliers and employment intensities will remain unchanged in future.[34]

To estimate Germany's share of the world market for the equipment needed to manufacture PtX, we examine various international trade statistics. The central element of the investment in PtX technology is the electrolyser. At 157 of 215 billion euros, around three quarters

[32] The assumptions for renewable energies are exemplary for photovoltaics/wind combinations in North Africa. Despite the very considerable investment volume for renewable energies compared to the remaining PtX costs, but comprises a comparable share of total costs (including RE investment costs) as in other studies (Prognos et al. (2018)): Status and Perspectives of Liquid Energy Sources in the Energy Transition.

[33] The investment costs of renewable energies are not considered any further, since they would also be required to a considerable extent in the alternative scenario of full electrification and should therefore not necessarily be regarded as an additive for PtX.

[34] Accordingly, it constitutes an indicative calculation rather than a forecast.

of the investment volume in the middle scenario is accounted for by this type of facility (Figure 18).

Figure 18. Estimated global investments per year in PtX technologies up to 2050

	Estimated investments in billion euros per year			Share
	Low Case	*Reference Case*	*High Case*	
Electrolysers:	78	157	313	73%
Conversion facilities	22	42	86	20%
CO_2 capture	8	16	31	7%
Total	**108**	**215**	**430**	**100%**

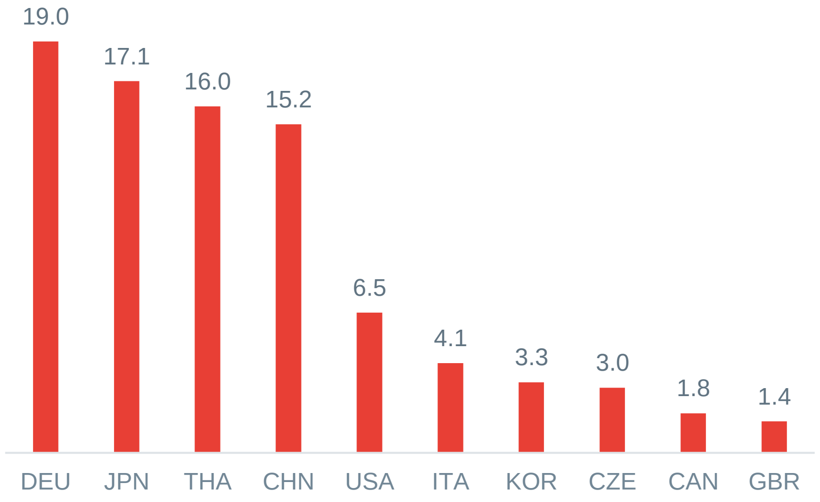
Source: Frontier Economics

Note: Assumption of CO_2 capture from the air (direct air capture); other costs of seawater desalination plants are negligible (Prognos et al. (2018), Agora Verkehrs- und Energiewende and Frontier Economics (2018)) and[35] excluded from this rough calculation.

In international trade statistics, electrolysers can be clearly identified as a separate category of goods. Based on exports from the various countries, global market shares in the production of electrolysers can thus be determined.

Figure 19 shows the global market shares of the top ten countries by export volume for the class of goods concerned in 2016. Germany thus comprises 19% of global exports, which makes it the world's largest exporter of electrolysis facilities as things stand.[36]

Figure 19. World market share of electrolysers 2016



Source: UN (2018), own calculations

Note: Germany's global market share of electrolysers is stable – save minor fluctuations between individual years, but its figure for 2000 was already comparable (19.7%).

[35] Agora Verkehrswende, Agora Energiewende and Frontier Economics (2018): Future costs of electricity-based synthetic fuels. Prognos et al (2018): Status and Perspectives of Liquid Energy Sources in the Energy Transition.

[36] Although Germany's global market share of electrolysers and capital goods fluctuates between individual years, its global market share in 2000 resembled that of 2016.

19%

of global electrolyser exports are accounted for by Germany.

In addition to the electrolyser's role as the central component of PtX technology, further installations to facilitate the production of synthetic methane or liquid fuels are required in PtX facilities. These include methanisation, PtL conversion and direct air capture facilities (see Figure 15).

For such installations, official trade statistics exclude a clear classification of goods, which would represent the main components of these installations. A different distribution key must be defined for the remaining 58 billion euros.

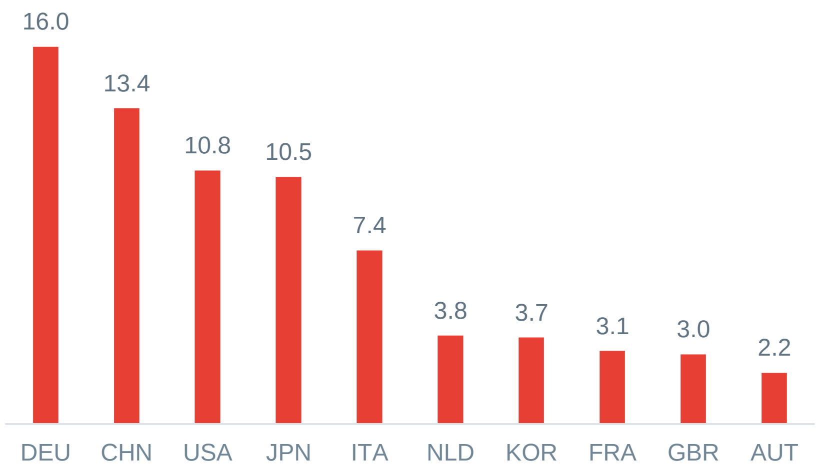
The capital goods export figures for plant engineering go some way toward explaining how the production of these facilities is distributed (Figure 20). Here, too, Germany accounts for the largest share of a single country at 16%.

A further

16%

of worldwide plant engineering exports are accounted for by Germany.

Figure 20. World market share of capital goods in plant engineering 2016



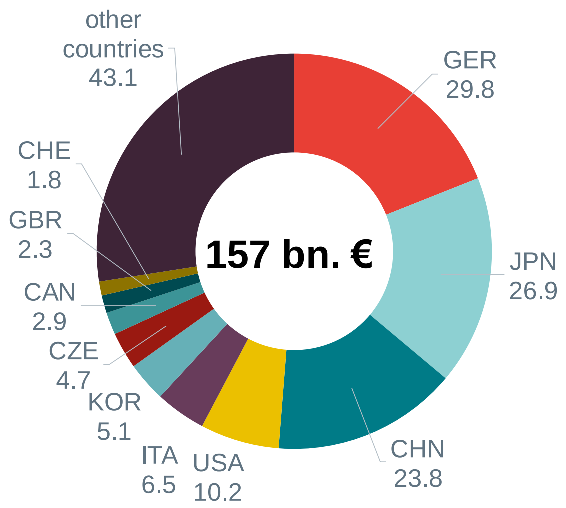
Source: OECD (2018), own calculations

Note: World market share excluding exports from trading hubs. Germany's global market share of capital goods is stable – save minor fluctuations between individual years, but was already at a comparable level in 2000 (17.4%).

Expanding PtX capacities internationally would open up great export opportunities for Germany

Assuming electrolyser demand is met by manufacturers in the individual countries in a similar proportion to that implied by current global market shares (i.e. assuming Germany's global market shares remain constant), this would entail annual production of electrolysers in Germany worth 29.8 billion euros (Figure 21). The calculated annual investment volume has to be seen as an average to be expected in the run-up to 2050 and does not take into account the potential for considerable fluctuation in the actual investment volume between individual years.

Figure 21. Expected annual manufacture of electrolysers for PtX production

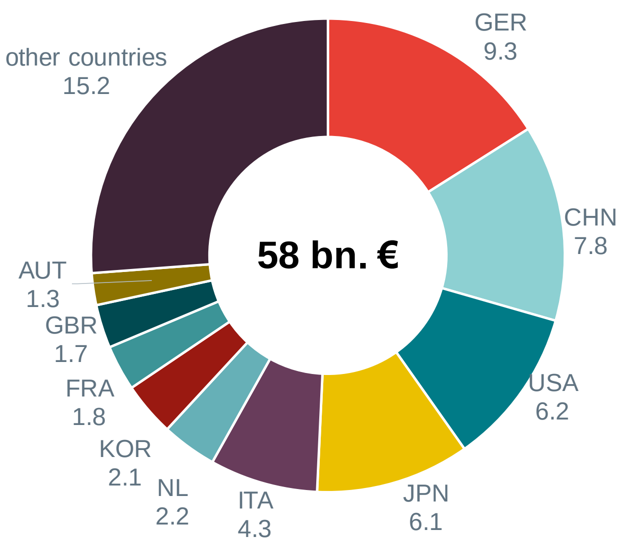


Source: UN (2018), own calculations

Note: Global market shares excluding exports from trading hubs; the top 10 exporting countries that can be regarded as individual countries in the impact calculation; PtX world market: Reference Case.

Demand for further facilities and components apart from electrolysers worth a total of 9.3 billion euros per year would have to be added (Figure 22).

Figure 22. Expected production of other PtX installations 2020



Source: OECD (2018), own calculations

Note: Global market shares excluding exports from trading hubs; the top 10 exporting countries that can be regarded as individual countries in the impact calculation; PtX world market: Reference Case.

Combining these two direct demand effects German manufacturers of PtX facilities (including electrolysers) would comprise an additional 39.1 billion euros, which approximately equates to the total industry-wide production value in Schleswig-Holstein. The direct production effect corresponds to Germany's global market share in the manufacture of PtX production equipment, multiplied by the expected annual demand for capital goods in each scenario.

PtX facilities worth

39.1

billion euros

could be produced by the German economy – equivalent to the production value of the entire industry of Schleswig-Holstein.

Hereafter, we examine the effects in terms of added value and employment triggered by this factor. To this end, we also include any advance payments for constructing the facilities and for the consumption of the workforce there additionally employed. To avoid double counting, we will focus on added value, where inputs are deducted from production value.

In terms of added value and employment, a wealth of opportunities open up for Germany as a technology supplier

The demand for capital goods for PtX production, as outlined in the previous section, will add value and boost employment in Germany: All of which would significantly aid the German economy thanks to climbing demand for PtX production equipment.

In the following section, we determine the economic effects of the demand for PtX technology in Germany via economic multiplier effects and employment intensities. In this context, we assume the current market conditions and multipliers will remain positive in future.

36.4

billion euros

in additional added value per year for the German economy by manufacturing and exporting PtX systems.

1.1% points

Increase in German GDP due to value added effects.

Assuming, for example, an annual investment volume based on the benchmark of 215 billion euros, this calculation would result in additional value-added effects for the German economy; totalling around 36.4 billion euros annually. This would correspond to an increase in the expected gross domestic product of around 1.1 percentage points in 2020.

This approach could elicit up to

470,800

new jobs

for Germany.

The German job market is also expected to benefit. The German economy may profit from up to 470,800 new jobs in total, if the current employment intensities are taken as a benchmark with simplification in mind.[37] This would correspond to about half the current workforce in the automotive industry in Germany. Accordingly, this may elicit potentially significant benefits for economic growth and employment in Germany.

Given the large volume of investment, the additional demand would therefore trigger considerable growth and employment effects. Significant demand for imports from China, for example, is of a similar magnitude; triggering comparable effects for the German manufacturing industry. If the Chinese economy had grown at only half the pace over a period of five years, the production (or production value) of the German economy would have been 1.3 percentage points lower.[38]

An overview of the multiplier effects – differentiated according to electrolyser and other plants (synthesis facilities to convert hydrogen into synthetic methane and liquid energy sources) – shows the great leverage that additional demand for PtX production would trigger (Figure 23). The figures also illustrate the high input generated by plant engineering, as the greater part of the additional value added is not generated by direct manufacturers, but their upstream suppliers and subcontractors.

Figure 23. Overview of the multiplier effects

		Electrolysers:	Plant engineering	Total
Added value	direct	11.7	3.7	15.4
	indirect	11.8	4.5	16.3
In billion EUR	induced	3.5	1.2	4.7
	Total	***27.1***	***9.3***	***36.4***
Employment	direct	133.4	41.6	175.0
Average in 1,000	indirect	163.6	60.9	224.6
	induced	53.0	18.2	71.2
	Total	***350.0***	***120.8***	***470.8***

Source: Destatis (2018), OECD (2018), UN (2018), WIOD (2016), own calculations

Note: PtX world market: Reference Case.

DERIVATION OF MULTIPLIER EFFECTS WITH INPUT-OUTPUT TABLES

Multiplier effects are determined by analysing input-output tables. Working with input-output tables and their analysis is one of the most widespread approaches taken for empirical economic research today. The input-output calculation tables are a comprehensive information system that sets out the goods

[37] In reality, the employment intensity for the production of electrolysers, for example, is likely to fall due to economies of scale – no assumption is made here on this subject.

[38] Lang et al., 2015.

interdependencies of the national economy in detail when it comes to producing goods and services. This information has numerous analytical and prognostic applications.

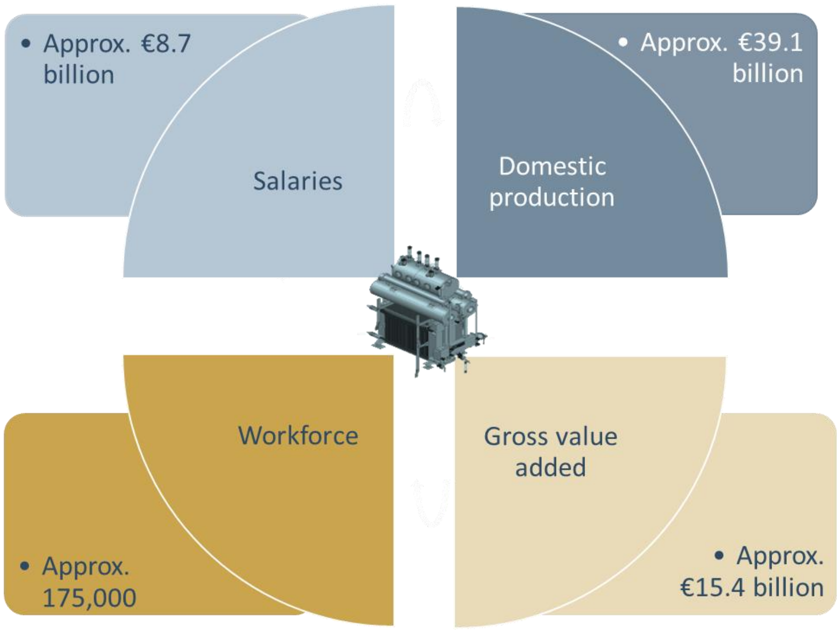
International organisations and the European Union also use input-output analyses to assess the impact of certain measures. They are also often used to assess the impact of policy measures. Such tables can also be used for economic development forecasts.[39]

In the following section, we examine the individual components of the effects listed and explain how the analysis works. First, we examine the direct effects triggered by increased demand from direct producers.

Direct effects with added value of 15.4 billion euros

Producing plant components for PtX extraction in Germany would directly generate additional added value of 15.4 billion euros. These new selling markets could generate up to 175,000 jobs in the plant engineering sector. This comprises about 15% of the current industry workforce (Figure 24).

Figure 24. Direct effect: Export of equipment for PtX production



Source: Destatis (2018), OECD (2018), UN (2018), own calculations
Note: PtX world market: Reference Case.

[39] Kuhn, Destatis, 2010, with further sources.

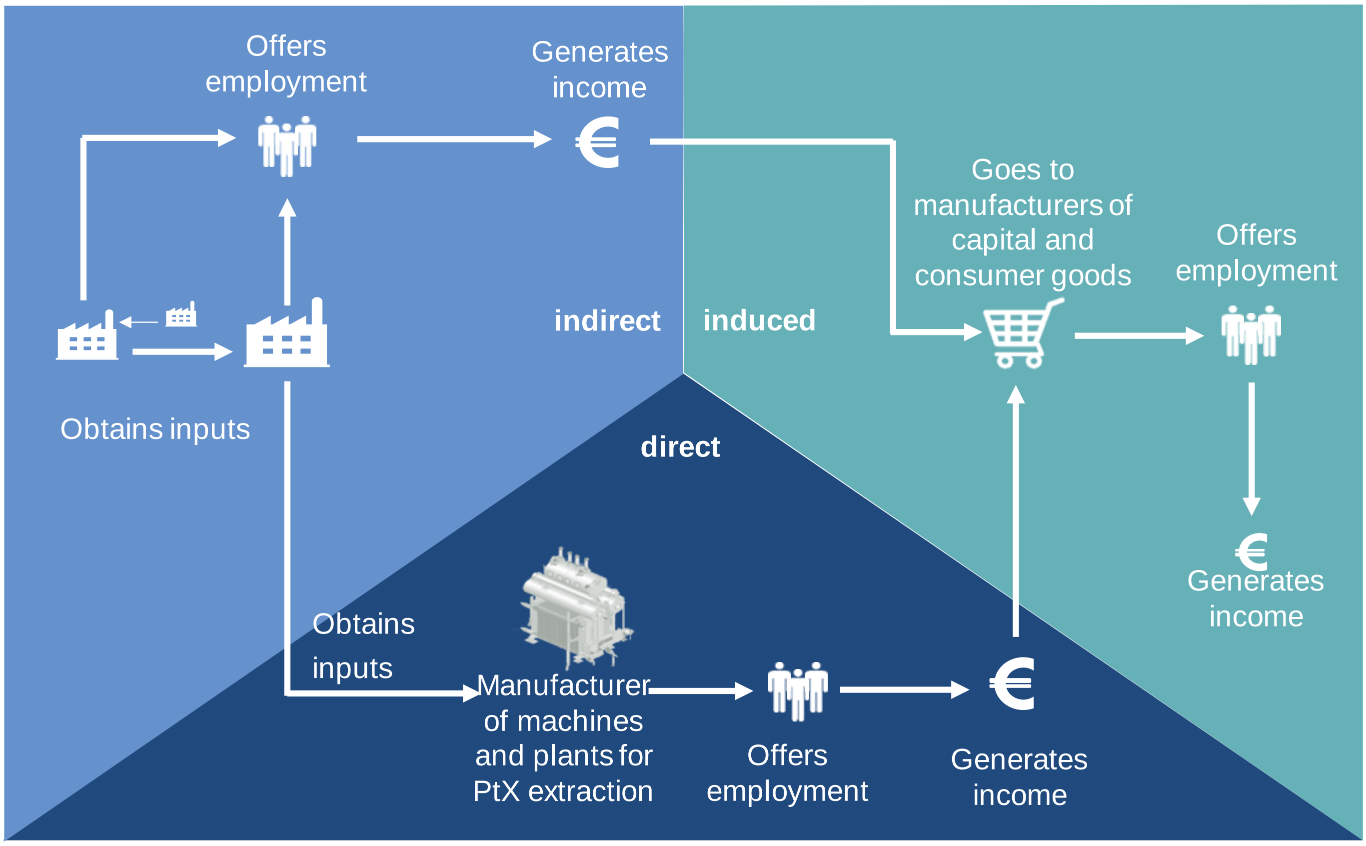
> The added value and employment effects far transcend the direct demand effects in plant engineering.

Indirect effects achieve a multiplier of 1.36 in relation to added value

However, stimulating demand for PtX production facilities would benefit the German economy far more than just the direct demand effects mentioned (Figure 25). Plant engineering projects would purchase input and thus increase the level of added value from suppliers. Suppliers would need to hire additional staff.

PtX equipment manufacturers would increase demand for parts and services from domestic and foreign markets and generate additional demand for products made by German input producers of the plant manufacturers. Additional jobs would be created in the supply sectors along the upstream value-added chain in Germany (indirectly), to meet this spike in demand. This scope covers all value-added processes at input level and required by PtX plant constructors for their production.

Figure 25. Illustration of direct, indirect and induced effects



Source: IW

That way the added value that would be generated for suppliers of plant engineering projects is calculated. The demand in the PtX engineering industry for these input products would spawn increased added value and employment for the supplier companies, which depends on such demand.

However, this does not yet fully cover all effects, since these suppliers, in turn, procure intermediate inputs from other companies, which, in turn, employ staff, purchase intermediate inputs and make investments (so-called interlinking of intermediate inputs). Consequently, indirect effects of the first, second and nth order are felt, whereby the scale of effects is reduced from step to step.

The additional employees, conversely, ensure increased consumption and thus additional demand for consumer goods. These newly created jobs at PtX plant constructors would generate additional income and collectively boost private consumption in Germany. Rising consumer demand is benefiting producers of consumer goods in Germany. Here, too, additional added value, employment and income are generated in Germany in a final induced effect. The induced effects include all activities triggered by the spending of wages by those employed by German PtX plant constructors and the input companies have received.

While the direct and indirect effects can be derived directly from interdependencies in the value added chain, the induced effects in consumer demand are subject to greater uncertainty.

1.36 euros

could be added for every euro of value added from the direct demand for PtX systems in Germany.

The detailed macroeconomic effects show that for every euro of value added from the direct demand for PtX systems produced by Germany, an additional 1.36 euros of indirect and induced added value would be accrued. These unusually high multiplier effects are explained by the fact that the indirect gross value added effects not only originate from the demand among German PtX plant constructors for inputs, but also the fact that PtX plant constructors from abroad procure significant inputs from German companies. Around 30% of the indirect effects, namely around 32 cents per euro of direct added value are based on demand from foreign plant engineering companies focusing on the PtX business.

The overall effects can be broken down as follows:

In the chosen scenario, a total of 15.4 billion euros in added value is generated directly by German PtX plant manufacturers and 16.3 billion euros indirectly in Germany along the upstream value chain (Figure 26).

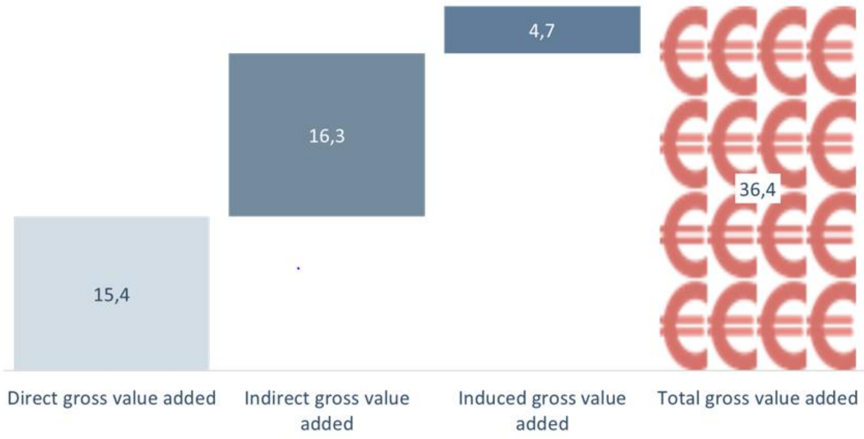
The induced effects amount to an additional 4.7 billion euros in total for Germany, which means the total impact of the demand for PtX facilities collectively comprises 36.4 billion euros overall per year.

36.4

billion euros

in added annual value for the German economy, while worldwide PtX investments amount to 215 billion euros per year.

Figure 26. Effects of added value caused by the export PtX production plants
Figures in billion euros



Source: Destatis (2018), OECD (2018), UN (2018), WIOD (2016), own calculations
Note: PtX world market: Reference Case.

As described above, such a scenario would also have a strong positive impact on the German labour market. Up to 470,800 jobs in total would be generated by the demand impulse for PtX plants in Germany described in the scenario, if the current employment intensity were taken as a simplified basis (Figure 27). Around 175,000 of these would be employed by plant engineering companies. Up to 224,600 additional jobs would be created in the upstream sectors of the value-added chain employed by German suppliers of domestic and foreign PtX plant manufacturers. The increased prosperity in Germany could also create up to 71,200 additional jobs, for example in service and other industries producing goods and services for private consumption. For each job in the factories of the German PtX manufacturers, 1.69 additional jobs would be created in Germany.

Up to

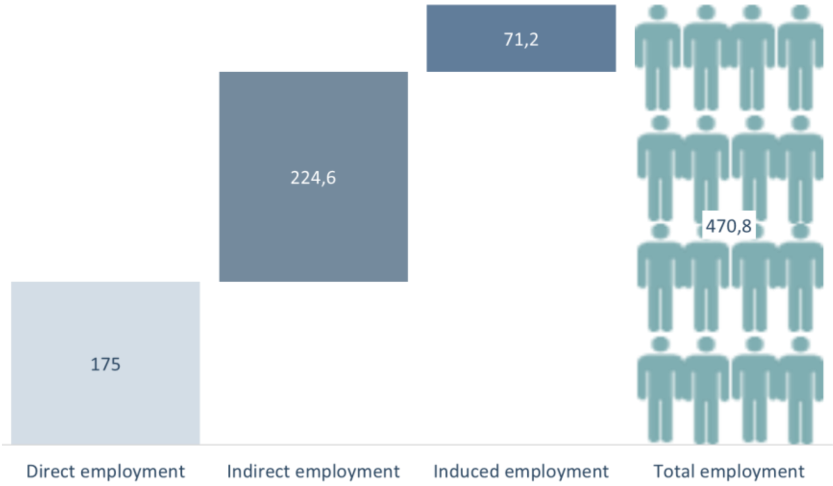
470,800

new jobs

could be created.

Figure 27. Employment effects through the export of equipment for PtX production

Figures in thousands of employees



Source: Destatis (2018), OECD (2018), UN (2018), WIOD (2016), own calculations

Note: PtX world market: Reference Case.

The demand for electrolysers has the greatest leverage

The production of electrolysers alone provides significant added value: 11.7 billion euros would be generated by German manufacturers. At 11.8 billion euros, the indirect value-added effect for suppliers is even greater. Together with the consumer spending of employees, this results in total added value of 27.1 billion euros through additional electrolyser production (Figure 28).

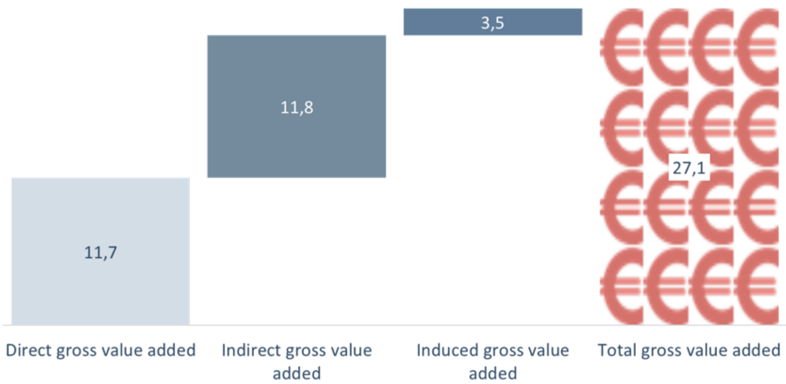
27.1

billion euros

in additional annual added value through the production of electrolysers in Germany.

Figure 28. Value-added effects of the export of electrolysers for PtX production

Figures in billion euros



Source: Destatis (2018), OECD (2018), UN (2018), WIOD (2016), own calculations

Note: PtX world market: Reference Case. Deviations result from rounding differences.

Up to

350.000

new jobs

could be added through the export of electrolysers alone.

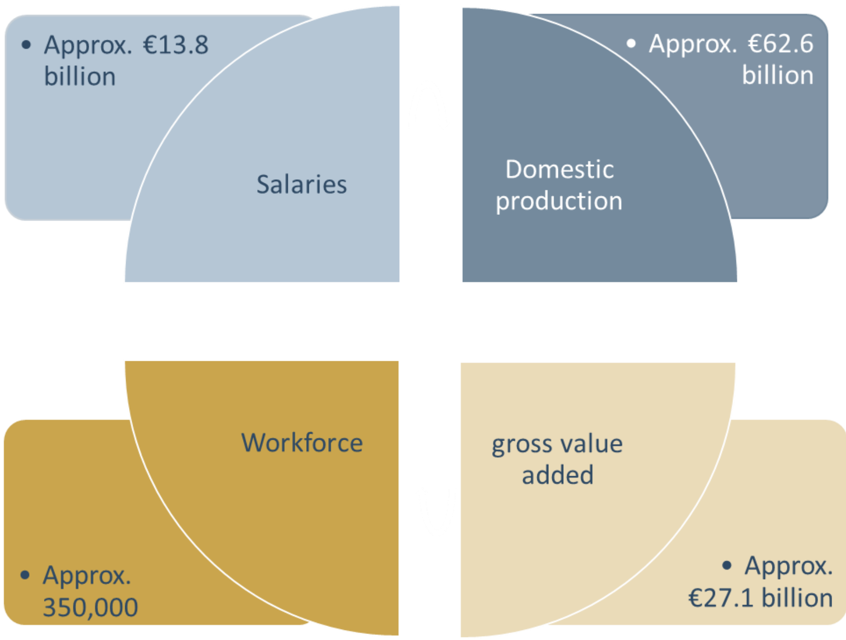
The production of electrolysers for the PtX technology would – assuming today's employment intensities – create up to 350,000 jobs. More than 133,000 jobs would be created directly through electrolyser production and just under 164,000 further jobs in the input sector (Figure 29).

Figure 29. Employment effects caused by the export of electrolysers for PtX production
Figures in thousands of employees

Source: Destatis (2018), OECD (2018), UN (2018), WIOD (2016), own calculations
Note: PtX world market: Reference Case.

In total, the German production of electrolysers would generate around 62.6 billion euros in production value while 13.8 billion euros would be paid as salaries (Figure 30).

Figure 30. Multiplier effects from exporting electrolysers for PtX production



Source: Destatis (2018), OECD (2018), UN (2018), WIOD (2016), own calculations
Note: PtX world market: Reference Case.

The plant engineering sector would also experience growth in areas other than the electrolyser

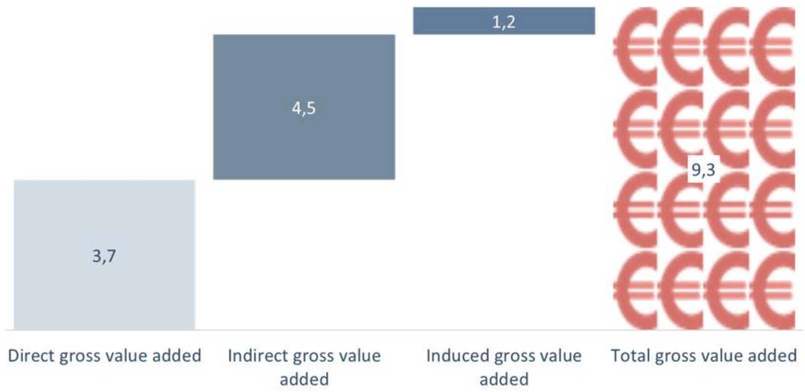
When producing liquid fuels, as well as electrolysers, other facilities are also required. These include methanisation plants, but also PtL conversion plants and plants for direct CO_2 capture from the air.

The direct value-added effects for the German plant engineering sector amount to around 3.7 billion euros, with additional added value of 4.5 billion euros for manufacturers of input products. If consumer spending by employees is added, the total value-added effect exceeds that of direct electrolyser production by 9.3 billion euros (Figure 31).

9.3 billion euros

in additional annual added value for German plant manufacturers, excluding electrolyser production.

Figure 31. Value-added effects from the export of other PtX production equipment
Figures in billion euros



Source: Destatis (2018), OECD (2018), UN (2018), WIOD (2016), own calculations
Note: PtX world market: Reference Case. Deviations result from rounding differences.

Plant engineering is defined by high input production. In addition to the 41,600 jobs created directly in plant construction, up to 60,900 additional employees would be employed by upstream producers and up to 18,200 through additional consumer demand. This would create up to 120,000 additional jobs for the plants required in addition to the electrolyser for PtX production (Figure 32).

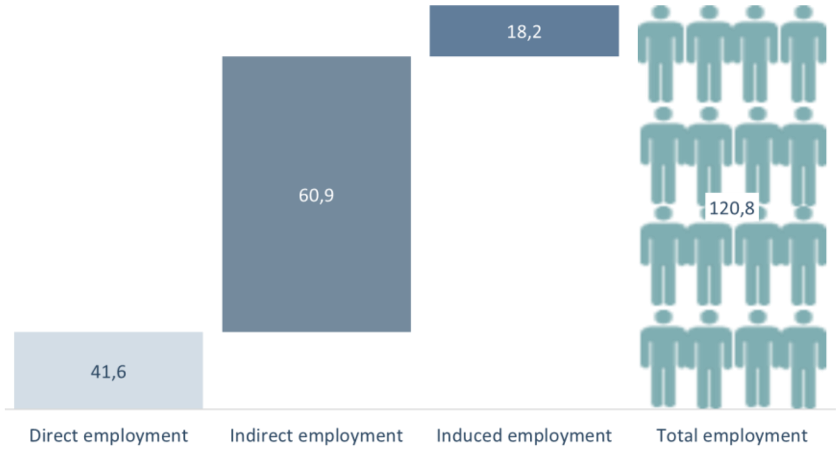
Up to

120,800

new jobs

in excess to those in electrolyser production.

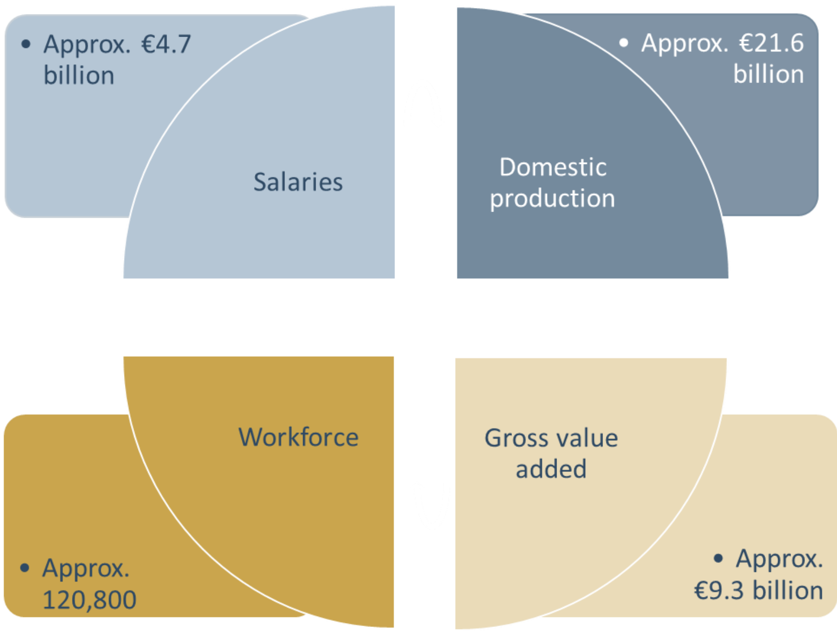
Figure 32. Employment effects caused by the export of other equipment for PtX production
Figures in thousands of employees



Source: Destatis (2018), OECD (2018), UN (2018), WIOD (2016), own calculations
Note: PtX world market: Reference Case. Deviations result from rounding differences.

Other plants, apart from electrolysers, achieved a gross production value of 21.6 billion euros. The additional plants, plant manufacturers, their suppliers and producers of consumer goods would mean payment of salaries amounting to 4.7 billion euros, the creation of 120,000 jobs and additional added value of 9.3 billion euros (Figure 33).

Figure 33. Multiplier effects caused by exporting other equipment for PtX production
Figures in billion euros



Source: Destatis (2018), OECD (2018), UN (2018), WIOD (2016), own calculations
Note: PtX world market: Reference Case.

5. SYNTHETIC FUELS CAN CREATE DEVELOPMENT POTENTIAL FOR PRODUCER COUNTRIES AND PROMOTE INTERNATIONAL COOPERATION

In the previous section, we demonstrated the effects of a growing world market for PtX technology on economic growth and employment in Germany.

In addition, potential PtX export countries will profit from PtX infrastructure, because synthetic fuels will spawn additional growth, employment and prosperity prospects locally through foreign investments and exports.

Moreover, establishing new export options can help consolidate the international integration of potential producing countries and, not least, strengthen their willingness to cooperate with regard to international climate protection efforts – which would then benefit Germany equally.

Potential exporters of synthetic fuels is a heterogeneous group

Section 3 has shown, inter alia, how numerous countries may become part of the supplying world market for PtX in future.

Beyond this initial assessment, these countries can be categorised separately based on their economic power, political framework conditions (energy policy and beyond) and in particular their motivation to start producing and exporting synthetic fuels. Potential exporting countries have very different characteristics which can be classified into three main groups:

(i) Emerging and developing countries: PtX production with the greatest renewable energy potential and the lowest production costs proliferate in regions currently requiring development, particularly in emerging and developing countries; including large portions of Africa, South America and Central Asia.

(ii) Today's exporters of fossil energies: There are also countries with very strong PtX export potentials that currently export fossil fuels. These include Saudi Arabia, North America, Australia, Russia and Norway.

(iii) Countries in which reinforced international cooperation through PtX exports can boost political stability (in energy supply terms). This includes numerous countries worldwide, particularly those rated politically, economically and institutionally more unstable or less stable than previously (e.g. Somalia or Angola).[40]

It is noteworthy that establishing an export infrastructure for PtX in all these groups is likely to trigger progress in the foreseeable future, but in some cases in very different ways – as the following sections illustrate.

Export of synthetic fuels may constitute an important stimulus in emerging and developing countries

Particularly in global regions that are socioeconomically weaker, investing in PtX production can elicit significant growth and employment effects, helping consolidate these countries.

Strong PtX export potentials can be found in emerging and developing countries in particular

Favourable locations for PtX production and regions intersect over a wide range and with a low level of development (Figure 34):

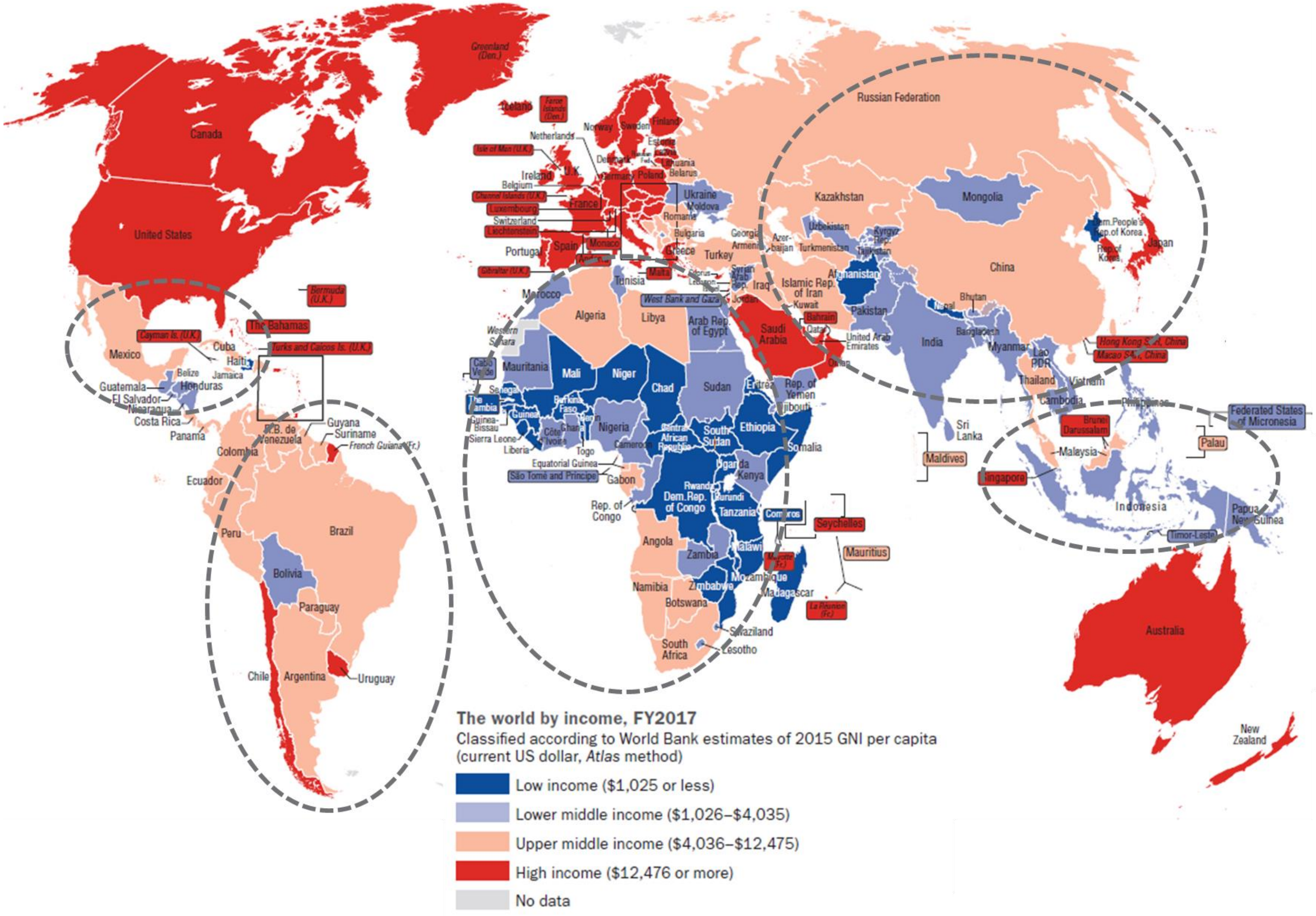
- Considerable parts of Africa, but also Asia, comprise the global regions most economically in need (dark to light blue marked regions).
- Some middle-income Asian countries qualify as emerging (light-red regions), such as China and Kazakhstan, as well as parts of the MENA region and South-West Africa. Most Central and South American countries also feature in this category of emerging countries, with a few exceptions (e.g. Chile and Uruguay, which are already developed high-income countries, and Bolivia, which is one of the poorer global nations).

A combined analysis of regional economic development and renewable energy potentials (Figure 35 and Figure 36) shows that most of the countries located in regions with strong renewable energy potentials and identified in section 3 tend to be in the less developed or developing regions of the world. Countries with a high potential for renewable energy due to the availability of resources currently include particularly unstable examples such as Somalia, Mauritania, Madagascar, Sudan and Nicaragua.[41]

[40] Ease of Doing and Corruption Index, as well as other development indicators (according to World Bank, Transparency International).

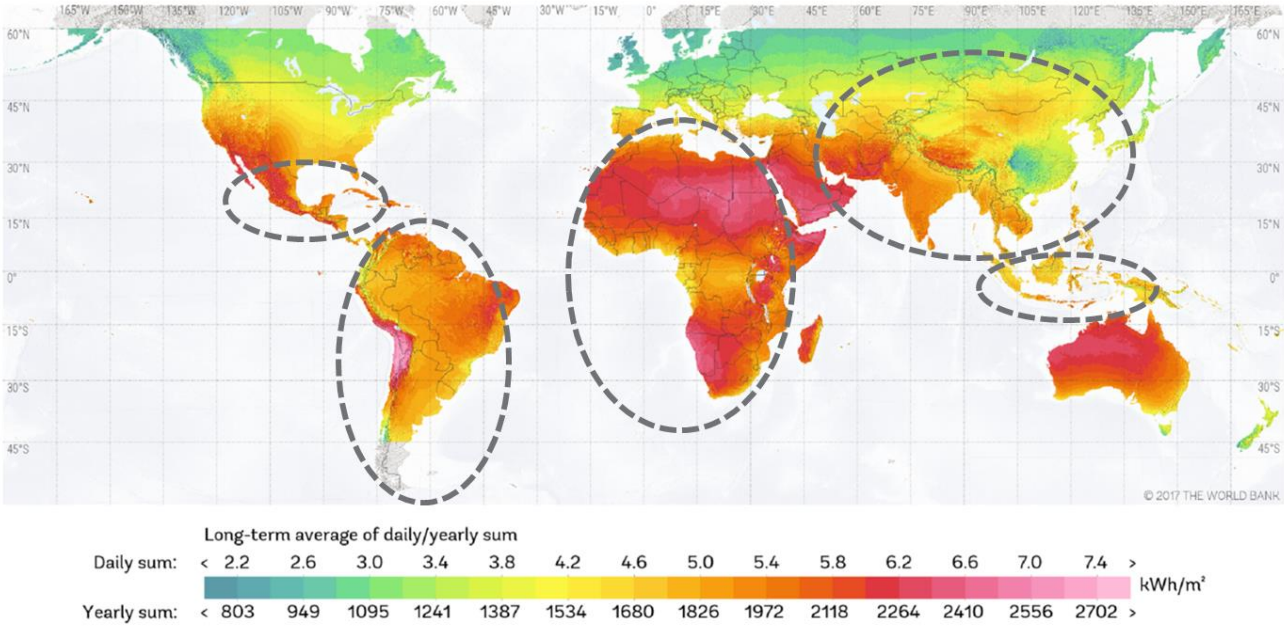
[41] World Bank, Heavily indebted poor countries (HIPC).

Figure 34. Intersection of potential PtX export regions with lower level of development by income



Source: World Bank, https://data.worldbank.org/products/wdi-maps

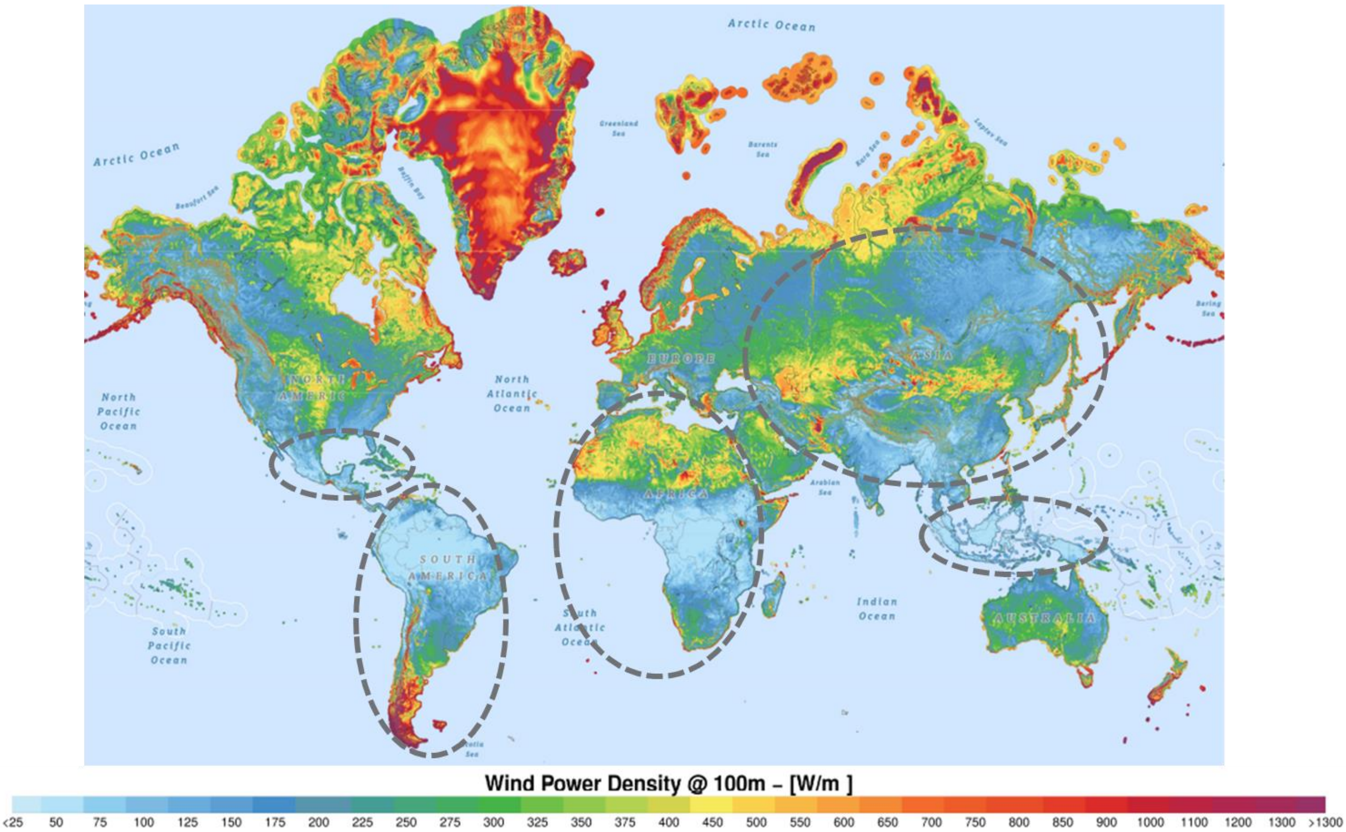
Figure 35. Emerging and developing countries with PV potentials on the world map



Source: World Bank Group, Global Wind Atlas

Note: Global horizon irradiation (GHI) - [kWh/m2]; annual scale from green (803 kWh/m2) to pink (≥ 2,700 W/m2).

Figure 36. Emerging and developing countries with wind power potential on the world map



Source: World Bank Group, Global Wind Atlas

Note: Wind Power Density Potential @100m - [W/m]; spectrum from light blue (25 W/m) to dark red (≥ 1,300 W/m).

The export of synthetic fuels would boost the economy and employment in these countries

Annual investment of around 215 billion euros in PtX production facilities means these countries could benefit significantly from foreign investment, even if it comprised only a small portion of the total investment volume. Foreign investment in the billions could significantly benefit economic growth and employment in these countries.

Apart from the economic growth through investment and the expansion of the synthetic fuel export industry, indirect effects would also generate positive development impulses, such as new jobs, which are often what stimulate stability in these countries.

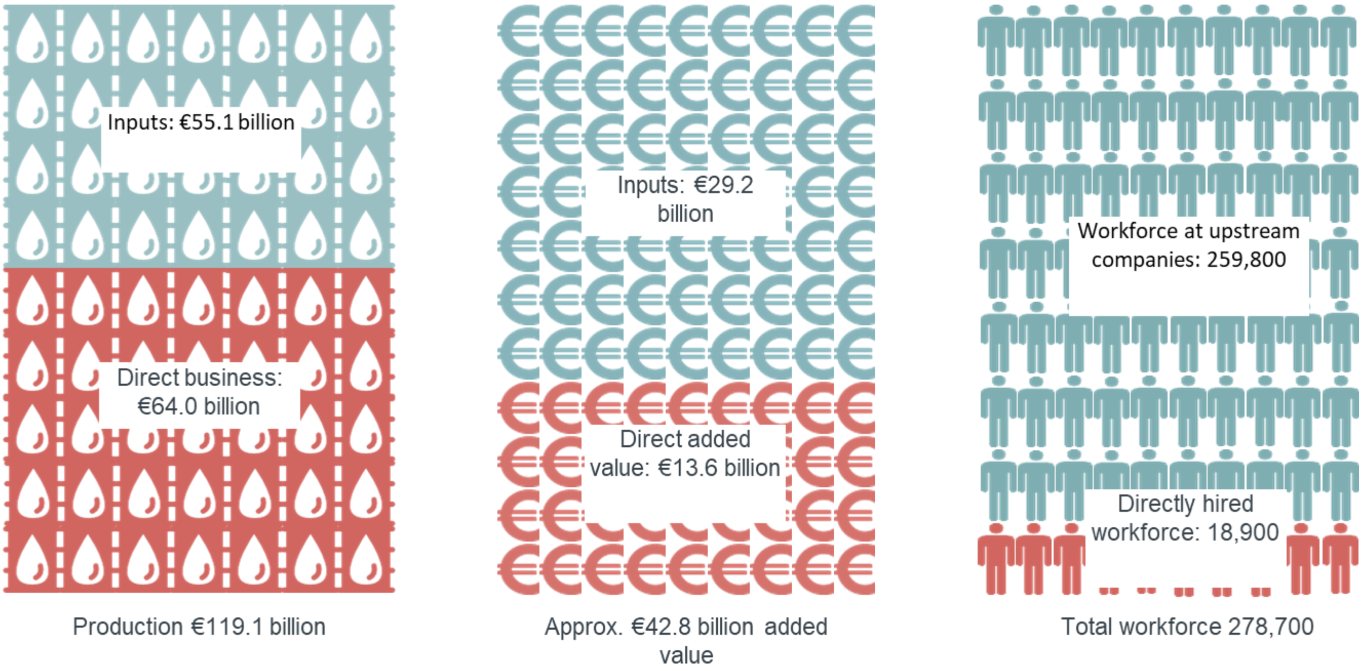
Even in economically stronger developing and emerging countries, such as South Africa, Algeria, Morocco or Brazil, these investments have a considerable volume and can have a strong economic impact. However, there is also a need to consider whether these countries have a considerable (and concealed) demand for energy, so that – at least in the short term – investments in the energy sector would initially serve to secure the domestic energy supply in these countries. This factor would mean additional motivation; allowing for the relatively rapid implementation of PtX generation capacities in these countries. Depending on further expansion, there would then be plenty of scope for PtX exports as an additional perspective.

Multiplier effects increase the impact of local investments

Like the macroeconomic effects of investment in facilities and equipment for the Germany economy previously demonstrated, facility operations in these countries would trigger further economic effects transcending those of direct investment.

As a matter of course, such estimates applied to new industries are subject to considerable uncertainty. If, however, analogous effects are assumed as in the crude oil processing field, corresponding volume ranges can be presumed.

Figure 37. Illustrative: Local value added and job effects per country



Source: Own calculation IW

Based on this, Figure 37 shows exemplary analysis of potential added value and job effects, assuming a national production volume of 400 TWh.[42] Accordingly,

- this would generate direct additional business of around 64 billion euros per country,[43] which, in turn, would correspond to around 14 billion euros in added value, taking into account typical value-added ratios in comparable industries;
- these would also favour further local effects, e.g. via input procurement, so that the overall effect would increase to around 120 billion euros in production value or 43 billion euros in added value – each year. So, every euro of value added from PtX production would generate a further 2 euros of value added generated by national suppliers.
- This would also spawn respective impetus for jobs in these countries: Assuming similar employment conditions to refineries in terms of gross output, up to 19,000 and 260,000 jobs could be created directly and indirectly in these countries respectively.

42 The underlying assumption is that future global PtX demand of around 20,000 TWh will be covered equally by approx. 50 countries – meaning a 400 TWh national production volume. This assumption is merely an example to illustrate the mechanism and can be adapted iteratively.

43 The assumption is based on a cost of 160 euro per MWh according to Agora Verkehrswende, Agora Energiewende and Frontier Economics (2018): Future costs of electricity-based synthetic fuels.

2,000

billion euros of value-added potential

from PtX production for a PtX world market generating 20,000 TWh per year roughly equates to the collective GDPs of the 120 poorest countries worldwide.

The value added through PtX production offers considerable development potential for large parts of the world

If the above estimates are extrapolated to the overall market, this figure illustrates the development potential entailed when building up an international export market. Based on the exemplary correlation gleaned earlier of around 40 billion euros in added value given a national production volume of 400 TWh (Figure 37), the realistic total market volume of 20,000 TWh PtX per annum, as estimated in section 4 of this report, elicits total added value of around 2,000 billion euros per year. This corresponds roughly to the collective GDPs of the 120 poorest countries worldwide.

Even if these calculations are only approximate, it becomes clear that international investments in PtX technologies, in addition to the 4 positive effects on the Germany economy, as outlined in section 4, would pave the way for numerous developing countries to multiply their regional value added in the long term through PtX generation. Accordingly, there are considerable associated potentials in terms of development aid policy.

Countries currently exporting fossil fuels in bulk can use PtX to develop alternatives for the „post-fossil age“

If international climate protection targets, like those agreed in Paris for example, are to be met long term, this would inevitably require a far-reaching transition from fossil fuels to „green energies“ – and usher in the „post-fossil age“. Demand for fossil fuels, especially in developed countries with ambitious CO_2 targets, is thus set to decline significantly over time, whereupon raw material prices could fall in the long term due to falling demand and oversupply simultaneously. These factors would exert increasing pressure on global commodity markets and ultimately render the export of fossil fuels uneconomical.

Already at present, corresponding economic diversification measures are visible in many classic oil-exporting countries. Accordingly, synthetic fuels could offer an alternative growth perspective for countries currently exporting fossil fuels in bulk for the long term. This could drive structural change in these countries and resolve areas of tension for exporting countries. Last but not least, these countries would be in a position to contribute significantly to global climate protection.

> PtX offers today's oil and gas exporting countries an economic perspective for a smooth transition into a post-fossil age.

Exporting CO_2-neutral chemical energy sources using renewable energies can provide a further building block to protect against disruptions caused by the „end of the fossil age“, while sustaining an established export industry. In other words, this scenario would not only generate alternative value-added potential for all countries involved, but also retain the currently high-level integration of international trade flows and a comprehensive world market – all of which would have stabilising political effects. PtX provides these countries with the economic perspective to transition smoothly into a „post-fossil age" without undergoing massive structural disruptions.

A number of the identified potential PtX production countries have been classified as bulk exporters of fossil fuels – this applies first and foremost to oil-exporting countries, but also to natural gas and coal exporters. Crude oil and natural gas production combined comprises more than 27% of the national GDP of Saudi Arabia, for example (Figure 38). Qatar also generates more than 21% of its GDP from crude oil and natural gas production.

Figure 38. Major countries of the top 20 oil and natural gas producers worldwide

Source: World Bank, Share of natural gas and crude oil production in national GDP, 2016

Note: Selected countries which could become potential PtX exporters because they met to the „hard" criterion of resource availability.

International cooperation is strengthened – boosting political stability

Finally, strengthening international political interdependence also boosts political stability. This applies to trade in synthetic fuels as well as to all other (civil) trade goods.

The focus on economic sectors where special country-specific advantages are of relevance alongside the international „exchange" of goods and services, will benefit consumers in all associated countries – trade essentially creating a „win-win situation". A conceivable international trade in synthetic fuels might also form part of this network.

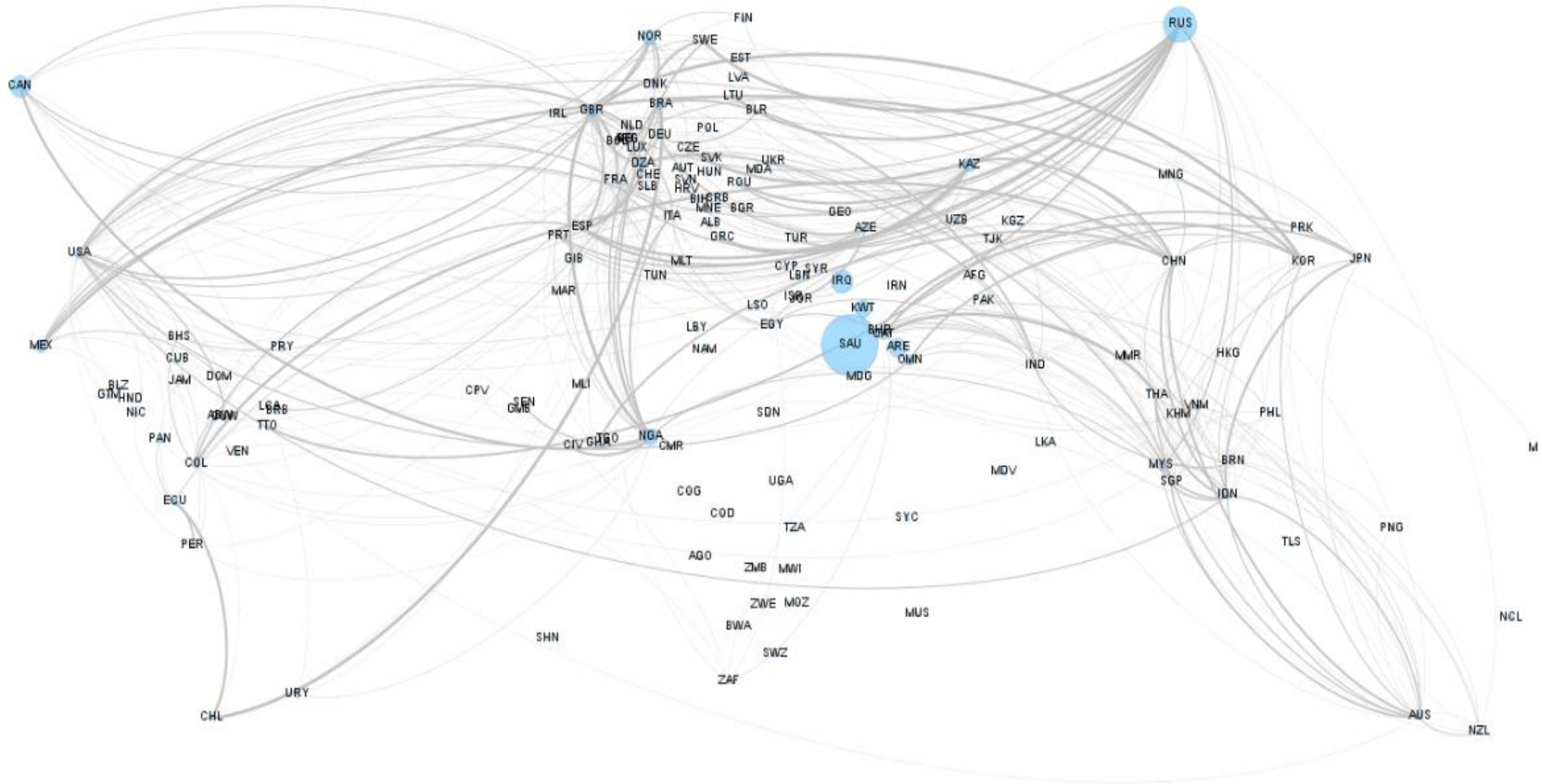
Based on the trade flows for crude oil, Figure 39 illustrates existing international trade relations exists in the area of fuels and combustibles in particular; hardly any other product group maintains such a network. The great opportunity here is that PtX also allows countries without corresponding export products to date to participate in these structures as suppliers.

All in all, it can be seen that the technologies which synthetic fuels offer considerable developmental leverage: Even with conservative assumptions, a global market for PtX will emerge on a scale capable of sparking business and investments in potential PtX-producing countries, enabling novel and highly effective economic growth impulses in the same. If it were possible to link such value-added potential with development aid policy goals, this could see considerable future scope for further international cooperation. In this context, it is especially helpful that economically disadvantaged regions have resources and locations allowing low-cost PtX production.

Even for countries having thrived from exporting fossil energy sources to date, establishing PtX structures in parallel may still make sense to protect themselves against possible declines in demand due to international climate protection efforts, while simultaneously retaining their own participation in international trade relations.

As a starting point for an international development partnership, this technology thus not only offers direct economic advantages for Germany, but can also provide an important stabilising element for the global economy.

Figure 39. Clip of trade patterns and crude oil networks



Source: *IW according to UN Comtrade*

Note: *Shows bilateral exports worth 10 million euros or more in 2015. The size of the nodes is equivalent to the export volume of crude oil. Not all countries are shown.*

6. CONCLUSION: SYNTHETIC FUELS SHOULD BE PART OF THE INTERNATIONAL ENERGY AND CLIMATE CHANGE AGENDA

The analysis shows that PtX is responsible for significant benefits in several areas, globally as well as nationally:

- **Benefits for the transformation of the energy industry:** Synthetic fuels will be cornerstones of an energy shift towards greenhouse gas neutrality, if only because chemical energy sources are crucial for various sectors and the only way to store energy in bulk is chemically.
- **Benefits for technology suppliers**: Germany can blaze a trail in terms of the manufacture and export of capital goods. This will benefit both the economy and the workforce in Germany.
- **Benefits for exporting countries**: PtX exporting countries can benefit from domestic energy investments. This applies in particular to economically weak countries as well as those whose economic performance is (still) largely dependent on the export of fossil fuels.

“

The task is to create a contextual framework for the emergence of a global PtX market!

Realising these benefits means taking political decisions at an early stage. The focus here would not be to define today a specific target volume for synthetic fuels, e.g. for 2050, but to create the framework conditions for the emergence of a global PtX market. Key elements in this context:

- **Technological development** – In terms of technology and science, Germany is currently a global leader in PtX technology development. An extensive PtX industry network is needed to realise the cost reductions which a broad market roll-out requires. Large-format pilot projects and demonstration plants are needed to pave the way to realise effective economics of scale.
- **Global approach** – If the economic benefits of establishing a worldwide PtX industry are to be realised, especially for Germany, the import and international trade of synthetic fuels must underpin the energy and climate protection strategies of Germany and Europe. Energy imports are already common and accepted – this trend should continue in a largely decarbonised energy world. Consequently, technological development and economics of scale must be promoted on a global scale.

- **PtX as an inherent component of the international energy and climate protection agenda** – With this in mind, international energy cooperation should be promoted both bilaterally and multilaterally. Synthetic fuels should be an integral part of international energy agreements, energy partnerships, cooperation projects and climate protection negotiations.

LIST OF ABBREVIATIONS

GHG	Greenhouse gas emissions
CO_2	Carbon dioxide
H_2	Hydrogen
CH_4	Methane
PtX	Power-to-X
PtL	Power-to-liquids (liquid fuels)
PtG	Power-to-gas
$PtCH_4$	Power-to-methane
PtH_2	Power-to-hydrogen
RE	Renewable energies
PV	Photovoltaics
DAC	Direct Air Capture
kW	Kilowatt
TWh	Terawatt hours
TWh_{el}	Terawatt hours (electric)
GW	Gigawatt
GWh	Gigawatt hours
HV	High-voltage
AC	Alternating current
DC	Direct current
NDP	Network development plan
PJ	Petajoule
ETR	Economic Trends Research
DE	Germany
RWTH	Rheinisch-Westfälische Technische Hochschule Aachen

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