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Not to be taken for granted: climate protection and sustainability through PtX

Discussion of requirements for and first approaches to developing verification criteria for a climate-friendly and sustainable production of PtX

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1. Background

The decision of the Paris Agreement in 2015 to limit the increase in the global average temperature to well below 2 degrees Celsius, if possible to 1.5 degrees Celsius, has given the global community a framework for climate protection which makes it necessary for industrial nations such as Germany to reduce greenhouse gas emissions significantly and, by 2050 at the latest, to produce almost no more climate-impacting emissions. At the same time, it has become clear in recent years that, due to priority use as food and animal feed and the limited availability of suitable areas for biomass cultivation, biomass will only be available on a limited scale for energy and material use in the long term. For some years now, the importance of synthetic, electricity-based materials (**P**ower-**t**o-**X**) as an option for reducing greenhouse gases has therefore been increasing in the debate on how to achieve climate protection targets in Germany (e.g. BDI 2018; Oeko-Institut; Fraunhofer ISI 2015), but also at international level (e.g. IPCC 2018; EC 2018).

It is undisputed in the discussion that the use of sustainably manufactured PtX products[1] with different functions (e.g. applications without any other technical alternative to energy sources with high energy density and hydrocarbons as a raw material source, long-term storage of volatile power generation) will be necessary in the long term for the success of climate protection. However, there are different assessments concerning the quantity required. This differs depending on other developments: The lower the availability of sustainable biomass for energy and material use, the lower the reduction in energy demand due to changes in consumption and behaviour patterns, the lower the direct use of renewable electricity and the more ambitious the climate protection target is, the more sustainable PtX materials are needed.

However, the discussion about the production of PtX substances is no longer a theoretical one. The first pilot plants exist[2] and the German government is driving the scaling of the technology to demonstration plants via real laboratories (BMWi 2018). In addition, private-sector players want to put the first commercial plants into operation at the beginning of the 2020s (Holen und Bruknapp 2019). And climate protection is urgent: Germany runs the risk of failing to meet the climate protection targets it has set itself[3] and which it has bindingly agreed at EU-level in the non-ETS sectors[4] (including heat and transport). Considerable compensation payments for the greenhouse reduction achieved in other European countries and a burden on the federal budget would be the result of this failure to meet the targets (ÖI 2018). For this reason, some players consider it necessary to use PtX products in the short term as a relevant greenhouse gas reduction option by 2030 despite the high greenhouse gas reduction costs (BDI 2019). For these actors, cost reduction and a supportive framework are at the centre of attention. However, there is no consensus in the debate (Oeko-Institut 2019) as to whether this can be a suitable and, above all, technically feasible short- to medium-term climate protection option.

Sustainability criteria for the production of PtX materials are already of relevance for the development of PtX production capacities in the short term. Most studies on PtX materials focus on possible cost developments and future preferred production locations. Although they address sustainability criteria as necessary, no detailed proposals have been made concerning what form these should take. What

1 In this impulse paper we use the term 'PtX material'. Often the focus is on the use of PtX products as energy carriers, which is why the term efuels is often used. The material use as hydrogen or carbon carrier often remains unmentioned.

2 For example, Audi e-gas plant in Werlte (http://www.powertogas.info/power-to-gas/pilotprojekte-im-ueberblick/audi-e-gas-projekt/).

3 For example, BMUB (2016): Klimaschutzplan [climate protection plan] 2050

4 EU (2018): Effort Sharing Regulation

is more, no process of negotiation has yet taken place in society on this topic, although this is necessary if criteria are to be developed that can be applied for as long a period as possible and remain as constant as possible (see different positions in Oeko-Institut 2019).

From an industrial perspective, sustainability criteria provide the framework within which production capacities must operate in the future (MWV; IWO; MEW; Uniti 2018). They are necessary in order to make an investment decision for or against PtX production plants in the first place. They also have to be sustainable for as long as possible, so that plants built at an early stage will still comply with the set framework conditions at a later date. Accordingly, there is a lot of pressure being exerted by industry on politicians to adopt the framework conditions for PtX production, including the sustainability criteria, as soon as possible; if necessary, even before an EU-wide agreement is reached, which is planned for the year 2021 within the framework of the Renewable Energies Directive II.

The following core questions have still not been at the centre of the debate on PtX substances:

What are the requirements for PtX production that ensure the most positive sustainability effects possible and exclude negative effects as far as possible?

And how can these requirements be verified?

Only by answering these questions and translating them into verifiable procedures will PtX production, from our point of view, gain the legitimacy it needs to get politicians to promote it in the form of public funds and other policy instruments. Without this step, there is not only a danger of establishing PtX materials on the market with little or no sustainability impact for the climate and for local civil society at the production site. What is more, there is also a risk that PtX materials will end up having a negative image PtX in German and European civil society if they are expensive to produce but do not keep their promise of providing the benefit of a positive sustainability effect. And for the investors and manufacturers of this technology, there is a risk that unsuitable criteria will have to be adapted over time and that the framework conditions for PtX production will change again and again, thus increasing the investment risk.

This paper therefore intends to provide an impetus towards answering the questions posed above. However, the paper also aims to identify at what points along the production chain, in our view, social and ecological requirements for PtX production can already be formulated today and at which points civil society needs to negotiate. Where possible, suggestions should also be given on how verifiable methods can ensure that the requirements discussed are fulfilled. The paper does not, however, develop any defined sustainability criteria.

1.1. Guidelines for assessing the sustainability of PtX substances

Before we discuss sustainability requirements for various aspects of PtX production in this paper, we will first present guidelines for the following discussion. After all, assessing sustainability is not easy. We do not have a white paper on which only the PtX plant itself can be assessed as a separate unit in terms of sustainability impact (direct effects). Rather, PtX plants will be new demanders within existing energy and economic systems that already have legal and fiscal framework conditions in place, so that they will always also have an effect on other parts of these existing systems (indirect effects). And to make things even more complex: The energy and economic systems as well as the level of ambition for greenhouse gas reduction are dynamic, meaning that they change over time. And energy and economic systems are developed and organised differently from region to region and country to country. In addition, they interact and changes in one region can cause a strong reaction in other regions of the world (spatially and temporally differentiated as well as interacting effects).

As a result, what is associated with positive sustainability impacts at one location or time can have less positive or even negative impacts at another location or time. Accordingly, it is important to note that this system concept always takes centre stage in the analysis of sustainability impacts and the sustainability requirements derived from them.

The introduction of biofuels is a suitable example to illustrate the necessity of system analysis in the formulation of sustainability requirements. As is to be expected with PtX fuels, there is a global production and demand system for biofuels. Decisions concerning production conditions and promoting demand in Germany and the EU will thus lead to developments in other world regions and other subsystems of our economy.

Although negative direct effects from the production of biofuels have been limited from the beginning of their promotion, the sustainability impact of food- and feed-based biofuels is highly controversial due to systemic effects and is rejected by some actors as a non-sustainable energy supply option (oxfam 2012; UBA 2013). The increased demand for food and feed resulted in, among other things, the following developments: food prices rose in some regions of the world; small farmers were displaced by large corporations; and land pressure for food and feed crops was created, leading to negative indirect land-use changes (ILUC[5]) and primary rainforest deforestation (IEEP 2010; oxfam 2012; UBA 2013). For example, the recent Global Environment Facility study estimated that palm oil, soybean and cattle farming together account for 80% of global deforestation in recent history (GEF 2016), and the Food and Agriculture Organization of the United Nations (FAO) considers limiting biomass production for energy use globally as an important building block in ensuring sufficient food supplies in the coming decades (FAO 2018).

These negative systemic effects led not only to a civil society discussion about the usefulness of biofuel use, but also to considerable regulatory adjustments. The sustainability criteria have been gradually adapted: The ILUC Directive[6] initially limited the eligible share of these biofuels in the transport sector to 7% in 2015. In the Renewable Energy Directive II, the eligibility was further reduced: The amount of these fuels that can be taken into account is more or less limited to the amount produced in 2020[7]. EU states can also choose a lower eligibility level. In addition, biofuels that entail a high risk of indirect land use change will be completely excluded from inclusion in the Renewable Energy Directive II from 2030 onwards.

Due to the lack of consideration of possible indirect impacts when formulating the original sustainability criteria, the biofuels were not able to deliver their promised benefits - the reduction of greenhouse gases - to the expected standard. In addition, they had a negative impact on developments in other areas of the economic system and led to undesirable social developments in some regions of the world. For biofuel producers, too, the changing framework conditions for biofuel production were and remain problematic due to the lack of investment security (IEEP 2016; DG Ener 2017; ARUP und URS 2014).

From the example of the market launch of biofuels, we have derived a second guideline for the formulation of sustainability criteria for PtX substances. It is tempting, especially in the very early stages of a developing and marketing a technology, to make the sustainability requirements as "soft" as possible in order to reduce costs and promote the technology. However, as soon as the transition from pure technology development and demonstration phase to technology upscaling takes place and business models are developed, the framework conditions must be designed in such a way that

5 Indirect Land Use Change

6 EU 2015/1513

7 The eligible quantity is limited to the share of renewable energy in the fuel demand of road and rail transport in the respective country in 2020 + 1% point. The maximum charge is 7%.

they ensure positive sustainability effects and exclude possible negative effects. Above all, pathways must be avoided that cause a steering effect towards less sustainable manufacturing processes and applications and might generate an economic and regulatory "lock-in" in such processes. This is the only way that future plant and business concepts can develop that actually deliver the benefits promised by PtX production.

- When deriving sustainability requirements and verification procedures, not only direct effects but also indirect effects (e.g. effects on other sectors and other sustainability categories; effects on other regions and countries) resulting from integration into the energy and economic system must be taken into account.
- The sustainability requirements for PtX production change over time due to the changed GHG reduction requirements. Criteria formulated today must be compatible with the reduction requirements set for the whole period up to 2050.
- At the latest, when the transition from demonstration phase to upscaling of the technology takes place, sustainability requirements must promote potential positive sustainability effects and exclude potentially negative ones. Pathways that generate a steering effect towards less sustainable production processes and possibly a new “lock-in” in such processes must be avoided.

2. The production of PtX and the importance of the different input streams for sustainability and greenhouse gas assessment

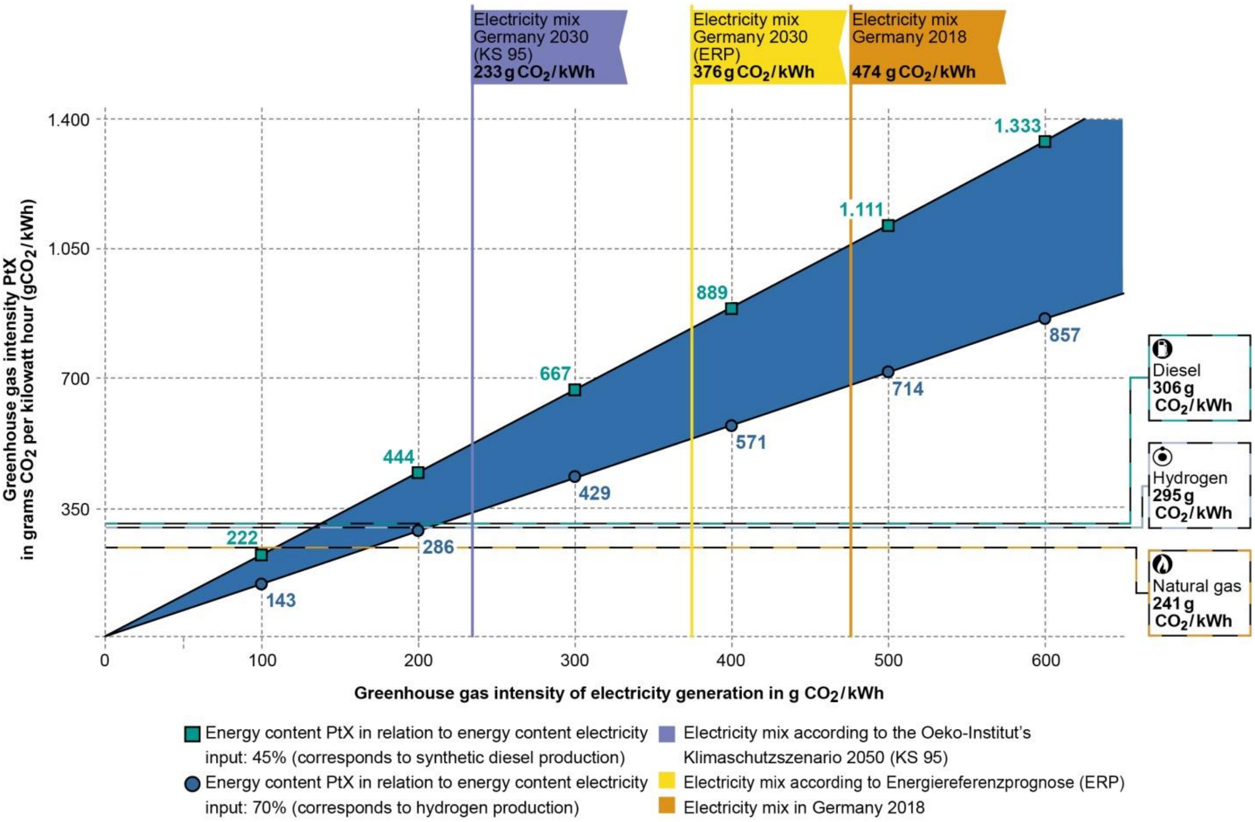
We do not want to go into the production processes of PtX materials in detail in this paper. There are already numerous studies and papers on this subject (e.g. Lappeenranta University of Technology 2017; CTH; IVL 2017). Nevertheless, a basic understanding of the process chain and cost structures is necessary and helpful for the subsequent discussion on sustainability criteria.

A central process step for all PtX products is electrolysis, in which hydrogen (H_2) and oxygen (O_2) are obtained from pure water (H_2O) by means of electricity with conversion losses. The hydrogen can be used directly in various applications; before being stored or distributed for storage and distribution, however, the hydrogen must be compressed or liquefied, which requires additional energy. Except in the industrial sector, hydrogen is a little-used raw material. Fuel cell technology and combustion engines must be further developed or adapted, and transport and distribution infrastructures must be almost completely rebuilt if hydrogen is to be used directly without further processing.

In a further process step (synthesis), however, hydrogen can also be processed into hydrocarbons such as methane, diesel and kerosene as well as plastics and chemicals. In addition to hydrogen from electrolysis, carbon in the form of carbon dioxide (CO_2) is required for this. The CO_2 can come from different sources, from which it is separated with different energy input (electricity and heat energy) and it may have to be transported to the PtX production plant. A further process step in the case of hydrocarbons is processing the end products, for example, in refineries and gas purification plants. These process steps are also associated with conversion losses and energy expenditure. Existing combustion engines and process plants can use the end products produced, unlike hydrogen. Existing transport and distribution infrastructures can also be used, which may have to be adapted and expanded depending on the production location and application.

What all production plants have in common is that electricity is the main energetic input into PtX production and considerable conversion losses occur along the process chain. The type of electricity procurement is thus the decisive factor in terms of the greenhouse gas emission and sustainability effect of the PtX materials (see Section 3.1 for requirements for electricity procurement). Figure 2-1 illustrates the significance that the greenhouse gas emissions of the electricity input have for the climate protection effect of PtX materials. In the face of the greenhouse gas emissions of the German electricity mix we see today and what is expected in the medium term, PtX materials have a worse greenhouse gas balance than their fossil alternatives; and this already without the inclusion of possible greenhouse gas effects from CO_2 usage.

Figure 2-1: CO_2 intensity of PtX substances as a function of the CO_2 intensity of the electricity input at different levels of conversion losses; other GHG effects not taken into account (e.g. indirect effects, heat consumption)



Data on CO_2-Emissions of fossil energy sources from ecoinvent 3.5, 2018 and GaBI 6.0, 2018

But, in hydrocarbons, the type of CO_2 usage is also a relevant aspect in assessing the climate protection effects. The use of electricity-based substances releases CO_2 to the same extent as fossil hydrocarbons. A reduction in greenhouse gases can therefore only occur if the CO_2 bound in the synthesis process has been removed from the atmosphere beforehand or would have been released into the atmosphere anyway (see Section 3.2). The use of unsuitable CO_2 sources alone can therefore produce the same greenhouse gas emissions as the use of fossil hydrocarbons.

Another input stream into PtX production is water. From a global perspective, water is of little importance from a climate protection point of view. For further ecological and social sustainability criteria, however, water use can have a relevant impact at the local level at the production sites, even if the quantity of water required for PtX production is comparable to that required for other industrial processes. For this reason, it would also make sense to take a look at the water availability in the vicinity of PtX production plants in any assessment of sustainability (see Section 3.3).

Renewable electricity generation and CO_2 capture from air are surface-area-intensive technologies. Indirectly, however, the land use of preferred areas for renewable electricity production can have an impact on the electricity system in the respective production region, which may bring with it social and climate-relevant consequences. Section 3.4 therefore discusses possible requirements for land use.

To some extent, the same key parameters are relevant for the production costs as are for assessing sustainability (CTH; IVL 2017; Agora Verkehrswende; Agora Energiewende 2018). Due to high conversion losses, the power procurement costs are a central parameter in PtX production. In connection with possible intermediate hydrogen storage facilities, electricity procurement also defines the possible capacity factor of a PtX plant, which is a relevant factor for production costs because of the high investment costs for plants. And, depending on the source of supply, the CO_2 procurement can have a noticeable impact on production costs. The more concentrated CO_2-inflows are and the greater the quantity, the cheaper and more economically attractive the respective CO_2 source is. The high capital costs of PtX plants result in depreciation periods of 20 years and more (MWV; FuelsEurope 2018), so that the sustainability assessment must also relate to effects over the entire depreciation period.

In the following discussion on sustainability criteria, the cost factors mentioned should therefore always be taken into account, as they partly work in the opposite direction to the sustainability requirements[8]. They will be essential for the choice of production sites and the input flows used within the sustainability framework set by policymakers. It is also obvious that a cost reduction will take place by scaling the size of production plants and that production will gradually shift to preferred locations with low electricity production costs for renewable electricity production and sufficient available land (MWV; IWO; MEW; Uniti 2018; Agora Verkehrswende; Agora Energiewende 2018; DECHEMA 2017). These factors indicate that the production of PtX products will take place only to a limited extent in Germany. The locations for PtX production preferred by Germany and the EU are still open, but they range from Norway and Iceland, via the MENA[9] region, to more distant regions and countries such as South Africa, Chile and Australia (The Weltenergierat - Deutschland e.V. 2018; IWES 2017). And for all these possible countries – as with biofuels – the sustainability criteria must be applied.

8 One example is sustainable production based on "surplus electricity". This only occurs in a few hours of a year, so that the utilization of a PtX plant, which is to be operated with "surplus electricity" as a system service, is very low. A low utilization of the PtX plant, however, leads to high production costs for the PtX materials.

9 **M**iddle **E**ast and **N**orth **A**frica

- Electricity procurement is the most relevant parameter for the climate protection effect of electricity-based substances. If electricity is not procured appropriately, PtX production can result in more emissions than if fossil alternatives were used.
- The type of CO_2 use is a relevant parameter for the climate protection effect of electricity-based substances. If the CO_2 source is inappropriate, electricity-based hydrocarbons can have equivalent GHG emissions to their fossil counterparts, thus not contributing to a GHG reduction.
- The use of water and land can have both positive and negative social impacts at the local level at the production sites. Land use can also have an indirect effect on the emission of greenhouse gases.
- Electricity and CO_2 use are relevant factors for the costs of PtX production. Low-cost production is associated at many points with production that does not contribute to a GHG reduction. Sustainable access to water and land can also be a limiting factor for the production volume and scaling of PtX production.

3. Potential sustainability effects and possible production criteria

3.1. Power purchase

Direct effects of electricity purchase

The production processes of PtX manufacturing require large amounts of electricity (see section 2). Almost all studies and stakeholders assume – to some extent implicitly – that renewable energies (RE) are mostly used in the form of solar and/or wind energy for PtX production (e.g. MWV; IWO; MEW; Uniti 2018; VDA 2017). In our view, however, a further quality criterion for renewable electricity is necessary in order to actually assess PtX production as 100% renewable: The **additional** generation of electricity from renewable energies; namely an additionality at **system level** beyond the already existing regulatory framework. This is the only way to avoid additional emissions in the electricity system to the greenhouse gas reduction trajectory specified by the regulatory framework, with the use of PtX technology actually achieving a greenhouse gas reduction at system level (Figure 3-1).

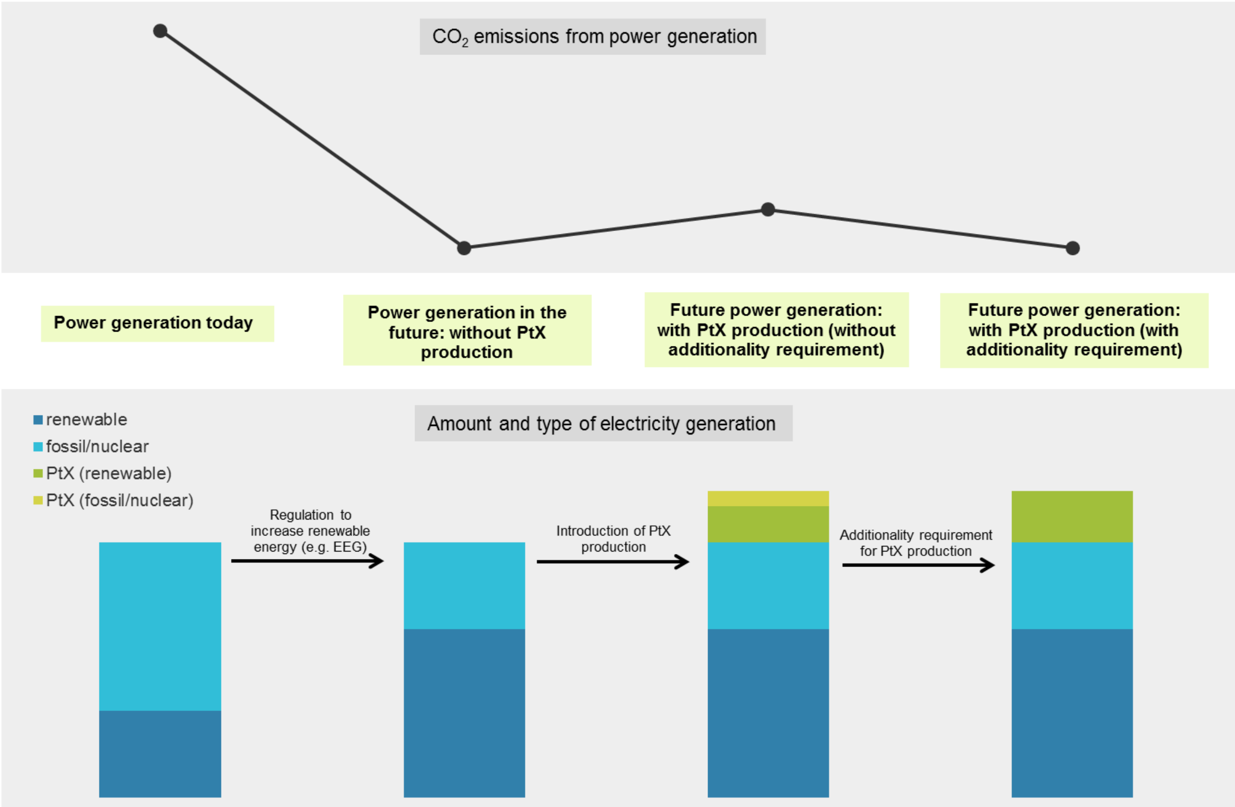
But why this additional qualitative requirement? It results from the way in which electricity production is organised in Europe and many other markets and the expansion of renewable electricity capacities is promoted. If there is an increased demand for electricity - as is the case with PtX production - electricity production for the additional demand in hours without a fully renewable electricity supply (and still available overcapacities) is based on fossil and nuclear power plants, which increases the utilisation of these power plants and greenhouse gas emissions in the electricity system (ÖI 2017c).

The necessary additionality of renewable electricity generation for PtX plants can be achieved in two ways. On the one hand, renewable electricity can be used which would otherwise remain unused due to a lack of customers or sufficient transport capacities (market or grid-related "surplus electricity"[10]), and on the other hand, additional electricity generation capacities can be built which would otherwise not be created by the existing regulations and support systems in the electricity sector.

[10] "Surplus electricity" means quantities of electricity that cannot be used due to distribution bottlenecks and lack of demand.

That is why the existing regulatory and promotional landscape must be taken into account when assessing additionality.

Figure 3-1: Effect of additional electricity demand from PtX production on the type of electricity generation and the resulting CO_2 emissions at system level with and without additionality requirement for renewable electricity (schematic diagram)



Source: own illustration

We do not assume that the EU ETS and other instruments that set the framework for the future (e.g. CO_2 pricing) will generate enough innovative power to enable the expansion of renewable electricity capacities on the necessary scale. Specific instruments will continue to promote the expansion of renewable energy plants. In Germany, for example, new renewable electricity generation capacities will be subsidised under the Renewable Energy Sources Act (EEG)[11] up to a relative volume target. From a systemic perspective, more electricity demand would therefore only be accompanied by a proportionate increase in RES generation in line with the relative target, while the remaining shares would be covered by additional fossil and nuclear generation. Only by increasing this target to fully cover the quantity of electricity required for PtX production or by not taking renewable electricity for PtX plants into account to meet the EEG target would the claim of no additional emissions at system level be met[12].

[11] Renewable Energy Sources Act (EEG): According to the Renewable Energy Sources Act, the share of renewables in gross electricity consumption should be 55% to 60% by 2035 and at least 80% by 2050. The coalition agreement of the federal government provides for an increase in the target to a 65% share of renewables by 2030.

[12] ÖI (2017b) discusses in more detail the requirements for additional electricity demand due to battery electric mobility. The same principles apply to the additional power demand from PtX products.

At system level, it can be assumed that at least a portion of the electricity used for PtX production would come from additional renewable electricity capacities if electrolysers participate financially in the expansion of renewable electricity capacities via the EEG levy. In this case, the electricity mix can be used as an approximation for the greenhouse gas assessment at systemic level[13]. Figure 2-1 clearly shows, however, that electricity-based substances, for example in the case of production in Germany for this case, do not lead to a reduction in greenhouse gases compared with fossil alternatives in the medium term until after 2030 and that even additional emissions are generated.

The geographical location and operating mode of the electrolysers are also important from a system point of view for the release of greenhouse gases when the PtX plants draw electricity from the grid. As a new electricity consumer, there is a risk of increasing the load on the electricity grids as an additional consumer behind an electricity grid bottleneck. In order to enable greenhouse-gas-reducing operation of the electricity-based plants in the first place, it is therefore necessary to connect to the grid before grid bottlenecks occur and to manage operations in line with the operating situation of the grid.

In contrast to the system approach, the individual perspective of the operators of PtX plants is relevant for a possible crediting of electricity-based materials to promotion instruments (e.g. renewable energy share quotas, investment subsidies). There are no verification schemes yet in place to promote the additionality of renewable electricity procurement at this level. An adaptation of the existing system of guarantees of origin for renewable electricity has already been proposed by the Öko-Institut (ÖI 2017c; 2017a). The system of certificates of origin could be adapted using quality criteria such as, for example, the requirement for recently built renewable power generation plants that are financed without public funding such as the EEG. The use of "surplus electricity" and grid-compatible operation could be certified by grid operators if necessary, whereby a concept for suitable, independently verifiable criteria for certification would still have to be defined. The basic prerequisites for additionality at system level, however, remain the above-mentioned criteria and changed political framework conditions.

In our opinion, PtX production plants cannot be described as emission-free and completely renewable without taking the above-mentioned requirements into account. For such plants, the average CO_2 emissions or the average renewable energy share of the respective electricity system can at best be the basis for calculating the greenhouse gas emissions of a PtX substance in hours without purchasing "excess electricity" (see Figure 2-1). Without participating in the costs of the already planned expansion of renewables (e.g. exemption from the EEG levy in Germany), the PtX plant would even have to take into account the marginal greenhouse gas emissions due to the additional electricity demand.

When describing possible criteria in the previous sections, we often referred to the German policy framework, as it is the one we are most familiar with. However, the above principles for greenhouse gas assessment apply to all electricity systems, regardless of production location. This poses an additional problem for imports of electricity-based substances from regions outside Europe. Methodologically equivalent monitoring procedures for the GHG intensity of electricity generation do not exist in most countries outside the EU. Suitable methods for the GHG assessment of electricity procurement in non-European countries must therefore be developed.

13 In support systems with absolute renewable energy expansion targets, the need to adjust the renewable energy expansion target or not to take renewable energy plants into account for electrolysers is even more relevant, as the same amount of renewable electricity is available despite the additional demand and high conversion losses of the PtX plants. The additional demand for electricity would thus largely be provided by thermal power plants and the greenhouse gas reduction of the electricity system in general would slow down (see discussion of possible indirect effects of electricity procurement).

For many countries, the IEA annually publishes information on the average CO_2 intensity of electricity generation (International Energy Agency 2019); as described above, however, the effect of the additional electricity demand at system level due to PtX production is decisive for the climate protection effect, which often cannot be represented by average emission factors. To the best of our knowledge, there are no methods for evaluating and demonstrating the additionality requirements for renewable electricity procurement from PtX production at international level. The existing methods for GHG assessments of the Clean Development Mechanism (CDM) and other international climate protection projects[14] could, with a further development of the standards, form the basis for the verification of additional renewable electricity generation in PtX plants outside the EU.

Indirect effects of electricity purchase

International trade in electricity-based substances raises the question of its impact on the exporting country and its energy and economic system. Possible external investments in innovative technologies can generate positive impulses in the exporting country, but negative effects cannot be ruled out either. It can be assumed here that these indirect effects will become stronger due to the additional demand for electricity, the larger the production volume and the larger the share of the additional demand for electricity in the electricity system.

The additional impetus provided by an expansion in renewable energies and process plants can improve value creation and living standards locally; for the electricity system in particular, there is also an opportunity to develop personnel (e.g. skilled workers), organisational (e.g. preparatory planning processes) and technical (e.g. special cranes) structures that can lead to a faster and more cost-effective development of renewable electricity generation capacities independent of PtX materials. Exploiting this potential for the regional and local added value provided by PtX production plays a central role for the success of PtX technology, according to many actors. Only then will the decision-makers and the population in the exporting country accept the necessary technical facilities bring built and the resources available in the country being used (Oeko-Institut 2019).

However, the additional demand for renewable electricity, which is not available to supply electricity to local consumers, can also lead to negative developments. In principle, the same renewable power generation plants can save more greenhouse gas emissions in the electricity sector through the substitution of fossil fuels than through PtX substances. The cost and resource efficiency (e.g. favourable locations, critical raw materials) of PtX substances is lower than that of direct electricity use. This means that less climate protection can be achieved with the same financing and resource costs. In the worst-case scenario and faced with limited resources for plant construction (e.g. lack of structures for construction, lack of favourable locations and areas for use), building PtX plants can reduce the greenhouse gas reduction compared to efficient operation in the electricity sector. The reduction of emissions in the electricity sector of the country of production should therefore have higher priority than the rapid expansion of PtX production for export.

A further effect results from the lower energy efficiency of PtX production in comparison to direct electricity use. The electricity production costs as well as the high number of full load hours thus have a greater impact on the costs of electricity-based materials and the end customer prices than is the case with direct electricity use. It is therefore likely that renewable electricity from preferred RE sites with the lowest production costs will be used primarily for PtX generation plants and that these

[14] Tools for calculating electricity emission factors in the context of CDM projects (https://cdm.unfccc.int/methodologies/PAmethodologies/tools/am-tool-07-v7.0.pdf/history_view); Standard (The Greenhouse Gas Protocol) of the World Resource Institute for the calculation of GHG reductions through grid-integrated electricity projects (https://ghgprotocol.org/sites/default/files/standards_supporting/Guidelines%20for%20Grid-Connected%20Electricity%20Projects.pdf)

preferential RE areas will no longer be available for the exporting country's own electricity supply. Depending on the scarcity of preferred RE locations, the additional electricity requirement for the export of PtX materials increases the electricity costs for the consumers and the system costs of decarbonising the energy system in the country of production. In countries already struggling with high electricity supply costs and low access to electricity, PtX production for export can cause social problems and possibly reduce access to electricity.[15]

The extent to which the scarcity of RE preferential locations affects electricity costs and access to electricity in the exporting country depends strongly on the respective regional context and the existing electricity system. There is a lack to date of regional-specific and global scenario calculations and studies, so it is difficult to make quantitative statements. Qualitatively, however, we can state this: The lower the share of fossil electricity generation in the electricity system, the more preferential areas for renewable energies are available and the cheaper and more widespread access to electricity is, the more suitable the production location will be for the manufacture of PtX products.

We can derive various sustainability guidelines from the possible indirect effects of the increased electricity demand in the producing countries listed above. The potential to have a positive effect on the value creation and local living standards must be exploited. At the same time, PtX production must not slow down the decarbonisation of the regional electricity and economic system and effects that might lead to higher energy-supply costs in the exporting country must be prevented, especially in countries and regions where access to electricity and energy is already expensive compared to purchasing power and where there is no nationwide supply of electricity anyway.

Translating these requirements into verifiable sustainability criteria takes time, research and social negotiation processes. But it is necessary. Instruments for the promotion of local value creation[16] (e.g. through support for company start-ups and suitable job training support[17]) and local acceptance[18] should apply to all PtX plants. Best practice implementation of known requirements for infrastructure projects (e.g. Equator Principles[19]) and the independently evaluated implementation of measures should be the minimum requirement for PtX plants supported by policy instruments (e.g. minimum quotas, investment grants), without which no support should made available.

In order to avoid the potentially negative effects on the respective energy system and the resulting consequences, it would be possible - as in the case of biofuels - to completely or partially exclude sites with a very high risk of indirect effects from promotion measures and at least limit those with a lower risk in the promotion until it can be demonstrated with positive criteria that the negative effects can be largely excluded. To this end, risk assessment methods would first have to be developed. They should include, among other things, an assessment of the existing preferential areas for renewable energies required for the own energy system, the current share of electricity generation from nuclear and fossil energy sources as well as renewable energy generation, possible effects on the costs of energy supply, access to electricity, etc. Simplified initial criteria that should be further developed, concretised and supplemented are:

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15 The percentage of households with the possibility of purchasing electricity is generally used for evaluation purposes. We do not know of any indicator that relates the cost of electricity purchases to the disposable income of households.

16 DIE (2013) mentions, for example, local content requirements, financial incentives for the use of local value creation, as wel as local R&D promotion as possible instruments for promoting local value creation.

17 see Altenburg; Assmann (2017).

18 Terrapon-Pfaff et al. (2019) refer to the importance of expectation and information management as well as the fair distribution of local benefits for the acceptance of industrial (renewable) infrastructure projects.

19 https://equator-principles.com/

- a quantitative limitation of PtX production in regions and countries with low shares of renewable electricity generation/high CO_2 intensity in the electricity generation, if no reduction of CO_2 intensity of the remaining electricity supply of the exporting country/region is discernible,
- a quantitative limit on the use for the PtX production of preferential RE areas with high generation and utilisation potential for direct electricity use (enabling high numbers of full load hours in the vicinity of residential areas and existing electricity consumers),
- limiting the share of preferential RE areas used for PtX exports in the total potential preferential RE areas of a region or country, and
- plant-specific verification methods for the effect on electricity access and the electricity costs for local and regional consumers.

The above criteria are to be understood as initial ideas that are to be further discussed and checked for their effectiveness and practicability. A specific recommendation for action are not to be derived from this discussion. It is becoming apparent, however, that specific expert opinions will have to be drawn up for countries that are potential production locations for electricity-based substances in order to meet sustainability requirements. In keeping with this paper, the aforementioned criteria should serve as an impulse for discussion about sustainably produced PtX substances and the production criteria required and potentially implementable at short notice.

- PtX production releases no additional GHG emissions only if the energy used is fully renewable and meets criteria for additional renewable power supply at system level. To this end, the political framework conditions for the promotion of renewable electricity generation must be adapted (e.g. increase in renewable energy expansion targets, no inclusion in existing renewable energy expansion targets). The plants must also not reinforce possible grid bottlenecks.
- Viewing the matter at individual plant level is relevant for consideration in promotion instruments. So far, there are no verification procedures that secure promotion of the additional power supply to the PtX plants. It is possible to further develop the existing system of renewable energy guarantees of origin for PtX production in the EU.
- If necessary, approaches from the GHG assessment in international climate policy could be further developed to prove the additionality of renewable power generation for PtX production outside the EU.
- PtX plants, as large infrastructure projects, can have a positive impact on local value creation, local living standards and structures for the development of renewable electricity generation. In the case of PtX plants supported by policy measures, best practice measures and independent evaluation of these measures should be mandatory in order to avoid negative impacts and to ensure that the impacts at local level are as positive as possible.
- The additional demand for electricity from PtX production can lead to increased emissions in the electricity system and higher electricity costs for consumers in the producing countries due to the high conversion losses if the potential for setting up renewable electricity generation plants (e.g. lack of available space, lack of structures for setting up the plants) is limited. Simplified indicators for risk assessment of these effects could initially be used to limit PtX production in regions/countries with a high risk for these effects until more suitable criteria are developed, if necessary.

3.2. CO_2 purchase

Direct effects due to CO_2 purchase

The process of hydrocarbon synthesis from hydrogen requires a carbon source, e.g. carbon dioxide (CO_2), as resource input. However, pure CO_2 streams are not naturally available, and must first be separated from potential sources with energy input and, if necessary, processed and transported. The use of biogenic and atmospheric carbon sources can allow a CO_2 loop process without causing an additional greenhouse gas effect. In addition, CO_2 that is concentrated in industrial and combustion processes mostly comes from fossil sources. CO_2 from geological sources can also be used for PtX production. For the latter two CO_2 sources, however, a greenhouse gas-reducing effect can only be achieved under certain conditions. Furthermore, the energy used to make the CO_2 available (e.g. separation, preparation for synthesis, transport) must be subject to the principles for sustainability and greenhouse gas assessment set out in Section 3.1 above in order to be considered a sustainable CO_2 source with low greenhouse gas emissions.[20]

CO_2 from the air is available in large quantities and is therefore regarded by many actors as the central carbon source for PtX applications in the long term (Agora Verkehrswende; Agora Energiewende 2018; MWV; IWO; MEW; Uniti 2018). Other sustainability principles are not to be applied except with regard to possible impacts on land use (see Section 3.4) and the energy procurement criteria from the section above. However, the disadvantage of this carbon source is the current state of technology (now in transition from the pilot to the demonstrator stage) and its economic disadvantages compared to the other possible sources of supply resulting from the low concentration of CO_2 in the air. The technology will therefore only be available in practice in the medium term and as a comparatively expensive option.

By sequestering the carbon in biomass, an "indirect" renewable carbon cycle can be created by using biogenic carbon sources. Low capture costs are offset by the limitation of the available amount of sustainable carbon (per site, but also in absolute terms) as well as the low availability of biomass at some preferred RE sites. From the point of view of sustainability, the same use criteria apply to this CO_2 source as in the existing discussion on biomass use.

In the case of geological CO_2, the sustainability of direct effects is not assessed from a possible CO_2 cycle. As a basis for assessing whether a greenhouse gas reduction effect will occur or not, it must be considered to what extent CO_2 would have been released into the atmosphere even without industrial use. Due to the high carbon concentration, geothermal processes in which CO_2 dissolved in water is brought to the surface are particularly suitable as an economically attractive, potential source of CO_2. As soon as the geothermal reservoir has been activated and thus more CO_2 reaches the surface than without the industrial process, the prerequisite for CO_2-neutral operation is no longer given. In this case, the CO_2 released must be regarded as non-GHG neutral (VDA 2017).[21]

The capture of CO_2 from industrial point sources is attractive from an economic point of view, above all because of the high availability of CO_2 at a location and the low energy requirement for CO_2 capture. It is obvious that we cannot speak of a renewable CO_2 source as long as fossil resources are used in industrial processes. In addition, CO_2 separation from industrial processes has an effect on the production processes themselves and considerably reduces the efficiency of the processes.

[20] Section 3.1 deals only with electricity as an energy resource. Similar effects and the sustainability principles derived from them also apply to energy consumption in the form of heat.

[21] The extent to which the carbon used in the existing power-to-methanol plant in Grindavik (Iceland) meets this criterion is unknown to us. However, the methanol produced is recognised as a renewable fuel of non-biological origin under the Renewable Energy Directive.

Reiter und Lindorfer (2015) indicate for CO_2 capture from various power plant and industrial processes that, for 100kg of separated CO_2, between about 15kg (CO_2 capture in the refinery) and about 50kg (CO_2 capture in the cement plant) additional CO_2 equivalents are released into the environment as emissions. Proponents of the use of these carbon sources argue, however, that unavoidable CO_2 emissions (e.g. CO_2 emissions from lime burning in cement production) occur in some industrial processes and that CO_2 emissions will continue to occur for several decades despite the industry's climate protection efforts.

This argumentation in favour of using CO_2 from fossil and geological sources shows the importance of the projected emission development of these sources, which is necessary for climate protection, in assessing the sustainability PtX substances. From our point of view, the development of CO_2 emissions necessary for climate protection purposes as well as the envisaged further development of the industrial processes must be the point of reference for assessing sustainability. The use of CO_2 as a resource for PtX production must not slow down this reduction and must not increase CO_2 emissions by more than the reference required for climate protection.[22] Any increase – such as that which automatically occurs due to the poorer efficiency of industrial processes when CO_2 capture is used, for example – that exceeds the underlying reference development is therefore to be evaluated as additional greenhouse gas emissions and must be taken into account in the calculation of the GHG emissions of PtX substances. For example, PtX products can have the same climate impact as comparable fossil fuels simply because of the type of CO_2 they contain.

But what does this mean in concrete terms for the greenhouse gas assessment? Over time, industry needs and expects more efficient and new processes to protect the climate and reduce emissions (ISI 2013). For geological processes, a closed cycle for CO_2 could gradually become the standard for climate protection reasons (VDA 2017). And for the short-term binding of CO_2 from these sources, a competitive situation will arise in the long term in relation to concepts that bind CO_2 in recyclable products (e.g. plastics in long-term applications) and, if necessary, can cause negative emissions.[23] The use of CO_2 in PtX materials can counteract all these necessary climate protection developments if they bind carbon only in the short term.

Some of these necessary developments (e.g. long-term binding of CO_2 in recyclable products) appear to be far away in time and not relevant for PtX plants to be built in the short and medium term over the next 10 years. From our point of view this is not the case. With a depreciation period and an operating life of 20 years and more, these plants are in operation at a point in time at which we, as a society, have to bind CO_2 emissions in products over the long term in order to comply with the Paris Agreement and, if necessary, achieve negative emissions. What we need at a much earlier point in time is a reduction in greenhouse gas in industry through increased efficiency and changed processes; changes in industry must therefore take place promptly. The benchmark for the climate protection effect of PtX plants cannot therefore be the current situation and the current level of emissions; rather, the development of industrial point sources over the entire operating period of the PtX plant, which is necessary for climate protection, must be regarded as the assessment reference.

In the discussion on the sustainability of PtX substances, some actors use the EU Emissions Trading Scheme (EU ETS) as a basis for ensuring that the use of greenhouse gas emissions from plants

22 This requirement applies to all PtX products that do not sequester carbon in the long term and therefore cannot be counted as carbon storesPtX.

23 Many of the climate protection scenarios that comply with the Paris Accord point to the need for negative emissions by 2050. The binding of CO_2 in biomass and CO_2 capture from air are the basic prerequisites for achieving long-term carbon storage through advanced processes. Negative emissions are achieved if the resource input used for the entire storage process chain causes less CO_2 emissions than are bound in the CO_2 storage.

subject to emissions trading (e.g. industrial processes) is unproblematic from a sustainability perspective due to the "cap" on emissions (see discussion of stakeholder positions in ÖI 2019). We have our doubts about this: if CO_2 emissions are reused in plants that are not subject to the EU ETS (e.g. PtX production processes), they are allocated to the original plant[24]. The CO_2 reduction requirements are therefore not reduced by the further use of CO_2 and the greenhouse gas reduction path is not initially slowed down, even if the CO_2 is not bound in the long term. However, it becomes problematic if a "market" for CO_2 as a raw material develops and concentrated quantities of CO_2 receive an economic value. In this case, the quantity of emission certificates to be deposited will not be reduced, but the release of CO_2 then has a “selling price”, meaning that the effectiveness of emissions trading could potentially change[25]. This could slow down the reduction in CO_2 emissions from industrial point sources deemed to be necessary as well as the transformation of the sector; the GHG emission reduction under the "cap" would then have to be achieved by other regulated areas.

The long operating time of PtX installations also poses a further problem: it is likely that changes will take place to the emissions trading system over the operating period of a PtX plant, which means that the current design of emissions trading cannot be used as a basis for assessing the interaction of emissions trading with a PtX plant over the entire operating phase of the plant. And, of course, plants outside the EU are not subject to the requirements of the EU ETS either. All in all, it becomes clear that, from today's point of view, no guarantee can be given that PtX production will not slow down the development of CO_2 emissions in the industrial sector, something that is necessary for climate protection, and may potentially lead to additional CO_2 emissions.

As with sustainability requirements for electricity procurement, we cannot at this point present a developed set of realisable criteria and verification procedures for the sustainable use of CO_2 in PtX synthesis processes. Even coming up with a definition of what a reference development for CO_2 necessary from a climate protection point of view is appears to be very difficult. The variant with the lowest risk from a sustainability and climate protection perspective is therefore to exclude CO_2 sources with a high risk of additional CO_2 release (e.g. CO_2 from industrial processes based on fossil fuels) for PtX production (Agora Verkehrswende; Agora Energiewende 2018; Öko-Institut 2017a; WWF Germany 2018)[26].

Where appropriate, criteria can be developed for access to support instruments or the operation of PtX plants that allow the use of fossil emissions in PtX products at least for a transitional period and at the same time ensure that PtX production does not give rise to any or few additional greenhouse gas emissions. Approaches could be,

- that when CO_2 emissions from fossil sources are used for the synthesis process, it is stipulated that the proportion of fossil CO_2 must be reduced during the operating phase of the PtX plant,

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24 Article 48 of the Monitoring Directive (EU) 601/2012 with the exception of emissions that are stored in the long term (Article 49).

25 A very simplified thought experiment can help to clarify this: Let us assume the costs of 40 EUR / t CO_2 for CO_2 capture from a cement plant and 100 EUR / t CO_2 for CO_2 capture from the air as an optimistic assumption (derived from ICCT (2018)). In this case it is more favourable for a PtX plant operator to obtain the CO_2 emissions from the cement plant and to pay the cement plant operator 50 EUR / t CO_2 as the price for the "delivery" of the CO_2 (40 EUR / t CO_2 + 50 EUR / t CO_2 = 90 EUR / t CO_2 < 100 EUR / t CO_2) as CO_2 from the air in addition to the technology costs of CO_2 separation.

26 See non-recognition of high-risk biofuels for indirect land-use changes in the Renewable Energy Directive II.

- that when calculating the greenhouse gas emissions of a PtX plant, the CO_2 emissions from fossil sources are initially given less weighting, but this increases over the operating phase of the plant up to full weighting,
- that, regardless of the specific PtX plant, the weighting of CO_2 emissions from fossil sources increases from a low weighting over time to a full weighting,
- that the use of CO_2 from fossil sources is only permitted from very efficient technological processes.

The approaches listed here are by no means to be understood as final recommendations for action. As in the previous chapter, they should be regarded as food for thought in considerations as to whether it is possible, when ensuring reductions in greenhouse gas effects, to make use of economically favourable carbon sources for a transitional phase. It is not certain whether this will allow a set of criteria for the sustainable use of fossil CO_2 emissions in PtX substances to be developed.

Indirect effects of carbon purchase

The amount of cheap and sustainable CO_2 as a raw material for industrial processes will be limited. In principle, this may have similar potential indirect effects as electricity procurement. The difference to electricity procurement, however, is that CO_2 is not a relevant resource used in industry today. It is therefore more difficult to assess the impact of CO_2 use on the overall system of our economy than it is for the use of electricity. These effects also depend strongly on the amount of CO_2 required for PtX production in the long term and on what other applications will make use of it. However, it can also be said here that the stronger the demand for carbon-containing PtX products in the future, the stronger the indirect effects will be through the use of the scarce commodity "sustainable and economically favourable CO_2".

CO_2 will become a resource for industrial processes that will not only be in demand for use as an energy source. There will also be demand for the use of materials in basic and specialty chemical products (e.g. plastics, solvents, pharmaceuticals) for which only partial alternatives exist or for which CO_2-based processes represent a possible path that is neutral in terms of greenhouse gases.[27] Material use is generally preferable due to the possibility of more efficient cascade use of carbon. If there is strong competition for use, it can therefore be expected that, similar to biomass use, there will be competition for CO_2 as a resource and, if there is a high demand for carbon-containing PtX products, there will have to be increased recourse to expensive and space-intensive CO_2 capture from the air. Thus, for CO_2 applications for which there are no alternatives, an inappropriate allocation of CO_2 would result in unnecessarily high costs and possibly quantitative bottlenecks for CO_2 emissions. This indirect effect may also have an impact on the competitive situation with regard to the potentially necessary long-term storage of CO_2 in terms of generating negative emissions, which was already addressed in the previous section.

At this point we do not formulate any further possible sustainability criteria. However, it has once again clearly been shown that sustainable, low-cost carbon – in a similar way to renewable electricity - will be a scarce commodity and that reducing demand must therefore be an essential component in any climate protection strategy. A priority allocation of CO_2 to processes with a higher efficiency potential and to processes with a low potential for alternative material input flows would therefore appear to make sense.

[27] One example is the production of ethylene oxide, which is now a supplier for industrial CO_2 use. Conversion to a CO_2-based electrochemical production path is a highly researched greenhouse-gas-neutral production option for ethylene oxide (see http://www.co2exide.eu/).

- The use of sustainable CO_2 from biomass and air are the only renewable sources that do not cause greenhouse gas emissions if the necessary sustainability rules for biomass use and energy procurement are complied with. CO_2 from geological and fossil sources (e.g. industrial point sources) does not lead to additional emissions only if the greenhouse gas reduction trajectory required for the Paris Convention is not slowed down by the use of CO_2 in PtX substances.
- CO_2 capture from the air is in the demonstrator and development phase. A technology-specific promotion for the further development and scaling of the technology appears to be expedient.
- The currently valid framework conditions do not ensure that CO_2 use from fossil and geological sources does not lead to additional emissions compared to the GHG reduction trajectory required for climate protection. PtX substances based on these CO_2 sources can therefore have the same climate protection effect through CO_2 use alone as their fossil counterparts. As long as no suitable criteria exist for avoiding CO_2 emissions, PtX production with CO_2 from these sources is associated with a high risk of CO_2 emissions and a slowed transformation of the industrial sector. The exclusion or limitation of these CO_2 sources for PtX production would prevent this risk. If necessary, suitable criteria for the use of these CO_2 sources can be developed for a temporary and limited transitional phase.
- Sustainable and cheap CO_2 will be a scarce commodity. A priority allocation of the available CO_2 in PtX applications with a high efficiency potential or in applications with few alternative technology options to greenhouse-gas-neutral hydrocarbons would seem to be sensible in order to avoid higher costs and possibly availability limitations of climate-friendly options in these applications.

3.3. Water supply

Electrolysis requires water as a material input for the production of hydrogen. UBA (2016) derives the water requirement for electricity-based kerosene production from the stoichiometry of the processes and indicates the required quantity of water to be around 1.4 litres of water per litre of fuel. Further water requirements may also be required for cleaning solar cells or solar mirrors if they are used to generate electricity. Cerulogy (2017) assumes that the water requirement for cleaning the solar systems will be considerably higher (~70 litres per litre PtX fuel) than the hydrogen production in the electrolysis itself.

Currently discussed best locations for PtX production often have high solar radiation and are among the driest regions in the world. From a sustainability point of view, it is undisputed that PtX production must not adversely affect the local drinking water supply (availability and costs) for agriculture and households. Ideally, where water is scarce, even the local population should benefit from water supply technologies (e.g. building new desalination capacity).

Indicators that analyse water availability at the national level (e.g. Falkenmark indicator or Water stress index, IWMI classification[28]) evaluate the best locations for PtX production as regions with water shortages (e.g. South Africa, Australia, the MENA Region, the south-west region of the USA, China). In some regions with water shortages, a further increase in the population and a change in eating habits towards more meat and dairy products are also to be expected, so that the regional demand for water to supply the population in these regions is highly likely to increase (PwC 2015).

[28] International Water Management Institute

Overall, we can therefore assume that some of the preferred regions for PtX production are already suffering from water shortages and that the problem of water availability will increase over time.

Cerulogy (2017) points out that the quantity of fresh water required for PtX production is of a similar order of magnitude to that required for other industrial processes and should therefore be assessed similarly. Compared to agricultural demand, the potential water abstraction for PtX production is low and is unlikely to significantly change the water abstraction of these countries and regions at the national level. However, it is questionable how justified the use of fresh water for PtX production is if PtX products are mainly exported and the small amount of water available is therefore not used in the country where PtX substances are produced.

In addition, the possible development of PtX production over a short period of time, especially around new plant constructions, can cause changes in water availability at local level, both in a positive sense (e.g. through co-benefits in the water treatment of the PtX plant) and in a negative sense (e.g. decline in water availability or rising water prices). Using the example of a solar thermal solar power plant in Morocco Terrapon-Pfaff et al. (2019) show that negative effects on water availability can be expected at the local level during plant construction and operation if no appropriate countermeasures are taken. According to Terrapon-Pfaff et al. (2019), infrastructure measures can potentially intensify existing sustainability challenges that do not relate solely to water abstraction.

New desalination plants are a possible countermeasure to avoid negative effects on local water availability and, if necessary, to generate positive sustainability development. The dominant technology for treating fresh water today is the industrial reverse osmosis of salt water (Jones et al. 2019). From the point of view of the climate protection effect, it is obvious that the energy used for seawater desalination - even if it is a relatively small energy input - must meet the requirements set out in Section 3.1.

Local environmental problems can arise as a result of desalination, above all through the release of brine enriched with salt and partly mixed with chemicals into water bodies. They are mostly limited to the close vicinity of the backflow into the respective water body (Miller et al. 2015) and affect benthic organisms (e.g. mussels, worms, algae), which live on the seabed and also have an effect on fish stocks via the food chain. However, long-term studies on environmental impacts do not exist (Roberts et al. 2010). A key avoidance measure for these effects is the choice of brine backflow sites: marine areas with high vulnerability should be excluded as sites for brine backflow (Roberts et al. 2010). Another way of minimising the effects of the recycled brine is to dilute it with feed water, although this involves additional costs (Roberts et al. 2010; Jones et al. 2019).

From our point of view, it therefore makes sense to carry out a sustainability assessment on the basis of local indicators with regard to the impact on fresh water, which, in addition to the effect on water availability, also take into account changed costs and possibilities of adaptation by the population[29]. If desalination plants for fresh-water production are part of PtX production, the sustainability assessment should also include their ecological impacts. Such an assessment and the sustainability measures derived from it as well as their independent evaluation should be mandatory for plants supported by policy measures. But also from point of view of companies, the implementation of effective sustainability measures seems to be expedient in order to avoid the companies from gaining a negative image among the public, as well as of the technology itself[30].

[29] The "Water Poverty Index" seems to be a suitable indicator for a detailed assessment of local effects Sullivan et al. (2003).

[30] PwC (2015) mentions, among other things, the risk of negative public perception as entrepreneurial risk when entrepreneurial activities collide with local water supply needs. Some stakeholders in Öko-Institut (2019) made similar comments, referring to the tank vs. food discussion on biofuels.

The development of PtX production capacities can lead to negative (e.g. rising water costs, lack of water availability) but also to positive (e.g. increased water availability through seawater desalination plants) effects in terms of water availability in regions with water shortages at local level. In desalination plants, local ecological effects can also occur as a result of the return of brine enriched with salt and chemicals. For plants supported by policy measures, the implementation of sustainability measures and their independent evaluation should be mandatory.

3.4. Land use

PtX production itself, like similar industrial process plants, takes up little space. Extensive areas, on the other hand, are used for renewable power generation, which electrolysis and the other process steps require as energy input. Another area-intensive technology is CO_2 capture from the air, which raises the question of sustainable land use and utilisation for PtX technology, and some stakeholders see the insufficiently available area (or lack of acceptance) alongside the higher costs as a factor that greatly limits the expansion of the technology in densely populated countries such as Germany (Öko-Institut 2019). However, land use is low compared to the use of CO_2 on the basis of cultivated biomass (UBA 2016).

The quality of land requirements is also different from that of biomass use. While the focus in biomass use is on areas with nutrient-rich soil under preferential climatic conditions, solar irradiation or constant strong winds are of central importance for PtX production in order to produce renewable electricity as cheaply as possible. In contrast to biomass use, this means that there is competition for land compared to other uses of renewable electricity (see discussion in Section 3.1). This is another reason why PtX products are often compared with applications that directly use electricity with a much lower area intensity (e.g. direct use of electricity in battery electric vehicles and heat pumps) and do not fare well in this comparison in terms of area requirements due to conversion losses.

Despite the changed focus, PtX production from a sustainability point of view must impose minimum requirements with regard to biodiversity and carbon storage on the areas used[31]. It should be noted here that even areas with a rather unproblematic effect, such as arid marginal yield locations, can certainly be areas with a high level of biodiversity that can be classified as worthy of protection. In the ideal case, more demanding criteria are applied with regard to carbon capture and biodiversity protection, including social aspects such as local uses (e.g. HCV, HCSA, KBA[32]).

So far, the focus of the land debate has not been on the competition situation with other possible uses of the preferred locations for renewable energy. To our knowledge, therefore, there are no criteria for assessing this competitive situation and we believe that they should be developed. As already indicated in Section 3.1, approaches could be the renewable power generation potential (e.g. assessment of possible full load hours for various power generation technologies, the availability and the quantity of renewable energy best sites already used in the respective energy system, the cultural significance of areas) and the potential use of electricity (e.g. the distance to settlement areas, the possible integration into the electricity system). Such quality assessments for areas are the prerequisite for the development of verifiable sustainability assessment procedures, which are mentioned in Section 3.1 (RES-E generation capacities) and 3.2 (CO_2 capture from the air).

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31 Requirements for bioenergy are listed in the Renewable Energies Directive II (EU 2018/2001) and in ISO Standard 13065 ("sustainability criteria for bioenergy").

32 High Conservation Value (https://hcvnetwork.org/)); High Carbon Stock Approach (http://highcarbonstock.org/); Key Biodiversity Areas (http://www.keybiodiversityareas.org/home)

Already existing criteria regarding the social acceptance of land use are difficult to define. In Germany, for example, in the expansion of renewable electricity generation capacities, attempts are being made to create acceptance for additional plants by means of participation procedures and distance regulations from settlement areas. Participation procedures for the local population and compliance with distance regulations should be the minimum standard for renewable energy expansion as a result of PtX production (see also introduction in Terrapon-Pfaff et al. 2019). The extent to which the population in potential countries producing PtX products accepts the use of entire regions, as shown in some studies with technical-economic potential assessments, must be just as much a part of sustainability certification as the previously required impact analyses on the availability of electricity and water and their costs (see Sections 3.1, 3.2 and 3.3).

In addition, such analyses are necessary in order to move from the techno-economic production potentials of PtX substances presented in many studies today to the evaluation of realistic, sustainable quantity potentials. Today, there is no reliable production potential for this, so that the possible significance of PtX technologies for climate protection in Germany and at the global level is not clear from the present state of knowledge.

- To evaluate land use potential for PtX production, criteria must be developed for the evaluation with regard to the potentials for generating renewable electricity as well as for the use potential of the electricity. Such assessment criteria are a prerequisite for the development of verification procedures regarding electricity and CO2 carbon purchases (see Sections 3.1 and 3.2).
- The areas used for all plants along the value chain must comply with the applicable standards for the protection of biodiversity and carbon storage in soils and biomass.
- Procedures for the participation of the local population and compliance with possible distance regulations are the minimum standards for the construction of PtX plants. In the long term, further research is necessary to assess the maximum land use and the resulting socially accepted PtX expansion per region.

4. Conclusions for the promotion of the development of PtX production capacity

PtX materials are expensive to produce; today and in the long term (Agora Verkehrswende; Agora Energiewende 2018; MWV; IWO; MEW; Uniti 2018). The reason for this is the high investment costs in the necessary power generation and process equipment as well as the conversion losses of the electricity in the various process steps (electrolysis and, if necessary, synthesis processes), which make the indirect use of emission-free electricity in non-electrical applications possible. In addition, an economically optimised operation is normally not compatible with the sustainability requirements for PtX production (see Section 2). Electricity-based materials therefore require a supportive framework if they are to enter the market. In addition to direct funding in research contexts and via real laboratories, a possible existing funding instrument is the Renewable Energies Directive II, which is about to be implemented nationally in the EU member states. Some actors are also introducing direct support measures such as tendering procedures and acceptance guarantees into the debate on the commissioning of first commercial PtX plants (Oeko-Institut 2019). In our view, it is therefore necessary to establish these sustainability principles at an early stage within the framework of support measures for PtX technology.

In the following conclusions on the promotion of PtX plant capacities, we would like to refer again in part to the market launch of biofuels. In our opinion, research institutes, regulators, but also potential manufacturers of PtX substances can learn a lot from the promotion of biofuels and bioenergy for the formulation of sustainability criteria for similar questions regarding PtX substances.

It is obvious that "soft", not comprehensively formulated sustainability criteria that failed to take into account systemic indirect effects such as indirect land-use changes, have not led to the hoped-for investment security for biofuels. The sustainability criteria initially had a strong steering effect towards non-sustainable biofuels. From this, we conclude that sustainability criteria for PtX substances must already be formulated in such a way that negative sustainability impacts are ruled out at the transition from technology development and demonstration projects to plant scaling. Since some economic drivers of PtX production speak in favour of less sustainable production (e.g. high capacity utilisation of the plant regardless of the quality of the electricity used, use of electricity without additional requirements, unregulated use of fossil CO_2), this is necessary for an early steering effect to prevent a possible "lock-in" and investments in unsustainable business models and plant concepts.

Something else that has been learned from the market launch of biofuels is the regulatory "lock-in": as sustainably certified biofuels, their sustainability effect and eligibility for promotion are often no longer questioned - even if negative sustainability effects are obvious. This results in a regulatory "lock-in" effect. For this reason, too, we believe that sustainability rules should be formulated at an early stage in such a way that they exclude direct and indirect negative effects as comprehensively as possible in the long term.

The discussion of necessary sustainability criteria carried out in Section 3 shows the complexity of the sustainability assessment of PtX production. This is also comparable with the effects of material and energetic biomass use. In the short term, it does not seem possible to develop verification procedures and design negotiation process in society that sufficiently address this complexity; however, it also remains open in the long term whether verifiable methods for assessing sustainability can be developed for all the aspects mentioned.

In our view, the lessons learned from the market introduction of biofuels and bioenergy use (see e.g. ILUC problem) are that a risk reduction strategy to avoid probable negative sustainability effects can be advantageous for the long-term development of PtX technologies. In this way, the desired climate protection effect, investment security for the capital-intensive PtX plants and social acceptance in the possible production countries as well as in the importing countries can be ensured. In our opinion, it is highly probable that unsustainable production processes or modes of operation should be excluded from political support measures when scaling technology, even if, for example, there are no precise methods for calculating the greenhouse gas reduction of PtX substances for indirect effects.

A central aspect of the greenhouse gas reduction effect is the design of the conditions for electricity procurement, which ensures that additional, renewable electricity is used at the system level of the respective electricity system. Without this requirement, the production of PtX materials in the energy systems of many European countries today and in the medium term is associated with higher GHG emissions than the respective fossil alternatives. If hydrogen carbons are produced, a second important point for the greenhouse gas reduction effect is the regulation of CO_2 emissions: if CO_2, which is to be classified as fossil CO_2, is used, no greenhouse gas reduction is associated with the use of PtX substances. Land and water consumption are particularly relevant for the local population at potential production sites. In our view, best practice measures for sustainable development at the production sites and binding, independent evaluations of the measures are a basic prerequisite for the promotion of PtX plants.

The discussion in this paper points to another "problem" in assessing the sustainability of PtX materials. With regard to PtX technologies, technology development has been and continues to be the focus, and research and knowledge of the effects that the integration of PtX production will have on our energy and economic system is only just beginning. Much less is known about the extent to which possible developments in PtX manufacturing will affect these sustainability aspects as global demand for PtX materials develops. Here, too, a comparison with sustainable biomass use is possible. Scientific analyses today show that the sustainable potential of biomass use is many times smaller than was assumed some time ago. The technical-economic potential for PtX applications is enormous, as is the case with biomass use; the extent to which it decreases if different sustainability requirements are placed on PtX production cannot be estimated in the present state of science.

From this, a further guideline for the sustainable use of PtX potentials can be derived. There are material and energetic applications that have no or few alternatives to greenhouse gas reduction. As long as no well-founded studies provide information on the quantities of PtX products that can be produced sustainably in the long term, PtX substances should be treated as a scarce commodity for climate protection. The promotion of PtX substances for applications with little or no further technical climate protection alternatives should therefore have priority. In this way a possible "lock-in" of PtX use in applications with promising and often more efficient and cheaper alternatives (e.g. battery electric mobility, heat pumps) can be avoided.

List of References

Agora Verkehrswende; Agora Energiewende (ed.) (2018): Frontier Economics. Die zukünftigen Kosten strombasierter synthetischer Brennstoffe., Studie im Auftrag von Agora Verkehrswende und Agora Energiewende. Frontier Economics. Berlin, 2018.

Altenburg, T.; Assmann, C. (ed.) (2017). Green Industrial Policy, Concept, Policies, Country Experiences. UN Environment; Deutsches Institut für Entwicklungspolitik. Geneva, Bonn, 2017.

ARUP; URS (2014): Advanced Biofuel Feedstock: An assesment of sustainability, Framework for Transport-Related Technical and Engineering Advice and Research (PPRO 04/45/12) - Lot 2 (Road Related Technical Engineering And Advice), 2014.

BDI - Bundesverband der deutschen Industrie (ed.) (2018): Gerbert, P.; Herhold, P.; Buchardt, J.; Schönberger, S.; Rechenmacher, F.; Krichner, A.; Kemmler, A.; Wünsch, M. Klimapfade für Deutschland. The Boston Consulting Group; Prognos. Berlin, Basel, Hamburg, München, 2018.

BDI - Bundesverband der deutschen Industrie (ed.) (2019). Analyse Klimapfade Verkehr 2030. The Boston Consulting Group; Prognos AG, 2019.

BMUB - Bundesministerium für Umwelt Naturschutz, Bau und Reaktorsicherheit (ed.) (2016). Klimaschutzplan 2050, Klimaschutzpolitische Grundsätze und Ziele der Bundesregierung. Berlin, 2016.

BMWi - Bundesministerium für Wirtschaft und Energie (ed.) (2018). 7. Energieforschungsprogramm der Bundesregierung, Innovationen für die Energiewende. Berlin, 2018.

CTH - Chalmers University of Technology; IVL - Swedish Environmental Research Institute (2017): Brynolf, S.; Taljegard, M.; Grahn, M.; Hansson, J. Electrofuels for the transport sector: A review of production costs. Göteborg, 2017.

DECHEMA - Gesellschaft für Chemische Technik und Biotechnologie e.V. (ed.) (2017): Wagemann, K.; Ausfelder, F. E-Fuels - Mehr als eine Option, White Paper. Frankfurt am Main, 2017.

DG Ener - European Commission - DG Energy (ed.) (2017): Bauknecht, D.; Förster, H.; Hünecke, K.; Bracker, J.; Bürger, V.; Cook, V.; Emele, L.; Greiner, B.; Heinemann, C.; Hesse, T.; Kasten, P.; Keimeyer, F.; Kühnel, S. et al. Study on Technical Assistance in Realisation of the 2016 Report on Renewable Energy, in preparation of the Renewable Energy Package for the Period 2020-2030 in the European Union, RES-Study. ENER/C1/2014-688. Oeko-Institut e.V.; e3 Modelling; ObservER; COWI; eclareon. Freiburg, 2017.

DIE - Deutsches Institut für Entwicklungspolitik (ed.) (2013): Johnson, O. Exploring the Effectiveness of Local Content Requirements in Promoting Solar PV Manufacturing in India (Discussion Paper, 11/2013). Bonn, 2013.

EC - European Commission (2018): A Clean Planet for all – A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy, In-depth analysis in support of the commission; Communication COM (2018) 773, 2018.

EU - European Union (2018): Regulation (EU) 2018/842 of the European Parliament and the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013. In: *Official Journal of the European Union (OJL)* (L 156), pp. 26–42.

FAO - Food and Agriculture Organization of the United Nations (ed.) (2018). The future of food and agriculture, Alternative pathways to 2050. Summary Version. Rome, 2018, last accessed on 1 Jul 2019.

GEF - Global Environment Facility (2016). Taking Deforestation Out of Commodity Supply Chains, 2016, last accessed on 5 Jul 2019.

Holen, G.; Bruknapp, R. (2019): 100% Carbon Neutral, Disrupt or be disrupted. Kraftstoffe der Zukunt - 16. Internationaler Fachkongress für erneuerbare Mobilität. Nordic Blue Crude. Berlin, 22 Jan 2019.

IEEP - Institute for European Environmental Policy (2010): Bowyer, C. Anticipated Indirect Land Use Change Associated with Expanded Use of Biofuels and Bioliquids in the EU – An Analysis of the National Renewable Energy Action Plans, 2010, last accessed on 19 Mar 2019.

IEEP - Institute for European Environmental Policy (2016): Allen, B.; Baldock, D.; Nanni, S.; Bowyer, C. Sustainability criteria for biofuels made from land and non-land based feedstocks, 2016.

International Energy Agency (2019): Emissions per kWh of electricity and heat output. IEA CO2 Emissions from Fuel Combustion Statistics (databse), International Energy Agency. Online available at https://doi.org/10.1787/data-00432-en.

IPCC - Intergovernmental Panel on Climate Change (ed.) (2018): Rogelj, J.; Shindell, D.; Jiang, K. Mitigation Pathways Compatible with 1.5°C in the Context of Sustainable Development Global Warming of 1,5°C, Chapter 2 of Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global to the threat of climate change. sustainable development, and efforts to eradicate poverty, 2018.

IWES - Fraunhofer Institut für Windenergie und Energiesystemtechnik (ed.) (2017): Pfennig, M.; Gerhardt, N.; Pape, C.; Böttger, D. Mittel- und Langfristige Potenziale von PtL und H2-Importen aus internationalen EE-Vorzugsregionen, Teilbericht im Rahmen des Projektes: KLIMAWIRKSAMKEIT ELEKTROMOBILITÄT - Entwicklungsoptionen des Straßenverkehrs unter Berücksichtigung der Rückkopplung des Energieversorgungssystems in Hinblick auf mittel- und langfristige Klimaziele. Fraunhofer Institut für Windenergie und Energiesystemtechnik. Kassel, 2017.

Lappeenranta University of Technology (ed.) (2017): Fasihi, M.; Breyer, C. Synthetic Methanol and Dimethyl Ether Production based on Hybrid PV-Wind Power Plants, Conference Paper. Lappeenranta, 2017.

MWV - Mineralölwirtschaftsverband e.V.; FuelsEurope (2018). Vision 2050, Weiterentwicklung von raffinierten und flüssigen Energieträgern, 2018.

MWV - Mineralölwirtschaftsverband e.V.; IWO - Institut für Wärme und Oeltechnik e.V.; MEW - Mittelständische Energiewirtschaft Deutschland e.V.; Uniti - Bundesverband mittelständischer Mineralölunternehmen (ed.) (2018): Hobohm, J.; Maur, A. auf der; Dambeck, H.; Kemmler, A.; Koziel, S.; Kreidelmeyer, S.; Piégsa, A.; Wendring, P.; Meyer, B.; Apfelbacher, A.; Dotzauer, M.; Zech, K. Status und Perspektiven flüssiger Energieträger in der Energiewende, Endbericht. Berlin, 2018.

Oeko-Institut (2019): Kasten, P.; Kühnel, S. Positionen zur Nutzung strombasierter Flüssigkraftstoffe (efuels) im Verkehr, Darstellung von Positionen verschiedener gesellschaftlicher Akteure zum Einsatz von efuels im Verkehr. Erstellt als Teil des Kopernikus Fördervorhabens Power2X - Erforschung, Validierung und Implementierung von „Power-to-X"-Konzepten gefördert durch BMBF Förderkennzeichen: 03SFK2H0. Berlin, 2019.

Oeko-Institut; Fraunhofer ISI (2015): Repenning, J.; Emele, L.; Blanck, R.; Dehoust, G.; Förster, H.; Greiner, B.; Harthan, R.; Henneberg, K.; Hermann, H.; Jörß, W.; Ludig, S.; Loreck, C.; Scheffler, M. et al. Klimaschutzszenario 2050, 2. Modellierungsrunde. Studie im Auftrag des Bundesministeriums für Umweltschutz, Naturschutz, Bau und Reaktorsicherheit, August 2015.

ÖI - Oeko-Institut (2017a): Bracker, J.; Timpe, C. An outline of sustainability criteria for synthetic fuels used in transport, Policy paper for Transport & Environment. Freiburg, 2017. Online available at https://www.oeko.de/fileadmin/oekodoc/Sustainability-criteria-for-synthetic-fuels.pdf, last accessed on 8 Mar 2018.

ÖI - Oeko-Institut (2017b): Kasten, P.; Bracker, J.; Timpe, C.; Hacker, F. Klimavorteil Elektromobilität?, Handlungsempfehlungen zur Gestaltung des Beitrags der Elektromobilität zum Klimaschutz. Policy Paper. Berlin, 2017.

ÖI - Oeko-Institut (2017c): Timpe, C.; Seebach, D.; Bracker, J.; Kasten, P. Improving the accounting of renewable electricity in transport within the new EU Renewable Energy Directive, Policy paper for Transport & Environment, 2017.

ÖI - Oeko-Institut (2018): Gores, S.; Graichen, J. Abschätzung des erforderlichen Zukaufs an Annual Emission Allowances bis 2030. Berlin, 2018.

oxfam - oxfam international (2012): Kelly, R. The Hunger Grains: The fight is on. Time to scrap EU biofuel mandates. (OXFAM Briefing Paper, 161), 2012.

Reiter, G.; Lindorfer, J. (2015): Evaluating CO_2 sources for power-to-gas applications - A case study for Austria. In: *Journal of CO2 Utilization* 10, pp. 40–49.

The Weltenergierat - Deutschland e.V. (ed.) (2018): Perner, J.; Bothe, D. INTERNATIONAL ASPECTS OF A POWER-TO-X ROADMAP, A report prepared for the World Energy Council Germany. Frontier Economics, 2018, last accessed on 5 Dec 2018.

UBA - Umweltbundesamt (ed.) (2013): Jering, A.; Klatt, A.; Seven, J.; Ehlers, K.; Günther, J.; Ostermeier, A.; Mönch, L. Umweltbundesamt: Globale Landflächen und Biomasse - nachhaltig und ressourcenschonend nutzen. Umweltbundesamt, 2013.

VDA - Verband der Automobilindustrie (ed.) (2017): Siegemund, S.; Trommler, M.; Kolb, O.; Zinnecker, V.; Schmidt, P.; Weindorf, W.; Zittel, W.; Raksha, T.; Zerhusen, J. E-Fuels Study: The potential of electricity-based fuels for low-emission transport in the EU, An expertise by LBST and dena. Deutsche Energie-Agentur GmbH; Ludwig-Bölkow-Systemtechnik GmbH. Berlin, 2017.