Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

An outline of sustainability criteria for synthetic fuels used in transport

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Author

Joß Bracker

With contributions from Christof Timpe

Head Office Freiburg
P.O. Box 17 71
79017 Freiburg

Street address
Merzhauser Strasse 173
79100 Freiburg
Tel. +49 761 45295-0

Office Berlin
Schicklerstrasse 5-7
10179 Berlin
Tel. +49 30 405085-0

Office Darmstadt
Rheinstrasse 95
64295 Darmstadt
Tel. +49 6151 8191-0

info@oeko.de
www.oeko.de

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Key results

- The electricity-based production of hydrogen and hydrogen-based liquid and gaseous synthetic fuels can potentially lead to significant additional CO_2 emissions and other negative environmental effects (e.g. increasing water scarcity).
- To achieve significant CO_2 emissions savings through the use of hydrogen and synthetic fuels in transport compared to conventional fuels, their production must be based on additional renewable energy generation, and in order to ensure long-term sustainability, only atmospheric carbon sources should be used.
- To ensure that the use of hydrogen and synthetic fuels has a positive climate impact and only sustainably produced hydrogen and synthetic fuels are used to substitute conventional fossil fuel in transport, appropriate sustainability criteria need to be established. If the EU intends to account hydrogen and synthetic transport fuels towards EU renewable energy targets and as a contribution to meeting the fuel blending obligation, such sustainability criteria and respective certification schemes should be established, similar to the existing EU biofuels criteria.
- Sustainability criteria should address the overall CO_2 balances of hydrogen and synthetic fuels, based on lifecycle assessments that take into account the upstream emissions of electricity production required for all production processes, including CO_2 capture and water desalination, where required.
- In order to avoid negative sustainability impacts similar to the introduction of crop-based biofuels, the process for the development of such criteria and the establishment of a respective certification scheme should be initiated in the near future, before a large market for synthetic fuels develops.

1. Introduction

Today road transport in the EU relies almost entirely on the use of fossil fuels. As a consequence, transport is a major source of CO_2 emissions and one of the main polluting sectors in Europe. Decarbonisation of the transport sector can only be achieved if the share of renewable energy use in transport increases significantly. The electrification of road transport by direct use of electricity and indirectly through hydrogen and electricity-based synthetic fuels (in the form of methane and liquid fuels) is an inevitable strategy for reaching this objective and achieving the desired CO_2 emission reductions.

As the direct use of electricity is much more effective than synthetic fuels in terms of energy required for reaching a certain mobility output, the direct use of electricity via battery electric vehicles should be preferred to the less efficient use of synthetic fuels. Several mobility sectors such as aviation and maritime transportation cannot be easily operated by batteries. Therefore hydrogen and synthetic fuels are needed as low-emission alternatives to replace carbon-intensive fossil fuels in these sectors. However, the use of hydrogen and synthetic fuels does not always lead to a reduction of CO_2 emissions and their production can negatively impact local natural resources (e.g. water supply). The risk associated with hydrogen and synthetic fuels and the need for sustainable production is therefore similar to conventional crop-based biofuels.

The impact of biofuels on sustainability issues was and is still an on-going issue, and the current Renewable Energy Directive (RED) includes detailed sustainability criteria for biofuels (Article 17, Directive 2009/28/EC). In contrast, no requirements for the sustainable production of synthetic fuels and hydrogen currently exist, nor are they included in the European Commission proposal for a revised Renewable Energy Directive. In fact, the potential sustainability issues of synthetic fuels have barely been discussed so far, and an environmental benefit or even zero emission balance of using such fuels is often implicitly assumed without further assessments. Significant problems may arise as soon as a global market for these fuels will have established.

If relevant volumes of hydrogen and synthetic fuels are to be used in the European transport sector until 2030, there is a need for sustainability criteria for these fuels to ensure their environmental benefit. Such criteria should not only address CO_2 emission savings but also broader aspects of sustainability such as the use of natural resources (e.g. water and land) and social impacts (e.g. land right issues and welfare of local population in production countries). As electricity-based synthetic methane can also be used in other sectors (e.g. for heating), the development of sustainability criteria is not only relevant for transport but also for the climate policy framework of other sectors.

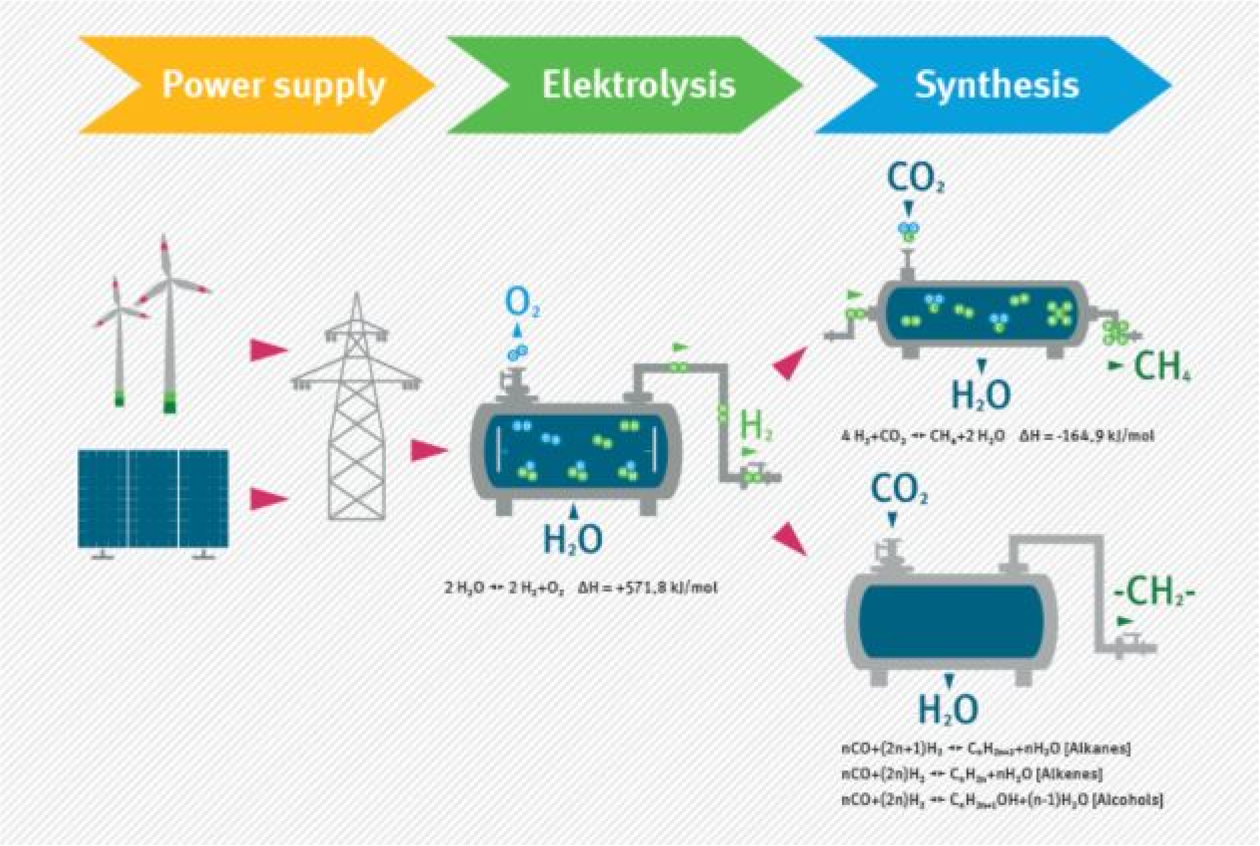
This policy paper sets out the most important issues which should be addressed by such criteria and outlines possible criteria approaches. For the development of a concrete criteria set, a much more thorough assessment of the relevant issues is necessary than it is possible in this short paper. The analysis in this paper concentrates on the sustainability aspects of the production of liquid synthetic fuels (methanol, liquid hydrocarbons), with most arguments also applying to hydrogen.

2. Characteristics of synthetic fuels and their production processes

Generally, electricity-based synthetic fuels are fuels based on hydrogen and hydrocarbons, which can be produced by electricity. Hydrogen produced by electricity (Power-to-Gas) can serve as a transport fuel in fuel cell-based vehicles without further processing. With the input of CO_2 (e.g. from biogas plants), hydrogen can be synthesised and refined to different liquid transport fuels (Power-to-Liquid) that have a higher energy density than pure hydrogen and a broader range of possible applications.

The first step of the production process of any synthetic fuel is the production of hydrogen via electrolysis of water. With the input of electricity and fresh water, the electrolyser splits the water into hydrogen and oxygen. The produced hydrogen can be used directly or it can be synthesised through input of carbon to liquid hydrocarbons, which can be further refined to different synthetic fuel types (e.g. methanol, higher hydrocarbons usable as jet fuel). Thus, input resources for the production of hydrogen and synthetic fuels are electricity, fresh water, and in case of synthetic fuels, carbon. Figure 2-1 illustrates the production process.

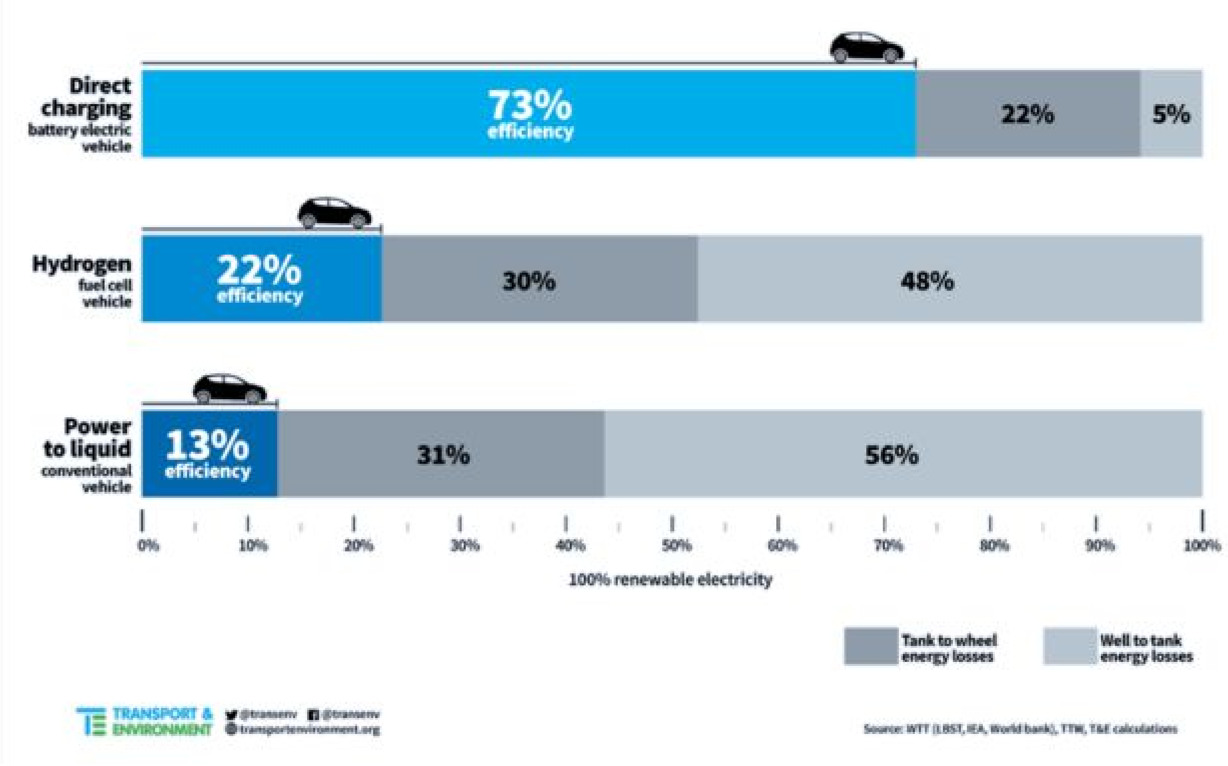
Figure 2-1: Working principle of synthetic fuels



Source: Purr et al. 2016

The described production processes involves high energy losses. This means that a large share of the required energy input is not contained in the produced hydrogen and liquid fuels. The electrolysis involves energy losses of about 30-40%, depending on the specific electrolysis process (Bertuccioli et al. 2014). In the future, the energy losses might be reduced to 10% if high temperature electrolysis, which is currently still in the research phase, is applied (Bertuccioli et al. 2014). Depending on the type of synthesis process, additional energy losses of about 20% (methanisation) to 40% (Fischer-Tropsch process for production of higher hydrocarbons) occur, which further reduce the overall energy efficiency (Klerk 2011).

Figure 2-2: Efficiency of different electricity-based transport options



Source: Transport & Environment 2017

Due to the substantial losses in the production processes, synthetic fuels and hydrogen differ significantly in the amount of electricity that is needed to reach a certain mobility output in terms of kilometres. Figure 2-2 depicts the differences in efficiency of different electricity-based transport options (including losses that occur at the vehicle level). The high energy losses of hydrogen and synthetic fuels demonstrate the great advantage of the direct use of electricity (e.g. in battery electric vehicles). From an environmental and energy efficiency perspective, the direct use of electricity should therefore always be preferred if the specific use case allows for it.

Production plants for synthetic fuels will usually be operated 24 hours per day (“baseload”), as the chemical processes are difficult to interrupt and the high investments in the plants require a maximum usage of the available production capacity.[1] While the technological maturity of the individual process steps along the synthetic fuel pathways is relatively advanced, an integrated synthetic fuel production chain based on electricity and CO_2 only exists for pilot plants producing synthetic methane, but not yet for liquid transport fuels.[2] For hydrogen as a transport fuel, a very limited market already exists but the hydrogen is usually produced from natural gas and not from electrolysis. It can be expected that the hydrogen market will develop further until 2030 and also that “green” renewable electricity-based hydrogen products will become available. In terms of synthetic fuels, it is expected that large market penetration will only occur after 2030, although smaller niche markets could already develop in the period up to 2030.

Currently, the costs for the production of synthetic fuels are significantly higher than for conventional fuels. Cost competiveness is therefore crucial for market development. Since the cost of electricity is the main cost factor in synthetic fuel production, and given the fact that synthetic fuels are easily transportable, low generation costs of electricity will likely be the determining factor for the location of synthetic fuel production plants. To ensure synthetic fuel production does not lead to significant CO_2 emissions, the production process needs to be based on renewable electricity and cannot simply be operated by electricity from the grid (see Chapter 3.1). In the following, it is assumed that the producers of hydrogen and synthetic fuels have an interest in using electricity from renewable energy sources instead of fossil or nuclear energy.

Since yields of renewable electricity are much higher in several regions outside the European continent, it can be expected that a global supply chain for synthetic will develop. With high full load hours of renewable generation plants, the costs of electricity production and subsequently the overall costs of the production process can be lowered significantly. A combination of solar and wind generation plants can achieve relatively high full load hours for renewable generation. Figure 2-3 shows the full load hours for hybrid PV-wind power plant sites in the world.

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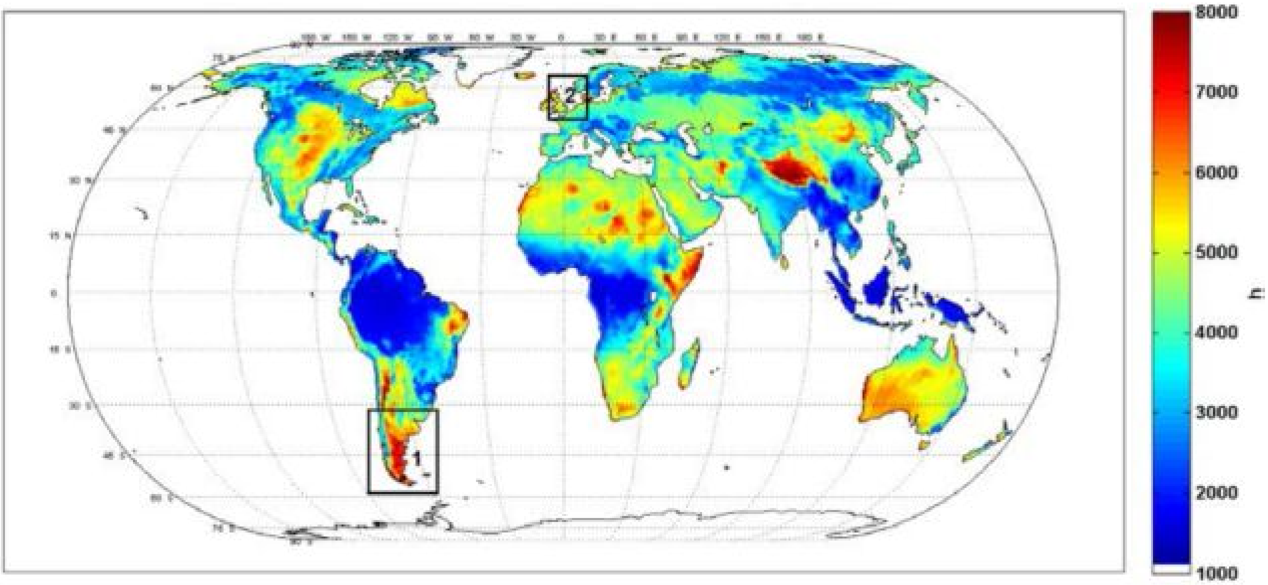
[1] A study for hydrogen production based on Power-to-Gas in the Netherlands shows that approximately 5.000 to 6.000 operating hours a year are required to realize a positive business case (Joode 2014).

[2] Since end of 2013 the German automobile manufacturer Audi is operating a synthetic methane production plant in Germany that uses CO_2 from a nearby biogas plant.

Figure 2-3: World's hybrid PV-Wind power plant full load hour map in 2030



Source: Fasihi et al. 2016 (The numbers 1 and 2 indicate production and consumption regions analysed in the specific case study)

Besides high full load hours for renewable production, potential production regions should also have an accessible water source (e.g. sea water for desalination) and be located at the shore to allow for the low cost transport of fuels via shipping. Given these factors, potential regions for synthetic fuel production are North Africa, the Middle East, Somalia, Brazil, Patagonia, Australia, Norway and Iceland.

These regions differ greatly in terms of their renewable electricity potential, level of economic development, the power generation and infrastructure, as well in the availability of natural resources. Therefore, synthetic fuel production can have different negative environmental impacts, which need to be taken into account for a comprehensive evaluation of the sustainability of synthetic fuels. For example, Saudi Arabia is amongst the driest regions on earth and water demand is already increasing due to population growth and a rapid increase of per capita water demand. Large scale synthetic fuel production could therefore strongly negatively affect the local water supply that is already under stress.

3. Sustainability issues of synthetic fuel production and key elements of respective sustainability criteria

3.1. Electricity demand

Producing synthetic fuels requires large amounts of electrical energy. As described above, more than half of the required energy input is lost in the production processes. It is therefore essential that production processes are based on renewable electricity generation, otherwise the use of synthetic fuels would lead to significantly higher CO_2 emissions compared conventional fossil transport fuels (Zhang et al. 2017). It is often implicitly assumed that synthetic fuels are based on renewable electricity and their use automatically entails carbon savings. However, this is not always the case, as specific requirements need to be fulfilled to ensure emission-free production of hydrogen and synthetic fuels. This is particularly the case if production plants consume power from the public electricity grid, which can be expected due to the need for a high security of supply of the production plants.

To understand the impact on CO_2 emissions of additional electricity consumption from production plants that use electricity from the grid, it is important to understand the functioning of electricity markets. In general, electricity markets are based on the Merit Order principle, which means that generation plants are dispatched based on their marginal generation cost. From this follows that plants with low marginal cost (e.g. wind and PV plants) are dispatched first and thus are usually fully utilised during most hours of the year. Therefore, in power systems with a relevant share of fossil fuel generation, any additional demand by synthetic fuel productions plants will most likely lead to an increase of fossil power generation and thereby cause significant additional CO_2 emissions (see Timpe et al. 2017).

This negative effect on CO_2 emissions can be avoided if synthetic fuel production is based on additional renewable electricity generation – either by utilising renewable surplus production, which would otherwise be curtailed, or by adding additional renewable generation from new plants to the respective power system. This avoids a higher utilisation of fossil power plants and related CO_2 emissions.

A closer look at the availability of renewable electricity surpluses in Europe reveals that the potential to use them for synthetic fuel production is restricted in several ways. Firstly, system-wide renewable surplus production will only occur in Member States with high shares of wind and solar production, and even then the overall surplus volumes will be rather limited. Relevant surpluses are only expected at renewable electricity shares above 60% (Agora Energiewende 2014; Bauknecht et al. 2016). Renewable energy curtailment at certain grid substations might also occur with lower renewable shares due to network congestion. However, these surpluses are limited to the regions of network congestion and are usually counteracted by measures of grid reinforcement. Secondly, the production of synthetic fuels would have to be located at the grid substations or branches where the surpluses occur, and they would have to operate only during those hours when surpluses are actually available. As described, such intermittent operation would be difficult in terms of management of the technical processes and it would reduce the usage of the capital-intensive plants, in turn increasing the specific production costs for the synthetic fuels significantly. The actual potential to use “surplus renewable electricity” in Europe is therefore rather limited, and large-scale production of synthetic fuels based on renewable surpluses unlikely.

Thus it is more promising at least in Europe and other industrialised regions of the world, to establish a link to additional renewable energy generation through electricity supply from new generation plants. Such a link can be established by connecting synthetic fuel production facilities directly to new renewable electricity generation plants with no possibility to consume electricity from the public grid (off-grid installations). However, due to the intermittent nature of wind and PV generation, such a production set-up would also require additional storage facilities to ensure a continuous fuel production. It is therefore likely that most production plants will depend on electricity from the public grid for continuous operation. To ensure that renewable electricity consumption from the grid is truly additional, the electricity supply needs to meet so-called “additionality” criteria (see below).

If synthetic fuel production takes place outside of Europe, in general the same principles apply and additional renewable generation needs to be ensured. As described above, if electricity is taken from the public grid (e.g. in times of low renewable generation) and the regional power system is only partly based on renewable generation, additional CO_2 emissions from fossil power plant are likely to occur. In order to operate with global responsibility, electricity from renewable energy should thus be used first, to ensure a low carbon energy supply for the population and economy of the country in question, before potentially scarce resources of renewable energy and related land for wind and solar power plants are used for the production of synthetic fuels for Europe. Therefore, synthetic fuel production should only take place in regions with well-developed electricity systems and abundant renewable energy potentials.

Key elements for sustainability criteria

It is indispensable for the production of synthetic fuels which have a lower CO_2 footprint than conventional fossil transport fuels, that the required electricity demand is met by additional renewable energy generation. Sustainability criteria for synthetic fuels should therefore include requirements regarding the electricity supply of synthetic fuel production (including all associated processes such as desalination and CO_2 capture).

To account for a low emission intensity of energy demand of the production processes, the required electricity supply, has to come from renewable energy sources and has to adhere to “additionality” criteria. Without such criteria, the allocation of renewable energy attributes (e.g. by Guarantees of Origin or power purchasing agreements) to certain consumers (e.g. an electrolysis plant) will only lead to a redistribution of already existing renewable generation volumes between different consumer groups and not to an actual increase in renewable energy generation (Timpe et al. 2017).

Therefore, the simple use of Guarantees of Origin, as they are currently used in Europe, does in no way ensure that power consumption for synthetic fuel production is based on additional renewable generation and thus does not justify accounting this consumption with low or zero CO_2 emissions. The same applies to long-term power purchasing agreements if the respective renewable production plants do no fulfil specific additionality criteria.

A pragmatic version of such additionality criteria includes a maximum age for the production plants, which is lower than the depreciation period of the related technology, and the exclusion of participation in public support schemes. With the supply from “young” plants a continuous demand, and thereby investment incentives, for new renewable power plants is created. The exclusion of participation in public support schemes ensures that the transport sector also bears the costs for the investments and that these costs are not borne by other consumer groups (e.g. households through electricity surcharges that finance renewable support schemes). Furthermore, the use of renewable surplus production should also be considered additional renewable generation.

Establishing a link between fuel electricity demand and additional renewable generation could theoretically be achieved by directly connecting new additional renewable plants to the production facilities. However, as stated above, it is more likely in practice that fuel production will also depend on electricity from the grid to avoid additional costs for storage systems. In case of electricity supply from the grid, reliable verification schemes are necessary which ensure a link to additional renewable production. The introduction of “*guarantees of origin Plus”* could establish a reliable and transparent proof of “additionality” in the European electricity sector (see Timpe et al. 2017). Long-term power purchasing agreements could also create a link to additional renewable production if the fulfilment of the described additionality criteria is ensured and if guarantees of origin or GO Plus are used in order to avoid double counting of the respective energy volumes. In the case that the electricity supply is only partially covered by additional renewable generation (e.g. the supply of solar power via a direct connection to an additional solar power plant during the day and the supply of electricity from the grid at night times), only a part of the produced fuels can be considered based on additional renewable energy and thus a proper calculation of CO_2 emission factors and renewable energy shares is needed.

3.2. Carbon demand

For the production of liquid synthetic fuels carbon is required as an input resource. During the combustion of synthetic fuels, the contained carbon is converted to CO_2 and released into the atmosphere. In principle, carbon is available from the following sources:

- Fossil carbon from industrial manufacturing processes (e.g. from cement production) and combustion processes for electricity and heat production based on fossil fuels (e.g. from coal-fired power plants)
- Biogenic carbon from regenerative processes (e.g. from biogas power plants)
- Atmosphere / ambient air

In our current carbon-based economy large volumes of fossil carbon are theoretically available and could be captured via Carbon Capture technologies. Using captured fossil carbon for synthetic fuel production would be a “recycling” of carbon that would otherwise be directly emitted into the atmosphere. Thus no *additional* CO_2 emissions would occur, and the use of carbon from such “Carbon Capture and Use” approaches could be considered emission-neutral.

However, the use of fossil carbon is problematic in regard to a sustainable long-term strategy for several reasons. First of all, a fossil carbon source is by nature not renewable and therefore synthetic fuel production that uses fossil carbon does not adhere to the concept of a circular economy. But most importantly, in the medium- to long-run on the pathway towards a decarbonised economy, fossil carbon sources will become scarce and not be available in the required amounts. Therefore, the use of fossil carbon from industrial and combustion processes could only be sensible for the limited period that fossil processes are still operating. If fossil carbon is used, it is of crucial importance that the “recycling” of carbon from existing processes does not incentivise their increase or extension (e.g. power generation from coal power plants).

In contrast to fossil carbon, biogenic carbon (e.g. from residual and waste biomass) is a renewable resource. But the overall availability of biomass is very limited compared to the carbon volumes required for large scale synthetic fuel production. The respective biomass sources might also not be available at the potential locations of synthetic fuel production sites (e.g. Middle East). In case biogenic carbon is used, the same issues of sustainability as for biofuels production arise. Therefore the same sustainability criteria should be met to avoid adverse effects (e.g. regarding LULUCF emissions and biodiversity).

Given the above-mentioned problems with fossil and biogenic carbon, capturing carbon directly from ambient air is the only feasible and environmentally sensible option for a large scale production of synthetic fuels. From a technical perspective, it is available in sufficient amounts and at every potential production site. From an environmental perspective, it can ensure a closed-loop of CO_2 and can therefore be the basis for potentially almost carbon neutral products. However, the process is much more energy intensive.[3] Compared to the use of concentrated fossil or biogenic carbon, the use of carbon air capture reduces the overall efficiency of production process by about 10 percentage points (see Table 3-1). In addition, the cost of CO_2 supply is approximately eight times higher for direct capture from air compared to the use of concentrated carbon sources, which increases the total costs of fuel production by 30% (German Environment Agency 2016; Schmidt et

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[3] A demonstration plant currently requires about 1,7 MWh of energy per ton of CO_2 (Fasihi et al. 2016). 80-90% of the required energy can be supplied by heat. As heat is a by-product of electrolysis and the synthetic fuel production (Fischer-Tropsch synthesis), CO_2 air capture is suited to be combined with these processes. The additional electricity required could be reduced to about 200-250 kWh/t CO_2 (Fasihi et al. 2016).

al. 2016). Due to this strong difference in costs, concentrated carbon sources are likely to be used if no restrictions on eligible carbon sources are applied.

Table 3-1: Synthetic fuel production efficiencies (fuel output vs. electricity input)

Pathway*	**Production efficiency today**		
	Air	**Exhaust gas (e.g. wood burner)**	**Fermentation (e.g. biogas upgrading)**
Low-temperature electrolysis	38%	47%	48%
High-temperature electrolysis	45%	60%	62%

*Differences between the Fischer-Tropsch and the methanol pathway are negligible

Source: German Environment Agency 2016

Key elements for sustainability criteria

To avoid an overall increase of CO_2 concentration in the atmosphere, the carbon must ideally not originate from fossil sources. Sustainability requirements for carbon-based synthetic fuels should therefore require the use of atmospheric CO_2 either via direct air capture or via biogenetic sources. Only in these cases is a closed-loop of CO_2 ensured and an almost zero-emission balance is possible at all.

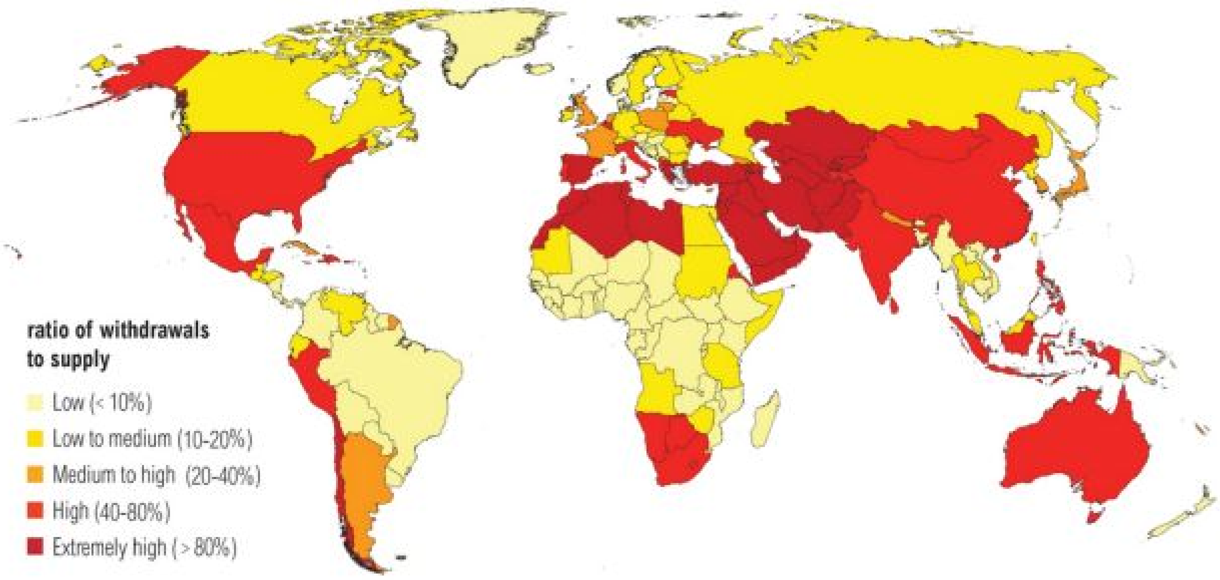
In the case of biogenic carbon sources, it should in addition be required that the EU sustainability criteria for biomass/biofuels be met. Since the use of carbon from industrial processes via Carbon Capture and Use technologies bears the risk of incentivising and prolonging these CO_2-based processes, its use should not be allowed.

3.3. Water demand

Synthetic fuel production requires input streams of fresh water for electrolysis. Fresh water is therefore an indispensable feedstock for any synthetic fuel production. The amount of water needed for the production can be estimated based on the overall process stoichiometry. The water demand depends on the carbon number of the produced hydrocarbons. For example, for jet fuel with an assumed carbon number of 11, the amount of water needed is about 1,3 to 1,4 litres per litre of jet fuel (German Environment Agency 2016). The total net water demand for such a synthetic jet fuel has been estimated at about 0,04 m^3 per GJ (German Environment Agency 2016). This demonstrates that the fresh water demand associated with large scale synthetic fuel production will be significant.

In many of the potential regions of future synthetic fuel production water availability is already critical, and it cannot be assumed that the required water demand can easily be satisfied by the existing regional water supply. The Middle East and North Africa (MENA region) are already today among the world's driest regions, and climate change will lead to a further increase in aridity in many regions of the world. For example, in the MENA region, a 20% reduction in rainfall and higher rates of evaporation will further increase water scarcity (World Bank Group 2014). At the same time, water consumption is constantly increasing in this region due to population growth and growing per capita water consumption. Figure 3-1 shows which countries will experience severe water stress by 2040. The results clearly indicate that regions of potential synthetic fuel productions such as Northern Africa, the Middle East and Patagonia will face severe water scarcity. Additional water demand from large scale synthetic fuel production in these countries could therefore cause significant problems in terms of the environmental sustainability of these fuels.

Figure 3-1: Water Stress by Country: 2040



Source: World Resources Institut 2015

If no sufficient fresh water supply is available, desalination of sea water is the only feasible option of fresh water supply. Although large improvements in the energy efficiency of desalination plants have been achieved over the last decades, desalination is still an energy intensive process with no great further efficiency gains expected. Large-scale technologically-advanced plants with the most efficient desalination process (reverse osmosis) currently require about 3-4 kWh of electricity per m^3 of water (Upeksha Caldera et al. 2016).

Key elements for sustainability criteria

For a sustainable production of synthetic fuels it needs to be ensured that the additional water demand from production facilities does not negatively affect the local water supply. Sustainability criteria should therefore address the issue of water supply. Depending on the environmental context, a sustainable water supply could be achieved in different ways. For example, in non-arid regions where water supply is based on natural fresh water sources such as rivers and groundwater (e.g. Norway), a sustainable water supply could be ensured by establishing and adhering to standards of water management plans. In arid regions, where the fresh water supply already relies on desalination plants, criteria could require that additional desalination plants be built for the synthetic fuel production facilities. To avoid significant additional CO_2 emissions from the electricity consumption of desalination plants, these plants need to be powered by renewable electricity, just as the actual synthetic fuel production plant.

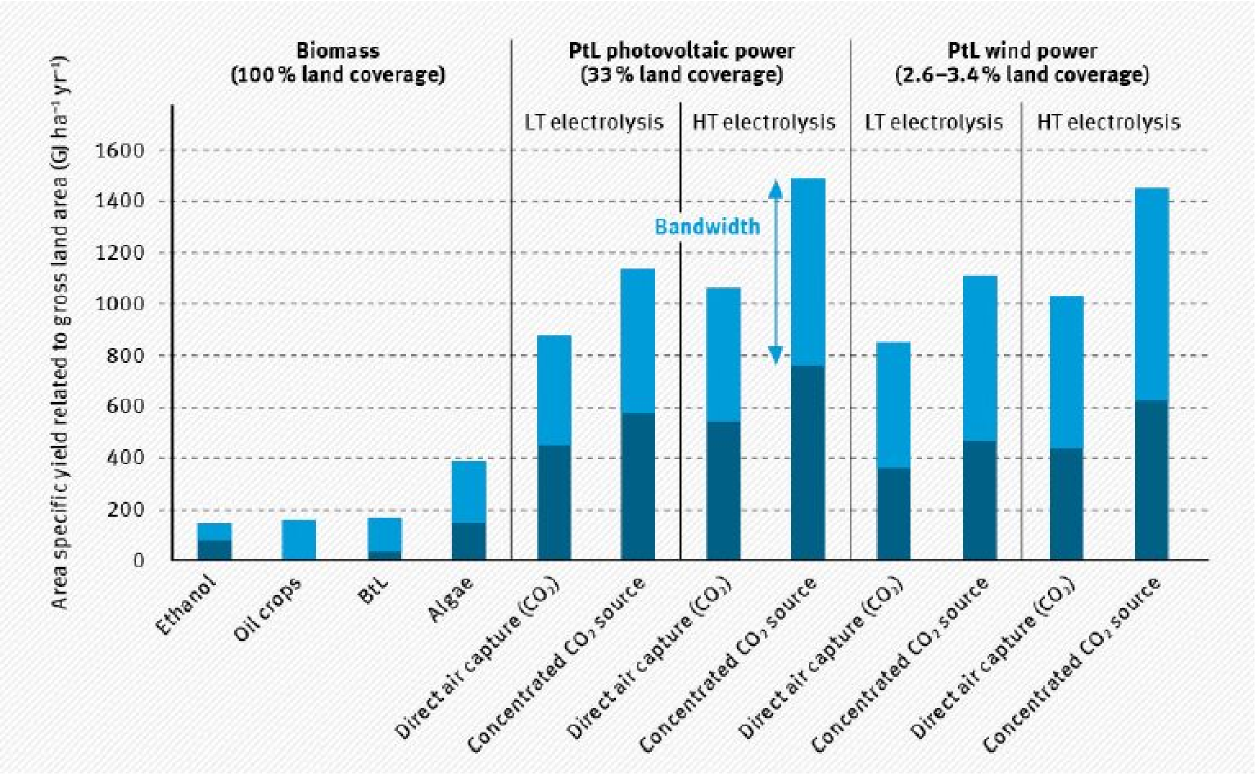
3.4. Land use

Every infrastructure project inevitably requires land. Depending on the extent of required land space, the production of synthetic fuel production could also have a negative impact regarding the use of land.

From the different infrastructure facilities for synthetic fuel production, the renewable energy production plants take up most of the required space. Calculations for the area-specific yield in terms of air mileage based on synthetic jet fuels show similar levels for electricity generation based on PV and wind power. In the case of PV, about 5.000 – 9.000 km of air mileage can be achieved per hectare of land and about 4.000 – 8.900 from onshore wind power (German Environment Agency 2016). The CO_2 source also is relevant for the land requirements. As direct air capture is more energy intensive, about 15-20% more land is required for renewable generation plants to achieve the fuel output (see Figure 3-2).

For the impact of the land requirement two factors are highly relevant: the possibility to use the required land for other purposes and the requirements regarding the land type. In the case of wind power, up to 95% of the land can still be used for other purposes (e.g. agriculture). In contrast to biofuel production, requirements regarding the type of land are also relatively low, as no arable land is needed. Wind and PV installations can also be located in areas where other uses such as agriculture are not possible (e.g. in deserts). Therefore the danger of competition between food and energy production is far lower in the case of synthetic fuels than for biofuel production.

Figure 3-2: Comparison of gross area specific yields of synthetic fuels from PV, wind power and biomass



Source: German Environment Agency 2016

In regions with high population density or where the land is intensively used for agriculture (e.g. Europe), additional land requirements by synthetic fuel production could increase competition for useable land. Finding new suitable sites for renewable energy production has already become an issue in many European countries, and the problem will grow in the future with the continuous extension of renewable energy production.

But also in regions where human use of land is low, the infrastructure, in particular the renewable energy generation plants, could negatively impact the natural habitat and could also be perceived as unwanted alien infrastructure by the national population.

Key elements for sustainability criteria

How far the issue of land use for synthetic fuel production is problematic in terms of sustainability differs greatly between potential production regions. Even though land use is probably less problematic compared to other sustainability aspects, potential sustainability criteria should also take the issue into account.

In order to avoid a negative impact, synthetic fuel production sites and the related electricity generation facilities should be prohibited in regions of high environmental value, such as nature protection areas. The concrete criteria could also be oriented by the EU sustainability criteria and categories of protected areas defined by the International Union for Conservation of Nature (IUCN). Furthermore, monitoring and reporting requirements regarding land use management aspects could be introduced to identify and prevent potential negative impacts.

3.5. CO_2 balance

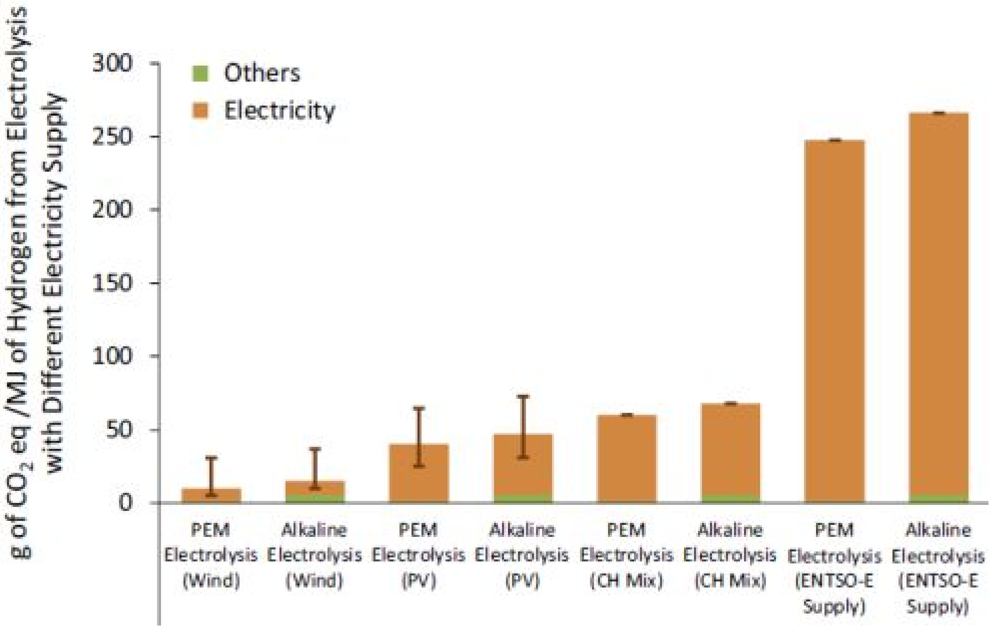
The overall climate benefit of synthetic fuels depends on the total CO_2 balance of synthetic fuels. As described, CO_2 emissions can result from various processes required for the fuel production. In order to assess the CO_2 emissions of synthetic fuels, all relevant production processes and related energy-intensive activities need to be taken into account.

Most importantly, potential emissions can occur from the large electricity demand required for the production of hydrogen via electrolysis, the synthesis of hydrogen to liquid hydrogen and further refinery processes. In addition, the direct carbon capture from ambient air and desalination of sea water are also highly energy intensive and could potentially lead to additional emissions. All these potential upstream emissions of the electricity generation must be taken into account in the overall CO_2 balance for synthetic fuels. For the accounting of CO_2 emissions from the required electricity demand, it is highly important that potential renewable electricity generation is only accounted with low emission-intensity if the production can be considered as *additional* (see Chapter 3.1).

A recent life cycle assessment of GHG emissions of synthetic fuels has shown that synthetic fuels only have lower carbon footprints than conventional fuels in the case of electricity supply with a very low CO_2 intensity and the use of atmospheric carbon (Zhang et al. 2017). As an example, Figure 3-3 shows the life-cycle GHG emissions of hydrogen production based on different electricity supply mixes. It compares the GHG emissions for two different electrolysis techniques (polymer electrolyte membrane and alkaline electrolysis) either based entirely on renewable energy (wind or photovoltaic), the Swiss consumption mix (with large shares of hydro and nuclear energy) and the average European grid mix (with a significant share of fossil fuels). The figure clearly illustrates that hydrogen production, which is only the first step for synthetic fuel production, leads to significant GHG emissions if accounted for with a mix of fossil and renewable generation (e.g. the mix of the ENTSO-E region). Electricity generation only from fossil fuels has even higher emissions (typically

740 to 910 gCO_2eq/kWh for coal and 410 to 650 gCO_2eq/kWh for natural gas according to IPCC 2014). The average emission factor of the EU-28 in 2030 is expected to be approx. 200 g/kWh according to the Reference Scenario of the European Commission (European Commission 2016).

Figure 3-3: **Life cycle GHG emissions of hydrogen production**



Source: Zhang et al. 2017

Therefore, emission safeguards based on comprehensive lifecycle assessments should be introduced in order to ensure that synthetic fuels actually have a positive effect on CO_2 emission savings,

Key elements for sustainability criteria

Sustainability criteria should require that synthetic fuels achieve at least the same CO_2 emission savings as biofuels. Therefore the minimum requirement of 70% lower GHG emissions compared to conventional fuels, as included in the proposed revision of the RED for biofuels, should be applied as well to synthetic fuels and hydrogen used in road transport.

The GHG emission balance of synthetic fuels needs to be based on a comprehensive lifecycle analysis since the involved material flows (e.g. CO_2 and electricity) cross different sectors (industry, power and transport).

3.6. Social impact

In the longer future synthetic fuels will likely be produced in large production facilities in order to achieve competitive production costs. These facilities will be large industrial complexes that combine extensive renewable energy plants (e.g. wind parks combined with large PV plants) with electrolysis, refinery and storage facilities. Infrastructure project of that scale will inevitably have a social impact on the respective regions. Besides economic opportunities, the building and operation of these facilities could also lead to various negative impacts in the respective countries. The sustainability analysis of synthetic fuel production should therefore not only focus on the environmental impact, but should have a broader scope that also takes the issue of local acceptance and the social impacts of the fuel production into account.

If production takes place in economically less developed countries, the technologically advanced and environmentally-friendly production plants might stand in stark contrast to the national energy system in which they are located. The local power system could, for example, be in poor condition, be based on fossil-fuel generation and the local population might struggle with energy poverty and unsecure power supply. Such unequal economic and technical conditions could lead to social tensions and give rise to local opposition. Depending on the underlying economic partnerships between exporting and importing countries, the international production chain could also be perceived as unfair if the economic assets and profits from harvesting the local natural resources (sun and wind) remain with foreign companies.

In principle, synthetic fuel production based on renewable energy could lead to large economic, environmental and social benefits for the respective regions. If projects are implemented in a responsible manner, they could provide employment opportunities and lead to additional public revenue streams from related trading activities (e.g. from export duties). Therefore the participation of local actors and the establishment of equitable partnerships between exporting and importing countries are crucial to avoid potential negative social and economic impacts.

Key elements for sustainability criteria

To ensure that synthetic fuel production causes no negative impact on the local level, the principles “local welfare before synthetic fuel production” should be followed as a minimum requirement. This means that production should only take place in regions where an adequate supply of energy and water is ensured for the local population. In addition, the participation of local actors in the planning processes is necessary to ensure that production facilities do not interfere with the interest of the local population.

As a first step, the economic and social context of synthetic fuel production should be monitored. This could be implemented via reporting requirements for production companies or the European Commission. In the case of a negative impact on the social level, more concrete criteria regarding the social and economic environment in which the production takes place could be developed in the medium-term (e.g. need for stakeholder participation).

4. Conclusions

Hydrogen and synthetic fuels can play an important role in the decarbonisation of the transport sector, but their production is highly energy intensive and involves significant energy losses. Therefore the direct use of electricity is always preferable if the specific use case technically allows it. If this is not the case (e.g. in aviation and maritime transportation), hydrogen or synthetic fuels can be an environmentally advantageous substitute for fossil fuels. However, the use of hydrogen and synthetic fuels only leads to a positive environmental impact if production takes place under specific conditions. Most importantly, a significant reduction of CO_2 emissions compared to the use of fossil fuels is only achieved if the fuel production is based exclusively on additional renewable generation. From a long-term sustainability perspective, the use of carbon from fossil sources should be avoided. Furthermore, fuel production can also lead to significant negative impacts with regard to water consumption and land use.

To ensure that synthetic fuels contribute to a transition towards a sustainable transport sector, the revised RED should ensure that only truly sustainable synthetic fuels are accounted towards the EU climate targets and used for the blending obligation.

As it can be expected that a broader market for hydrogen and synthetic fuels will develop until 2030, sustainability criteria, similar to the EU biofuel criteria, should be introduced in the context of the revised RED to avoid possible negative impacts on CO_2 emissions and resources. Such sustainability criteria should address the following aspects:

- Minimum CO_2 savings:

  Similar to advanced biofuels, the use of hydrogen and synthetic fuels should result in emission savings of at least 70% compared to conventional fuels, including all relevant upstream emissions.

- Proper accounting of renewable energy-based production processes:

  As an important part of the assessment of the CO_2 effects of electricity-based hydrogen and synthetic fuels (including associated processes such as water desalination and carbon capture), the supply of electricity needs to be accounted for properly. Renewable energy should only be associated with low emissions if the production is additional. Fulfilment of additionality criteria either requires the exclusive use of renewable surplus production or electricity supply from new and unsupported renewable plants. All electricity which is not from additional renewable energy sources should be accounted for with grid average emission factors.

- No use of fossil carbon:

  To ensure a closed-loop of CO_2, all carbon used for synthesising liquid hydrocarbons should originate either from sustainable biogenic sources or from direct air capture.

- Sustainable resource use of water and land:

  The water required for the production of hydrogen must not negatively impact the local water supply. A sustainable water supply could for example require the building of additional desalination plants or implementations of strict water management plans that ensure that the additional water demand does not negatively affect the existing water supply (e.g. by limiting the respective water demand). In terms of land use, the production facilities and associated renewable generation plants must not be located in areas where they have strong negative effects on the natural habitat (e.g. nature protection areas or zones of high biodiversity).

Besides criteria on the environmental impact of fuel production, the social dimension of sustainable fuel production should also be addressed. In this regard, the principle “local welfare before synthetic fuel production” should be followed to ensure that production only takes place in regions where an adequate supply of energy and water is ensured for the local population and economy. In addition, the economic and social context in which fuel production takes place should be monitored.

The supply chain of synthetic fuels from international production facilities can be complex. For the effective monitoring, reporting and verification of sustainability criteria, the European Commission should set up an appropriate certification scheme, which covers all criteria mentioned.

This report can only outline the most relevant aspects for sustainable fuel production. For the formulation of a concrete set of criteria a much more thorough assessment of the issues is necessary. In the revision process of the RED such detailed sustainability criteria and related certification procedures should be developed. All synthetic fuels accounted for EU or Member States renewable energy targets or for the fuel blending obligation should be required to meet these criteria, proven by the related certification.

The process for the development of such criteria should be initiated before a large market for synthetic fuels develops, in order to avoid negative sustainability impacts similar to the situation of crop-based biofuels. The experience of the regulation of the market for biofuels in the EU has shown that a late introduction of appropriate requirements bears the danger of stranded assets and could undermine the credibility of synthetic fuels and EU renewable energy policy. Furthermore, similar sustainability criteria should be defined for electricity-based hydrogen and synthetic methane that is used in other sectors than transport in order to ensure an environmental benefit in these sectors as well.

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