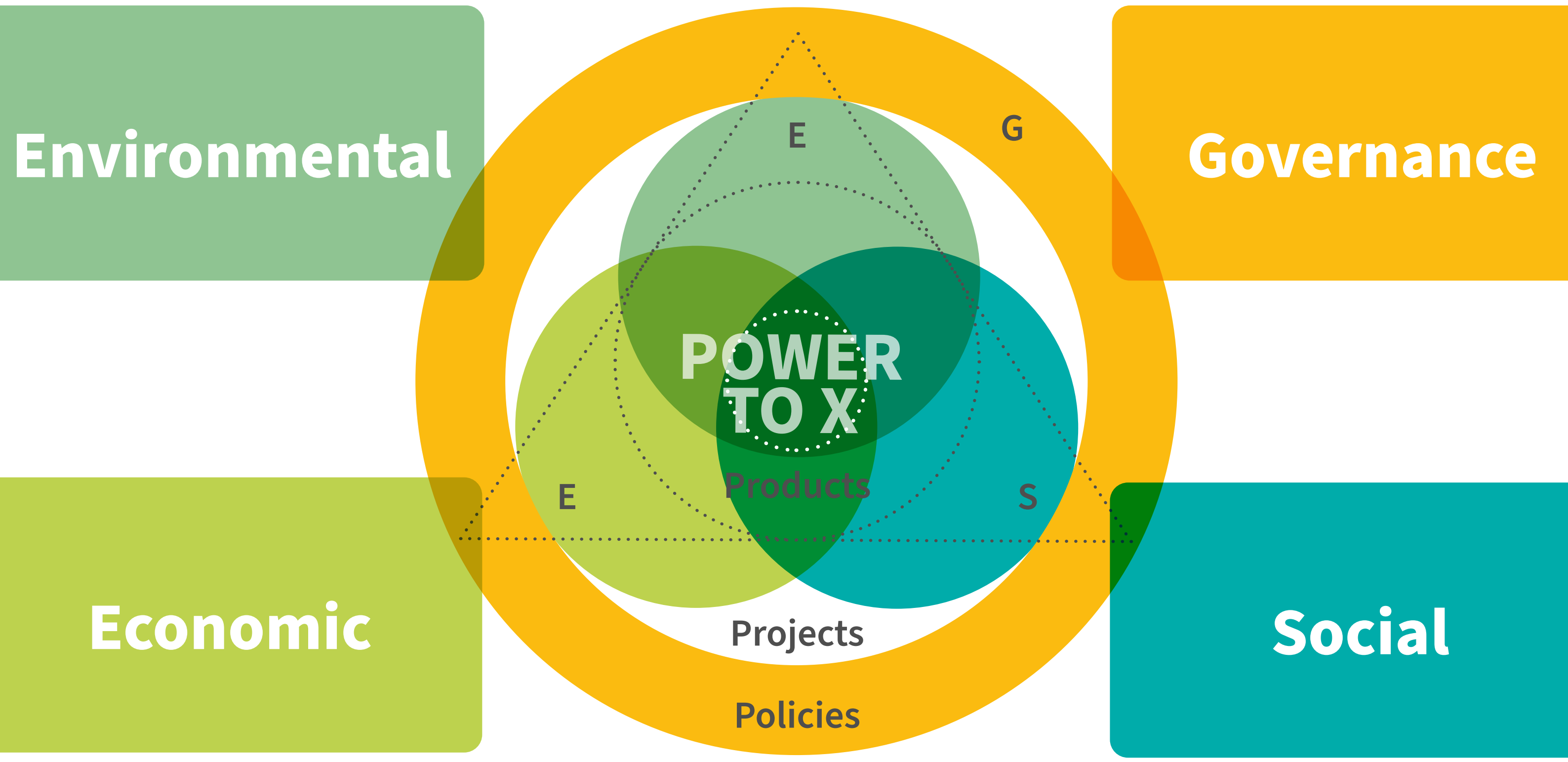
On behalf of:
Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety
of the Federal Republic of Germany

giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

PtX Hub Berlin

PtX.Sustainability
Dimensions and Concerns



Towards a conceptual framework for standards and certification

IMPRINT

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CONTENT

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INTRODUCTION

Power-to-X, the conversion of renewable electricity into molecules that can be used as fossil-free fuels and feedstocks in industry and transport, is an indispensable technology for a successful **transition towards a climate-neutral, defossilised economy and society**. However, this groundbreaking transformation must be a 'just transition' that contributes to economic prosperity, social equity and environmental integrity.

The PtX Hub was established in 2019 by the German Federal Government with the aim of catalysing PtX solutions on a global scale. A core component of its mission is to ensure that this process of transformative innovation contributes to the sustainable development of countries and communities, including in particular developing and emerging economies.

This **scoping paper on PtX sustainability** aims to

- contribute to the international debate on regulatory frameworks for hydrogen and its derivatives (e.g. ammonia, e-kerosene, etc).
- identify the key sustainability dimensions and concerns;
- outline a comprehensive and coherent framework for sustainability assessments;
- provide a solid basis for the implementation of sustainability standards and certification schemes.

The proposed **conceptual framework for PtX sustainability** presented in this paper:

- distinguishes four sustainability dimensions E-nvironmental, E-conomic, S-ocial and G-governance;
- sorts and groups the multitude of sustainability concerns into 16 distinct clusters.

In **Part I** of the paper, the context and fundamentals of PtX production and use are briefly outlined and the EESG-framework for sustainability assessment is presented.

In **Part II**, each of the 16 sustainability clusters is discussed in terms of its relevance for assessing PtX policies, projects, processes and products. This should reflect different territorial levels from (inter-) national to local and be applied along the entire PtX value chains.

While the conceptualisation and analyses have benefited from the intense debate on sustainability criteria in Germany and the EU, this paper also seeks to reflect in particular their relevance for PtX development in other parts of the world.

Thus, this scoping **paper does not yet define a PtX sustainability standard** with measurable indicators and thresholds. However, it aims at providing a conceptual basis for later translation of sustainability concerns into criteria for certification.

In **a next step**, evaluation checklists for specific purposes will be created. They should make it possible to define and evaluate PtX policies and to sketch-out related partnership agreements. They should provide guidance for PtX projects and investments and could help in setting-up and implementing funding and support programmes. They can also play a role in shaping conditions for internal and external trade and investment flows.

With a series of **PtX sustainability workshops**, the PtX Hub provided platforms for discussing the state of the debate on key sustainability issues. The preparation of this paper has benefited greatly from these international exchanges.

This **scoping paper is a stepping stone** on the way to developing and implementing standards and their certification based on measurable indicators, criteria and agreed thresholds. We welcome feedback and suggestions for amendments, additions and refinements. We by no means claim to provide definitive answers. However, we hope to make a useful contribution to the **urgent challenge of establishing regulatory frameworks** to ensure the sustainability of hydrogen and other PtX products and projects.

KEY MESSAGES

This section provides a brief summary of the main findings and conclusions of this scoping paper. For each PtX sustainability dimension and cluster of concerns, it highlights key messages concerning sustainability issues that should be considered when designing and implementing PtX projects and policies.

Key environmental messages ENV

PtX production, transport, storage and trade have manifold environmental implications. They should be carefully analysed in systematic risk assessments and environmental impact assessments (EIAs).
How inputs to PtX production such as water, land and minerals are sourced and managed is extremely important for assessing the sustainability of PtX projects and processes and products.

ENV 1: Energy and Carbon Cycle

- PtX electricity supply should always be renewable and additional.
- Carbon sources that guarantee a closed CO^2 cycle should be prioritsed.
- The use of carbon from industrial point sources should be limited

ENV 2: Water, Land and Biodiversity

- The use of hydric resources should not aggravate regional water stress.
- Desalination plants should respect strict standards for brine management and electricity supply.
- Even though PtX requires significantly less land than comparable technologies, the siting of installations should avoid areas with high carbon stocks or biodiversity value.

ENV 3: Resources and Recycling

- The PtX value chain relies heavily on critical raw materials (CRM). Options for prevention and extension should be analysed and recycling strategies adopted.

ENV 4: Pollution Risks and Safety

- PtX production, transport and storage must respect strict anti-pollution and safety standards based on EIA.
- The emissions linked to transport and storage should be included when assessing PtX carbon intensity.

Key economic messages ECO

PtX production and trade should contribute to improving economic prosperity and well-being.
Leap-frogging potentials should be taped.

ECO 1: Value Added and Decoupled Growth

- PtX can offer opportunities for leapfrogging over fossil dependency.
- PtX production should be well integrated into local productive networks, leveraging their potential.

ECO 2: Energy Mix and Transformation

- PtX should be an integral part of the energy transition.
- Stability of a region's power grid should be taken into account when assessing PtX sustainability.

ECO 3: Trade and Technology Transfer

- PtX export strategies should not hamper but stimulate domestic energy transition towards renewables.
- Technology transfer, promotion of innovation and the development of local knowledge should be key priorities.

ECO 4: Investment and Public Finance

- PtX should be included in public and private investment and funding schemes.
- Infrastructures such as pipelines and ports will have to be made PtX compatible
- Public finance should use the full spectrum of potential incentives and support mechanisms, including public procurement.

Key social messages SOC

The transformation of the energy systems and the introduction of new technologies like PtX always have major social implications
This is not just a transition. It must become a "Just Transition"

SOC 1: Access to Energy and Resources

- PtX should not weaken the fight against energy poverty.
- PtX should not conflict with people's access to essential resources, in particular water and land. This should be guaranteed and monitored along the entire value chain.

SOC 2: Jobs and Skills

- The potential for local and regional employment creation should be taped and where necessary, the transition from fossil to renewable industries should be facilitated.
- This implies e.g. reskilling and training of the labour force

SOC 3: Human Rights and Labour Standards

- Human rights and basic labour standards must be respected along the entire value chain.
- Sustainability assessments must include social concerns.
- Communities and workers should have access to grievance mechanisms and remedy

SOC 4: Health and Safety

- PtX health and safety standards must follow strict guidelines, with constant audits and updates

Key governance messages GOV

National and international standards and certification schemes should provide proper regulatory frameworks for ramping-up PtX markets and trade
Clear policy commitments, empowerment and participation of stakeholders are essential

GOV 1: Policy Commitment and Coherence

- Green hydrogen and PtX should be part of energy and climate strategies and included in NDCs

GOV 2: Stability and Rule of Law

- Political stability and respect for the rule of law should be important considerations when setting-up bilateral or multi-lateral partnerships

GOV 3: Transparency and Participation

- PtX policies and projects should follow strict transparency rules and establish effective anti-bribery mechanisms.
- PtX councils and roundtables should be established, and stakeholder trainings should take place.
- Inclusive bottom-up approaches should be encouraged

GOV 4: Standards and Certification

- PtX standards will play a key role in kickstarting the market and should cover the entire value chain.
- PtX Certification schemes should be transparent about assessment procedures and criteria.

1

PtX sustainability

Conceptual bases and frameworks

1 REACHING THE PARIS GOAL
PtX for defossilisation

In 2015 the **Paris Agreement on combating climate change** was reached at the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP 21). It aims to „holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change".

To achieve these targets global Green House Gas emissions (GHG) must be drastically reduced. In particular, energy related carbon dioxide (CO_2) emissions must decline. More recent reports (IPCC, 2020 and 2022) underline, that in order to meet the 1.5°C target CO_2 emissions should be halved by 2030 and net-zero should be reached globally by mid-century or sooner to avoid the worst impacts of climate change. Consequently, many countries raised their climate abatement targets and pledged to reach **carbon neutrality by 2050** or before.

Global CO_2 emissions
Paris Delta and Net Zero

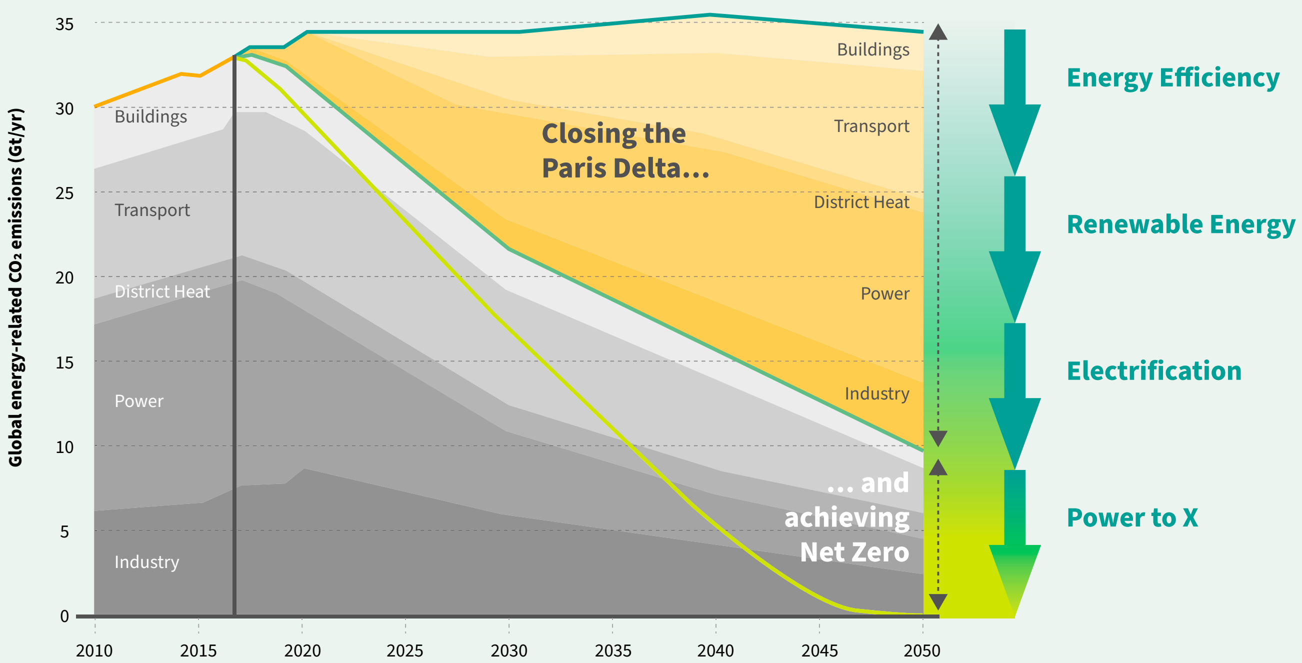


Figure 1. Source: Own adaptation based on IRENA (2018): Hydrogen From Renewable Power Technology Outlook for The Energy Transition p.10/1.

Figure 1 illustrates the enormous challenge. All sectors of the global economy will have to contribute to closing the gap between a business as usual scenario with almost stable CO_2 emissions and a pathway of massive reductions that is compatible with the Paris commitments. To **close the „Paris Delta"** it needs four transitions demonstrated by the downward arrows in Figure 1: (1) energy efficiency, (2) renewable energy, (3) electrification and (4) Power-to-X. They must all be advanced quickly and simultatiously. The first three alone will not be sufficient.

To effectively close the remaining „loop holes" and get to **a climate-neutral net-zero world** the fourth transition must be ramped-up in particular: Defossilisation with Power-to X (PtX) processes and products. The X stands for a wide variety of sustainable fossil-free fuels and feedstocks (S4F), which are required to reach net-zero GHG emissions also in those sectors of industry and transport, that can (so far) not be electrified. Here, in addition to green electrons, green molecules are needed.

2 DEFOSSILISED ECONOMIES
renewable and carbon neutral

For reaching climate neutrality with net-zero GHG emissions two complementary but distinct transformative changes are indispensable: **Decarbonisation and defossilisation.** Figure 2 illustrates both and demonstrates how PtX can contribute.

Whenever possible, e.g., by using wind turbines instead of coal-fired power plants or electric cars instead of cars with internal combustion engines, **direct electrification with renewable energy** sources should be prioritised. This change is called **decarbonisation.** It does not rely on carbon, neither from fossil sources such as coal, oil or gas, nor from renewable carbon such as CO_2 from the ambient air, carbon from biogenic residues or carbon captured from unavoidable industrial point sources.

However, there are sectors of industry and transport, which so far are **"hard-to-electrify",** or better, "hard or impossible to decarbonise". Examples are branches such as chemicals and pharmaceuticals, steel and cement as well as aviation and maritime shipping. These sectors need molecules which mostly contain carbon.

Here **indirect electrification with Power to X technologies** should be used to provide commodities that are either carbon free, like green hydrogen from electrolysis, or use only renewable carbon from closed cycles. This process is called **defossilisation**; thus, decarbonisation is a subset of defossilisation.

Power-to-X (PtX)
facilitating defossilisation

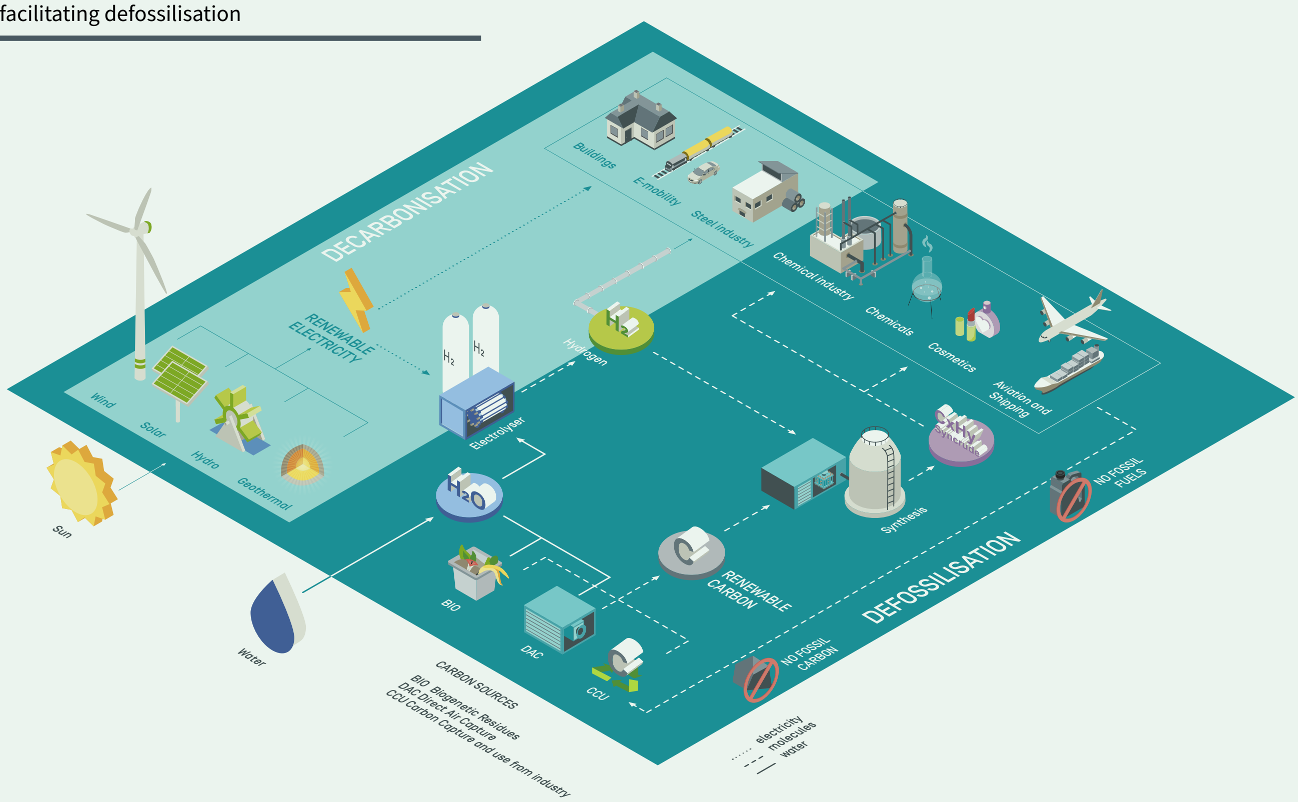


Figure 2. Source: Own adaptation based on nova Institut (2020): nova-paper-#12 on Renewable-Carbon 2020-09

PtX is the process of converting renewable electricity, from wind and sun, but also from hydro or geo-thermal power plants, into a wide variety (X) of end products. It starts with **producing hydrogen in electrolysers** using renewable electricity to split water (H2O) into its components hydrogen (H2) and oxygen (O2). These elements can then either be used directly or can be processed further in **PtX synthesis units.**

In **Haber-Bosch synthesis,** hydrogen is combined with nitrogen (N2) and converted into ammonia (NH3), a key feedstock for fertiliser production, but also used in chemical industry or possibly as fuel in maritime shipping.

In **Fischer-Tropsch synthesis,** hydrogen is combined with carbon monoxide (CO) to form all kinds of hydrocarbons, or a kind of synthetic crude oil often called syn-crude. Further processed, the syn-crude can be turned into specific products, such as Jet-fuel for aircrafts (Power-to-Liquid, PtL). In order to be carbon neutral, the carbon used should either stem from non-fossil, renewable sources, such as direct air capture (DAC) and biogenic sources, or be recycled from unavoidable industrial point sources (Carbon-Capture and Use, CCU).

As is the case for fossil fuels, there is **no one-size-fits-all** approach to PtX. Which technical route or end product makes the most sense in a certain context depends on factors such as demand, efficiency, robustness, and local conditions. Given the individual circumstances, there will always be more than one best solution conceivable.

Figure 3 puts this into a global perspective. It compares **mankind's global carbon flows** today (on the left) and in a defossilised future (on the right). First, total carbon demand will be much lower (i.e., decarbonisation), illustrated by the graphic on the right being smaller overall. Second, carbon from fossil sources (black area) must be eliminated altogether (i.e., defossilisation).

Mankind's carbon flows
today and tomorrow (2050)

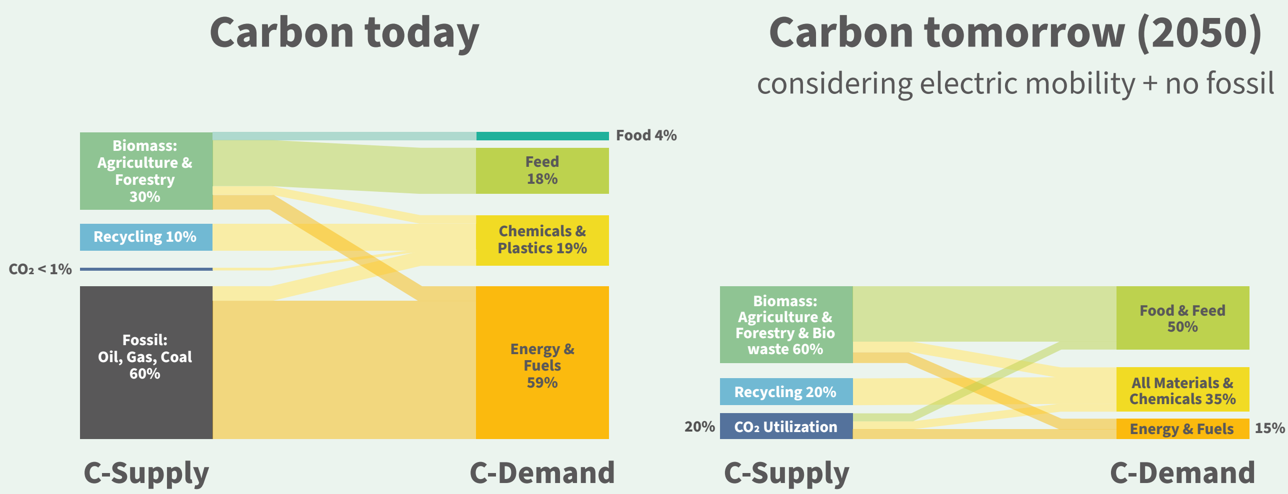


Figure 3. Source: Based on nova Institut (2020): nova-paper-#12 on Renewable-Carbon 2020-09

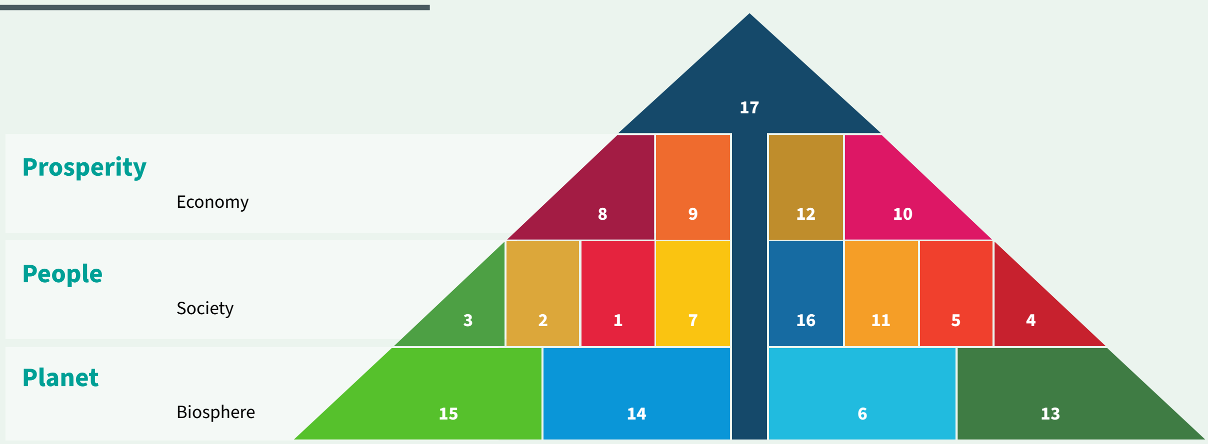
3 ACHIEVING THE SDGS

PtX for sustainable development

Climate policy and energy transformation should not be pursued in isolation. They must be in tune with **other global policy priorities and transitions.** Focussing on climate action and reducing emissions of carbon and other GHGs should not lead to ignoring other global environmental, societal and economic development challenges such as biodiversity loss, poverty, health and hunger. or growing inequalities.

In September 2015, shortly before the Paris Climate Agreement, the UN General Assembly adopted **“Transforming our world: the 2030 Agenda for Sustainable Development”** agreed by a summit of Heads of State and Government.
Agenda 2030 refers to the following dimensions: **planet, people, prosperity, peace and partnership.** In total, it sets out 17 sustainable development goals, the SDGs. (See them listed in Figure 4).

The SDG Pyramid
planet – people – prosperity



- 1 No poverty
- 2 Zero hunger
- 3 Good health and well-being
- 4 Quality education
- 5 Gender equality
- 6 Clean water and sanitation
- 7 Affordable and clean energy
- 8 Decent work and economic growth
- 9 Industry, innovation and infrastructure
- 10 Reduced inequalities
- 11 Sustainable cities and communities
- 12 Responsible consumption and production
- 13 Climate action
- 14 Life below water
- 15 Life on land
- 16 Peace, justice and strong institutions
- 17 Partnerships for the goals

Figure 4. Source: Own illustration inspired by the SDG‘s Wedding Cake by Johann Rockström, Pavan Sukhdev

Taking “urgent action to combat climate change and its impacts” (SDG 13) is only one of them. Yet, progress towards the Paris climate goals can have many positive effects on achieving also other SDGs. However, this will not be automatic. **Co-benefits and positive synergies** must be explicitly searched, maximised and supported. PtX policies, projects and processes should therefore be designed and implemented in a manner, that contributes to a “Just Transition”, which is at the same time economically efficient and effective, socially fair and environmentally sound.

To structure the 17 SDGs, three different layers can be distinguished: biosphere (environment), society and economy. In Figure 4 this is illustrated with **the SDG pyramid** inspired by the graphic “SDG’s wedding cake” proposed by Rockström and Sukhdev (2016). The EESG framework for PtX sustainability presented in the following sections is building on this conceptualisation and is extending it by adding a fourth dimension: governance.

4 THE EESG FRAMEWORK
for PtX Sustainability

Power-to-X is key to reaching climate neutrality.
PtX, converting green electrons into green molecules, will enable the defossilisation of economies necessary to reach the goals of the Paris Agreement. PtX will also contribute to reaching the Sustainable Development Goals (SDGs) by facilitating a just energy transition.

Critical bottlenecks for launching PtX production and ramping up PtX markets are not only technological or financial. What is missing in particular are **reliable regulatory frameworks** for green hydrogen (H2) and PtX products, projects and policies. Developing such frameworks, defining credible **PtX sustainability standards** and establishing corresponding **certification schemes** are priority tasks for all stakeholders involved. The private sector should proactively engage in their design. Yet, they must finally be endorsed and enforced by national policy and international agreements.

To kickstart the discussion on truly sustainable PtX with all its facets, the International PtX Hub Berlin has drawn up an **EESG Framework for PtX.** (See Figure 5)
It encompasses four basic dimensions: **Environmental, Economic, Social and Governance.**

While conventional ESG schemes often tend to be considered as add-ons to the core of economic and financial reportings, the PtX Hub's EESG proposal aims at **a more balanced approach** by fully integrating the economic dimension into an overall sustainability assessment.

For each of these dimensions, a multitude of sustainability concerns can be relevant. In order not to get lost in complexity, it is suggested to group them into **sets of four clusters for each dimension.** They indicate the main topics to be addressed. However, clusters and concerns have different weight depending on the relevance and risk profile of the specific assessment case, be it a production process, an investment project or a policy initiative.

PtX Sustainability
The EESG Framework

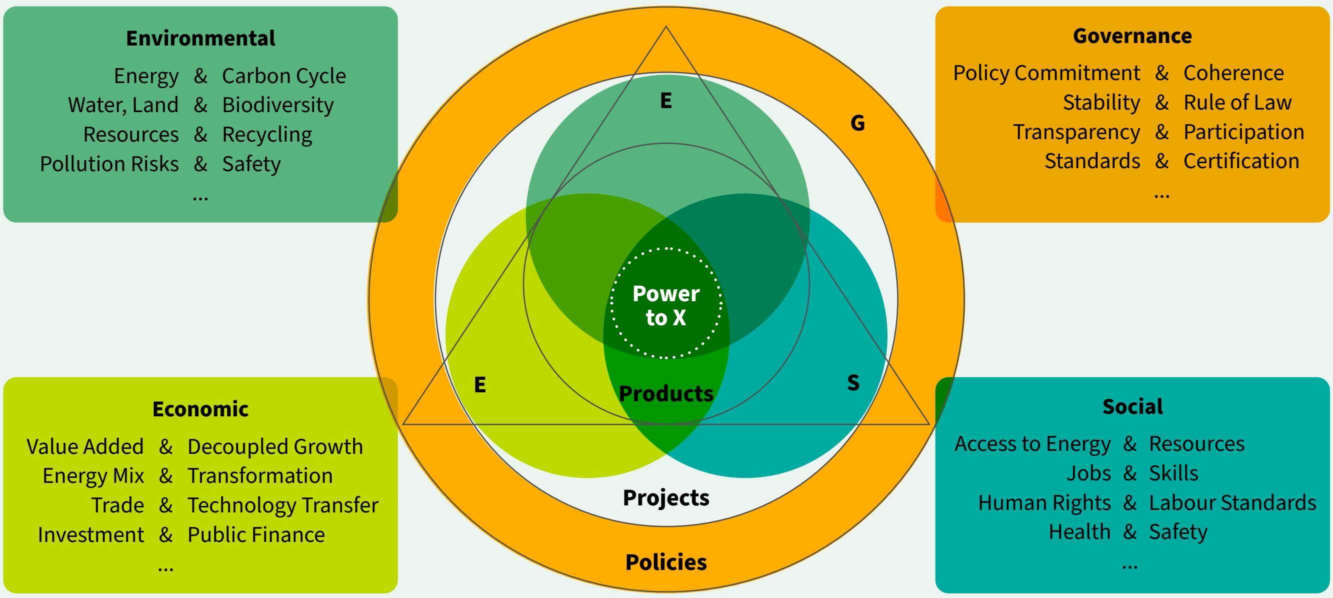


Figure 5. Source: International PtX Hub Berlin (2021) Own Illustration

4.1 Environmental Dimension

Energy & Carbon Cycle
Water, Land & Biodiversity
Resources & Recycling
Pollution Risks & Safety

Checking the environmental footprint of PtX is essential for any sustainability assessment. The **electricity used** in electrolysis, synthesis and refinement processes **should stem from renewable sources.** It should also be **additional** compared to an already envisaged path to expand renewables.

Another key concern is to ensure a **closed carbon cycle of PtX production and use.** This is relevant both for the initial power input into hydrogen production as well as for the carbon used in synthesis processes. It must be assessed whether the carbon stems from either Direct Air Capture (DAC), biogenic sources or Carbon Capture and Use (CCU), and how potential leakages can be avoided.

Hydrogen and PtX production must also go hand in hand with **sound management of water, land and biodiversity.**

In addition, **resource requirements,** such as the amounts of critical rare raw minerals needed and their recycling options, must be analysed.

Finally, **pollution and safety risks** of hydrogen and PtX production, storage, transportation and use must be carefully screened and subject to Environmental Impact Assessments.

4.2 Economic Dimension

Value Added & Decoupled Growth
Energy Mix & Transformation
Trade & Technology Transfer
Investment & Public Finance

From a (macro-)economic perspective, the production, use and trade of PtX products shall above all contribute to **creating added value and stimulating growth in income and employment.**

Economic growth, however, should be de-coupled from harmful environmental and climate emissions. PtX has great innovative potential. Together with international technology transfer this should ensure that the **energy transformation** – leading to a fundamental shift in the **energy mix** – away from fossil sources towards renewables – is mutually beneficial to all parties involved. This is particularly relevant when PtX products are traded internationally.

Assessing the economic dimension also requires a look at **infrastructure equipment and logistic needs.** In many cases transport costs are highter than PtX production costs.

Finally, **public finance** will be affected in many ways – through revenues from taxes and trade as well as expenses for infrastructure investment, support for renewables and PtX or by assistance for efforts ensuring a just transition.

4.3 Social Dimension

Access to Energy and Resources
Jobs & Skills
Human Rights & Labour Standards
Health & Safety

Developing PtX economies based on renewable energy has manyfold social and societal repercussions. The transformation of the energy system is not just a transition. It should **contribute to a Just Transition.**

Hence it is essential that PtX production does not negatively affect people's **access to energy or resources like water and land.** On the contrary, PtX projects could include new installations of renewable power capacity or desalination plants, which might even generate co-benefits. Wherever possible, such positive synergies and win-win opportunities should be sought and exploited.

PtX projects are promising **additional jobs,** yet energy transition may also result in job losses in fossil energy and related sectors. **Capacity building and trainings** that focus on new skills requirements must be deployed to ensure a net-positive outcome.

Ensuring **respect of human rights and of the ILO Core Labour Standards,** not only in the first tier but along the entire value chain, is non-negotiable. ILO conventions against forced labour, child labour, and discrimination must be respected as well as freedom of association and the right to collective bargaining. In many instances, however, this is not the case.

In analogy to the environmental pollution concerns, **health and safety risks** of PtX production, transportation and use must be monitored and avoided.

4.4 Governance Dimension

Policy Commitment & Coherence
Stability & Rule of Law
Transparency & Participation
Standards and Certification

Governance concerns are relevant for both public administration and corporate business conduct.

The **policy commitment to climate protection** should be reflected in the country's Nationally Determined Contribution (NDC) to the Paris Agreement. Hydrogen strategies and PtX roadmaps should be consitent with climate and sustainable development goals. Policy coherence, the degree to which climate policy is integrated across economic sectors and supported by societal groupings, is an important indication of its sustainability.

For domestic and international investment decisions **political stability, the rule of law and regulatory quality** are essential parameters. **Transparency** is key to avoid and fight bribery and corruption.

Broad participation and early involvement of local communities in the planning process, implementation and monitoring is critical. Only if all relevant stakeholders are not only informed and involved but **actively engaged and empowered,** will the transition to an energy system based on renewables and PtX result in a strengthened and sustainable economy and society.

Clear and consistent regulatory frameworks are essential for ensuring sustainability of PtX products, projects and policies. **Standards and certification schemes** must be established and enforced through effective governance structures and procedures.

4.5 Assessing the sustainability of Power-to-X

The EESG Framework for PtX aims at **sketching out a complete dashboard.** Yet, its actual use and the **prioritisation of concerns** will have to depend on the respective evaluation task and the specificity of the observed case.

The **full set of sustainability clusters and concerns** is not always relevant at every assessment level – it depends on whether the focus is on PtX projects, products, processes or on policies. Neither do they apply at every link in the PtX value chain.

Their relevance should be screened in a **due diligence process** reflecting the respective risk profiles. For example, while some environmental and social concerns will be particularly relevant for impact assessments at the local and regional level, governance concerns are often more relevant when assessing the broader context of national and regional economies, societies and administrations.

5 ASSESSMENT FOCUS levels and links

Comprehensive sustainability assessments need to be undertaken
- **at different levels** – territorial and analytical - and
- **at every step** of the value chain.

Focussing sustainability assessments on **PtX product characteristics** alone is not enough. In addition, it is necessary to consider the **entire production process.** Both **up-stream,** along the supply chain, from the generation of renewable energy and the conversion of water by electrolysis into oxygen and hydrogen, as well as **down-stream** towards the final feedstock and fuel use options, taking into account synthesis and refinement processes, as well as storage, transport and logistics.

Finally, beyond the levels of PtX products as well as PtX processes of their production and dissemination it is important to also assess the wider **policy context and governance frameworks** set for regulation and support.

PtX Sustainability assessments
at different levels

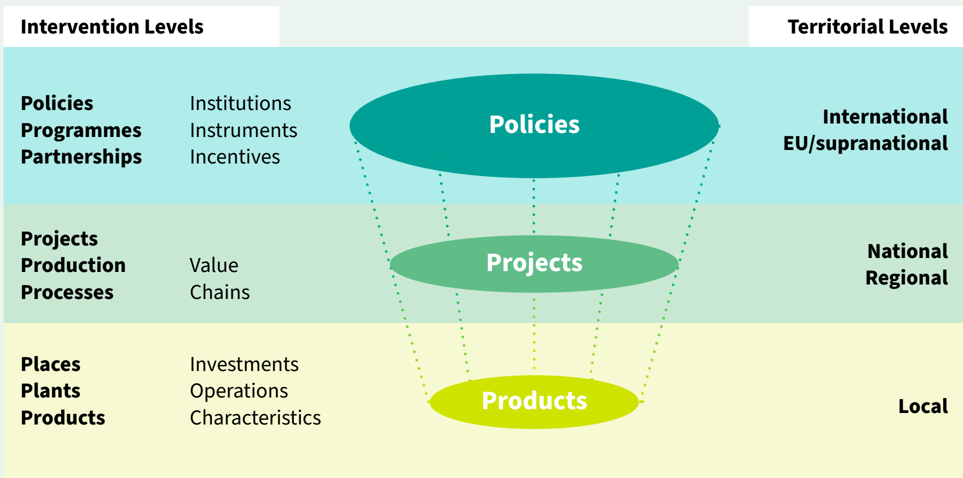


Figure 6. Source: International PtX Hub Berlin (2021) Own Illustration

Accordingly, sustainability assessments will have to distinguish and identify the appropriate **territorial levels of analysis.** They reach from the **local level,** where the focus is on plant operations and investments, and their impact on local ecosystems, economies and societies, to the **regional and national level,** where structural and systemic inter-linkages must be analysed. Finally at international level even global **geo-physical and geo-political balances** might be affected.

PtX Sustainability assessments
at every step of the value chain

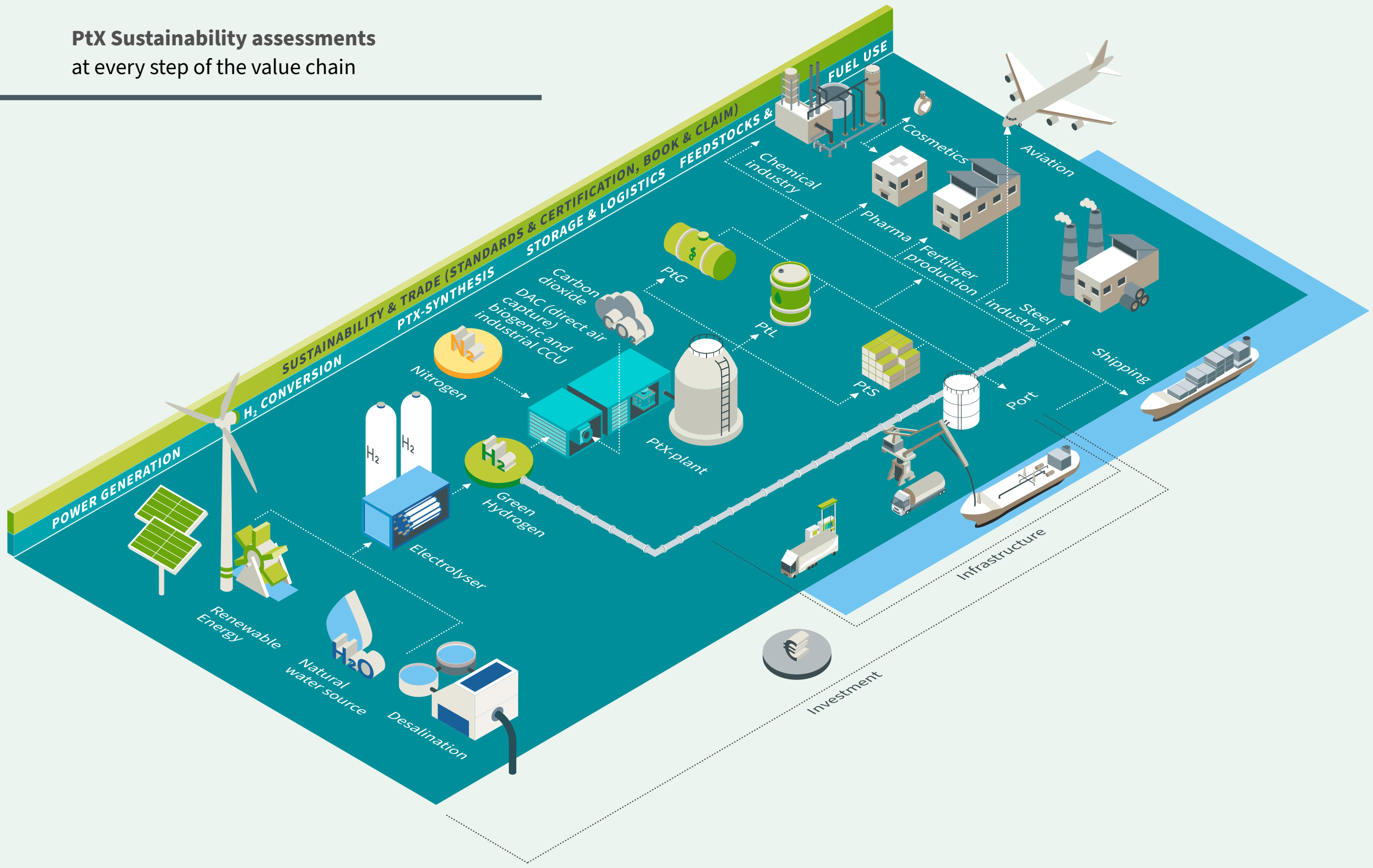


Figure 7. Source: International PtX Hub Berlin (2021) Own Illustration

Sustainabilty concerns must also be considered **along the entire PtX value chain,** from the footprint of renewable power instalations, such as solar instalations, on- and off-shore wind parks, as well as hydro and geo-thermal power facilities to the final end use of feedstocks and fuels for industry and transport sectors. Availability and management of water and carbon sources must be assessed. Opportunities and risks of handling hydrogen and derived PtX products, their storage and tranportation require careful analysis.

2

PtX Sustainability

Dimensions and Concerns

The EEG Framework for assessing PtX sustainability – presented in PART I of this paper - distinguishes four sustainability dimensions related to the Environment, Economy, Society and Governance. Each dimension covers a wide range of sustainability concerns, which can be grouped into four clusters. Figure 8 provides an overview on the total of 16 sustainability clusters which will be addressed in this paper.

PtX Sustainability
4 dimension – 16 clusters of concerns

ENV	Concerns	ECO	Concerns	SOC	Concerns	GOV	Concerns
Energy & Carbon	ENV 1	**Value Added & Decoupled Growth**	ECO 1	**Access to Energy & Resources**	SOC 1	**Policy Commitment & Coherence**	GOV 1
Water, Land & Biodiversity	ENV 2	**Energy Mix & Transformation**	ECO 2	**Jobs & Skills**	SOC 2	**Stability & Rule of Law**	GOV 2
Resources & Recycling	ENV 3	**Trade & Technology Transfer**	ECO 3	**Human Rights & Labour Standards**	SOC 3	**Transparency & Participation**	GOV 3
Pollution Risks & Safety	ENV 4	**Investment & Public Finance**	ECO 4	**Health & Safety**	SOC 4	**Standards & Certification**	GOV 4

Figure 8.

Each cluster and concern merits careful assessment. Only comprehensive and rigorous analyses of risks and impacts finally leading to solid standards and certification schemes will help to avoid future failures due to neglected hazards. They must ensure that the emerging PtX markets are developing in accordance with fundamental sustainability principles.

Since at this stage the main focus of the PtX sustainability debate is focussing on environmental matters, the paper starts off with the environmental dimension.

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1 ENVIRONMENTAL DIMENSION

The PtX value chain starting from its energy sources and the generation of electricity, to the production of hydrogen and its further processing to a range of different final PtX products through synthesis and refinement, their storage and transportation, has many environmental linkages. On the one hand environmental resources such as water are used as production inputs. On the other hand the integrity of ecosystems and biodiversity may be threatened by actual or potential impacts. The following section will discuss some of the most relevant aspects.

1.1 ENV 1: Energy and Carbon

1.1.1 Electricity

Electric power is the main input to Power-to-X (PtX) production. Therefore, the origin of electricity and its integration into the power system are decisive factors for determining its sustainability. Two characteristics are of key importance: Renewability and additionality.

1.1.1.1 Renewability

For PtX products and processes to be considered sustainable they should be fossil-free produced with electricity stemming from renewable sources, such as wind, solar, hydro or geothermal energy. The type of energy used to produce hydrogen and PtX products has the strongest impact on its carbon footprint.

Converting electricity into hydrogen and PtX products inevitably leads to a loss of available energy. To produce 1TWh of hydrogen 1.4 TWh of electricity is required – with significant variations e.g., due to electrolyser full load hours. Accordingly, the Green House Gas (GHG)-intensity incorporated in power-based hydrogen from water electrolysis will always be higher than that of the electricity used for its production.

In Figure 9 this is reflected in the declining line assuming an efficiency of 70%. If, for example, the electricity used in electrolysis has a carbon intensity of 500 g CO_2/kWh the CO_2 intensity of the hydrogen produced will be in the order of 700 g CO_2/kWh. Carbon intensity of grey hydrogen from natural gas is currently in the order of 300 g CO_2/kWh. Thus, electricity-based hydrogen will only be preferable if the carbon intensity of the electric current used is significantly below 200 g CO_2/kWh.

In 2018 the carbon intensity of power from the the German electricity grid was still in the order of 470 g CO_2/kWh. Even under an ambitious Climate protection scenario it would not get below 230 g CO_2/kWh in 2030. Thus, carbon intensity of hydrogen would still be above 300 g CO_2/kWh. So using electricity from the grid, which still includes power of fossil origin, would still not result in less emissions. A significant reduction, e.g. of 70 % could only be achieved if approximately 90% of the electricity used would be carbon-free (Global Alliance Powerfuels, 2020a).

However, renewability of the electricity source alone is not enough to qualify PtX as sustainable. It must also meet the condition of additionality.

CO_2 intensity of hydrogen
from German grid electricity (2018, 2030)

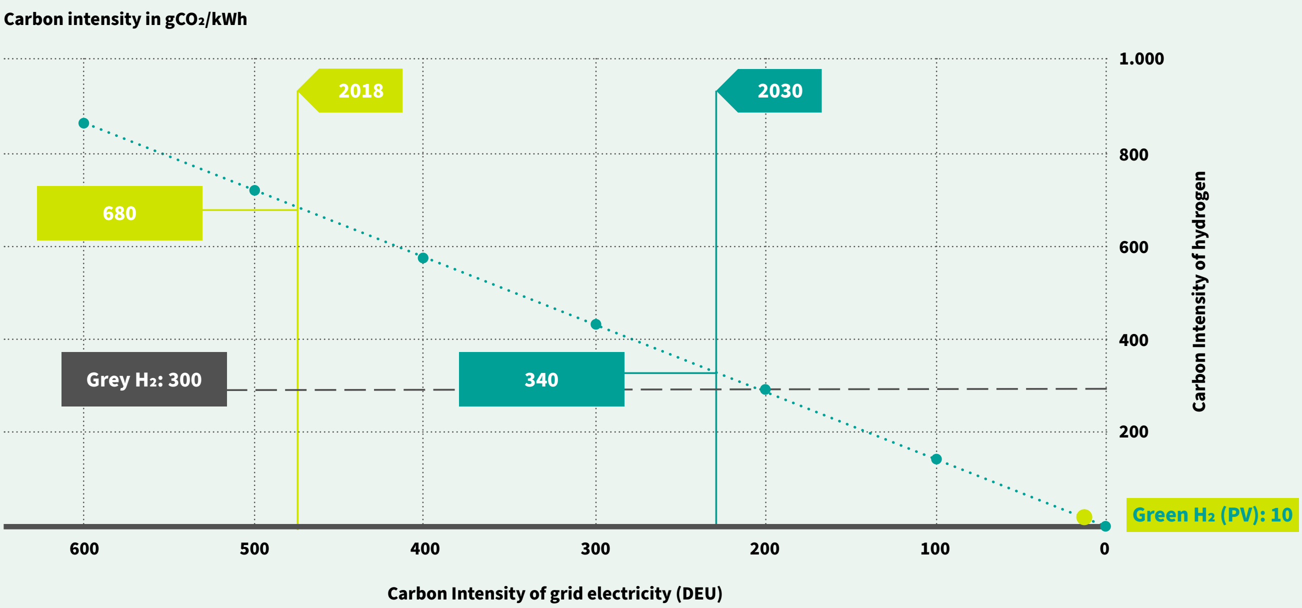


Figure 9. Source: Own illustration adapted from Öko-Institut (2019). Not to be taken for granted: climate protection and sustainability through PtX

1.1.1.2 *Additionality*

The energy used for PtX production should stem from **additional renewable capacity** explicitly dedicated towards PtX production. Otherwise, renewables based PtX production would – "through the back door" – lead to an increase in fossil-based power use in other market segments. Without additionality PtX production risks undermining the overall energy transition and defossilisation efforts.

As visualised in Figure 10 PtX production must meet both conditions: Renewability and additionality. Without adding new renewable capacity, the increase in electricity demand caused by PtX production would be covered by fossil sources.

PtX electricity demand
with and without additionality

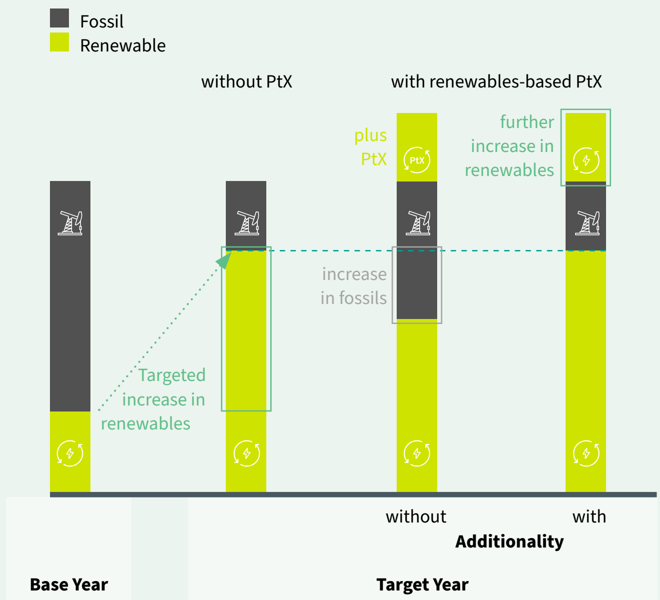


Figure 10. Source: Öko-Institut (2019)

Depending on the type of electricity sourcing for PtX the conditions for ensuring renewability and additionality will need further specification. For the EU market the Renewable Energy Directive (RED II) is defining how additionality should be understood. With the up-coming Delegated Act renewability and additionality conditions will be further specified. For example, the EU is demanding further information on both

- the geographic correlation and
- the temporal correlation

between the generation of electricity and its use in PtX production facilities.

In case the PtX unit has a direct connection to a new local off-grid installation generating renewable electricity, it is obvious that its electricity supply can be considered renewable. However, according to the EU regulation, the additionality condition is met only if the plant does not benefit from policy schemes aimed at supporting the overall power shift towards renewable electricity.

If electricity is sourced from the grid, PtX producers should be able to provide evidence that their electricity use is neither weakening the stability of the power system nor undermining efforts to defossilise the power mix.

While Guarantees of Origin (GOs) can provide information on the geographic links, they do not provide evidence on the temporal correlation. Therefore, more detailed Power Purchasing Agreements (PPAs) are required providing further specific information on the synchronisation between power generation and consumption.

Geographic correlation should prevent the aggravation of potential bottlenecks in power transmission between supply and demand locations. For example, in the case of pre-existing grid congestions, the renewable electricity unit and the PtX production plant should be situated on the same side of potential bottlenecks.

Within the EU these considerations already raise issues of how to properly define the respective territorial units (bidding zones, market areas, etc) and the temporal synchronisation required between power generation and the consumption by PtX facilities such as electrolysers, carbon sequestration, synthesis and refinement installations.

With regard to PtX ex- and imports it remains to be seen, how the EU's REDII rules can be applied to hydrogen and derived products such as ammonia or e-fuels. Conditions may have to be further specified, reflecting i.a. differences in the electricity market designs among countries. Exporting countries should at least be able to prove how PtX production pathways are integrated into their overall energy development and climate protection strategies, as well as their Nationally Determined Contributions (NDCs)

In order not to stall efforts for domestic and international market ramp-up with high entry barriers it may be necessary to consider transition clauses allowing for a phasing-in period, defining until when geographic and temporal correlation conditions should be met.

Another aspect to consider relates to the way, renewable energy supply is supported by policy schemes such as feed-in tariffs paid by consumers. PtX production should not divert and benefit from public funding aimed at supporting the transformation of the power mix towards renewable electricity. Instead, PPAs should specify how PtX producers contribute to the funding of expansions of renewables capacity.

1.1.2 Carbon Cycle

Hydrocarbons. mainly in the form of gases (e.g methane) or liquids (e.g. synthetic e kerosene), but also as waxes (e.g. paraphing) or polymers (polyethylene), are among the most sought-after PtX products. They consist of hydrogen and carbon.

These synthetic products can only contribute to climate-neutrality if not only the hydrogen part is “green”, produced with a carbon intensity close to zero, but also if the carbon used in the synthesis process (Fischer-Tropsch) is not adding to the atmospheric accumulation of Green House Gases (GHG). Therefore, the carbon component embedded in synthetic PtX fuels and feedstocks should ideally stem from a closed carbon cycle.

A carbon cycle describes the process by which carbon atoms are exchanged from the atmosphere to the earth and then back into the atmosphere. Figure 1.1.2-1 illustrates different kinds of carbon cycles for PtX products. In a closed cycle, every carbon molecule that is emitted in the air is sequestrated back into the earth. The smaller the cycle, the less time carbon stays in the atmosphere.

Assuming PtX production is based on renewable carbon inputs, sequestered from the atmosphere and stocked in synthetic hydrocarbons, then combusting these synthetic hydrocarbons, would emit CO_2 back into the atmosphere, thereby closing the PtX carbon cycle.

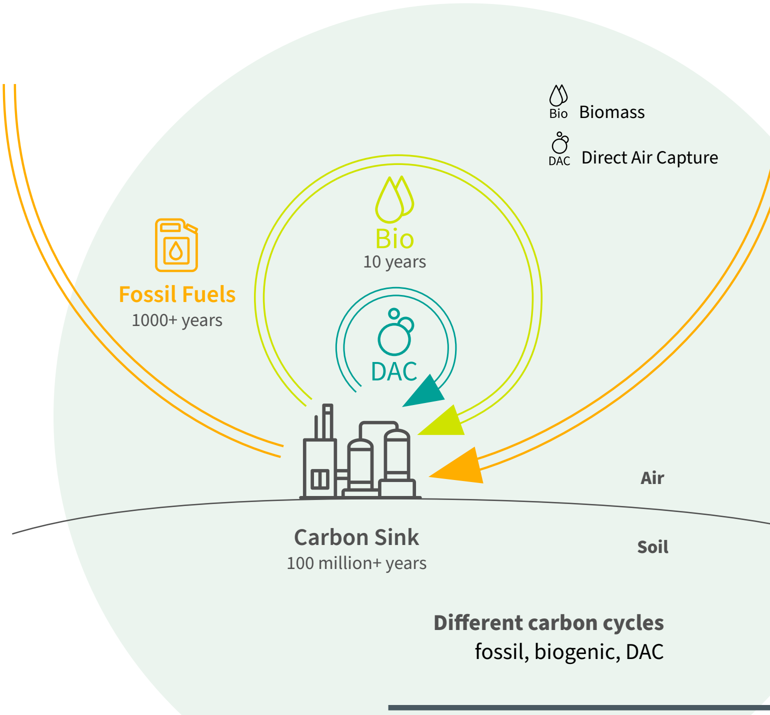


Figure 11a. Source: Own illustration

1.1.2.1 Ambient air

Capturing carbon from ambient air through **Direct Air Capture (DAC)** ensures a closed carbon cycle. CO_2 concentration in ambient air shows little variability across different regions and its availability as a feedstock is not expected to decrease significantly in the long-term. For these reasons, atmospheric CO_2 can be regarded as the best long-term solution.

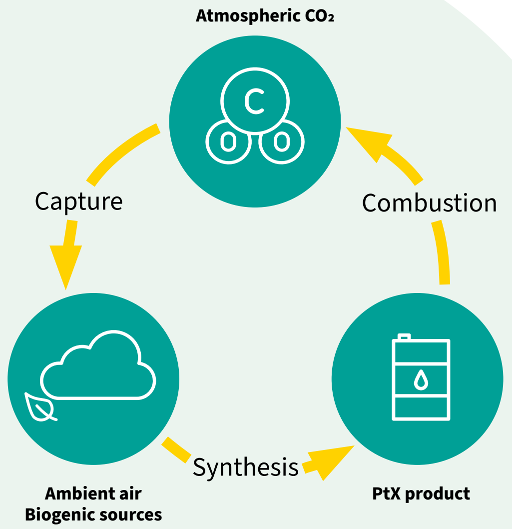
However, DAC is an **energy intensive process** also occupying significant amounts of land. Thus, the same **requirements as for electricity** (see section 1.1.1) **as well as for land and biodiversity** (see section 1.2.2) should be met.

Currently, DAC technologies have **not yet reached the level of technology readiness** needed for them to dominate PtX production in the short-term. They are likely to stay expensive for quite some time (Öko-Institut, 2019).

1.1.2.2 Biogenic sources

Carbon captured from **biogenic sources** such as biogas, bioethanol, solid biomass combustion or fermentation processes also has the potential to ensure a renewable, closed carbon cycle. However, the availability of biomass is **limited** and **unevenly distributed.**
For example, in Europe up to 500 Mt of biogenic CO_2 per year are currently available, which could theoretically satisfy approximately 10% of the projected 2050 demand (Global Alliance Powerfuels, 2020b). However, the actual utilisation potential is only a fraction of this amount, due to the variable dilution of flue gases. Moreover, only production units with a certain dimension can efficiently allow for carbon capture, reducing the usable fraction of biogenic carbon even more. This means that the use of biogenic carbon sources has **limited scalability** and will **not be able to satisfy future demand on its own.**

However, the capture of carbon from biogenic sources could play an important role in kickstarting the PtX market, as it is the only renewable carbon source to offer sufficient levels of technology readiness.
In this context, it is important that the used biomass respects all the established **sustainability criteria for biomass products,** especially for the risks related to direct and indirect land use change (ILUC) and biodiversity (see section 1.2.2).



Different carbon cycles
renewable carbon (biogenic, DAC)

Figure 11b. Source: Own illustration

1.1.2.3 Industrial point sources

Industrial point sources can also provide options to collect CO_2 via Carbon Capture and Usage technologies (CCU). However, they do **not ensure a closed carbon cycle,** since the carbon comes from fossil resources used in industrial processes. Therefore, **carbon coming from industrial point sources cannot be considered renewable.**

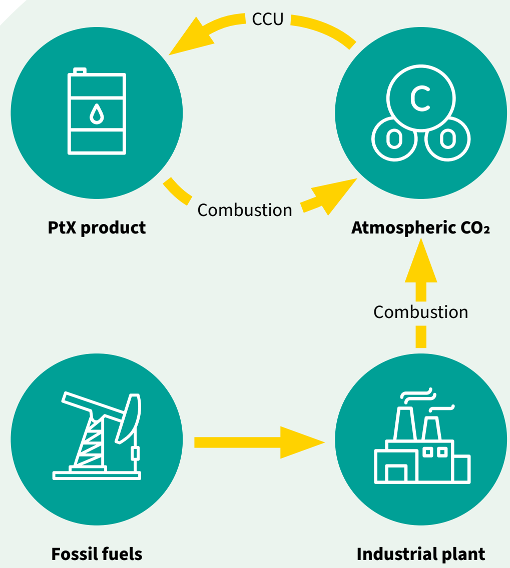
The use of CCU technologies is problematic in other respects as well (Öko-Institut, 2019). They affect the industrial processes, and risk reducing their **efficiency** thereby potentially inflating fossil energy demand. They also may lead to a **lock-in** into technologies that should be phased out or they may create price incentives in favour of fossil powered processes.

On the other hand, CCU technologies have the advantage of demanding much lower energy requirements compared to DAC. They also have a higher level of technological readiness compared to DAC units. CO_2 concentration of industrial exhaust gases can be between 100 and 300 times higher than for ambient air, which makes them **economically attractive** (Global Alliance Powerfuels, 2020b).

Recycling industrial carbon emissions may thus be a valuable option allowing for a **fast upscaling of PtX** production. Ideally, this should only be promoted in sectors where emissions are inevitable even in a defossilised and fully electrified economy, such as cement production.

In case there is further need to make use of CCU technologies (e.g., for kick-starting PtX production and markets) it should be ensured that lock-in effects are avoided, e.g. by establishing guidelines for contracted industrial plants. No new streams of carbon should be used, and the proportion of fossil CO_2 emitted should be reduced over time (Öko-Institut, 2019).

Finally, to address the efficiency issues, it should be guaranteed that contracts are given only to plants that can prove highly efficient processes.



Different carbon cycles
fossil carbon with CCU

Figure 11c. Source: Own illustration

PtX Hub
Berlin
On behalf of:
Federal Ministry
for the Environment, Nature Conservation
and Nuclear Safety
of the Federal Republic of Germany
giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH

Figure 12 provides an overview on the pros and cons of the potential carbon sources for Fischer-Trobsch PtX synthesis processes, with regard to their availability and scalability, their technological maturity and current costs. It also lists potential sustainability issues.

Comparison of different carbon sources
DAC, biogenic, CCU

Sources	Closed carbon cycle	Availability & Scalability	Technology maturity	Costs	Sustainability requirements
Ambient air (DAC)	✓	high	low	high (currently)	**Upscaling needs** **Energy requirements** **Land use management**
Biogenic sources	✓	medium	high	**low,** but depend on **regional availability**	**Land use risk** (ILUC) **Biodiversity risk** **Efficient allocation** (e.g. biofuels)
Industrial point sources (CCU)	X	low	medium-high	low	**Lock-in risks** (for fossil technologies) **Phase-out trajectories** **Contracts only with** highly efficient **hard to electrify industries**

Figure 12. Source: Own illustration

1.2 ENV 2: Water, Land and Biodiversity

1.2.1 Water

Water is at the very base of green hydrogen and PtX production. In addition to electricity, it is the most important input to water electrolysis. Analyses of water stress and resource needs are essential for any PtX sustainability assessment. Potential water conflicts and possible solutions, such as desalination should be evaluated. Economic costs but also ecological impacts on aquatic ecosystems as well as social implications and eventual co-benefits should be taken into account.

1.2.1.1 Water stress

Most regions with the greatest wind and solar potential for generating renewable electricity and hydrogen are already today facing severe water stress. These include North-Africa and the Gulf region but also Australia, Chile and even Spain. (See Figure 13)

Water stress
regional risk levels

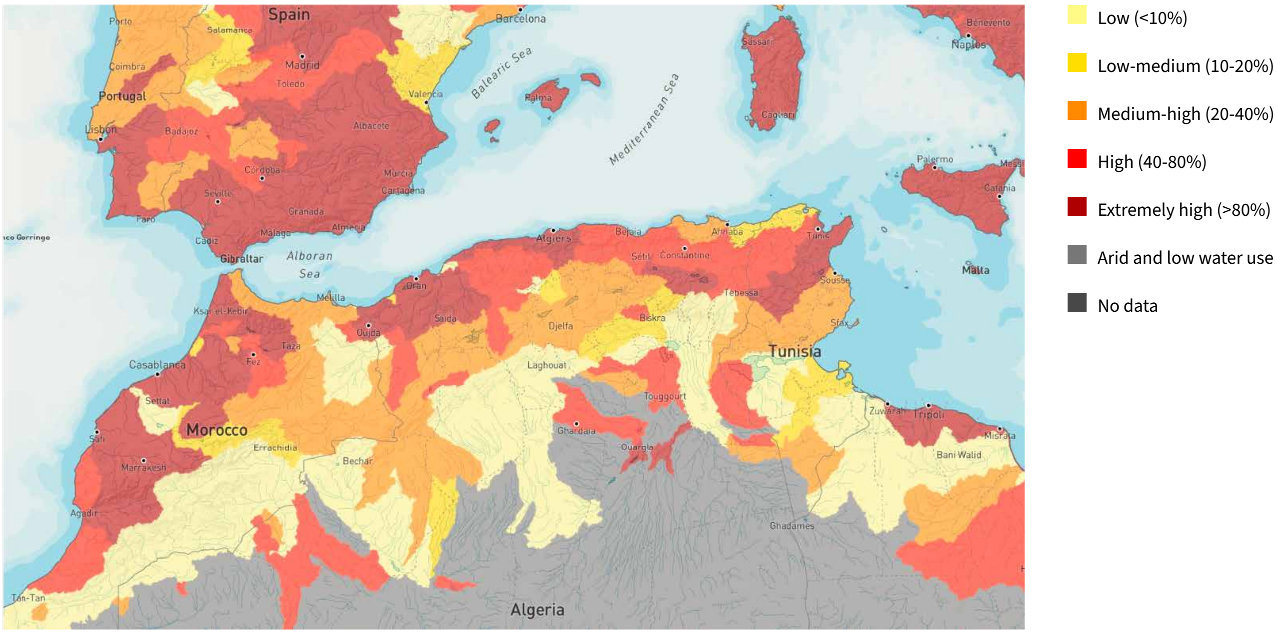


Figure 13. Source: World Resource Institute (WRI Aqueduct) Aqueduct Water Risk Atlas 3.0

Global warming is likely to deteriorate the situation. Conflicts over access to water between PtX production on the one hand, increased drinking water demand from growing populations the other, must be avoided. Potential trade-offs and negative impacts need to be carefully assessed. According to IRENA (2022) more than 70% of planed electrolyser projects will be in water-stressed countries.

Data bases and indicator systems such as the World Resources Institute's Aqueduct 3.0 (WRI, 2019) or the Water Risk Filter 6.0 by WWF (2021) provide already solid evidence for assessing not only physical but also regulatory and reputational risks. They could serve as blueprints for the further development of water related PtX sustainability standards.

1.2.1.2 Water footprint

Fortunately, a closer look at overall figures reveals that PtX requires much less water than other uses and might even help reducing water stress and improving water management.

For the 409 million tonnes of green hydrogen needed by 2050 in IRENA's 1.5°C pathway approximately 7-9 billion cubic metres of water a year would be required. This is less than 0.3% of current freshwater consumption. Today's municipal and industrial water consumption together is 50 times higher than the expected water needs for hydrogen production in 2050. Agricultural water consumption is even 100 times bigger (IRENA 2022). But also compared to fossil thermal power generation or to blue hydrogen, water intensity of green hydrogen from from wind, sun and electrolysis is significantly lower. Thus, shifting from fossil to renewable power and hydrogen would actually help ease water stress.

Water Use for Sustainable Aviation Fuels (SAF)
(litre H_2O / litre SAF)

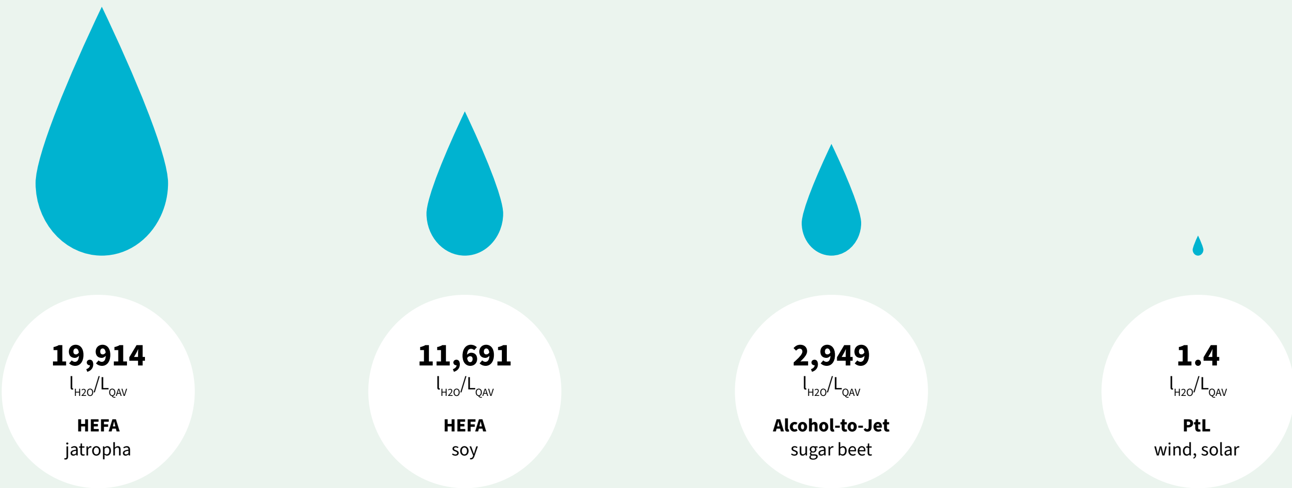


Figure 14. Source: Own calculations based on UBA (2016)

According to the German Environment Agency (UBA, 2016), water demand for PtL kerosene is around 1.4 litres of water per litre of fuel. As shown in Figure 1.2.1-2 this is several orders of magnitude lower compared to water demands for biomass feedstock. Sustainable Aviation Fuel (SAF) requires water in the range of 3,000 litres per little of AtJ (Alcohol-to Jet) from sugar beets to even 20,000 litres for HEFA (Hydrotreated Esters and Fatty Acids) from oil plants such as Jatropha. Even considering potential water **requirements to clean and cool solar systems,** which can increase the overall water demand to around 70 litres per liter of fuel (Cerulogy, 2017), the water demand is still comparatively low.

1.2.1.3 Desalination

None the less, in many arid regions PtX production will have to go hand in hand with water desalination. According to IRENA (2022) over 85% of the currently planned green hydrogen projects may need to source water via desalination.

Desalination is energy intensive and the electricity needed should meet the same standards as for electrolysis (See Section 1.1.1). Yet, the additional costs for hydrogen production are marginal. With USD 0.02 to 0.0.5 the price increase per litre of hydrogen would be less than 5%. (Blanco, 2021). Therefore, in an integrated manner PtX projects should systematically consider potential co-benefits of desalination, which could contribute to alleviating local and regional water stress by providing water also for households, industry and farming. (See Section 3.1)

However, desalination raises serious environmental issues, in particular with respect to the disposal of brine. For every litre of potable water, about 1.5 litres of brine is produced, a hyper saline liquid polluted with chlorine, copper and chemicals. If disposed in sea or fresh water, it has negative effects on aquatic ecosystems. Increased salinity and temperature can decrease the dissolved oxygen content, potentially affecting various organisms along the food chain. These effects appear to be mostly limited to the backflow area of the considered water body, but there are currently insufficient studies on the effects in the long term (Öko-Institut, 2019).

To minimize negative externalities of brine disposal, independent ecological assessments based on local indicators should be made mandatory. Governments should establish policies obliging companies to treat the brine before disposal and to choose the location with the least impact. Options for recycling parts of the brine's minerals and chemicals and integrating them into industrial value chains should also be explored.

1.2.1.4 Other options

In the long run, making use of **DAC technologies** could help diminishing water demand. With regional variation, water concentration in ambient air could allow for the collection of water as a by-product, potentially supplying it as input to PtX production, therby ensuring a partially closed water cycle.

1.2.2 Land and Biodiversity

Growing PtX production will have significant implications for land use and will thereby also affect biodiversity. Even though PtX production plants alone don't require a lot of space, the renewable electricity generation facilities that run them do. DAC technologies are area-intensive as well. Moreover, due to their lower energy efficiency compared to direct electricity applications PtX products carry a bigger land use footprint.

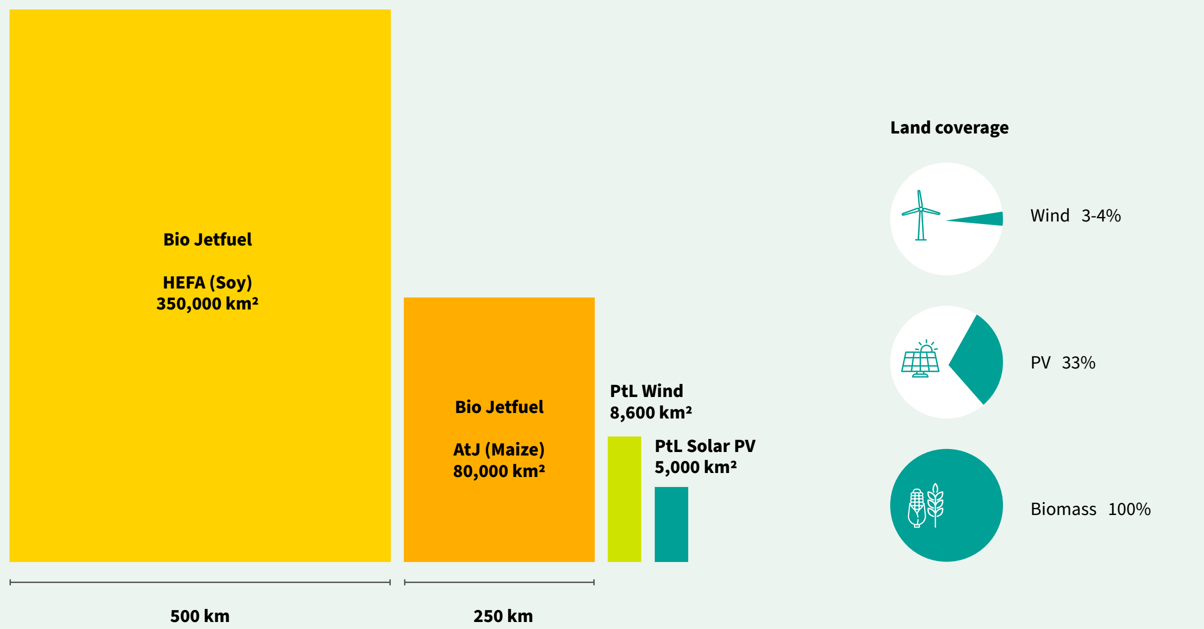
1.2.2.1 Land use footprint

In densely populated Northern countries such as Germany the installation and extension of wind and solar parks is already hitting limitations in many areas. Not only on-shore but also off-shore spacial planning must consider and prioritise overlapping land use functions and competing claims.

In Southern arid regions, with vast unoccupied areas without vegetation PtX production from renewable electricity is usually not facing major land use constraints. None the less environmental implications should be thoroughly analysed when new installations are put in place.

Like with the water footprint graph in the previous section Figure 15 tries to illustrate orders of magnitude of the land footprint of different Sustainable Aviation Fuel (SAF)-types, assuming a 5% blend in total global jet fuel consumption or 17 billion tons p.a.. The land area required ranges from 5 to 350 thousand square kilometre. For biofuels the footprint is up to 70 times bigger than for E-kerosene.

Land Use for Sustainable Aviation Fuels (SAF)
(Area required for 5% Jet-fuel blend)*



* Area required by different SAF types for a 5% blend in total International Jet Fuel (17 mil tonnes Jetfuel)

Figure 15. Source: Own calculations based on UBA (2016)

Furthermore, while biomass production is covering 100% of the land, wind turbines only occupy 3-4%, PV panels only about a third. This means, land demand for PtX SAF is far less competing with farming activities. As innovative agro-photovoltaic (APV) systems, combining energy generation with food production, demonstrate, wind and solar installations can even trigger beneficial synergies with horticulture, arable production or animal grazing. In arid climates, potential benefits can be expected through additional shading and resulting improvements in water productivity. (Weselek, Ehmann et.al. 2019)

1.2.2.2 Biodiversity impact

PtX induced land use changes might also have biodiversity implications. They should be carefully monitored, although in most cases PtX interference with landscape ecology and species diversity is less severe than the impacts of biomass production. Wind turbines, however, often represent risks for birds and bats. Off-shore wind parks also interfere with marine ecosystems and fish populations.

To avoid negative biodiversity impacts, PtX plants and the renewable electricity sites powering them, should not be located in high-nature-value landscapes and protected conservation areas, be they on land or off-shore. Huge installations, sometimes covering several thousands of hectares, can fundamentally alter habitats not only ecologically. They also change the aesthetic of landscape amenities and can thereby infringe upon cultural heritage and identities.

1.3 ENV 3: Resources and Recycling

The availability, use, dispersion or recycling of raw materials is an important aspect in assessing the sustainability of PtX production processes and technologies. This is particularly true for so called critical raw materials which are scarce, hard to replace or produced under conditions exposed to human rights challenges etc. The following sections exemplify the relevance of access to resource, availability of critical raw materials as well as of options for redesign and recycling primarily with a focus on electrolyser technologies. Similar challenges are, however, also relevant for other parts of the value chain, such as wind turbines, solar panels or fuel cells.

1.3.1 Resources for Renewables

1.3.1.1 Global dependencies

The global energy transition will result in significant changes in resource demands and trade dependencies. The shift towards renewables is likely to cause a steep increase in the use of some **scarce raw materials.** According to the World Bank Group, already today more than 50 million tons of minerals are needed (World Bank Group, 2020). This value is estimated to increase **to 3.1 billion tonnes by 2050** to meet the 2-degree scenario.

A recent IEA report revealed the strong concentration of energy transition materials on only a few countries. Figure 16 shows that for copper and nickel about half the global production is concentrated on only three countries. For graphite, rare earths, lithium and platinum more than 80% of production is concentrated on just three countries. For graphite and rare earths China is controlling 60% and more of the production. A look at the processing shares reveals an even bigger dependence on China, with more than 50% for lithium, over 60% for cobalt and almost 90% for rare earths elements.

Critical Raw Materials (CRM) for energy transition
degree of concentration (2019)

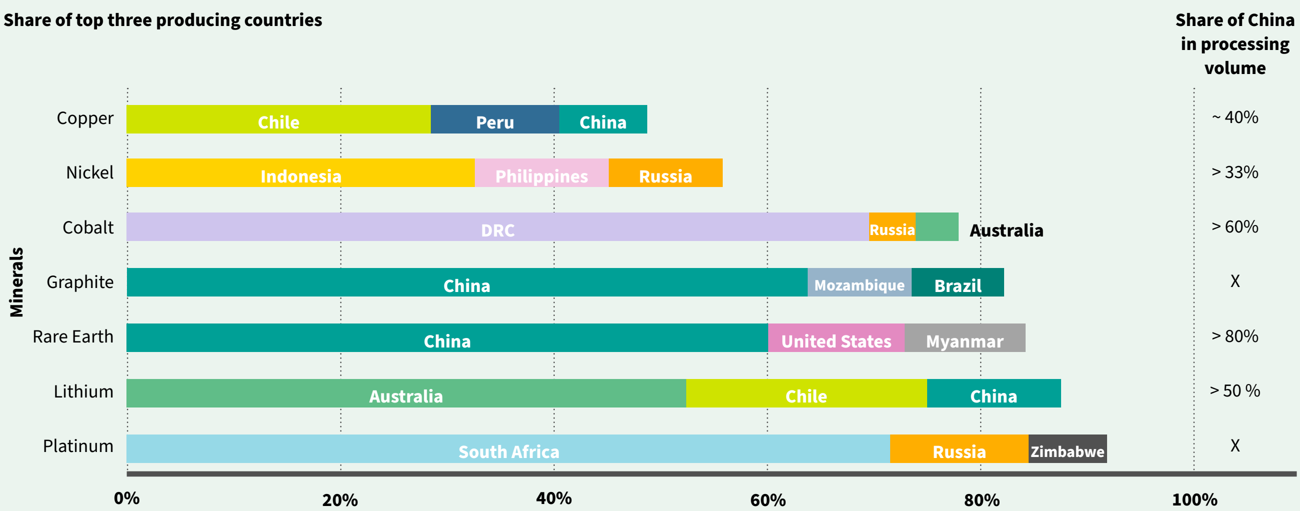


Figure 16. Source: Based on IEA (2021)

1.3.1.2 CRMs for electrolysis

Currently, **the most widely commercialised electrolysis technologies,** such as Polymer Electrolyte Membrane electrolysis (PEM) and Alkaline water electrolysis (AEL) **require materials that are classified as Critical Raw Materials (CRM)** according to the European Union's Methodology for establishing the EU list of critical raw materials. Iridium, platinum, tantalum, cobalt, and nickel are some of the ones used by most common electrolyzing technologies (UE, 2017).

Critical Raw Materials (CRM) for electrolysis

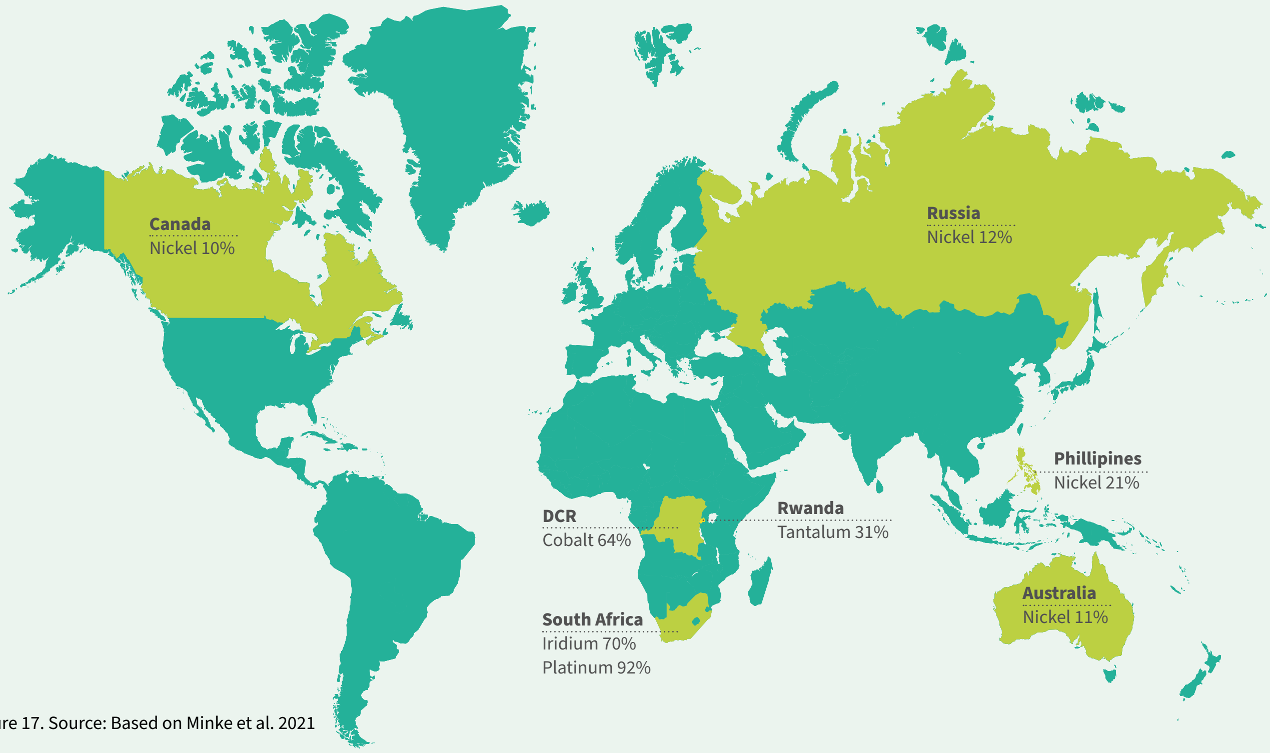


Figure 17. Source: Based on Minke et al. 2021

PEM electrolysers are the technology that has the **biggest critical raw material demand.** Their structure has a high oxidizing potential (> 1.4 V), meaning very few materials can ensure long-term operation (IRENA, 2020b). Therefore, PEM electrolysers require **significant amounts of iridium and platinum-coated materials,** some of the scarcest, most energy and emission intensive metals. Their combined production emits more than 20 tonnes of carbon dioxide per kilo of metal (IRENA, 2020b). Translating this into hydrogen production would still mean a relatively small quantity when compared to the overall hydrogen production process (about 0.01 kg CO_2 -eq /kg H2), but nevertheless significant (IRENA, 2020b). Other options are available, and **tantalum** seems to be a promising alternative for the coating, but it is classified as critical in the EU methodology (European Commission, 2020) as well.

AEL electrolysers use nickel, **platinum,** and **cobalt** — although there are some commercial examples that do not use any of these (IRENA, 2020b).

SOEC electrolysers look very **promising** from a critical raw material use perspective, having very low demand. However, **technology readiness is still relatively low** and most projects are currently at pilot level (Weltenergierat Deutschland, 2018), meaning these technologies will not likely play a big role in the short-term market ramp-up of PtX products.

Given the hypothesis that the entire world production of **platinum** went into electrolysers, the **current level of platinum use** and production would allow for the deployment of **200 GW per year,** reaching 2000 GW in the next decade.

With iridium, the same hypothesis would support the deployment of **3-7.5 GW/year,** meaning 30-75 GW of electrolyser capacity in the next decade (IRENA, 2020b). (European Commission, 2020)

Critical Raw Materials
demand for electrolysers*

CRM	% global CRM production p.a.
Iridium	122
Tantalum	33
Platinum	25
Raney-Ni	0,4
Nickel (class 1)	2
Cobalt	0,1

* Hypothesis: Reaching EU 2050 green H_2-target with 50% AEL and 50% PEM

Figure 18. Source: Gavrilowa, A. (2020), unpublished paper, VoltaChem

Global iridium demand
in various applications

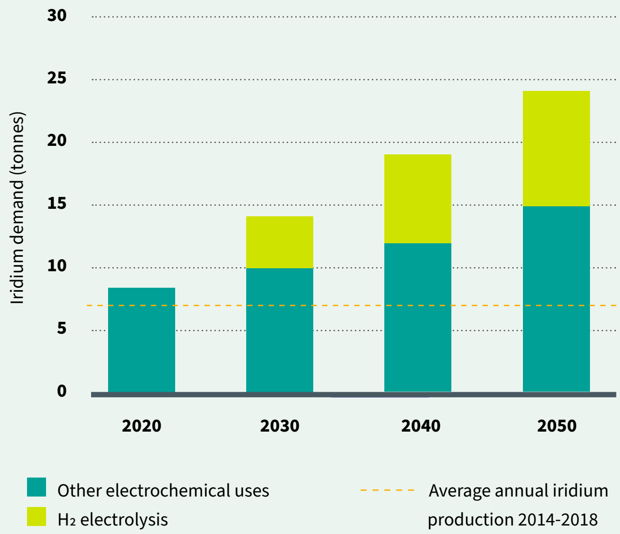


Figure 19. Source: Own calculations based on UBA (2016)

It is then clear that use of critical raw materials, in particular iridium, has the potential to exacerbate **supply-chain bottlenecks** and hinder the defossilisation potential of PtX products. Therefore redesign and recycling options must be considered.

1.3.2 Recycle and Redesign

To ensure the sustainability of the mineral resources value chain multiple approaches should be used.

The first possibility is **prevention.** Strategies that allow reduction or substitution of the raw materials used in the production process help limiting their use. Some of these strategies include improving catalyst manufacturing techniques to increase the catalyst surface area or using a thinner layer of coating material. Additionally, simply using a mix of different technologies (e.g., 50% PEM, 50% AEL) can significantly reduce the raw materials demand.

Technology **lifetime extension** is a second possibility to reduce the need for critical raw materials. By building more durable electrolysers and improving process efficiency, the productivity of raw material components increases, reducing the need for new resources.

Recycling, reuse, and **refurbishment** also play important roles in limiting and meeting future demand for minerals. Among these strategies there are hydrometallurgical treatment, transient dissolution, acid process and selective electrochemical dissolution. Increases in recycling rates could help to reduce growing mining of primary minerals. For example, today 26% of South Africa's produced platinum comes from urban mining and this number is likely to increase. However, concerning electrolysers materials, recycling is currently almost exclusively available for platinum materials.

According to IRENA (IRENA, 2020b), the implementation of these strategies, together with technological improvement of electrolysers, **can ultimately reduce iridium demand by 96% and platinum content by 97.5%,** significantly improving the environmental, social and economic impact of electrolysers. Therefore sustainability standards should include provisions for the use of mineral resources and their recycling.

Critical Raw Materials
savings strategies

Type	Strategy		PEM	AEL
Prevention	Reduction	of CRM amount used	IR, Ta, Pt	Pt,Ni
	Substitution	replacement of CRM	–	Pt, Co
	Technology mix	AEL/PEM/SOEC	IR, Ta, Pt	Pt, Co, Ni
Extension	Higher productivity	of stacks	IR, Ta, Pt	Pt, Co, Ni
	Extended lifetime	of stacks	IR, Ta, Pt	Pt, Co, Ni
Recycling	Hydrometallurgical treatment		Pt	–
	Transient dissolution		Pt	–
	Acid process		Pt	–
	Selective electrochemical dissolution		Pt	–

Figure 20. Source: Quelle Gavrilowa, A. (2020), unpublished paper, VoltaChem

1.4 ENV 4: Pollution and Safety

1.4.1 Risk and Impact Assessment

Like for any major industrial installation PtX production sites must be subject to thorough environmental impact assessments (EIAs) and regular inspections of their operation. Production, storage, transportation and final use of their outputs, such as hydrogen, ammonia, methanol or e-fuels, must meet clearly defined standards. While there are already a multitude of safety standards established for gases and fuels, the emergence of new PtX products and applications will require further refinements and amendments to the existing body of rules and regulations.

Any gas or fuel inherently represents a potential risk. Hydrogen, for example, is a dangerous substance. Key hazardous properties are its wide range of flammability and a low ignition point compared to other gases. It burns at high temperature with an almost invisible flame. It can easily explode. Spectacular accidents like the Hindenburg airship disaster in 1937 or the Challenger spaceshuttle catastrophe in1986 have seriously damaged to public image of hydrogen. This is particularly relevant when new applications in heating systems or private cars are considered.

Another issue relevant for hydrogen storage and transport is embrittlement. When exposed to hydrogen, some metals can become brittle. This needs to be taken into account when repurposing existing infrastructures such as pipelines.

If hydrogen is converted to other PtX products, this can reduce some of the risks but may trigger others. For example, ammonia is easier to transport, since its energy density is significantly higher. (3.3 kWh/l compared to liquid hydrogen at -253 °C: 2.4 kWh/l or compressed hydrogen at 1000 bar: 1.7 kWh/l). Yet, ammonia comes with other environmental and safety risk. It is toxic, severely corroding lungs, eyes, and skin. It can also negatively affect fish and aquatic ecosystems. Acute toxicity is of a similar magnitude as for heavy fuel oil. Under real environmental conditions, however, ammonia concentrations are expected to decrease more rapidly after a spill.

1.4.2 Transport and Storage Risks

Any assessment of PtX sustainability must not only focus on product characteristics. It is important to consider the entire value chain including logistics and infrastructures. This is particularly relevant, if PtX products are not only used in a domestic local context but are traded internationally.

Impact assessments and safety standards are not only relevant for PtX production sites. PtX products must be stored and transported for further conditioning, refinement and finally to end users for consumption. They can be transported via pipelines, shipping, rail or road, depending on the final product. Correspondingly, environmental and safety standards must be defined for every branch and segment of the value chain.

PtX logistics generate additional costs and energy consumption, thus impacting PtX products' overall sustainability and energy efficiency. For example, liquifying hydrogen by cooling it down to -250 °C and then transporting it in vessels with diesel engines could easily destroy the entire balance. Consequently, GHG emissions derived from conditioning, storage and transportation must be accounted for in the calculation of PtX's carbon intensity.

2 ECONOMIC DIMENSION

The necessary transformation of the global energy system, shifting from fossil fuels to renewable sources, will have groundbreaking economic implications. It comes with major challenges. Yet, it also offers great opportunities for sound economic development, inclusive growth and prosperity. Fundamental changes in the energy mix will lead to power shifts, not only technologically but also with respect to economic and (geo)political power structures. The energy transition will alter not only industrial production structures but also patterns in consumption, heating, transport and logistics. Supply and value chains will be modified, with consequences for global economic and geo-political balances and dependencies. The distribution of value added and wealth will be affected within and across countries as well as among societal groups.

Any sustainability assessment of policies, partnerships and projects promoting hydrogen and PtX must therefore pay due attention to economic foundations and frameworks, implications and impacts. Thus, the PtX Hub's EESG framework suggests to broaden the focus of standard ESG-reporting for sustainable finance and investment analyses to an EESG (Economic, Environment, Social and Governance) perspective with economic concerns and impacts as integral parts of sustainability evaluations.

2.1 ECO 1: Value added and decoupled growth

PtX production of green hydrogen and fossil-free derivatives offers new economic opportunities for countries and sub-national regions with high potential for wind and solar, hydro or other renewable power sources. Sometimes PtX may even benefit remote rural territories and communities that so far were disadvantaged and marginalised. Thanks to a more decentralised structure of renewable energy generation, they may benefit from new development impulses for green growth in jobs and income.

Traditional economic indicators, such as **Gross Domestic Product (GDP)** or Gross Value Added (GVA)[1] provide only limited insights into national or local development progress. While they can serve as important reference figures measuring economic productivity and performance, they should not be assessed in isolation. **Beyond GDP,** economic analyses need to be complemented with additional information on income and wealth distribution as well as **indicators for other material and immaterial living standards.**

From a climate and sustainability perspective, it is essential to gradually **decouple GDP growth from energy consumption and greenhouse gas (GHG) emissions.** "Weak decoupling", where GHG intensity per unit of output declines only in relative terms - i.e., emissions are still growing, but less than GDP – is not sufficient. To reach carbon neutrality, "strong decoupling" with absolute emission reductions must be achieved.

While cross country comparison seems to suggest that growth in GDP and GHG emissions is highly correlated, closer analyses based on timeseries by country show that decoupling can also be achieved at lower levels of GDP per capita. Thus, for developing countries and emerging economies, hydrogen and PtX in particular may offer great opportunities for **leapfrogging over fossil and energy intensive stages** of economic development.

The extent to which hydrogen and PtX create local economic value and jobs is also a key indication for judging their contribution to a just transition. The more **PtX production is integrated into local productive networks,** the better. This will trigger positive economic impulses through up-stream and down-stream linkages to related manufacturing and services branches. Consequently, project promotion and policy support should consider the potential **regional multiplier effects** for income and employment growth benefiting local communities and regional economies.

[1] level and growth in absolute terms or per capita

Many resource rich countries have in fact not been successful in translating the exploitation of their oil and gas or mineral assets into economic prosperity and inclusive development trajectories. On the contrary, they suffered from the so called **"resource curse"** or **"Dutch disease".** Distorted currency exchange rates create competitive disadvantages for other economic sectors. No strategic investment of revenues, illicit financial flows, lack of transparency are only some of the related risks. In particular countries that decide to tap their abundant wind and solar potentials primarily for hydrogen exports need to analyse and address these risks. Measures should be taken to ensure that natural assets and advantages actually contribute to an overall sustainable development of countries and communities benefitting all citizens.

2.2 ECO 2: Energy mix and transformation

Sustainability assessments for PtX and hydrogen will have to consider the energy mix of countries, the diversity of and dependence on different energy sources, their domestic or foreign origins. Accordingly, national energy transformation targets and carbon reduction commitments will differ. In many countries considered as future hydrogen champions and PtX powerhouses, renewable energies make up only a minor fraction of their total primary energy consumption.

As Figure 21 illustrates, **the share of renewables in electricity generation is still significantly below fossil shares.**

Share of renewables
in total power generation (2020)

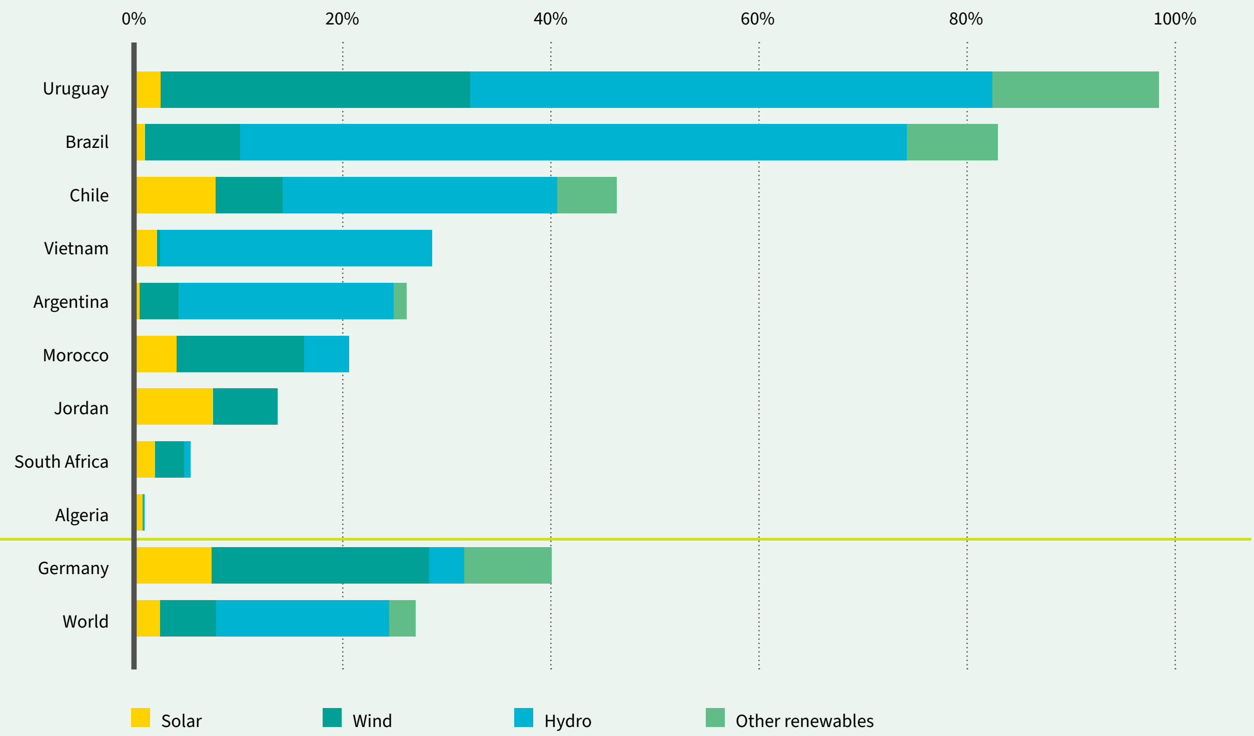


Figure 21. Source:Own calculations based on Our World in Data: https://ourworldindata.org/renewable-energy#solar-in-the-energy-and-electricity-mix

Analysing the energy mix is essential for understanding national priorities and evaluating the balance of **domestic use versus export of PtX.** Furthermore, PtX exports would entail various degrees of processing, from pure hydrogen to ammonia, or further refined synthetic fuels or feedstocks.

The criterion of additionality (see section 1.1.1.2) can only be judged properly against the background of a reference scenario describing **anticipated defossilisation trajectories.** Disconnected "island" approaches for export oriented PtX pathways risk to ignore the need for combating energy poverty of local communities and advancing the energy transition at home. It should also be carefully analysed to what extend H2 strategies risk to **lock countries into fossil fuel dependencies,** which may result in stranded assets.

From a transformation perspective attention should be paid to three independent dimensions of design:

- both **centralised and decentralised** approaches
- both **modular and monolithic** plant design concepts
- both **large and small** production volumes

Constraints in feedstock (electricity, water, carbon, nitrogen) are obvious design parameters. Also the potential for generating local benefits and impulses for integrated, participatory economic development of local communities should be taken into account. Furthermore secure and robust plant operation, scalability of the PtX concept (by size or by number), systemic resilience, etc., should be considered.

Experience from solar energy shows that innovation speed and cost reductions have been significantly underestimated over the last decades. If PtX concepts could be designed to be an extension of solar energy with similar characteristics, a roll out in time to reach the Paris agreement's goal is still possible.

2.3 ECO 3: Trade and technology transfer

Ramping-up PtX production will have stimulating effects on internal and external energy trade. The German hydrogen strategy for example foresees that more than 80 percent of the 2050 hydrogen demand will have to be covered by imports.

Countries with high production potential will have to choose how to balance possible trade-offs between **internal energy transformation needs and international trade opportunities.** Priorities should be clarified in national development and climate mitigation strategies. Should dependency from fossil fuels, domestic or imported, be reduced first, before considering exports? Should export strategies target long distance markets or rather focus on neighbouring countries with positive multipliers for regional integration and internal market stimulation?

Hydrogen trade routes
expanding networks

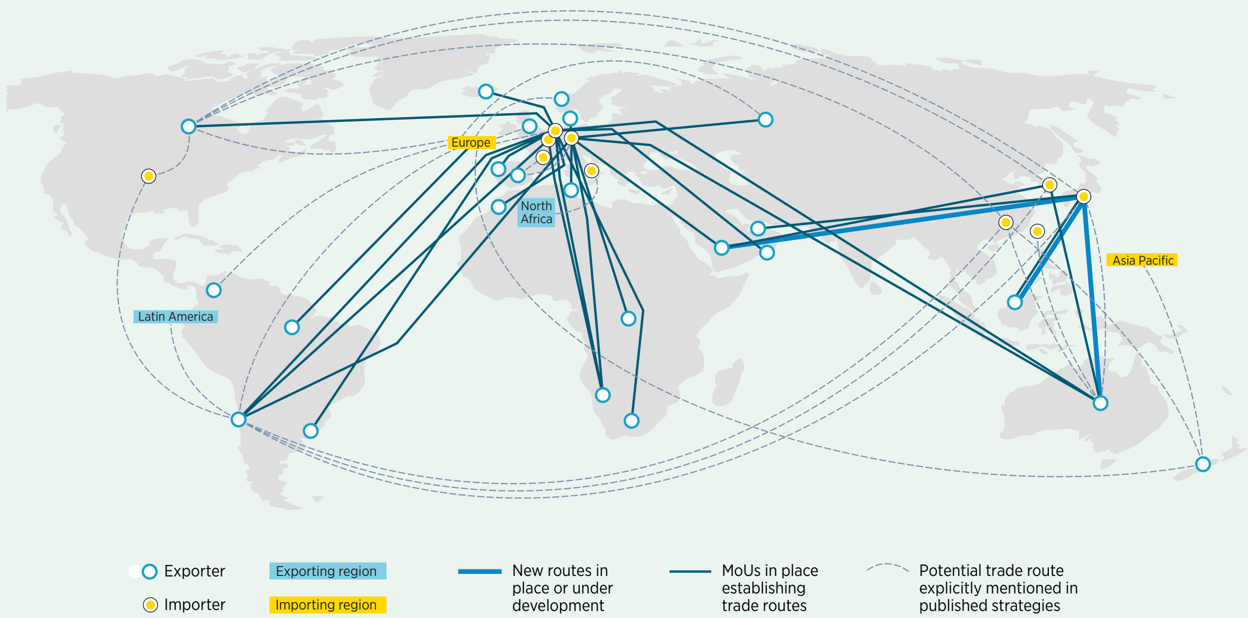


Figure 22. Source: IRENA 2022

Trade and transport considerations are closely related. Can hydrogen be transported via pipelines or should derived products such as ammonia be shipped by vessels? The answers have implications for logistical infrastructure needs. Are ports prepared with hinterland connections, storage capacities and functioning terminal equipment?

Finally, this raises the fundamental issue of whether trade has to result in the **physical transport of products** or if it can happen in **virtual transfers of certified properties.** From a climate and sustainability perspective it makes a huge difference, if tons of hydrogen are shipped around the globe or if GHG-reduction certificates are exchanged via electronic trading platforms. Such "book-and-claim" arrangements might be beneficial from a climate focused defossilisation perspective. Yet, this would have implications for the competitiveness of countries and industries and could result in major shifts in global value chains and industrial structures.

The development of a global PtX market is however not only an issue of trading outputs. On the input side there are also great opportunities for boosting production and reducing costs through **innovation and technology transfers.** Production potentials cannot be judged without considering access to and transfer of technologies.

The expected boom in demand for electrolysers is likely to benefit manufacturing branches in developed countries and could create mutually beneficial relations for the partner countries involved. Before global markets for hydrogen and other PtX products emerge, trade relations will mostly rely on **bilateral partnership agreements.** Beyond trade these should also include initiatives for technology transfer and **joint ventures in R&D and capacity building.** Figure 23 shows the current linkages established through hydrogen partnerships.

Bilateral trade agreements and MoUs
selected countries (2021)

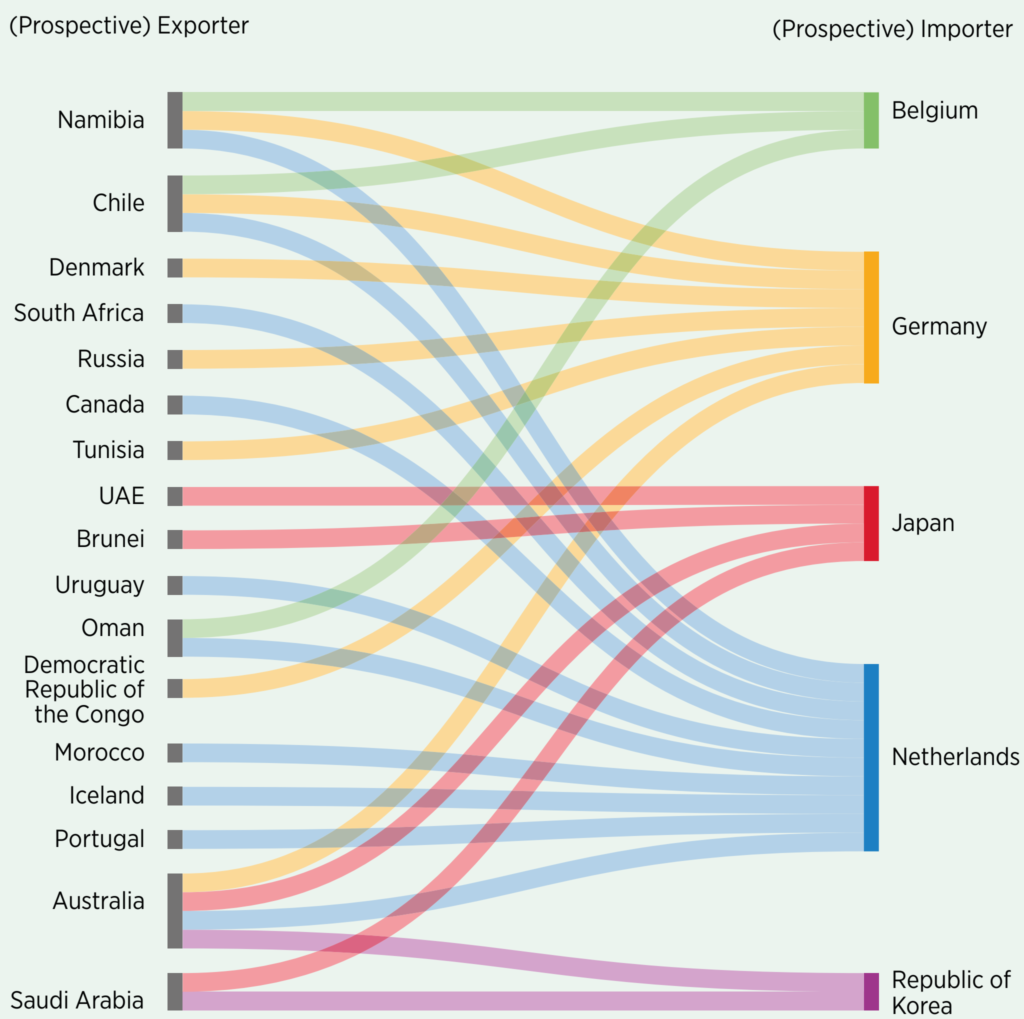


Figure 23. Source: IRENA 2022

2.4 ECO 4: Investment and public finance

Kick starting and ramping-up PtX production and markets will require **massive investments by both the private and the public sector.** Given current cost structures and market uncertainties, major private investments will only be undertaken, if adequate public support is provided. This can take many different forms from investment grants and loans, contracts for difference (CfDs) bridging the price gap between supply and demand, quota and blending mandates or public procurement regimes.

Whenever such public support mechanisms are offered, they should be made **conditional on compliance with standards and safeguards** ensuring that PtX projects and investments comply with basic sustainability requirements. Special support could thus be targeted to best practice examples meeting ambitious premium standards going beyond minimum conditions.

PtX investment needs are significant along the entire value chain from power generation to conversion in electrolysers, synthesis and refinement facilities or installations for desalination and direct air capture (DAC). In addition, infrastructures for storage and transportation, be it by pipelines or by ports and ships, need to be established or refurbished.

All these investments should be subject to **environmental and social impact assessment.** Most financial institutions, such as regional development banks (e.g. EIB 2022) have meanwhile established detailed guidelines for identifying risks and checking compliance with environmental, social and governance standards. They also include governance provisions with respect to public consultation or even prior consent by affected stakeholders and communities.

Whatever the balance between private and public funding of investments is, up-scaling PtX operations will have **major public finance implications.** While PtX production and trade can generate budget revenues from taxes or export duties, it is likely that in the initially take-off phase public expenditure will exceed revenues. Often investment support for capital costs (CAPEX) will not be sufficient to launch PtX activities. In early stages also operating costs (OPEX) may have to be subsidised. Funds will also be required for **public procurement measures** helping in the run up of markets for PtX and green products, e.g., for green steel or synthetic e-fuels. In comparison, quota and blending mandates may be less burdensome for public budgets, yet overall economic costs due to market distortions and lack of flexibility could be significant.

PtX would also benefit from **carbon pricing mechanisms** or decisions to reduce or restrict the use of competing fossil alternatives. Carbon taxes, be they applied generally or as a carbon border adjustment mechanism (CBAM), as well as a phase-out of fossil products from public procurement would be powerful tools.

In any case, all these economic incentives and market regulations depend on **clear definitions of qualities and properties** that projects or products have to comply with. Thus, they will not only help launching PtX projects and products but also advancing the establishment and enforcement of sound sustainability standards.

3 SOCIAL DIMENSION

The fundamental transformation of energy systems and the defossilisation of economies will lead to massive structural changes affecting societies, communities and people's livelihoods. Switching from a fossil to a renewables-based economy will impact all economic sectors, from industrial production to service provision, and thereby income and employment opportunities for workers. Changes in mobility and consumption patterns will impact on everybody's lives. **This is not just a transition, it must become a "Just Transition", leaving no one behind.**

Growth of PtX production and applications will create **more and better jobs and income** in certain sectors and territories. On the other hand, the decline of fossil-dependent mining and manufacturing, energy and mobility sectors will result in losses and adjustment challenges elsewhere. Gains and losses will not be distributed equally across countries, communities and citizens.

To ensure that PtX policies, partnerships and projects contribute to a balanced and inclusive sustainable development, their social impacts must be considered from access to resources and incomes to living and working condition. Like for environmental impact, social impact assessments should be undertaken.

3.1 SOC 1: Access to energy and resources

Green hydrogen and PtX production will require rapidly raising amounts of green electricity as well as of resources such as water, land and minerals. This can trigger or exacerbate conflicts with other requirements and entitlements. Thus, property and user rights – including customary rights not formally documented – need to be respected.

SDG 7: "Ensuring "access to affordable, reliable, sustainable and modern energy for all" will be particularly relevant here, given the high electricity demand for electrolysis, but also for direct air capture (DAC).

In many developing countries energy poverty is still a major problem. As Figure 24 reveals, in many parts of Africa **less than half the population has access to electricity.** In India or Nigeria access rates are higher, yet the absolute number of disconnected people is significant - together exceeding

100 million (IND: 30 m, NGA: 90 m). While access rates improve, this happens at a low rate. In recent years, only in Kenya growth exceeded 5 percentage points per year. Against the background of population forecasts seeing population in Sub-Sahara Africa almost double by 2050, the challenge is huge. It is therefore important to ensure that PtX strategies do not run counter to the achievement of SDG 7, but rather seek to reduce potential conflicts and create synergies.

Access to power
deficit countries by access rate (2010-2019)

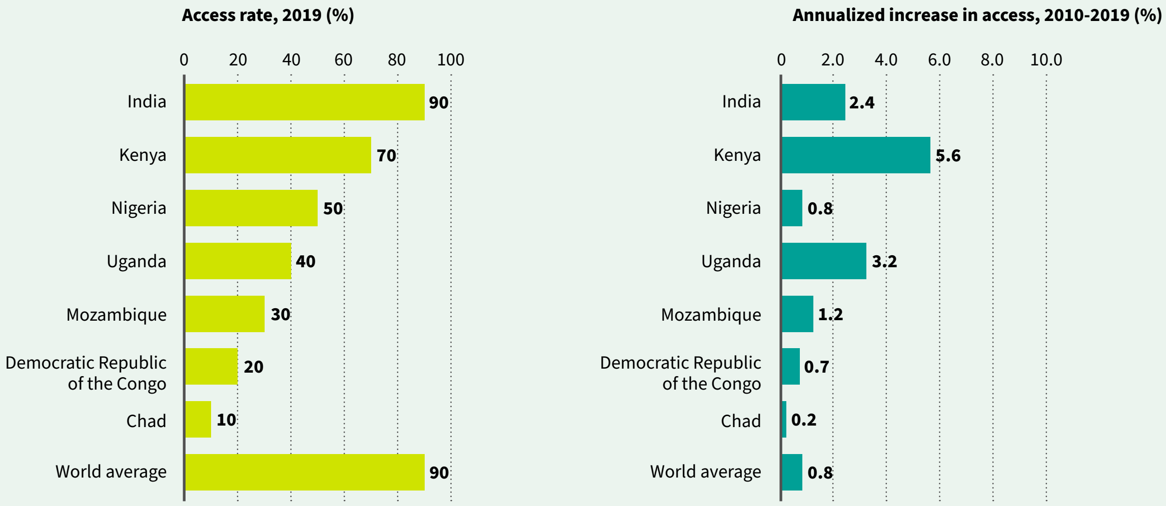


Figure 24. Source: IEA, IRENA, UNSD, World Bank, WHO (2021)

Similarly, it must be ensured that PtX production does not undermine efforts to reach **SDG 6: "Ensure availability and sustainable management of water and sanitation for all".** As already discussed in section 1.2 (ENV 2) wind and solar potentials are particularly high in arid regions already today facing severe water stress. This situation will deteriorate even further with climate change.

In many parts of Africa more than half the population is deprived of access to safely managed drinking water services. PtX projects should thus not aggravate water shortages but help reduce water stress through investment and management efforts. If **desalination plants** are built, they should also help to improve the provision of water to local communities and eventually also to farms for irrigation. Since desalination costs are marginal compared to overall PtX production costs, it should be possible to **tap potential synergies** benefiting local populations and businesses.

Again, **early involvement of local populations and stakeholders** in the design of integrated development projects, reaching beyond the narrow PtX project horizon, could help to reveal and realise synergies, thereby also raising acceptance and support ownership.

Like with access to water, project **implications for land use** or infringements on often uncodified customary grazing rights could become contentious issues. In many countries, the development of wind and solar parks is facing opposition from local populations. Even if generally supportive of renewable power and climate mitigation efforts,people are opposed to changes in their immediate neighbourhood. This should not be dismissed as NIMBY reflex ("not in my backyard"). Problems related to noise, interference with natural habitats or landscape amenities should be taken seriously and addressed at an early stage. With active involvement and participation of local communities and affected citizens socially acceptable solutions should be sought and found.

3.2 SOC 2: Jobs and skills

Energy transition will have **significant labour market implications.** As shown in Figure 25, IRENA estimates that by 2050 the energy sector will see a global net increase in job opportunities, with expected job losses in the fossil sector (-27%) and strong gains in the renewable sector (+64%) (IRENA, 2020c)

Global jobs in the energy sector
(2017 and 2050)

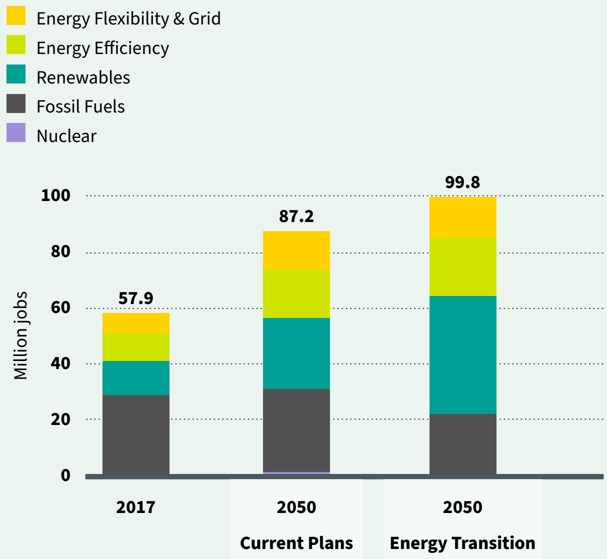


Figure 25. Source: IRENA (2020)

PtX projects will create jobs during the initial installation phase as well as long-term during operation. Despite the **overall positive effect,** employment opportunities and threats will differ across countries and subnational regions. They will also depend on the skill profiles of the available workforce. Regions with high renewable potential will see a net-positive balance on their economies and job markets, while fossil-dependent regions (e.g. former coal regions) are likely to suffer from negative effects (IRENA, 2020c).
Investment in **training and re-skilling** of different target groups, such as women, youth or ethnic minorities should play a major role, with proactive action needed at national, local and corporate level.

3.3 SOC 3: Human rights and labour standards

PtX standards and certification schemes will have to be in tune with **international codes and guidelines for responsible business conduct.** Like for any other business PtX project operators must respect fundamental human rights and core labour standards such as those defined by the UN Guiding Principles on Business and Human Rights (UNGP), the ILO Core Labour Standards, and the OECD Guidelines for International Enterprises and their Due Diligence Guidances.

Protection of labour rights must be a core requirement for any sustainable hydrogen and PtX production and should be ensured at every step of the value chain. Forced or compulsory labour, as well as child labour must be excluded as well as all kinds of discrimination, in particular against women. It should also be guaranteed that companies respect the freedom of association of workers and their right to collective bargaining. While this may seem obvious and easy to agree upon, the realities in many countries and at certain steps of the supply chains are far from satisfactory. Establishing whistle-blower channels and grievance mechanisms for raising complaints can help operators and administrations to reduce related risks.

Breaching these international standards implies not only reputational risks. National as well as EU legislation is becoming more and more demanding with respect to supply chain due diligence and has established legal sanctions for ignoring these basic social norms.

3.4 SOC 4: Health and safety

As described in Section 1.4 (ENV 4) the production, handling, storage and transportation of PtX products such as hydrogen, ammonia or e fuels are associated with sometime **severe health and safety risks.** Workers in production and handling of PtX products as well as people living next to PtX facilities must be properly protected.

For many PtX products standards and certification schemes have already been developed used and applied to their fossil-based equivalents. With the massive increases in production and logistics these may need **adaptation or amendment,** in particular where explosion risks of plants or pipelines and toxicity of products are significant.

Constant **monitoring and regular comprehensive audits** are essential to ensure safe and sustainable PtX operations.

4 GOVERNANCE DIMENSION

Governance concerns matter for PtX sustainability assessments at the level of public policies as well as at corporate and project level.

Energy policy always has to consider not just technological or economic aspects, but also **geo-political governance and security implications** of energy supply and demand patterns and their changes. This is particularly true in times of a fundamental transformation of the global energy system, which is altering trade relations and mutual dependencies thus far shaped by fossil energy markets.

The transition towards renewable energy and the emergence of a global hydrogen and PtX market will lead to **major power shifts,** not only towards green electric power but also in terms of a geo-political power relations. Traditional fossil energy export nations – such as Russia, the Gulf States or Venezuela -- will lose, unless they invest massively in clean alternatives. Other countries that had no stakes in fossil energy markets – such as Chile or Morocco – will emerge as new renewable power players. Moreover, PtX production has the potential to be more decentralised and widespread, since renewable energy resources are abundant and more geographically diverse than fossil energies, playing into increasing diversity of supply and number of potential producer/exporting countries.

For importing countries – such as Germany or Japan – dependency on and security of energy supplies is a major economic and foreign policy concern. Formally established long term **"energy partnerships"** are a means to reduce potential risks. They can not only ensure energy access and trade but may also lead to joint engagement in transformation efforts. For Germany and the EU, up-scaling hydrogen and PtX production in partner countries can also provide opportunities for exporting equipment such as wind turbines, electrolysers or synthesis plants as well as for sharing expertise in production, storage, transport and trade.

At the company level, corporate governance issues matter with respect to their **responsible business conduct (RBC),** in particular regarding transparency, accountability and participatory stakeholder relations.

4.1 GOV 1: Policy Commitment and coherence

Policy commitment and coherence are important to judge the status and stability of national PtX policies. A growing number of countries have already agreed or are in the process of developing **national hydrogen strategies.** However, there are still many others with high PtX potential that have not yet embarked on analysing scenarios and setting-up national or regional plans.

PtX projects should be aligned with such hydrogen strategies or PtX roadmaps. They should also be consistent with the country's industrial policies or mobility strategies. It should be transparent how projects contribute to the country's overall energy transition and defossilisation agenda.

Ideally, strategies and roadmaps should contain reference scenarios and quantified targets, also providing indications on the intended application priorities. This would also help assessing the additionality of renewable electricity capacity used for PtX electrolysis and synthesis. The policy commitment and credibility of PtX ambitions would also be revealed by corresponding budget commitments.

Furthermore, strategies should foresee mechanisms for continuous monitoring. They should be accompanied by advisory bodies establishing basic standards, reviewing progress and compliance as well as steering the evolution and evaluation of projects.

4.2 GOV 2: Stability and rule of law

Considerations to engage in bilateral or multilateral hydrogen and PtX partnerships will not only be based on a global mapping of wind and solar potentials. Like with any other trade and investment co-operation agreement broader geo-political strategies and governance issues will play an important role. In this context, political stability and the rule of law are always key concerns.

There are **multiple country rankings** covering different aspects of political stability or fragility. They are either based on survey results summarising subjective perceptions, or on objective data sets monitoring specific stability aspects.

One example is the **Fragile States Index,** edited by TheGlobalEconomy.com[2], which encompasses a dozen of sub-indicators measuring vulnerability and conflict risk such as the functioning of the security apparatus, group grievance, state legitimacy, public services quality, human rights, and rule of law. Other examples are **the Global Peace Index** published by the Institute for Economics and Peace (IEP), which covers aspects such as political instability, violent demonstrations, crime rates, intensity of internal conflict and terrorism impact, or **the Freedom and Democracy Indices**[3] compiled by Freedom House.

Such country labelling exercises are always controversial and must therefore be subject to debate. All these indices and rankings are based on many explicit and often less obvious implicit value judgements. Nonetheless, they are widely used in international policy making and in particular by financial institutions, such as the World Bank or multi-lateral, regional development banks, to provide important indications on what type of country risks require attention in decisions on investment, policy co-operation and partnership agreements.

Also, the business sector relies on these data sets and country rankings, since it is their responsibility to respect human rights and sustainability standards along the entire supply and value chains.

[2] https://www.theglobaleconomy.com/

[3] https://freedomhouse.org/

One should, however, always be mindful of **"Campbell's Law":** *"The more any quantitative social indicator is used for social decision-making, the more subject it will be to corruption pressures and the more apt it will be to distort and corrupt the social processes it is supposed to monitor."* (Campbell, 1979)

A recent example is the World Bank's **"Doing Business" Index.** Its conceptual design and methodology had often been criticised before, since "doing business" may appear easier in countries with autocratic, authoritarian regimes abandoning social safeguards, lowering taxes or suppressing trade union activities. In 2020, however, the World Bank even had to discontinue its Doing Business reporting because of data manipulations that would have benefited some countries to the detriment of others (Reisen, 2020)

4.3 GOV 3: Transparency and participation

Sustainable PtX projects and policies must rely on governance structures and procedures facilitating transparency and participation. **Access to information** matters in particular with major investment projects and related funding schemes. Through risk based due diligence and compliance the risks of bribery and corruption can be reduced.

In countries known for **high corruption risks** special care is warranted. Project promotors should thus be able to provide evidence of their corruption prevention efforts. They should provide information on the main characteristics and structures of their corporations or consortia, in particular beneficial ownership of project developers and companies should be involved.

Operators must establish and maintain a transparent and easily accessible grievance mechanism open to all workers and stakeholders. **Integrity and accountability policies,** procurement and compliance mechanisms should be explained and codes of conduct and anti-corruption safeguards should be communicated. These informations should be made available and checked during certification processes.

Like under the EITI standard for extractive industries, also hydrogen and PtX exporting countries and companies should develop and enforce rules allowing to track the flow of payments made to and financial revenues received by public budgets.

Information and involvement of stakeholders are important preconditions for successful PtX policies and project. Taking account of the opinions, interests and concerns of affected people, organisations and communities is essential for raising awareness, acceptance, building trust and mobilising support. Participation should ideally evolve from consultation to consent and co-operation, creating the foundations of effective partnership. Effective two-way communication is needed for mitigating conflicts and maximising co-benefits.

Early engagement with local communities and civil society organisations (CSOs) such as environmental NGOs can help raising awareness and acceptance, while avoiding and easing conflicts. PtX project developers and operators should undertake careful stakeholder mappings based on analyses of land and water rights. It should be checked, who is affected by negative environmental or social impacts. Special attention should be given to vulnerable, marginalised or discriminated-against groups. Based on such a mapping **appropriate formats for consultation and consensus building** should be developed, from hearings to interactive co-operative workshops allowing for good-faith engagement, negotiation or mediation.

Positive and productive stakeholder relations can also be strengthened by regular review and reporting. **Grievance mechanisms** for raising concerns and complaints, accessible and protected whistle-blowing channels or the nomination of ombudsmen can be effective arrangements to promote inclusive, participatory PtX development policies and projects.

4.4 GOV 4: Standards and certification

Compliance with standards and certification is essential for ensuring PtX sustainability. They must provide clarity and orientation for investors, managers and customers. Without, it will be impossible to attract investment or to establish and ramp-up functioning markets.

Currently there are several initiatives underway to define hydrogen and PtX standards, at the level of governments and administrations, as well as by private business. While public initiatives tend to focus on minimum requirements – "guard rails" or "must haves" – private initiatives rather aim at defining premium labels allowing for the creation of high-end market segments.

To ensure **credibility and reliability of standards and certified labels,** the integrity of the governance structures and procedures for certification must be robust. Risks of "greenwashing" due to low and flawed standards or hidden loop holes resulting from excessive flexibility must be avoided.

Consequently, fundamental governance principles should be met. A central requirement is a functioning, transparent system of **independent third-party evaluation.** Auditors should be accredited only, if they meet clearly defined qualifications and if their work is subject to regular reviews. It should also be established that auditors can only have contracts for a certain period (e.g., of 3-5 years), after which audits have to be performed by another independent assurance provider.

Governments must make sure that accreditation and certification meet internationally agreed quality standards. Furthermore, **H2 and PtX registers** must be established, keeping track of certified product quantities, their origin, trade and final use. Once products have reached the final off-taker, certificates will have to be cancelled. Only if acceptable, reliable schemes can be established will it be possible to operate "book and claim" or "mass balance" systems for ensuring quality properties of products and facilitating their market transfers.

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