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Part 2: Major greenhouse gas emitting sectors
Sectors

Chapter 3-1

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3. Major greenhouse gas emitting sectors

3.1. Power generation from fossil fuels

3.1.1 Coal

3.1.1.1 Presentation of global production volumes and emissions

In 2021, global coal reserves were estimated by BP at 1,074,108 million tonnes (Mt).[1] By far the largest share is concentrated in the Asia-Pacific region (42.8 %), followed by North America (23.9 %), CIS[2] (17.8 %), Europe (12.8 %), Middle East & Africa (1.5 %) and South and Central America (1.3 %). In terms of countries, the US has the largest reserves (23.2 %), followed by Russia (15.1 %), Australia (14 %), China (13.3 %), India (10.3 %), Germany (3.3 %), Indonesia (3.2 %), Ukraine (3.2 %), Poland (2.6 %) and Kazakhstan (2.4 %). BP also calculates the "reserves-to-production ratio", which shows how many years coal reserves will last at current production levels. According to this, the world has 139 years until the reserves are used up. This value varies depending on the region and the deposits available there. North America will need its coal for 484 years, the CIS countries for 367 years and Europe for about 300 years. In the Asia-Pacific region, where coal consumption is very high, as well as in the Middle East and Africa, which have very low reserves and increasing energy consumption, the reserves will last for far less than 100 years.[3]

Coal production increased by about 6 % (440 Mt) in 2021 to 167.58 exajoules (EJ), more than pre-Covid in 2019 and the highest level since 2014, with China, Indonesia, and India accounting for about 70 % of this growth, increasing their production to 80 EJ (+6 %), 13.91 EJ (+9.2 $) and 12.63 EJ (+6.9 %) respectively. Tagliapetra describes that coal production has more than doubled in the last four decades (from 3900 Mt in 1981 to 7906 Mt in 2021).[4] However, it is interesting to note that in 1981 production was relatively evenly distributed between regions, whereas today it is substantially concentrated in the Asia-Pacific region. Coal consumption mirrors this trend, with China and India consuming even more than is produced there (86.17 EJ and 20.09 EJ) thus importing coal and Indonesia exporting mostly coal (3.28 EJ consumption). In contrast, globally, North America, Europe, CIS and the Middle East and Africa account for only a marginal share of consumption (7 %; 6.3 %; 3.2 $; 2.6 %). China and India have increased production and consumption by a factor of six over the last forty years, while the US and Europe have reduced production. [5]

This can be explained by the increasing energy and especially electricity demand of the two countries. The Chinese power sector is thus the largest coal-consuming sector globally. One out of four

[1] Cf. BP, 2021, p. 45.
[2] CIS means "Commonwealth of Independent States" and refers to Russia, Armenia, Azerbaijan, Belarus, Moldova, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan and Uzbekistan.
[3] Cf. BP, 2021, P. 46.
[4] Cf. Tagliapietra, 2020.
[5] Cf. Tagliapietra, 2020, p. 86.

tons of mined coal is used for electricity production in China today.[6] Compared to other fossil fuels such as natural gas and oil, coal has decisive advantages: it is available in large quantities and cheaply. The price of coal is less volatile because of its global reserves. From an energy security perspective, coal is therefore the first choice, especially for developing and emerging countries with an emerging economy and easy access to energy supply. However, in view of the threat of natural gas shortages caused by Russia's suspension of gas deliveries to Europe in response to Western economic embargoes, high income countries are also turning back to coal as a "reliable energy source" for power and heat generation.[7] In 2021, industrialised countries reduced the share of electricity and heat produced by coal to 27 %, while the share in developing and emerging countries increased to 46.5 %. Furthermore, these countries account for 83 % of the global consumption of coal in steel and iron production.[8]

In addition to the advantages, however, coal has the crucial disadvantage of its ecological footprint about climate change. De facto, coal combustion is the largest contributor to air pollution among fossil fuels. While the CO_2 emissions of the various types of coal range from 317 to 353 kg CO_2 /MWh, the combustion of natural gas produces "only" about 180 kg CO_2 /MWh. The IEA estimates the CO_2 emissions related to total energy at 33 gigatonnes (Gt) in 2021. Coal alone accounts for 14.8 Gt.[9]

Coal contributes a smaller share to the world's primary energy supply than oil and yet causes almost half of the energy-related CO emissions.$_2$[10]

In its report on coal (published before the war in Ukraine), the IEA forecasts an all-time high demand of 8031 Mt for 2024 (vs. 7,906 Mt in 2021), mainly caused by still further increasing demand in China (+135 Mt) and India (+129 Mt).[11] CO_2 emissions from coal thus increased to about 15 Gt. In the United States and the European Union, on the other hand, demand is expected to continue to fall (however, it is to be expected that these figures will have to be revised in view of current reports). [12]

Developments in the so-called least developed countries and emerging economies in the global South will also be decisive for future coal demand. As described above, Africa in particular currently accounts for only a marginal share of global coal consumption. Current construction projects for coal-fired power plants are mainly financed by China, but the country announced in 2019 that it will not support any new plants abroad. China thus joins the ranks of international investors (states,

[6] Cf. IEA, 2021a.
[7] At the time of writing, no definitive figures were available on the renewed increase in coal consumption in Europe in the context of the war in Ukraine.
[8] Cf. Tagliapietra, 2020, p. 88.
[9] Cf. IEA, 2021b.
[10] Cf. Our World in Data, 2021.
[11] Cf. IEA, 2021a.
[12] Cf. Meyer, 2022.

multilateral organizations and development banks) who want to enforce a financing freeze for coal-fired power plants.[13]

3.1.1.2 Sources of CO_2 emissions

Coal is used to generate 65 % of electricity and heat.[14] As mentioned, coal has the highest carbon content of all fossil fuels. Coal emits de facto the highest amount of CO_2 per unit of energy output when it is burned. A coal-fired power plant emits 40 % more CO_2 than a gas-fired power plant and 20 % more than an oil-fired power plant. In addition, coal-fired power plants are responsible for most emissions of sulfur oxide, nitrogen oxide and particulate matter.

A coal-fired power plant for electricity generation consists of a furnace, a turbine, a generator, a transformer and a cooling system and works roughly as follows: After the coal is pulverised, it is burned in the furnace to generate heat. This produces the climate-damaging emissions that are released into the atmosphere through a chimney. The heat is used to generate steam, which is fed to a turbine via a pipe system. In the turbine, the water vapour expands again and drives the turbine. In this way, thermal energy becomes mechanical energy. The turbine is in turn connected to a generator whose rotation converts the mechanical energy into electrical energy. The steam is discharged into a condenser and the resulting water is returned to the cycle. Coal-fired power plants are located near water points because of the quantities of water they require.

3.1.1.3 Possibilities for technical CO_2 reduction

An obvious but decisive lever for the reduction of coal-related emissions is the reduced use of the fuel for power generation. The conventional substitution is the use of natural gas for the generation of electricity or heat (*coal-to-gas switch*). Natural gas contains less carbon than coal. When it is burned, about 40 % less CO_2 is released into the atmosphere. It also emits fewer air-polluting gases such as sulphur and nitrogen oxide. During the shale gas revolution in the USA, promoted by a technological breakthrough in deep drilling, the country began to use more natural gas for energy production due to the resulting price collapse. According to IEA estimates, the USA was thus able to reduce its CO_2 emissions by 25 %.[15] In addition, natural gas in liquid form as Liquified Natural Gas (LNG) could become an internationally traded energy carrier, which contributes to the diversification of the energy portfolio in countries that, due to their geography, have insufficient possibilities to cover their needs autonomously (e.g. Japan) and could contribute to the reduction of CO_2 emissions in importing countries in the future. China, which suffers from high air pollution in its industrial

[13] Cf. IEA, 2021a, p. 55; Tagliapietra, 2020, p. 95.
[14] Cf. Tagliapietra, 2020.
[15] Cf. Tagliapietra, 2020.

centres due to its immense coal consumption, also wants to rely more on natural gas in the future. [16]

Nevertheless, it should not be ignored that significant amounts of methane are emitted today during the production, transport, and consumption (Scope 1-3 emissions) of natural gas (fugitive emissions), a much more potent greenhouse gas that, unlike CO_2 , only remains in the atmosphere for about 10 years. Globally, fugitive methane emissions accounted for about 2.5 billion tons of CO_2 equivalent in the atmosphere, according to Our World In Data 2018. According to the IPCC, 50-80 % of methane emissions could be avoided with technology available today for a price of less than USD 50/t CO equivalent.$_2$[17] With increasing production due to the *coal-to-gas switch and* (today still for economic reasons[18]) lack of monitoring and capture of this methane slip (through Carbon Capture and Storage (CCS)), the greenhouse gas pollution associated with natural gas could continue to increase. However, if countries were to use increasing policy instruments such as a CO_2 price to mitigate climate change, this could lead to fossil power generation projects without capture technologies becoming *stranded assets,* as climate-friendly power generation would become more competitive. For electricity generation, the leading expert bodies are therefore pushing for an increased expansion of CCS and renewable energy generation plants (RE plants) in the *long term* (*coal-to-clean switch*).

The use of RE systems plays a central role in the IPCC's simulations for limiting global warming. According to these simulations, a sustainable reduction of greenhouse gas emissions requires a far-reaching global energy transition that curbs the *unabated* burning of fossil fuels and instead relies on renewable energies and CO capture technologies.$_2$[19] Under point C.4.3, the Panel summarises that electricity supply systems based predominantly on RE plants are becoming increasingly feasible with technological progress.[20] It is more difficult to switch the entire energy system to renewables. This requires further research and implementation of technologies to compensate for volatility, such as battery storage and electrolysis hydrogen[21] , but also *demand-side management*, *smart grid* and sector coupling.[22] The latter is particularly relevant to connect the energy sectors (electricity, heat, gas) with the consumption sectors (household, commercial, industrial and transport). The bridge to this is built by increasing electrification (e.g. the installation of heat pumps in households) and the

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[16] Cf. IEA, 2021a.
[17] Cf. IPCC, 2022, p. 33.
[18] Monitoring and intercepting methane slip increases investment and operating costs. As a result, the market price for the product and later in the supply chain, e.g. the electricity price, increases. To make technologies like CCS economically viable, subsidies and a price for CO_2 emissions are necessary.
[19] Cf. IPCC, 2022, P. 33.
[20] Cf. IPCC, 2022, P. 33.
[21] In an energy system based on renewables, coal-fired power plants are not suitable compared to gas-fired power plants, as they can be ramped up and down less flexibly. Instead, gas-fired power plants that can also run on hydrogen in the future will be necessary.
[22] Cf. IPCC, 2022, P. 33.

expansion of power-to-X technologies (e.g. hydrogen for steel production). Oxy-fuels, CCS, green power have already been mentioned in chapters 2.1 and 2.3.

3.1.2 Natural gas

Natural gas is a hydrocarbon mix consisting mainly of methane (90 %), carbon dioxide (5 %), nitrogen, helium, butane, and ethane. Natural gas can be found in underground rock formations, in other hydrocarbon reservoirs such as coal beds or methane clathrates. A distinction is made between conventional and unconventional reserves. Conventional reservoirs accumulate when natural gas migrates from gas-rich shale into an overlying sandstone formation, where it is sealed off by an impermeable formation. On the other hand, there are three different types of unconventional reservoirs: shale gas, tight sand gas and coal bed methane. Shale is the source rock for many natural gas resources and has become directly accessible in recent years, mainly through so-called fracking. In the case of tight-sand gas, the natural gas migrates from the primary rock into a sandstone formation where its ability to migrate further upwards is restricted by reduced permeability. Coalbed methane does not migrate from the shale but is generated during the transformation of organic material into coal.

3.1.2.1 Presentation of global production volumes and emissions

In 2021, global natural gas reserves were estimated at 190.3 trillion cubic meters. Of this, 40.3 % is accounted for by the Middle East, especially Iran (17.1 %) and Qatar (13.1 %), 30.1 % by CIS, especially Russia (19.9 %), 8.8 % by Asia-Pacific, 8.1 % (China 4.5 %) by North America (USA 6.7 %) and 6.9 % by Africa (Nigeria 2.9 %). Europe has only very small *proven* natural gas reserves in global comparison (1.7 %). Russia and Iran accordingly have the largest natural gas reserves on a country-by-country basis worldwide. It is interesting to note that proven natural gas reserves have increased significantly over the last two decades, especially in the US, as a result of the shale gas revolution (from 4.8 trillion cubic meters in the late 2000s to over 12.6 trillion at the end of 2019). Significant shale gas deposits are also suspected in Europe but are currently not allowed to be extracted.

It is also interesting to note that the USA is now the largest natural gas producer on the globe, even though its reserves are smaller than those of Russia or Iran. In 2020, 1109.9 billion cubic meters of natural gas were produced here, slightly more than half that in Russia (638.5 billion cubic meters) and 250.8 billion cubic meters in Iran. In Africa, only 6 % of the global production volume is recorded, despite the similarly large deposits as in North America.

The ratio between reserves and production indicates that at current consumption levels and known natural gas reserves, the world will have about 48.8 years of natural gas left if more reserves are not explored. As with coal and oil, this figure varies regionally. Due to the large production volume and, at the same time, globally smaller reserves, the USA could run out of gas in as little as 13.7 years if production remains constant. The Middle East and CIS, on the other hand, with their large reserves and smaller production volumes, have 110.4 and 70.5 years respectively. Africa will still have 55.7 years of gas, although it can be expected that with increasing investments more natural gas will be found and the reserves will rise accordingly. The Asia-Pacific region and Europe are also dependent on imports to continue to be supplied with natural gas. Here, the reserve-to-production ratio is 25.4 and 14.5 respectively.

At the same time, the annual demand for natural gas has increased from 961.4 billion cubic meters in 1970 to 4037.5 billion cubic meters in 2021.[23] Initially, natural gas was a predominantly regionally traded energy source due to its aggregate state, consumed in North America, the CIS countries and Europe. However, with technological progress and increasing globalisation, the Middle East and Asia-Pacific regions also used natural gas. The US remains the largest global consumer of natural gas (826 billion cubic meters in 2021), as it is heavily used here for power generation, as described, and was historically produced first. But in China, Iran, and Saudi Arabia, the market has grown by a factor of 83, 80, and 74, respectively, over the past 50 years.

According to the current Gas Market Report, which also estimates the consequences of the Ukraine war, global demand for natural gas is expected to increase by 140 billion cubic meters between 2021 and 2025 to 4,177.5 billion cubic meters. This corresponds to about half of the originally projected demand and is due to the reduced switch from coal to gas for power generation caused by the conflict and the weaker economic activity.

Furthermore, CO_2 emissions associated with natural gas are estimated at 7.5 Gt in 2021 (compared to 15.4 Gt for coal and 10.7 Gt for oil). The methane emission rate from natural gas for power generation is estimated at 41 Mt (out of 570 Mt worldwide).[24]

3.1.2.2 Sources of GHG emissions

Compared to the other fossil fuels, natural gas is *relatively* "clean" as described. Its combustion produces 40 % less CO_2 emissions than coal and 20 % less than oil. In addition, the pollution from sulphur and nitrogen oxides as well as fine dust is significantly lower. If, for example, coal is burnt in a power plant with an average efficiency of 35 %, about 1.17 kg of CO_2 are produced per kWh of electricity generated. In a natural gas combined cycle power plant with an efficiency of 60 %, the figure is only 0.33 kg CO_2 .

[23] Cf. BP, 2021.
[24] Cf. IEA, 2021c.

3.1.2.3 Opportunities for technical GHG mitigation

To contain so-called upstream and downstream emissions (mainly methane emissions) that occur during the production and subsequent distribution of natural gas, there are several options. In a paper on the subject published by Global Energy Solutions, author H.J. Wernicke describes that concrete measures are the "sealing of leaks and the trapping of residual gases in fossil energy production". In other words, the search for and closure of leaks at wells, pipelines, pumps and compressors along the entire process chain. According to the report, emissions could be reduced by 57 % in this decade with known technologies if "all sources of emissions were addressed simultaneously, worldwide and at high financial cost". When it comes to detecting methane leaks, an odorless gas, for example, aircraft and drones equipped with novel infrared laser technologies could help detect them and seal them in the next step. Today, natural gas is mostly used for electricity generation (40 %), followed by industry (23 %) and buildings (21 %). In recent years, the use of hydrogen and PtX products (e.g. ammonia) in particular has been discussed for the substitution of natural gas, for example in the steel industry. For example, Salzgitter recently announced that it would invest 723 million euros to switch to hydrogen reduction and electric steel furnaces.[25] For direct reduction, hydrogen is then used instead of natural gas. This can be produced free of CO_2 emissions via electrolysis (see chapter 2.2.) with green electricity. The use of hydrogen is also being discussed for electricity generation. However, as described in 2.2, the volume-related energy content of the energy carrier is about 3 times lower than natural gas or methane and can also lead to corrosion. Gas-fired power plants must therefore be "H2-ready" for use, i.e., connected to a hydrogen supply network and hydrogen-resistant, but also have a suitable combustion system. Currently, there are no gas turbines ready for series production that can be operated with hydrogen. DLR expects hydrogen-capable gas power plants to be ready for the market by 2030.[26] Especially in combination with renewable energy plants, such gas power plants will be particularly important, along with battery storage, to compensate for the volatility of wind and solar power. Hydrogen could also play a role in heat supply, for example through its use with fuel cells or H_2 boilers. However, the Federal Environment Agency, for example, notes that there are also enough fuel-free renewable alternatives in this sector, such as solar thermal energy, geothermal energy, environmental heat and unavoidable waste heat. These are more energy-efficient because they do not require complex conversion processes.[27]

3.1.3 Oil

In addition to coal and gas, oil also plays a role (albeit a minor one) in energy generation (electricity). Today, oil is used overwhelmingly in the transport (56 %) and industry (mainly petrochemicals, 12

[25] Cf. Handelsblatt, 2022.
[26] Cf. DLR, 2020.
[27] Cf. Federal Environment Agency, 2022.

%) sectors and only about 6 % for electricity and heat generation. Therefore, only an overview of global reserves, production and consumption is given in this part of chapter three. Chapters 3.2. to 3.4. provide solutions for technical CO_2 reduction for the use of oil in industry, the transport sector and the building sector. Chapter 3.1.4. deals with the substitution of diesel generators for power generation in the global South.

3.1.3.1 Presentation of global production volumes and emissions

In the last fifty years, oil production has tripled, from 31.8 mbl/d (million barrels per day) in 1965 to 89.8 mbl/d in 2021.[28] The strongest region in the production of oil the Middle East (28.1 mbl/d) and here above all Saudi Arabia (10.9 mbl/d). But North America has also renewed its status as an oil power in the wake of the fracking revolution (23.9 mbl/d). The USA is now the world's largest oil producer (16.5 mbd). Russia is the third largest oil producer, while the amount of oil produced has remained almost the same over the past years (10.9 mbl/d or 12.2 %). China in particular has been able to steadily increase its share (4 mbl/d or 4.4 % in 2021). Comparatively little oil is produced in Europe. The region had a share of 3.8 % of global production in 2021. The largest producer in Europe is Norway (2.3 % or 2mbd).[29]

The increased production rate is the answer to an ever-growing demand for oil in the world. In 1965, consumption was 30.7 mbl/d; in 2021, it will be 94 mbl/d. The largest observed dynamic in oil consumption has been the progressive shift from North America (23.7 % share) to the Asia-Pacific region (38.1 $ share). The USA remains the largest oil-consuming country in the world (18 mbl/d, 19.9 % share). This is followed by China (16.4 %) and India (5.2 %).[30] In the last 50 years, oil consumption has increased 1.7 times in the USA, 60 times in China and 18 times in India. Shares in Europe and CIS have declined over the years, while shares in the Middle East have tripled and doubled in Africa.[31] In view of the rising economic growth and individual prosperity, which contributes to increased purchasing power and increases individual oil consumption, it is to be expected that demand in the emerging economy will increase even further. In particular, developments in the transport sector will be crucial for oil consumption, as indicated above. For 2023, the IEA and other institutions project global oil demand to exceed 100 mbl/d (more precisely: 101.6 mbl/d) for the first time.[32] Consumption is thus again above those before the Covid 19 pandemic, driven mainly by the growing oil hunger in the emerging economies of China and India. Non-OECD countries will account for about 80 % of the growth in oil consumption. In 2020, oil-related CO_2 emissions were 11.07 billion tonnes. Oil is thus the second most CO_2 emitting fuel after coal.

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[28] Cf. BP, 2022.
[29] Cf. BP, 2022.
[30] Cf. BP, 2022.
[31] Cf. Tagliapietra, 2020.
[32] Cf. IEA, 2022.

Oil-related CO_2 emissions could increase to around 12 billion tonnes per year.

3.1.4 Developmental relevance

In the countries of Sub-Saharan Africa[33] (SSA), 573 million people did not have access to reliable electricity in 2017 and 900 million rely on biomass for cooking due to cost and availability, with devastating social, health and economic consequences.[34] The United Nations' SDG 7 therefore makes it its goal to ensure access to stable and sustainable electricity for all by 2030. But building a reliable and, in perspective, climate-friendly energy system faces profound challenges on the subcontinent. Considering the UN's projected population of 4.7 billion by 2100, accompanied by urbanisation, industrialisation and the expansion of the middle class, which will increase the future demand for energy, these challenges are even greater.

3.1.4.1 Centralised and decentralised power supply systems

Proposed solutions, such as the Africa Energy Outlook recently published by the IEA, essentially envisage the expansion of *on-grid* and *off-grid* energy infrastructure. On-grid infrastructure in SSA, i.e. the central power grid, is either insufficiently developed in many regions or only provides unreliable electricity for the population. According to the IEA, 80 % of all companies and 60 % of all households experience regular and persistent power cuts.[35] The reasons for this are manifold: failures of widespread hydropower generation due to drought, poor maintenance of plants, lack of fuel supply, and inadequate transmission grid expansion. In order to promote sustainable socio-economic development in SSA, there is a need to modernise and expand on-grid infrastructure, with particular potential for hydropower and natural gas (e.g. in Nigeria, Algeria and Mozambique).[36] In parallel to on-grid, off-grid and mini-grid systems provide innovative ways to supply electricity, especially in areas that are cut off from the central grid and where it will remain uneconomical for operators to expand the grid. Currently, mainly polluting diesel generators are used in households to produce electricity. According to the latest IPCC report, diversifying power generation away from traditional fossil fuels and towards old and new renewables, which can also be used in a decentralised manner, can avoid vulnerabilities associated with climate change, especially in rural areas of the global South.[37] As prices fall, solar PV is increasingly providing cheap access to electricity in combination with so-called *pay-as-you-go schemes.* In its Sustainable Africa Scenario, the IEA simulates that for universal access to sustainable electricity supply in 2030, 42 % of SSA's population gets its electricity from the

[33] SSA excludes South Africa.
[34] Cf. Tagliapietra, 2020, p. 215.
[35] Cf. International Energy Agency, 2022.
[36] Cf. Tagliapietra, 2020.
[37] Cf. IPCC, 2022.

grid, 31 % from mini-grids and 27 % off-grid. The former share mainly in urban areas and the latter two in rural areas.[38]

On-grid and off-grid systems are characterised by fundamentally different economic constraints. The expansion of the central electricity grid requires substantial initial investment costs (CAPEX), which companies are only willing to invest if the risk of investing can be minimised by credible legislation and a *return on investment can be* expected. If these conditions are met, such investments promise a stable profit and become attractive for large corporations or the government. Off-grid solutions and mini-grids, on the other hand, are not very lucrative for energy companies. This endangers the supply of rural populations for the reasons described above. Therefore, the international community and development cooperation is focusing on supporting local communities, entrepreneurs or *small and medium-sized enterprises* that drive such initiatives in cooperation with local stakeholders. The pay-as-you-go schemes mentioned above, through which solar PV systems can be financed by consumers, are repeatedly cited as a promising business model. [39]

The reform of government structures and subsidies, as well as the expansion and focus of international donor funding, will be crucial to the success of these measures. Countries in the SSA region subsidise the energy sector to the tune of approximately USD 25 billion annually.[40] Most of these subsidies go to inefficient and wasteful power infrastructure, which would run a budget deficit without these subsidies.[41] The revenues are less than the profit collected and are not enough to maintain the power system. Power generation is abused by governments in the region as a way to secure their rule, because control over this critical infrastructure comes with power. The result is corruption and inefficient management that necessitates subsidies and blocks the urgent expansion and modernisation of the grid. Tagliapietra identifies two fundamental problems with subsidies: First, they are given out as a lump sum. This means, for example, that they do not flow into the expansion of infrastructure for the population cut off from electricity supply but benefit the high-income groups and companies that are already connected and consume the most electricity. Secondly, subsidies have the effect that operators invest less in the expansion or maintenance of the grid, as their operations are kept artificially alive even in the event of any loss of revenue. [42]

A reform of subsidies and governance is therefore necessary to enable secure electricity supply for more people in SSA. At the same time, there is a need for stronger coordination between international donor institutions such as the World Bank, the African Development Bank and the EU, but also China, whose financial support could also catalyse the urgently needed private investments (e.g. through risk-sharing mechanisms). While official development assistance in the sector has

[38] Cf. International Energy Agency, 2022.
[39] Cf. International Energy Agency, 2022, p. 117.
[40] Cf. Tagliapietra, 2020.
[41] Cf. Tagliapietra, 2020.
[42] Cf. Tagliapietra, 2020.

quadrupled in recent years, from 2 billion in 2005 to 8 billion in 2015, this support is not sufficient for the growing energy needs on the continent. Divergent agendas and donor bureaucracy continue to lead to high transaction costs and the financing of smaller projects with lower investment risk.

3.1.4.2 Establishing fair hydrogen markets at eye level

The current *hype* around renewable hydrogen in the course of the transformation of energy systems in many countries, fueled for example by the announcement of the EU to import 10 million tons of hydrogen annually by 2030, can represent a potential for economic diversification for economies in the Global South. Countries such as Angola, whose GDP is fed to more than 50 % by revenues from the sale of oil (with corresponding risks if revenues from this sector collapse) and at the same time have good production conditions for renewable hydrogen, see an opportunity here to compensate for the potential loss of revenues from the oil industry due to lower demand in the industrialised countries.

But new players are also entering the scene that were previously energy importers and could now become exporters, such as Morocco. Thus, theoretically, a global market can emerge that, on the one hand, helps to decarbonise energy systems, but also breaks existing dependencies that the fossil age brought with it, with benefits for energy security for the importing countries. On the other hand, it offers new income opportunities for producing countries in the global South. But for such a hydrogen market to be established on an equal footing between importers and exporters, reliable framework conditions are needed to ensure that one-sided value creation is avoided (as is often the case in extractive industries, cf. *resource curse*).

Think tanks such as the Öko-Institut, but also the PtX Hub, are therefore working on developing approaches that ensure the sustainable production of PtX products. Four dimensions for the production of renewable hydrogen are named in summary: Environmental, Economic, Governance and Social.[43] Environmental aspects include, for example, the principles of ensuring the use of renewable electricity, the additional construction of RE plants, the geographical proximity of the electrolyser to the RE plant and the temporal correlation between the generation of the electricity and the hydrogen, which are also anchored in the delegated act on Article 27 of the RED II Directive. Furthermore, processes should be implemented to mitigate the environmental pollution that can be associated with electrolysis (e.g., by introducing processes to remove salt sponge produced by desalination of seawater for electrolysis). It is also important to ensure that the CO_2 used for PtX products such as synthetic fuels does not add to the atmospheric burden. From an economic perspective, as mentioned, intersectoral benefits should arise from the production of green hydrogen. This means, for

[43] Cf. PtX Hub, 2022.

example, that the construction of renewable energy plants for PtX is also accompanied by the expansion of the local electricity grid, which benefits the local economy and population.

The same applies to desalination plants that could contribute to local water supply. The overarching social aspect is *just transition,* which means, among other things, the retraining of staff who lost their jobs due to the transformation of the energy market and now have to find work in the new industries such as PtX production. It also refers to the involvement of local stakeholders in order to avoid *green grabbing, in* which inhabited areas are forcibly cleared in order to build renewable energy plants. Finally, transparent and coordinated governance structures are needed to establish fair hydrogen markets at eye level. Above all, energy partnerships between governments will be crucial to establish certificates and standards that ensure what is described here and avert market fragmentation.

[44] Cf. Oxford Economics, 2019.
[45] Cf. Oxford Economics, 2019.
[46] Cf. World Steel Association, 2022.