



Article The Nexus of World Electricity and Global Sustainable Development

Veronika Wittmann^{1,*}, Elif Arici² and Dieter Meissner³

- ¹ Faculty of Social Sciences, Economics & Business, Johannes Kepler University, Altenbergerstraße 69, 4040 Linz, Austria
- ² Energy Institute, Istanbul Technical University, Istanbul 34469, Turkey; aricibogner@itu.edu.tr
- ³ Department of Materials and Environmental Technology, TalTech, Ehitajate tee 5, 19086 Tallinn, Estonia; profdieter@gmail.com
- Correspondence: veronika.wittmann@jku.at

Abstract: The main part of mankind's ecological footprint is the carbon footprint, a measure of the environmental impact of humanity's energy release from fossil fuels. The use of fossil fuels will have to change in the forthcoming decades to a largely climate-neutral use of solar energy enabled by dramatic cost reductions for PV and wind energy systems. The impact of this trend on world society has been discussed in a previous paper. In connection with these important technical developments, the role of electricity, its transport and storage will alter in the coming decades, allowing the design and use of larger and larger electricity grids and a parallel use of hydrogen for both storage and energy transport. This will further change the energy landscape of the world. All these developments and their relationship to global sustainable development are elaborated in this cross-disciplinary paper by specifically analyzing whether the Sustainable Development Goals by the United Nations are an effective road map for humanity to handle global climate change risks.



1. Introduction

Technical and scientific developments changed the socio-economic and political structure of the world, such as in the Industrial Revolution in the 18th century, when agricultural societies in states of the Global North became industrialized societies. The transcontinental railroads, trains powered by steam power for transport, electricity and machines for mass production permanently changed world society. The impact of photovoltaics has been discussed in Part 1 of the authors' nexus analysis [1]. In this second paper, we describe the potential impacts of new technological developments in the world's energy system and its consequences for global sustainable development, namely superconductive electricity grids and hydrogen technology.

Starting with a compelling motivation, the latest calculations showed that humanity has a remaining global carbon budget of 420 Gt carbon dioxide (CO₂) to keep global warming below a value of 1.5 K above the pre-industrial level (K or Kelvin being the unit of temperature change used in meteorology, equal in magnitude to 1 °C). All states across the globe signed the Paris Agreement on climate change in 2015 [2], the first ever universal, legally binding global climate change agreement. Therefore, most countries of the world have agreed to reduce their CO₂ emissions according to individually set Nationally Determined Contributions (NDCs). All states have different timetables for their CO₂ reduction measures. National CO₂ emissions reported by individual countries cannot be directly measured or verified by third parties, and there is certainly no consensus on how the targets should be financed, pursued and in what time frame they should be achieved. Certainly, the extent of the impacts of climate change will affect world regions differently



Citation: Wittmann, V.; Arici, E.; Meissner, D. The Nexus of World Electricity and Global Sustainable Development. *Energies* **2021**, *14*, 5843. https://doi.org/10.3390/en14185843

Academic Editor: Ricardo Bessa

Received: 27 July 2021 Accepted: 13 September 2021 Published: 15 September 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). and will vary over time, but humanity will bear the consequences globally, although the most affected world regions are located in states of the Global South. Therefore, a public awareness of this imbalanced affectedness is important, which in turn would catalyze the indispensable contribution of International Non-Governmental Organizations (INGOs) and civil society movements.

In this paper we discuss the ambivalent impact of technological developments in the energy sector on global sustainable development. Through avoiding CO_2 emissions, the use of solar energy (directly in photovoltaics (PV), or indirectly as wind energy (WE)) as the only source of primary energy can do more than just reduce the negative impacts of climate change, such as (among others) loss of sea ice, accelerated sea level rise and longer, more intense heat waves, destruction of marine life by rising water temperatures, an increase in extreme weather events, and shifting wildlife populations and habitats [3]. It will also protect the environment from poisonous and radioactive emissions released when burning fossil and nuclear fuels, as well as from connected particle and particulate emissions producing smog, still one of the greatest environmental problems today mainly in Asia. In addition, it will change the world economy by lowering energy prices. As such it holds the opportunity to make electric power accessible to everyone to mitigate or adapt to new challenges associated with climate change. The levelized cost of electricity (LCOE) for solar PV is already lower today than all fossil fuel or nuclear generation sources and is set to decline further as installed costs and performance continue to improve. Globally, the LCOE for solar PV will continue to fall from an average of about USD cents 3 per kilowatt-hour (kWh) today to about USD cents 2 by 2050 [4]. Since it is inalienable that renewables, like solar and wind energy, have to be the technologies of choice with their ecological and economic advantages, the decisive 'scientific' influence will come from the chosen strategy for the technology of renewable energy distribution. Therefore, in this paper we focus on the implications of new and emerging technological developments for energy transmission, distribution, and storage/non-storage systems such as Ultra High Voltage Direct Current (UHVDC), Ultra High Voltage Alternating Current (UHVAC) lines [5], superconductive lines and hydrogen technologies reporting the technological readiness level and the actual status of challenging situations of global system integration. Decentralized energy systems for small communities that cover daily needs with the help of a small energy storage units, as well as regionally centralized PV and wind systems, can be set up with the technologies mentioned above [6], with the possibility of expanding the energy grid which will also globally enable the involvement of new players. Thereafter, the main part of our work assesses the links between the energy distribution scenarios described and the global policy framework regarding carbon-free energy resources. The term global policy framework, as understood here, is the framework of worldwide processes, structures, and fields of action, i.e., including various stakeholders (states, business, civil society, etc.). As such, it involves the framework of multi-level policy making by public and private actors, thereby the term global transcends national, regional, and international scopes. The concept of the world risk society and the enforcement of multilateralism to solve global implementation problems are discussed, considering the emergence of the global carbon budget agenda and the legitimacy of the Sustainable Development Goals (SDGs) proclaimed by the UN in 2015 for climate change adaptation.

2. Energy Transport

Electrical grids (also called power grids) connect power stations generating electrical energy with power consumers, utilizing the electricity to power machines, or lighting systems and dissipating the energy to finally heat at ambient temperature. Nearly all countries around the world operate national grids connected by synchronized alternating current power lines on different voltage levels, together forming the transmission network. Main voltage levels are 110 V in the USA and 230 V in Europe for distribution: 33–66 kV as so-called subtransmission lines. Voltages above 765 kV are considered extra-high voltages and are used mainly for long-distance transmission. Ultra-High Voltage Alternating

Current (UHVAC) Transmission was developed in the Soviet Union in the 1980s to bring electricity from the coal mining and power plants in the central region of Kazakhstan to the industrial centers in its European parts. The power transmission lines operate at \pm 750 kV and had a power of about 6000 MW. The necessary DC equipment had been developed nearly completely in the former Soviet Union and had already passed all type tests. However, due to various reasons, the project was never put into operation.

In China, research on UHV transmission technology started much later but developed very fast. Since the beginning of 2009, China has realized many UHVAC and UHVDC transmission projects [7]. It tries to learn from developments in Germany and the USA to tackle the immense problems of an energy system, which is based by more than 2/3 on fossil power plants into a CO₂-neutral system [8].

Transmission lines for overhead transmission are made mainly from aluminum strands surrounding steel strands (for stability) for overhead lines without isolation. Underground transmission cables have to be isolated. Here, the development of new materials as well as new technologies have already revolutionized possibilities. New isolating materials have allowed the development of high-voltage, direct current (HVDC) technologies to transmit energy by direct current over long (>750 km) distances. At certain distances, the HVDC has lower overall transmission losses than transmission with three-phase alternating current, despite the additional converter losses. Examples are the unfinished HVDC Ekibastus Center in Siberia, the 1700 km long HVDC Inga-Shaba in the Congo and the over 1000 km long HVDC from Québec—New England between Canada and the USA. In Europe, due to the comparatively short distances between power stations and consumers, there are currently no HVDC systems in this length range.

However, in the 1990s Gerhard Knies developed and promoted the idea of a Trans-Mediterranean Renewable Energy Cooperation (TREC), started in 2003 by the Club of Rome and the Jordanian Energy Research Center. From this the Desertec Foundation evolved, which in 2009 initiated the DII GmbH [9]. By the end of 2014, however, DII had shrunk again from 17 partners to just three (Germany's RWE, Saudi Arabia's Acwa Power and China's State Grid). Now, Desertec and DII are working independently with different African partners on solar projects for energy export, an intense and quite diverse competition in bilateral cooperation.

These projects require energy transport over a few thousand kilometers, for which at the beginning of this idea hydrogen pipelines seemed to be the ideal solution. However, progress in high voltage (HV) and Ultra High Voltage (UHV) technologies today also allow the transport of direct current. Figure 1 shows the long-distance lines used already in 2006 in designs [10]. The German electricity grid development plans until 2035 can be found on the website of the "Netzentwicklungsplan" [11]. They mainly aim at providing electricity transport from offshore wind parks in the North Sea and the Baltic Sea to industrial areas in the south of Germany.

Most of the world is already connected in wide-area synchronous grids; the largest of which being the Synchronous Grid of Continental Europe (compare the status of 2010 in Figure 2). Whereas in many parts of the world several countries are connected by these grids, the USA, Japan, and Australia are separated by private grids operating in different regions of these countries.



Figure 1. HVDC lines for connecting North Africa with Europe in DESERTEC and DII plans of 2006 [10]. EU-MENA-Connection by Benderson2 is licensed under CC BY-SA 2.5.



Figure 2. Map of synchronous electricity grids in different parts of the world [12]. Map of synchronous grids by Alinor is licensed under CC BY-SA 3.0.

Especially China is very actively expanding its grid with the aim of connecting the whole of East Asia using UHV lines as a backbone (Figure 3) [13]. Thereby China is trying to learn from developments in Germany and the US to tackle the immense problems of converting a fossil fuel-based energy system into a CO_2 -neutral system [8].

Zhenya Liu, former Chairman of the State Grid Corporation of China, describes in his books [14–16] China's activities and plans from both the technical as well as the political

side. From a strictly global energy perspective, Liu analyzes the status quo and challenges of global energy development. His conclusion is the need for what he describes as "two replacements": replacing high-carbon with low-carbon energy sources and going from local balancing to wider-scale network development.



Figure 3. Asia super-grid as planned by State Grid (China), Korea Electric Power, Japan's Softbank, and Russian power company Rosseti to connect those nations and Mongolia [13]. Asia Super Grid by Jean.julius is licensed under CCBY-SA 4.0.

By analyzing future electricity supply and demand, he develops a concept for developing global energy interconnections using UHV AC/UHV DC grid technology and connects these with smart grid technology. Based on strategic thinking, he develops a detailed roadmap including brand new solutions to promote safe, clean, efficient, and sustainable energy development worldwide (compare Figure 4). In his 2015 published book Liu even proposes a world UHV backbone structure to form a world electricity grid [16]. Thereby worldwide collaboration could solve the problem of intermittency of renewables with very little need for storage.

Superconductivity promises further breakthroughs in electricity transport since it allows electron flow without resistance. However, it requires very low temperatures, i.e., for classical superconductors even temperatures near to absolute zero at 0 K or -273.15 °C. Many metals become superconductive when cooled below their critical temperature at ambient pressure, several non-metals like boron or sulfur only at high pressures. Of special interest are the high-temperature superconductors (HTS) with critical temperatures above 30 K; especially those which can be made superconductive by cooling with liquid nitrogen. Liquid nitrogen is produced large scale and has a boiling point of 77 K (-203 °C): YBa₂Cu₃O₇, (YBCO), one of the first cuprate superconductors to be discovered, has a critical temperature above 90 K, and mercury-based cuprates have been found with critical temperatures in excess of 130 K. Thereby both materials can simply be cooled by liquid nitrogen.

Large-scale HTS applications have now been successfully demonstrated for almost all interesting applications including motors, power cables, transformers, magnetic and flywheel energy storage systems, and wind as well as solar generators. Until today, the number of HTS wire manufacturers operating commercially has grown quite considerably mainly in recent years and seems to grow continuously. Today, there are already a dozen companies offering to supply significant quantities of wire, and about the same number is in a pre-production ramp-up phase. Nevertheless, the total capacity for production is well below the projected demand, so that supply issues limit a faster progress [17]. However, practical applications, especially those for use in electricity transport, are still in the development phase. One of the most advanced projects currently in progress is certainly the DEMO 2000 project, which is coordinated by Vision Electric Super Conductors GmbH (VESC) to install a 200 kA superconductive power line with a rate current of 200 kA in the German Trimet aluminum smelter Voerde [18].



Figure 4. Backbone structure of a globally connected energy network as developed by Zhenya Liu [16], p. 211. Reproduced with permission from © China Electric Power Press Ltd.

3. Hydrogen

3.1. History

The vision of a solar-based hydrogen economy has been developed by electrochemist John O'M. Bockris based on ideas of biologist J.B.S. Haldane [19]. Bockris' 1976 book "Energy: The Solar-Hydrogen Alternative" [20] already describes a hydrogen economy, in which cities in the United States are powered by solar energy. In Germany it was published by Bockris together with Eduard W. Justi, another pioneer in solar energy and hydrogen [21]. At that time Carl-Jochen Winter had already directed a good part of R&D in the German Aerospace Center (DLR) towards solar hydrogen and was working on projects with Saudi Arabia, where in 1985 Hysolar started to demonstrate large-scale photovoltaic water electrolysis. A few years later, a first self-sufficient PV-based energy system was demonstrated in the Research Center Jülich, Germany, in which short-term energy storage was performed by batteries and seasonal storage by hydrogen utilizing electrolyzers and fuel cells [22]. Joachim Nitsch, a close coworker of Winter, developed renewable energy scenarios for Germany [23] and beyond [24], which much later also became the scientific background for the German Energiewende (renewable energy transition).

3.2. Production

 H_2 has the highest energy per mass of any fuel—33.3 kWh per kg; however, as a gas the energy density is just 3 kWh/m^3 [25]. Therefore, the development of storage methods for a higher energy density is one of the most important R&D targets. Liquid storage of H₂ offers a possibility to increase the energy density; but liquefaction is an energy intensive process, especially for H₂ (10–15 kWh/kg), because cryogenic temperatures of -253 °C at 1 atm are needed. In total, 1/3 of the chemical energy content of H₂ would be already consumed for cooling [26]. Additionally, safety problems together with special handling requirements present a bottleneck for the implementation of liquid H₂. As of 2020, more than 95% of the world's H_2 production comes from fossil fuels, with nearly half via the steam reforming of methane (SMR), followed by partial oil oxidation and coal gasification (grey H_2). Thereby, it is neither renewable nor sustainable and part of a fossil fuel energy system. Typically, regional resource availability currently determines technology deployment. SMR has a large market share in the United States, in the Council for the Arab States of the Gulf (GCC) and Europe. China uses coal, which is explained by abundant, cheap resources. Methods are being developed that can capture carbon emissions during H_2 production. These carbon compounds can be removed from the environment, making H_2 production more climate friendly, a way to change the status from grey H_2 to blue H_2 . However, it is clear that green H_2 technology, in which water electrolysis powered by renewable energy, is the only sustainable technology for governments' carbon neutrality targets under the Paris Agreement [2]. Not only can the green H_2 vision reduce H_2 production costs in the long term, but it also strongly supports the integration of fluctuating renewables such as wind and solar energy into the power system. In situations where the demand for electrical energy is on the increase, the stored H_2 can be used in fuel cells to produce electricity when needed. In the current state of development of H_2 technology, it is expected that new import/export opportunities for countries will emerge through the construction of additional east-west as well as north-south corridors for green H_2 transport.

3.3. Storage and Transport

Storing compressed hydrogen at high pressures (e.g., 700 bar) in high-strength carbon fiber tanks is possible, but also costly and fraught with mechanical risks. A new generation of liquid compressors with a specific low energy consumption of 2.7 kWh/kg was developed in the 1990s by Linde AG. For H₂, they have an energy saving of about 40% compared with conventional dry-running piston compressors for 900 bar [27], due to the very low vapor solubility and the incompressibility of ionic liquids.

Synthetic H₂ derivatives such as ammonia can also be counted among the alternatives as liquid H₂ carriers, a feedstock which can be "cracked" in a Haber-Bosch plant allowing H₂ and N₂ to be harvested [28]. The storage of ammonia can be done using old technologies under well-known security codes and standards, so the risks, such as the toxicity of ammonia, are cheaper to control than storing liquid hydrogen, which is highly flammable and explosive in air. Therefore, the principle here is to efficiently synthesize ammonia in remote areas using PV (or wind) energy and transport the 'H₂ carrier' via sea transport methods. Ammonia can also be used directly as a fuel, e.g., in shipping, so transportation costs are also affordable. However, the first step in the realization of this approach is the emergence of market demand [29]. On the other hand, dedicated H₂ pipelines operating at 10–40 bar are at the test phase in the USA (2500 km) [30] and also in China (100 km) [31]. To make the H₂ compression technology more durable seems to be one of the problems that need to be solved. However, also, the choice of piping material is not standardized yet; fiber reinforced polymer pipelines have the potential to replace steel pipelines and reduce material costs by 20% [32].

One possibility to integrate H_2 into the existing energy system could be to feed H_2 into the natural gas pipeline, which is technically possible with minor system modifications up to a volume share of about 15–20%. Higher H_2 percentages will however require major modifications of the equipment. H_2 is about three times less energy dense than CH₄. As

the ratio of H_2 in the gas mixture rises, the volume of energy being delivered through the same pipelines decreases, so that modifications in metering are required. The long-term effects of H_2 at different mixtures on different piping materials also need to be evaluated in more detail. The large range of hydrogen concentrations forming explosive mixtures (4–74% by volume) in comparison to methane (5–14%) is also of great importance for safety and engineering challenges. There should be no sparks in the pipeline, as H_2 is explosive at almost any air/fuel ratio. H_2 also has about eight times greater flame speeds than methane [33]. According to the European Hydrogen Backbone (EHB), a group of leading European gas transport companies, Europe plans a 39,700 km hydrogen network by 2040. About 30% of the hydrogen network will be newly built, 70% of the network will be reused after retrofitting of the existing natural gas network [34].

Not only will the transportation of H_2 over long distances but also the H_2 production costs contribute to the question of how far H_2 technology can be utilized for zero-CO₂ emission targets. As above mentioned in 2020, 95% of current H_2 production is fossil fuel based and just 4% blue (mainly) and green H_2 . Indicative production costs for the three forms of H_2 today are 1.5 EUR/kg (38 EUR/MWh) for *grey* H_2 ; 2.0 EUR/kg (50 EUR/MWh) for *blue* H_2 and 2.5–5.5 EUR/kg (65–135 EUR/MWh) for *green* H_2 [35]. It is important to emphasize that in the literature one can find a wide range of calculated values based on different geographically arrangements and assumptions. However, generally speaking, *green* H_2 is 2–3 times more expensive than *blue* H_2 . To be price competitive, three key drivers need progress: renewable investment costs and electricity, electrolyzer costs and electrolyzer capacities.

3.4. Regional Aspects

In the last 5 years, national plans to accelerate the commercialization of hydrogen and its supply chain have been developed to facilitate the transition of the chemical, transportation, electricity, and heating sectors to H₂ economy worldwide [33–36]. By 2030, the EU proclaimed the ambitious goal of 40 GW of electrolyzer capacity within Europe to produce *green* H₂, plus an additional 40 GW in Europe's southern and eastern neighbors (e.g., Ukraine or Morocco) which could export renewable hydrogen to Europe to reach the EU target volume of 10 million tons of H₂ per year [37].

Converting offshore wind energy from the North Sea region and from the Baltic Sea into green H_2 as an energy carrier is one of the strategies for the Northwest European region. In order to realize this, it would require retrofitting and expanding gas infrastructures for H₂ transport. The Danish Island of Bornholm is planned as a green bunker hub, where 60,000 ships per year can refuel with sustainable fuels in 2030, reducing Danish CO₂ emissions by 70% [38]. Additionally, in China, the aim is for the decarbonization of H_2 production and the expansion of its use mainly in the transport segment (e.g., 1 million Fuel Cell Driven Electrical Vehicles and 1000 hydrogen refueling stations by 2030) [39]. A further ambition is to create new H_2 end-users in energy-intensive sectors such as the cement and steel industries, refining industry using hydrogen to lower the sulfur content of diesel fuels as well as to focus on the electricity storage segment. A large-scale electrolysis-based hydrogen production plant, a hydrogen-based direct reduced iron (DRI) plant combined with electric arc furnace (EAF) steelmaking, and all related downstream equipment would lead to a 90% reduction in the carbon footprint compared to a classical steel plant. Further investments are needed to scale up electrolyzer manufacturing capacity to improve the supply chain.

Worldwide, 36 so-called hydrogen valleys, a geographic area such as an island, a city, or an industrial cluster, have recently been developed in 19 countries, where several applications of green or blue H_2 are integrated into an ecosystem to explore the entire H_2 value chain: its production, storage, distribution, and final use in order to develop a pathway for upscaling. Europe hosts a large share of the projects, followed by Australia, USA, China, Japan, Chile, and Thailand. About 20% of these Hydrogen Valleys would produce less than 1 ton of hydrogen per day, while 40% will produce 1–10 tons per day.

The remaining 40% will produce more than 10 tons per day with up to a production of more than 2000 tons per day [40].

Oil-exporting countries such as Saudi Arabia are investing large amounts of money into green H_2 technologies for export. The Saudi Arabian NEOM project aims at 4 GW solar and wind power plants for the production of 650 tons of H_2 per day and 1.2 million tons of green ammonia per year—one of the world's biggest H_2 investments. When it opens in 2025, NEOM will be a new model for urban sustainability, powered by 100% renewable energy. Other, bigger projects are in planning, but with longer development periods, like the InterContinental Energy's Asian Renewable Energy Hub with 15 GW or Siemens's Murchison Renewable Hydrogen Project with 5 GW, with the aim of importing renewable energy from Australia [41].

In African countries, on the other hand, the multilateral cooperation is still very vague; not a single H₂ valley is located in Africa. The H₂ATLAS-AFRICA project is a joint initiative of the German Federal Ministry of Education and Research (BMBF) and African partners in the Sub-Saharan region to create an interactive map showing the potential of hydrogen production from renewable energy sources in the Sub-Saharan regions [42]. This situation cannot be explained by technological barriers. On the contrary, Spain is already connected to Morocco via two submarine cables with a capacity of about 800 MW, while Algeria and Libya export natural gas to Spain and Italy via several pipeline connections with a capacity of more than 60 GW [41,42]. To our knowledge, there is just one signed partnership agreement between Morocco and Germany representing interest in green H_2 production. In 2020 the European Investment Bank (EIB) provided more than EUR 3 billion in new financing in Africa, which will finance climate-related investments as well as sustainable development; but a thematic focus on H_2 and on energy networks is not given. Even if today Africa still plays a subordinate role in the CO_2 balance, this will change with population growth, success in fighting poverty, and rising living standards. Additionally, Africa will be most affected by climate change due to its hot climate zone and water stress. In places with water scarcity, seawater desalination can be used, so that water consumption does not become a barrier to scaling up electrolysis in coastal Africa. A forward-looking planning towards a H_2 strategy would certainly have a major impact on raising living standards. Studies related to energy, water and agriculture linkages could serve in many ways to achieve the SDGs.

3.5. Policy

There is also a growing number of H_2 studies being conducted by intergovernmental organizations such as the International Energy Agency (IEA) and the International Renewable Energy Agency (IRENA), making hydrogen policy one of the most popular topics in the private sector [31,37]. To be timely for decision makers to provide alternatives, the Hydrogen Council—a UN agency under the World Economic Forum—was launched as a CEO-level advisory body of leading companies with currently more than 90 members in June 2017 [41]. Accordingly, hydrogen is projected to make a large contribution to the transportation sector (about 150 million tons per annum (MTPA)), the industrial sector (about 110 MTPA), followed by power generation (about 140 MTPA), and other sectors.

In summary, green hydrogen technology is very close to its technological maturity and the next actions are very crucial for its integration into global energy grids for energy security. The main global challenges are still effective storage, long distance transport costs and dependence on technology monopolies. Models for system design have not yet been fully evaluated. However, there is the possibility to import *green* H_2 from far away and for distribution by ship without high investment costs and with low risk. Surplus H_2 can then be transported via gas infrastructure. As for electricity, the larger the network of gas infrastructure, the more opportunities will exist for import/export business in the energy sector. This argument applies to both states in the Global North as well as in the Global South.

4. Global Sustainable Development

Discussing the topic of sustainable energy development from a global perspective first requires elaboration on the notion of sustainable development from a theoretical viewpoint. As a second point, the question is raised of whether the SDGs proclaimed by the UN in 2015 can be labeled as a global agenda for sustainable energy. Regarding sustainable energy development and its global outlook, there are two SDGs of specific importance: SDG 7 and SDG 17. The third point deals with global challenges endangering humanity and gives an insight into the universality of risks. Fourthly, the role of global cooperation and the enforcement to multilateralism in relation to world risk society is discussed. Sustainable development needs global cooperation, as does sustainable energy development. Fifthly, regarding climate change and energy transition multi-stakeholder partnerships for the SDGs ranging from states, global civil society and the private sector are outlined. The sixth point looks at the impact of energy transition and climate change mitigation on humanity. Finally, the legally binding international treaty on climate change, the so-called Paris Agreement, and the political agenda of the Decade of Sustainable Energy for All as pronounced by the UN are debated.

4.1. The Narrative of Sustainable Development

Since the publication of the report "Our Common Future" by the World Commission on Environment and Development in 1987, sustainable development has been the dominant global discourse of ecological concern. In this report one finds the most widely quoted definition of sustainable development:

"Humanity has the ability to make development sustainable—to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs." [43] (p. 8.)

This so-called Brundtland report systematically combined several issues that have often been treated in isolation: global environmental issues, peace and security, development, population, and social justice within and across generations. Beyond reiterating Brundtland, the organizers of the 2012 UN Conference on Sustainable Development in Rio stated that sustainable development emphasizes a holistic, equitable and forward-looking approach to decision making at all levels. It highlights not only strong economic performance but intragenerational and intergenerational equity. It builds upon integration and a balanced attention on economic as well as environmental goals and objectives in both public and private decision making [44].

This holistic view of sustainable development can also be found in the four dimensions of sustainable development being developed by the UNESCO in 2005. According to this model see [45], a holistic view of "environment" includes:

- Natural systems that provide the resources—air, water, soil, etc.—that support all life—human and non-human.
- Economic systems that provide a means of livelihood (jobs and income) for people.
- Social and cultural systems that provide family, community, and wider support for people to live together in ways that are culturally appropriate.
- Political systems through which social power is exercised to make policies and decisions about the way social and economic systems use resources in the natural environment.

The UN has made sustainability a priority by defining sustainable development as outlined by the World Commission on Environment and Development in 1987 [43] (p.43); by articulating the four dimensions of sustainable development [45]; by declaring the period from 2005 to 2014 to be the Decade on Education for Sustainable Development [46] as stated by the UN General Assembly in 2002. Furthermore, the SDGs, proclaimed by the UN in 2015, can be labeled as a benchmark for the international community to follow the path of sustainable development.

The term global sustainable development generates a multiplicity of meanings; here it is used to refer to the worldwide scope of the concept of sustainable development as is already being outlined by the Brundtland report. As such, it emphasizes the need for a global perspective on sustainable development. Looked at from another viewpoint: sustainable development will not be sustainable if it does not have a global outlook and impact.

4.2. The Sustainable Development Goal on Energy

The SDGs as indicators refer to countries of the Global South, but also apply to all states. Industrialized states are also accountable for taking steps on a national and international level to ensure sustainable development. Governments across the globe need a concrete implementation plan which is elaborated jointly with all ministries, federal states, and civil society. However, a successful enactment of the SDGs also requires informed and committed people who demand the implementation of the goals.

The UN Millennium Declaration [47], in resolution 55/2 of the General Assembly on 8 September 2000, pointed out in Chapter IV the importance of joint efforts made by humanity to protect the common environment:

"We must spare no effort to free all of humanity, and above all our children and grandchildren, from the threat of living on a planet irredeemably spoilt by human activities, and whose resources would no longer be sufficient for their needs."

The Millennium Development Goals (MDGs) was a landmark milestone entered into by world leaders in 2000 with the aim to "(...) spare no effort to free our fellow men, women and children from the abject and dehumanizing conditions of extreme poverty" as articulated by the former UN General secretary Ban Ki-Moon [48]—but they did not have a focus on environmental risks. However, the turn toward sustainability came in the post-2015 development planning period, as illustrated in the statement by the UN Deputy Secretary-General Amina Mohammed [49]:

"We are the first generation that can put an end to poverty, and we are the last generation that can put an end to climate change, so we [must] address climate change."

Overall, the 17 SDGs highlight with the consensus of all UN member states that development and the environment are inseparable, that there will be no preservation of the ecosystems on the earth without overcoming poverty, and the need for inclusive economic growth and reducing inequality at all levels. At the same time, none of these goals will be achieved if humanity does not succeed in slowing down human-caused climate change. The goals are therefore not to be considered individually: it is important to stress the connections between them. Considering sustainable energy development, specifically two SDGs address the role of energy in a global context: SDG 7 and SDG 17. As such, reflecting on sustainable energy development: both SDGs are strongly interlinked.

The Sustainable Development Goal 7 on energy claims to ensure access to affordable, reliable, sustainable, and modern energy for all. Having sufficient energy to boil, cool or heat, or even to see in the dark, is an important factor for quality of life. Energy is central to the major challenges and opportunities the world faces today: for jobs, security, climate change, food production, etc.

The UN has in 2015 defined five Targets and six Indicators for SDG 7 [50].

- Universal access to electricity by 2030.
- Universal access to clean fuels and technologies for cooking by 2030.
- Increase substantially the share of renewable energy in the global energy mix.
- Double the global rate of improvement in energy efficiency.
- Enhance international cooperation to facilitate access to clean energy research and technology.

• Expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular the Least Developed Countries (LDCs).

SEforALL (sustainable energy for all) is an international organization that works in in partnership with the United Nations and leaders in government, financial institutions, philanthropies, the private sector, and civil society, to support the achievement of SDG 7. They distinguish three pillars of sustainable energy: energy access, energy efficiency and renewable energy. Of these, only energy efficiency is advancing with nearly the pace of change required to meet the 2030 objective [51].

With respect to the progress of SDG 7 so far (see [52]) the proportion of the global population with access to electricity increased from 78% to 87%, and the number of people living without electricity was below 1 billion from 2000 to 2016. Furthermore, the proportion of people with access to electricity more than doubled between 2000 and 2016 in the LDCs. However, 41% of the world's population were still cooking with polluting fuel and stove combinations in 2016. The share of renewables in final energy consumption remained basically constant, being 17.3% in 2014 and 17.5% in 2015. Additionally, even of this small share only 55% of the renewables was derived from modern forms of renewable energy.

In 2019, 2.6 billion people worldwide still did not have access to clean cooking facilities and the number of people without electricity access was 770 million, 75 % of which live in Sub-Saharan Africa [53]. These statistics prove that the world is falling short of achieving the global energy targets as set out in SDG 7.

Overall, a halt in the usage of fossil energy resources is not listed at all in the targets of SDG 7. This would be a clear steppingstone for stopping climate change and thereby enabling further pathways for mankind to achieve global sustainable development.

The definition of sustainable energy development, as understood here, refers to various processes and pathways for how the transition to zero-carbon energy forms can be achieved at a global level. As such, using zero-carbon energy resources has to be a common human endeavor.

4.3. Global Challenges and the Universality of Risks

Looking at global challenges in this century, there are numerous joint risks endangering humanity and influencing world politics and international relations: loss of biodiversity, limits to growth, climate change, pandemics, lack of contemporary digital governance, etc. Science and states have to take these global challenges into account and contribute with expertise to find sustainable solutions. Specific state initiatives, as Germany's initiative to support renewable energies, can develop strategies for solving climate-related risks. However, any state-related or disciplinary solo efforts will not be sufficient to provide adequate answers to how humanity can manage and cope with the global risks of the 21st century. The results of climate change are here interpreted as being the most urgent threat for humanity in the following decades. The consequences of climate change can be catastrophic: be it the rising sea levels or the thawing of permafrost soil in the Commonwealth of Independent States (CIS). The "Global Risks Report 2021" by the World Economic Forum (WEF) [54] lists, among seven mentioned global risks for humanity in terms of likelihood, five environment-related global threats. Climate action failure has hereby always been itemized among the top 5 global risks for mankind ever since 2018. This scenario calls for global cooperation.

Regarding the political landscape across continents in current times and the question of global disunity versus global cooperation, one can state that: "Nationalism is globalizing," as Colin Crouch pointed out [55]. On example of this world-political trend was given in the address to the UN General Assembly by Ex-US President Donald Trump [56]: "Wise leaders always put the good of their own people and their own country first. The future does not belong to globalists. The future belongs to patriots."

This kind of realpolitik is clearly favoring unilateralism, which can be defined as: "The process or fact of deciding a policy or action without involving another group or country." [57]. The counterprogram to unilateralism is multilateralism, being defined as: "A situation in which several different countries or organizations work together to achieve something or deal with a problem." [58]. Are the implications from the realpolitik landscape of the world that humanity has to say farewell to multilateralism, and enter a global political scenario of "Every Nation for itself," [59] as Ian Bremmer stated? Considering global sustainable development, the question has to be raised of whether the SDGs are an effective road map for humanity to handle global risks. The SDGs are unique in the history of global politics—the consensus of all UN members states that development and the environment are attached; there will be no preservation of the ecosystems on the earth without transcending poverty, and the goals are interlinked.

4.4. The Sustainable Development Goal on Global Partnerships in Relation to World Risk Society

Regarding global sustainable development as it is understood here, SDG 17 matters most in as much as it is *the* goal for multilateralism. It focuses on global cooperation and multilateralism by declaring that it aims at strengthening the means of implementation and developing a global partnership for sustainable development.

SDG 17 contains many targets that indicate how far states are willing to implement multilateralism. There is an urgent need for multilateral action, as much as humanity lives in world risk society as being stated by Ulrich Beck [60]. The dangers facing humanity are transnational. Nation-state environmental laws are only limited in their outcome since, e.g., contaminants transcend nation-state borders. The ethical reference point for the model of world risk society is the survival of humanity.

The universality of risks enforces international and transnational cooperation. Global contemporary problems—like limits to growth, atomic power, the ozone hole—implicate that classical questions of social sciences loose importance. Faced with ecological hazards and technological changes—between poor and rich, center and periphery—old inequalities are no longer of central importance. Global threats affect every human being: regardless of sex, age, profession, etc., and have an equalizing moment: all humanity lives in a world-hazard-community. "Social misery can be excluded, global threats no longer. Hunger is hierarchical. (. . .) But global warming is egalitarian and, in this respect, democratic" [60] (p.77). Henceforth, in a world risk society global risks can be interpreted as driving forces for multilateralism; universal threats and their practical treatment generate transnational communities.

Sustainable development needs global cooperation: this statement is based on the following three aspects:

- 1. SDGs address all UN member states.
- 2. Taking the theoretical framing of world risk society into account: the three main global risks are endangering humanity and creating the following world-political trends: firstly, global risks cause global commonalities; secondly, there is an urge for cooperative international institutions; thirdly, there is a rise in global civil society; fourthly, global risks create transnational communities.
- 3. Challenges are the implementation of the goals: the SDGs are a strong rhetorical agenda of the international community, but the difficulty is their implementation.

4.5. Multi-Stakeholder Partnerships

SDG 17 addresses multi-stakeholder partnerships for achieving the goals: states (governments), private sector and civil society. This is a complex task. States are the main political players for the implementation of the goals: fragile states and the rising of nationalism are a big hindrance for reaching the targets. A further blockage to the successful realization of the SDGs on a worldwide scale is a lack of global solidarity. Using the amount of Official Development Assistance (ODA) as an indicator for global solidarity, a lamentable picture comes up: only 6 out of 29 DAC members devoted 0.7% of their Gross National Income (GNI) to ODA until 2020 [61]. Regarding statistics, there is also a lack of data. Only 141 UN member states were implementing national statistical plans in

2019 [62]. As such, the hindrances to implementing the SDGs and to measuring progress or regression in reaching the targets on a global scale effectively are so far numerous.

SDG 17 calls for multiple stakeholders to implement multilateralism. A successful sustainable development requires the collaboration of states, private sector, and civil society. Inclusive partnerships are needed, built upon common values, a joint vision, and shared goals that place people and nature at its core, at the global, regional, national, and local level.

The rising and globalization of nationalism in realpolitik is endangering multilateralism. SDG 17 is a seismograph of how states are taking global cooperation and multilateral action seriously. No state in the world can manage on its own the environmental challenges of the 21st century. At the moment a high number of states are not the best performers of global cooperation in the context of the SDGs, but global civil society is: a variety of transnational networks, diverse age groups of representatives of civil society worldwide demonstrate that people are capable of cooperating on a global scale.

Whereas on the side of states "nationalism is globalizing" [55], civil society and the private sector are aware of the fact that global challenges in this century can only be tackled by multilateral cooperation. Regarding the private sector: e.g., the Tesla CEO Elon Musk wants mankind to stop using fossil fuels and turn to renewable energy sources by increasing battery production to store electricity [63]. Considering global civil society: people all over the world are creating transnational political spaces and reshaping global politics specifically regarding the global risk of climate change. Millions of people participated in 5000 events in 156 countries on 20 September 2019 at rallies ahead of the UN climate summit [64].

For global sustainable development, SDG 17 matters the most. In the long run, in world risk society those who welcome nationalism and push back the ideas of multilateralism and global cooperation will lose: "Whoever draws the national card, loses" [60] (p. 368) as Beck articulated. As such, at the end of the day, nationalists will not be the winners, but the costs of their actions are enormous:

- Global migration due to environmental destruction like desertification, rising of sea level, etc., means a high risk of endangered human security.
- Human security: states will be endangered; not only in conflict regions of the world, but in the long run also in consolidated democracies like in Europe.
- The costs of not acting are as such higher: political instability causes fragile states.

In a world coined by global risks, nationalism is outdated and endangering humanity: the private sector is already acting on a global scale. Regarding the energy sector: e.g., solar energy enables energy-independent states. The global energy grid undermines nationalistic approaches; energy storage systems can be located within states. Technological developments can be effective tools to reduce environmental destruction which is posing a threat to humanity.

SDG 17 clearly reminds states to focus on multilateralism and global cooperation. It also requests civil society and the private sector to participate in the challenge to make the world more sustainable. The diagnosis presented here is that among the three stakeholders for the implementation of SDG 17 the civil society can be labeled as an active agent for global cooperation and multilateralism. In this sense, "People have the power to redeem the work of fools," [65] as Patti Smith noted.

4.6. Impacts of Energy Transition and Climate Change Mitigation on Humanity

After a full discussion, are the SDGs an effective agenda for transforming the world in a sustainable way? Ensuring that no one is left behind is a fundamental guiding principle for implementing the 2030 Agenda for Sustainable Development. To accomplish sustainable development requires the active participation of all sectors of world society and all types of people.

As a matter of fact, the SDGs can only be successfully implemented by states. However, global civil society plays a watchdog role in what governments are doing with their

commitments. As such, the SDGs will only be an effective global agenda for transforming the world, if civil society is a driving force for governments to implement them.

Energy has had a major impact on the lives of people across the globe. However, this energy was released from fossil fuels in a rate million times higher than nature had produced them now leading to unprecedented global challenges due to climate change. Now it is high time to overcome small state or world-regional container thinking in energy landscapes, and to accept the unavoidable role of sustainable energy for all to address global hazards.

Mankind shares universal risks, which can only be dealt with by multilateral cooperation and common efforts. Although the vulnerability of people across the globe is different, the global challenges in the energy sector demonstrate at the same time clearly that the shift to energy resources and uses that are sustainable has to be a universal human endeavor.

The challenge of the world's energy system is quite an urgent one, specifically considering the difficult task of linking growth with planetary boundaries. Due to CO₂ emissions, the energy sources which have been used over the last two centuries have become in contemporary times a threat to the world. Enabling human access to clean, affordable, and renewable energy is a central challenge of humanity, thereby specifically energy efficiency has to be part and parcel of solutions for global sustainable development. In the future, there will be the need for more energy, so the basic challenge is to enable this demand by establishing clean, affordable, and renewable energy. What is urgently needed is a far-reaching decarbonization of the world's energy system. Zero-carbon source is the central task for humanity—as such, the agenda of today has to be zero carbon. States already have their specific zero-carbon strategy, but an effective agenda to achieve global sustainable energy development is also needed by the private sector. China, as one of the big CO₂ producers, has already realized this pathway. Hydrogen technology, ammonia as an example, and a global electricity grid can support sustainable solutions to how humanity can reach zero carbon. In order to be successful in terms of global sustainable energy development, every single corner of the world has to join this three-part course.

Technologies like solar and wind power as well as energy efficiency are central in order to reach a zero-carbon future. Specifically, the fast-declining prices for solar power as well as for electricity grids and hydrogen technologies are positive signs to enable this future. Sustainable development calls for a coordinated global effort in a focused manner and in a relatively short period of time.

Immanuel Kant [66] stated back in 1795 in his work on "Perpetual Peace" that "need compels insight". Contemporarily, the needs of humanity are already obvious. Humanity will face severe conflict due to climate change in the following decades: the impacts of climate change trigger displacement; refugees, internally displaced people (IDPs) and the stateless are already on the front lines of climate emergency and environmental conflict scenarios. The "Global Trends in Forced Displacement" report by UNHCR [67] states that 95% of all conflict displacements in 2020 took place in states vulnerable or highly vulnerable to climate change. The number of environmental refugees will rise in the future, more climate wars [68] will happen and endanger human security, specifically in vulnerable world regions like, e.g., parts of the African continent. Climate change and violent conflict will sharpen the already existing conflicts and will weaken the resilience structures of fragile states. The "Fragile States Index" by the Fund for Peace [69] lists for 2021 only 1 out of 55 states in Africa as politically stable; all the other states are categorized as "alert" or "warning" fragile states. One can imagine what happens if these already existing weak governmental structures will be confronted with high numbers of refugees due to climate change. Environmentally caused migration will not only lead to humanitarian catastrophes, e.g., in Sahel region, North Africa and Southern Africa and endangering human security [70], but it will at the same time also destabilize political systems in Europe. At this point it becomes obvious: climate change and its effects are of global human concern.

4.7. The World Energy System: The Corporate Blueprint for Handling Global Climate Change Risks

All states across the globe signed the Paris Agreement [2] on climate change, which aims at keeping the global temperature to 1.5 K above pre-industrial era levels. If humanity continues to emit gases that cause climate change, temperatures will rise beyond 1.5 K levels, endangering the lives and well-being of people all over the earth. It is for this reason that a growing number of states have already made commitments to reach net-zero emissions within the following decades.

Zero carbon is a plan that calls for ambitious actions starting in the present. States have to exemplify how they will realize this task. All of their efforts to achieve zero carbon have to be accompanied by adaption and resilience measures, and the rallying of climate financing for economically weak states in the Global South. The positive news as being outlined in this article in the section on energy transport and storage is that the technology already exists to reach zero carbon—and will also be affordable. Zero carbon is realistic, if every state, municipal, financial institution, and corporation across the globe adopts realistic plans for transitioning to zero carbon emissions by 2050. Key emitters, like the G20 countries, need to significantly increase their current levels of ambition and action. This is also true for the other highly industrialized countries. However, far more effort to establish resilience is required also in vulnerable world regions and specifically for the most vulnerable people; as a matter of fact, this part of humanity does the least to cause climate change but pays the heaviest price. Nevertheless, resilience and adaption action still does not receive the subsidy it needs. States in the Global North therefore " (\ldots) must deliver their commitment to provide USD 100 billion a year for mitigation, adaption and resilience in developing countries." [71].

The UN General Assembly, with resolution 74/225, initiated in 2021 a high-level dialogue in 2021 to promote the implementation of energy-related SDGs of the 2030 Agenda, also in connection with the UN Decade of Sustainable Energy for All (2014–2024), to promote the global plan of action for the decade and to initiate a high-level forum on sustainable development. The High-level Dialogue on Energy in 2021 is the first global meeting on energy under the auspices of the UN General Assembly after the 1981 UN conference on New and Renewable Sources of Energy in Nairobi (see [72]). It can be labeled a historic turning point for the next energy transition and climate change mitigation, an urgent call for humanity to come up with transformational action for climate change adaption in the years of the SDGs Decade of Action and can assist the implementation of the Paris Climate Agreement. As the main source of CO_2 emissions, the world energy sector is the corporate blueprint for handling global climate change risks. The future of humanity has to be coined by using zero-carbon energy resources; otherwise, it will be a future characterized by humanitarian catastrophes for mankind.

5. Discussion

Science has provided all the technological means to transform the world's energy systems into a sustainable and CO_2 emission-free one based on photovoltaic and wind energy. The conversion into a world powered predominantly by electricity not only increases efficiency, but also flexibility; so that decentralized solutions for remote areas as well as very large-area electricity grids can be installed and even combined. Technological solutions for energy storage such as advanced batteries, large scale redox flow-batteries, and electrolysis combined with fuel cells have been developed and are on the way to reaching very low costs. Hydrogen technology is already so advanced that low-income countries are building transportation and networks among themselves.

On the other hand, renewables compete with established fossil fuel-based technologies, encountering covert resistance from powerful industries around the world that have been able to successfully delay necessary changes for far too long [73].

After now more than 5 years of basically no political action, the Paris Agreement's minimum goal to prevent more than 1.5 K global temperature increase seems to many

experts already impossible to reach simply by CO_2 reduction measures (the "net-zero goal"). Three of them, all leading members of the Intergovernmental Panel on Climate Change (IPCC), an intergovernmental body of the UN, very recently published an update on the current greenhouse gas emission predictions [74]. In 2019, they assumed a total remaining carbon dioxide budget of 420 Gt to stay below the critical 1.5 K temperature increase limit. Assuming constant CO_2 emissions, this budget will be used up within 9 years. If we assume that CO_2 emissions are reduced to 1/3, the time span for critical climate-related changes is delayed until 2028; for net zero emissions until 2050 (Figure 5).



Figure 5. Graph demonstrating how fast CO₂ reductions must happen to stay below a 1.5 K increase [74]. Reproduced with permission from © Robbie Andrew.

It is only through the political actions of global civil organizations, e.g., INGOs like Greenpeace or social movements like "Friday for Future" that politicians around the world finally seem to acknowledge that promising changes and promised reductions in CO₂ emissions, as in the 2015 Paris Agreement, can come through serious global cooperation and multilateralism.

The remaining CO_2 budget of course can be used only once. Nevertheless, there is yet not even an increased consensus as to how to distribute this remaining CO_2 budget among the states of the world. As shown before, cooperation of states will make the replacement of fossil fuels by renewables much easier and sharing the burden of storage would alleviate it, if possible, through international electricity grids or hydrogen pipelines. All these tasks require cooperation and the action of transnational agreements and organizations. However, an international organization like the UN is also needed in cases in which states do not follow the agreements. Here, sanctions by the international community will have to be used to enforce global needs. Good governance, transparency, and the specification of definitions such as net-zero carbon [75] or clean hydrogen are needed for fair communication as well as global implementation. States in the Global South not only have a high potential to produce green hydrogen, but also the need to improve socio-economic living conditions, so that despite climate change the foreseen environment-related migration of peoples will not occur. Therefore, the interconnection of the worldwide electricity and H_2 transport routes could also contribute

to geopolitical stability and enable a higher degree of human security. Science and technology have provided the means for avoiding unacceptable climate change. However, states do not perceive the urgency of the global challenge of climate change, which can effectively only be solved by global cooperation and multilateralism. Furthermore, the need for far-reaching and sustainable global solutions and strategies also requires the establishment of strong world institutions, which are capable of handling global risks effectively and are probably even empowered to use sanctions.

Considering the notion of global sustainable development, the limitation of resources on planet Earth require a fair distribution of remaining CO_2 emissions. If it is zero, then it is zero for all 194 UN member states. As such, the pathway to sustainable development has to be global in scope.

6. Conclusions

As a conclusion it can be stated that the world needs a "new enlightenment" as being elaborated by Ernst Ulrich Weizsäcker and Anders Wijkman [76] in their report for the 50th anniversary of the Club of Rome. To do this, humanity needs to stop working in "containers" and follow a more systemic approach: this will require people to rethink their approach to science and education. Humanity needs world citizenship and cosmopolitanism 2.0.

In order to meet complex challenges like climate change and the loss of biodiversity in a sustainable way, humanity has to foster global cooperation and multilateralism in order to find sustainable solutions. As such, there also has to come about a global turn in science. Globally orientated and cross-disciplinary research and teaching is still yet to be established. However, due to global risks endangering humanity there is an urgent need for global and cross-disciplinary research and teaching. Global problems like climate change require solutions developed by scientists from diverse backgrounds with a worldwide scope. Nation-state orientated "container-research and teaching" cannot provide humanity with the scientific solutions needed in this century anymore. Albert Einstein [77] (p. 6) had already made this point by stating: "Problems cannot be solved with the same way of thinking that created them!".

Author Contributions: Conceptualization of the introduction and conclusions were performed by all authors: of Section 2 by D.M., of Section 3 by E.A. and of Section 4 by V.W. Methodology, resources, writing—original draft preparation, writing—review and editing come from all authors. Funding acquisition was performed by all authors separately. All authors have read and agreed to the published version of the manuscript.

Funding: This research was partly funded by Johannes Kepler University, V.W. holds the national Austrian leadership for SDG 17 (Partnerships for the Goals) at UniNEtZ (Universities and Sustainable Development Goals). SDG 17 grant: REGI13800004UniNEtZ SDG 17. D.M. was partly funded by the European Regional Development Fund, Project TK141.

Data Availability Statement: All sources of data are listed in the references.

Acknowledgments: D.M. acknowledges financial support by the European Regional Development Fund, Project TK141. V.W. acknowledges financial support by Johannes Kepler University. Very valuable suggestions came from our referees whose contributions are gratefully acknowledged. Open access funding was generously supported by Johannes Kepler University Linz.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

References

- 1. Wittmann, V.; Meissner, D. The Nexus of Energy for Free and World Society. *Int. J. Sustain. Energy Dev.* **2019**, *7*, 384–391. [CrossRef]
- 2. United Nations Paris Agreement. Available online: https://unfccc.int/process/conferences/pastconferences/paris-climate-change-conference-november-2015/paris-agreement (accessed on 6 September 2021).
- 3. IAEA. *Adapting the Energy Sector to Climate Change;* IAEA: Vienna, Austria, 2019. Available online: https://www-pub.iaea.org/ MTCD/Publications/PDF/P1847_web.pdf (accessed on 6 September 2021).
- 4. US Energy Information Administration. *Levelized Costs of New Generation Resources in the Annual Energy Outlook* 2021; EIA: Washington, DC, USA, 2021. Available online: https://www.eia.gov/outlooks/aeo/pdf/electricity_generation.pdf (accessed on 6 September 2021).
- Kalair, A.; Abas, N.; Khan, N. Comparative study of HVAC and HVDC transmission systems. *Renew. Sustain. Energy Rev.* 2016, 59, 1653–1675. [CrossRef]
- Kazerani, M.; Tehrani, K. Grid of Hybrid AC/DC Microgrids: A New Paradigm for Smart City of Tomorrow. In Proceedings of the IEEE 15th International Conference of System of Systems Engineering (SoSE), IEEE, Budapest, Hungary, 2–4 June 2020; pp. 175–180. [CrossRef]
- Zhou, H.; Qiu, W.; Sun, K.; Chen, J.; Deng, X.; Qian, F.; Wang, D.; Zhao, B.; Li, J.; Li, S.; et al. (Eds.) Ultra-High Voltage AC/DC Power Transmission; Zhejiang University Press: Hangzhou, China; Springer-Verlag GmbH: Berlin, Germany, 2018.
- 8. Zhu, T.; Wang, L. *State Energy Transition*; Palgrave Macmillan: Singapore, 2020. [CrossRef]
- 9. Düren, M. Understanding the Bigger Energy Picture; Springer: Cham, Switzerland, 2017. [CrossRef]
- 10. Wikipedia. Desertec. Available online: https://de.wikipedia.org/wiki/Desertec (accessed on 6 September 2021).
- 11. German Netzentwicklungsplan. Available online: https://www.netzentwicklungsplan.de/en/ (accessed on 6 September 2021).
- 12. Wikipedia. Synchronous Grid of Continental Europe. Available online: https://en.wikipedia.org/wiki/Synchronous_grid_of_ Continental_Europe (accessed on 6 September 2021).
- 13. Wikipedia, Asian Super Grid. Available online: https://en.wikipedia.org/wiki/Asian_Super_Grid (accessed on 14 September 2021).
- 14. Liu, Z. Electric Power and Energy in China; China Electric Power Press, Published by Elsevier: London, UK, 2013. [CrossRef]
- Liu, Z. *Ultra-High Voltage AC/DC Grids*; China Electric Power Press, Published by Elsevier: Waltham, MA, USA, 2015. [CrossRef]
 Liu, Z. *Global Energy Interconnection*; Elsevier: London, UK, 2015. [CrossRef]
- 17. Mele, P.; Prassides, K.; Tarantini, C.; Palau, A.; Badica, P.; Jha, A.K.; Endo, T. (Eds.) *Superconductivity*; Springer: Cham, Switzerland, 2020. [CrossRef]
- 18. Alu-Web.de. Erste Aluminiumhütte Setzt auf Nachhaltige Supraleitertechnologie and Trimet Voerde Nimmt Flexible Gießanlage in Betrieb. Available online: https://alu-web.de/erste-aluminiumhuette-setzt-auf-nachhaltige-supraleitertechnologie/ (accessed on 6 September 2021).
- 19. H Facts: The History of Hydrogen. Available online: https://web.archive.org/web/20100714141058/http://www. hydrogenassociation.org/general/factSheet_history.pdf (accessed on 6 September 2021).
- 20. Bockris, J. Energy, the Solar-Hydrogen Alternative; Architectural Press: London, UK, 1976; ISBN 978-0851395838.
- 21. Bockris, J.; Justi, E.W. Wasserstoff, Energie für Alle Zeiten; Udo-Pfriemer Verlag: Munich, Germany, 1990.
- 22. Meissner, D. PHOEBUS, die autarke solare Stromversorgungsanlage der Zentralbibliothek des Forschungszentrums Jülich. In *Petra Mann (Herausgeberin) Schule und Energie, 1. Seminar Energiesparen, Solarenergie, Windenergie;* Forschungszentrum: Jülich, Germany, 1998; pp. 77–86. ISSN 1433-5646. ISBN 3-89336-231-2.
- 23. Nitsch, J. Szenarien einer künftigen Energieversorgung. In *Solarzellen;* Meissner, D., Ed.; Friedrich Vieweg & Sohn: Braunschweig, Germany, 1993; pp. 238–263. [CrossRef]
- 24. Winter, C.-J.; Nitsch, J. Wasserstoff als Energieträger; Springer: Berlin/Heidelberg, Germany, 1986. [CrossRef]
- 25. Miller, E.L.; Thompson, S.T.; Randolph, K.; Hulvey, Z.; Rustagi, N.; Satyapal, S. US Department of Energy hydrogen and fuel cell technologies perspectives. *MRS Bull.* **2020**, *45*, 57–64. [CrossRef]
- 26. European Commission. A Hydrogen Strategy for a Climate-Neutral Europe. 2020. Available online: https://ec.europa.eu/ energy/sites/ener/files/hydrogen_strategy.pdf (accessed on 4 July 2021).
- 27. Elgowainy, A.; Wang, M.; Joseck, F.; Ward, J. Life-Cycle Analysis of Fuels and Vehicle Technologies. *Encycl. Sustain. Technol.* 2017, 317–327. [CrossRef]
- 28. Kyriakou, V.; Garagounis, I.; Vourros, A.; Vasileiou, E.; Stoukides, M. An Electrochemical Haber-Bosch Process. *Joule* **2019**, *4*, 142–158. [CrossRef]
- 29. Hansson, J.; Brynolf, S.; Fridell, E.; Lehtveer, M. The Potential Role of Ammonia as Marine Fuel-Based on Energy Systems Modeling and Multi-Criteria Decision Analysis. *Sustainability* **2020**, *12*, 3265. [CrossRef]
- 30. Cerniauskas, S.; Junco, A.J.C.; Grube, T.; Robinius, M.; Stolten, D. Options of natural gas pipeline reassignment for hydrogen: Cost assessment for a Germany case study. *Int. J. Hydrogen Energy* **2020**, *45*, 12095–12107. [CrossRef]
- 31. Ripson, P.; Van't Noordende, H. Integration of Gigawatt Scale Electrolyzer in Five Industrial Clusters; Institute for Sustainable Process Technology (ISPT): Amersfoort, The Netherlands, 2020. Available online: https://ispt.eu/media/ISPT-samenvattend-rapport-GigaWatt-online-def.pdf (accessed on 6 September 2021).

- 32. Singlitico, A.; Campion, N.J.B.; Münster, M.; Koivisto, M.J.; Cutululis, N.A.; Suo, C.J.; Karlsson, K.; Jørgensen, T.; Waagstein, J.E.; Bendtsen, M.F. Optimal Placement of P2X Facility in Conjunction with Bornholm Energy Island: Preliminary Overview for an Immediate Decarbonization of Maritime Transport. 2020. Available online: https://backend.orbit.dtu.dk/ws/portalfiles/portal/ 235161506/WP_P2X_Analysisv4.pdf (accessed on 6 September 2021).
- 33. COAG Energy Council Hydrogen Working Group. Australia's National Hydrogen Strategy. 2019. Available online: https://www.industry.gov.au/data-and-publications/australias-national-hydrogen-strategy (accessed on 6 September 2021).
- 34. Nagashima, M. Japan's Hydrogen Strategy and Its Economic and Geopolitical Implications. 2018. Available online: https://www.ifri.org/sites/default/files/atoms/files/nagashima_japan_hydrogen_2018_.pdf (accessed on 6 September 2021).
- Hydrogen Production Technical Team Roadmap. Available online: https://www.energy.gov/eere/vehicles/downloads/usdrive-hydrogen-production-technical-team-roadmap (accessed on 6 September 2021).
- 36. IEA. The Future of Hydrogen: Seizing Today's Opportunities' Report Prepared by the IEA for the G20, Japan. 2019. Available online: https://www.iea.org/reports/thefuture-of-hydrogen (accessed on 6 September 2021).
- IRENA. Green Hydrogen Cost Reduction: Scaling up Electrolysers to Meet the 1.5 C Climate Goal. 2020. Available online: https://irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA_Green_hydrogen_cost_2020.pdf (accessed on 6 September 2021).
- Brandes, E.; Möller, W. Sicherheitstechnische Kenngrößen. Band 1: Brennbare Flüssigkeiten und Gase; Wirtschaftsverlag NW: Bremerhaven, Germany, 2008.
- Menoukeu Pamen, O.; Mophou Loudjom, G.A.; Bah, B. *The Africa Strategy of the BMBF*; Federal Ministry of Education and Research (BMBF): Bonn, Germany, 2020. Available online: https://www.bmbf.de/bmbf/en/international-affairs/worldwidenetworking/middle-east-and-africa/the-africa-strategy-of-the-bmbf.html (accessed on 6 September 2021).
- 40. Jens, J.; Wang, A.; Van der Leun, K.; Peters, D.; Buseman, M. Extending the European Hydrogen Backbone. Available online: https://gasforclimate2050.eu/wp-content/uploads/2021/06/European-Hydrogen-Backbone_April-2021_V3.pdf (accessed on 6 September 2021).
- Weichenhain, U.; Kaufmann, M.; Benz, A.; Berger, R.; Matute Gomez, G.; Hydrogen Valleys Insights into the Emerging Hydrogen Economies Around the World. EU Project Report. 2021. Available online: https://www/h2v.eu/ (accessed on 6 September 2021).
- 42. H2ATLAS-AFRICA Project. Available online: https://www.h2atlas.de/en/ (accessed on 6 September 2021).
- 43. World Commission on Environment and Development. Our Common Future; Oxford University Press: Oxford, UK, 1987; p. 8.
- 44. United Nations Conference on Sustainable Development, Rio + 20. Available online: https://sustainabledevelopment.un.org/rio20 (accessed on 6 September 2021).
- UNESCO. Sustainable Development. Available online: https://en.unesco.org/themes/education-sustainable-development/ what-is-esd/sd (accessed on 6 September 2021).
- United Nations. Decade of Education for Sustainable Development: Resolution. Available online: https://digitallibrary.un.org/ record/482207 (accessed on 6 September 2021).
- 47. UN General Assembly. UN Millennium Declaration 2000. Available online: https://undocs.org/A/RES/55/2 (accessed on 6 September 2021).
- Ki-Moon, B. 'We Are the First Generation that Can End Poverty, the Last that Can End Climate Change', Secretary-General Stresses at University Ceremony. 2015. Available online: https://www.un.org/press/en/2015/sgsm16800.doc.htm (accessed on 6 September 2021).
- 49. Mohammed, A. UN Under-Secretary-General and Special Adviser on Post-2015 Development Planning. 2015. Available online: https://www.un.org/press/en/2015/sgsm16800.doc.htm (accessed on 6 September 2021).
- UNDP SDG 7. Available online: https://www1.undp.org/content/oslo-governance-centre/en/home/sustainable-developmentgoals/goal-7-affordable-and-clean-energy.html (accessed on 6 September 2021).
- International Bank for Reconstruction and Development; The World Bank and the International Energy Agency. Sustainable Energy for All. *Global Tracking Framework. Progress Towards Sustainable Energy.* 2017. Available online: https://trackingsdg7 .esmap.org/data/files/download-documents/eegp17-01_gtf_full_report_for_web_0516.pdf (accessed on 11 October 2018).
- 52. United Nations. Sustainable Development Goal 7. 2020. Available online: https://sustainabledevelopment.un.org/sdg7 (accessed on 25 December 2020).
- 53. IEA SDG 7: Data and Projections. 2021. Available online: https://www.iea.org/reports/sdg7-data-and-projections (accessed on 6 September 2021).
- 54. World Economic Forum. The Global Risks Report 2021. Available online: http://www3.weforum.org/docs/WEF_The_Global_ Risks_Report_2021.pdf (accessed on 6 September 2021).
- Crouch, C. Der Nationalismus Globalisiert Sich. 2017. Available online: https://www.zeit.de/wirtschaft/2017-02/globalisierungwiderstand-rechte-nationalismus-donald-trump-marine-le-pen-is/komplettansicht?print (accessed on 6 September 2021).
- TIME. Trump Defends 'America First' Policy in U.N. Speech, Says the Future Belongs to 'Patriots' Over 'Globalists'. 2019. Available online: https://time.com/5684890/trump-un-address-america-first/ (accessed on 6 September 2021).
- 57. Cambridge Dictionary 2020a. Available online: https://dictionary.cambridge.org/de/worterbuch/englisch/unilateralism (accessed on 6 September 2021).
- 58. Cambridge Dictionary 2020b. Available online: https://dictionary.cambridge.org/de/worterbuch/englisch/multilateralism (accessed on 6 September 2021).

- 59. Bremmer, I. Every Nation for Itself: What Happens When No One Leads the World; Penguin: New York, NY, USA, 2013.
- 60. Beck, U. Weltrisikogesellschaft [World at Risk]; Suhrkamp: Frankfurt, Germany, 2007; Polity Press: Cambridge, UK, 2009.
- 61. Official Development Assistance (ODA). Available online: https://www.oecd.org/dac/financing-sustainable-development/ development-finance-standards/official-development-assistance.htm (accessed on 6 September 2021).
- 62. United Nations Statistic Division 2021. Available online: https://unstats.un.org/sdgs/report/2020/goal-17/ (accessed on 6 September 2021).
- 63. Brown, M. Tesla's Elon Musk Lays Out How to Transition Earth to Clean Energy. INVERSE. 2021. Available online: https://www.inverse.com/innovation/elon-musk-transition-earth-to-renewables (accessed on 6 September 2021).
- Zeitonline 2020. Available online: https://www.zeit.de/politik/2019-09/fridays-for-future-demonstrationen-klimaschutzweltweit-klimastreik-fs (accessed on 6 September 2021).
- 65. Smith, P. People Have the Power. 1988. Available online: https://www.lyrics.com/lyric/1290995/Patti+Smith/People+Have+the+Power (accessed on 6 September 2021).
- 66. Kant, I. Perpetual Peace. A Philosophical Essay; George Allen & Unwin: London, UK, 1903.
- 67. UNHCR. Global Trends. Forced Displacement in 2020. Report by the United Nations High Commissioner for Refugees. 2021. Available online: https://www.unhcr.org/60b638e37/unhcr-global-trends-2020 (accessed on 6 September 2021).
- 68. Mann, M.E. The New Climate War: The Fight to Take Back Our Planet; Public Affairs: New York, NY, USA, 2021.
- 69. Fund for Peace. Fragile States Index 2021. Available online: https://fragilestatesindex.org/wp-content/uploads/2021/05/951-21-Map.pdf (accessed on 6 September 2021).
- 70. The Map of Future Conflict Scenarios by the German Advisory Council on Global Change WBGU, Welt im Wandel— Sicherheitsrisiko Klimawandel. 2007. Available online: https://www.wbgu.de/fileadmin/user_upload/wbgu/publikationen/ archiv/wbgu_jg2007.pdf (accessed on 6 September 2021).
- 71. UN News 2021. Available online: https://news.un.org/en/story/2020/12/1078612 (accessed on 6 September 2021).
- 72. UN. Stakeholders Thematic E-Consultation for the United Nations High-level Dialogue on Energy Summary Report. 2021. Available online: https://sdgs.un.org/publications/stakeholders-thematic-e-consultation-HLDE-summary-report (accessed on 6 September 2021).
- 73. Götze, S.; Joeres, A. Die Klimaschmutzlobby. Wie Politiker und Wirtschaftslenker die Zukunft Unseres Planeten Verkaufen; Piper Verlag: Munich, Germany, 2020.
- 74. Dyke, J.; Watson, R.; Knorr, W.; Climate scientists: Concept of net zero is a dangerous trap. The Conversation, 22 April 2021. Available online: https://theconversation.com/climate-scientists-concept-of-net-zero-is-a-dangerous-trap-157368 (accessed on 6 September 2021).
- Rogelj, J.; Geden, O.; Cowie, A.; Reisinger, A. Net-zero emissions targets are vague: Three ways to fix. *Nature* 2021, 591, 365–368. [CrossRef] [PubMed]
- Von Weizsäcker, E.U.; Wijkman, A. Come On. 2018. Available online: https://50thclubofrome.com/en/come-on/ (accessed on 6 September 2021).
- 77. Einstein, A. Quoted in WBGU—German Advisory Council on Global Change, Towards our Common Digital Future; Summary; WBGU: Berlin, Germany, 2019; p. 6. Available online: https://www.wbgu.de/fileadmin/user_upload/wbgu/publikationen/hauptgutachten/hg2019/pdf/wbgu_zf_hg_digi_de.pdf (accessed on 6 September 2021).