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Climate

Nuclear fusion with renewable energies as a way out of the global climate crisis

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Declaration of consent

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Abstract

Climate change is occurring worldwide at an unpredictable pace and countermeasures are becoming increasingly urgent. A large part of the climate change is attributed to fossil fuel emissions. In order to reduce these, it is necessary to generate energy in a sustainable manner and thus first reduce and eventually replace the use of fossil fuels. It is therefore necessary to obtain an overview of the energy sources currently in use and under development and to compare and evaluate them with regard to the aforementioned goal.

The focus of this paper is to present a possible way of energy production in the future: nuclear fusion in combination with renewable energies, how these work and to provide an outlook on future viability. For this purpose, different possibilities of energy production were examined with regard to efficiency and price-performance and forecasts were made on the basis of studies. For this purpose, I conducted interviews with experts on the topic of the climate crisis, nuclear fusion and renewable energies and consulted the relevant literature listed in the bibliography.

The prevailing opinion is that nuclear fusion, which is quite advantageous in terms of safety, sustainability and electricity production costs, will probably only come into commercial operation from the 1950s onwards in this century.

Content

1. Introduction

1.1 Introduction to the topic

Year after year, energy consumption and the (currently) associated environmental pollution continue to increase. The enormous increase in environmental pollution caused by the use of fossil fuels is particularly noticeable from 1950 onwards, as since then more than "98% of mechanical work in industry and the economy is performed using energy". [1]

In order to minimise this environmental burden, most of the world's countries have come to an agreement via numerous climate conferences that the main polluters of this danger should be limited as much as possible.[2] In addition, targets were set at the Paris Agreement in December 2015 to limit the global temperature increase to below 2°C and if possible to 1.5°C[3] - binding not only for Europe, but also for other important countries such as the USA and China, which together already account for almost 40% of greenhouse gas emissions.[4] The main component of emissions of environmentally harmful gases from fossil energy production - namely greenhouse gases - must be minimised in energy production. Moreover, the increase in the consumption of natural resources resulting from population growth and human globalisation has reached an "objective limit"[5] . From this it can be concluded that not only the climate, but also our current energy system is in crisis.[6] The "resulting future task of a sustainable energy system"[7] thus requires a differentiated examination.

1.2 Objective

This paper aims to shed light on a key question in the search for a way out of the climate crisis, namely how energy can be produced in the future without further burdening the climate. Various literature sources and renowned experts were consulted for this purpose.

1.3 Structure of the work

In the following section, further important terms are defined and possibilities of energy production are named and characterised. Section 2.2 takes a critical look at the previously mentioned energy groups and then, in section 2.3, explains the resulting goal of science.

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[1] Peperkorn, Colin; Herweg, Antonia; Wegner, Claas: *Energies der Zukunft als Unterrichtsthema, in: Mint-Zirkel,* page 6
[2] IPCC: *Technical Summary, in: IPCC Special Report, Global Warming of 1.5 °C,* page 32
[3] Lajčák, Miroslav; Council of the European Union: *Council Decision 2016/1841 of 5 October 2016, Paris Agreement*, Page 1
[4] United Nations: *Report of the Conference of the Parties on its 21st Session, held in Paris from 30.11 to 11.12 2015 Part one: proceedings*, page 30
[5] Marenbach, Richard; Jäger, Johann; Nelles, Dieter: *Electrical Power Engineering, Fundamentals, Power Supply, Drives and Power Electronics*, page 382
[6] Wesselak, Viktor; Schabbach, Thomas: *Regenerative Energy Technology*, Page 2
[7] [6]: Wesselak, Viktor; Schabbach, Thomas: *Regenerative Energy Technology*, page 2

The theory of nuclear fusion and the current state of development are presented in section 2.4 and compared with the previously presented types of energy generation in the following section 2.5. The main part is concluded in section 2.6 with the challenges and forecasts.

Section 3 provides a more in-depth outlook for the future and concludes by summarising the findings of this paper.

2. Main part

2.1 Definitions and possibilities of energy generation

Energy is a fundamental requirement of modern civilisation. "The benefits humans derive from energy can be ostensibly divided into three areas: Food, Heat and Transport." Nowadays, energy sources are used within a societal level, not only with technical aspects, but also political, economic and philosophical aspects. These energy sources are used by energy systems that are subject to the technical and ecological conditions that prevail in the respective places.[8]

Increasingly, current political discussions are debating climate change or even the climate crisis. Why climate crisis and what exactly does it imply?
According to the prevailing narrative, this emergency is caused by the man-made[9] accumulation of CO_2 in the atmosphere, which is increasingly leading to global warming and the environmental disasters that accompany it.[10] Examples of these disasters include "more intense and prolonged heat waves, unprecedented droughts and floods, accelerated sea level rise and storm surges affecting many regions and peoples."[11] Around the world, many people are affected by these impacts and "consider climate action to be extremely urgent."[12] However, with the burning of oil, coal and gas for energy production, more and more carbon dioxide is being put into the atmosphere, adding to the problem.[13] The term climate change suggests a harmlessness of these changes that does not do justice to the listed, harmful effects. The term climate crisis, on the other hand, suggests that although this is a major problem for humans and nature, it can also be overcome.[14] .

Ways of generating energy without further harming the environment are therefore sought, and the most important ones for critical consideration are mentioned in this paper. A type of energy production is sustainable if it is compatible with the environment, does not harm the livelihood of future generations and brings about a balance between "North" and "South".[15]

[8] Cf. [6]: Wesselak, Viktor; Schabbach, Thomas: *Regenerative Energietechnik,* page 1
[9] Cf. [7]: IPCC: *Summary for Policymakers, in: Sixth Assessment Report WG1*, page 4.
[10] Cf. [8]: IPCC: *Summary for Policymakers, in: Sixth Assessment Report WG2,* page 35.
[11] [9]: IPCC: *Full report, in: Sixth Assessment Report WG2,* page 73
[12] [9]: IPCC: *Full report, in: Sixth Assessment Report WG2,* page 74
[13] Cf. [10]: Rich, Nathaniel: *Losing Earth*, page 1
[14] Cf. [11]: Berger, Michael: *E-mail enquiry about short interview, 21.12.21*
[15] Cf. [6]: Wesselak, Viktor; Schabbach, Thomas: *Regenerative Energietechnik,* page 11

Nuclear energy, also known as nuclear power, involves the fission of atoms by bombarding them with other atoms at high speed, which in turn fission others and consequently release "heat energy that can be used to produce steam (in a kettle)." through the movement of the fission products.[16]

Fossil power plants are steam power plants in which oil, coal or gas is burned and (again) converted into electrical energy via a steam cycle.[17]

Renewable energies are by definition energy sources that are self-renewing (within human standards), i.e. inexhaustible, and "can provide an alternative to conventional energy supplies such as coal, oil, gas and nuclear power".[18] Renewable energies are for the most part CO_2 -neutral energy sources and thus ecologically sustainable.[19]

Renewables" include tidal energy, solar and wind energy, geothermal energy and biomass. [20]

Tidal power plants are hydroelectric power plants, i.e. power plants in which water is dammed up and energy is then produced by turbines that are located in the sea and whose turbines are cranked underwater by currents.

Wind power plants function similarly to the aforementioned hydroelectric power plants; they also consist of turbines and generators, which are, however, driven by moving air (instead of water).

Solar energy, also known as *photovoltaics*, is the "direct conversion of solar energy into electrical energy using solar cells". [21]

Geothermal energy is the process of extracting energy from boreholes in the earth 1000-2000m deep. Cold water is pressed into these holes in the earth and hot water is drawn off from a second borehole. The temperature increases by 30K per kilometre towards the centre of the earth. [22]

Biomass energy uses the reaction of photosynthesis in plants. By "adding light from CO_2 and water hydrocarbons (biomass) and oxygen are produced. "[23] In biogas plants, organic waste is thus used to produce gas.

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[16] [5]: Marenbach, Richard; Jäger, Johann; Nelles, Dieter: *Electrical Power Engineering, Fundamentals, Power Supply, Drives and Power Electronics*, page 336

[17] Cf. [5]: Marenbach, Richard; Jäger, Johann; Nelles, Dieter: *Electrical Power Engineering, Fundamentals, Power Supply, Drives and Power Electronics*, page 336.

[18] [5]: Marenbach, Richard; Jäger, Johann; Nelles, Dieter: *Electrical Power Engineering, Fundamentals, Power Supply, Drives and Power Electronics*, page 336

[19] Cf. [12]: Kiessling, Andreas: *personal interview, 24.05.22*

[20] Cf. [12]: Kiessling, Andreas: *personal interview, 24.05.22*

[21] [15]: Ramona Gawlick, in Stromgewinnung.net: *Stromgewinnung - Welche Methoden der Stromerzeugung gibt es?*

[22] Cf. [13]: Richard Marenbach; Johann Jäger; Dieter Nelles: *Electrical Power Engineering, Fundamentals, Power Supply, Drives and Power Electronics*, page 362.

[23] [13]: Richard Marenbach; Johann Jäger; Dieter Nelles: *Elektrische Energietechnik, Grundlagen, Energieversorgung, Antriebe und Leistungselektronik*, page 361

2.2 Critical view of nuclear energy, fossil energy and renewable energies

In contrast to renewable energies, which regenerate themselves independently of human influence, nuclear and fossil energy sources have formed in the lithosphere over a long period of time and are exhaustible. Consequently, their resources are becoming increasingly scarce due to human influence. [24]

The following main advantages are attributed to nuclear energy: Energy produced by nuclear fission is inexpensive and associated with low to no Co2 emissions.[25] However, the following disadvantages are mentioned: The "danger of a core meltdown with radioactive contamination, problematic final storage of the spent, radioactive fuel elements and demolished power plants, incidents, e.g. during the reprocessing of nuclear power plants with a release of radioactive materials and proliferation of nuclear weapons through the training of many nuclear specialists."[26] Moreover, the reserves of nuclear power plant fuel, uranium U-238, are only available for a few decades if used intensively and a few countries have a monopoly over the fuel and therefore the reserves are not "fairly" divided geologically.[27] If you also take into account the upstream emissions of nuclear power, i.e. the production process and resources used, you quickly realise that nuclear power plants also have CO_2 emissions[28] and are therefore not actually sustainable.

Renewable energies, on the other hand, have the advantage of emitting less CO_2 and are therefore more environmentally friendly. If one looks at the total amount of emissions including upstream chains for greenhouse gases, it can be seen that renewable energies have the lowest amount.[29] Moreover, once they are put into operation, they have low costs ("the sun doesn't send a bill"[30]), are less dangerous than e.g. nuclear power and can be built geographically "fairly", in places independent of industry or rich countries.[31] In practice, however, a serious disadvantage of renewable energies is their variability and unpredictability, i.e. the difficulty of guaranteeing a continuous energy supply with them, since the output of such plants often depends on external circumstances, such as weather conditions. They do not offer reliably constant energy production, i.e. they are hardly "base-load capable" and not in line with demand. [32]

Fossil energy sources have the advantage of being used as needed, even continuously. They account for the majority of energy production, with crude oil accounting for a third, coal for a quarter and natural

[24] Cf. [12]: Viktor Wesselak; Thomas Schabbach: *Regenerative Energy Technology*, page 53

[25] Cf. [13]: Richard Marenbach; Johann Jäger; Dieter Nelles: *Electrical Power Engineering, Fundamentals, Power Supply, Drives and Power Electronics,* page 346.

[26] [13]: Richard Marenbach; Johann Jäger; Dieter Nelles: *Elektrische Energietechnik, Grundlagen, Energieversorgung, Antriebe und Leistungselektronik,* page 346

[27] Cf. [16]: Quaschning, Volker: *Erneuerbare Energien und Klimaschutz: Hintergründe - Techniken - Anlagenplanung - Wirtschaftlichkeit,* Page 34

[28] Cf. [12]: Kiessling, Andreas: *personal interview, 24.05.22*

[29] Cf. [15]: Lübbert, Daniel: *in: Deutscher Bundestag: CO2-Bilanzen verschiedener Energieträger im Vergleich, Zur Klimafundlichkeit von fossilen Energien, Kernenergie und erneuerbaren Energien,* page 23.

[30] Cf. [16]: Alt, Franz: *Die Sonne schickt uns keine Rechnung: Neue Energie, neue Arbeit, neue Mobilität*, p. 23

[31] Cf. [17]: Kröll, Sabrina: *Function and Tasks of the European Energy Union*

[32] Cf. [18]: Dutton, A. John: *Technologies for sustainability systems, base load energy sustainability*

gas for a fifth.[33] However, the fuels used are polluting and therefore not sustainable. Moreover, according to current estimates, the reserves of fossil fuels will only be available for between 41 and 200 years and will therefore no longer be able to meet the demand for energy in the not too distant future and are very unevenly distributed worldwide.[34]

To compare the power plant efficiency of different types of energy production, the ratio of the amount of energy produced throughout the life cycle to the amount of energy required for production and energy generation itself is used. This is called the "harvest factor".[35] If the harvest factor is below 1, more energy is needed for the production of that plant than is produced by it. If the harvest factor is above 1, the plant is profitable to build and thus produces more energy in its life cycle than is needed for production. [36]

The harvest factor for different energy generation is as follows. Nuclear energy has a harvest factor of 75, coal 30, CCGT - a type of gas turbine - 28, solar energy 19, wind energy 16 and biomass by grain 3.5. [37]

In order to complete the consideration of an energy system, a deeper understanding of the electricity production costs of the different plant types is necessary. The electricity production costs result from all costs within the entire life cycle of the energy system divided by the total yield of electricity. These costs include operating fuel and capital costs during the lifetime of the power plant.[38] For this consideration, it is important to know that the electricity production costs are given in euros per megawatt hour [MWh]. One megawatt hour is equal to 1000 kilowatt hours, of which one kilowatt hour is 3.6 million Ws (=joules). This unit is often used in the field of electricity.[39]

Nuclear energy shows an average of 10 euros per MWh.[40] For coal-fired power plants, the range is around 29-33 euros per MWh and depends on whether lignite or hard coal is used. For natural gas power plants 42 euros per MWh. The electricity production costs of solar energy are much higher - a ground-mounted system at 520 euros per MWh and a roof-mounted system at 620 euros per MWh. The remaining renewable energy power plants have an electricity production cost of 102 euros per MWh for hydroelectric power plants, 96-144 euros per MWh for wind power plants in rural areas, and 96 euros per MWh for biomass plants using wood.[41]

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[33] Cf. [6]: Wesselak, Viktor; Schabbach, Thomas: *Regenerative Energietechnik,* page 4
[34] Cf. [6]: Wesselak, Viktor; Schabbach, Thomas: *Regenerative Energietechnik,* page 7
[35] Cf. [19]: Spektrum.de: *Harvest factor , in: Lexikon der Physik*
[36] Cf. [20]: Doelling, Robert John: *Harvest factor and energetic amortisation of power plants*
[37] Cf. [21]: Weißbach, D.; Ruprecht, G; Huke, A.; Czerski, K.; Gottlieb, S.; Hussein, A: *Energy intensities, EROIs, and energy payback times of electricity generating power plants*, Page 29
9
[38] Cf. [22]: Acker, Ursula: *Power generation costs*
[39] Cf. [23]: Kunst, Sabine: *Energy units, in LEIFIPhysik*
[40] See [24]: Badouard, Thierry; Moreira de Oliveira, Débora; Yearwood, Jessica; Torres, Perla: Altmann, Matthias: *Cost of energy, Energy costs, taxes and the impact of government interventions on investments: final report, in: Publications Office of the European Union,* page 50.
[41] Cf. [25]: Wissel, S.; Rath-Nagel S; Blesl M.; Fahl U.; Voß A: *Electricity generation costs in comparison, in: Arbeitsbericht No. 4,* pp. 14-15.

From these values, it can be concluded that the efficiency and price-performance ratio of many renewable energies is rather poor compared to fossil energy sources. However, as fossil fuels drive the climate crisis and atmospheric pollution through CO_2 emissions, they are not sustainable. However, renewable energy systems are not able to guarantee permanent energy use (base load). However, they can cover peak loads due to rapid start-up.[42]

2.3 Objective of science

The global energy system is in dire straits. The goal of science is to find a way of generating energy that is not only sustainable, but also suitable for long-term use, has a fair distribution of resource sources, is safe and can provide a base load in the long term.[43] The current dominant baseload sources, fossil fuels and nuclear energy, are increasingly viewed critically for the reasons described above, and so alternatives are urgently sought.[44] The base load is the "amount of electricity that is permanently in demand during the course of the day or the year and never falls below". The base load is mainly consumed by systems that are continuously switched on. Base-load power plants "run virtually continuously to always provide the required amount of electricity." [45]

2.4 Nuclear fusion in theory and prototypes

Our sun. The sun as we know it is essential, not only for humans but also for all other living beings on earth. It provides an almost limitless amount of energy and is a cosmic powerhouse.[46] In the sun there is a fuel, plasma, an ionised gas in which hydrogen atoms fuse to form helium. The plasma is held together thanks to the enormous force of gravity. This kind of energy production could also be realised on Earth. Research and work on the use of this type of energy has been going on since the 1940s.[47]

Nuclear energy releases a much smaller amount of energy with the fission of the uranium atom than the fusion of hydrogen atoms into helium. This fusion, on the other hand, requires very high particle velocities on the one hand because of the physical conditions of the earth, and on the other hand protective measures to keep outsiders safe from the high temperatures inside. [48]

A gigantic force is needed for two atoms to come so close to each other that they fuse. To do this, the fusion atoms, mostly deuterium and tritium because of their frequency of fusion, are heated in the nucleus until they become plasma. Then they are brought to fusion by a further increase in temperature, to about 150 million degrees. However, this process must be made possible in a power plant without the container evaporating. This is circumvented in prototypes of nuclear fusion with the help of magnetism.

[42] Cf. [6]: Wesselak, Viktor; Schabbach, Thomas: *Regenerative Energietechnik*, page 508
[43] Cf. [26]: Max Planck Institute for Plasma Physics: *Why fusion research?*
[44] Cf. [12]: Kiessling, Andreas: *personal interview, 24.05.22*
[45] [27]: Kröll, Sabrina: *Definition of base load and information on base load power plants*
[46] Cf. [28]: Nunner, Bernhard: *Grundlagen der Kernfusion, in: Deutsche Physikalische Gesellschaft e. V.*
[47] Cf. [29]: Max Planck Institute for Plasma Physics: *50 Years Max Planck Institute for Plasma Physics, Garching and Greifswald, Research for the Energy of the Future,* page 6
[48] Cf. [5]: Marenbach, Richard; Jäger, Johann; Nelles, Dieter: *Electrical Power Engineering, Fundamentals, Power Supply, Drives and Power Electronics*, page 344.

Since "electric particles in magnetic fields are deflected from their trajectory transverse to the instantaneous motion and transverse to the magnetic lines", if you have a tube and it is longitudinal to the magnetic field, the plasma cannot reach the interface. [49]

In France, this concept of confining plasma in a magnetic field is used in the experimental nuclear fusion reactor "ITER". To prevent the particles from being shot out at the end of the tube, several tubes are welded together to form a ring. This type of reactor was developed by Russian scientists and christened the "Tokamak".[50] Other known test reactors of the tokamak type still in operation are ASDEX Upgrade and JET. The construction of a tokamak is comparably simple, but the main challenge is to predict the achievable plasma temperatures and pressures with the help of complex theories, and such plants are still mostly "determined by experimentally obtained findings and their empirical extrapolation".[51] Such plants have so far only operated in "pulse mode". An important prerequisite of fusion power plants for future benefit is to enable worthwhile long-term or continuous operation. [52]

Another concept of fusion power plants developed early on, which enables long operation from the beginning, is the "stellarator" type of construction. In a plant of this type in Greifswald, Germany, called "Wendelstein 7-X", experimental work is supported by theoretical plasma physics, with highly advanced high-performance computers quantitatively reproducing results and experiments.[53] Stellarators are also ring-shaped magnetic coils like tokamaks, but those of the stellarator type are much more complex in shape. While tokamak-type systems have a simple design with gigantic coils that produce strong annular magnetic fields and operation is maintained by current pulses, stellarators produce a twisted magnetic field that holds the "plasma particles in place even without current pulses."[54] Stellarators have the property of continuous operation, the ability to magnetically confine a hot plasma for long periods at will. This was impossible before because magnetic coils heat up considerably in the presence of very strong magnetic fields. Superconducting coils are used to make this possible. When superconducting materials are cooled to zero, current can be transported without losses and thus without any heating. [55]

There are also fusion methods based on entirely different concepts. These are not well developed at best, as the main focus is on tokamaks and stellarators. One of these is laser bombardment of boron.[56] In laser

[49] [30]: Hofmann-Reinecke, Hans: *Nachgefragt: Kann Kernfusion die Energiewende retten?*
[50] Cf. [29]: Max Planck Institute for Plasma Physics: *50 Years Max Planck Institute for Plasma Physics, Garching and Greifswald, Research for the Energy of the Future* , page 28
[51] [29]: Max Planck Institute for Plasma Physics: *50 Years Max Planck Institute for Plasma Physics, Garching and Greifswald, Research for the Energy of the Future*, 27-28
[52] [29]: Max Planck Institute for Plasma Physics: *50 Years Max Planck Institute for Plasma Physics, Garching and Greifswald, Research for the Energy of the Future*, page 5
[53] Cf. [29]: Max Planck Institute for Plasma Physics: *50 Years Max Planck Institute for Plasma Physics, Garching and Greifswald, Research for the Energy of the Future*, page 5
[54] [31]: FOCUS.de: *Efficiency remains one of the biggest challenges, Two concepts come into question: Tokamak reactor and stellarator*
[55] Cf. [29]: Max Planck Institute for Plasma Physics: *50 Years Max Planck Institute for Plasma Physics, Garching and Greifswald, Research for the Energy of the Future,* page 14
[56] Cf. [12]: Kiessling, Andreas: *personal interview, 24.05.22*

bombardment of boron, accelerated protons strike a plasma of boron nuclei.[57] One advantage of laser bombardment is that the laser energy is converted directly into electrical energy by induced fusion energy, in contrast to nuclear power plants and other fusion approaches in which the excursion is required via thermal energy utilisation through heated liquids and steam turbines.[58] However, even with this laser bombardment, no more energy can be extracted than is added and, in terms of technological advances, is further away from potential power plant commissioning than tokamak-type power plants.

2.5 Critical view of nuclear fusion in comparison with other types of energy generation

Fusion energy is expected to have an electricity production cost of 50-80 euros per megawatt hour.[59] This puts it in the lower range of the electricity production costs of the various energies considered earlier and would be quite worthwhile. Furthermore, nuclear fusion, if made competitive, will have an "enormously positive harvest factor".[60]

Fusion power is free of environmentally harmful carbon dioxide emissions and produces no "long-lived radioactive waste".[61] The fusion fuels deuterium and tritium are cheap and evenly distributed around the world. Deuterium fuel is almost unlimited in the world. "A bathtub full of water and the lithium in a spent laptop battery could power a family for 50 years."[62] Tritium is radioactive, but has a half-life of only 12.3 years and despite being rare, "can be formed from lithium within the power plant." Lithium reserves in the world are enormous. This is in contrast to fossil fuels, which emit environmentally harmful emissions. Nuclear energy sources, on the other hand, also count as fossil energy sources, but are supposedly CO_2 -neutral. However, "in the long term, up to 10% of the carbon dioxide is released back into the atmosphere. "[63] Nuclear energy also has enormous risks in waste disposal due to radioactivity and accidents and is therefore not a sustainable way of generating energy. [64]

One gram of fuel in fusion power could theoretically produce 90 megawatt hours of energy, the equivalent of 11 tonnes of coal.[65] Furthermore, because of the fast decaying radioactivity of the fuel tritium, nuclear fusion does not need a "geological repository" and thus does not have the waste problems

[57] Cf. [32]: Labaune, C., Baccou, C., Depierreux, S. et al.: *Fusion reactions initiated by laser-accelerated particle beams in a laser-produced plasma,* page 2.
[58] Cf. [33]: Kiessling, Andreas: *Infinite History of Nuclear Fusion, Long Distance Run to Nuclear Fusion, Hope with Laser Pulses and Boron*
[59] Cf. [34]: Max Planck Institute for Plasma Physics: *What will fusion power cost?*
[60] [35]: Ridley, Matt: *Unlimited energy through nuclear fusion*
[61] [29]: Max Planck Institute for Plasma Physics: *50 Years Max Planck Institute for Plasma Physics, Garching and Greifswald, Research for the Energy of the Future*, page 4
[62] [29]: Max Planck Institute for Plasma Physics: *50 Years Max Planck Institute for Plasma Physics, Garching and Greifswald, Research for the Energy of the Future*, page 4
[63] [14]: Quaschning, Volker: *Erneuerbare Energien und Klimaschutz: Hintergründe - Techniken - Anlagenplanung - Wirtschaftlichkeit*, page 88
[64] Cf. [12]: Kiessling, Andreas: *personal interview, 24.05.22*
[65] Cf. [36]: Max Planck Institute for Plasma Physics: *What is Nuclear Fusion?*

of nuclear energy. Furthermore, unlike renewable energies, nuclear fusion leads to an enormously high concentration of energy and accordingly requires minimal space.[66]

Renewable energies are subject to strong time-dependent fluctuations and are therefore not suitable for base-load operation.[67] Nuclear fusion, however, is "independent of daily or yearly fluctuations and therefore ideal for base load supply of conurbations and large industrial plants." [68]

2.6 Challenges and forecast

Challenges of nuclear fusion consist mainly of technological hurdles. The magnetic confinement behaviour from plasma in nuclear fusion must be improved to make the nuclear fusion reactor possible. "Advances in confinement behaviour can only be achieved by building geometrically larger facilities."[69] In addition, "energy-efficient heating of the plasma, current drive in the tokamak, further development of resistant low-activation materials, and energy-efficient blankets to absorb the fusion energy at the highest possible wall temperature"[70] must be improved. However, billions of investment dollars are being poured into experimental reactors like ITER or JET every year and have been for several years. Research into nuclear fusion is therefore very cost-intensive. [71]

If research goes according to the current plan, with first the construction of ITER and then a subsequent demonstration power plant, nuclear fusion will become economically viable in around 30 years. "Concept studies[72] for a fusion power plant suggest that it will have an electrical output of at least 1000 megawatts" and thus will be particularly suitable for base-load electricity supply."[73] To ensure a CO_2 -free energy supply in the future, renewable energies would cover the peak load, while nuclear fusion would cover the base load.[74]

3. Conclusion

In summary, it can be stated that with increasing population growth, the consumption of resources will also increase and the earth will probably run out of fuels for fossil energy sources in 100-200 years at

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[66] [29]: Max Planck Institute for Plasma Physics: *50 Years Max Planck Institute for Plasma Physics, Garching and Greifswald, Research for the Energy of the Future,* page 4

[67] Kiessling, Andreas: *personal interview, 24.05.22*

[68] [29]: Max Planck Institute for Plasma Physics: *50 Years Max Planck Institute for Plasma Physics, Garching and Greifswald, Research for the Energy of the Future,* page 4

[69] [37]: Raeder, Jürgen; Borrass, Kurt; Bünde, Rolf ; Dänner, Wolfgang; Klingelhöfer, Rolf; Lengyel, Lajos; Leuterer, Fritz; Söll, Matthias: *Kontrollierte Kernfusion: Grundlagen ihrer Nutzung zur Energieversorgung, in: Teubner Studienbücher Physik,* Page 372

[70] [38]: Max Planck Institute for Plasma Physics: *Where does fusion research stand? Which physical and technological problems still need to be solved*?

[71] Cf. [39]: Katz, Joschua: Iter *fusion reactor, "Too expensive, too late and too uncertain".*

[72] Cf. [40]: Maisonnier, D.; Campbell, David J.; Cook, I.; Di Pace, L.; Giancarli, L.; Hayward, Jessyca; Li Puma, A.; Medrano, M.; Norajitra, Prachai; Roccella, M.; Sardain, P.; Tran, M.Q.; Ward, D., *Power plant conceptual studies in Europe. Nuclear Fusion,* page 1527

[73] [41]: Max Planck Institute for Plasma Physics: *The Fusion Power Plant*

[74] Cf. [12]: Kiessling, Andreas: *personal interview, 24.05.22*

the latest. The burning of fossil fuels causes more CO_2 to accumulate in the atmosphere and leads to global warming. To prevent uncontrollable climate change and hazards, the use of fossil fuels such as coal, oil and gas must soon be replaced by another sustainable baseload fuel. Nuclear fusion would be a possible suitable alternative base load carrier. Compared to other types of energy generation, nuclear fusion has a high harvest factor and also comparatively favourable electricity production costs of 50-80 euros per MWh. Thanks to its concept, nuclear fusion can guarantee permanent power generation (base load). Moreover, fusion power is completely free of environmentally harmful CO_2 emissions and does not produce long-lasting radioactive waste like nuclear energy. Finally, the reserves of fusion fuels are uniformly and almost inexhaustibly available worldwide.

Nuclear fusion also has a high energy concentration, thus requires minimal space and is disaster-proof. However, the rate of technological progress is uncertain and the date of operational maturity can only be vaguely predicted.

In nuclear fusion, two atoms, deuterium and tritium, fuse under temperatures of 150 million degrees in a magnetic field and thereby, in theory, generate more energy than is added. Various fusion concepts are being worked on, the most promising of which is ITER, a tokamak reactor in France, in the construction of which billions are invested every year.

The challenges from the path to nuclear fusion centrally include improvements to the technological concept to enable the high temperatures in the reactor for a longer time. If one considers the human development to date since industrialisation and takes into account that work on nuclear fusion has been going on since 1940, the conclusion of an early start-up is obvious. In fact, studies for fusion power plants suggest that in about 30 years the economic operation of those will start and both ITER and the following demonstration power plant and Wendelstein 7-X as a stellarator will develop in the future.

Renewables have harvest factors in the lower range and slightly higher electricity production costs, but can take on the peak load and would complement nuclear fusion as the base load to provide the energy supply for the second half of this century.

4. Bibliography

[1] Peperkorn, Colin; Herweg, Antonia; Wegner, Claas : *Energies der Zukunft als Unterrichtsthema*, in: Mint-Zirkel 11. Jahrgang, Mai 2022, Ausgabe 2, 15

[2] Allen, Myles R.; de Coninck, Heleen; Dube, Opha Pauline; Hoegh-Guldberg, Ove; Jacob, Daniela; Jiang, Kejun; Revi Aromar; Rogelj, Joeri; Roy, Joyashree; Shindell, Drew; Solecki, William; Taylor, Michael; Tschakert, Petra; Waisman, Henri; [...]: *Technical Summary of IPCC Special Report, Global Warming of 1.5 °C*, https://www.ipcc.ch/site/assets/uploads/sites/2/2019/05/SR15_TS_High_Res.pdf [accessed 18.06.2022].

[3] Lajčák, Miroslav; Council of the European Union: *Council Decision 2016/1841 of 5 October 2016, Paris Agreement*, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32016D1841 [accessed 18.06.2022].

[4] United Nations: *Report of the Conference of the Parties on its 21st Session, held in Paris from 30.11 to 11.12 2015 Part one: proceedings*, http://unfccc.int/resource/docs/2015/cop21/eng/10.pdf [accessed 18.06.2022].

[5] Marenbach, Richard; Jäger, Johann; Nelles, Dieter: *Elektrische Energietechnik, Grundlagen, Energieversorgung, Antriebe und Leistungselektronik,* 3rd edition, Wiesbaden, Springer Vieweg, 2020.

[6] Wesselak, Viktor; Schabbach, Thomas; Link, Thomas; Fischer, Joachim: *Regenerative Energietechnik,* 2nd edition, Springer-Verlag, Berlin Heidelberg, 2013

[7] Allan, P. Richard; Arias, A. Paola; Berger, Sophie; Canadell, G. Josep; Cassou, Christophe; Chen, Deliang; Cherchi, Annalisa; Connors, L. Sarah; Coppola, Erika; [...]: IPCC: *Summary for Policymakers, in: Sixth Assessment Report WG1, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM.pdf* [accessed 20.06.2022].

[8] Pörtner, Hans-O.; Roberts, C. Debra; Adams, Helen; Adler, Carolina; Aldunce, Paulina; Ali, Elham; Begum, Rawshan Ara; Betts, Richard; Kerr, Bezner Rachel; Biesbroek, Robbert; Birkmann, Joern; [...]: IPCC: *Summary for Policymakers, in: Sixth Assessment Report WG2, https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_SummaryForPolicymakers.pdf* [accessed 20.06.2022].

[9] Pörtner, Hans-O.; Roberts, C. Debra; Adams, Helen; Adler, Carolina; Aldunce, Paulina; Ali, Elham; Begum, Rawshan Ara; Betts, Richard; Kerr, Bezner Rachel; Biesbroek, Robbert; Birkmann, Joern; [...]: IPCC: *Full report, in: Sixth Assessment Report WG2, https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_FinalDraft_FullReport.pdf* [accessed 20.06.2022].

[10] Rich, Nathaniel: *Losing Earth*, 1st edition, Verlag Rowohlt Berlin, 2019

[11] Berger, Michael (21.12.21). *E-mail request for short interview* (attached)

[12] Kiessling, Andreas: *personal interview,* 24.05.2022: videoconference: https://drive.google.com/file/d/1hW2aSSkGGJcEydspeafcJDfuOOz4dTjZ/view?usp=sharing [accessed 21.06.2022], transcription in the appendix.

[13] Gawlick, Ramona: *Stromgewinnung, Welche Methoden der Stromerzeugung gibt es?* http://www.stromgewinnung.net/methoden-der-stromerzeugung.shtml [Accessed 19.06.2022]

[14] Quaschning, Volker: *Erneuerbare Energien und Klimaschutz: Hintergründe - Techniken - Anlagenplanung - Wirtschaftlichkeit,* 2nd, updated edition, Munich, Carl Hanser Verlag GmbH & Co. KG, 2009.

[15] Lübbert Daniel: *CO2-Bilanzen verschiedener Energieträger im Vergleich, Zur Klimafreundlichkeit von fossilen Energien, Kernenergie und erneuerbaren Energien, in: Deutscher Bundestag WD* https://www.bundestag.de/resource/blob/406432/70f77c4c170d9048d88dcc3071b7721c/wd-8-056-07-pdf-data.pdf [Accessed 19.06.2022].

[16] Alt, Franz: *Die Sonne schickt uns keine Rechnung: Neue Energie, neue Arbeit, neue Mobilität,* 5th edition, Munich, Piper, 2016

[17] Kröll, Sabrina: *Function and Tasks of the European Energy Union,* https://www.net4energy.com/wiki/energieunion [Accessed 19.06.2022].

[18] Dutton, A. John: *Technologies for sustainability systems, base load energy sustainability*, https://www.e-education.psu.edu/eme807/node/667 [accessed 19.06.2022].

[19] Spektrum.de: *Harvest factor, in: Lexikon der Physik,* https://www.spektrum.de/lexikon/physik/erntefaktor/4493 [accessed 19.06.2022].

[20] Doelling, Robert John: *Harvest factor and energetic amortisation of power plants*, https://www.energie-experten.org/energie-sparen/energie-berechnen/energiebedarf/erntefaktor#c45007 [accessed 20.06.2022].

[21] Weißbach, D.; Ruprecht, G; Huke, A.; Czerski, K.; Gottlieb, S.; Hussein, A: *Energy intensities, EROIs, and energy payback times of electricity generating power plants*, https://festkoerper-kernphysik.de/Weissbach_EROI_preprint.pdf [accessed 20.06.2022].

[22] Acker, Ursula: *Stromgestehungskosten*, https://www.photovoltaik.org/wissen/stromgestehungskosten [accessed 20.06.2022].

[23] Kunst, Sabine: *Energieeinheiten* , *in: LEIFI-Physik,* https://www.leifiphysik.de/mechanik/arbeit-energie-und-leistung/grundwissen/energieeinheiten [accessed 20.06.2022]

[24] Badouard, Thierry; Moreira de Oliveira, Débora; Yearwood, Jessica; Torres, Perla: Altmann, Matthias: *Cost of energy, Energy costs, taxes and the impact of government interventions on investments: final report, in: Publications Office of the European Union* , https://op.europa.eu/en/publication-detail/-/publication/e2783d72-1752-11eb-b57e-01aa75ed71a1/language-en, [accessed 20.06.2022].

[25] Wissel, S.; Rath-Nagel S; Blesl M.; Fahl U.; Voß A: *Stromerzeugungskosten im Vergleich, in: Arbeitsbericht Nr. 4,* https://www.ier.uni-stuttgart.de/publikationen/arbeitsberichte/downloads/Arbeitsbericht_04.pdf [Accessed 20.06.2022].

[26] Max Planck Institute for Plasma Physics: *Why fusion research?* https://www.ipp.mpg.de/ippcms/de/pr/fusion21 [Accessed 20.06.2022]

[27] Kröll, Sabrina: *Definition of base load and info on base load power plants*, https://www.net4energy.com/wiki/grundlast [20.06.2022]

[28] Nunner, Bernhard: *Grundlagen der Kernfusion, in: Deutsche Physikalische Gesellschaft e. V..* , https://www.dpg-physik.de/vereinigungen/fachlich/smuk/fvp/weiterfuehrende-informationen/grundlagen-der-kernfusion [20.06.2022]

[29] Max Planck Institute: *50 Years Max Planck Institute for Plasma Physics, Garching and Greifswald, Research for the Energy of the Future*, 1st edition, IPP Munich, 2010

[30] Hofmann-Reinecke, Hans: *Nachgefragt: Kann Kernfusion die Energiewende retten*? https://www.tichyseinblick.de/video/nachgerechnet-kann-kernfusion-die-energiewende-retten/ [Accessed 20.06.2022]

[31] FOCUS.de: *Efficiency remains one of the biggest challenges, Two concepts come into question: tokamak reactor and stellarator* , https://www.focus.de/wissen/weltraum/odenwalds_universum/forscher-aus-geheimprojekt-abteilung-wollen-fusionsreaktor-bauen-tokamak-reaktor-und-stellarator_id_4215710.html [accessed 20.06.2022]

[32] Labaune, C., Baccou, C., Depierreux, S. et al.: *Fusion reactions initiated by laser-accelerated particle beams in a laser-produced plasma*, https://www.nature.com/articles/ncomms3506.pdf [accessed 21.06.2022], Nat Commun 4, 2506 (2013).

[33] Kiessling, Andreas: *Unendliche Geschichte Kernfusion, Langstreckenlauf zur Kernfusion, Hoffnung mit Laserimpulsen und Bor* , https://energieorganismus.de/unendliche-geschichte-kernfusion [accessed 20.06.2022]

[34] Max Planck Institute for Plasma Physics: *How much will fusion power cost?* https://www.ipp.mpg.de/2545460/faq7 [Accessed 20.06.2022]

[35] Ridley, Matt: *Unlimited energy through nuclear fusion* , https://www.novo-argumente.com/artikel/unbegrenzte_energie_durch_kernfusion [accessed 20.06.2022]

[36] Max Planck Institute for Plasma Physics: *What is nuclear fusion?* https://www.ipp.mpg.de/ippcms/de/pr/fusion21/kernfusion/index [accessed 20.06.2022]

[37] Raeder, Jürgen; Borrass, Kurt; Bünde, Rolf ; Dänner, Wolfgang; Klingelhöfer, Rolf; Lengyel, Lajos; Leuterer, Fritz; Söll, Matthias: *Kontrollierte Kernfusion: Grundlagen ihrer Nutzung zur Energieversorgung, in: Teubner Studienbücher Physik ,* 1st ed., Stuttgart, Teubner Verlag, 1981

[38] Max Planck Institute for Plasma Physics: *Where does fusion research stand? Which physical and technological problems still need to be solved?* https://www.ipp.mpg.de/2542802/faq2 [Accessed 20.06.2022]

[39] Katz, Joschua: *Fusion reactor Iter, "Too expensive, too late and too uncertain", in: EnergieZukunft.eu* , https://www.energiezukunft.eu/politik/zu-teuer-zu-spaet-und-zu-ungewiss/ [accessed 20.06.2022]

[40] Maisonnier, D.; Campbell, David J.; Cook, I.; Di Pace, L.; Giancarli, L.; Hayward, Jessyca; Li Puma, A.; Medrano, M.; Norajitra, Prachai; Roccella, M.; Sardain, P.; Tran, M.Q.; Ward, D., *Power plant conceptual studies in Europe. Nuclear Fusion* , 2007 https://www.researchgate.net/profile/D-Maisonnier-2/publication/47670823_Power_plant_conceptual_studies_in_Europe/links/02e7e5360acf6e3bcc000000/Power-plant-conceptual-studies-in-Europe.pdf [Accessed 20.06.2022].

[41] Max Planck Institute for Plasma Physics: *The Fusion Power Plant*, https://www.ipp.mpg.de/9809/kraftwerk [Accessed 20.06.2022]

5. appendix

Transcript of the topic relevant:

1 Personal interview with Andreas Kiessling [24.05.2022]

If we did nothing to change our situation, for how long would the resources of the energy system continue to supply us?

The next 100-200 years with coal, oil, nuclear fission→ if space travel comes more into play, the possibility of extra-terrestrial resource extraction would also exist; but the question that mainly confronts us is whether the environment or planet Earth can tolerate the next centuries with coal or oil energy.

There are various sources that say that nuclear energy produces practically no carbon dioxide and yet others that note considerable levels, what is their view on this?

In itself a CO_2 -free way to generate energy. But there is the concept of so-called upstream emissions. When you build a nuclear power plant, you need a lot of material, such as cement, and cement is very energy-intensive. Similarly, you can also look at other components of upstream emissions, i.e. preceding production and resources used, so if you want to answer the question, you have to look at the whole system in order to be able to assess it. In this respect, nuclear power plants have CO_2 emissions because they have to be built.

In your opinion, what are the sustainable options for energy supply with lower greenhouse gas emissions that can be used in the future?

Solar and wind energy, geothermal energy, everything that can be done with water - from running water to wave energy, tides, etc. - these are the classic terms for renewable energies.

If you include nuclear energy in the discussion, first of all there are enormous risks with radioactive waste and accidents, as we have already seen with Chernobyl. Consequently, nuclear fission is not a sustainable energy supply option.

Is nuclear fusion technology better than the rest of the energy production alternatives or should humanity focus on solar and wind energy? Do you think mankind should continue to work and invest in nuclear fusion despite the continuous postponement of its completion date (since 1950)?

I am convinced that in the long run, over the next centuries, not just a few decades, humanity needs a basic energy. People should use a lot of renewable energies like solar and wind energy and the ones mentioned before, so that everyone can produce their own energy, but as a base load for humanity and also for new tasks like continued space travel and experiments, I am firmly convinced that we need nuclear fusion.

In the end, you also have to consider the risks. You don't know what would happen in the case of meteorite impacts or solar changes like solar storms where a lot of damage can be done to the central system or major volcanic eruptions that darken the sky. Every few hundred years it happens that the earth goes through small or big climate changes like volcanic eruptions. If we suddenly didn't have enough sun, we wouldn't know how to meet our basic needs, so of course we need a basic load. Even if we want to get away from space travel, we would need a stable, sufficient energy supply in the first place.

On the subject of nuclear fusion: How do you assess nuclear fusion? Would the concept with deuterium and tritium as fusion atoms fit?

Yes, in principle you will start with hydrogen as the basis, not to mention that 99% of the matter in the universe is of the water stuff type and is therefore available everywhere. The question is rather what kind of process will be used to make this concept functional. At the moment there are two ways. The tubular reactor, which then builds up a magnetic field there, in which the fusion reactions then take place, and the second way, in which you have small spheres, which you then bombard from the outside with strong lasers like pulses. However, the second method is not the most advanced. The process that is currently being worked on the most is the one with the reactor, the tokamak process, the one with the permanent magnetic field in which the tube maintains the plasma at very high temperatures.

What about solar energy? Can humans get by on solar energy alone?

[...] No, the biggest energy consumer is industry - the steel and aluminium industry. Since these and other systems need too much energy, which would have to be imported from outside the country, for example in Germany, so that it is still solar energy - No, people cannot get by on solar energy alone. Iceland, for example, can get by on solar energy alone, but in most of the world we have to at least, or at the moment the plan is to use not only wind and solar energy, but also geothermal and tidal energy. There is great potential in these types of energy. However, these energy sources have fluctuations and weaknesses - if the system gets out of step due to strong climate changes such as large volcanic eruptions, humans no longer have a secure basis for energy production. There is no one who can say with absolute certainty "I know exactly, it is not enough with renewable energies" but one really has to create 100% of the entire mobility, electricity, industry, chemical industry with renewable energies and no one can say that convincingly today. The future energy demand of mankind would also have to be covered, whereby it is often forgotten that today most of the electricity or energy in the world is consumed by only 1-2 billion people. Another 1-2 billion people do not have electricity, are not even connected to the energy system. The middle part - the middle level of development - has much lower energy consumption than we do. If the whole world - 8 billion people - says it wants to consume as much energy as the USA or Europe, for example, then energy consumption will explode many times over. At the end of the day, it is legitimate, these countries are entitled to the same development and resources as we are and I really doubt that we can do that only with current energy sources and that there is definitely a need to find new forms of energy and thus cover the base load. [...]

As physicists, we always say that everything is energy. Even matter consists of energy, of vibrations. We always say it is waves, the standing waves, which then create nodes and these are felt as mass. Mass is energy, everything is driven by energy and development is also driven by energy and in this respect we need every form of energy generation, we need it sustainably; so that we do not damage our environment. The more we humans expand and the more humans we become on earth; there is not the same amount of sun everywhere, then we will need other forms of energy. On Earth we need nuclear fusion, I am convinced of that. But not only nuclear fusion, I am against a few large, rich companies supplying 8 billion people with electricity, because we will become dependent on them. We are currently experiencing what dependencies mean. Everyone should have the right to get energy where they can get it. One of the great physicists and a great role model, Tesla, basically invented the entire electricity system; that is, everything that revolves around the method of alternating current generation of the motors, the generators, the transmission via lines. His great goal was to be able to generate and transmit electricity neutrally at any location. That's why I'm in favour of any form of energy generation that everyone can use, including small villages, businesses and cities, and not companies that we then depend on.

You often see that the workers who are working on, in this case, ITER and Tokamak; most of the time they don't even know what they are working on, besides, the technological steps to use nuclear fusion as a way of producing energy are still huge - why do you think nuclear fusion is taking so long? →Can you say if there are any breakthroughs coming in the near future on the subject?

So, maybe that's our problem too, Tokamak is the best example here and it's still the same principle today. In physics, technological development is quite slow. As a physicist you know, we actually wrote a new physics ~over 100 years ago. In 1926, insights into quantum mechanics by Schrödinger, Heisenberg and today we are 100 years later. And it is only 100 years later, i.e. today, that we are really reaping the fruits of this physics. The microprocessor, with the development of computers in the 70s and 80s and the reduction in the size of transistors, is actually a consequence of quantum mechanics. But until the whole of humanity, the life of humanity, changed with this technology, communication, the Internet, it took about 80 years after quantum mechanics. Scientific changes take a very long time until they are really recognised and implemented in technologies. However, the world today is apparently developing quite fast. When I did my diploma thesis and got my first computer with 64kB main memory [...] and that today you have huge units in the smallest structures - only 40 years have passed, so we have an enormous pace of technology and apparently people are always so fast. But as a rule, humanity is not that fast, actually slow, and that's why we are usually so impatient with changes that take such an extremely long time, even though many billions in funding have been invested. However, I am very convinced that we must not give up at this point, otherwise humanity will go round in circles.

2 Personal interview with Andreas Burkert [29.12.2021]

Mankind is dependent on fossil fuels. However, these fossil fuels are ultimately the cause of global warming. How would this be remedied?

"There are two options in the long term, in my opinion. Nuclear energy and solar energy. Nuclear energy has the disadvantage that you have to worry about disposal. You could shoot it into space, then it would be gone. But if that fails and it falls down again, then it results in a catastrophe and you can't guarantee that it will always work that way. Burying it somewhere would also be unsafe, because we don't know the earth well enough and there could be a leak, for example, and then contamination etc. We have already seen this with Chernobyl. That would also create a long-term problem and is not reliable.

The only clean energy is solar energy, but there I see the problem that there is also hydrogen as a possible fuel element and fusion. Mankind is too energy-hungry to get by on solar energy alone. In the long term, fusion would be the only solution, but there again you have radioactive problems. More precisely, a fusion reactor, similar to what runs in the sun, e.g. hydrogen fusion, etc. The disadvantage here is that we are not that far yet, we would have to determine or find out everything. The sun, for example, does it with the help of its mass, the shell doesn't let anything out, the earth doesn't have that mass. But humans are only at the beginning, the earth is 4.5 billion years old, what are 1000 years in comparison. [...]

Do you think that within the next century humans will be sent to habitable planets and how far is the nearest habitable planet?

I don't think so [...] because of the lack of energy and mass that the spacecraft will need and the human being in there. You don't have the resources to send humans to the nearest habitable planet, Proxima

Centauri (just in the habitable zone in the Alpha Centauri solar system), which is four light years away, so 70,000 years of flight or 1000 human generations. So you have to solve the problem of short life.

Some believe that man is at the peak of development right now, I don't believe that, we are like the ancient Greeks. What are 1000 years compared to the earth. Development continues exponentially and we are still very primitive.

How will the Earth survive the climate crisis?

If man no longer exists, then after thousands of years the earth will return to its normal household, the same ratio as it was tens of thousands of years ago. Something will survive, whether ants or insects, etc. People always imagine life idyllic, people with animals and yet they still have control. In the end, people destroy themselves or their idyll. However, nature is so robust and diverse, it will survive, there are living beings a kilometre deep in the earth's soil that don't care what people do or whether they exist. Humans cannot destroy the earth.

What about the Anthropocene era and the human role there?

[....] Every human being is unique, every planet has the possibility to make more, one cannot foresee what will happen to humans in tens of thousands of years and whether they will evolve into a "superhuman" who can survive the Anthropocene epoch.

Do you think there is life on Europa (Jupiter's moon)?

We don't know, but it's good to think about it. We always assume things based on the habitable zone. But Europa is not in the habitable zone. The gas planets are further out. Nevertheless, one can imagine that Europa contains liquid water, and I can imagine life there. If life can develop everywhere, it can also develop there. That is the interesting question here. Has life been unique on Earth? Has it only been possible for life to arise once? The interesting thing about life is that it does not arise spontaneously. You can't yet create life in the lab, from the test tube, just copy it. On the other hand, to imagine that life has only succeeded once on Earth and that it will die in five billion years anyway because the sun will explode also sounds impossible. If life is a part of the universe, then one cannot imagine that it only came into being there. All this is philosophical now. That's why it's important to find life somewhere, even if it's only on Mars. If you find traces of earlier life on Mars, then you know life is not unique in the universe. I can imagine it on Europa, why not, we still have to see.

2 E-mail from Michael Berger [21.12.21]:

Good evening, Mr Berschin,

I assume you will at least start work over the holidays. An interview with me would certainly not be short, so a few hints in advance.

1. I prefer to use the term climate crisis, because that's where politics starts. Climate change sounds nice and harmless, but climate catastrophe sounds very dramatic and unavoidable. Crisis is something that is there and that can be managed if it is taken seriously.
2. When the Club of Rome published its Limits to Growth in 1972, I was about your age. Since then, we actually know what is going to happen. Basically, we missed 50 years. And it was my generation!
3. The IPCC always documents the latest developments. I don't like to interfere with that, because it's reliable data. The state of the art reports are always particularly interesting, and there is usually a summary that you should read in a quiet hour. If you can, read it over the holidays. Maybe your parents or siblings will be interested and you'll have someone to discuss it with. Have a look at https://www.deutsches-klima-konsortium.de/de/ipcc-ar6/uebersicht-ar6.html.

   [...]