EPJ Web of Conferences **268**, 00003 (2022) https://doi.org/10.1051/epjconf/202226800003
LNES 2021

Energy: from yesterday to tomorrow

Christoph Buchal(*)

Forschungszentrum Jülich - Jülich, Germany

Summary. — The extensive global changes and achievements of the Industrial Revolutions combined with the ever growing utilization of plentiful fossil energies are considered as a challenge for today —and even more so for tomorrow. After a short historical review of the technological developments and some remarks on climate, interesting changes of the paradigm of energy supply and usage are explained, including possible future developments. Some of the ideas and the consequences of the new analysis ("Net Zero 2050") of the International Energy Agency are presented and discussed.

1. – Introduction

The value of energy has gone through very different stages of appreciation:

For centuries, energy was rather scarce and of significant value. For example, coal frequently was mined underground in deep pits under terrible conditions, which caused health problems and deadly accidents.

The discovery of plentiful oil changed the picture. The prices dropped and the consumption of oil products soared. Short political crises with reduced supply did not

(*) E-mail: c.buchal@fz-juelich.de

influence the long-term trend of a permanent growth of production. The sufficient availability of oil and gasoline was taken for granted by the public and the positive feeling of ample and safe supplies was reinforced by reliable electrical power from nuclear plants.

Within the last decades of this abundance, public awareness and discussions on climate change due to CO_2 emissions spread and caused a change of acceptance. Negative news on energy use became more frequent and the blessings of energy for the daily life and industry were more or less ignored. While energy was still sufficiently available, oil, coal and natural gas acquired a prevailingly negative connotation of a malicious drug for mankind. All of a sudden, the war in Ukraine and the perspective of radical energy embargoes changed this picture. Facing the consequences of national energy starvation, political leaders and even deeply committed environmentalists had to admit that energy is not a pathogenic drug, but the essential "life sustaining blood" of all modern industrial societies. The prime importance of a reliable, affordable and safe energy supply for life, farming, industry, mobility and information was taught "the hard way". Under the present conditions of imminent shortage and rising prices a reliable energy supply returned into the centre of attention.

Looking back in history, the development of different energy sources and energy systems form the basis of the Industrial Revolutions. Two centuries of fantastic achievements by scientists, engineers and technicians, by tinkerers and nerds have changed our world irreversibly and drastically, and mostly to the very much better.

In the preceding volume of this conference a compact review of the benefits of the Industrial Revolutions and the up-to-date developments has been presented [1]. For more than two centuries Science and Technology had invented new machines, factories, electricity, communication and transport systems. They were fuelled by fossil energies, first coal, thereafter oil and later natural gas. These new fuels greatly empowered the general advancement of mankind in historically unique dimensions.

The most obvious results are

- a strong growth of the world population, supported by improved nutrition, hygiene and medicine,
- in parallel much better health conditions and even a doubling of the average lifespan,
- a rapidly advancing standard of living in most nations,
- a widespread reduction of difficult, hard and dangerous working conditions,
- and, last but not least, much more personal freedom with more time and resources for education, travel and recreation.

The above-mentioned review also covers the basic energy facts of our daily needs [1]. There is little doubt that the energy related emissions into the atmosphere should be reduced as much as possible. Unfortunately this is not easy to accomplish, especially in time of military conflicts and limited international cooperation. Certainly the search for

all kinds of improvements of energy systems with lower emissions will dominate the next decades and offer an abundance of new jobs in these fields.

We may add that the classical branches of energy technologies presently are expanded into the new research fields of "Bioenergy". Their aim is a better understanding of the details of photosynthesis, plant growth and the energetic use of biomass. Of high priority remain the improvements of global food supply, animal feed and to some extend also technical biofuels. The associated conflicts are obvious: animal feed, human food and meat consumption on the one hand and on the other hand, the use of bio-energies for cooking, heating and increasingly also as biofuels.

2. – The changing General Narrative of Life, Climate and Energy

What has been on people's mind in earlier times and what is their present mind-set? What are people discussing as important guidelines for life? What motivates families and especially the youth? The common mind-set on important issues within the population of a nation is of strong influence for personal plans and decisions.

For thousands of years mankind had been struggling against the strong forces of nature. The constant fight for survival was simply "natural" and this judgement frequently was confirmed by personal experience. Nature per se does not know any mercy: "Mother Nature" as well as "Mother Earth" sometimes are bountiful, but sometimes dangerous, cruel and deadly. History describes the pre-industrial era as a constant battle against hunger, diseases and premature death [2].

The pre-industrial concept of energy was fairly simple. Energy was needed for heat: daily firewood for cooking, for surviving the cold winters and charcoal for working with metals. Work was performed primarily by human muscles and by some animals as horses or oxen. In addition, water and wind power could be used for mills and ships. Rich nations and wealthy people could enjoy the help of many servants, and frequently even slaves as victims of war.

The invention of the steam engine and the science of thermodynamics slowly, but irreversibly changed the picture. Coal became the most precious source of energy. Coal mines, growing factories and steam trains emerged in the first phase of the industrial revolution. Later followed by electrical power, then by petroleum, cars and airplanes. The modern world became dependent on sufficient supply of energy in the form of coal and oil as the basis of all industrial societies and their every days life.

Looking back, modern industrialization and especially the general availability of energy and electrical power changed the historic narrative of a dangerous life due to the perils of nature towards a growing admiration of our technical achievements. With very good reasons, scientific and technical progress was regarded as a wonderful blessing. Progress opened possibilities of greater personal liberty. The modern and advanced forms of industrialization terminated the wide spread child work, stopped overly hard or slave-like working conditions and permitted general schooling and even university education.

"Electricity", "Smoking chimneys", cars and "Roaring airplane engines" stood for progress and better life. Within the developed rich countries the awareness of the

constant battle for survival completely faded out, while the narrative of a safe and better life by superior technology became generally accepted. This optimistic and positive picture of technology and future emerged more strongly than ever in the second half of the 20th century. Cars became very common. Cities were reconstructed for better conditions for automobiles. New highways permitted easy long-distance travel and vacation trips for most people.

In addition, the overwhelming power and impact of the newly discovered nuclear energy became visible for everyone. In the following years, nuclear energy found an important civil application at many nuclear electrical power stations. Therefore, the verdict on energy was generally clear and undisputed:

> *Technological progress is important and desirable. Oil must provide the lion's share of the modern energy supply. The future will be even brighter with friendly, clean and safe nuclear power stations everywhere. Coal and oil should not be burned in the long run, but are needed for the production of the wonders of the chemical industry, for instance the new world of plastics, colours, chemicals and medicines. Electricity will be generated mostly by nuclear energy "too cheap to meter" and should provide ample power for machinery, light, radio, TV, telephone and possibly even the newly emerging art of electronic computing.*

As a highly motivated young student of physics, I was sharing this optimism. Coal in Germany was still wide spread, but had always been rather dangerous to mine, dirty to use, generating very unhealthy smoke, fumes and particles. There was hope to phase out this ugly and cumbersome energy carrier smoothly, at first from all the households, where it was used for heating and cooking.

At the same time, the very hard human labour of farming was replaced by Diesel engines everywhere in the Western world. In the developed nations, farming was increasingly a matter of using huge machines, converting "*Diesel to bread*". The population became used to constantly reliable and successful harvests. This was due to scientific plant breeding and the optimized use of fertilizers and pesticides, provided by the chemical industries.

> *In rich and advanced nations, only very few people have to worry about the availability of their food. Instead, a reliable energy supply at affordable prices for living, housing and mobility has become a matter of general concern and controversies.*

Around 1970 this positive narrative about nuclear energy became somewhat clouded and disputed by the "Anti-Nuclear"-movement. The protesters mistakenly emphasized the dangers of nuclear energy by confusing the obvious dangers of nuclear war with the carefully controlled operation of civil nuclear power plants.

The two major oil crises of 1973 and 1979 fortunately did not result in the expected dreadful effects, but rather boosted new coal-fired and nuclear power stations. Unimpaired nearly everybody continued to enjoy the mobility with new cars. Living quarters spread out into the country, as cars provide convenient means for individual commuting. Combined with a growing tourism industry, a new European network of highways invited to vacations in foreign countries, using the family car. Within the entire Western World and the OECD countries this modern lifestyle coexisted in happy harmony with the advancement of technology and the ample supply of the needed fuels.

2˙1. *Some intermediate remarks on the ever changing climate.* – Before discussing the present-day Narrative of Energy, it should be pointed out, that the 20th century was characterized by a mild climate with very few weather catastrophes, especially very few severe river floodings [3]. While such good centuries had happened before, they are in contrast to many previous time periods, which were either too wet, or too dry, or too cold. In fact, the scientific "Climate Narrative" around the Sixties must sound strange to young people of today. Climate discussions were dominated by the fact that the climate of the Earth had strictly followed a periodic pattern during the last million years [4, 5]. Long glacial ("ice covered") and rather short interglacial ("warmer times") periods characterize the "present geological ice age" of our planet. After the last 10000 years of relatively mild climate, science expected the new glaciation arriving soon. Everybody hoped, that this natural cycle would be somewhat delayed and not soon picked up again, because the consequences for all living conditions, especially farming and the food supply of the extremely grown world population would be unimaginably catastrophic. The challenges and dangers of the ever changing weather were well known, and the cold time of the Little Ice Age (1450–1850), the cold winters of the war times or, for instance, the complete freezing of Lake Constance and others in 1963 represented the obvious dangers of a possible climate change —the threat of another change towards lower temperatures. There was no fear of too much warming. Warmer times even would be welcomed, exactly as before during the Roman temperature optimum or the medieval optimum. The general Narrative on Energy remained optimistic, because a sufficient supply of cheap and reliable energy was available and would be most helpful to battle the challenges of a coming colder climate.

As far-fetched as it may sound, one might argue that humans changed the climate already much earlier than generally discussed, because the CO_2 and methane emissions from farming in earliest human history until the Industrial Revolutions of the 20th century probably retarded the natural geological trend towards the expected next glaciation [6]. This observation is completely compatible with the present understanding of the excessively rising emissions and a climate change towards unfavourably high temperatures. Nevertheless, one should keep in mind, that climate science is extremely complex, even considering only the past and the present. The changes of the global climate zones depend on many coupled nonlinear global interactions between them, involving all of the Earth, the Sun and human impacts. Physical models and mathematical simulations may reveal significant trends, but do not allow exact solutions ("predictions") for many decades into the future [4, 5, 7].

3. – A time of more and new fears

Today, the Narrative has changed again. A new fear was arising concerning the possible dangers of global warming due to the observed CO_2-enrichment in the atmosphere. Unfortunately, the previous public expectations for nuclear energy had been shattered by the accidents of Chernobyl (1986) and later Fukushima (2011). The German reaction was especially strange and hasty. In an unexpected political move during the weeks after the Fukushima tsunami, the German government decided to phase out all older nuclear power plants in Germany immediately and to terminate the newest and best of our nuclear plants latest by 2022. By sudden political ruling, more than 35 GW of reliable and CO_2-emission free nuclear electrical power became officially unwanted. Although in 2011 many arguments about the unpleasant consequence of rising CO_2-emissions were already raised, they were not strong enough or they were simply ignored. Instead, *ad hoc* ethical arguments against nuclear power were thought up and the expectation was spread, that a national program for installing renewable power from photovoltaics and wind ("Energiewende") would be able to replace the nuclear energy swiftly —and even satisfy the entire energy demand of Germany.

It seems, that the public easily and strongly reacts to fear and has a hard time understanding numbers and probabilities, balancing risks and benefits in a clear and rational way. Now, in addition to the nuclear fear, the climate fear had entered the public discussion. The IPCC-reports on climate change plus the discussions of possible tipping points of the future climate together with the Paris Agreement (2015) urged termination of the use of fossil fuels rapidly. Otherwise, an uncontrollable temperature rise is feared. Therefore, the global goal of Zero Emissions in 2050 has become a widely used slogan. Until 2022, "Climate Protection and Zero Emissions" dominated the German news and the public showed a great amount of good will towards all related projects, however expensive and inefficient they may turn out to be. The complex and sobering details of physics and technology on the global scale remain of limited interest. After the military aggression of Russia against Ukraine in February 2022, the details of these ambitious renewable energy projects have become even more uncertain and controversial, because the intended embargoes, the different national interests and the limited national potentials are facing enormous global problems.

4. – The analysis of the International Energy Agency (IEA)

The IEA is a subdivision of the OECD. It was founded in 1974 by 16 nations as a reaction to the oil crisis of 1973. The IEA has acquired the reputation of a competent and respected institution. They publish the famous *World Energy Outlook* and always have been concerned about a reliable data base, analysing production and demand as well as providing a realistic forecast. For example, in 2015 the IEA new policies scenario made a prediction of the global energy needs in 2040. Fully aware of the emission problem, they expected a reduction of the fraction of fossil fuels from 85% to 70% until 2040. To achieve this goal, the installation of renewable energies (RE) had to be strongly supported and

increased. Nevertheless, the yearly production of fossil energies would keep on growing until 2040. In other words: in spite of the strong worldwide growth of RE production, the IEA predicted that RE would not even satisfy the steady increase of the global demand. This IEA outlook presented little hope for a significant reduction of the coal, oil or gas production until 2040. Of course, this view was in disaccord to the Paris emission goals and the IEA contracted the image of a protector of "yesterday's fossil industries".

In a carefully prepared approach, the IEA was able to bridge the gap between their well-founded scenarios and other possibly overoptimistic climate goals. In May 2021, the IEA "took the bull by the horns" and responded directly to the goals of IPCC. The IEA published a comprehensive new analysis, which looks very different at first glance. Nevertheless, it turns out to be a realistic continuation of their previous work. It is called "NET ZERO by 2050" and presents the emission budgets of three examples of global pathways into the future. This study does not provide any new climate model. Instead, it relies completely on IPCC data and climate studies. The IEA uses the calculated emission data from their own database and scenarios and combines these "energy related emission data" with the climate projections, which have been published in the IPCC reports. The study covers 220 pages, is clearly organized and well worth reading [8].

4˙1. *Pathway No. 1: Continue along the presently stated policies (STEPS).* – The STEPS scenario takes into account all policies, which are backed up by existing legislation and ruling. Future "possibilities", hopes and wishes are not considered. Under these circumstances most probably the global emissions will not decrease. Instead, they will remain at about 36 Gt CO_2/year and keep this level until 2050. It is noted, that the strong recession of global travel due to COVID-19 pandemic resulted in a small dip of 2 Gt CO_2/y or approximately 6% only. A recovery after the pandemic is expected. Under these conditions, a global temperature rise of 2.7 °C until 2100 is estimated (50% probability). This scenario ends up far away from the Paris goals and comes close to previously published expectations.

4˙2. *Pathway No. 2: All open promises become true (Announced Pledges Case, APC).* – The APC pathway is much more optimistic. It is assumed, that all promises and already-mentioned possibilities are fulfilled completely and in a timely matter. With other words: It is the lowest emission path, which we can hope for under the present political conditions. This path demands significant efforts from all nations and shows that the CO_2-emissions would drop to 22 Gt/y until 2050. Certainly this would be progress —but only half the way to NET ZERO in 2050. The largest contributions to the emission reductions are provided by very high investments into sustainable electrical power generation. The global demand in electrical power doubles. New power grids for underdeveloped countries and areas are installed. The investments in photovoltaics and wind turbines are growing especially fast and in 2050 their production of electrical energy is ten times higher than in 2020. Nuclear power and hydro are growing moderately. A fraction of the remaining coal power plants is fitted with carbon capture and storage (CCS) technology. The total end-energy needs for industry, buildings and mobility will

stop growing and remains essentially stable. Also, the mineral oil demand and supply for mobility remains stable, not increasing and not yet decreasing. Although many new cars are running on electricity, the need of mineral oil for cars, trucks, airplanes and ships drops slightly. Hydrogen very slowly becomes a fuel for transportation. It is the authors (ChB) opinion, that this APC case will imply rigorous global changes and regulations, but indeed may describe a realistic option, which one might use for future planning.

4˙3. *Pathway No. 3: The NET ZERO EMISSIONS by 2050 Scenario (NZE).* – What would you do, if you were directly confronted with a possibly over-optimistic scenario, which describes the complete abandonment of fossil energies with the claim: "Yes, we can do it!"? The best answer may be to take the optimists by their words and check all the needed requirements and conditions. The IEA has chosen this approach as well and carefully executed the calculations on the basis of the available data and information.

It takes a couple of hours or days to study ref. [7] and its colored graphics in detail. In the following, a few facts are summarized. They provide an excellent guideline for scientific and political discussions and planning, although the actual conditions and goals will be difficult to meet.

The entire scenario is based on very strong international cooperation and needs world-wide implementation. The IEA is very optimistic about the general economy and assumes further economic growth with a doubling of the global GDP and a world population of 10 billion until 2050. In view of the total restructuring of the energy world, the spending on energy investments has to double at minimum —but no investments whatsoever are acceptable for new coal, oil or gas projects. The annual investments in photovoltaics (PV) and wind turbines have to be increased by a factor of 10(!). In parallel, the role of nuclear power becomes more significant with the doubling of the number of nuclear power plants. Thorium technology and fusion are not mentioned. All the remaining coal power plants must be retrofitted with carbon capture and storage (CCS) —or they will be shut down, with serious consequences for the availability of electrical power.

The known oil and gas fields are sufficient to provide the entire remaining demand and the oil companies have to change into different projects of geological exploration, as CO_2 storage as well as the further exploration and search for metals like lithium and other minerals. All nations with large fossil resources have to expect strongly falling sales and revenues. Their cooperation and the reconstruction of their economies will be essential, but remain a challenge. In contrast to the APC scenario, oil will become much less important even for mobility and will be reserved for the chemical industries. The oil price probably will drop by 50% due to the shrinking demand. Of course, this opens frightening prospects for many nations living on oil revenues.

For coal, there is little room left either. Clean coal technologies together with CCS provide the only chance for survival of coal mines and coal power plants. To some degree, even bio-energy as wood shall be burned in power plants, if these are equipped with CCS. This permits an additional direct removal of carbon from the biosphere. The further lowering of the total emitted CO_2 becomes an important element of the overall net zero emission concept.

The NZE scenario demands several immediate decisions and many checkpoints for 2030 are provided as benchmarks for success towards 2050. The final scenario comprises more than 400 milestones until 2050. In summary, it is extremely drastic and overly demanding. The NZE scenario requires the immediate start and implementation of all possible energy *efficiency* programs. In addition, the IEA guidelines demand to forcefully expand all technologies, which are already sufficiently developed and available. For example, the yearly investments and installations of market-ready technologies as PV and wind turbines must quadruple and the sales of electric cars have to grow by more than an order of magnitude. The IEA considers battery-electric cars as the most important change in mobility and ranks fuel cells and other less developed technologies as synthetic fuels as less relevant. Nevertheless in parallel, the research for future concepts as carbon capture and storage (CCS), better batteries, electrolysers and the entire range of hydrogen technologies need to speed up. The further development of immature technologies needs strong support to permit their implementation as soon as possible.

In the IEA scenarios, hydrogen becomes very important. Soon after 2030, huge quantities of hydrogen, produced in electrolysers by renewable electricity, will be needed for the chemical industry, for fuel cell vehicles and for the fabrication of synthetic fuels for aviation and ships. A world market for sustainable fuels (methanol, hydrogen, synfuels, ammonia, *e.g.*) has to be established. New chances are opening up for nations within the sunbelt for large-area PV installations. In many coastal and windy regions, a forest of wind turbines must be erected. The generated renewable electrical energy must be transported by high-voltage dc lines or converted onsite to synfuels by large plants. A world market for sustainable fuels is expected. Again, international cooperation becomes essential in order to bring these investments and technologies into the less developed areas. This supports the demand of the IEA that the developed nations have to strongly support the rest of the world in order to achieve the global climate goals.

Electrical power from environmental friendly sources will become of prime importance everywhere and for every use. In contrast to the German decision, the number and output of nuclear plants is expected to double. Hydropower is greatly favoured, but not available everywhere. Wherever coal plants remain indispensable for supply security of electrical power, they must be coupled with CCS. Will clean coal technology be market ready in time?

What about the human aspect? Will this long list of demands, regulations and drastic changes be acceptable by the general public? Will people change their lifestyle? The IEA suggests intense public involvement, increased awareness and better education on all aspects of this agenda, but remains very cautious about deep cuts in behavioural patterns. In summary, they do not expect more than 4% of the total reductions from direct changes in behaviour. For instance, air travel is not banned, but should not grow further. Rail transport, especially high-speed trains for passengers and freight, should gain importance.

Aside from technology and behaviour, there is a third sector with significant impact. Farming, forestry and land use contribute 25–30% to the greenhouse gas (GHG) emissions. For example, the IEA estimates that a moderate reduction of the meat con-

sumption in countries with the highest levels of meat consumption down to the global average level would reduce the GHG emissions by 1 Gt-equiv. per year.

5. – Conclusion

In the past, the extraction and use of fossil fuels had offered fantastic benefits for mankind. We all became dependent on lots of easily available fossil energy. Today, we are used to the best possible fuels for combustion engines, because Diesel and gasoline are perfect for a planet with oxygen available everywhere in the atmosphere. These fuels have a high-energy density and they are available as long as oil is plentiful. The expected end of the fossil reserves is far in the future, possibly many decades or in the case of coal even two centuries away.

The perspectives and promises of science are reassuring: In the future, nuclear energy plus the radiation from the sun will be sufficient to provide us with all the energy needed. Of course, it will take many devoted scientists and engineers to develop and deploy all the future new technologies and installations needed.

This scientific promise is not exaggerated. Unfortunately, there are problems arising: Do we have sufficient time for a swift and gentle change? Do we have peace and international cooperation for the development of huge wind parks and solar plants in those foreign areas with the optimum harvesting conditions? The goal itself, the complete change of our energy system to zero emissions, including renewable energies and nuclear technologies, remains unavoidable in the long run.

Presently, the ongoing Russian invasion of Ukraine has shattered the plans for the German Energy Turn-Around. One basic "bridge" technology towards renewable energies was the intermediate use of natural gas predominantely imported from Russia to replace coal and nuclear power. Presently, all trade with Russia is reconsidered and a full embargo for natural gas, oil and coal from Russia is discussed. Outcries about the doubling of oil and fuel prices are dominating the public discussions. They shifted the focus away from the emission problems towards the secure availability of energy at acceptable prices. Domestic coal and imports from different suppliers are attractive again and nuclear energy is reconsidered.

The IEA had suggested a peaceful and very tough, but under peace conditions possibly feasible pathway into a Net ZERO Emission Future by 2050. It even expected continuous economic growth —but not automatically for everyone. Instead, it predicts significant hardship for nations, companies and individuals, who work with fossil fuels and depend on them. The most difficult situation is expected for nations with large fossil resources, because they have to stop extracting and selling them. Is it possible to convince these nations to give up their valuable assets? Or will they continue to sell their resources in order to maintain their income, even at much lower prices? [9] Without intense international cooperation and without mutual technical and financial support the NET ZERO proposal finally might turn out to be unrealistic. Considering the fact, that humans unwillingly have changed the climate for millennia by deforestation and farming, even studies of climate engineering should not be excluded and ignored anymore.

* * *

I thank all my colleagues of the Italian and European Physical Societies for their encouragement and efforts to lead this international conference to success as a lively ZOOM-based meeting in times of strict Covid-19 restrictions.

REFERENCES

[1] Buchal Ch., *The challenge of discussing energy facts and climate change*, in *Energy: Where we stand and where we go*, edited by Cifarelli L. and Wagner F., *Course 5, EPS-SIF International School on Energy, Varenna 2019*; All lecture notes are available as pdf in open access in the internet, see `https://epjwoc.epj.org/articles/epjconf/abs/2020/22/contents/contents.html`.
[2] Fogel R. W., *The Escape from Hunger and Premature Death 1700-2100* (Cambridge University Press) 2004.
[3] Pfister Ch., *Wetternachhersage – 500 Jahre Klimavariationen und Naturkatastrophen* (Verlag Paul Haupt, Bern) 1999.
[4] Schönwiese Ch.-D., *Klimatologie*, 5th edition (Ulmer, Stuttgart) 2020.
[5] Buchal Ch. and Schönwiese Ch.-D., *KLIMA*, 3rd edition (MIC Verlag, Köln) 2016.
[6] Ruddiman W. F., *Plows, Plagues and Petroleum – how humans took control of climate* (Princeton University Press) 2005.
[7] Koonin S. E., *Unsettled?* (BenBella, Dallas) 2021.
[8] `www.iea.org/reports/net-zero-by-2050`.
[9] Sinn H. W., *The Green Paradox – A Supply-Side Approach to Global Warming* (MIT Press) 2012.