Energy and Sustainable Development

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The term *Sustainable Development* is used frequently, for rather different goals. Here we recall the fundamental, natural science definition based on the laws of physics. On a few examples, we show how one can apply this quantitatively, for natural, technological, economic and social processes.

In the last century, the population of the World quadrupled the use of fossil energy increased by more than an order of magnitude and the economic production of goods increased by a factor of twenty. In view of this, the question is how we can satisfy the needs of an increasing population at a given or improving living standard, while we are constrained by limited territory and limited material reserves.

This concern is not new. Already Thomas Malthus in “An Essay on the Principle of Population” (1798) saw an emerging problem in that the growth in food production could not keep pace with the growing population. Eventually, therefore, the consumption of large groups of the people would be driven down to subsistence levels, leading to starvation, misery and vice. Some 70 years later, the economist William Stanley Jevons in “The Coal Question” (1865) was concerned by the increasing scarcity of coal in England that would make progress stop and lead to an economic turndown within a foreseeable future. Likewise, the Club of Rome in “The Limits to Growth” (1972) a good century later, pointed to the limited amount of energy resources, and projected that the reserves and the expected new reserves of energy resources such as aluminum, tin, zinc, crude oil and natural gas would be exhausted by 2020.

In retrospect, all of this has, of course, turned out to be way too pessimistic. Strong counterforces are at work to relieve the burden of limited resources. Increasing scarcity of resources leads to increasing resource prices that triggers reduced resource consumption, more exploration for new reserves, substitution of alternative resources as inputs in production, and stimulation of research for new methods and technological progress. These processes are so strong that the gloomy prospects of earlier writings have been proven wrong. In the future, such processes will continue to work. Indeed, several economic model projections (e.g. using the DICE model by William Nordhaus) show that the world’s per capita consumption will continue to increase even when limited natural resources and climate change mitigation are taken account of.

Sustainable Development

The challenge confronting us is how we can ensure a continued sustainable development in the future. A frequently quoted definition of sustainable development is that given in the Brundtland report "Our Common Future" (1987). This definition states, "Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The technology and social organization should achieve the environment's ability to meet present and future needs. Some people and some organizations advocate that this can be reached only by serious limitations, on technology and living standards. The definition does not specify what the needs of future generations are. These cannot be the same as that of the earlier generations because then the development would be reversed! Some prefer to use the term Sustainability hiding that our goal is Development. We should emphasize that we aim for development and not for Sustainable Stagnation or Sustainable Degradation.

A particular concern relates to energy resources that are very dominant as an essential input in all kinds of economic activity and in life in general. The energy is also among the prime ones of the UN Sustainable Development Goals (SDG), where the sevenths is to "Ensure access to affordable, reliable, sustainable and modern energy for all". At the outset, we clearly seem to have sufficient energy available, by using directly and indirectly the energy arriving from the Sun (like solar radiation, wind, water and fossil materials), gravitational energy in tides, and nuclear energy in fission and fusion. Taking proper advantage of these sources the society would not necessarily have to change its values and goals!

We are confident that the sustainable development can be continued the same way as in the previous centuries and year-thousands with finite material resources and on finite territory.

The limited amount of resources and territory was present for a long time on the Earth. Still about 3.8 billion years ago, life appeared first in the form of single-celled prokaryotic cells, such as bacteria. Since then the matter on the surface of the Earth undergoes a continuous development in the direction of increasingly complex organization, both biologically, then in technology and even in the human society. This development continues also today, although from time to time worries come up that we have limits of our growth. History then regularly falsifies these worrisome prophecies. Interestingly not all of our resources are limited, even on a scale of many billions of years.

We discussed the subject of sustainable development already at the 2nd European Blue Sky Conference, so here this topic will just briefly repeated. This is not a new problem. Erwin Schrödinger, who invented the quantum mechanics, in his book, "What is Life" (1944) [1] already, discussed this problem of development, with finite material resources and finite space. He concluded that development is only possible in the direction of increasing Complexity (he used the term "orderliness"), that is with decreasing entropy. Furthermore, he pointed out that the development is only possible if it is based on already complex material ingredients, which are then converted to even more complex ones. These development processes are frequently connected to others, which include entropy increase. The materials, which represent this entropy increase, should be removed from the more complex systems. At his time, he could not show and calculate how these processes are realized, but by now, we have sufficient knowledge. In a recent article, it is quantitatively shown how this development takes place with special attention to the chemical and biological development [2].

Material or tissue	**Entropy, S, for 1 kg [J/K^o]**
H_2 – ideal gas hydrogen	$58.3 \cdot 10^{3}$
H_2O – water vapor, ideal gas	$8.24 \cdot 10^{3}$
H_2O – liquid water, T = 100 C^o	$4.43 \cdot 10^{3}$
H_2O – liquid water, T = 0 C^o	$3.12 \cdot 10^{3}$
H_2O – water ice, T = 0 C^o	1900.2
UF_6 – Uranium-hexa-fluoride, ideal gas	513.2
C_{60} – Fullerene, ideal gas	263.2
DNA molecule* of Candidatus Carsonella ruddii (CCr)	$1.79 \cdot 10^{-96105}$
Human DNA	$3.96 \cdot 10^{-1\,974\,000\,000}$
One state of the Human brain tissue	$\sim 10^{-301\,000\,000\,000\,000}$

*DNA molecule of the smallest bacteria, with only N = 159 662 base pairs.

Table 1. Based on ref. [2]. The development of the complexity of materials quantitatively presented by the decreasing entropy of 1 kg matter or tissue. For this quantitative assessment a single state of the configuration of the matter should be well defined and determined (e.g. the physical "phase space" should be quantized), and all existing (non-lethal) states should be counted. In case of DNA-s, there are different possible, non-lethal, sequences, (Polymorphisms) that should be added up. Furthermore, the spatial configuration of the DNA changes at different stages of cell development: the DNA can be curled up into the 23 unique shaped compact chromosomes, or can be stretched out for replication. In this second state, the entropy of the same molecule is significantly larger. For the Human nervous system, the unique determination of a single physiological state is also uncertain, and to count the possible brain microstate corresponding to a given well-determined macro-state is highly problematic, especially if we are including the vegetative nervous system. Just as for the DNA, the status of the brain permanently changes including also the change of the entropy of the system. This entropy change requires of course energy, which causes the approximately 50W energy consumption of the brain. The same methodology can be applied for technology development, and even for economic or societal structures.

We are able to show quantitatively, what the direction of the development is, and which systems are more developed, using the physical quantity of entropy. This can be applied to all systems, not only to simple materials, but also to complex molecules up to even the DNA, complex organs up to the Human nervous system and to industrial and technological constructions. One can even extend the applicability of this concept further to living organizations, social organizations, economic structures and intellectual products.

As Schrödinger showed already, the sustainable development should be based on the previous highest level of development, and the final level of development should not be constrained (such a constraint, usually leads to extra entropy production).

Although, there are attempts aiming to constrain our needs and demands in order of sustainable development [3], but these are erroneous, as they point in the direction of a previous lower level of development. This attitude is usually coupled to a mistrust in the improving technology and development, which is generally harmful and counterproductive. In the history less developed countries passed those neighboring societies, which constrained their own development for a longer period. This in most cases led to the disappearance of these societies. An example is the ancient Roman Empire.

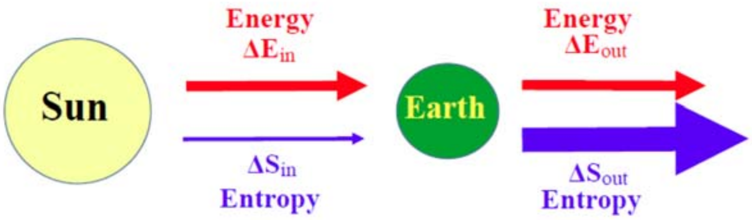
The next fundamental question arises when we observe the increasing complexity and decreasing entropy of the World. Is this a new phenomenon, or it follows the laws of physics? According to our everyday experience, closed systems deteriorate with time that is their entropy increases, i.e. the disorder increases.

Do we need new laws of nature to explain development? Schrödinger also observed and discussed this problem, and concluded that there exist mechanical systems, which do avoid entropy increase for very long times. He used the example of mechanical clocks. He concluded that new physical laws are not needed to describe development in the direction of increasing complexity or decreasing entropy.

The fundamental concept of entropy is tightly connected to the energy, E, and temperature, T, which are also widely and intensively, discussed subjects today. The physical definition of entropy change, ΔS, is given, by the amount of absorbed energy by the system, ΔE, divided by the temperature: $\Delta S = \Delta E / T$. This explains that the development on the Earth is caused and governed by external conditions.

The energy arriving from the Sun and the energy radiated out by the Earth are nearly equal, but the temperature of the incoming solar radiation is high, $T_{in} \approx 6000$ K, while the Earth's radiation back to the cosmos is at much lower, $T_{out} \approx 300$ K. Thus the change of the entropy of the Earth is, $\Delta S = \Delta E / T_{in} - \Delta E / T_{out} < 0$, i.e. negative, the entropy is decreasing. In other words, the complexity of the matter is increasing on the surface of the Earth. This arises from the external conditions of our planet, and due to the fact that the Earth has an atmosphere, with **water** on its surface in three phases: ice, water and vapor. This acts as thermostat keeping the temperature on the Earth stable, and the reflected radiation at lower temperature can take away more entropy than the one arriving from the Sun [4].

Fig. 1: The energy and entropy balance of the Earth: While the energy from received from the Sun and radiated out from the Earth are roughly equal, the entropy radiated out from the Earth is much higher. This ensures a permanent entropy decrease, i.e. increase of complexity on the Earth.



These external (boundary) conditions make it possible to decrease the entropy of the Earth; in fact, this boundary condition enforces entropy decrease and increasing complexity. Thus, new laws are not necessary. Schrödinger does not discuss this astrophysical observation in his book, but physicists knew it already earlier, when the "Heat Death of the Earth" was discussed and discarded at the early development of thermodynamics. Other planets without such an atmosphere reflect back the solar radiation without temperature change, so life cannot develop on those, furthermore changing day and night temperatures do not provide constant condition for such development.

On the Earth, the highest level of complexity is represented by life, and quantitatively by the human nervous system [2]. In the technology, the highest complexity is exhibited by the present computing technology and nano-technology. Nevertheless, the largest massive development on the Earth is connected to energy production, or more precisely conversion of energy to a form, which is usable for our purposes. We use the word *conversion* (instead of transformation) to indicate that losses are included in the process.

Energy

The next part of this presentation is based on publications and talks [4-8], with E.S. Amundsen, N. Kroo, D. Strottman, S. Vaagen, I. Papp, S. Spinnangr, S. Velle, Y.-L. Xie and on discussions with my colleagues at iASK.

Most of the energy we use is originating from the Sun, the so called "**renewable energies" (RES)**, like solar panels, wind turbines, water power, as well as the fossil fuels arising from historical solar radiation and biofuels from more recent solar radiation. In addition, tidal power plants exploit gravitational energy, but their role is modest. Finally but the prospectively most important source is nuclear energy. This can be in the form of fission power plants, fusion power plants and in natural form in geothermal energy. Most of these energy conversion processes are entropy-increasing processes, with very few exemptions, like the ***photosynthesis*** and the ***nuclear fusion***. In these last two processes, increase of complexity is present in the prime reaction, but there are several connected processes and for the correct evaluation, the basic energy producing process as well as all connected processes should be analyzed for the whole life cycle of the involved materials.

In case of *energy conversion* processes, the ***efficiency*** of the process is the decisive aspect and not necessarily the increase of complexity. Still if we do a quantitative analysis, we have to avoid the destruction of highly complex materials for energy production.

Consequently, the so-called biofuels cannot be considered as a sustainable way of energy production! This is a process, which is very strongly violating the rules observed by Schrödinger: that complex material should be the basis of further development toward even more complex products. Burning such materials is not serving sustainable development. One should not use biological materials as fuel, but these should rather be used as food, or feed or fertilizer.

One has to mention that the word "sustainability" is frequently used (without development). This may be used to cover the tendency of aiming for stagnation or even for reversing development. This certainly cannot be our goal, and historical examples show that such tendencies lead to losing competitiveness, which then hurts the part of society characterized by this tendency.

Another, energy related fundamental issue, is the difference between ***heat*** (thermal energy) and ***mechanical energy***. Mechanical energy can be converted to heat with ***100% efficiency***, while heat cannot be converted without losses to mechanical energy. Thus, mechanical energy is more valuable for us. The word "mechanical" of course covers several forms of energy, like electric energy, water energy, kinetic energy of motion, etc. Due to historical reasons the dominant energy production or energy transfer process uses fossil fuels, and can have an ***efficiency*** as little as 30%. When we convert heat energy to mechanical energy, we take heat from a higher temperature *heat reservoir*, a *heat engine* converts part of it to mechanical energy and the rest is released to a lower temperature *hear reservoir*. The temperature difference determines the level of efficiency, higher temperature difference leads to higher efficiency. That is why diesel engines with higher burning temperature in the cylinders have better efficiency than gasoline engines. The ***process of burning***, (usually oxidation for the material of the fuel) is an entropy producing process, the exhaust is usually of low complexity, so it is counteractive for sustainable development. Especially so, for highly complex biological materials! An exception is nuclear fusion, where the larger fused nuclei are more complex and having lesser entropy than the initial fusion fuel (light atomic nuclei).

We have both heat energy and mechanical energy as our energy resources. Burning different fuels leads to heat energy. The energy mix of different resources is very different from country to country, and it is an important and political question today.

Next, we will review different usual energy conversion processes from the point of view of entropy production, which is the same as the efficiency of the conversion. If the conversion efficiency is less than 100%, the loss is directly or indirectly leads to heat released to the atmosphere or to the water of lakes, rivers or seas. Sometimes, part of this waste heat is used for heating in colder climates, which is practical, but leads to entropy and heat production anyway.

Heat engines

The heat produced by fuels can be converted to mechanical energy in "*heat engines*". The efficiency of this process is determined by the so-called Carnot efficiency, which is rather low, about 30-40% for most heat engines. The coal, oil, gas, and other power stations, diesel, gasoline, LNG, and hydrogen burning engines, in cars, trains, ships, etc. belong to this category. This efficiency even applies to the heat engines (usually steam turbines) in nuclear fission or fusion power stations (although the fusion process is entropy decreasing itself, contrary to oxidation).

From physical point of view, burning bio-fuels is belonging to this category, and it is even worse than other fuels, as bio-fuels are more complex and their burning leads to an additional very high entropy increase because of their initial low entropy. That bio-fuels can be reproduced by agriculture at shorter or longer periods is irrelevant as the whole life cycle of this energy production is negative [9]!

Solar radiation, when used directly as thermal heating belongs to this category also, as it is also converted to mechanical energy by heat engines.

Renewable Energies - Natural forms of mechanical energy

Unfortunately, the term “Renewable Energy” is highly misleading as **energy is conserved**. It is available continuously on our timescales usually due to solar radiation as source. (The exception is geothermal and tidal energy.)

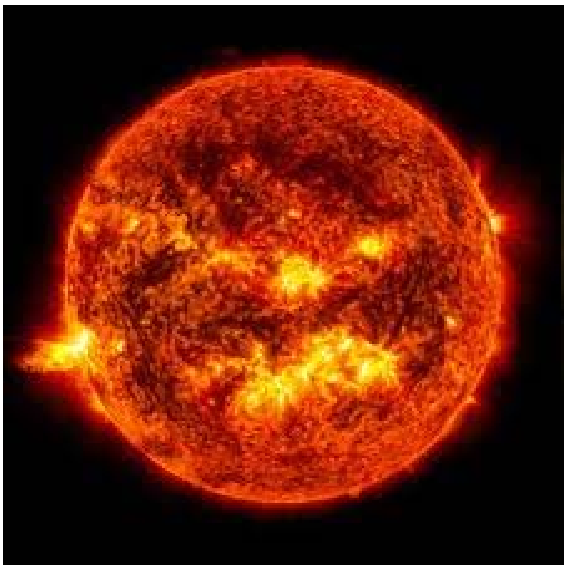


Fig. 2. Most of the energy arriving from the Sun becomes Heat: radiation is absorbed by air, waters, solid surface, i.e. atmosphere, seas, rivers, lakes, earth, plants, etc.

Solar energy on Earth leads to many natural forms of mechanical energy, river flow, waves, wind, water from precipitation to high altitude reservoirs, monochromatic electromagnetic radiation from solar radiation, etc. These can be converted to usable forms of mechanical energy with near to 100% efficiency, if we have the adequate technology. Unfortunately, not all presently used technologies are optimal.

We have seen earlier that the entropy has a specific role in sustainable development, which requires entropy decrease, and the excess entropy is radiated out from the Earth to the universe. Energy conversion processes are all producing some waste heat, which thus should be radiated away to maintain sustainable development. As a consequence we should minimize waste heat production, which is the same as entropy production. In energy conversion processes most of the entropy production appears in form of heat, which can be radiated away. Still some part of extra entropy is in the material of exhaust, dust, smoke, waste materials of low complexity and high entropy. These cannot be radiated away; these remain on the Earth and counteract sustainable development.

The energy conversion processes are very different from the point of view of produced entropy, and this from the point of view of sustainable development. In the following, we will discuss how much waste heat or extra entropy is produced in energy conversion processes.

In order to compare quantitatively different energy conversion processes, we take a typical amount of the initial energy of **E = 1 TWh = 3600 TJ. (**The average household electricity use in the US is about 11,700 kWh each year, so 1 TWh is about the consumption of a settlement of 100 000 family houses in the US, and this is the one month production of a modern nuclear power station.) If this energy is directly converted into heat at T = 300 K ambient temperature, the resulting entropy production is **S_{Th} ≈ 12000 GJ/K** (Giga Joule / Kelvin)[1].

As discussed above the direct heating by traditional fuels produces this amount of entropy. There are some differences: biofuels produce even more extra entropy from their very low

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[1] We use the unit qualifiers **k**ilo, **M**ega, **G**iga, **T**era and **P**eta. Each is 1000 times larger than the previous one.

initial entropy, while fusion fuel produces less as the produced fused nuclei have less entropy than their fuel.

When **1 TWh** initial heat energy is converted to mechanical energy **with heat engines**, we have the Carnot efficiency, which is in the range of 20-40%. Consequently, their waste heat production is **ΔS = 7000-9000 GJ/K**. and the resulting mechanical energy is **0.2-0.4 TWh**. There are only moderate differences among the different realizations of this type of energy conversion, so here; we do not discuss this further.

Conversion of Natural Mechanical Energy

Let us start with the best example, the use of kinetic energy of water in rivers, lakes, reservoirs, etc. The water turbines were developed for centuries by now and these can reach a very high efficiency of **η = 90-97%.** The waste heat is minimal, just as the produced entropy, which is few percent of S_{Th} **.**

Water energy

From rain, water is led to reservoirs on rivers or mountains and one can have substantial adjustable energy and energy storage. With enclosed turbines in different water power stations (WPSt) we have continuous production of:

- Tree Gorges Dam 22.5 GW (103 TWh/yr) 2014 China (largest existing WPSt), - Itaipú Dam 17 GW (90 TWh/yr) 2016 Brazil & Paraguay, - Grand Inga Dam 39 GW, DR Congo (planned).

Fig 3. The Three Gorges Water Power Station on the Yangtze River in China, the presently largest on the Earth. The dam is 4 km long; the height difference is 126m.

From ocean tidal currents (Wave of 54cm height around the Earth), regularly changing energy production in enclosed turbines: - Rance Tidal Power Station 0.24 GW (0.5 TWh/yr) 1966 France, - Sihwa Lake Tidal P.St. 0.254 GW (0.55 TWh/yr 1way) 2011 S.Korea, - Penzhin Tidal Power Plant 87 GW Russia (planned).#

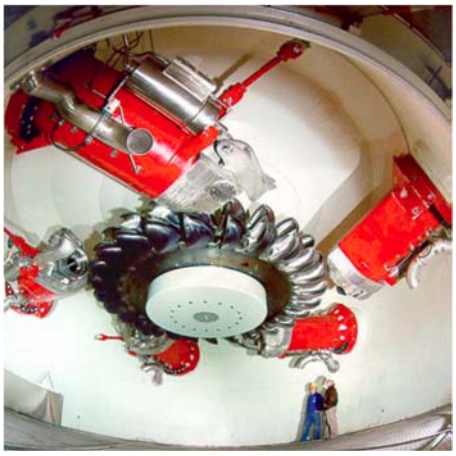

*Fig. 4: This compact **423 MW** Pelton turbine is installed in the Bieudron power station in Switzerland, the diameter of the wheel is **4.63 m**, and its effectivity is η = 90-95%. Consequently, the entropy production is minimal.*

From pumped reservoirs on mountains, one can have substantial adjustable energy storage with enclosed turbines. E.g.: - Afourer Pumped Storage P.St. 0.465

GW, Francis t., 2004 Morocco drop: 800/480 m; - Aura Kraftverk, P.St. P=0.29 GW, drop: 783 m, Pelton t., 1953 Norway.

The water turbines are rather compact with very high power production and efficiency. For different heights, different turbine configurations are used, like the Francis, Kaplan and Pelton turbines.#

*Fig. 5: This P=**767 MW** Francis turbine at the Three Gorges dam, in China, of diameter: **10 m**, efficiency: η~94%. Loss is ~ 6% and small waste heat and small entropy production.*

The largest hydropower turbines (Enclosed turbines.) are - A P= 767 MW Francis turbine at the Three Gorges dam, China, diameter: 10m, efficiency: η~94%. Loss ~ 6%, consequently the waste heat is $\Delta S = (1-\eta)\, P\, \Delta t\, /\, T$, small, (with T~300 K, ambient temperature). - A compact P= 423 MW Pelton turbine in the Bieudron P.St. Switzerland, diameter: 4.63 m, efficiency: η =90-95%, loss ~ 5-10%, thus the waste heat is small. Large Power and Small size characterize these turbines!

Another way to convert water flow energy is via open under-sea propellers and tidal sails (TS). Less data are available and efficiency is yet uncertain. Furthermore, for TS, in low viscosity water the flow remains largely laminar, and maintains its kinetic energy. This moderates entropy production. Thus, for 1 TWh the entropy production is ***ΔS* = 100-1000 GJ/K.**

A large advantage of water energy that it can be regulated in a wide range and in reservoirs one can store large amounts of energy for very long times even for seasonal storage with negligible loss. This is needed to balance **intermittent energies (iRES)** (wind and solar) as well as constant energy production (e.g. nuclear) to varying load (varying consumption). In case of rivers, this feature can be used also to manage floods and low water in droughts. These additional features of Water P.St.s, can be more important and more valuable than the produced electric energy! Thus in countries where still unexploited waters (rivers and lakes) exist, the installation of water power stations are highly beneficial (e.g. Norway or Hungary).

Wind Power

While water power stations have very high efficiency, negligible entropy production and their output can be adjusted to the demand perfectly, present wind turbines and wind farms are much less optimal. Wind is intermittent (iRES), and can be utilized for wind-speeds in the range of ***v* = 5 to 25 m/s** only!

A typical offshore floating windfarm the HyWind pilot park of Statoil, 25 km out of Peterhead in Aberdeenshire, Scotland has 5 floating wind-turbines with 6 MW installed power each. The height of each turbine is 253 m above sea level, their draft is 78 m and the rotor diameter is **d = 154 m.** (Compare this to the diameter of water turbines!) The tower of each turbine is made of **2200 tons** of steel, and its ballast is 8100 tons of concrete. This material cost for 6 MW installed power is extreme!

Fig. 6 An offshore wind-turbine of the HyWind floating pilotpark of Statoil, in front of Scotland.

The nominal, 6 MW, installed production power is reached around 14 m/s wind-speed and it remains then constant. At this wind-speed the kinetic energy of the wind crossing the rotor is 32.6 MW. At 25 m/s the turbine must be stopped to avoid its destruction. Up to this wind-speed, the rotor blade pitch is adjusted so that the rotation speed remains constant as well as the produced power remains at the maximum. At 14 m/s wind-speed the efficiency, compared to the kinetic energy of the wind crossing the turbine, is about 18%, but when the wind speed increases to the maximal 25 m/s, and its energy increases tremendously (with the 3-rd power of the wind-speed, $\boldsymbol{v^3}$) to 185.6 MW! So, its **efficiency drops to 3% !** This is much less than the Carnot efficiency for any fossil fuel or any kind of fuel. The rest energy in this case leads to turbulence, large entropy production and to the heating of the atmosphere.

The question arises what part of this 97% loss leads to this heating and entropy production. Does not it remain in the kinetic energy of the wind? Pictures in humid air show a condensation cloud formation of tremendous size. This condensation releases the large latent heat of the water vapor condensation (opposite of cooking the same amount of water). Furthermore, the production of turbines in the second and third row of turbines is strongly reduced. This indicated that most of the loss is heating the atmosphere. This leads to **ΔS = 9790 GJ/K** entropy production at v = 14 m/s wind speed and to **ΔS = 11600 GJ/K** at v = 25 m/s for 1 TWh incoming wind energy. In this last case, almost all of the energy of the wind crossing the rotor will heat the atmosphere! The large entropy production, according to Schrödinger's definition, makes this energy production method **the least sustainable** at extreme cost**!**

Some other uses of wind power can be much more optimal, e.g. large, 45', America's Cup sailing boats with hydrofoil; can reach 100 km/s speeds. These **sails** can be well adjusted to the wind-speed and lead to minimal thermal loss. Furthermore, the kinetic energy of the wind is directly converted to the kinetic energy of the boat, without additional losses of other conversion steps.

Fig. 7 Cloud formation in a wind farm in high humidity air. The turbulence behind the turbines leads to nucleation of water droplets. The condensation releases the large latent heat of the vapor to fluid phase transition to the atmosphere. The size of the formed cloud indicates the level of atmospheric heating by the wind turbines.

The intermittency is an **additional reduction** of the produced power compared to the installed power because the when the wind-speed is not in the production range the turbine does not supply any electric power. Thus, the **produced** power for a longer period is only **20-30% of the installed power**! This is typical for iRES. In addition to intermittency, the usable production of iRES is even less due to the mismatch with the consumption. According the recent studies in Germany [10] the used iRES power is only around **15% if the installed power**.

Due to the above reductions **for 1.2 GW** average production (avg. of a modern Nuclear Power Station) one needs about 1000 wind turbines. To avoid additional reduction of produced power these cannot be close to each other so the **needed areal is ~ 1000 km^2!** This indicates that the possibility of installation of wind energy is limited**.**

Photovoltaic (PV) Solar Energy

Solar panels are also intermittent (iRES), but the most recent ones can reach 25% efficiency, which makes them competitive, especially if they are **installed on roofs, parking places, etc.**, except agricultural land. PV panels convert solar radiation to electricity.

Solar energy is Electro-Magnetic (EM) radiation with different frequencies of thermal energy distribution corresponding to T = 6000 K temperature. The presently usual efficiency is around η ~ 25%, i.e. the thermal losses are substantial and the entropy production is considerable. From this point of view, it is close to the efficiency of standard heat engines and are thus competitive.

On the other hand monochromatic EM radiation is a form of mechanical energy, it can be transferred in wave conductors or coaxial cables with small loses and can be converted to electric energy also with little loss. Specific, high gain antennas have high efficiency, with the most modern nano-technology, the solar radiation can be split up to frequency bands, amplified with moderate losses and an efficiency up to ~ 40% can be reached. These types of PV panels on the other hand are still very expensive today. In this best case, for

1 TWh incoming solar energy the extra entropy production is about ***ΔS* = 7200 GJ/K,** which is quite competitive.

Other Forms of Energy Conversion

Ocean, tidal energy: the same principles as water energy hold. There exist open and enclosed versions of turbines or sails. Enclosed turbines have better efficiency, while in open waters underwater sails in slower currents have an advantage. It is important to mention that water has 800 times higher density than air, thus the energy converting devices can be more compact.

Geothermal energy: Originates from radioactive nuclear decay. Practical where naturally present, for example in hot springs in Island or Hungary. Use these, as thermal health bath is usually better and more profitable.

Heat pump: To heat with electric energy. This reduces electric energy consumption about 3-4 times, for the same heat production. This is done with an inverse heat engine that heat from a lower temperature heat reservoir (outside air or water) is converted to heat in the heated room. The installation is more expensive that direct heating but profitable even without any subsidies. The waste heat and entropy production of the inverse heat engine is minimal! The overall entropy change is negative, as this is not a closed system and external (electric) energy is used.

Electric cars: Advantageous only if electricity is taken from water, nuclear and renewable energy sources with high efficiency. In cold climate, heating with electricity is a waste (direct heating with electricity)! Local advantage in large, dense, polluted cities! Otherwise, if electricity is from fuel burning, then the several energy conversions impair the efficiency and the additional transport of batteries requires additional energy. If the required energy is coming from fossil fuel burning power stations the overall pollution and energy consumption will actually increase due to the several energy conversions and the larger weight of the vehicle.

Energy storage: The overwhelming majority of energy storage installations is **pumped hydroelectric storage (PHS)**. In fact, even without pumping hydroelectric power stations serve also as energy storage facilities because these can provide energy according to the demand. Installed PHS power in the World is 165 GW. Li-Ion battery storage power is 1.1 GW, and 1.3 GWh. There are also Compressed Air (CAES) facilities and Flywheels, with 0.4 and 0.1 GW installed power Worldwide for specific uses.

Fuel Energy Storage: Nuclear fission and fusion fuel has extreme energy concentration. Oil, coal, wood, gasoline, bensin, diesel, LNG, L-Propane, L-Butane have large energy concentration. Hydrogen at extreme high pressure has also large energy concentration (but highly explosive). All these fuels have Carnot efficiency if we convert their energy to mechanical energy.

In the field of energy, the sustainable development and its optimal solution is not a solved problem, and there is no generally optimal solution as the conditions of countries and even regions are different.

Energy Policies

The EU recently tries to form an “**Energy Union**” but at this moment this procedure is politically dominated, and it somehow dominated by the interest of the largest countries in the EU. A more fundamental and science based analysis of sustainable configuration and sustainable development would be highly beneficial for the whole EU, as well as to the strongly connected surrounding countries like Norway.

An example for this problematics is Germany, where the installed wind turbine capacity is 41 GW (2015) and the installed Photovoltaic solar panel capacity is 39 GW (2015).[2] The total demand (or load) is around 97 GW. This was installed with large subsidies, which led to a doubling of the electricity price for costumers. This intermittent energy supply (iRES) is a very large fraction (~80%) of the demand, and if it unexpectedly drops out one should have sufficient backup energy. Even if foreign countries are used for balancing, Germany needs about 30 GW backup power. In this moment, this is provided the cheapest way by lignite fueled power stations, where the fire is kept on even without production to be there when this backup is suddenly needed. At the same time, emission free nuclear power stations are turned off, increasing the need for balance power. This is clearly not a stable and sustainable organization, neither economically, nor environmentally friendly. Thus, the recent installations, dominated by preferences of political parties, led to a highly non-optimal configuration. It would be a significant and demanding work to estimate the level of sustainability quantitatively. It is in principle possible, based on the fundamental principles of Schrodinger, introduced in the beginning. The economic relations and arrangements complicate the problem further and with the politically dominated subsidies, thus these are hardly optimal either.

A better example is the system in the Nordic countries. Norway with 96% waterpower, which can be regulated in a wide range and Sweden with 10 nuclear reactors providing base-load, is a much better functioning system, with a lower electricity price and a better functioning **NordPool Spot** economic market organization. This leads to varying prices in time and region-by-region. Of course, the geographical conditions are responsible largely to this advantageous situation.

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[2] 1 GW is the power of one present nuclear power station or the average production capacity of ~1000 wind turbines, considering that there is no optimal wind all the time.

Nuclear Energy

Nuclear energy (NE) is the most advanced and most modern form of energy conversion. This is clearly the energy source of the future increasing massive energy needs, when other (mainly fossil) energy resources are exhausted. Natural forms of it are known as the source of geothermal energy and the natural fusion of large uranium concentration in craters, where due to rainwater chain reaction may occur. This is observed e.g. in South Africa.

Fig. 8 The ITER magnetic confinement fusion project under construction in Caradasch, France

Nuclear energy can be gained from **fission** of heavy radioactive nuclei (Nuclear fusion reactors) and **fusion** of light nuclei. This latter is the way, in which the energy of the Sun's radiation is gained. This does not produce heavy radioactive nuclei, which would lead to radioactive waste. On the Earth, the peaceful human use of fusion energy is under technological development. It is done in two forms: Magnetic Confinement Fusion (MCF in several Tokamaks like ITER and in a Stellarator) or Inertial Confinement Fusion (ICF). Research with MCF technology development is pursued in several laboratories. ICF technological research is pursued in three US facilities. The most advanced is the National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory (LLNL). Here 192 highest energy lasers from all sides irradiate a ~ 2 mm size spherical Deuterium-Tritium (DT) pellet. So far, one succeeded to ignite a smaller part of the DT pellet, but with very low energy efficiency. Recent advances in ultra-relativistic heavy ion research and in nanotechnology combined in a special way, may lead to a much more affordable configuration for ignition with only two laser beams. We plan to verify and realize this new methodology. This can be done with existing lasers in Hungary also [7]. We are planning these type of test in the near future, also with the support of iASK.

World Energy Future

The World energy use is increasing. In 2018, the total use was 14.5 Gtoe (Giga ton oil equivalent) including Oil, Coal, Nat. Gas, Nuclear, Hydro, etc. This is **168 PWh**. (1 Mtoe = 11.6 TWh), and doubling every 50 year. With increasing population and increasing living standard, the energy use will continue to grow. The electricity use is also increasing. In 2018, the World electricity generation was **26 PWh.** This is 15% of the total energy use, but it is doubling in every 36 years, so the fraction of electricity generation will increase further. Data are from the IEA (International Energy Agency).

How this human activity does compare to the natural astrophysical energy balance and entropy conditions of the Earth? From the data above, the human energy production power is **19.2 TW** (168 PWh/yr.) in total. From this **2.97 TW** (26 PWh/yr.) electric (15%). Most of this energy is released by heat engines, so the efficiency and the waste heat is ~ 30 – 40 %. This leads to entropy production and heating. That is 6.7 TW.

The average power of **solar radiation is 31 TW** (274 PWh/yr.). This is given by an average irradiation of 175 W/m2 and 1000 maximum. Thus, the irrespective of the atmospheric reflection or greenhouse effect by GHGs, the direct human heating is already 20% of the solar radiation. Note that most of this 20% is just converting the present and past solar energy to other energy forms for human use. Therefore, only the part of this human use leads to additional heating, which originates from Natural Kinetic Energy forms from solar radiation, and from non-solar energies like gravitational, tidal, and nuclear. The rest leads to heating anyway even if it is not used for human purposes. This is only a smaller part of the total human use. So, at this time it can be estimated to be of the order of 1 TW. Still with rapid increase of human energy use, this part may become significant. The message and conclusion of these studies that we have to attempt to increase the efficiency of the energy conversion processes as much as possible. At the same time, we have to abandon the ones with low efficiency and excessively large entropy production.

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