Mitigating Climate Changes: A Global Approach

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Mitigating Climate Change Effects: A Global Approach

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The following theses are claimed, several contrasting current climate policies and taxonomies. Analysis, based on solely carbon dioxide emission and energy budget, concludes a set of concrete solutions for mitigating climate change effects. Some of the theses violate more orthodox policy which is thus protested against in order to move forward.

- **Our long-term goal must be to stop using all carbon-containing fuels,** including natural gas and other fossil products as well as biofuels.
- **We must electrify society and industry,** with electricity from only non-carbon-based power including nuclear power, hydroelectric, wind and solar power.
- **We must prepare ourselves for changes.** Even if the present emission volumes of carbon dioxide were possible to stop immediately, various lag effects are inevitable and negative development will therefore continue for considerable time.
- **We must count with continued melting of land ice,** the complete liquifying of the Antarctica ice expected to lead to a global sea level rise by some 60 m, flooding most capitals. Among various solutions to mitigate the effects of ice melting, including lowered global temperatures, the following is proposed.
- **To mitigate sea level rise, stationary water reservoirs should be built around the world.** With estimated melting rates it would require ca 1 million reservoirs be deployed or expanded during the next 20–40 years.
- **Such reservoirs could also solve the emergent problem of lack of fresh water** in many places. They could also be used for local **storage of hydroelectric energy by using pump storage hydroelectric (PSH) technology.**
- **All energy production sources should be analyzed according to a Total Balanced Energy Budget (TBEB)** with the main objective of minimizing the emissions of greenhouse gases.
- **For each region/country, a table of available or conceivable complementary electric energy sources** should be made and ranked according to TBEB—the sources given priority weights depending on feasibility, significance, and environmental friendliness. Tables are presented for Sweden, Norway, Denmark, Germany, France, Ukraine, California, Massachusetts, Maine, Peru, Australia, China and Japan. Generally, we find the following rank of priority applicable.
- **Solar energy from desert arid areas is given highest priority** in replacing carbon-based forms of energy. Submarine electric cables may be deployed along the Australia-Singapore model, if the available power grids are insufficient for the energy transport.
- **Electrolysis of water producing clean hydrogen gas is given very high priority** both for using hydrogen as fuel as well as for energy storage. Improved efficiency should be achieved by the development of electrolysis catalysts.
- **Hydroelectric power in combination with PSH is given high priority** to mitigate both grid power fluctuations as well as source (solar and wind) intermittence.
- **False hope should not be seeded** among society and politicians by inflating projects that are less realistic or suboptimal for technological, economic or other reasons. Here, probably most forms of “biofuels” (which although being “carbon neutral” do produce carbon dioxide) and “carbon capture” (catching carbon dioxide gas at the combustion site, compressing it to liquid

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and depositing it in salt mines or empty oil fields) are considered less significant compared to other more direct solutions. Both biofuels and carbon capture may be associated with social and environmental issues.

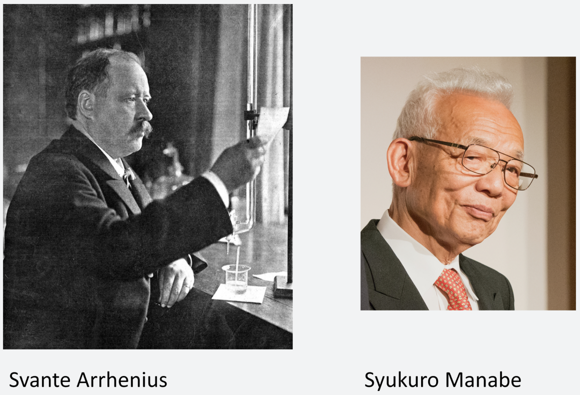
- **Political legislation and instruments ("taxonomy") invented with the original objective of mitigating negative climate change effects should be reanalyzed and changed if not functional.** The EU Emissions Trading System (EU ETS)—a market for outlet rights, for example, is a local initiative which despite its valuable ambition might be suboptimal with respect to goal of efficient decrease of carbon dioxide emission globally. Similarly, "climate taxonomy" can create loopholes bypassing a sound TBEB.
- **Science-based targets (SBT) to decarbonize the private sector** as part of global efforts to achieve the temperature goal of the Paris Agreement should be further encouraged.
- **Solve economic and political challenges** allowing and promoting establishment of required international energy collaborations (e.g., for solar energy cross-continental transport programs).

***Keywords*:** Mitigating Climate Change; Solar Energy; Sea Level Rise; Demand of Fresh Water; Wrong Thinking About Biofuel and Carbon Capture; Electrifying All Energy; Total Balanced Energy Budget; Submarine Electric Cable; Pump Storage Hydroelectric Energy.

INTRODUCTION

While the diagnosis of emergent climate change problems and their mechanistic origins are today generally accepted, and the principles understood—in fact since very long, mainly thanks to two Nobel Laureates (Figure 1), a strategic and globally coherent pathway how to mitigate the development and restore a stable climate is not fully agreed upon. As a matter of fact, there is no consensus about the priority of possible actions for getting a complete and satisfactory solution!

While organizations like IPCC and UNFCCC deal in detail with the origin and consequences of the problem they do not offer solutions[4,5]. As long as no reasonable and unified action plan is agreed upon, there is, understandably, often a political reluctancy to make serious efforts. Several (some of them quite populistic) decisions that point in the right direction have been made, but in reality, they appear insignificant in a global environmental perspective, and are often only incremental contributions and cannot radically solve the problems. Such actions may detract attention from the central tasks.


Svante Arrhenius

Syukuro Manabe

Figure 1. Svante Arrhenius, physical chemist, the first Swedish Nobel Laureate (Chemistry 1903). Discoverer of what he called "The Greenhouse Effect" (1895). He predicted that a doubled CO_2 concentration in the atmosphere should increase the temperature 6°C (later modified to 4°)[1]. In 2020, Sherwood calculated expected increase to 2.6–3.9°[2]. Arrhenius' theory was verified and improved (heat transfer by convection included) in the 1960s by Japanese meteorologist Syukuro Manabe, who received the 2021 Nobel Prize (Physics) for "Physical models of Earth's climate" (shared with Klaus Hasselmann and Giorgio Parisi, other achievers)[3].

Thus, a cacophony of voices incessantly requests that we urgently attend to the climate emergency in different ways, but usually many suggested actions or legislative regulations are associated with new problems, such as "politically problematic" hurdles rather than solving any significant problem. Usually, long lists of environment-friendly activities are presented without assessing their respective importance. It is true that we should never ignore any contribution as too small, but we must also be aware of the importance and relative proportions to be able to judge what actions should have the highest priority. And which are the most realistic? An example of an activity to which we all devote ourselves is "waste sorting": to separate waste into different "elements" make us feel (almost religiously?) good and might to some degree compensate the bad conscience we have when driving a carbon dioxide exhausting gas-guzzling car or using polluting aviation flying off on vacation. Not everybody is aware about how waste sorting might sometimes be waste of effort if not being identical to a "waste segregation" ensuring pure, high-quality materials by the end. This example, of course, does not question the value of waste sorting but only serves the purpose of illustrating how important it is to always ask "why?" and try to understand how important one action may be in a general context compared to others.

We all agree that we need to minimize the use of fossil fuels, but there seems no consensus about priority order in which different actions should be deployed. To "electrify," i.e., to change energy from fossil fuels to electricity, seems generally agreed to be a wise strategy as very clearly explained recently[6]. However, both how (what distribution among energy sources?) as well as according to what temporal plan this decarbonization transition could occur is yet an open question. Many different electric power sources will be necessary to use in parallel, but orthodox environmentalists do not consider nuclear power necessary, but accept only "renewable energy" listing (often rather vaguely) sun, wind, and water without detailing their respective absolute or relative contributions to a total energy budget. To be realistic, a plan on how to amend the environment/climate problems must detail the various electric energy sources and how their contributions can be scaled-up so they add up to the 100% required in a revised total energy budget.

We here present, based on a critical analysis, a path to embark upon to most efficiently restore the atmospheric carbon concentrations to desirable levels by decreasing the carbon dioxide. We shall look for solutions, not barriers! Then, a number of concepts need to be reconsidered and some rules even be ignored or circumvented. One example of a problematic barrier is the assumption that the only politically correct activities are such that fulfill certain criteria: *energy sources should be "renewable" and "sustainable,"* which means they are replenished on a human timescale—in contrast to fossils that require very long times. Typically, the only energies considered as renewable are sunlight, wind, and geothermal heat, and also combustion sources that are "*carbon dioxide neutral*." Then, *biomass fuels* may be renewable and also use of fossil fuels if the carbon dioxide they produce is *captured* and permanently kept away from the atmosphere. We claim that this way of looking can be severely misleading and seriously counteract our main objective of solving the climate problem globally.

One reason why this way of defining *renewable energies* is problematic is that it creates a false feeling of improvement while little significant net decrease of carbon dioxide might be achieved. Consider growing forests, which nicely absorb carbon dioxide during photosynthesis, but if then the trees are cut and the timber burnt a stoichiometrically identical amount of carbon dioxide is released again. We claim that growing forests and other plants in order to absorb carbon dioxide from the atmosphere should be a prime target, not burning the timber or any biofuels that crops may be converted into.

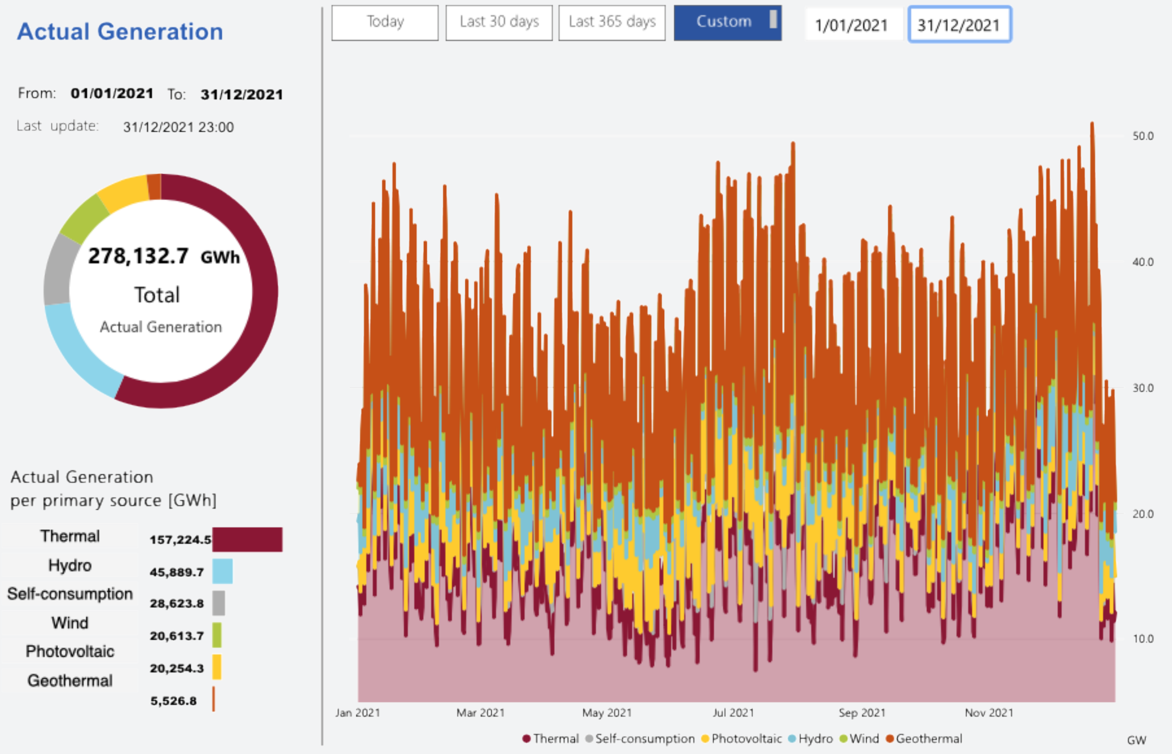
To produce carbon neutral biodiesel (Europe) or ethanol (United States) from crops or forest timber may at the surface appear smart as it does not increase the atmospheric carbon. But a much better idea, which would *decrease* the carbon dioxide, is to use the timber for building houses (instead of using cement that produces a lot of carbon dioxide). The biodiesel is clearly more expensive to produce than fossil diesel and, because it is hygroscopic and hydrophilic, could be problematic. For example, hydroxyl and ether groups abundant in biofuels make them prone to attract moist and provide a grow ground for microbial growth which clogs filters of combustion engines – potentially risky when used in aviation. We thus strongly advise against use of biofuels for trans-Atlantic flights.

Further potential environmental risks have to be considered, especially toxicity of products and effluents from the biodiesel industry has not yet been sufficiently investigated. We shall below suggest that we continue using a certain (relatively minor) amount of fossil carbon products for transatlantic aviation and for petrochemical industries, including the production of pharmaceuticals. In parallel we can see a certain role for making biofuels from cattle manure as well as from waists in forestry. Clearly, degrading debris with organisms producing methane - a worse greenhouse gas than carbon dioxide - should be taken care of and made use for as a legitimate biofuel. These amounts, however, are estimated relatively modest in the total picture.

Against this backgound, we shall henceforth avoid the use of the concepts *renewable* and *sustainable* in energy contexts. Instead, we will take an overall grasp and present a Total Carbon-balanced Energy Budget (TCEB). As we shall see this will give us the opportunity to reconsider in parallel various options and activities, so that our major goal of reducing CO_2 emissions to the atmosphere can be reached without closing any viable doors.

The balance of carbon dioxide production means that all fuels that produce carbon dioxide will be treated equally. Thus, the use of biofuels, which produce as much (or more) carbon dioxide as fossil fuels, will be discouraged if they are not motivated economically or by being more pure than corresponding fossil fuels. This blatantly contrasts a decision taken by nations in Europe (EU, the European Union) about using biofuels "*as a renewable alternative in airliners can help reduce the EU's carbon footprint*." The use here of "renewable" as a kind of permission letter makes us vigorously protest against this recommendation (and EU law).

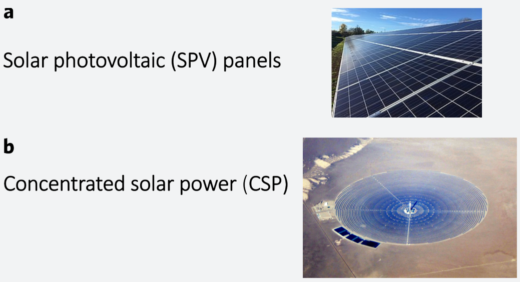
Of course, natural gas (despite "natural" sounding nice, but still generally being of fossil origin) must be avoided. As a result of this way of reasoning, the use of fossil oil may be allowed in certain contexts and even encouraged and reserved for certain specific purposes: transatlantic aviation and for important petrochemical industry (producing pharmaceuticals, plastic materials, etc). In our TCEB budget, this kind of remaining, specially permitted, use of fossil fuel will be fortunately relatively small (ca 2%) but can be motivated for safety or economic reasons. This (minor) carbon dioxide emission may be well compensated by what we may call Natural Carbon Capturing (NCC) by photosynthetic green plants (forests on land, here rain forests are particularly important, and algae in oceans and lakes). Thus, planting new trees is important, but note that they should never be converted into "biomass fuel" but the timber, when harvested after typically 15–30 years, should be used as valuable building materials (potentially replacing carbon dioxide–producing cement). Yet, since methane is also a greenhouse gas (even worse than carbon dioxide), biomass fuels based on tak-



Actual Generation
per primary source [GWh]

Thermal	157,224.5
Hydro	45,889.7
Self-consumption	28,623.8
Wind	20,613.7
Photovoltaic	20,254.3
Geothermal	5,526.8

Figure 2. Current distribution of electric energy consumption in Italy.


a

Solar photovoltaic (SPV) panels

b

Concentrated solar power (CSP)

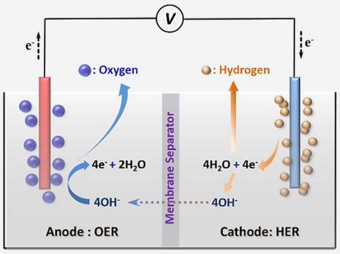
*Figure 3. **a. Solar photovoltaic (SPV) panels.** The electricity may be transformed into hydrogen gas (Figure 4) that can be stored and converted back to electric power at night in fuel cells. A problem with SPV is that efficiency drops at high temperature. Another that they may contain rare elements (e.g., silver). **b. Concentrated solar power (CSP)** plants. Thousands of metallic glass panes focus the reflected light of sun at the top of a tall central tower. The tower has a reservoir of potassium and sodium nitrate—typically 25,000 metric tonnes—heated in advance to 288 °C, the mixture then a clear, water-like liquid. This is circulated in narrow, thin-walled tubes, rising in temperature to typically 560 °C when exposed to the concentrated sunlight at the top of the tower. The molten salt efficiently maintains the heat and when the energy is required (also at night) it is converted to electricity through a conventional steam turbine. In contrast to photovoltaic panels, CSP is a dispatchable generator and can adjust power output according to an order – and work at night too.*

ing care of cattle manure and fermentation of forest wastes may be allowed and encouraged. However, as we shall see, this part is anticipated to become only a minor contribution to the total. As we will also explain later in more detail, artificial carbon sequestering (taking away carbon dioxide from the air or directly from combustion exhaust at the smokestacks) is an industrial process without any convincing realistic future—both for technological, social and economic reasons and of course not needed in a society without any carbon combustion.

Our TCEB budget will depend on where on the planet we are, so we have considered some examples of countries: Sweden, Australia, United States, China etc. Tables 1–13—see also Figure 2. It may also depend on to what extent the country is developed—a poor country facing other problems than a rich industrialized one, etc. The energy sources that we will consider here are the following, ranked according to their technological, environmental, and economic significance.

SOLAR ENERGY

Among various processes by which solar light may be converted to electric power, the standard silicon-based solar photovoltaic (SPV) cell, in the future further improved by perovskite (Figure 3) may be considered the simplest solution, both from economic and efficiency point of view. At a given *longitude*,



Electrolysis of water

+ pole (anode): $2\,OH^- \rightarrow H_2O + ½\,O_2 + 2\,e^-$

- pole (catode): $2H_2O + 2\,e^- \rightarrow H_2 + 2\,OH^-$

Overall: $H_2O \rightarrow H_2 + ½\,O_2$

Figure 4. Hydrogen produced by electrolysis of water. Electric energy from solar plants or wind power is stored as hydrogen gas under pressure in gas cylinders. Efficiency, today only 50–60%, is anticipated to be improved in the future by development of new electrocatalysts. The hydrogen (combining with air oxygen) regains electric power in fuel cells with high efficiency, to deliver power immediately upon demand, when no solar or wind power is available.

the solar energy is intermittent in a predictable way (12 h/24 h). To harvest solar electricity at a phase-shifted longitude, to mitigate intermittency, is generally not considered feasible. An exception may be some 3-h energy economy shift between the west and east coasts in the United States, and similarly in Russia.

By contrast, *latitude* shifts could make a big difference. While at the North Pole there is no intermittency but the sun is up all 24 h in the summer, the light intensity is extremely weak, proportional to cosine of the latitude (cosine 90° = 0). For the same reason, in Sweden, e.g., at Malmoe (latitude 55°, cosine 55° = 0.57) or at Haparanda (latitude 66°; cosine 66° = 0.41), has lower projected sunlight intensities compared to Sahara latitude 20° (cosine 20° = 0.94), even on a sunny summer day. However, the difference is much bigger than these latitude projection factors indicate, as a result of fewer sun hours during the winter (3 h in Haparanda on 1st January) and moreover also frequently cloudy weather in the northern countries, making the difference at least an order of magnitude less than in Sahara where 4300 sun hours yearly is close to the theoretical maximum 4450 h.

As is obvious from this background, a lot may be gained by harvesting solar light on a solar panel farm at a sunny latitude, such as in the Sahara desert (Figure 5). For example, the current electric energy consumption in Sweden (170 TWh) can be covered by a farm slot of only 6 km × 6 km in Sahara (185 TWh assuming 36 GW, 4300 sun hours and 40% transfer efficiency). Correspondingly, the whole of Europe's electric demand may be covered by the solar electricity from a solar panel park of 70 km × 70 km. For several US states, closeness to desert arid areas is obvious. In Ukraine, most of the plain areas are reserved for valuable production of grain crop, but southern Crimea areas experience solar irradiation levels reaching approximately 5.8 kilowatt-hours per square meter per day on average over a year.

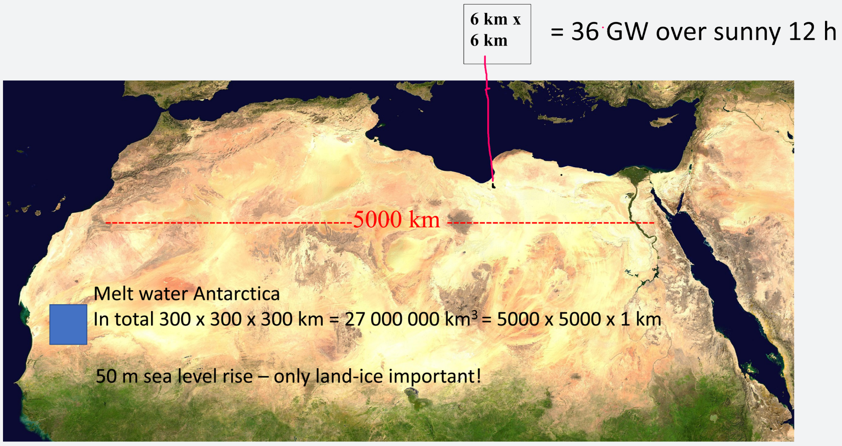


Figure 5. Desert electric energy and freshwater reservoirs. Size of solar SPV or CSP plant that could deliver today's electric energy consumption in Sweden. Also shown is the size of a "melt water cube" corresponding to the land ice of Antarctica, which if going into the ocean would raise the sea level by ca 60 m. This fresh water could be envisaged distributed to freshwater reservoirs maintained at suitable locations around the world. It would suffice with 10 million reservoirs each 100 m deep and size 5 km × 5 km = 2.5 Gm^3 each to mitigate the sea level rise and at the same time take care of the need for fresh water and magazines for storing hydroelectric "pump-back" energy. With current sea-level rise rate, less than 1 million reservoirs would be needed for the following 20–40 years. Note that the reservoirs only in Sweden correspond to 40 Gm^3 and thus a significant contribution.

The distances between the Sahara desert to various European countries (2500 km Tripolis–Malmoe) may be considered problematic to transporting electricity, but they are comparable to or less than the 4200 km that the currently projected submarine cable providing Singapore with solar electricity harvested in Australian desert—opening in 2027, the largest solar farm and battery storage facility in history. The project anticipates 17–20 GW of peak solar power generation (from a 11 km × 11 km piece of land) and some 30–40 GWh battery storage at both entrance and exit terminals of the submarine cable[7].

An alternative or complement, although somewhat less effective, to direct electric cable transport of energy is hydrogen gas produced by electrolysis of pure water (Figure 4), which could be transported in vessels from Mediterranean harbors to countries like Sweden in northern Europe. Hydrogen produced in this way is environmental-friendly in that it produces electric power with only water as exhaust when combined with oxygen from air in a fuel cell. However, the efficiency of the electrolysis step is still less perfect (only 50–60%)—a loss that may be tolerated, however, in a situation with excess of solar energy (Figure 5). Future electrolysis catalysts are anticipated to significantly improve efficiency.

A drawback of SPV-based power is its intermittency, no power in the nighttime. Another is the use of rare elements in today's PV cells (silver). A third is the fact that the efficiency drops significantly with temperature, making SPV parks far from optimal in heat desert contexts. Then another technology, also shown in Figure 3, so-called concentrated solar power (CSP) is worth considering. CSP requires a more sophisticated design with thousands of mirrors reflecting the sun on the top of a central tower where molten salt is heated to higher temperatures. The heat is transferred to water and electricity is generated in a traditional steam turbine. CSP has several advantages to SPV: (i) the molten salt heat reservoir may produce energy also at night, (ii) the design is not sensitive to ambient temperature, and (iii) the construction does not involve any rare elements, but uses only steel tubes and ordinary sodium and potassium nitrate salt. Due to the more complicated and immobile construction, CSP energy is with higher investment costs somewhat more expensive per MWh than SPV.

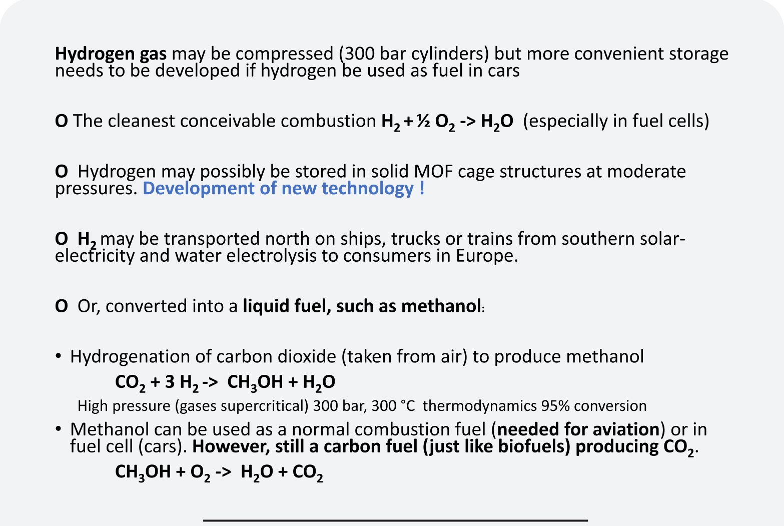
In conclusion, solar electric energy is generally relatively simple and inexpensive, so also developing countries should have great possibilities to contribute to solving both their own as well as other nations' climate problem—especially when considering the fact that states near the Equator (say in Africa) have ample opportunities to expand on and benefit from this kind of energy project. It is important that politicians as soon as possible analyze and address potential collaboration problems, both regarding the installment and potential leasing of land for the solar energy production, as well as the collaborations that the transit and transport of electric energy across the third country involves. Again, the global aspect is important to consider, including how the demographic development will cause problems or offer opportunities.

WATER—HYDROELECTRIC ENERGY

Hydroelectric power is available in most countries that have mountains, such as Switzerland, France, Norway, United States, Australia, South America, and Sweden. Depending on the size of the water magazines, hydroelectric power can be the main adjustable source of electric power to mitigate the intermittency of solar and wind power. It is also one of the most environment-friendly and inexpensive sources of energy. In Norway, current electric power is by 96% hydroelectric, in Sweden 40% while in Finland only 23%.

In Sweden, many smaller rivers could be still exploited by establishing small electric power stations to add significantly to the whole. More importantly, one of the big rivers (Vindelälv), not yet exploited for various preservative environmental reasons, should be considered a next major project for the accelerated establishment of a hydroelectric power station and, we suggest, also developing the option of a "pump back" facility for energy storage (Figure 7)[8].

Under favorable circumstances, hydroelectric reservoirs may thus serve also for storing electric energy using



Hydrogen gas may be compressed (300 bar cylinders) but more convenient storage needs to be developed if hydrogen be used as fuel in cars

O The cleanest conceivable combustion $\mathbf{H_2 + ½\, O_2 \rightarrow H_2O}$ (especially in fuel cells)

O Hydrogen may possibly be stored in solid MOF cage structures at moderate pressures. **Development of new technology !**

O H_2 may be transported north on ships, trucks or trains from southern solar-electricity and water electrolysis to consumers in Europe.

O Or, converted into a **liquid fuel, such as methanol**:

- Hydrogenation of carbon dioxide (taken from air) to produce methanol

$$CO_2 + 3\,H_2 \rightarrow CH_3OH + H_2O$$

High pressure (gases supercritical) 300 bar, 300 °C thermodynamics 95% conversion

- Methanol can be used as a normal combustion fuel (**needed for aviation**) or in fuel cell (cars). **However, still a carbon fuel (just like biofuels) producing CO_2.**

$$CH_3OH + O_2 \rightarrow H_2O + CO_2$$

Figure 6. Hydrogen as fuel or for energy storage.

pump-back technology. In a future fully electrified society, storage of energy will be of utmost importance as a buffer to mitigate the negative effects of intermittency power dips, including mitigating blackout accidents. We shall deal with available power storage alternatives below.

TIDAL ENERGY

A special form of environment-friendly hydroelectric power is tidal energy.[8] Early installations were electric turbines placed in barriers built at ocean sites exhibiting large sea-level variations, emptying and filling-up some big lake inside the barrier. More recent developments are under-water windmill-like farms of turbines harvesting the kinetic energy of tidal currents close to coasts. An advantage to wind power is that tidal energy has a predictable intermittency, the tide occurring at defined times every day. A disadvantage is the limited number of sites close to coast having tides of sufficient current energy to warrant the use of tidal-power systems.

WIND POWER

This is considered one of the most inexpensive and environment-friendly forms of energy source. However, like the solar energy, it is intermittent (but unfortunately in an unpredictable way), which will require both backup continuous energy sources, like nuclear energy or hydroelectric energy, and/or big and evenly distributed energy storage systems (see below). Depending on the distance between the windmill parks and major consumers, the electric grid system may face severe challenges requiring installing extensive nets of power lines. When combined with the additional requests for electricity as a result of total electrification (say, typically a doubled total electric energy power), this is a major challenge to a country's energy politics.

Despite the economical and environmental factors speaking in favor of wind power, the installment of new windmill parks has not been uncontroversial. In Sweden, several communities have objected also against establishments of windmill parks at sea outside the windy west-coast ("a park of windmills could disturb the wild life and also the scenic view by breaking the horizon"). Such local resistance seems to become more often overruled lately, the need for auxiliary energy sources becoming more generally accepted.

NUCLEAR POWER

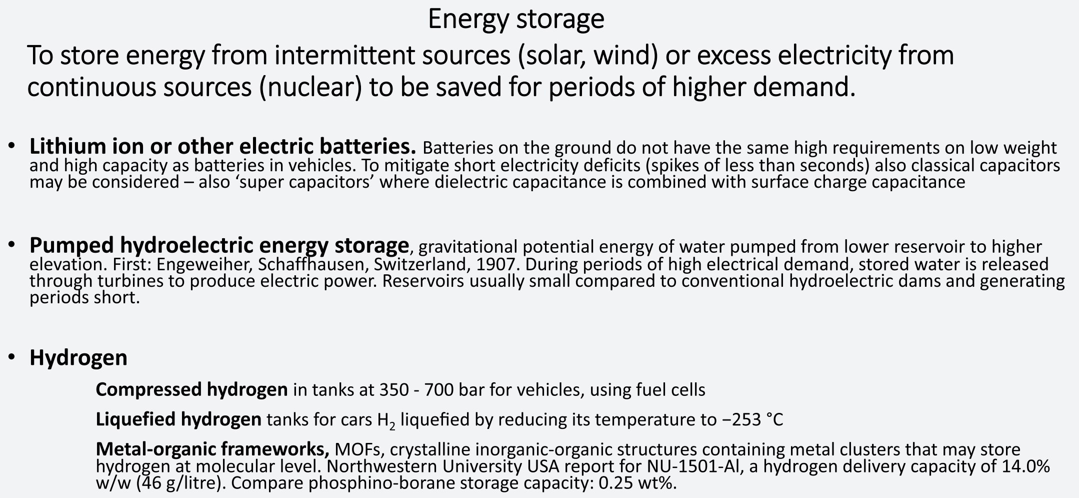
Nuclear power is the orphan energy source in many countries, including Sweden where the cost for each MWh of delivered electricity must defray also all costs for future dismantling of the power stations and final deposit of the radioactive waste for at least 100,000 years, etc. Thus, nuclear power electricity is the most expensive form of energy, but at the same time also the most reliable, and the only one may trust when the temperature drops below –20°C and there is no wind.

There have been several suggestions about alternative nuclear power plants, including the Next Generation Nuclear Power Plant Project[10] (which seems to have stalled) and Thorium Nuclear Power (tried in China and Indonesia), the latter having the advantage of shorter-lifetime waste products[11]. Recently, small modular reactors (SMR) are being developed[12], which could be produced in large number industrially and provide electric power at different points in a geographically extended country thus decreasing transport problems. In Sweden, nuclear power is only allowed at a few sites according to the law. While SMR sounds practical and (relatively) safe, a network with many plants all over clearly makes the security substantially harder to supervise than a few reactors (currently at three sites). Two reactors at another site (Barsebäck) 20 km from Copenhagen have closed down, the second one in 2005. However, this might be a promising site for a set of new safe SMR reactors in view of the great electric power demand in the southern-most part of Sweden and the fact that the electric power lines still exist using Barsebäck as a connection node.

ENERGY STORAGE—BATTERIES, HYDROGEN, AND HYDROELECTRIC

As mentioned, an energy buffer is a prerequisite in an energy system with considerable intermittency. There are three main alternatives for storing electric energy (Figures 6 and 7): batteries, pump-back hydroelectric storage, and hydrogen produced by electrolysis of water and stored under pressure. A potential storage capacity spread homogeneously over a country could be all the cars and trucks that are charging their batteries at nighttime. Against appropriate economic compensation, the car owners can provide access to their batteries which represent a large capacity that could smooth sudden short electricity demands. An electric car has typically a lithium-ion battery with capacity of 100 kWh. With a park of 5 million cars, a total capacity of 500 GWh may be anticipated—say 1 TWh when all trucks too are electrified. In addition to the low-weight Li^+ batteries also traditional heavier lead and nickel–iron batteries should be used stationary on ground since they do not depend so sensitively on the mining of rare elements.

Clean hydrogen gas produced by electrolysis of fresh water (not salt water) provides a convenient way to store electric energy that can be provided on demand when not available from sun or wind. The electrolytic hydrogen production has still limited efficiency, but the development of new electrocatalysts are being developed, and the reverse process of producing electricity in fuel cells



Energy storage

To store energy from intermittent sources (solar, wind) or excess electricity from continuous sources (nuclear) to be saved for periods of higher demand.

- **Lithium ion or other electric batteries.** Batteries on the ground do not have the same high requirements on low weight and high capacity as batteries in vehicles. To mitigate short electricity deficits (spikes of less than seconds) also classical capacitors may be considered – also 'super capacitors' where dielectric capacitance is combined with surface charge capacitance

- **Pumped hydroelectric energy storage**, gravitational potential energy of water pumped from lower reservoir to higher elevation. First: Engeweiher, Schaffhausen, Switzerland, 1907. During periods of high electrical demand, stored water is released through turbines to produce electric power. Reservoirs usually small compared to conventional hydroelectric dams and generating periods short.

- **Hydrogen**

  Compressed hydrogen in tanks at 350 - 700 bar for vehicles, using fuel cells

  Liquefied hydrogen tanks for cars H_2 liquefied by reducing its temperature to −253 °C

  Metal-organic frameworks, MOFs, crystalline inorganic-organic structures containing metal clusters that may store hydrogen at molecular level. Northwestern University USA report for NU-1501-Al, a hydrogen delivery capacity of 14.0% w/w (46 g/litre). Compare phosphino-borane storage capacity: 0.25 wt%.

Figure 7. Energy storage alternatives.

(taking the oxygen from air) is very efficient and clean—the products being only electricity and water.

An especially environmental-friendly and effective method for electric energy storage is the pump-back technique in hydroelectric power contexts: pumped storage hydroelectricity (PSH)[8]. The method stores energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost surplus off-peak electric power is typically used to run the pumps. During the periods of high electrical demand, the stored water is released through turbines to produce electric power. Pumped-storage hydroelectricity allows energy from intermittent sources (such as solar and wind power) or excess electricity from continuous base-load sources (such as nuclear) to be saved for periods of higher demand. The reservoirs so far used with pumped storage have been quite small when compared to conventional hydroelectric dams of similar power capacity, and generating periods are often less than half a day. A good example is the Ffestiniog Power Station, a PSH scheme in north-west Wales. The power station can deliver 360 MW electricity within 60 seconds of the need arising. The scheme has the capacity to power the whole of North Wales for several hours. In Sweden, it is suggested that the river Vindelälv is exploited for additional hydroelectric power in combination with a system for pump-back power storage.

FOSSIL CARBON PRODUCTS

As will be argued, biofuels are unsuitable for certain applications, such as transatlantic aviation where standard fossil fuels are more safe. Biofuels may be even environmental threats due to their hydrophilic properties making them quickly dispersing pollutants when leaked into sea or groundwaters. Therefore, we shall argue that fossil products should be reserved and preferentially used for certain purposes such as long-range (transatlantic) aviation and in petrochemical and pharmaceutical industries. Politicians often seem prone to accept biofuels as they are considered 'carbon neutral' despite the fact that they produce as much (or more) carbon dioxide as fossil fuels. It is important here to note that the use of fossil combustion can be wisely balanced by considering the natural capturing of carbon dioxide that a calculated aliquot of green plants may take care of. Thus, green crops, forests, and other photosynthetic carbon dioxide assimilating organisms, including algae, should be promoted and allowed to do their work. But they should never be transformed into biofuels! The use of fossil petroproducts reserved for transatlantic aviation and chemical industry should correspond to a relatively modest part (ca 2%) of the total energy budget.

BIOFUELS

Contradictory factors in application of CO_2 sequestration with sustainable biofuel benefits have been reviewed and although there are certain environmental advantages of biofuels there are also harmful ecological, social and economic impacts - food shortages in poorer countries, for example, referred to as possible consequence. Also, production of biofuel feedstocks, particularly food crops could increase water pollution from emitted nutrients, pesticides and sediment. In addition, growing the same crop every year may deprive the soil of nutrients that are put back into the soil through crop rotation[13,14].

Biofuels are often considered politically preferable to fossil fuels because of formally being "carbon neutral" but they produce (at least) as much CO_2 as the latter and are associated with disadvantages due to their hygroscopic properties. Biofuel is less suitable for use in low temperatures and is more likely to attract moisture than fossil diesel, which creates problems in cold weather. As mentioned, also microbial growth could be an issue.

As has already been noticed in pollution contexts, biofuels are hard to retrieve when leaked into sea or rivers where they have toxic impact[15–18].

In conclusion, it is debatable whether it be wise to use biofuels in combustion engines, especially for aviation (in conflict with what has been proposed by EU) or transported in large quantities where risks for leakage into sea or groundwater exist. However, an exception is the methane produced by fermentation of manure or wood or other organic debris from forestry – methane being an even worse greenhouse gas than CO_2 and, therefore, ought to be a legitimate biofuel[13–15].

CAPTURING CARBON DIOXIDE

There are two ways carbon dioxide may be retrieved: one that we shall call natural carbon dioxide capturing from the atmosphere (NCC) and one we call engineered carbon capturing (ECC). While NCC is taken care of naturally by all green plants, especially rain forests and algae in the sea, the ECC is not practically possible from the atmosphere but has to be implemented at the sources at the smokestacks of the coal- or gas-burning power plants. From fundamental thermodynamic laws, the energy costs for extracting a chemical compound from a mixture are high if the concentration of the compound is low. This is the so-called entropic part of the free energy (or *exergy*) associated with the extraction process. In the case of CO_2, this corresponds to the chasing of one molecule among 200 other molecules (oxygen and nitrogen) and one has then to pay a corresponding extra energy (this energy might have to be obtained by combustion, then further producing more of the undesirable CO_2). Therefore, the extraction of CO_2 from air is practically unfeasible. One step toward reducing CO_2 emissions is to capture the CO_2 generated during combustion and store it in a suitable place. This process of carbon capture and storage (CCS) has theoretically the potential to reduce future world emissions from energy by as much as 20%. CCS is already operating in trials, with 3 megatons of CO_2 per year from power plants or natural gas cleanup being captured and stored. Norway early applied CCS and separated CO_2 from their natural gas which contains up to 10% CO_2. However, to commercialize carbon capture, as well as transport of liquified carbon dioxide and its storage in exploited oil fields or saline formations, many technological, commercial, and political hurdles remain to be overcome. Separation of CO_2 is the step that consumes the most energy and results in the highest cost. Historical examples of CO_2 separation, if scaled-up, could consume 25–40% of the fuel energy of a power plant and be responsible for 70% or more of the additional costs in CCS[19–21]. There is also the question of thermodynamic stability of depositing carbon dioxide under high pressure, including the risk of hazardous amounts of CO_2 bursting up to the surface (potentially killing people). In view of our end-aim of total exclusion of carbon combustion, we conclude that ECC will probably never become significant (<1%). By contrast to the ECC, the NCC i.e. plants capturing carbon dioxide should be promoted as much as possible but, as we have argued, the plants never be converted into biofuel. Instead they should be allowed to keep the CO_2 as carbohydrates and to produce oxygen.

RISING SEA WATER LEVELS AND INCREASING NEED OF FRESH WATER

The threat of rising sea levels as a result of land ice melting with an increased global temperature scenario might be mitigated by installing big permanent water reservoirs. They could also address another serious challenge: global lack of fresh water. It would suffice with some 10 million reservoirs, each 100 m deep and size 5 km × 5 km = 2.5 Gm^3, to fully mitigate the sea level rise and at the same time take care of the need for fresh water and magazines for storing hydroelectric "pump-back" energy. With current sea-level rise rate, less than 1 million reservoirs would suffice to compensate the melt water for the following 20–40 years. Note that the reservoirs and lakes only in Sweden correspond to 40 Gm^3 and thus constitute a significant contribution.

POLITICAL RELUCTANCY AND CLIMATE POPULISM

There are many examples, at least when viewed hindwise, of unwise political decisions driven by populistic opinions. We mention two examples, both based on militant protests in the early 1970s: the antinuclear movements in Germany (Die Grünen), leading to the annihilation of nuclear power, despite lack of any sensible complements, and in Sweden protests leading to abandoning exploitation of river Vindelälv—a potential addition of hydroelectric power. Developing hydroelectricity presents challenges due to public concern about the environmental impact of generating facilities and, therefore, development of further river sites has been prohibited, to maintain their natural state.

Another more recent example in Sweden, are protests from local communities which have obviated the establishments of off-shore windmill parks outside the windy west-coast.

That politicians seem to be so afraid of analytical conflicts and have avoided reconsidering or reverting such decisions is regrettable, but hopefully the urgent need for significant further contributions to electric power may make them change their minds.

LEGISLATION TO MITIGATE CLIMATE CHANGE CAN BE COUNTERPRODUCTIVE

The formation of new laws in the idealistic interest of assisting mitigation of the emergent climate change seems to follow the same process: in some model, certain "undesirable loopholes" are identified and an action taken to close them. This should lead to barriers that will conduct development, like a river, to follow certain boundaries. An example is defining and greenwashing processes that are "renewable" and "sustainable" believing that they will always contribute to a movement in the right direction. The problem that a law that is not based on true insight about the basic facts, such as available engineering technology, is very much like prohibiting thinking or speaking about certain things. In some religions such militant prohibits exist, as in dictatorships the freedom of the word does not exist, etc.

An example of strange legislation blatantly violating freedom of thinking and speaking was the Swedish *thought ban* according to a decision in 1987 by the Parliament as a result of the Chernobyl nuclear disaster: "*Nobody may make construction drawings, estimate costs, purchase equipment or undertake any such preparations in purpose of building a nuclear reactor within the country. Penalty according to the law be jail of length corresponding to causing someone else's death.*"

HOW URGENT IS ACTION—SHOULD WE PANIC?

You often hear that with the current neglect of seriously attending to the task of mitigating the emergent climate change, we may soon pass tipping points that take us irreversibly into catastrophic situations from which there is no return. However, while the opposite, a big *lowering* of the Earth's temperature would clearly take us into an irreversible catastrophe (a white planet that will inevitably lead to eternal ice age), there is no scientific evidence that increasing temperature will have irreversible climate consequences that cannot be repaired by a restored temperature. Of course, an example of irreversible development is if species go extinct. When it comes to a stage where the land ices of Antarctica and Greenland melt and the sea levels rise beyond 50 m, a very awkward situation no doubt arises—with most capitals becoming submarine like Atlantis, and some low-lying nations even subject to complete extinction. But other drastic changes of climate change may then occur too which could take very long to restore. For example, a dying out of the Gulf Stream, the warm and swift current that makes Scandinavia having a mild climate compared to that of the same latitudes in North America, would have drastic effects. It could even change the abundant winds so that cool northerly winds could make a cold climate even cooler—potentially leading to a new Scandinavian ice age. Climate represents dissipative systems that are far from equilibrium and therefore often impossible to predict—the current observations of higher frequency, as it appears, of hurricanes may indicate another undesirable consequence of the climate change.

SCIENCE-BASED TARGETS

The role of Science-based targets (SBT) to decarbonize the private sector as part of global effort to achieve the temperature goal of the Paris Agreement has intensified. SBTs provide a clearly defined pathway for the private sector to reduce greenhouse gas emissions[22]. The pathways are considered 'science-based' if they are in line with what the latest climate science deems necessary to meet the goals of the Paris Agreement[23]. But more research is needed to distinguish between substantive and symbolic SBTs[24]. Further research from a diversity of approaches is required to better understand how SBTs may facilitate or hinder a transition to low-carbon societies.

SBT adoption by larger, more visible companies in high-income countries has accelerated. These companies tend to have a prior reputation for managing climate impacts. Lower rates of SBT are found in low- and middle-income countries, in certain emission-intensive sectors, and by small- and medium-sized enterprises[22].

CONCLUSIONS

There seems to be only rather incremental progress and many partly incoherent ways the governments of our world address the climate effects of human-caused emissions of greenhouse gases. Many concrete ways of action, to mitigate climate change, seem considered politically (read: economically) problematic. Lack of international consensus seems to paralyze the politicians. One gets a feeling lately that economists and lawyers have hijacked the organizations that should exert leadership, instead of the scientists and engineers who ought to be in the driver's seat. Unfortunately, the seriousness of the climate change together with the manifold and complexity of proposed cures presents a situation where the details make us confused and unable to see the global features of the problem, let alone how to amend them. Here the favoring of 'solutions' that are just complicated ways of bypassing some uncomfortable basic rules are worrying. However, there are already feasible solutions to eliminating carbon dioxide emission, so why not focus on the simplest and most effective ones, irrespective of whether they are uncomfortable? Phrased as a set of theses some of which can be seen as objections against some of today's too cemented climate views and policy, we here claim that:

- **Our long-term goal must be to stop using all carbon-containing fuels,** including natural gas and other fossil products as well as biofuels.
- **We must electrify society and industry,** with electricity from only non-carbon-based power including nuclear power, hydro-electric, wind and solar power.
- **We must prepare ourselves for changes.** Even if the present emission volumes of carbon dioxide were possible to stop immediately, various fast as well as slow lag effects are inevitable and negative development will therefore continue for considerable time.
- **We must count with continued melting of land ice,** the complete liquifying of the Antarctica ice expected to lead to a global sea-level rise by some 60 m, making most capitals submarine. Among various solutions to mitigate effects of ice melting, including lowered global temperatures, the following is proposed.
- **To mitigate sea level rise, it is proposed that stationary water reservoirs be built around the world.** With estimated melting rates, it would require ca 1 million reservoirs be deployed or expanded during the next 20–40 years.
- **Such reservoirs could also solve the emergent problem of lack of fresh water** in many places. They could also be used for local **storage of hydroelectric energy by using PSH technology.**
- **All forms of energy production sources and consumption should be analyzed according to a TBEB** with the objective of minimizing the emissions of greenhouse gases.
- **For each region/country, a table of available or conceivable complementary electric energy sources** should be made and ranked according to TBEB—the sources given priority weights depending on feasibility, significance, and environmental friendliness. Tables are presented for 13 countries. Generally, we find the following rank of priority applicable.
- **Solar energy from desert arid areas is given highest priority** in replacing carbon-combustion-based forms of energy. Submarine electric cables may be deployed along the Australia-Singapore model, if available power grids are insufficient for energy transport.
- **Electrolysis of water producing clean hydrogen gas is given very high priority** both for producing environment-friendly fuel as well as for energy storage. Improved efficiency should be achieved by development of electrolysis catalysts.
- **Hydroelectric power in combination with PSH is given high priority** to mitigate grid power fluctuations and source (solar and wind) intermittence.
- **False hope should not be seeded** among society and politicians by inflating projects that are less realistic or suboptimal for technological or other reasons. Here, probably most forms of biofuels (which although being carbon neutral do produce carbon dioxide) and carbon capture (catching carbon dioxide gas at the combustion site, compressing it to liquid and depositing it in salt mines or empty oil fields) are considered less significant compared to other more direct solutions. Both biofuels and carbon capture may be associated with social and environmental issues.
- **Political legislation and instruments invented with the original objective of mitigating negative climate change effects should be reanalyzed and changed if not functional.** The EU ETS—a market for outlet rights, for example, is a local initiative, which despite its valuable ambition appears suboptimal with respect to goal of efficient decrease of carbon dioxide emission globally. Similarly, "climate taxonomy" can create loopholes bypassing a sound TBEB.
- **Science-based targets (SBT) to decarbonize the private sector** as part of global efforts to achieve the temperature goal of the Paris Agreement should be further encouraged.
- **Solve economic and political challenges** allowing and promoting establishment of required international energy collaborations (e.g., for solar energy cross-continental transport programs)

CONCLUDING REMARK

We have for simplicity focused on total conversion to electric energy without discussing the optimizations that choice of storage and transfer forms of energy involve, such as storage and cost restrictions in comparison e.g. between electric battery and hydrogen gas storage. An alternative to electricity transport in power cables is hydrogen transported in gas pipelines (or in vessels), where variations in transfer rates and related costs could be of decisive economical and technical importance. While electric power needs to be consumed directly, if not stored in battery, the storage and delivery of hydrogen can be done more independent from consumption rate and is scalable without dependence on precious materials like Li and Co (in batteries). Because of this, converting the electricity into hydrogen is often preferable when the alternative battery storage has been exhausted. To cover this aspect of immediate handling of all produced solar and wind energy various energy storage options must be compared, i.e. batteries vs hydrogen gas storage vs PHS and so on.

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CONFLICT OF INTEREST

The author declares no conflict of interest.

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Tables 1–13 compare distributions over various kinds of electric energy sources for selected countries, together with anticipated distributions in a future scenario with totally electrified society and industry. Focus is on percentages of energy production. Data for total national energy productions may be obsolete or uncertain.

Tables 1A and B. Sweden.

Current electric power consumption per year in Sweden 170 TWh (Table 1A) is compared to a future anticipated situation when 98% of all energy is electrified (Table 1B, hopefully already in 2040).

Table 1A. Electric Power in Sweden 2021: 170 TWh per Year

Hydroelectric power	43%
Nuclear power	31%
Wind power	16%
Fossil heat power	9%
Solar power	1%
Storage capacity:	0 GWh

Total energy: **540 TWh per year. Fossil energy: 370 TWh**

Fresh water magazines: 24.3 Gm^3

Table 1B. Electric and Fossil Power in Sweden Anticipated in 2040 (If Transition to All-Electricity Is Deployed as Proposed): 600 TWh per Year

Solar power (SPV and CSP in Sahara and Spain)	39%
Wind power (expanding off-coast)	24%
Hydroelectric power (incl. Vindelälv)	20%
Nuclear power (incl. 3 new SMR)	13%
Fossil*	2%
Biofuels	1%
Technical carbon capture	1%

Electrical storage capacity: 4 TWh of which 1 TWh in vehicles during nighttime charging, 1 TWh permanent batteries, 1 TWh compressed hydrogen, 1 TWh pump-back hydroelectric.

Standing fresh water magazines: 40 Gm^3

*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 2A and B. Italy. See also Figure 2.

Current electric power consumption per year in Italy 278 TWh (Table 2A) is compared to the situation anticipated when 98% of all energy is electrified (Table 2B, hopefully already in 2040).

Table 2A. Electric Power in Italy 2021: 278 TWh per Year

Fossil thermal power	56%
Hydroelectric power	16%
Wind power	9%
Solar PV power	8%
Geothermal	2%
Storage capacity:	0 GWh

Total energy: **700 TWh per year. Fossil energy: 450 TWh**

Fresh water magazines: ? Gm^3

Table 2B. Electric and Fossil Power in Italy Anticipated in 2040 (If Transition Deployed as Proposed): 700 TWh per Year

Solar power (SPV and CSP in Sahara and Sicily)	52%
Wind power	24%
Hydroelectric power	20%
Fossil*	2%
Biofuels	1%
Technical carbon capture	1%

Electrical storage capacity: 4 TWh of which 1 TWh in vehicles during nighttime charging, 1 TWh permanent batteries, 1 TWh compressed hydrogen, 1 TWh pump-back hydroelectric.

Standing fresh water magazines: 30 Gm^3

*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 3A and B. Ukraine.

Current electric power consumption per year in Ukraine 158 TWh (Table 3A) is compared to the situation anticipated when 98% of all energy is electrified (Table 3B).

Table 3A. Electric Power in Ukraine 2021: 158 TWh per Year

Nuclear power	54%
Fossil thermal power	30%
Wind / renewable power	8%
Hydroelectric power	7%
Imported electric energy	1%
Storage capacity:	0 GWh

Total energy: **800 TWh per year. Fossil energy: 600 TWh**

Fresh water magazines: ? Gm^3

Table 3B. Electric and Fossil Power in Ukraine Anticipated in 2040 (If Transition Deployed as Proposed to All-electric): 800 TWh per Year

Nuclear power	40%
Solar energy (from Crimea)	46%
Wind / renewable power	15%
Hydroelectric power	8%
Fossil*	2%

Electrical storage capacity: 4 TWh of which 1 TWh in vehicles during nighttime charging, 1 TWh permanent batteries, 1 TWh compressed hydrogen, 1 TWh pump-back hydroelectric.

Standing fresh water magazines: 20 Gm^3

*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 4A and B. Peru.

Current electric power consumption per year in Peru is 60 TWh (Table 4A) compared to a future anticipated situation when 98% of all energy is electrified (Table 4B, hopefully already in 2040).

Table 4A. Electric Power in Peru 2021: 100 TWh per Year

Fossil (gas/oil) power	58%
Hydroelectric power	37%
Wind power	3%
Solar power	2%
Nuclear power	0%
Storage capacity:	0 GWh

Total energy: **550 TWh per year. Fossil energy: 500 TWh**
Fresh-water magazines: 30 Gm^3

Table 4B. Electric and Fossil Power in Peru Anticipated in 2040 (If Transition to All-Electricity Is Deployed as Proposed): 700 TWh per Year

Solar power (expanding in the Andes?)	40%
Hydroelectric power	35%
Wind power (expanding)	20%
Fossil*	2%
Biofuels	1%
Technical carbon capture	1%

Electrical storage capacity: 4 TWh of which 1 TWh in vehicles during nighttime charging, 1 TWh permanent batteries, 1 TWh compressed hydrogen, 1 TWh pump-back hydroelectric.
Standing fresh water magazines: 50 Gm^3
*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 5A and B. Norway.

Current electric power consumption per year in Norway 122 TWh (Table 1A, production 148 TWh) is compared to a future anticipated situation when 98% of all energy is electrified (Table 5B, hopefully already in 2040).

Table 5A. Electric Power in Norway 2021: Production 148 TWh per Year, Consumption 122 TWh per Year

Hydroelectric power	95%
Fossil heat power	3%
Wind power	1%
Solar power	1%
Nuclear power	0%
Storage capacity:	10 GWh

Total energy: 300 **TWh per year. Fossil energy: 150 TWh**
Fresh-water magazines: 60 Gm^3

Table 5B. Electric and Fossil Power in Norway Anticipated in 2040 (If Transition to All-Electricity Is Deployed as Proposed): 600 TWh per Year

Hydroelectric power	80%
Wind power (expanding off-coast)	16%
Fossil*	2%
Biofuels	1%
Technical carbon capture	1%

Electrical storage capacity: 4 TWh of which 1 TWh in vehicles during nighttime charging, 1 TWh permanent batteries, 1 TWh compressed hydrogen, 1 TWh pump-back hydroelectric.
Standing fresh water magazines: 60 Gm^3
*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 6A and B. Denmark.

Current electric power consumption per year in Denmark 70 TWh (Table 6A) is compared to a future anticipated situation when 98% of all energy is electrified (Table 6B, hopefully already in 2040).

Table 6A. Electric Power in Denmark 2021: 70 TWh per Year

Wind power	57%
Fossil coal/gas power	20%
Bioenergy + waste	20%
Solar power	3%
Hydroelectric power	0%
Nuclear power	0%
Storage capacity:	0 GWh

Total energy: **150 TWh per year. Fossil energy: 100 TWh**
Fresh-water magazines: - Gm^3

Table 6B. Electric and Fossil Power in Denmark Anticipated in 2040 (If Transition to All-Electricity Is Deployed as Proposed): 200 TWh per Year

Wind power (expanding off-coast)	50%
Solar power (SPV & CSP Sahara and Spain)	46%
Hydroelectric power	0%
Nuclear power	0%
Fossil*	2%
Biofuels	1%
Technical carbon capture	1%

Electrical storage capacity: 4 TWh of which 1 TWh in vehicles during nighttime charging, 1 TWh permanent batteries, 1 TWh compressed hydrogen, 1 TWh pump-back hydroelectric.
Standing fresh water magazines: ? Gm^3
*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 7A and B. France.

Current electric power consumption per year in France 2000 TWh (Table 7A) is compared to a future anticipated situation when 98% of all energy is electrified (Table 7B, hopefully already in 2040).

Table 7A. Electric Power in France 2021: Production 2000 TWh per Year

Nuclear power	44%
Hydroelectric power	18%
Wind power	16%
Solar power	9%
Fossil coal/gas power	10%
Bioenergy	2%
Storage capacity:	0 GWh

Total energy: **4000 TWh per year. Fossil energy: 2000 TWh**
Fresh-water magazines: 50 Gm^3

Table 7B. Electric and Fossil Power in France Anticipated in 2040 (If Transition to All-Electricity Is Deployed as Proposed): 4000 TWh per Year

Solar power (SPV & CSP Sahara & Spain)	40%
Nuclear power	20%
Hydroelectric power	20%
Wind power	15%
Fossil*	2%
Biofuels	1%
Technical carbon capture	1%

Electrical storage capacity: 10 TWh of which 3 TWh in vehicles during nighttime charging, 3 TWh permanent batteries, 2 TWh compressed hydrogen, 2 TWh pump-back hydroelectric.
Standing fresh water magazines: ? Gm^3
*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 8A and B. Germany.

Current electric power consumption per year in Germany 484 TWh (Table 8A) is compared to a future anticipated situation when 98% of all energy is electrified (Table 8B, hopefully already in 2040).

Table 8A. Electric Power in Germany 2021: Production 484 TWh per Year

Fossil coal/oil/gas	45%
Wind power	20%
Nuclear power	12%
Solar power	10%
Biomass	8%
Hydroelectric	4%
Storage capacity:	0 GWh

Total energy: **1000 TWh per year. Fossil energy: 700 TWh**
Fresh-water magazines: ? Gm^3

Table 8B. Electric and Fossil Power in Germany Anticipated in 2040 (If Transition to All-Electricity Is Deployed as Proposed): 1200 TWh per Year

Solar power (SPV & CSP Sahara)	48%
Wind power	20%
Nuclear	18%
Hydroelectric	10%
Fossil*	2%
Biofuels	1%
Technical carbon capture	1%

Electrical storage capacity: 7 TWh of which 2 TWh in vehicles during nighttime charging, 2 TWh permanent batteries, 2 TWh compressed hydrogen, 1 TWh pump-back hydroelectric.
Standing fresh water magazines: 50 Gm^3
*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 9A and B. California.

Current electric power consumption per year in California 200 TWh (Table 9A) is compared to a future anticipated situation when 98% of all energy is electrified (Table 9B, hopefully already in 2040).

Table 9A. Electric Power in California 2020: Production 200 TWh per Year

Fossil (natural gas, coal, oil)	42%
Solar	20%
Hydroelectric	18%
Nuclear	8%
Wind	7%
Geothermal	5%
Storage capacity:	0 GWh

Total energy: **500 TWh per year. Fossil energy: 350 TWh**
Fresh-water magazines: 50 Gm^3

Table 9B. Electric and Fossil Power in California anticipated in 2040 (If Transition to All-Electricity Is Deployed as Proposed): 700 TWh per Year

Solar power (SPV & CSP in deserts)	45%
Wind	30%
Geothermal	10%
Hydroelectric	10%
Fossil*	2%
Biofuels	1%
Technical carbon capture	1%

Electrical storage capacity: 7 TWh of which 2 TWh in vehicles during nighttime charging, 2 TWh permanent batteries, 2 TWh compressed hydrogen, 1 TWh pump-back hydroelectric.
Standing fresh water magazines: 80 Gm^3
*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 10A and B. Maine.

Current electric power consumption per year in 2020, 14 TWh (Table 10A) is compared to a future anticipated situation when 98% of all energy is electrified (Table B, hopefully already in 2040).

Table 10A. Electric Power in Maine 2020: Production 14 TWh per Year

Hydroelectric	33%
Wind power	24%
Fossil (natural gas)	20%
Biomass	20%
Solar	0.1%
Nuclear	0%
Coal	0%
Storage capacity:	? GWh

Total energy: **14 TWh per year. Fossil energy: 3 TWh**

Fresh-water magazines: ? Gm^3

Table 10B. Electric and Fossil Power in Anticipated in 2040 (If Transition to All-Electricity Is Deployed as Proposed): 30 TWh per Year

Solar power (SPV & CSP from Nevada?)	50%
Wind power	25%
Hydroelectric	20%
Fossil*	2%
Biofuels	1%
Technical carbon capture	1%

Electrical storage capacity: 4 TWh of which 1 TWh in vehicles during nighttime charging, 1 TWh permanent batteries, 1 TWh compressed hydrogen, 1 TWh pump-back hydroelectric.

Standing fresh water magazines: ? Gm^3

*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 11A and B. Australia.

Current electric power consumption per year 250 TWh (Table 7A) is compared to a future anticipated situation when 98% of all energy is electrified (Table B, hopefully already in 2040).

Table 11A. Electric Power in Australia 2020: Production 250 TWh per Year

Fossil (gas/oil/coal)	93%
Wind	2%
Hydro	2%
Solar	2%
Biomass	1%
Storage capacity:	GWh

Total energy: **500 TWh per year. Fossil energy: 400 TWh**

Fresh-water magazines: ? Gm^3

Table 11B. Electric and Fossil Power anticipated in 2040 (If Transition to All-Electricity is Deployed as Proposed): 600 TWh per Year

Solar power (SPV & CSP desert)	80%
Wind	12%
Hydroelectric	5%
Fossil*	2%
Biofuel	1%

Electrical storage capacity: 8 TWh of which 3 TWh in vehicles during nighttime charging, 2 TWh permanent batteries, 2 TWh compressed hydrogen, 1 TWh pump-back hydroelectric.

Standing fresh water magazines: 50 Gm^3

*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 12A and B. China.

Current electric power consumption per year 1130 TWh (Table 12A) is compared to a future anticipated situation when 98% of all energy is electrified (Table 12B, hopefully already in 2040).

Table 12A. Electric Power in China 2021: Production 1130 TWh per Year

Fossil (gas/oil/coal)	66%
Hydroelectric	17%
Nuclear power	6%
Wind power	6%
Solar power	3%
Biomass	1%
Storage capacity:	GWh

Total energy: **2500 TWh per year. Fossil energy: 2200 TWh**

Fresh-water magazines: ? Gm^3

Table 12B. Electric and Fossil Power in China anticipated in 2040 (If Transition to All-Electricity is Deployed as Proposed): 3500 TWh per Year

Solar power (SPV & CSP)	59%
Hydroelectric	15%
Wind	15%
Nuclear power	7%
Fossil*	2%
Biofuels	1%
Technical carbon capture	1%

Electrical storage capacity: 15 TWh of which 5 TWh in vehicles during nighttime charging, 3 TWh permanent batteries, 5 TWh compressed hydrogen, 2 TWh pump-back hydroelectric.

Standing fresh water magazines: ? Gm^3

*Reserved for aviation (transatlantic) and petrochemical industry.

Tables 13A and B. Japan.

Current electric power consumption per year 950 TWh (Table 13A) is compared to a future anticipated situation when 98% of all energy is electrified (Table 12B, hopefully already in 2040).

Table 13A. Electric Power in Japan 2021: Production 950 TWh per Year

Fossil (gas/coal/oil)	76%
Hydroelectric	8%
Solar power	8%
Wind power	6%
Nuclear	4%
Storage capacity:	GWh

Total energy: **4500 TWh per year. Fossil energy: 4200 TWh**

Fr**esh-water magazines**: ? Gm^3

Table 13B. Electric and Fossil Power in Japan anticipated in 2040 (If Transition to All-Electricity is Deployed as Proposed): 2000 TWh per Year

Solar power (SPV & CSP)	60%
Hydroelectric	15%
Wind	12%
Nuclear power	9%
Fossil*	2%
Biofuels	1%
Technical carbon capture	1%

Electrical storage capacity: 15TWh of which 5TWh in vehicles during nighttime charging, 3TWh permanent batteries, 5TWh compressed hydrogen, 2 TWh pump-back hydroelectric.

Standing fresh water magazines: 60 Gm^3

*Reserved for aviation (transatlantic) and petrochemical industry.