Kicking the Oil Addiction: Facts and Fiction

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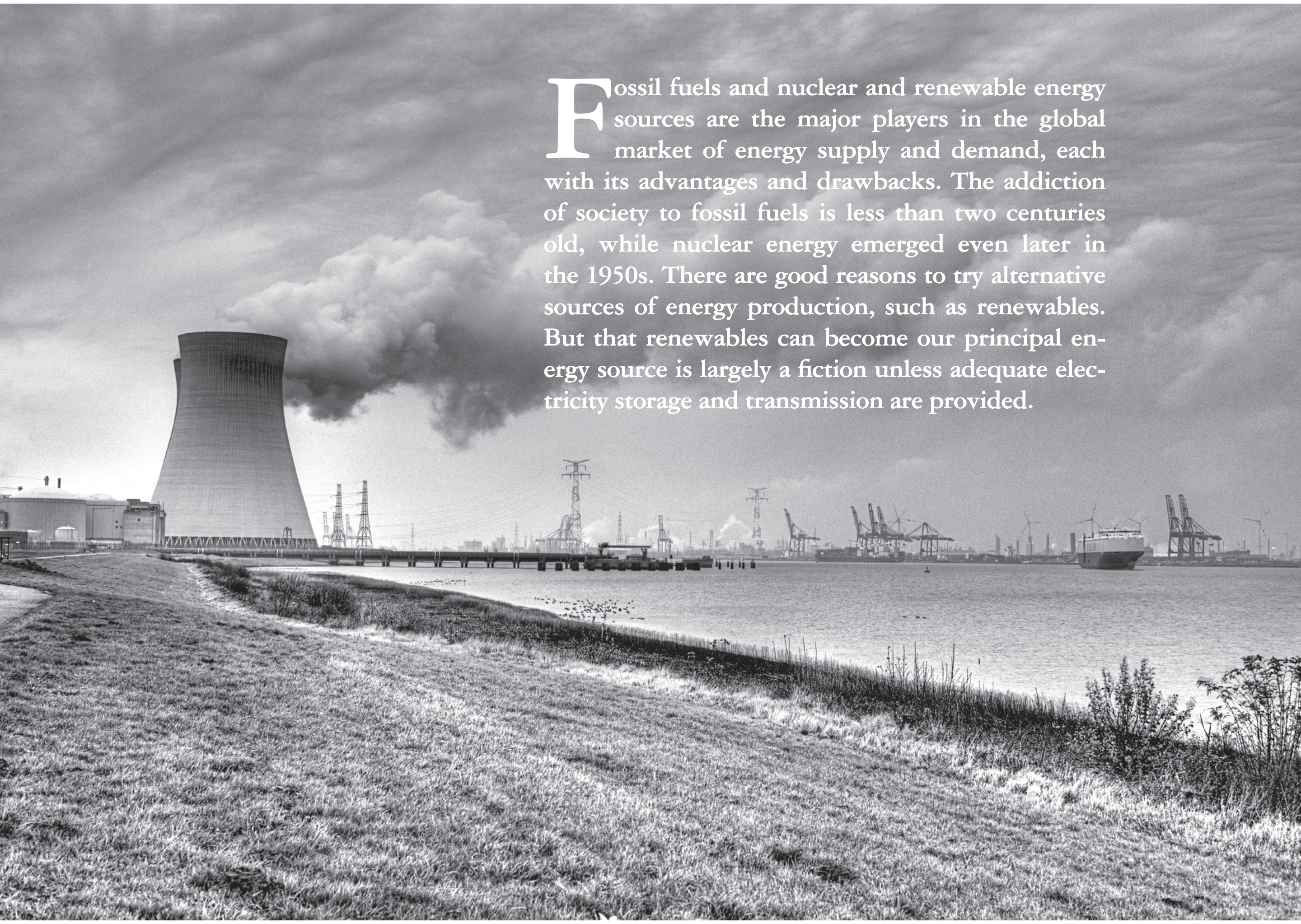

Fossil fuels and nuclear and renewable energy sources are the major players in the global market of energy supply and demand, each with its advantages and drawbacks. The addiction of society to fossil fuels is less than two centuries old, while nuclear energy emerged even later in the 1950s. There are good reasons to try alternative sources of energy production, such as renewables. But that renewables can become our principal energy source is largely a fiction unless adequate electricity storage and transmission are provided.

LENNART TANGE

When the International Energy Agency (IEA) was founded more than 40 years ago, in the wake of the Yom Kippur War in the Middle East and the 1973 to 1974 oil crisis that followed, the future global supply of crude oil seemed insolubly bleak. But today, our global energy challenges have taken a dramatically different turn. Following the large-scale development of shale oil and gas in the United States—coupled with new measures of conservation and efficiency—there is an oil glut on the market, and our main concerns have changed. Global warming, climate instability, air and water pollution all have a common origin—massive reliance on fossil fuels. Hence, our desire for a different kind of energy source that would not result in the same hazardous consequences.

The fear of a major nuclear accident is yet another ongoing concern. In some OECD countries, such as Germany, an intensive development of clean and renewable energy sources has been implemented in an effort to eliminate the nuclear risk while reducing dependence on fossil fuels. Indeed, about half of Germany's nuclear power plants have been closed since 2011, and the rest are headed for phase out by 2022. At the same time, however, there has been a parallel increase in the use of coal—the most polluting fossil fuel—for electricity generation. Moreover, electricity produced from renewable energy has led to a higher cost of electricity for customers, and the German route toward clean and safe energy does not seem to be a substantial success. More broadly speaking, there is little to suggest that mankind is on the verge of finding any better energy solution that would guarantee a secure future for the planet and its inhabitants.

ENERGY VS. ENTROPY

Still, before we try to analyze what has gone wrong in Germany and how this can be improved, it is important to understand what energy is and how it is generated. The word *energeia* was used by Aristotle to describe a "kind of action," but only in the 18th century was energy properly defined as the ability of any system to perform some activities, such as mechanical (climbing stairs), kinetic (shooting a rocket), thermal (heating water), chemical (wood fire), or electrical (running a computer).

The source of many of these forms of energy, with the exception of nuclear and geothermal, is both simple and singular—namely, the sun. The radiation (light and heat) coming from the sun is the main driving force for most energy sources on earth: fossil fuels, wind, electrical, chemical, and thermal. While we cannot create energy out of nowhere, we can transform energy from one form to another, and this is what we do in our daily lives. For example, our body metabolizes the food we eat, while chemically transforming its caloric value into vital functions needed to keep us alive. Our computer and portable electronic devices run on batteries that transform chemical energy into electricity. And we drive our cars thanks to their internal combustion engines that burns fossil fuel.

Unfortunately, the transformation of energy from one form to another is a process that can by itself waste energy. In order to understand it, we need to invoke the con-

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cept of entropy, the lesser-known twin sibling of energy. Entropy comes into play at its simplest level when we open a bottle of perfume. The perfume molecules evaporate into the air, and within a short time, without any external interference, they spread throughout the room. As the molecules have a lot of extra space to explore, they will not stay contained inside the bottle. Entropy is related to the amount of disorder, defined as the number of different positions available to the molecules.

One fundamental law of physics is that entropy cannot decrease in any process where energy is transformed from one form to another. Hence, the perfume molecules in a chamber will spread and fill uniformly the entire chamber. If we enlarge the chamber, the molecules will rush to fill the larger available space (and increase their entropy). However, the inverse process where molecules spontaneously restrict themselves to occupy, say, half of the space in the room, is not feasible. The random nature of the molecular motion makes it highly improbable. The only way to decrease entropy is by applying an external intervention (energy) and compressing them back into their original configuration.

This reduction of entropy (or disorder) is exactly what happened hundreds of millions of years ago, as our planet's high atmospheric concentration of carbon dioxide (CO_2) was reduced by storage in the form of fossil fuels and coal. Over many millions of years, the energy influx of solar radiation was harvested by photosynthesis—an ever-present process common to plants, algae, and green micro-organisms. Water and atmospheric CO_2 gas were transformed into organic matter (sugar) and oxygen. Some of the organic matter (plants, wood) decomposed, releasing CO_2 back into the atmosphere. But another fraction was buried, compressed, and transformed into coal and fossil fuels by extremely slow geological processes. Combustion of fossil fuels at any later time releases back into the air CO_2 molecules, which fill the planet's atmosphere while increasing its entropy, just as opening a bottle of perfume.

LOOK OUT FOR HIGH ENTROPY, CO_2

It is important to recall briefly the evolution of atmospheric CO_2 levels. Millions of years ago, CO_2 levels in the atmosphere were higher, and due to several reasons, including photosynthesis-assisted fossil fuel production, they reached a somewhat stable level. For the past several hundred millennia, the CO_2 atmospheric concentration has oscillated between 180 and 280 parts per million (ppm) (see Figure 1).

EMISSIONS HAVE INCREASED CONTINUOUSLY, IN SPITE OF KYOTO PROTOCOLS AND COMMITMENTS MADE BY VARIOUS COUNTRIES AND ORGANIZATIONS.

However, in the last two centuries, CO_2 levels have increased substantially. Between 1850 and World War II, CO_2 levels increased from 280 to 310 ppm at a rate of about 3 ppm for each decade. This period corresponds to intensified industrial activities, mainly in Europe and the United States, with the burning of coal to fire steam engines in factories, and for transportation and heating. The second period from the end of World War II to the present is characterized by an increase of CO_2 from 310 ppm to about 400 ppm (see Figure 2). This represents an accelerated rate of about 20 ppm per decade and it keeps increasing at a steep and alarming rate, compared with the shallow oscillations over the previous 800,000 years. A 2014 IEA report suggests that even if the continuous growth in CO_2 emissions may have stalled, atmospheric concentration of CO_2 would continue to rise—reaching some 600 ppm by the year 2100, which is *twice* the highest level reached in the last 800,000 years. These are disturbing projections. There is no historical precedent for such large and abrupt increases in atmospheric CO_2 levels, and predicting its consequences is difficult. So far, rising temperatures have been the focus of attention, but climate instability at elevated CO_2 levels may have an even more perilous and less predictable outcome.

Clearly that recent increase in atmospheric CO_2 concentration is tightly related to emissions of CO_2 of human origin. From past records, it's possible to estimate that up to a global fossil emission level of about 3 billion tons of CO_2 per year, emission and absorption of CO_2 nearly balance each other. However, today's yearly emissions are tenfold larger—about 35 billion tons (see Figure 2).

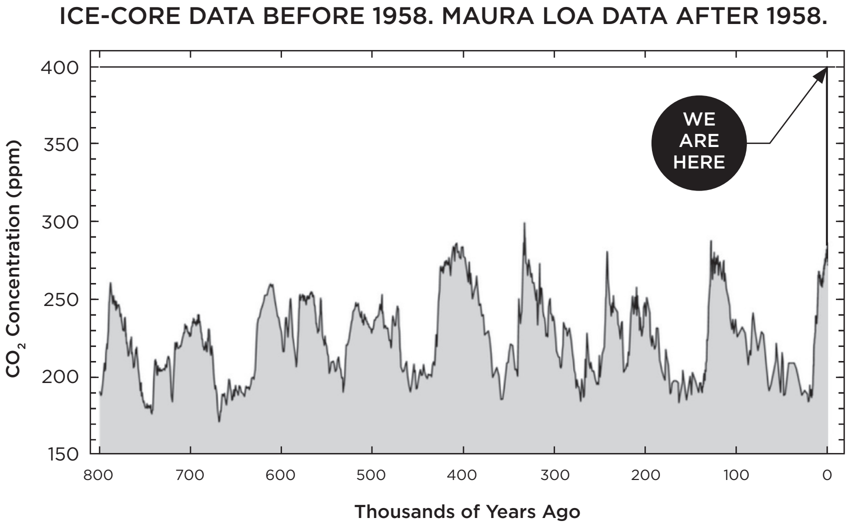


Figure 1. CO_2 concentration in the atmosphere (in parts per million) in thousands of years. Ice-Core data before 1958. Mauna Loa date after 1958.

Source: Scripps Institution of Oceanography.

These emissions have increased continuously, in spite of the Kyoto Protocols and commitments made by various countries and organizations on different occasions. This rate is so large that the solar energy influx coupled with vegetation photosynthesis and other chemical reactions is not sufficient to compensate for the increased entropy (or disorder), and the biosphere risks moving alarmingly out of balance.

To bring down the rate of CO_2 release to a value that can be compensated through the natural energy influx of the sun, a drastic reduction of 90 percent in the use of fossil fuels would be necessary. There are several possible solutions. The most obvious is to reduce global energy consumption, hence reducing CO_2 emissions. The other is to find ways of capturing and storing CO_2 at the source of its

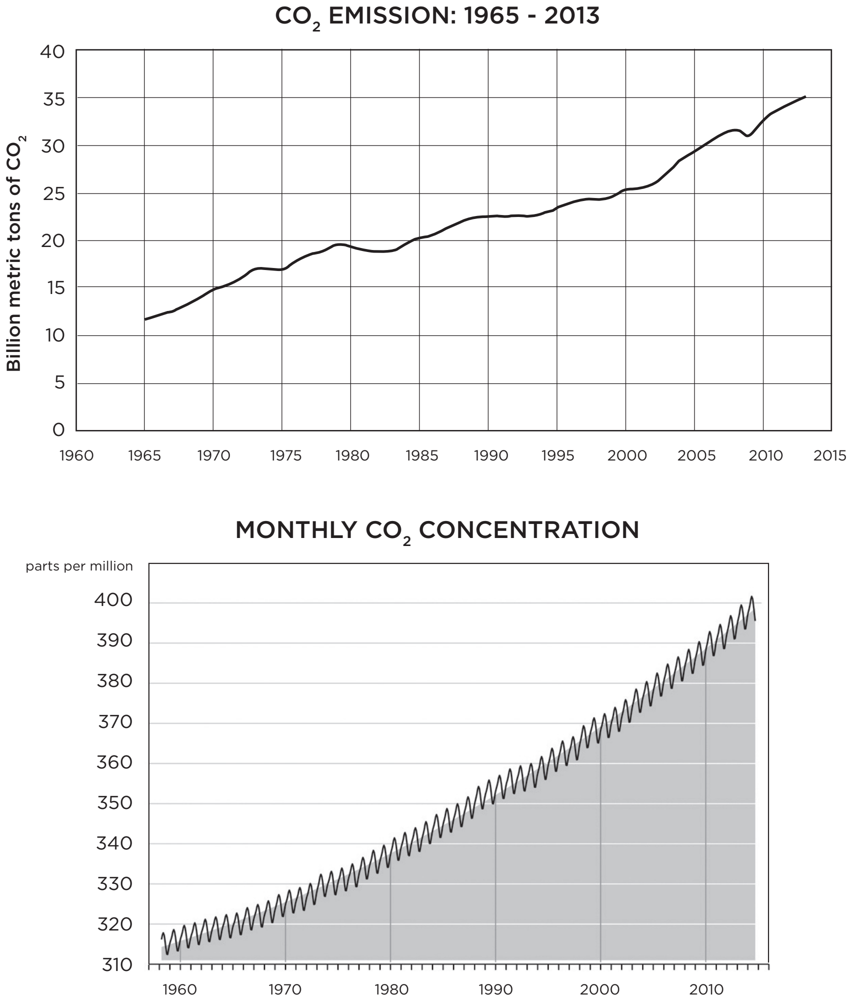


Figure 2. (top) CO_2 Emissions in billion metric tons for the years 1965–2013
Source: Robert Rapier – ConsumerEnergyReport.com;
(bottom) CO_2 concentration (in ppm) in the atmosphere for the years 1960-2014
Source: Scripps Institution of Oceanography.

emission (power plants). This is a possible but expensive solution because it will reduce the efficiency of the power plant energy conversion. And finally, the third possibility is to replace fossil fuels as the principal source of energy production by a massive development of renewable energy sources, such as solar, wind, hydroelectric, and geothermal. And then there is the nuclear energy option.

RENEWABLES: THE GERMAN CASE

Enormous industrial progress has been made in recent years to reduce the cost of electricity produced by wind turbines and solar panels to a level comparable to that of electricity produced by all non-renewable sources, except coal. This raises great hopes because it will facilitate global economic development without causing an even more extensive exploitation of fossil fuels and CO_2 emissions. It may even lead to a real energy revolution—but not yet.

A look at the German case is useful to assess whether these hopes can be realized because the share of Germany's renewable sources measured in terms of production capacity of electricity is one of the highest in the world. The immediate problem is that Germany's ability to substitute renewables for fossil fuels and nuclear production of electricity has been accompanied by a significant increase in the price of electricity, to the point where German energy is among the most expensive in Europe.

Renewables require using conventional power plants as backup, producing electricity at night or during calm weather, when solar and wind sources are unavailable. The cost of building and operating conventional power plants as backups substantially increases the overall cost of electricity. Of no less importance is that, under German law, renewable energy producers are guaranteed revenue for each kilowatt-hour (kWh) produced, independent of any momentary power need. Furthermore, to reduce operating costs, the backup power plants are using low-grade coal (lignite), which increases air pollution even further. Today, 43 percent of electricity is generated in Germany by burning coal.

The production of energy from renewable sources depends on local conditions. For example, solar panels are best placed in arid and sunny locations, while wind turbines are placed in windy areas. In Germany, wind-generated electricity is mostly a product of its North Sea shores, while it is needed more than 600 miles away in the nation's industrial south. Only a fraction of the needed long-distance transmission lines have been built. Meanwhile, the electric utilities must buy the missing electricity from neighboring countries such as Poland and the Czech Republic, which produce it by burning coal, and from France that uses nuclear power plants. Hence, German electricity policy is not viable on a pan-European scale.

In addition to transmission, an even more severe challenge is electricity storage. In the absence of massive storage capacity, electricity produced by intermittent renewable sources must be distributed and used as soon as it is produced. On the other hand, the public utilities are obligated, by their contracts, to provide electricity to consumers upon immediate demand, often leading to an unbalanced situation of supply and demand. A possible solution is to transform electricity into another form of energy that can be stored for later usage. In Switzerland, for example, water is pumped into reservoirs located on mountaintops using intermittent surplus of electricity. Then, the water that flows downhill is used to power hydroelectric turbines producing electricity during periods of peak demand.

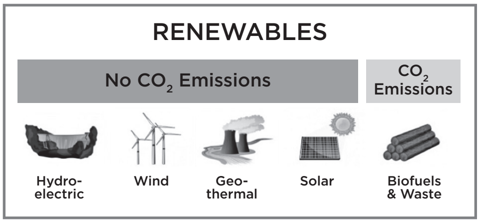
Other storage options include solar water heaters commonly used in Israel, and in the future, the production of hydrogen with excess electricity. Applying an electric current—the process known as electrolysis—breaks each water molecule down into its two constituents, hydrogen and oxygen. Hydrogen is a clean source of energy that can be stocked and used at will to produce electricity via fuel cells, without emitting any CO_2. There are already electric concept cars that operate on such fuel cells.

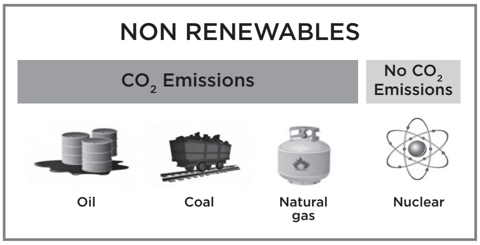
WHITHER ENERGY?

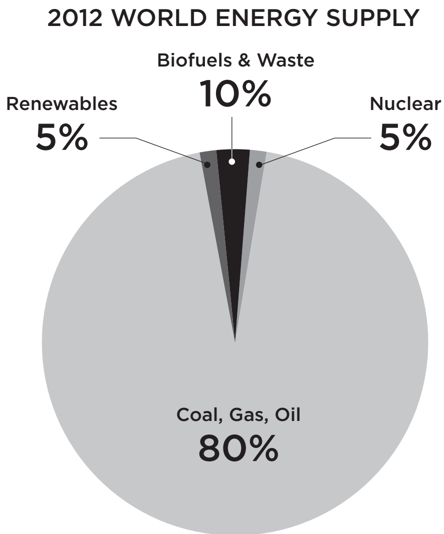
Although much progress has been made in terms of innovative materials and efficient devices providing cheaper and more reliable renewable sources, their current use (excluding biofuels and waste) is barely 5 percent of worldwide energy supply (see Chart). Renewables are not going to solve the global energy demand in the near future for several reasons. First, renewables are mainly designed to replace fossil fuels as a source of electricity production. But only about 20 percent of fossil fuel energy is consumed in this form. The rest is equally divided between transportation and heating, which means relying solely on electric vehicles for private and public transport, as well as electric heat pump systems for residential dwellings and the public sector. This will require an immense transformation, involving large investments in infrastructure, materials, and nationwide planning. Second and most importantly, the main problem of renewable energy sources is their scalability. So far, the use of renewables in most developed countries does not account for more than 10 percent of all electricity production.

The actions of green political parties have been confined largely to pressing governments to close nuclear power plants. Although they seem to be aware of the detrimental impact of the large use of fossil fuels on the biosphere, green parties have given priority to dismantling the nuclear option. This choice is wrong. Massive emissions of CO_2 are far more dangerous because they destabilize the entire biosphere. Nuclear incidents, even as serious as Chernobyl or Fukushima, can be avoided or at least minimized. They are local events. By contrast, when CO_2 molecules are released, nothing can stop them. Whether they are released nearby or on the other side or the planet is irrelevant. The entire biosphere is affected. The sharp increase of CO_2 concentration in the atmosphere in recent decades is unprecedented, and is likely to have potentially catastrophic and unforeseen consequences across the planet, such as rising temperatures and climate destabilization.

Analysis of the German experience has shown that, at least with existing technology, renewables have a limited impact on the overall energy sector, in the absence of a suitable infrastructure allowing for long-distance transmission of electricity and its massive storage. Fossil fuel and coal consumption, which represents about 80 percent of the worldwide energy consumption (see Chart), has not been reduced in Germany. On the contrary, it has even increased and was followed by a 5 percent increase in CO_2 emissions. From 2011 to 2014, emissions increased from 770 million tons to 800 million tons. This amount is calculated







even without taking into account the increased emission of CO_2 due to coal-burning power plants in neighboring Poland and the Czech Republic.

Typically, power plants provide electricity within a radius of about 100 miles from where they are located. Alternating current (AC), high-voltage line losses become prohibitive at longer distances. Bringing electricity generated from windmills in the north of Germany to the industrial regions in the south is not only expensive, but also technically challenging. High-voltage direct current (DC) lines, possibly underground and superconducting in the vicinity of urban centers, can provide a solution. Research and development of transmission solutions should be given high priority, especially the DC to AC conversion since most commercial applications are run off alternating currents.

No viable economical solutions exist yet for large-scale electricity storage. Feasible in the short to medium term (a few dozen years) is distributed storage. Driven by the foreseen shift to electric cars, there has recently been rapid progress in commercialization of storage units of a few dozen kWh for small or hybrid electric cars (Chevrolet Volt, for example, has a storage battery of about 20 kWh). Longer-range electric cars, such as Model S by Tesla Motors, have storage units of 70 to 85 kWh, which allows them to travel as much as 300 miles between charge. Recently, Tesla has started marketing similar units for the private and industry sectors. These units are optionally coupled with a renewable source and could be sufficient for most daily uses. Utilities could sell electricity at times of low consumption to be stored and used later during peak consumption. Storage could become economical if the price paid by the consumer will be adjusted according to the actual market price of daily and seasonal variation in electricity supply and demand.

FUTURE SHOCK

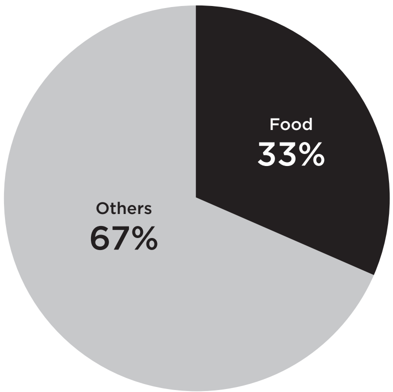
Renewables can make an important contribution toward the priority of cutting fossil fuel consumption, provided their large-scale introduction is not limited to electrical generation. Also central to achieving the goal of returning to manageable levels of CO_2 generation is conservation—consuming less energy through energy frugality. A vast kaleidoscope of means is already available: better thermal isolation of residential dwellings, more efficient heating and cooling systems, more economical ways to use private and public transport, and reducing the energy used to produce a vast range of goods and services by individuals, families, communities, nations, even the entire globe.

These conclusions are drawn mainly from observing the energy conduct in OECD countries, but may have important consequences for emerging countries as well. If Africa and other emerging nations follow the path of developed nations, where most of the energy consumed is still provided by massive use of fossil fuels, the future of our planet is bleak. Few African nations will be satisfied with energy levels as low as those of Senegal, whose average per capita daily energy consumption is barely one-40th that of the United States (see Chart). In the long run, such dichotomies are both unacceptable and destabilizing on a global scale.

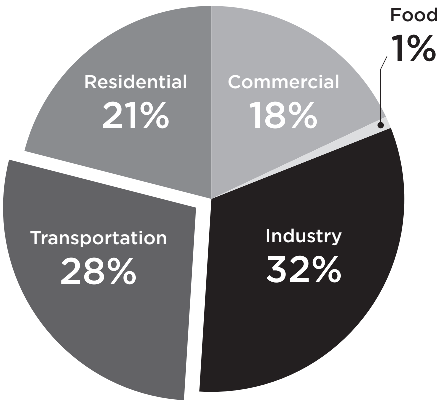
In Africa, a viable energy alternative could take the form of large-scale development of solar electricity generated in the desert areas of the Sahara. With long-range transmission (likely developed in OECD countries), this electricity could be delivered to many African nations both in the north (Morocco, Algeria, Tunisia, Libya, Egypt) and south of the Sahara (Mauritania, Senegal, Mali, Niger, Chad, Sudan, and even further south to the Central African Republic and the Republic of Congo). Coupled with electricity storage, such a development could offer a viable alternative for many of Africa's peoples and a direct path out of a subsistence economy, without compromising their own environment or the future of our planet.

Society is at a turning point. The danger of misusing nuclear energy is all too apparent. Accidents such as Chernobyl or Fukushima are engraved in our collective memory and underscore the potential risks of nuclear energy. But the danger of continuing to burn fossil fuels, though less dramatic, has far graver, possibly irreversible consequences for the biosphere and a stable, even a survivable, climate.

SENEGAL PER CAPITA DAILY ENERGY CONSUMPTION: 6 KWH



USA PER CAPITA DAILY ENERGY CONSUMPTION: 230 KWH



So far, great advances in materials research have led to more efficient and cheaper renewable energy sources. But only when appropriate and viable solutions for electricity transmission and storage can be implemented will renewable energy be positioned for a substantial impact on worldwide energy production. Implementing these solutions will take dozens of years.

IT WILL BE OF GREAT BENEFIT TO KEEP NUCLEAR POWER PLANTS RUNNING AS AN INTERIM SOLUTION FOR SOME DECADES TO COME.

Meanwhile, it will be of great benefit to keep nuclear power plants running as an interim solution for some decades to come—allowing us to maintain a viable pace of economic development, while at the same time reducing our oil addiction and CO_2 emissions.

Professor Deutscher thanks Roger Maynard for his in-depth discussions of the role of entropy in climate change. The authors would like to thank Ram Adar, Loic Auvray, Roy Beck-Barkai, Haim Diamant, Eliezer Gileadi, Bernard Holzapfel, Gilbert Morain, Ron Rosensweig, Didier Roux, Jean-Pierre Schwartz, Jacques Treiner, and Raoul Zana for their careful reading of the manuscript and helpful comments. ●