Chapter 1. Precision in energy use and generation: living more comfortably with less CO_2

'More with less' will lead us into a low-carbon future. Mankind will emit much less CO_2 while industrialized nations remain prosperous and many more people get access to satisfying levels of wealth. We put the moment of equivalence between fossil and renewable energies as early as 2040, contrary to the predictions of major scenario builders. Part of the story is that renewable energy sources, in combination with energy storage, have proven their reliability and can take off from here. But there is another, more silent revolution going on: precision energy use. Taken together, this will result in an energy system quite different from the present one. Turmoil in energy infrastructures seems to be around the corner, with many unpredictable consequences. After revolutionizing the world of communication, microelectronics will soon change many other sectors, with major effects on the energy system.

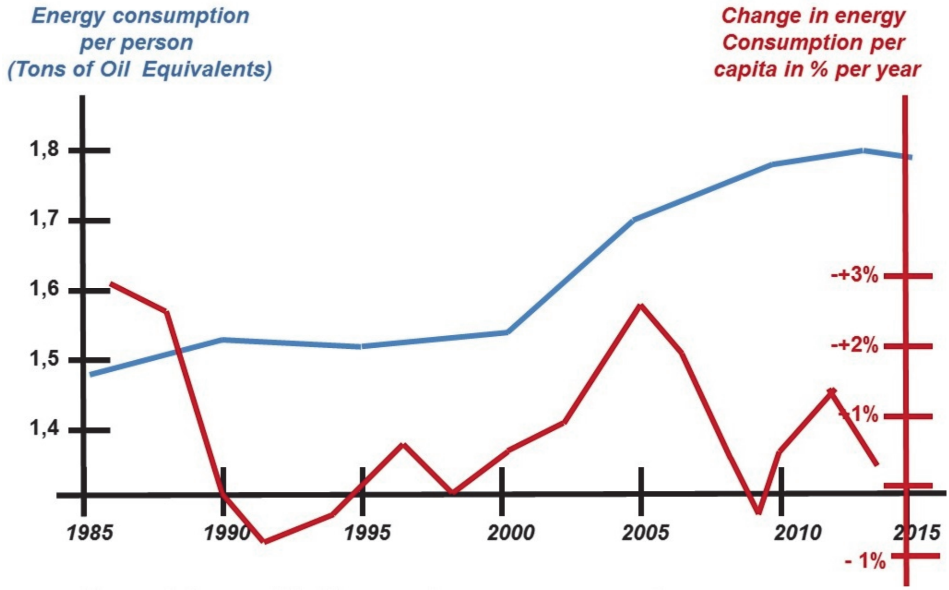

Figure 1.1. *World per capita energy consumption. Source: Gail Tverberg (www.OurFiniteWorld.com) and BP 2016 Statistical review of world energy.*

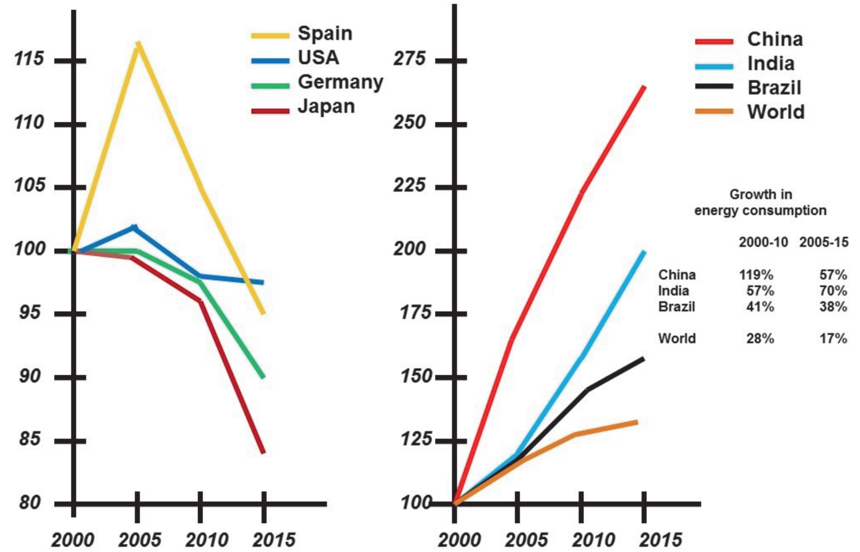

Figure 1.2. *Change in energy consumption in various countries, indexed, 2000 = 100. Only India still accelerating, others growing slower or decreasing. Source: https://yearbook.enerdata.net/.*

1.1. Peak global energy consumption, and 50% renewables in 2040

Energy is one of the areas that will witness major changes because of better precision. Firstly, precision in energy use will translate into a much slower growth of global energy consumption, or even zero growth: peak global energy consumption. Secondly, renewable energy sources will continue to grow very fast. Major energy forecasters like Shell and BP have not yet come to grips with these new phenomena; the International Energy Agency (IEA) only to a certain extent. If present trends persist, we predict that renewable energy will come at equal footing with fossil fuels (the 50-50 ratio) quite soon, say in 2040: the 50-50-40 scenario. This is far removed from official forecasts. Shell, BP and IEA all put the 50-50 ratio well after 2050.

Lower growth rates in global energy demand

Let's first look at energy demand. We point out some trends to substantiate our views. Which arguments do we have for the idea of peak global energy consumption?

- World per capita energy consumption grew at 2% p.a. over the past 40 years, but this has come to a standstill, it has not grown for 3 consecutive years. This is a very short period to establish a trend, but we judge this to continue: growth in global energy consumption in the near future will just be at the rate of population growth, for reasons that we will explain in this and the following paragraph. See figure 1.1.
- This does not mean that the global economy has come to a standstill: economic growth does not always result in increased energy consumption – mankind uses energy more efficiently every year. Over the past 20 years, the energy intensity of the world economy (the amount of energy required to produce $1 of national product) decreased by some 1½% p.a. We need less and less energy to produce the same amount of output.
- So a global economy that grows by 2% p.a. per capita (and this seems to be a reasonable estimate for the near future), will require an amount of energy per capita that grows by just ½% p.a. And the trend is downwards. As said before, growth in this area has been zero for the past 3 years.
- On top of that, world population growth has slowed down as well, and will slow down further. World population is expected to peak between 2040 and 2050 at 9 to 10 billion people.

Country	Energy consumption In million tons of oil equivalent 2000	2005	2010	2015	Energy consumption Index, 2000 = 100 2000	2005	2010	2015
Spain	122	143	128	116	100	117	105	95
USA	2,269	2,320	2,216	2,196	100	102	98	97
Germany	337	336	327	305	100	100	97	90
Japan	519	521	499	435	100	100	96	84
China	1,183	1,980	2,588	3,101	100	167	219	262
India	441	518	693	882	100	117	157	200
Brazil	188	216	266	299	100	115	141	159
World	9,791	11,355	12,540	13,423	100	117	130	135

Table 1.1. *Change in energy consumption in some representative countries. Source: https://yearbook.enerdata.net/.*

Year	IEA low	IEA high	Actual	Trend	IEA NP
2000	8,817	9,348	9,179		
2010	11,132	12,842	12,730		
2015	13,488	14,071	*13,900		
2020				14,773	14,922
2035				16,598	17,197

*Our estimate, IEA NP = New Policies

Table 1.2. *Forecasts and realisations in world energy supply, in million tons of oil equivalent (mtoe). Source: IEA. Energy consumption figures differ slightly because of different definitions.*

- Both trends taken together will result in peak global energy consumption by 2040 or a lot earlier.
- China is the energy efficiency champion of the world by far. In 2015, its energy efficiency rose by a staggering 5.6%, according to the IEA. At such rates, China's energy consumption will not increase much anymore from here. Whereas in the industrialized world, total energy consumption has been stagnant or falling for quite some time already.
- A historic analysis of the growth of world energy consumption, see figure 1.1, confirms this view, as well as a breakdown of energy demand figures by some representative countries, see figure 1.2. and table 1.1.

Therefore, a very coarse common-sense energy scenario might see world energy consumption per capita remain constant. This would result in global energy consumption to grow by some 19% till 2035; from ca. 13,900 million tons of oil equivalent (mtoe) (2015) to ca. 16,600 mtoe (2035). This equals an overall growth of about 0.8% p.a. Extrapolating along this trend curve, we will attain 0% growth in 2042. From then onwards, the curve predicts that world energy consumption will not grow anymore and might even fall. It would peak 24% higher than in 2013 at a level of 16,790 mtoe. In 2035 it would amount to 16,598 mtoe.

Leading scenario builders miss the point

How does this compare to scenarios for world energy consumption by the major forecasters in this field, Shell, BP and IEA? Our scenarios have a rather good fit with the latest IEA 'New Policy' scenarios (the last freely available scenario study is from 2012). And in the past, IEA projections had a good fit with actual outcomes as well, see table 1.2. Here, we listed as 'IEA low' and 'IEA high' the lowest respectively highest projections over the years.

IEA has a good track record in forecasting world energy consumption, although it struggled to forecast the high growth rate between 2000 and 2010, resulting from China's (and to a lesser extent India's) rapid industrialization. It forecasts a slowdown in growth now, as we would expect as China's energy intensity quickly falls. The good news here is that world energy consumption will stabilize. The bad news is that this will not be at a level sufficiently low to restrict global warming to 2^{o}C. So we do need extra policies that reinforce the slowdown in growth that we highlighted. The IEA 450-scenario (so called because its goal is to stabilize CO_2 concentration in the atmosphere to 450 ppm) projects 14,793 mtoe in 2035, which implies that global energy consumption would have to peak by 2020 already in order to prevent irresponsible global warming.

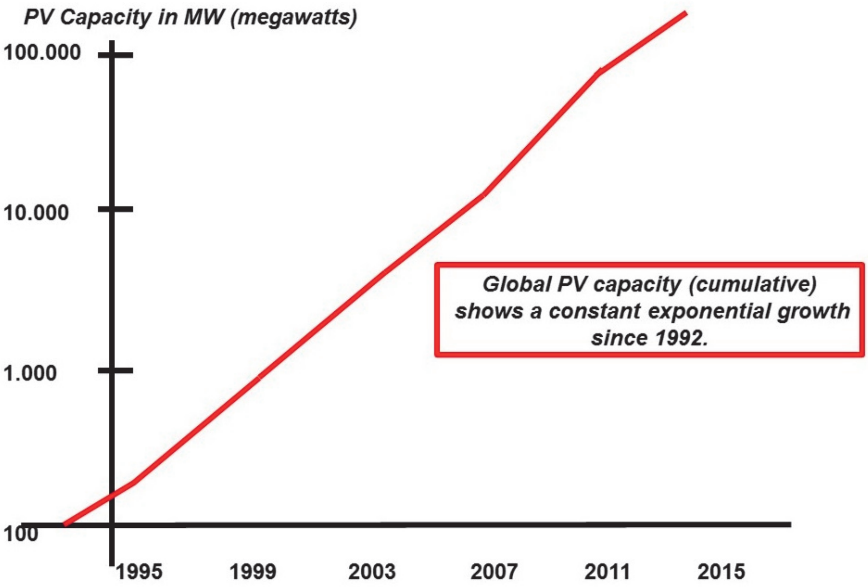

Figure 1.3. *Global PV capacity. The slope of the semi-logarithmic curve indicates an almost constant growth of close to 30% p.a.*

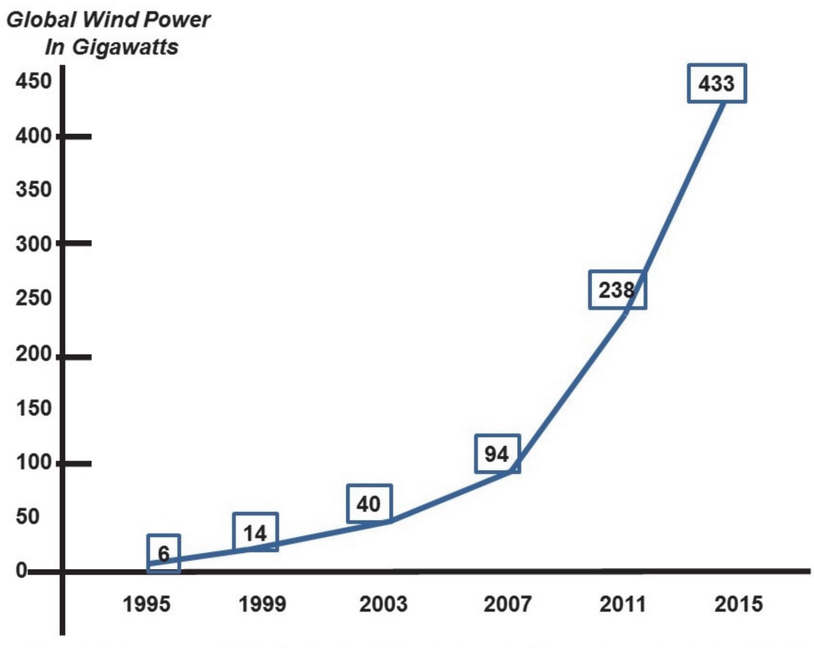

Figure 1.4. *Global wind turbine capacity. The curve shows a growth of 30% p.a. slowing down to ca. 17% p.a. Source: GWEC Renewables 2016 Global Status report.*

Shell and BP project even higher energy demands. The latest BP scenario shows a global energy demand of almost 18,000 mtoe in 2035, and still rising. In its various recent scenarios, Shell predicts as much as 60% more energy demand in 2040, and 80% in 2050. In order to counter worries about CO_2 emissions, Shell proposes the large-scale deployment of carbon capture and storage (CCS), but BP seems to be much more sceptical about this. And so are we. But we are confident that global energy demand will stabilize in the near future; and that this will contribute a lot to the maximization of CO_2 emissions that the global community has pledged to pursue at the 2015 Paris summit.

Sustainable energy continues to grow fast

The next question is: will renewable sources grow fast enough to reach the equivalence of fossil and renewable energies (the 50-50 point) as early as 2040 (the 50-50-40 energy scenario)? Over the past decade, traditional forecasters have made a mess in their treatment of growth of sustainable energy sources. They consistently underestimated the contribution of these sources, in particular of solar energy. Shell tells us that solar energy (photovoltaic, PV) will only take off after 2030, rather strange for an energy source that has shown a consistent 30% growth over the past 25 years and a strong and consistent cost reduction. IEA's track record in this field is notoriously bad. Each year, the agency has had to revise its forecasts upwards. The actual development of solar energy closely follows the agency's 450 scenario, that would keep CO_2 concentrations in the atmosphere below the 450 ppm level. And BP projects a sharp decrease in the growth rate of all renewables taken together, from 15-20% to below 10%.

BP tells us that it takes a long time for new energy technologies to penetrate the global market, and shows the example of oil and gas that preceded renewable energy. New energy sources need to develop new funding, they say, and this takes time. And equally importantly, the existing energy system, with many long-lived assets and much capital invested, will put a brake on the development of the new system. But we judge that BP is splitting hairs here. Market penetration for oil and gas was difficult primarily because oil companies would have to explore them. Once exploration technologies had matured, these technologies quickly penetrated into the market and surged. But solar and wind energies do not have to be explored. They are here, ready to harvest, so to speak. So as soon as solar and wind energies are propelled by market demand rather than by policies and subsidies (and this is increasingly true), there are no technological hurdles that stand in the way of an accelerated growth.

Nor do we see major hurdles for solar and wind energies to penetrate further into markets later down the road, as their technologies become more mature. Yes, they will clash with existing infrastructure and its regulations. But there are technological fixes to overcome these problems. And whereas oil and gas production becomes increasingly difficult over time (recovery in oceans, in polar regions, fracking, LNG transport etc.), the reverse is true for solar and wind energies. Mass production is likely to emerge and this will drive prices further down. As industry starts to earn more money, it can devote more funds to developing better devices, once more accelerating growth. Industry may run into materials shortages (e.g. rare earth metals), but so far it has managed to find innovative solutions. Regulatory obstacles, like zoning regulations and access to the grid, will be the most persistent ones, but in the end these too will give way to market demand. In sum, we judge that market penetration will become easier as market shares grow. In retrospect, the first percent might have been the most difficult one. Sustained high growth rates will turn renewables into the main energy sources within a few decades. Present trends for solar energy and wind power as shown in figures 1.3 and 1.4 speak for themselves.

The 50-50-40 scenario

Where will this take us? We cannot produce a full energy scenario. The major scenario builders have tens of staff that work all year on this subject, on a very detailed, sector-by-sector and country-by-country basis. We just point out some important trends.

- Even though solar and wind energies are still very small on a global scale (1% resp. 3% of global electricity production in 2014), sustained high growth rates would change this very quickly (but of course, growth rates will slow down sooner or later).
- A sustained solar growth rate of 30% would allow PV to cover 100% of all electricity demand (at the 2014 level) in 18 years, i.e. in 2032.
- A sustained wind growth rate of 15% would allow wind energy to cover 100% of all electricity demand (at the 2014 level) in 25 years, i.e. in 2039.
- Electricity's share in total global energy consumption is a mere 15% now, so even if 100% of global electricity were sourced sustainably, a lot more would have to be done to reach the 50-50 ratio. But the share of electricity will rise, mainly because of a rise in deployment of electric cars, heat pumps and electronic equipment.

- Growth of sustainable electricity production by itself will reduce total energy consumption, as it is much more efficient than electricity production from fossil sources: losses in the system will be lower.
- There are many more sustainable energy sources than PV and wind. Hydropower, that produces 17% of global electricity now, might still grow considerably. We have biomass and biofuels. And solar concentrating power.
- Low-level heat (by far the biggest slice in the heat market), now mainly provided by fossil fuels, can be provided by solar heat production, partly together with electricity; by heat pumps, with or without seasonal storage; and by geothermal energy.
- Nuclear energy, that other CO_2-free energy source, will continue to deliver electricity.
- By 2040, new technologies will have been developed, like bio solar cells and blue energy, and new devices to harvest wind energy.

We might see 50-50 as early as 2040. But that will not be the end of fossil fuels. They will be needed for a long time for specific tasks. Like producing concentrated heat. Or propelling heavy transport. On the other hand, we see no real obstacles to a dazzling take-off for renewable energy technologies, in particular for solar energy, as we will show later in this chapter. And always keep in mind the important role that precision, i.e. better energy efficiency plays in our energy systems, year after year.

1.2. The silent miracles of energy efficiency

In the field of energy, precision is called energy efficiency. This is a great driver behind peak energy consumption. Often, this subject is treated rather condescendingly, called 'energy conservation'. Take for instance the typical trajectory followed by scenario studies. First, analysts establish the probable energy demand under the conditions stipulated, in this they already take 'energy conservation' into account. Then, they fill up this energy demand, that they now assume to be fixed, with energy sources. This procedure is fundamentally flawed: at any moment, investments in better energy efficiency can be pitched against more expenses on energy sources. If for any reason (price, availability or climate problems) energy use poses problems, we can always return to energy efficiency and investigate to what extent it can alleviate these. The only limits to this are the laws of physics; but hardly anywhere do energy efficiencies approach physical limits (the only exception may be lighting, LED lamps transform up to 80% of incoming electricity into light; but often even here, much can be gained in

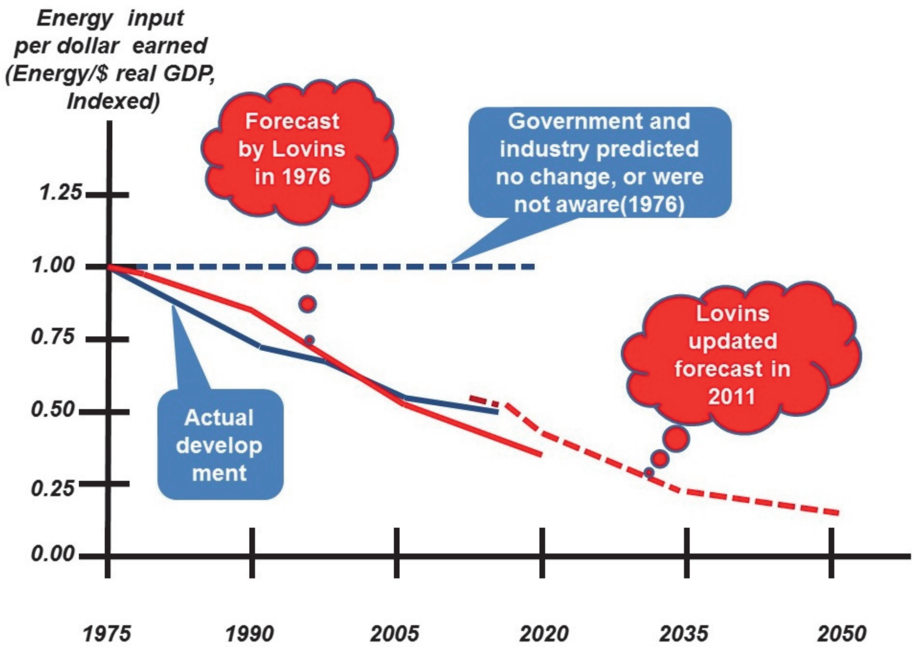

Figure 1.5. *US energy intensity – forecasts vs. actual. Source: Amory Lovins*.

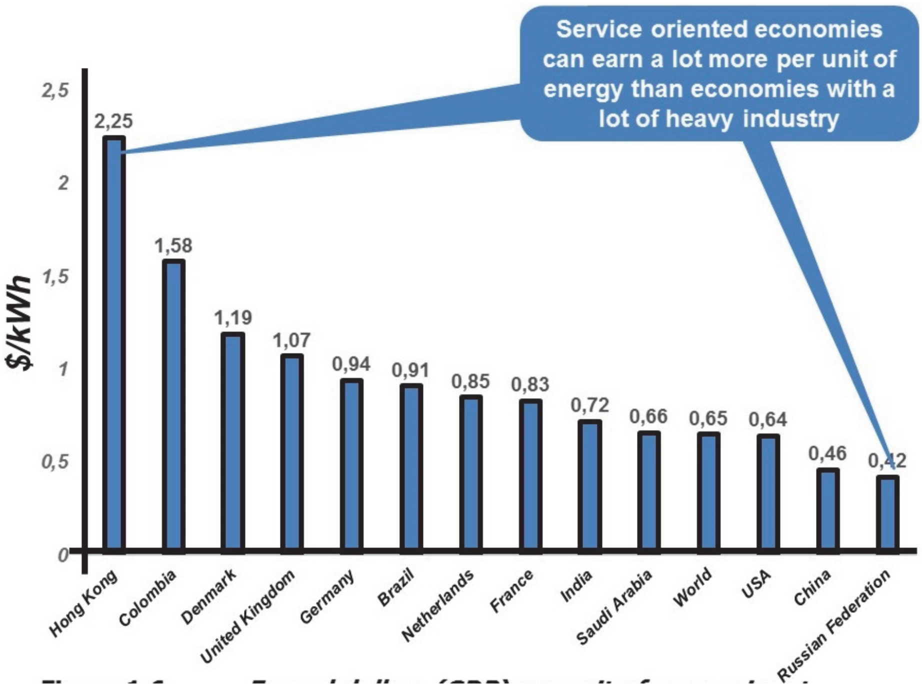

Figure 1.6. *Earned dollars (GDP) per unit of energy input. Source: World Bank data.*

efficiency by better lighting systems and adjusted lighting levels, many buildings are lit at unproductive times, places and levels).

The vast potential of energy efficiency

Therefore, contrary to public belief, there is a vast potential of energy efficiency to be gained. Take transport. Often, the energy efficiency of a transport system with internal combustion engines is put around 20%. But this merely regards the efficiency 'from well to wheel'. If we also take into account the efficiency of logistics, both in freight and in passenger transport, the energy efficiency of the system might be as low as 1%. First, a lot of deadweight is being moved around. And occupancy and utilization ratios are low, also because many return trips are empty. It is fair to say: the potential of energy efficiency is almost endless; the only limits to it are set by the economy.

In order to picture the importance of energy efficiency, let's go back to 1975, shortly after the first oil crisis (1973). The idea had dawned on policy makers that energy availability, in particular oil, was going to be one of the most important problems for the decades ahead. How to solve it? Nuclear? Coal? Speeding up oil and gas recovery in harsh environments like the North Sea? Energy efficiency was not even on the agenda. But one American whizz kid by the name of Amory Lovins predicted that in fifty years' time, the US might need just one third of the amount of energy per dollar of GDP, or conversely that it might do three times as much with one unit of energy. He was ridiculed, and even today he, now a senior citizen but not considering retirement, is left out of mainstream policy making. In a recent column on the blog of his Rocky Mountain Institute, Lovins looks back on this episode. He thumbs his nose at policy makers who in 1975 fiercely fought his ideas. In Deuteronomy, 18:21-22, the Old Testament already asked: how to distinguish false from true prophets? And answers: look at their past predictions, have they come true? Lovins passes this test gloriously. He shows that we are quite nicely on the trajectory he foresaw; in the US in 2014, energy intensity per unit of BNP was about half of that of 1975; following this trajectory, it will be one third in 2025; see also figure 1.5. And Lovins suggests that energy efficiency might increase again by a factor of 3 between now and 2050. Therefore, he argues that increased efficiency matters. Between 1974 and 2010, he writes, the drop in energy intensity (energy use per dollar of GDP) was the largest single energy resource in the 11 IEA member countries – 'bigger than either oil or the combined contributions of gas, electricity, and coal.' Energy efficiency, he states, 'has fuelled half the world's growth in energy services since 1970 – as much as all supply expansions. Who knew?' Viewed again from the other side, if the US had not improved its energy intensity, it would now have needed twice as many nuclear power stations, twice as much shale gas etc.

So, who would dare to call the contribution of energy efficiency to be insignificant? And all this has been accomplished with just a tiny bit of policy support. Energy efficiency was propelled by businesses and individuals who made money by producing more efficient appliances, products and services. During this period, energy supply has received trillions of dollars of support: coal mines, nuclear power stations, tax credits for oil companies, direct support for energy use to keep prices low in many countries. Often, energy efficiency was merely a footnote in official policies. Energy efficiency, so to speak, was left on its own, fought an uphill battle – and won gloriously.

Opportunities for everyone

Precision energy use has the future. In Europe, chemical industry has cut down energy use by 20% in twenty years' time while doubling production; in other words, energy efficiency more than doubled. This process has by no means come to an end: with better catalysts and the advent of enzymatic processes, chemical industry will move to much lower temperatures and less energy consumption as we will show in chapter 3. There are good prospects for better energy efficiency in other sectors as well (see also figure 1.6). Sensors, that restrict energy use to times and levels really required, have only just started making their advance. Even in moderate to cold climates, construction costs of zero-energy homes (with some government subsidies) are estimated to be just 10% over those of traditional houses (and will not incur energy bills any more). Retrofitting existing houses and buildings, with major efficiency improvements, can be cost-effective now. Newly constructed homes, buildings and greenhouses might even be going to produce, rather than consume energy. As better technologies are developed, proposals such as these are bound to multiply. Lovins judges that 'the low-hanging efficiency fruit keeps growing faster than it's harvested.' Moreover, in his latest book Reinventing Fire he argues that it will be corporate profit, rather than government policies, that will propel this new round of energy efficiency improvements.

All industrial sectors have long lists of energy efficiency improvements. Many industries consider a major overhaul of production technologies, particularly in order to reduce energy and resource use, under names like process redesign, process intensification or other optimization programs. Developing countries that do not have to drag with them old and inefficient equipment and infrastructures might even be quicker to adopt newer or state-of-the-art and efficient technologies. We can also have a look at the big chunks in world energy use. Take cement production, responsible for a stunning 5% of total global CO_2 emissions, according to IPCC. In search for emission reduction of greenhouse gases, we would have thought that the discovery by Drexel University of a cement that saves 97% of energy demand in the production process would trigger much interest, but this seems to have passed almost unnoticed. Steel production, responsible for 6 to 7% of global CO_2 emissions on the other hand, continuously improves its energy efficiency and curbs its CO_2 emissions, for instance by better energy recovery: heating incoming material with the heat of processed material that has to cool down. IPCC estimates that merely installing state-of-the-art technologies world-wide could reduce the energy requirement of world steel production by one quarter, and new technologies are still in development. Fertilizer production accounts for a full 1% of global energy demand. Biotechnologists work hard to develop crops that could take up nitrogen from the air, just as legumes, thereby saving much nitrogen fertilizer; but they admit that it may take decades to have such crops commercially available. In agriculture, precision technologies, in particular in horticulture, have reduced fertilizer use by 10 to 40%. Indeed, low hanging fruit is still available.

A special efficiency enhancing device is the heat pump. Essentially, it is a reversed refrigerator: it heats up a space (notably a home or a building) instead of cooling it down. It’s like having the back of your fridge in the room and the inside of the fridge outdoors. Heat pumps can use any source of ambient energy (like the outside air, even if the temperature is low) and ‘pump’ up the heat contained in it. The typical efficiency of an electric heat pump is between 2 and 3, i.e. every kWh of electricity used by the pump will produce 2 to 3 kWh of heat inside your home. Heat pumps (fig. 1.7 – 1.8) are particularly effective when temperature differences are moderate; therefore, often it is a better idea to use the heat stored in ground water (temperature 10-15^{o}C) than that in the air, that can be very cold, particularly when you most need the warmth. Overall system efficiency goes through the roof with solar or wind powered heat pumps. And even better efficiencies would be delivered by a system that stores heat in ground water in summer and extracts it with heat pumps in winter. Such systems are bound to flood the market soon. Moreover, heat pumps can be very effective in an industrial setting. Many industries produce much waste heat of low temperature, whereas they need heat of higher temperatures; heat pumps are very efficient devices to bridge this gap.

Precision systems

Let’s also have a look at the effect of microelectronics. Low-voltage electricity is of great importance in all our precision technologies: sensors,

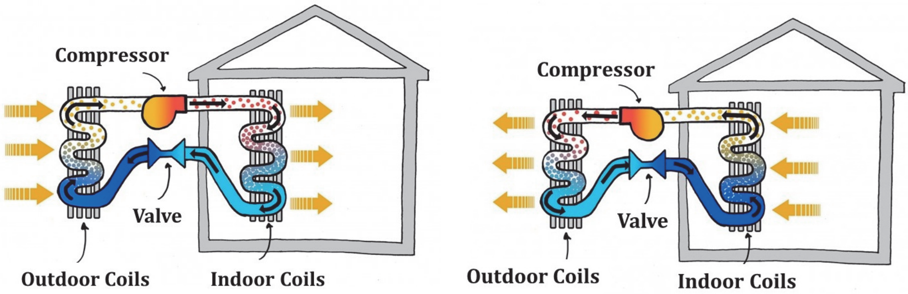

Figure 1.7. *Heat pumps, operating in winter (left) and in summer (right). The compressor 'pumps' energy. In winter, it withdraws heat from a low-temperature outside source (air, ground water or surface water – this will cool down somewhat further) and pumped at a higher temperature into the building. Just like a refrigerator, but in reversed direction. Because the source of the heat is an outside reservoir, the amount of heat pumped into the building can exceed the energy used by the pump: most heat pumps have an efficiency higher than 1. In summer, the system can work along the same principles but in reversed direction. Images: Wikimedia Commons.*

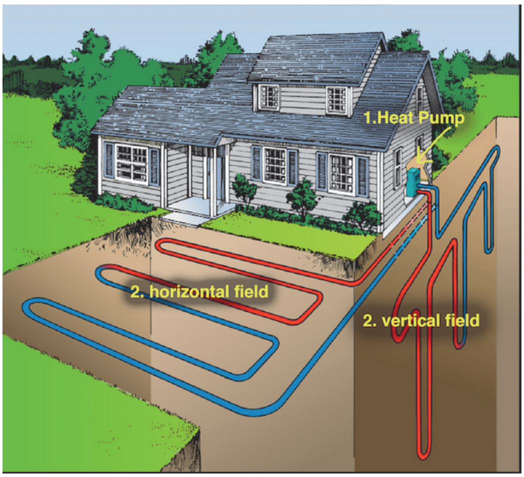

Figure 1.8. *Heat pumps coupled to seasonal heat storage make an efficient year-round climate control system. In summer, the heat pump withdraws heat from the house and stores it underground; in winter the heat pump withdraws the heat from the storage and pumps it back into the house. Image: Wikimedia Commons.*

nanotech, data handling, drones, internet of things, 3D printing and all equipment required in monitoring or improving the efficiency of our energy infrastructure. Microelectronics have revolutionized the world of communication and the effect on other sectors of society is yet to come. In the chapters to come we will show its great effects on sectors like agriculture, food supply and health care. With microelectronics, we can monitor the behaviour of plants, animals and people, allowing made-to-measure services, with higher added value and less energy use. Some of these applications might feel as more of the 'big brother watching you' pressure, but they can also serve goals like personal control over one's own life, and the freedom to arrange one's life making use of one's own resources, including energy resources like solar panels.

It's not just precision in energy use that will be mounting – we will also witness much better precision in the interface between energy production and energy consumption, particularly in the electricity sector. This is triggered by the intermittent nature of solar and wind energy production. Tuning of electricity demand to electricity production with smart instruments in so-called smart grids will save a lot of storage capacity, or of reserve capacity elsewhere in the electricity system. The country that moves fastest in this area is Denmark, that has invested much in wind energy over the past two decades. Tests have shown that much precision can indeed be attained in this field if automatic devices control electricity consumption, and that storage of excess electricity in the batteries of electric cars will further enhance overall efficiency. In this way we can arrive at not just precision use, but at a precision system as well. In many publications on the prospects of solar and wind energies, the importance of this adaption of the grid to a precision system is not highlighted – but it is an essential prerequisite for a major share of sustainable low-carbon electricity. We will elaborate on this in our paragraph on energy infrastructure.

Lifestyle can help

Please note that in what we have said so far, we did not include lifestyle changes. Opponents of the importance of energy efficiency often argue 'that people do not wish to make lifestyle changes'. Like: lower the temperature of their homes, buy more efficient (and smaller) cars, refrain from speeding and unnecessary acceleration, go on holiday by car instead of by plane, etc. But the cause of energy efficiency is not really dependent on all this. Although – people do make lifestyle changes. Many young people are not hooked on their car anymore; they happily share it with others, borrow one from friends or hire one from complete strangers living nearby. They become agnostic as to transport mode: choose whatever suits

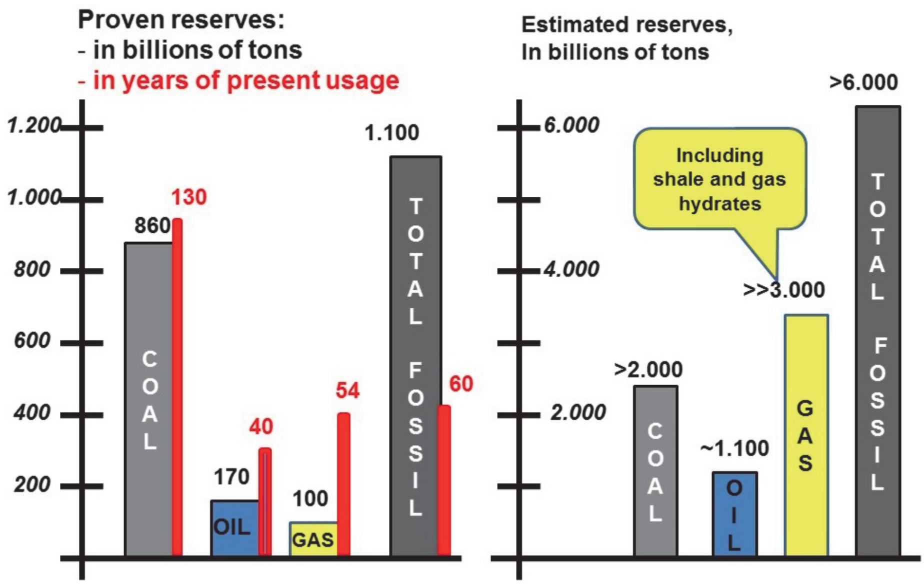

Figure 1.9. *Fossil energy reserves (in billions of tons). Various sources.*
Note: *estimated fossil reserves will account for 300 years of use at present levels.*

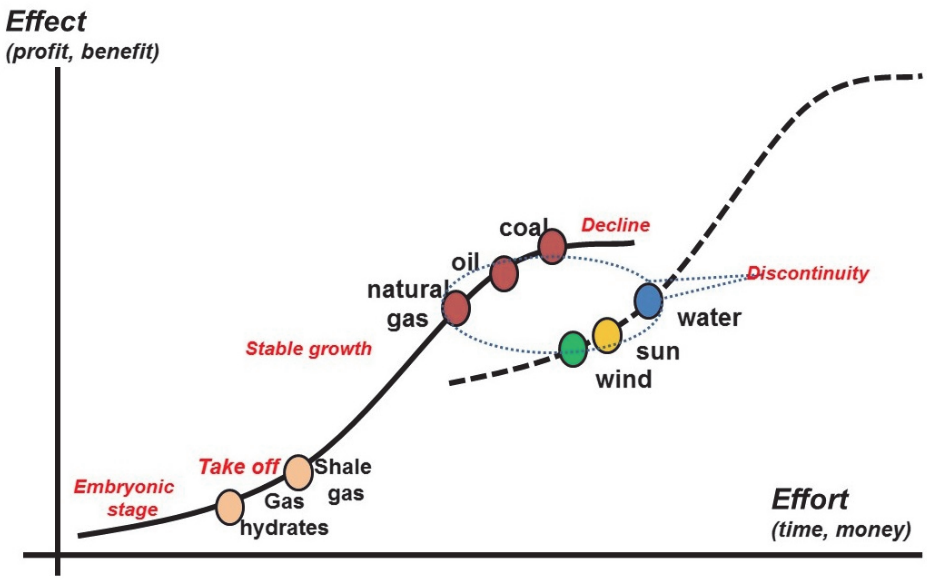

Figure 1.10. *S-curves as used in strategic energy discussions. The aim is to predict discontinuities of major importance to strategy.*

them best in the circumstances, including energy efficient public transport. Sharing of cars, and of appliances in general, will lower the demand for equipment and reduce energy consumption. We also notice that people's mind-sets are changing as they begin to get a real experience of climate change (see next paragraph). We feel that if there will be any surprises in the development of energy use in the decades to come, they will be in increasing energy efficiency and decreasing energy use.

1.3. A transition ready for take-off

Mankind produces way too much CO_2. Its concentration in the atmosphere keeps on rising; so far, anti-emission policies have been blatantly ineffective. The Paris 2015 agreement has kindled new hope, but the agreement is primarily a declaration of intentions – it will have to be strengthened by execution plans. A sufficient number of countries, together responsible for at least half of global CO_2 emissions, have ratified the agreement and it should come into force as of 2020. However, conflicts of interest and diverging perspectives might still stand in the way of effective emission reduction policies. On the other hand: if our view is correct, and if global energy demand will indeed level off, the task of lowering global CO_2 emissions might suddenly be much easier than officially thought – and certainly much easier than pessimistic NGOs predict.

Plenty of fossil energy

One factor seems to have changed decisively: the fear of shortages of fossil energy supplies has disappeared. On the contrary, there seems to be a glut of fossil fuels on the market. See figure 1.9 and table 1.3. CO_2 emission reduction will therefore not be driven by fear for fossil fuel shortages any more. This is in stark contrast with the factors that with a big bang positioned energy among the most important global issues in 1973, at the first oil crisis. The Limits to Growth study and the possibility of boycotts then framed the issue in terms of shortages. Industry and governments feared that shortages in energy supply would stall economic growth. Some analysts saw just one solution: nuclear power stations, by the dozens; and for others that was just one more energy problem. Other factors that kept energy in the forefront of policy issues, like acid rain, were successfully counteracted by technological innovations. In some countries, particularly the US that feared foreign dependence in such a strategic commodity as energy, future shortages stayed on policy makers' minds for a long time. But fear of energy dependence disappeared with the successful development of shale gas and shale

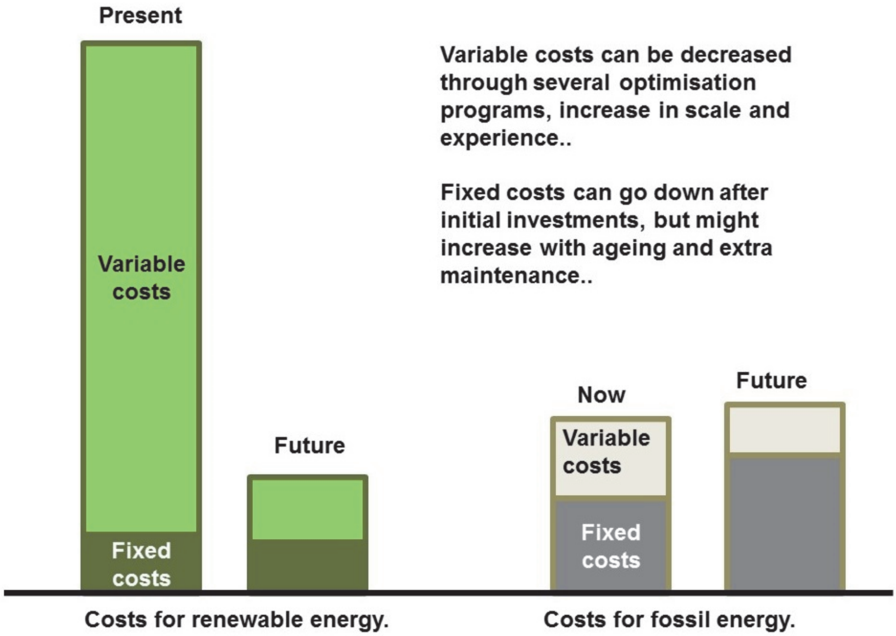

Figure 1.11. *Fossil energy producers know that their costs will rise, this hardly needs an explanation. Renewable energy producers are at the start of their learning curves and have many costs that will disappear or be reduced over time: development costs, up-front investments, pilot installations, manual labour to be substituted by automation and robots. They can also somewhat reduce their fixed costs by scaling up and mass production. Fixed costs usually define the level at which incumbent producers will defend their positions.*

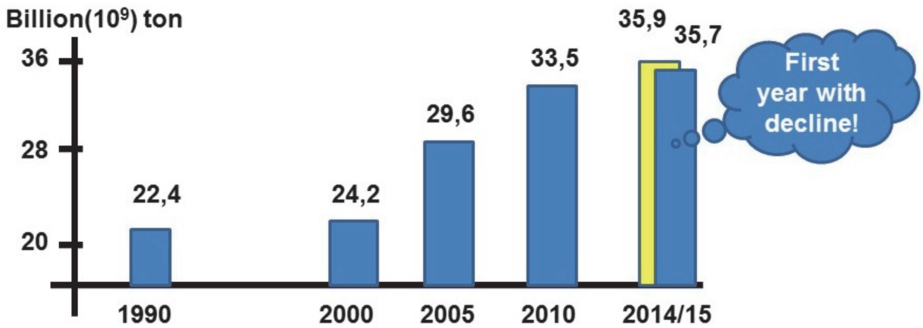

Figure 1.12. *Global energy related CO_2 emissions. Source: www.ipcc.org.*

oil. As economic reasons to address energy have become less important, these problems now have given way to the issue that overshadows them all: climate change.

Energy source	Proven reserves		Estimated reserves
	Billion tons	In years of present consumption	Billion tons
Coal	860	130	> 2,000
Oil	170	40	~ 1,100
Gas	100	54	>> 3,000
Total fossil	1,100	60	> 6,000

Table 1.3. *Fossil energy reserves (in billions of tons). Various sources.*

Climate change has become a public issue

Just five years ago, climate change was mainly a concept in scientists' minds. They had provided scientific evidence for the greenhouse effect, and shown that the consequences were likely to be severe. But their main arguments were about phenomena far off, like the melting of Greenland's ice cap. Now in many countries, people actually experience unusual natural phenomena directly attributable to climate change: droughts, flooding, hurricanes, intense rainfall and storms never seen in that season, extreme heat or cold, etc. The idea that we should do something about it (and that it's not 'just the weather') gradually gets hold of people's minds. We have no idea yet what this will mean for the future, but we feel that there are no stronger change agents than ideas in people's minds. Technological developments nicely tune in into this development. In almost all economic sectors, energy efficiency technologies keep on being developed, and renewable energy production technologies (particularly solar energy) advance at an unprecedented speed. As public opinion gradually turns to taking climate change seriously, there might arise much willingness to use them.

Even though the international community has acknowledged the severity of the greenhouse effect, many individual governments still have a problem to adhere to the policies they so boldly underwrote in Paris. There is a gap between words and deeds. The same holds true for part of the business community. This community has acknowledged the threats of climate change: the 2016 edition of the World Economic Forum's annual Global Risks Report lists 'failure of climate-change mitigation and adaptation' as the greatest risk facing the world over the next 10 years (the collective judgment of 742 surveyed experts and decision makers drawn from business, academia, civil society, and the public sector). But many individual companies do not include climate issues in their policies, although an increasing number of large international businesses have CO_2 limitations in their strategies. Partly of course, this results from our system that is tuned towards the short term: next quarter's financial results (in business), one's position in the next elections (in politics). If there is no short-term gain, it is hard to pursue policies that are beneficial in the long run. Moreover, in 2008-2012 there was a serious financial crisis going on, and as climate change did not make itself acutely felt, this crisis got all the attention.

The turning point

The Paris climate agreement should be the turning point (see also figure 1.10). Even though its substance is not very surprising, its strength lies in the far-reaching agreement between the great majority of countries. We should now see effective steps to stop the earth from heating up. Of course, the approval of the major powers, USA, China, Russia, the EU, has been decisive; the Paris agreement therefore is much stronger than the preceding Kyoto protocol. In particular the support of the two major countries responsible for greenhouse gas emissions, China and the US, has meant a lot. The new US administration might very well delay further plans, although all participants have agreed to formulate plans that will keep global warming within 2^{o}C, or rather even 1.5^{o}C. Preventing CO_2 emissions will make the most important contribution. Better energy efficiency and a shift from coal to natural gas, emitting just half of the amount of CO_2 per unit of energy produced, are the most important measures, followed by development of renewable energy sources: solar, wind, water. The agreement also specifies financial support for poor countries, enabling them to take part in the action, and to mitigate the effects of climate change on their developing economies.

Industry's views have started moving as well. Indeed, the Paris agreement may have been influenced decisively by changing industrial perspectives. Industry can very well disentangle itself from public bickering and keep an eye on business opportunities. In fact, industry has already made huge investments anticipating new business arising from the climate issue and will therefore try to prevent political bargaining. Damages done by extreme weather (or the prevention thereof) require new public investments. The flooding of English valleys was extremely disagreeable but will lead to many new infrastructural projects with