Why CO2 Should Worry You (Yes, Sceptics Too!)

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This article is also available in Dutch. The footnotes provide additional background information, and can safely be skipped or read separately.

I had originally planned to write my first article on a different subject, the ecological footprint. But World Climate Action Day and the UN Climate Summit last month persuaded me to write about CO_2 instead. I must admit, I think that maybe too much emphasis has been put on climate change over the last few years. It is but one aspect of an underlying problem, that of energy sources and energy use. Moreover, it distracts from other important problems, such as land use, biodiversity decrease and ethical issues. Sometimes one gets the impression that sustainability is equal to reducing CO_2-emissions, which is obviously not the case. Many people are tired of the discussion surrounding climate change. The arguments of climate sceptics and "climate deniers" have been quite effective in generating doubt among the general public. More than half of people worldwide do not believe climate change to be a serious problem.[1] Yet, despite all this, it is still important to talk about CO_2. Even if you doubt that climate change occurs, there are still good reasons to seriously reduce CO_2 emissions as soon as possible.

Six degrees and four kilos

So what's up with carbon dioxide? Relatively speaking, there's only a tiny amount of CO_2 in the air, less than one part in a thousand. In the natural situation[2] this is around 0.03% by volume, or ±300 ppm (*parts per million*). The rest of the air consists mostly of nitrogen gas (78%), oxygen (21%) and the noble gas argon (0.9%). So there's really not a lot of carbon dioxide in our atmosphere, but still this little bit is actually rather important. For plants and algae, this smidgeon of CO_2 is the source of nearly all carbon, the main building block of organic molecules. And together with water vapour and a couple of other gases, CO_2 is responsible for what we call the *greenhouse effect*.[3] And this is a good thing. Without this effect, things would be rather chilly on Earth, on average around -18°C. Thankfully this is not the case, average temperatures are a comfortable 14°C. The natural greenhouse effect therefore contributes roughly 33°C to our climate, which is important to keep it habitable.

There is, however, one problem: The magnitude of the greenhouse effect depends on *how much* of the various "greenhouse gases* we have in our atmosphere. And these amounts are not exactly constant. Before the industrial revolution, the air probably contained around 280 ppm CO_2 (on average). But since then, this concentration has been rapidly increasing. Currently it's over 400 ppm, with an annual increase of 2 ppm (and rising). CO_2 contributes roughly 6°C to the (natural) greenhouse effect, but this contribution is increasing…

Of course our atmosphere is not merely a reservoir that is slowly filled by various gases. Living organisms and other natural processes constantly exchange substances with the atmosphere. Plants and algae need carbon to grow, and as already mentioned, they get this from the air in the form of CO_2. However, breaking this CO_2 down into carbon and oxygen requires energy, and plants get this energy from sunlight. Animals do the opposite: they eat plants, and use a small fraction of the carbon from plant molecules as building material. What happens to the rest of the carbon, you may wonder? It is used as an energy source, to stay alive! The carbon reacts with oxygen from the air, which results in CO_2. This releases energy, in fact the same energy that plants needed to break the CO_2 apart in the first place. The reaction of (in this case) carbon-based molecules with oxygen is also known as *oxidation*, or more commonly, *combustion* or *burning*. An average human combusts quite a lot of food every day, and from it produces around 1 kg of CO_2. This means that on an average day, the carbon dioxide you exhale roughly has the weight of a pack of sugar!

To put it differently, together we humans exhale around 7 billion kilos of CO_2. That may sound like a lot (and it is), but it's only around 1% of the roughly 575 billion kg CO_2 that all living beings pump into the atmosphere on a given day. And us living beings have been doing this for quite a while, yet the CO_2-concentration in the air remains remarkably constant. The reason for this is that plants, algae and oceans also remove roughly 589 billion kg CO_2 from the atmosphere per day. Natural emission and absorption of atmospheric CO_2 are therefore almost in balance.[4] However, a significant source of extra CO_2 was added quite recently. Below ground are all sorts of fossil remains of plants and animals, buried in the course of millions of years. In some spots, these remains have formed a reservoir of concentrated carbon compounds. We know this as oil, natural gas or coal. From the 18th century onward, people have begun digging up these remains. Not that we particularly enjoy digging up dead things, but burning these carbon compounds does yield a lot of energy. And we need this energy to power our modern society: Over 80% of the energy produced by humans, is produced from such *fossil fuels*. In most western countries this percentage is higher, in my home country of The Netherlands for instance it is 92%.[5]

Obviously, burning all this dug up carbon does not just yield energy, it also yields CO_2. This relatively recent source emits around 23 billion kg extra CO_2 into the atmosphere on a daily basis. This comes down to an average of 3.3 kg per person per day, three times what we breathe out ourselves. And there is no extra sink for this extra source. Worse, the Earth's capacity to remove CO_2 from the air has *decreased* in recent centuries, in part due to the large scale removal of forests. The result is that the concentration of CO_2 in the atmosphere has increased, with almost 50% in two centuries. Moreover, this increase is accelerating.

So far, this is all not very controversial. The recent increase in CO_2 can be measured, and its causes are quite well known. Less clear however, is what effect this extra CO_2 will have. One of the consequences is an enhanced greenhouse effect. This is simply because the extra CO_2 will cause extra heat to be trapped by the atmosphere. The problem is, we're not sure *how much* extra heat, precisely, and we also don't know how this effect will develop in the coming century. There is no doubt that the average temperature is currently rising.[6] We can also say with a high certainty that this is, at least in part, due to an enhanced greenhouse effect. But the climate is a complex system with many feedbacks, so what will happen in the long term? Many predictions and projections have been made, but fact is that *no-one really knows what will happen*.[7] Basically, two centuries ago we started the largest experiment in human history. And this experiment is virtually uncontrollable, the outcome is unknown and there is no panic button, should things go wrong.[8] Maybe, this should worry us.

Acid is the new base

Of course, it might just turn out fine. Maybe the extra CO_2 will hardly have an effect, and all will be tickety-boo. On the other hand, maybe it will lead to runaway climate warming, rendering large parts of the planet unsuitable for agriculture. We don't know. Personally, I think that's a *pretty big* risk to take.[9] But even if you really don't believe that CO_2 contributes to climate change, or if you believe that this will not really be a problem, there are other reasons why an increase in atmospheric CO_2 *should* worry you.

Part of the extra CO_2 that ends up in the atmosphere, will eventually dissolve in surface water. For the global temperature this is a good thing, as it reduces the warming effect. But if carbon dioxide dissolves in water, it becomes an acid, known as carbonic acid. Dissolved CO_2 is what provides the "sparkle" in carbonated water (and in most soft drinks), and carbonic acid is what gives it a slightly sour taste. Carbonated water has a pH value between 3 and 4. Luckily, surface water contains rather less carbon dioxide than carbonated water does. Most of the surface water consists of oceans, and sea water tends to have an average pH just above 8. Those of you that have paid attention in chemistry class may know that this is not acidic. Rather, it's the opposite: slightly *basic*.[10] As far as we know, the average pH of sea water has remained fairly constant over the last 24 million years or so, between 8.1 and 8.3.[11] However, over the last decades, the average pH of the ocean water has been declining rapidly, from around 8.2 to just under 8.1. The oceans are becoming less basic, or to put it another way, they are becoming more acidic. A 0.1 unit decrease in pH may seem minuscule. In fact, in a glass of tap water it would be. But the oceans are not a glass of tap water, we're talking about a well-buffered system with *a LOT* of water. In this situation, structural decrease in pH isn't just a tiny natural variation. And for life in the oceans, a small decrease can be a big problem, especially given how fast it's happening. Many of the smaller sea animals have an external skeleton that consists of calcium carbonate. Think sea shells, but also coral, and even some types of plankton. If water becomes more acidic, calcium dissolves more easily, and it becomes harder to build and maintain an exoskeleton. The current, rapid acidification of ocean water can lead (and probably already does lead) to large-scale extinction of corals, plankton and molluscs. And as these creatures are at the base of the ocean food chain, this could endanger the stability of the entire oceanic ecosystem.

As with the climate, no-one really knows what's going to happen to the oceans. Even scientists cannot see the future, they can only extrapolate from current knowledge and trends. It could be that the effects of increased CO_2 levels are not so bad as we expected, and we'll wonder what all the fuss was about. In fifty years we'll probably know. On the other hand, the effects could also turn out as bad as we expected, or worse. In that case, we'll probably wonder why the hell we didn't act earlier. In any case, if we just sit around and do nothing, we're taking a pretty big risk. It would be like playing Russian roulette with the stability of both the climate and the ocean ecosystem. And that's, probably, not a good idea.

War, crises and resources

Risk management isn't the only reason to curb the human emissions of CO_2. The underlying cause of these emissions, burning fossil carbon for energy, is actually a problem in itself. The largest reserves of fossil fuels are controlled by a relatively small number of regimes. And let's just say that not all of these regimes are particularly known for their reliability and good will. Attempts to control and mine fossil fuel reserves have directly or indirectly led to many violent conflicts over the last century, and have caused much human suffering. Control over large fuel reserves gives some countries a lot more influence than might be desirable, and funnels a lot of money into corrupt regimes in Africa and Latin America.[12]

Apart from geopolitical considerations, if you value economic stability and poverty reduction, it is unwise to make the world's energy supply dependent on a small number of centralised energy sources.[13] If the supply is (temporarily) reduced, or is in danger of being reduced, the price of energy tends to sky-rocket worldwide. And with increased energy prices, the price of almost every product and service goes up fast. This is what happened for instance during the oil crises of 1973 and 1979, and to a lesser extent during the food crisis of 2007-2008.

Finally, apart from practical considerations, there are also ethical considerations. We could argue that every generation should leave the world as they found it, or preferably in a better state. Currently, this is not what is happening. Granted, socio-economic factors like wealth, technology and health do tend to improve considerably across generations. But playing roulette with the climate system and the oceans, and draining fossil fuels and other natural resources, clearly isn't part of "leaving the world in a better state". We still have sufficient fossil fuel reserves to last us at least a few decades. But fossil carbon shouldn't just be considered a fuel, it's a valuable non-renewable resource. One could argue that this resource is too valuable to simply be converted into heat by burning, within a timespan of less than three centuries…

A LOT of energy

There is no shortage of arguments for why we should reduce CO_2 emissions. Unfortunately this is easier said than done! If we add all direct and indirect emissions through consumption and services, then the average Dutchman or -women emits between 38 and 46 kg CO_2-equivalent per day. This is over forty times as much as we exhale ourselves! For other western countries the figures are similar: in the UK it's around 42 kg, in Germany 41 kg, in France 36 kg, and in the US it's a bit higher, around 78 kg. Of these emissions, around 88% is CO_2, the rest is mostly methane and N_2O.[14] And the difficulty is, almost everything we do causes CO_2 emission, because everything we do requires energy. Switching to alternative energy sources is basically the only way to significantly reduce emissions. But this is not so simple, because we currently use **a lot** of energy! An inhabitant of The Netherlands directly and indirectly uses something between 100 and 250 kWh *per day*, on average.[15] Again, for other westerns countries these figures are similar. In many countries, the electricity use is only a small part of the total *energy use*. Most of the energy is used to heat houses and offices, to drive vehicles and to produce all the stuff we buy. And that energy is almost entirely derived from fossil fuels.

Actually our energy use can already be reduced by a fair amount, simply by using the energy we have in a more efficient manner. I will write about this in more detail, in a separate article. But most energy is currently being wasted in transport and in heating. Internal combustion engines use only around a quarter of the energy from their fuel for actually moving a vehicle. The other three quarters are discarded into the air as heat, a "waste" product. An electromagnetic engine is much more efficient, with up to around 90% of input power getting converted into movement. Even if you would generate the electricity using coal (which also isn't very efficient), the indirect emissions of an electrical car would still be slightly less than the direct emissions from a conventional one. So switching to electrical transport is already a good idea, even though storage of electricity is still a problem. While batteries these days are much more advanced than those two decades ago, they are still impractical and inefficient. Batteries cost a lot of energy, material and money to produce, they're heavy, charging them is slow, their capacity is rather limited and they generally last only a few years.[16] Therefore, we badly need more investment in developing alternative energy storage!

In cold and moderate climates, houses and offices are probably the biggest causes of wasted energy. In many countries, buildings are heated by burning gas. The conversion of natural gas into heat is actually extremely efficient.[17] Unfortunately though, most of this heat tends to escape from buildings pretty rapidly. It is radiated by walls and windows, and it is carried away by moving air, that escapes through cracks, holes and ventilation systems. A lot of energy can be saved by simply keeping the heat inside the building a little longer! Think double glazing, insulating walls and ceilings, closing cracks, using heat exchangers, and in general better design of new houses and offices. Technology may help, but significant energy savings can already be obtained with merely low-tech solutions like insulation. Moreover, we don't really need to obtain all our heat from burning gas, or coal, or wood. Nearly everything we do produces heat as by-product. Heat is our main "waste-product", heat everywhere in our environment, and heat is relatively easy to store and move around. By better use of heat pumps and storage buffers, we can heat our buildings with a lot less fossil fuels. Currently there is a lot of interest in placing (photovoltaic) solar panels on houses. But if you live in a moderate to cold climate and want to cut down on fossil fuel use, it makes a lot more sense to start with placing a solar heater on your roof, installing a heat buffer below your house and modifying your heating system!

Alternatives wanted

By saving energy and increasing efficiency, we can certainly decrease CO_2 emissions by a sizeable fraction. But it will not be sufficient. To drastically reduce emissions we will need to solve the underlying issue of energy sources. This will however require some technological development. Many people believe that solar and wind power can provide all the energy we need, but currently this is not the case. Perhaps they could, one day, but the windmills and solar panels that are currently on the market produce relatively little energy, do cost a lot of energy and resources to produce, take up a lot of space and are relatively expensive. Moreover, our current energy infrastructure is not suited to such intermittent energy sources. We simply have no efficient way of storing lots of energy for later use. Better alternatives for batteries will no doubt appear at some point. Better solar cell technology is being developed, for instance at institutes like AMOLF in Amsterdam. But it will still take ten to twenty years for such technologies to reach the market. And the problem is, we can’t really afford to stand around for twenty years and wait for the technology to get better. If we want to reduce our use of fossil fuels any time soon, we’d better start placing as many conventional solar panels and windmills as is practical. They might not yet contribute much to the total energy picture, but they will contribute to an energy transition. The recent increase in demand for solar panels is already driving all kinds of developments in technology and infrastructure. Yet while technological development can be fast, infrastructure will take decades to adapt. We therefore need to invest more in modifying our energy infrastructure, and looking for ways to efficiently store surplus electricity. Especially the latter, energy storage, will be one of the great technological challenges for this generation.

Apart from renewable energy sources, other technologies are being developed that may contribute to significantly reducing CO_2-emissions. A thorium molten salt reactor may be able to produce nuclear energy without many of the dangers and drawbacks associated with traditional nuclear reactors. However, this technology will still require a few decades of research and development, before it is ready for large-scale application. This applies even more strongly to nuclear fusion, which will probably require another half a century or so of research and development. Until good, large-scale alternatives are available, CO_2 capture and storage could allow us to continue using fossil energy for a few more decades, without many of the associated greenhouse gas emissions. However, capture and storage of CO_2 isn’t free. It requires 20-40% of the energy that is produced, and currently it is not financially viable.

Whatever ways we will use to produce energy in the future, it’s important that we start acting now, and it's important that don't put all our eggs in one basket. If we want to decrease CO_2-emissions within a reasonable time frame, then we should start investing now in research and development of new energy technologies, rather than stalling and protecting existing interests. In this respect, most politicians and policy makers seem to show little vision and daring. Let's hope that this will change the coming years.

And what can normal people do?

Important transitions in societies are seldom to never driven by politicians and policy makers. Important transitions happen because sufficient people want them to happen, because they can happen, or because we don't have a choice. As a citizen and as a voter you influence politics, and you influence others around you. And as consumer, employee, researcher, entrepreneur, policy maker, teacher or whatever role you may fulfil, you don't have to wait for politics, science or business sectors to start making large-scale changes. In your work and in your private life you can make choices, and in this way influence society. Granted, probably only a small part of society, but a part nonetheless. So make choices. Try to reduce your energy use, and thereby your emissions. Set an example.

I will end with a rather superficial list of things you can do to reduce your CO_2-emissions. In one of my next articles I will break down our greenhouse gas emissions from consumption in more detail, to see where the largest gains can be made. But for now, it will suffice to state that by far the largest fraction of our *CO_2-footprint* is formed by our buying consumption goods, by road and air traffic and by energy use at home. This footprint can be significantly reduced with a few relatively simple measures:

- Don't buy things you don't need. This may sound obvious, but take some time to check with yourself how many of the things you buy are *actually* required. Collectively we buy enormous amounts of food we don't eat, clothes we hardly wear, trinkets and gadgets that sit unused in a cupboard, cheap devices that are outdated or break within a few months or years, and all kinds of other stuff that we think we need, but in the end doesn't really contribute to our happiness. But all this stuff does cost a lot of energy and other resources to produce.
- If you do really need something, first see if you borrow, rent or lease it, or try to buy it second-hand.
- If you stop using stuff, don't simply throw it in the garbage. Municipal waste tends to be either burned or sent to landfill. Either way, it ends up as CO_2, methane and/or as other forms of pollution. This is a shame, because many of the products and materials that are thrown away can easily be reused or recycled in some way. If things are still remotely usable, try selling them, giving them away or bring them to a second-hand store. Outdated or broken electronics equipment should be handed in at a recycling point, as it contains precious (and often toxic) materials that can easily be reused. It will cost you a little extra effort and time, but indirectly it can save a lot of energy and other resources.

- Make sure that the walls and attic (or roof, or ceiling) of your house, apartment or room are well insulated. Close cracks and holes through which warm air can escape. Consider adapting your warm water installation by fitting a heat pump, a solar heater and heat storage. Also consider installing photovoltaic solar panels, especially if you have a heat pump. If you rent your house, check with the house owner for possibilities regarding insulation and sustainable energy.
- If you don't live in a particularly hilly area and road safety allows it, consider using a bicycle for short-distance travels. You can also consider getting an electric bicycle for longer distances, or for hilly roads. When cycling is not an option but public transport is present and bearable, travelling by train or bus is preferable to car or aeroplane. If you know your way around the train systems (especially discount tickets) and book a few weeks in advance, international travel by train *can* be cheaper than flying, or can be just as cheap. This is the case in many European countries, e.g. between cities such as Amsterdam, Berlin, London, Brussels and Paris. Over such distances, the amount of time you can save by flying is quite limited anyway, due to the overhead of getting to and from the airport and standing in line.
  Moreover, one or two long holidays are preferable to a lot of short trips, especially for intercontinental travel. And if you do travel by car, try to take as many people as you can. Using car-sharing networks such as Blablacar may allow you to reduce both cost and fossil fuel use. And who knows, you may even meet some interesting people along the way...

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Notes

[1] *More than half of people worldwide do not believe climate change to be a serious problem.*

The exact figures will vary between polls and countries, of course. A 2010 Gallup survey in 111 countries indicated that on average 42% of adults worldwide considered global warming to be a threat. Countries that scored below 50% included China, Russia and many countries from Africa, Asia and Eastern Europe. However, it also included The Netherlands, Sweden, Finland and Denmark. The US, often considered a nation of climate sceptics, actually scores above 50% when it comes to climate worries. This year's Gallup environmental poll indicates that around 56-60% of Americans are worried about climate change, while 25% do not believe global warming to be a serious problem. A study by the European Commission in 2013 found that 69% of Europeans ranks climate-change as a serious problem, 21% ranks it as a moderate problem and 9% ranks it as being relatively unimportant. Interestingly, only 25% of Europeans seem to think they have a personal responsibility in tackling climate change. A 2011 report by Nielsen states that 19% of the Dutch respondents were not worried by climate change. Moreover, 33% did not have an opinion, and 48% were worried. This places The Netherlands far below the European average. However, according to a poll by TNS Nipo in 2007 90% of the Dutch public does believe that the climate is changing, and 80% believe that humans contribute to this. But 27% of respondents was not really interested in the issue, almost half was tired of the subject and more than half was not really sure what to believe anymore.

[2]*Relatively speaking, there's only a tiny amount of CO_2 in the air, less than one part in a thousand. In the natural situation this is around 0.03% by volume, or $\pm$300 ppm.*

Obviously, there is no such thing as a "natural" CO_2-concentration. As far as we know, the atmospheric CO_2-concentration has varied a lot over the last several hundreds of millions of years. During recent ice ages it was around 180 ppm, in the tropical climates of the Mesozoic era (the Triassic, Jurassic and Cretaceous periods) it was around 2000 ppm, and during the Cambrian era it is possible that concentrations were as high as 7000 ppm. However, the world was, quite literally, a different place back then. During the last two interglacials (the periods between ice ages), atmospheric concentrations of CO_2 seem to have been rather consistently between 260 and 300 ppm. Some studies do estimate slightly higher values, above 300 ppm, but this is still significantly lower than the current-day concentration, which is over 400 ppm. Moreover, measurements from ice cores suggest that the concentration has been remarkably stable during the last few millennia, around 280 ppm. Measurements that are based on plant stomata (the openings that plants use to breathe) suggest a somewhat higher variation over the last few centuries, between 260 and 320 ppm, and concentrations up to 400 ppm during previous interglacials. This still seems to be below current-day values, and because human societies mostly developed during the last few millennia, I will consider 300 ppm to be the "natural" pre-industrial average, with a "normal" variation of 20-40 ppm around this level.

[3]*... together with water vapour and a couple of other gases, CO_2 is responsible for what we call the greenhouse effect.*

Actually this name is somewhat misleading, because the mechanism behind the greenhouse effect is different than the mechanism in an actual greenhouse. However, the effect is the same: in both cases heat gets trapped. The Earth receives ***a lot*** of energy from the Sun on a daily basis, but around half of this is immediately reflected, and the other half is fairly rapidly radiated back into space. Water vapour, CO_2 and several other gases absorb a large part of this outgoing radiation, and re-radiate part of it back in the direction the Earth's surface. This video by the TED-Ed project nicely explains how the greenhouse effect works.

[4]*Natural emission and absorption of atmospheric CO_2 are therefore almost in balance.*

Seen over longer time scales, this isn't the case of course. During the Holocene (the last 4000 centuries or so) the atmospheric concentration of CO_2 varied between 180 and 300 (possibly 400) ppm. But during the current interglacial, the CO_2-concentration seems to have been fairly stable, which suggests that emission to and absorption from the atmosphere were roughly balanced. More importantly, the historical variations that did occur, seem to have occurred relatively slowly, especially if you compare it to the rate at which the CO_2-concentration is currently increasing.

[5]*Over 80% of the energy produced by humans, is produced from such* fossil fuels*. In most western countries this percentage is higher.*

According to the 2013 Key World Energy Statistics of the International Energy Agency (IEA), in 2011 the world used around 13113 Mtoe (*million tonnes oil equivalent*) of energy from primary sources. This is roughly 152504 TWh (*terawatt-hour*) of energy (1 TWh is a billion kWh, or 3600 terajoules, and 1 Mtoe is 11.63 TWh). This comes down to 21786 kWh per world citizen in 2011, or an average of 60 kWh per person per day. Of this energy, 31.5% comes from oil, 28.8% from coal and peat, and 21.3% from natural gas. All together, 81.6% of the energy we used in 2011 (124443 TWh) was derived from fossil fuels. The rest was mostly derived from biomass and waste material (10%), nuclear fission (5.1%), hydroelectric power (2.3%) and "other sources" (1%). This last category includes renewable energy sources, such as solar energy, wind power and geothermal energy. It's clear that, at a global scale, sustainable energy sources do not contribute significantly to our energy supply. The main renewable energy sources are firewood and hydropower, and both of these sources are often exploited at the expense of natural ecosystems and small communities.

A part of the energy from fossil fuels is converted into electricity, whereby a sizeable fraction (around 60%) of the energy is lost as heat. Due to such losses, around 8918 Mtoe (103716 TWh, or 68% of the primary energy) was available to end users, in the form of oil (40.8%), electricity (17.7%), natural gas (15.5%), biomass and waste (12.5%), coal and peat (10.1%) and other sources (3.4%). Oil is mainly (62.3%) used for transport, and gas, biomass, coal and peat are primarily used to produce heat for industry, offices and households.

In total, burning non-renewable energy sources in 2011 caused 31342 Mt (megatonnes) of CO_2 to be emitted, around 92% of total human CO_2-emissions, and 64% of total human greenhouse gas emissions. Of these emissions, 44% comes from burning coal and peat, 35.3% from oil, 20.2% from natural gas en 0.5% from waste and other sources.

Around 40% of our global energy supply (5239 Mtoe in 2012) is used by the 34 relatively wealthy OECD-contries (the Organisation for Economic Co-operation and Development). These countries represent roughly 18% of the world population (1.26 billion people in 2013). The average energy use per OECD-citizen is therefore more than two times the world average, around 48356 kWh per person in 2012, or 132 kWh per person per day.

In the Netherlands, the gross energy use in 2012 was 951 TWh (according to Eurostat). Of this, around 92% is derived from fossil fuels: 41.4% from oil, 40.4% from natural gas, 10% from coal, 4.3% from renewable sources (including biomass), 1.2% from nuclear energy and 0.9% from waste.

[6]*There is no doubt that the average temperature is currently rising.*

Even if you would doubt that such temperature measurements are accurate and representative, there is sufficient evidence for a structural increase in average global surface temperature. The extent of polar ice, glaciers and plant- and animal-populations are good natural indicators of long-term temperature trends. The size of nearly all of the world's glaciers has decreased significantly over the last few decades, and the same applies to land and sea ice at the poles. Many plant and animal species in moderate climates have shifted their range in the direction of the poles, and the tree line has shifted upward in many mountain regions.

[7]*But the climate is a complex system with many feedbacks, so what will happen in the long term? Many predictions and projections have been made, but fact is that no-one really knows what will happen.*

In my opinion, denying uncertainty does not contribute to the climate discussion. Granted, many climate deniers use the existence of uncertainty to generate doubt. The response is often to point to broad scientific consensus. Unfortunately this can be counterproductive, as to some this may suggest absolute certainty. And this is misleading, as there's no such thing as absolute certainty. In a recent interview with de Volkskrant (27 September 2014), logician Johan van Benthem said the following: "Many scientists choose that approach: we'll shout them into silence. We'll keep loudly insisting that we're right. And as long as we keep stamping out every spark, reason will prevail. Unfortunately, history has shown that it simply doesn't work that way. Often, scientists will present their knowledge as something fixed, something on which there is consensus. They're basically saying: we thought about the ins and outs with a number of very smart people, and now there's consensus, which you can use to convince others. Personally, I have a different idea about science. I see science as a form of organised discussion, and the power of science is in the quality of that discussion. The fact that we keep differences in opinion open for discussion, that is where we obtain progress. The image that science should emit is one of discussion and debate. I believe that this will make us stronger, because this way you indicate: we're familiar with differences in opinion. And if you open these for discussion, in our way and following our norms, you will gain progress."

It is true that there is broad consensus among scientists regarding *the existence of an enhanced greenhouse effect*. However, this consensus does not cover the scale of the problem, or the effects in the long term, and I think that it's important to be open about this.

[8]*Basically, two centuries ago we started the largest experiment in human history. And this experiment is virtually uncontrollable, the outcome is unknown and there is no panic button, should things go wrong.*

A cynic might state that this applies to the development of humanity in general. This does not make it less worrying.

[9]*Maybe the extra CO_2 will hardly have an effect, and all will be tickety-boo. Personally, I think that's a pretty big risk to take.*

A nice 15 minute explanation of global warming and why we should be worried, is given in this TEDx talk by David Roberts.

[10]*sea water tends to have an average pH just above 8. Those of you that have paid attention in chemistry class may know that this is not acidic. Rather, it's the opposite: slightly basic.*

pH is a measure of acidity. Pure water has a pH-value of 7, which is considered neutral. A pH below 7 is acidic, and higher pH is called basic. Strong acids can be damaging to life, as can strong bases. Think sulfuric acid, and potassium-hydroxide (a strong base, often used as chemical agent to unclog sinks). However, even small variations in pH can already have large effects on biological processes, especially where single celled organisms and small water-organisms are involved.

[11]*As far as we know, the average pH of sea water has remained fairly constant over the last 24 million years or so, between 8.1 and 8.3.*

This seems odd at first sight, as the atmospheric CO_2-concentration has been rather variable over the same period. You might expect that the pH of the oceans would follow the atmospheric concentration of CO_2, but this does not seem to be the case. Probably, the oceans are good at regulating the concentration of dissolved CO_2 and buffering the pH of the water, provided that the concentration changes aren't too rapid. Currently however, the rise in oceanic CO_2-concentration seems to outrun the ocean's buffering capacity.

[12]*Attempts to control and mine fossil fuel reserves have directly or indirectly led to many violent conflicts over the last century, and have caused much human suffering. Control over large fuel reserves gives some countries a lot more influence than might be desirable*

I do not mean to suggest that you should consider countries such as the US or Russia as "evil states". However, Russia does use its oil and gas reserves for geopolitical gain (for which you can't really blame them I guess). And since the *Carter doctrine*, it has been the policy of the US to secure their oil supply, using military force if needed. It is unlikely that this doctrine has done the stability of the Middle East much good. Moreover, the US army itself is probably the organisation that uses the most oil world-wide. In 2001 alone, the US army probably used more than 85 million barrels (an estimate from the book Crude: The Story of Oil). And in 2010 the author Mike Berners-Lee estimated the emissions from the military operation in Iraq at 250-600 billion tonnes CO_2-equivalent. This is roughly what all the inhabitants of The Netherlands emit in two years.

Obviously, mining fossil fuels can have some beneficial effects, mostly in the short term. Until around 1994, the Netherlands built their welfare state on the state income from selling natural gas. In the long term however, this isn't necessarily a good thing. In fact, the example of the Netherlands is known as the Dutch disease. Currently, the Dutch treasury receives over 10 billion euros per year from selling gas. But as the gas reserves in the north of the country are shrinking, this source of income is expected to decrease in coming years. And it is certainly not unthinkable that the reduced state income from fossil reserves will have to be compensated at some point by further spending cuts regarding the welfare society.

[13]*...if you value economic stability and poverty reduction, it is also unwise to make the world's energy supply dependent on a small number of centralised energy sources.* Note that this applies both to fossil fuels and sustainable energy sources. An important concept that is often promoted for sustainable energy production, is building large-scale solar power plants in the desert. But becoming largely dependent on desert solar power would provide single points of failure, and interruptions in the supply would be disastrous. On the other hand, it is unlikely that we would ever be as dependent on large solar power plants as we currently are on oil...

[14]*Of these emissions, around 88% is CO_2, the rest is mostly methane and N_2O.*

Methane (CH_4) as a greenhouse gas has around a 25-fold bigger effect than CO_2. And the greenhouse effect of nitrous oxide (N_2O, also known as laughing gas) is almost 300 bigger than that of CO_2. In both cases we're talking about estimated potential warming (*global warming potential*) over a period of 100 years (GWP_{100}). Both gases are present at very low concentrations in the atmosphere (less than 1 ppm), but both do have a significant warming effect. Methane is a relatively light gas, and therefore ends up relatively high in the atmosphere. Here it stays on average about 10 years, after which it degrades into water and CO_2. These are both again greenhouse gases, which moreover have a bigger effect at higher altitudes. Nitrous oxide has a much longer lifespan than other greenhouse gases, it remains in the atmosphere for over a century (on average). Moreover, it isn't just a greenhouse gas, but also contributes to degrading the ozone layer.

[15]*An inhabitant of The Netherlands directly and indirectly uses something between 100 and 250 kWh per day, on average.*

The kilowatt-hour (kWh, or technically kW·h) is a unit mostly used to express electricity-use. A kilowatt-hour is the amount of energy consumed in an hour, by a device that uses 1000 Watt. In SI-units this is 3.6 MJ (megajoule). However, following author David MacKay, I will use kWh as general unit for energy use, because many people are already familiar with it (e.g. from their electricity bill).

[16] *Batteries cost a lot of energy, material and money to produce, they're heavy, charging them is slow, their capacity is rather limited and they generally last only a few years.*

At the moment, the dominant type of electricity storage is the lithium-ion (Li-ion) battery. These are the batteries that are used in most phones, laptops and electric vehicles, mainly because they have a high energy-density (energy stored per unit weight or volume of battery). However, the drawback is that after about three years, the performance of most Li-ion batteries tends to start decreasing rapidly. Under optimal temperature- and charge-conditions, some types can be made to last at most 10-15 years or so. Higher temperatures will make a battery degrade faster, as will fully discharging it. A trick therefore used to extend battery life in electrical cars is to only partially discharge the batteries during normal use. This saves you having to replace the batteries every few years. The drawback is of course that you cannot use the batteries to their full capacity, while you do still have to haul their weight around (which requires energy). Additionally, the Tesla electric sports car and several other electric vehicles utilise a cooling system for their battery packs, which increases life span and safety, but again also increases weight. To compensate for the weight of the batteries, the Tesla's aluminium frame is designed to minimise weight and drag.

There are many Li-ion battery variants. Laptops and phones mostly use lithium cobalt oxide batteries, which have a high capacity but do not last very long. *Lithium iron phosphate* (Li-phosphate) batteries have a much longer life span, and are safe. However, they are less frequently used due to their somewhat lower (initial) capacity. The Tesla model S uses *lithium nickel cobalt aluminum oxide* (NCA) batteries, which have the advantage of high capacity and a relatively long life span, but are also more expensive and prone to overheating.

Apart from the most common types of batteries, such as lead acid ("car batteries"), Li-ion and NiMH, there are alternate battery technologies that may hold some promise. The venerable Nickel-iron battery, developed by Edison in 1901, is currently seeing a bit of a revival in solar-power storage, due to its low cost and extremely long life span. Modern lead-acid derivatives such as the CSIRO UltraBattery also hold promise, although the much-hyped EEStor ultracapacitor has spectacularly failed to materialise. Hydrogen fuel-cells, another big hype (in the 1990s), are also unlikely to be a viable solution for energy storage any time soon.

[17] *In many countries, buildings are heated by burning gas. The conversion of natural gas into heat is actually extremely efficient.*

In fact, all the energy released in burning gas (or anything else) is eventually turned into heat, so in principle one could say the conversion efficiency is 100%. However, in a gas-powered heating system, not all of the heat is released into the building. Some of it escapes through the exhaust, so the efficiency of most gas-heaters is somewhere from 70% to 95%.