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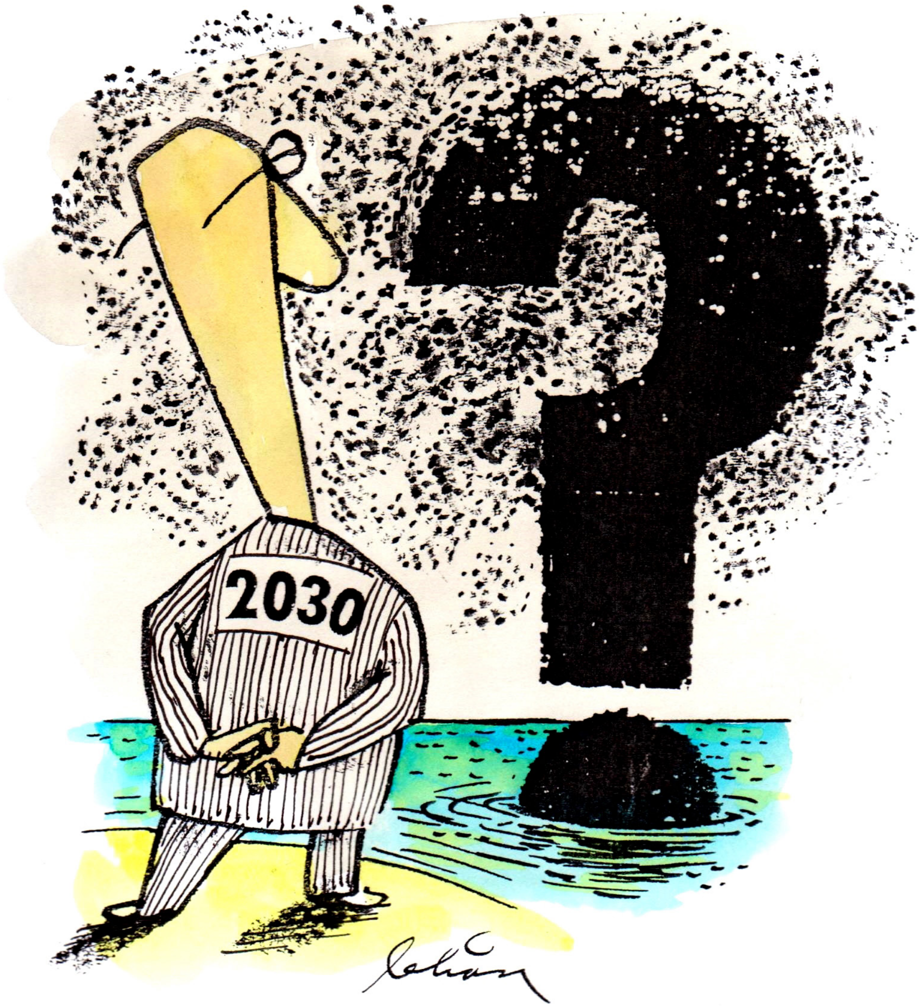
A vision for zero carbon emissions in the Nordic-Baltic region by about 2030

by Fredrik Lundberg



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A vision for zero carbon emissions in the Nordic-Baltic region by about 2030

A discussion paper by Fredrik Lundberg
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Summary

The Nordic-Baltic region can manage without any CO_2 emissions from the electricity, heat and industrial sectors by 2030, leaving only the transport sector, which is the subject of a parallel report. This can be done while phasing out nuclear power, and without carbon capture and storage. The scenario shows how this can be achieved mainly through energy efficiency and well-established renewables, primarily wind power and photovoltaic solar power. The wind and solar capacity that is needed can be added at a rate similar to the historic rate of development.

Cost is not quantified, but cannot be a big issue. Germany went for solar when prices were very much higher than today or tomorrow. Even since Denmark's solar boom in 2013 prices have dropped substantially, while cost estimates for fossil and nuclear power tend to rise.

While economics and technology look good for electricity and heat, there are some challenges for process industries such as steel, aluminium, lime, and cement, but nothing that should be impossible to solve technically within a few years and be implemented by 2030. Possible technologies are outlined.

Capacity is an issue for the power sector. The wind does not always blow, and the sun does not always shine. Sometimes there is too much wind or solar. The difficulties should not be exaggerated. Hydropower is a major power source in our region and can to a considerable extent balance variable renewable energy. So can biopower and bioheat. "Surplus" electricity, i.e. at very low or negative prices, can be stored either as heat or as hydrogen for steelmaking and other industries, and possibly for vehicles. The most important instrument for balancing variable renewable energy sources is however demand-side management, which can reduce peak consumption and thus cut the need for peak and reserve power plants. The need for some such "peakers" is still foreseen, but they will not be frequently used.

The zero-carbon target comes with a limited escape clause. The scenario foresees some remaining fossil use and associated CO_2 emissions, but this can be compensated for by exporting electricity to surrounding countries (Russia, Belarus, Poland, Germany, the Netherlands, and the UK) where it replaces fossil power for some time, assuming that decarbonization takes place later there. Net exports of 30 TWh of electricity are assumed for 2030.

In this scenario, wind power will increase from 29 TWh in 2014 to 110 TWh in 2030. This is less radical than it looks. Wind power almost trebled in 2007–2014, from 9.9 to 29 TWh, which is roughly the rate that will be required.

Solar will grow from 0.7 TWh in 2014 to 35 TWh in 2030. The 2030 target for solar in the NB8 region is less than Germany has already implemented. It will cost us much less to buy and build that solar than it did for Germany.

The scenario implies big change, but big change is always taking place, though often for other reasons than conscious political decisions. The phasing out of nuclear power was very difficult in Sweden and lasted four decades, but happened between 2011 and 2014 in Japan without any political decision. Japan managed without any of its 54 reactors for the whole of 2014, with no severe shortage. Lithuania was 70 percent dependent on nuclear power until 2010, when it was unceremoniously turned off because it was a requirement for Lithuanian EU membership.

A scenario is something that can happen. This scenario does not explain in any detail how it can happen, though it includes a list of possible instruments.

Chapter 1

Targets for this scenario report

The task set by the Air Pollution & Climate Secretariat (AirClim) is to produce a credible scenario for reducing CO_2 emissions to zero by around 2030 in the eight Nordic-Baltic countries: Denmark, Estonia, Finland, Iceland, Latvia, Lithuania, Norway and Sweden, referred to here as the NB8. Requirements for the scenario include:

- No CO2 emissions from electricity, heat or industry by 2030
- No nuclear power by 2030
- No new hydro
- No major increase in harvested biomass
- Stable electricity supply under all conditions; at least as stable as today
- No use of carbon sinks for accounting
- No use of carbon capture and storage for accounting
- No use of the clean development mechanism for accounting

The definition of zero CO_2 is strict, but three flexibility options are allowed, and specified here:

- Net exports of fossil-derived electricity to other countries can be credited against the avoided emissions from those power plants.
- Net exports of specific liquid, gaseous or solid biofuels (but not paper, timber or food) can be credited against emissions from remaining fossil fuel use.
- Net exports of hydrogen or hydrogen-derived fuels can also be credited, though this is not foreseen.

These credits are transitional. The assumption is that the surrounding nations of Germany, Russia, Belarus, Poland and the UK will also decarbonize, but not by 2030. An extra TWh of wind power in Norway can be used to cut remaining fossil power in any of the other nations. If they have decarbonized by 2040, there will be no more crediting. By using a transparent method, the credits will also be worth less if the avoided energy contains less carbon, for example where there is a fuel shift from lignite to gas or from fossils to renewables.

There are three main reasons for these "loopholes".

- The cost for storage or reserve plants can be cut substantially, by seldom-used plants. Eventually they will have to be replaced by storage, other renewable power plants or more finely tuned demand-side management.
- 2030 does not allow much time for transition in the steel, cement and refinery sectors, and even if there is a credible way forward, something could go wrong. It is therefore better to do more than needed where possible, such as producing more renewable power and exporting it. This can balance remaining emissions until the problem is solved.
- In an open economy, it is not possible to control the trade of biofuels or electricity. They are commodities that will be sold to the highest bidder, whether in the region or outside it. But government can to some extent control production of biofuels and electricity and make sure there is enough of them.

There are obviously more underlying assumptions for the scenario, such as social stability, no undue sacrifices for any population group, biodiversity conservation, cuts in non-CO_2 emissions etc., ground soil nutrient balance, risk aversion of big industrial accidents etc. These are not discussed in any detail, but if any reader finds a major fault regarding any such aspects of the scenario, please let us know!

This report does not in principle address emissions from transport and agriculture, but the distinction is not always clear.

Chapter 2: 100 percent by 2030 – it can be done

The Nordic-Baltic region could achieve a transition to 100 percent renewables by 2030, although there are some challenges.

Our region is moving in the right direction, though not fast enough. Emissions are lower than in 2005, and keep falling according to data for 2015 from the EU emission trading system. Emission trading (ETS) does not cover all CO_2 emissions, and CO_2 emissions are not all greenhouse gas emissions (GHGs). But it is still a fairly good proxy.

Table 1 ETS emissions, million tons from all stationary sources[1].

	Denmark	Estonia	Finland	Iceland	Latvia	Lithuania	Norway	Sweden	sum
2005	26,6	12.9	35.6	1.8	2.9	11.5	26.8	23.4	141.5
2007	29.4	15.6	44.9	2	2.9	11.5	27.5	22.8	156.6
2015	15.8	11.9	25.5	1.8	2.3	6.9	25.7	17.7	107.6

Throughout the boom years preceding the 2008 crisis, emissions went up, roughly following economic growth. This trend has reversed since the crisis. Emissions have dropped around 30 percent since 2007.

Some of this may be the result of irrelevant factors, but much of it is caused by a global trend towards efficiency and renewables, at the expense of all fossil fuels.

The biggest emissions outside the ETS come from the transport sector. Until recently, this looked extremely problematic. Now, however, we have a number of solutions at hand, some right now and all in hand by the early 2030s. Cars that still use petrol and diesel are more efficient than their predecessors, for example through hybrid drive systems. EU efficiency standards are delivering. Biofuels can decrease emissions further. Electric cars are coming, and hydrogen fuel cell cars are being introduced by the top car producers.

As for GHGs other than CO_2, there are positive trends for most of them. HFCs, which originated as substitutes for ozone-depleting freons, are now being phased out. PFCs, emitted mainly from aluminium smelters, are decreasing because obsolete technology is finally on its way out. Process changes are also reducing some of the N_2O (nitrous oxide) emissions. Methane from landfills is decreasing because landfills are changing.

Many challenges still remain, but what actually happens cannot be impossible.

A few years ago, many people believed that renewables and efficiency could not do the job alone. There was talk of a nuclear renaissance, flexible mechanisms and CCS.

Nuclear power has not recovered since the Fukushima disaster in 2011. Sweden, the nuclear giant in the region, will have closed at least 6 of its 12 reactors by 2020.

Lithuania, which had two big reactors in operation and one under construction, now has none. Plans to build new nuclear plants in Lithuania have failed to materialize.

Finland's fifth reactor, Olkiluoto 3, was planned to be operational by 2009, but is overdue by almost ten years. If it eventually does produce electricity it will be at a higher cost than from wind power.

Our neighbour to the south, Germany, will be nuclear-free by 2022.

1 www.eea.europa.eu/data-and-maps/data/data-viewers/emissions-trading-viewer

Another neighbour, Poland, has postponed its plans to build new nuclear capacity.

Still another neighbour is the Kaliningrad Russian exclave, where construction of a nuclear power plant started in 2011, but has since been deferred indefinitely.

The UK government intends to build new nuclear plants with enormous subsidies. This will probably happen, but will hardly set a trend. When the builder/operator Electricité de France (EDF) finally took the investment decision in 2016, its financial director resigned in protest.

EDF is the biggest nuclear power operator in the world. It is mainly owned by the French government, but a minority holding is traded on the stock market. Since Fukushima the share has lost 60 percent[2] of its value.

Other energy companies heavily exposed to nuclear and coal have also experienced huge losses, including Vattenfall (Ringhals and Forsmark) and E.On (Oskarshamn), Fortum (Loviisa, minority owner of Oskarshamn). As for TVO, the operator of Olkiluoto nuclear power plant, there is no share traded, and an unsolved dispute about who is going to pay for the additional cost for construction of Olkiluoto 3, currently more than €5 billion excluding lost proceeds from the sale of electricity for almost 10 years.

There is still some talk of new kinds of nuclear power, such as small modular reactors, thorium generation IV reactors, and even fusion, but those ideas have been around for a long time. The first fast-neutron reactor was commissioned in 1946, but the track record is awful.

Flexible mechanisms were an option to cut emissions somewhere else (than in Europe), when the EU 2020 climate target was decided upon. The idea then was that rich countries are already energy efficient and climate efficient, whereas there were lots of low-hanging fruit in poor countries such as China and India, so much cheaper carbon reductions could be bought there with European technology. This was wrong in all respects. China is the world leader in wind and solar, and its coal power stations are more modern and efficient than European coal power stations. Most poor countries have climate targets of their own. The market for CDM (the clean development mechanism) has vanished.

Carbon capture and storage (CCS) is getting nowhere. The idea that coal power could be cleaned up with this technology was politically attractive in some countries, but globally it is a dwarf compared to the booming wind and solar development. Most CCS projects[3] in the world (11 out of 14) use the captured CO_2 to enhance oil production, which means more, not less, CO_2. There are only three operating CCS projects in the world that do not enhance oil production. There is a CCS operation in Canada, Quest, which does not use its CO_2 for

2 https://www.edf.fr/en/the-edf-group/dedicated-sections/finance/financial-information/the-edf-share/edf-share-price as retrieved 17-1-6

3 http://www.globalccsinstitute.com/projects/large-scale-ccs-projects

enhanced oil recovery, but which is part of the oil sands operations, an especially dirty and unnecessary form of fossil fuel. It captures one-third of the CO_2 emissions from the site, so two-thirds will be emitted. There are two CCS projects in Norway, and both represent a tiny niche of fossil CO_2 emissions: the separation of CO_2 from natural gas before combustion, where suitable storage sites happen to be nearby. CO_2 is an unwanted component in natural gas, so it is always separated, and then usually released into the atmosphere. The big climate issue for natural gas is of course the CO_2 from its combustion, which this method does nothing to help. It is also of no use for reducing emissions from coal and oil. Nevertheless, the two Norwegian projects (Sleipner and Snøhvit) are two of, at best, four examples[4] in the world of CCS projects that actually reduce CO_2 emissions – if one assumes that the only alternative to capturing the CO_2 from gas processing is to release the CO_2 directly into the atmosphere. Between them, the Norwegian CCS plants reduce global emissions by 1.6 million tons per year. A coal power plant emits about 0.8 million tons of CO_2 per TWh of electricity. If just 2 TWh of coal were replaced by wind power, it would be as useful for the climate as all CCS so far. Global generation from wind power in 2016 totalled 960 TWh. Even in Norway, the champion of CCS, wind power produces more than 2 TWh.

The scenario requirement not to use CCS is not very demanding.

The Paris Climate Agreement, COP21, marked both the conclusion and the beginning of a paradigm shift. On the day of the Paris Agreement, the largest private coal company, Peabody, saw its shares drop 12.6 percent[5]. A few months later it filed for bankruptcy. The market now believes that world leaders are going to do something about climate change.

With the 2 degrees target more or less changed to a 1.5 degree target it is clear that most coal and a lot of oil and gas will actually be left in the ground. This is actually happening. Coal mines are closing every day. The UK shut its last underground mine in 2015, and now uses less coal than at any time since the 1840s. US coal use is falling. Coal use in China has either stagnated or peaked[6].

The Paris Agreement is very different from the Kyoto Protocol. The Kyoto Protocol had fixed targets and timetables, and specific penalties. Together with the use of various flexible mechanisms, this made sure that targets were achieved, but nothing more. The focus was on "cost effectiveness", i.e. getting things done as cheaply as possible

The Paris Agreement is not based on the carrot and stick approach, but on shame and glory. Shame comes from promising too little and not delivering. Glory comes from promising more and delivering more emission reductions

4 https://www.globalccsinstitute.com/projects/large-scale-ccs-projects, retrieved 21/07/2017 under dedicated storage.

5 http://www.nature.com/news/the-paris-agreement-has-solved-a-troubling-problem-1.19774

6 For a discussion see e.g. https://theconversation.com/has-chinas-coal-use-peaked-heres-how-to-read-the-tea-leaves-55611

than other comparable countries. If it works, it is much more dynamic. If a government finds that its neighbour has promised and achieved more, it will want to improve its act to avoid being put in the corner.

The two approaches, Kyoto and Paris, represent two contrasting views on human interaction, two views that keep reappearing not only in international law but also in management philosophy. A manager who wants employees to complete a complex task will often find that rigid control, bullying and threatening are not the best way to get the job done. Some trust, cajoling, flattery, evoking of team spirit and more generally, social control, may produce better results. Government agencies are often organized along the same lines.

Sometimes there is an iron fist beneath the silk glove. But it is not always necessary. Social control is a strong force in politics. Most people, including presidents, diplomats, top civil servants and CEOs, want to be appreciated and fear being outcast, even if it does not mean economic ruin or prison.

An example of the efficiency of "soft" methods in international relations is nuclear non-proliferation. Several nations considered going nuclear around 1960, including Sweden, Switzerland, West Germany, Brazil, Argentina, Japan, Spain and South Africa. None of them have atomic bombs now. This is not just for practical reasons such as being too expensive or that the extant nuclear powers might get dangerously angry at a new entrant. It has become a social norm. It is a thing not done. North Korea has the bomb, but is an international outcast. Iran stopped its project.

If the Paris Agreement leads climate policy as expected, the Intended Nationally Determined Contributions will compete with each other. That is what will set the pace, because the technical and economic constraints are not very important.

There is overwhelming evidence that industrial change can be rapid if needed.

In 1940, the US produced 3,611 airplanes. In 1944, it produced 84,853 bigger and better planes. During that time, the US also produced lots of other armaments, shifted millions of people out of productive work into the military machine, and sent enormous amounts of all kinds of goods to its allies.

Was this at a high cost for the economy of America? No. There was tremendous economic growth. Unemployment was almost eradicated, and living standards rose dramatically for the working class and the poor. The Americans did not choose between cannons and butter. A mobilized economy supplied both, and that was possible because the economy before the wartime boom did not work at even close to capacity.

Our economies today, especially in Europe, are also underutilized. There must be better ways than war to mobilize the economy.

There was spectacular growth in wind and solar power in many countries, especially from 2008 on. China and India both have more wind power than nuclear, even though their huge nuclear programmes go back 50–60 years, and wind power started only recently. In 2005, China had just over one gigawatt of wind power. By 2015, it had 145 GW. Solar has grown even faster. Within the fast-growing wind power sector, offshore wind has advanced even faster. In the rapidly growing solar power sector, tracker solar has grown even faster again, at 250 percent globally during 2016. There are now at least five major renewable power sources, all of which were globally negligible before 2007: onshore wind, offshore wind, fixed-tilt photovoltaics, tracker photovoltaics and biomass power.

A negative industrial change can also be very fast. It took Sweden 24 years to shut down 2 of its 12 nuclear reactors. But Japan phased out all nuclear capacity within about one year of the Fukushima disaster in 2011. Japan used to produce about 300 TWh of nuclear power per year, but this was cut by 94–100 percent in 2012–2016, without any plans or preparations for this.

Coal was the dominant source of electricity in the UK when power production began. In 2012, coal supplied 40 percent of UK electricity, 140 TWh. This was halved by 2015 and halved again in 2016.

There is no doubt that we could have essentially CO_2-free power production by 2030, if we really need to.

Chapter 3

How to get there. Policy, road maps and scenarios.

A road map can tell if a proposed route is possible or not, given a number of conditions. Driving from Oslo to Reykjavik by car alone is not possible. The map can also tell us whether it is a reasonable idea or not. Driving from Stockholm to Vilnius by car alone is possible, through northern Finland, but it is a very long journey.

An energy scenario should not be very different from a road map. Its usefulness lies in exploring routes and means to a chosen destination. It is not supposed to tell you where to go.

But actual energy scenarios and carbon reduction road maps, for example from the International Energy Agency, often mix up ends and means. They blur the distinction between what is wanted/needed and what is a likely development.

In map terms, this is equivalent to accepting advice from the map to go only part of the distance to the destination, say Stockholm to Helsinki instead of Stockholm to Vilnius.

The usual way to produce energy scenarios is to feed a lot of numbers into a computer, which returns even more numbers.

This is a kind of puppet show. The puppets have no existence of their own. There must be a puppet master.

One of the assumptions for a model is that there is a market, and that the market is in balance. This means, more or less, that if politicians do not change the rules, things will stay as they are, or whatever the market decides.

Energy models are economic models based on neoclassical theories on how people think and act. This theory has little relevance to the electricity market, which is far from an ideal market.

Obviously, the power system in the Baltic republics was not created by millions of well-informed consumers, it was planned and built by soviet ministries.

But it was not that different in capitalist countries. Hydropower was usually constructed as result of political decisions. So were nuclear power, district heating, power grids, gas grids, wind power, solar, much of biomass and often also specific plants.

Energy efficiency is also highly dependent on politics. It wasn't the market that killed the incandescent light bulb, it was the EU.

A large proportion of power plants are government-owned, in for example Sweden and Norway, but private companies are also a part of the political structure. The biggest nuclear power plant in the world, and the biggest power plant of any kind in our region is now being built in Finland, nominally as a private investment ordered by a private consortium and contracted to another private consortium. But the "private" contractor is owned by the French government. The investment decision was preceded by a vote in the Finnish Parliament, without which it could not have happened.

Governments have always interfered with the so-called market for several reasons, including security of supply, support for their industry, concern for regional and local employment, the local economy, public safety, health and environment, good (or bad) relations with other nations, social justice and so on. Even military considerations can weigh in; the early part of the huge Swedish nuclear effort was aimed at developing the atomic bomb option[7]. The bomb project was killed off in the 1960s, and none of the existing reactors is designed to produce plutonium for weapons, but Sweden still has the most nuclear power per capita in the whole world. The Lithuanian nuclear power programme began as part of the Soviet nuclear programme, without clear distinction between civil and military aspects. It was stopped because the EU considered graphite-water reactors unsafe.

One of the reasons why governments do not trust the market is that investments in electricity production are often very long term. It often takes 10–20 years to return the invested money. If the investment also includes a technical risk and a market risk (lower demand or lower prices than expected) it is hard to attract investors, unless the government somehow distorts the market so that the money rolls their way.

7 This produced a huge scientific and industrial infrastructure. Sweden built three independently designed heavy water reactors (all closed), uranium mines (all closed), a reactor fuel fabrication plant (extant), planned for reprocessing plants etc.

There are indeed market forces at work, both for electricity consumers and for the day-to day use of fuels by power plant operators. But market forces are just part of the picture, so a model based on economic balance is not useful for understanding what will happen, what can happen, what should happen or even what has happened.

Among the usual assumptions for economic models is the so-called Kaya identity, which states that the CO_2 emission level is a product of GDP, carbon intensity, energy intensity and population.

This may sound reasonable, but has serious flaws.

If everything else is equal one can assume that more people means more energy use and CO_2 emissions, and that a bigger economy will also increase energy and emissions. But this is not very useful, because every country has its own geography and history.

Modelling is supposed to assist decision-makers in understanding the choices, but Kaya modelling does just the opposite. Energy intensity and carbon intensity are derived concepts, with only a vague connection to reality. The real thing is the coal and the carbon, and the electrical energy. If "energy" is an elusive concept, electrical energy is not; one kWh can lift one tonne to a height of 360 metres. The heat content of a fuel is also understandable, but if you aggregate power, building heating, industrial processes and transport to give total "energy", you lose all contact with the real world. The probable reason for this energy input-output model is that a long time ago energy was almost synonymous with oil, in much of the world. You can use a ton of oil for heating, for transport or for power production. But oil is hardly used for power anymore, and some power sources, e.g. hydro, nuclear, wind and solar, produce power alone, not heat, not transport, not industrial processes. There is now little connection between fossil fuel prices and electricity prices.

Another flaw of conventional modelling is that it produces bad results. The IEA's annual World Energy Outlook is the leader of the pack and is treated with respect by the media and pundits. Other agencies, such as the US DOE EIA and the European Commission[8] are much the same. But they have all produced large over-estimates of energy use[9], nuclear power, coal and gas demand, and consistent under-estimates of solar and wind power growth, to name a few.

One of the underlying weaknesses of models such as the World Energy Model, which the IEA uses, is the use of econometric data. This data is taken from the real world but is usually a few years old, so it reflects history instead of the future, on top of the conceptual inadequacies.

8 For example, https://ec.europa.eu/energy/sites/ener/files/documents/20160712_Summary_Ref_scenario_MAIN_RESULTS%20%282%29-web.pdf

9 See for example https://www.greentechmedia.com/articles/read/predictions-about-global-energy-efficiency-were-wildly-conservative

In the NB8 region, emissions fell substantially from 2007 to 2014, with small changes in population and GDP.

The NB8 countries can cut their CO_2 emissions substantially. In fact, they did cut their emissions by 21 percent from 2007 to 2014. All the countries cut their emissions. Denmark's emissions fell by 33 percent, Finland's by 30 percent.

The reason for using 2014 data is that this is the latest available from the International Energy Agency. The reason for using 2007 as a kind of base year is that there was a huge financial crisis in 2008 which changed everything.

At about the same time that the European Union, the United States (under president Obama) and China started to take climate change seriously. Investment in renewable energy, grid infrastructure and efficiency became one of the ways to stimulate the economy.

The efforts to stimulate the economy in Europe were not successful, least of all in the Eurozone. Recovery has been very slow and some countries had lower GDP in 2014 than in 2007. The NB8 region showed modest growth, however. The 21 percent CO_2 drop took place in a growing economy. The population also grew, though not very much, and unevenly. Latvia and Lithuania had about nine percent fewer people in 2014 than 2007, but Norway and Sweden showed considerable growth.

So, while the economy and population grew, the region's CO_2 emissions dropped three percent[10] per year between 2007 and 2014. At that (linear) rate, emissions would reach zero by 1 April 2040. A case could be made that this could happen much faster. Several technologies have matured since 2007: onshore wind, offshore wind, photovoltaic fixed-tilt, photovoltaic trackers, solar thermal power, LED lamps, some heat pumps, and many others. They have become cheaper, more available and perform better.

Some of the competitors to renewables and efficiency have lost ground.

New coal power is no longer an option in most countries. Coal power plants with low emissions of SO_2, NOx, particles and mercury are complex and expensive. And they still emit very large amounts of CO_2, which makes it difficult to comply with the Paris Agreement. There were high hopes that carbon capture and storage (CCS) would solve this, but it has not happened, not even in Norway where the prime minister, Jens Stoltenberg, called CCS "our moon landing" in his new year speech in 2007.

"Our vision is that within seven years, we will put in place this technology which will clean emissions of climate gases. This will be an important breakthrough for cutting emissions in Norway, and if we will be successful, I believe the world will follow," he said[11].

10 Data from https://www.iea.org/countries/. Most of the 2007 and 2014 comparisons from this source.

11 http://www.vg.no/nyheter/innenriks/stoltenberg-regjeringen/co2-rensing-vaar-maanelanding/a/146966/ retrieved 170502

The reference to John F Kennedy's 1962 "We choose to go to the Moon" speech was unfortunate. The US did put a man on the moon within seven years, but Norway failed, and the world did not follow. CCS has essentially failed everywhere. Most of the CO_2 that is actually separated is used for enhanced oil recovery, i.e. to squeeze more oil out of a well before it is retired. This practice preceded the climate change policy context. It produces more, not less, CO_2.

In 2007, natural gas power was seen as the fossil fuel with a human face, or at least much preferable to coal power. Some new gas power capacity was added, but it produced less energy in the NB8 in 2014 than in 2007.

It is not just new fossil plants that are a losing their proposition. Existing plants are fighting for their existence. Fossil energy plummeted in the NB8 for electricity and heat generation, for gas, for oil and coal, and for peat and shale.

The so-called nuclear renaissance is dead. Globally, the world produced less nuclear energy in 2016 than it did in 2007. There are fewer nuclear reactors operating now than in 2007 in the region as well as in neighbouring countries. Lithuania has closed its last reactor. Sweden has shut down two reactors, and will close at least another two by 2020. Finland is building one, Olkiluoto 3, which is nine years behind schedule and one of very few projects under construction in the European Union. The others are: one in France, also far behind schedule, and two in Slovakia for which construction started in January 1987. Meanwhile, Germany has closed down eight reactors, and the UK three.

Lithuania expressed interest in new nuclear capacity some years ago, but nothing has materialized. Plans for new nuclear in Poland were approved in 2005 by the cabinet, but have advanced no further 12 years later[12]. Nominally, Russia is building a reactor in the Kaliningrad exclave, but its pressure vessel has been sent to Belarus so if it ever does start up it won't be anytime soon.

Advanced nuclear power, fourth generation and small modular reactors, which attracted a lot of attraction in 2007, are neither in operation nor under construction.

The way forward is undoubtedly more wind, solar and efficiency improvements, plus a (small) role for wave power. There is also room for more biomass, but this may be needed for vehicle fuel. There may be other renewables, such as geothermal, but they will not enter the equation.

12 http://world-nuclear.org/information-library/country-profiles/countries-o-s/poland.aspx (in Norwegian) retrieved 170502

Chapter 4:

Electricity: Trends and targets

The scenario for electricity is summarized in the first table below. The figures are justified further down. The assessment of what is achievable is mainly based either on present trends or on examples from other countries.

The most complex part of the balance is energy efficiency, so more space is dedicated to this.

TWh	2007	2014	2030	share 2014, percent	share 2030, percent
hydro	227.3	229.9	225	52.7	53.7
nuclear	100.2	88.5	0	20.3	0.0
coal	55.5	34.9	0	8.0	0.0
gas	23.6	14.8	5	3.4	1.3
wind	9.9	29	110	6.6	26.3
solar	0	0.7	35	0.2	8.4
waste	4.3	5.8	0	1.3	0.0
bio	21	25.6	32	5.9	7.6
oil	3.3	1.1	0	0.3	0.0
wave	0	0	5	0.0	1.2
geothermal	3.6	5.2	7	1.3	1.7
other	0.7	0.8	0	0.2	0.0
total production	449.4	436.3	419	100	100
export	2.2	-3.1	-30		
losses	-29.5	-23.3	-18		
el. consumption	422.1	409.9	371		

Hydropower

2014 share of NB8 electricity production: 53 percent.

Target for 2030: 225 TWh (no change).

Hydro is renewable and to a large extent flexible and dispatchable, meaning that it can match supply to demand, for example more production daytime and weekdays, less production nights and weekends. The NB8 region has a large resource of hydropower, which will be kept as it is.

Hydro GWh		
	2007	2014
Denmark	28	15
Estonia	21	27
Finland	14177	13397
Iceland	8394	12873
Latvia	2733	1994
Lithuania	958	1088
Norway	134736	136636
Sweden	66262	63872
NB8	227309	229902

The interannual variation is about ± 20 percent, and it is hard to tell what the average production is. Here we assume 225 TWh, slightly less than for the years 2007 and 2014 above. This could be conservative, as climate models suggest more rainfall in Scandinavia and thus more hydropower[13].

Nuclear power

2014 share of NB8 electricity production: 20 percent.

Target for 2030: no nuclear power.

Most NB8 countries have never had nuclear power, i.e. Denmark, Estonia, Iceland, Latvia and Norway. Lithuania shut down its last reactor in 2009. However, nuclear power is still important in two countries: Sweden, which got 40 percent of its electricity generation from nuclear in 2016; and Finland, which got 34 percent.

Sweden started phasing out its nuclear power in 1999, and by mid-2017 had shut down 4 of its 12 reactors. At least two more will be decommissioned by 2020. Nuclear power has decreased. The direction is clear but the speed is not.

Nuclear production, TWh

	2007	2014	
Finland	23.4	23.6	
Lithuania	9.8	0	
Sweden	67.0	64.9	
NB8	100.2	88.5	

It seems likely that no new nuclear capacity will be built in the NB8, except for Olkiluoto 3 in Finland, which may start operation in 2018 or 2019. The Olkiluoto 3 project is almost 10 years behind schedule and stands at almost three

13 See e.g. http://jwcc.iwaponline.com/content/4/1/17 or http://www.mistra.org/download/18.5114b7214fae9d7a8a733d2/1473225530817/MSW+rapport+no+1.pdf

times the initial cost estimate[14], without taking into account ten years of lost production. Nevertheless, there are advanced plans for another Finnish reactor, Hanhikivi 1, to be built by the Russian company Rosatom. If construction really does start it clearly runs against the trends in the Western world. No reactor construction project has started in the OECD since 2013, and the work that began on building four US reactors in that year was the result of an energy policy announced in May 2001 by George W. Bush. The reactors are far behind schedule and far beyond budget, and their destiny is uncertain as of June 2017, since nuclear contractor Westinghouse filed for bankruptcy due to losses from the reactor projects. South Korea also started construction of a nuclear reactor in 2013, but the new president, Moon Jae-In, has vowed not to start any new nuclear project, and has cancelled or suspended some projects that were underway.

The trend is against nuclear power in most of the EU, where many countries never had nuclear power; some have phased out their programmes (Italy, Austria, Poland, Lithuania) and some have policies to reduce/eliminate nuclear power (Germany, France, Belgium and Sweden). The Czech Republic is building two reactors, on which construction began in the 1980s, so it hardly represents a trend for the future.

Russia actively pursues nuclear power, at home and abroad, for example in Belarus where two reactors are now being built. The domestic programme in Russia is slow, with no new construction started since 2010, and all projects are well behind schedule. Russia began constructing a reactor in Kaliningrad, but this has been deferred indefinitely.

Can nuclear be phased out by 2030? Yes.

Lithuania was extremely dependent on nuclear power in 2009 when the last reactor was shut down. In that year its nuclear production was almost 11 TWh, with final electricity consumption of 8.4 TWh, a "nuclear dependence" of no less than 129 percent!

Lithuania has nevertheless managed without nuclear power since early 2010. This was achieved mainly by reducing exports and increasing imports, and to a lesser extent through efficiency measures and renewables.

Japan got about 30 percent of its electricity from nuclear in 2010. Following the accident in Fukushima, Japan shut down more than 95 percent of its nuclear power over the next five years.

Japan can't import electricity, as it has no overseas cables. It replaced nuclear power (300 TWh) with a combination of more fossil fuels, saving electricity (-150 TWh) and renewables (+50 TWh), mainly solar power[15]. This was highly improvised. There was no plan. Japan was not only dependent on nuclear power, it had planned to increase nuclear.

14 https://www.ft.com/content/36bee56a-3a01-11e7-821a-6027b8a20f23

15 Data from BP, for a discussion see http://www.renewable-ei.org/en/column/column_20170308.php

In Germany, where efforts to phase out nuclear and to reduce CO_2 emissions can be dated to at least 1998, when a red-green coalition won the general election promising to do just that, there was a plan. It has so far (2000–2016) managed to phase out almost half its nuclear capacity (from 170 to 92 TWh), while fossil use remained roughly unchanged. A huge increase in renewables, excluding hydro, from 13 to 161 TWh more than made up the difference, leading to a 57 TWh increase in net exports of electricity.

The UK has never intended to phase out nuclear and replace it with renewables but has nevertheless done so to an impressive extent. Its nuclear power peaked at almost 100 TWh in 1998, and has fallen to about 70 in the last few years, while renewables increased from 4 to 77 TWh. The renewables replaced some old nuclear reactors but their main purpose was to phase out coal.

California, which used to produce 20 percent of its power from nuclear around the year 2000, lost half its nuclear generating capacity in one go in 2011 when the two San Onofre reactors had to be shut down. California now plans to be nuclear-free by 2025, and to get 50 percent of its electricity[16] from renewables by 2030.

Fossil power

Coal power

2014 share of NB8 electricity production: 8 percent.

Target: no coal at all by 2030.

Coal (including shale and peat) is the worst fossil fuel, because of its high carbon content. This is compounded by a low efficiency for power use, and high emissions of other pollutants.

Coal is not a big problem in the NB8, however, and it is already in rapid decline, as can be seen in the table below. It should be no problem to eliminate the remaining 35 TWh of coal. Political attention is however needed in Estonia (shale) and Finland (peat) to avert disproportionate social consequences for some people and areas.

Coal for electricity, GWh			
	2007	2014	%chg
Denmark	19891	11064	-44.4
Estonia	11667	10872	-6.8
Finland	22054	11818	-46.4
Iceland	0	0	
Latvia	1	0	-100.0
Lithuania	12	2	-83.3
Norway	137	157	14.6
Sweden	1705	994	-41.7
NB8	55467	34907	-37.1

16 https://www.arb.ca.gov/html/fact_sheets/2030_renewables.pdf

Oil power

2014 share of NB8 electricity production: 0.3 percent.

Target for 2030: no use at all.

Oil is not widely used for power, in the NB8 or anywhere else.

Oil, GWh		
	2007	2014
Denmark	1288	317
Estonia	34	43
Finland	469	235
Iceland	2	3
Latvia	17	0
Lithuania	408	160
Norway	35	28
Sweden	1077	300
NB8	3330	1086

Not much of a problem.

Natural gas (fossil gas) power

2014 share of NB8 electricity production: 3.4 percent.

Target: much less gas power by 2030, about 5 TWh in 2030 compared to 15 TWh in 2014.

Natural gas, once seen as having a bright future, saw a steep drop between 2007 and 2014. The reasons are high marginal cost, decreasing production in Denmark, tensions between Europe and Russia, and increased importance of climate policy. Those factors can broadly be expected to be in operation for the foreseeable future.

Natural gas grids do not cover most of Sweden, Norway and Finland, and there is no grid coverage in Iceland.

Natural gas, electricity GWh			
	2007	2014	% change
Denmark	7037	2096	-70,2
Estonia	344	69	-79.9
Finland	10557	5521	-47.7
Iceland	0	0	
Latvia	1925	2337	21.4
Lithuania	2405	1749	-27.3
Norway	764	2601	240.4
Sweden	824	413	-49.9
NB8	23856	14786	-38.0

The reason for keeping some gas power plants is that this may be the cheapest option for balancing wind power for peak and backup purposes. Gas power can be ramped up fast and emits less CO_2 and pollutants than other fossil fuels.

Five TWh is an upper limit, and would emit up to two million tons of CO_2, which would have to be compensated for by exporting clean electricity, biomass or hydrogen to countries where such exports reduce emissions by at least as much, see below.

There is a possibility to feed biogas (bio-methane) into the gas grid, but the economics are not favourable.

Hydrogen can also be fed into the natural gas grid, but this option is limited by factors such as embrittlement of some pipeline steels and some safety issues[17], which can be resolved but not by 2030.

Waste power

Share of NB8 electricity production in 2014: 1.3 percent.

Target for 2030: none at all.

Waste for power and heat increased in 2007–2014, especially in Sweden.

Waste GWh		
	2007	2014
Denmark	1767	1609
Estonia	0	73
Finland	455	819
Iceland	2	0
Latvia	0	0
Lithuania	0	72
Norway	126	361
Sweden	1929	2855
NB8	4279	5789

Waste means mixed household waste. It consists mainly of biomass (potato peels, coffee grounds, etc.) and plastic materials of fossil origin, but also non-combustible fractions such as glass. Waste combustion on a such big scale is a societal failure, and a substantial source of CO_2 in Sweden at least. "Waste and other" produced more greenhouse gases than did fossil fuels for power and heat[18] generation in Sweden in 2015. Most of the waste combustion is used to produce district heat, and in some plants also power.

Waste has a "negative price"; the waste producer pays money to get rid of it.

17 For a review see http://www.nrel.gov/docs/fy13osti/51995.pdf

18 http://www.naturvardsverket.se/Sa-mar-miljon/Statistik-A-O/Vaxthusgaser-utslapp-fran-el-och-fjarrvarme/

The incentive to use it is strong. 2.4 million tons of waste for combustion was imported to Sweden in 2014, half of it from Norway and a quarter from the UK[19]. This means:

a) that there is no incentive for energy efficiency; the more you burn, the more you earn
b) that countries with a dysfunctional waste strategy can continue to produce mixed waste
c) that products which are no longer needed and could be reused or recycled, are burned instead.

The fuel is dirt cheap, but there are high capital and operational costs. An alternative fuel is biomass, such as wood chips, pellets or straw, or even well-separated waste without plastics. There are no technical arguments against such a fuel shift. But there are strong economic and institutional forces against it, so it takes a lot of political attention to bring about a change in waste combustion and to attack waste production at source.

An alternative use for the biogenic fraction of waste is to use it for biogas production. The alternative to burning plastic waste is to reduce it, recycle it, and to produce it from biomass.

The average EU municipal waste production[20] per capita in 2015 was 477 kg, meaning that a three-person household produces 4 kg per day. This figure has remained essentially stable over the last 20 years.

The NB8 countries are about the same as the rest. Waste cannot be eliminated, but can be reduced substantially. This could also have several side benefits. Residues from biogas production can supply fertilizer instead of synthetic ammonia, with its associated greenhouse gas emissions. Biogas buses and cars are much cleaner than diesel. If a lot less glass, wood, paper and plastics are produced, the stress on the climate and the environment would be less. Burning mixed waste has created health and environmental hazards, and the risks are still there.

The European Commission's Environment website puts it well:

> *Although the management of that waste continues to improve in the EU, the European economy currently still loses a significant amount of potential "secondary raw materials" such as metals, wood, glass, paper, plastics present waste streams. In 2010, total waste production in the EU amounted to 2.5 billion tons. From this total only a limited (albeit increasing) share (36%) was recycled, with the rest was landfilled or burned, of which some 600 million tons could be recycled or reused.*

Just in terms of household waste alone, each person in Europe is currently producing, on average, half a tonne of such waste. Only 40% of it is reused or recycled and in some countries more than 80% still goes to landfill (source: Environmental Data Centre on Waste, Eurostat)[21].

19 http://www.sverigesnatur.org/aktuellt/hogt-miljopris-for-sopimport/

20 http://ec.europa.eu/eurostat/statistics-explained/index.php/Municipal_waste_statistics

21 http://ec.europa.eu/environment/waste/

Not solving the waste issue often has awful consequences for people living near landfills or incineration plants in Europe, and worse still in the third word. Export of waste to the third world is illegal but still takes place.[22]

Renewable power

Biofuels

2014 share of NB8 electricity production: 5.9 percent.

Target for 2030: increase from 25.6 to 32 TWh.

Biofuels GWh		
	2007	**2014**
Denmark	2132	3407
Estonia	33	758
Finland	9666	11318
Iceland	0	0
Latvia	42	669
Lithuania	54	371
Norway	327	25
Sweden	8727	9,070
NB8	20981	25618

Biofuels are a very diverse category, ranging from used construction timber to, slaughterhouse waste, straw, the biogenic fraction of household waste, wood chips, and wood pellets. There is not a clear distinction between product and waste in the forest industry, agriculture and food industries.

The accounting or statistical problem is also a political problem. On average, biofuels are carbon neutral and good for the environment, but when we zoom in on specifics it gets a lot more complicated.

All agriculture and forestry is not sustainable, to say the least. There are issues with pesticides, eutrophication, depletion of nutrients and loss of biodiversity, issues which cannot be dealt with here.

There is also a bewildering mix of competition and synergies for other uses of the biomass resource: food, district and other heat, fibres for clothes, paper and buildings, vehicle fuels, feedstuff for chemical industries, and alternative land use.

It is thus no wonder that resource estimates arrive at very different results. One report from the Swedish Society for Nature Conservation[23] concludes that bio-

22 http://www.coalitionclimat22.org/en/2016/07/14/greenpeace-mediterranean-statement-on-the-shipment-of-italian-waste-to-morocco/

23 http://www.naturskyddsforeningen.se/sites/default/files/dokument-media/rapporter/rapport_biobranslen.pdf p13

power in Sweden can sustainably increase to 15–25 TWh, from about 9 TWh, indicating an accepted increase of 6–16 TWh for Sweden. That would mean about twice that figure for the region as a whole.

There can be no doubt that the resource is huge, even from forestry by-products alone. According to the Nordic-Baltic project Enerwood it represents hundreds of TWh:

"A survey shows that Sweden, Norway, Denmark, Finland, Estonia and Latvia have a total forest area of 61 million hectares with an annual increment of 275 million cubic metres of stemwood. The potential for primary forest bioenergy (logging residues, stumps and small wood) amounts to between 230 and 410 TWh after accounting for technical and ecological restrictions. Only a small proportion of these fractions are used today."[24]

Power is only a very minor part of biomass use. But it has a strategic role in balancing the system. Wind and solar power are intermittent, but biopower is both stable and dispatchable.

CHP for power and district heating is used mainly in the winter season, when demand for both electricity and heat is high. If demand for heat is high but demand for power is low, the turbines can be shut off. Some plants can operate in a third mode, called condensing. Then they stop producing heat and just produce power. The heat must be then produced in a separate boiler, using a fuel.

The societal value of such flexibility may become high when wind and solar increase, but that does not mean that a lot of flexible biopower will be at hand when we need it. The lead time, i.e. the time from idea to production for a CHP plant is five years or more. A major modification to an existing plant, for example adding a condensing stage, or switch of fuel, can take years.

The reason for a minor increase in biopower in the scenario is that it is both in line with the trend for 2007–2014 and helps balancing. Biopower also replaces waste power.

There are far too many aspects of biomass to deal with in this report, but here are some notes:

Wood and pellets can be stored for a long time. Such fuel can produce electricity and heat when needed. Other biofuels such as wet household waste, sawdust or wood chips are more difficult to store without causing offensive smells, fire hazards and mould formation. This is another argument for using much of such biomass to produce methane or other vehicle fuels rather than for heat and power.

Paper use is decreasing, as people read less on paper and more on electronic media (or not at all). This should increase the biomass resource, especially for trees (spruce) that have limited alternative markets.

24 http://www.nordicforestresearch.org/wp-content/uploads/2011/02/NV-1-2016.pdf

Warmer winters cause faster growth of forests, but may also create a better environment for attack by pests (insects and fungi), especially for monocultures. Changes in the physical environment, for example less soil frost, more water or less water, can make trees more vulnerable to other stressors. This creates a significant risk for catastrophic events where billions of trees can fall during one hurricane, as happened in the January 2005 hurricane, though the causal connection with climate change for that event is inconclusive.

Adaptability and resilience are good reasons for going from monocultures of spruce and pine to more diverse forests with more broadleaf. This can, if executed with some intelligence, also be good for biodiversity and leisure values. This is a very long-term project, but it could be started soon.

If possible, ash from wood combustion should be returned to the forests, to avoid soil depletion of nutrients and local acidification.

Methods of fertilizing forests other than ash recirculation should be avoided, as this creates conflicts with biodiversity, and may aggravate eutrophication in the Baltic and on land.

Wind power

2014 share of NB8 electricity production: 6.6 percent.

Target for 2030: increase from 29 to 110 TWh.

Wind power, GWh			
	2007	2014	change %
Denmark	7171	13079	82.4
Estonia	91	604	563.7
Finland	188	1107	488.8
Iceland	0	8	
Latvia	53	141	166.0
Lithuania	106	639	502.8
Norway	892	2216	148.4
Sweden	1430	11234	685.6
NB8	9931	29028	192.3

Wind power is relatively cheap, and not very controversial, on the whole. Obviously some projects meet resistance, justified or not, but it has been possible to build large wind capacities on land in densely populated countries such as Denmark and Germany, where resistance to big infrastructure projects is otherwise common. Offshore wind meets even less opposition.

Our region has a very large surface area and many suitable locations. Although it may seem challenging to increase wind power from 29 TWh in 2014 to 110 TWh by 2030, it is clearly possible.

On average wind power almost trebled in the NB8 in seven years.

In the two years from 2014 to 2016 it increased another 8 TWh[25]. This rate, 4TWh/year, is not quite fast enough, but just above 5 TWh/year would fit the bill.

The most recent data for Sweden, for the last 52 weeks, is 17 TWh, a 50 percent increase on 2014.

By the end of Q2 2017, Sweden had under construction 751 MW of wind power, permits for 12,262 MW and a further 8,810 MW[26] still in the permission process, together totalling around 22 GW. If these are all built, they should produce at least 60 TWh. Even if some permits are not granted there is enough time for other applications to cover up. Sweden could deliver more than its share by just sticking to the present plans.

Denmark has big near-term plans for wind power, mainly offshore and near-shore.

Norway is building Europe's largest onshore wind power park 1,000 MW (Fosen) and has plans to add 26 TWh of wind power[27].

WindEurope, formerly EWEA, projected 18 TWh of wind power[28] for Finland and 7 TWh for the Baltic republics by 2030 in its central scenario from 2015.

We can also compare with Germany. Germany has more money (GDP) than the NB8 together, but wind power is now much cheaper than when Germany built much of its present annual 75–80 TWh. We also have four times more area than Germany, and very much more coast both for offshore wind and for good locations onshore.

It is indeed possible to build 110 TWh of wind capacity, and some of it will be built with no further political action. That is not to say that it will happen. Sweden built the most wind capacity per capita in the world for some years, but it is now slowing down. This is due to low electricity prices, partly a result of lower taxes on nuclear and hydro, and also to falling subsidy levels for renewables. This policy has not purposefully suffocated wind power investment, but that is the result, and other unfortunate policies could produce similar results in other countries.

The main problem with high penetration of wind power is however not that it cannot be done. It is the balancing issue, see below.

25 From BP statistics, for DK, FI, LT, N and SE

26 http://svenskvindenergi.org/wp-content/uploads/2017/06/Statistics-and-forecast-Svensk-Vindenergi-20170626.pdf

27 http://www.vindinfo.no/ retrieved 16-06-07

28 https://www.ewea.org/fileadmin/files/library/publications/reports/EWEA-Wind-energy-scenarios-2030.pdf

Solar power

2014 share of NB8 electricity production: 0.2 percent.

Target for 2030: increase from 0.7 TWh in 2014 to 35 TWh.

Solar is one of the cheapest sources of new electricity globally. In our region insolation is far less than in the Sahara, but it still can produce large amounts of electricity and it is reliable and predictable over a year. As will be argued below, and elsewhere in the report, some solar will make the system more stable and resilient.

Solar has three political advantages. There is very little opposition to it. It can be built very fast, as we have seen in many countries (including Denmark) and on the global scale. The instruments to accelerate (or impede) strong solar growth are well known, both for rooftop solar and for large parks of ground-mounted panels.

At our latitudes, solar means photovoltaic solar cells. The standard technology is crystalline silicon with fixed tilt on roofs, or solar parks. Thin-film panels of cadmium telluride are commercially viable, and other active materials may break through any year.

Tracking systems that follow the sun (by flapping or twisting, but usually not both) are now taking a large share of the global market for solar parks, for example 70 percent in US projects[29] by June 2017. Tracking systems produce roughly 30 percent more energy per year, and have a better daily profile, with a less pronounced noon peak.

Germany had 38 TWh of photovoltaics in 2016. Germany is south of the NB 8, but the difference between south NB8 and north Germany is not very big[30]. Schleswig-Holstein has less insolation than some areas in Denmark, Sweden and the Baltic republics, but it has installed much more solar power than the NB8 combined. The important difference is politics, not insolation.

Within the NB8, there is Denmark (744 GWh in 2016) and essentially nothing anywhere else.

The cost cannot be a big issue. Germany went for solar when prices were very much higher than now or in the future. Even since Denmark's solar boom in 2013 prices have dropped substantially.

Solar can make a contribution to the annual electrical energy balance. It can do more than that. Experience from Germany shows that the variability of solar plus wind is less than for solar or wind alone. If it isn't bad weather (windy) it is a good chance that it is fair weather (sunny).

Hydro has many advantages, but a large share of hydro has one drawback. The interannual variability is strong, between "dry years" and "wet years". Solar is next to useless in mid-winter even in the best locations, but it makes a useful

29 www.greentechmedia.com/articles/read/NEXTracker-paris-solar-trackers-with-flow-batteries-and-expands-in-india?utm_source=Daily&utm_medium=Newsletter&utm_campaign=GTMDaily

30 See for example http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php

contribution in spring and early summer when the level is low in hydro dams. The water levels in the big dams reach maximum in September–October. Solar also acts as a long-term stabilizer of hydro. Solar is either not correlated or negatively correlated to rainfall, and it is negatively correlated to evaporation loss of water. (If it does not rain, there is a good chance of sunny weather!)

One study[31] concludes, for Sweden, "that the Swedish results should be generally applicable".

"On a national scale, negative correlations exist between wind and solar power at all time scales, from hourly (-0.2) to annual totals (-0.44). However, the strongest values are recorded for monthly (-0.74) totals due to systematic opposite variation in seasonal availability."

While solar in general terms produces most electricity when the demand is low, and almost no electricity at winter peaks, it is not a complete mismatch. Demand is higher daytime than night-time. Stores that use a lot of air conditioning, hotels, summer resorts and very many offices have a demand profile that does not differ that much from solar output. Many offices need more cooling than heating.

The mismatch should decrease, because better insulated buildings do not just save energy. They will also have lower peak demand for electricity for heating.

Too much solar can be a problem on a summer Sunday at noon, but not a big problem. It will not destroy the grid. If one percent of the energy is "curtailed", the economic loss will be even less than that, as this takes place when electricity prices are low.

From a systems point of view solar is more valuable in the southern areas, where seasonal variation is not quite as strong, but local insolation is also important.

Economy and efficiency is not everything, however. Solar installation, especially on rooftops, is relatively labour intensive, and provides the kind of jobs that are badly needed everywhere. Solar gives a rare advantage to rural people, as there is lots of space for it, for example on barns.

Geothermal

Geothermal power in the NB8 exists only in Iceland. It delivered 3.6 TWh in 2007 and 5.2 TWh in 2014.

Target for 2030: 7 TWh.

Geothermal power has a considerable global potential and the advantage of supplying either constant power 24 hours a day and 365 days a year, or as dispatchable power[32] to match demand and balance wind and solar. In Iceland, this feature is not much needed, but it may be of some value for exports to the UK.

31 J Widén, after Graabak and Korpås: Variability Characteristics of European Wind and Solar Power Resources—A Review Graabak

32 www.energy.ca.gov/research/notices/2016-01-28_workshop/presentations/Operational_Flexibility_of_Geothermal_Power.pdf

More geopower can be developed, and is likely to be developed, at least if the Iceland-UK cable is built. More is quite possible[33].

No special policy is assumed, but developing more geothermal power in Iceland creates expertise for developing it in other countries, as is sometimes already happening[34].

Geothermal power is assumed to be limited to Iceland, though it is possible in non-seismic areas with deep drilling and the use of organic coolant. There are some installations in Germany[35].

Geothermal heat, for district heating or industry, is an option in much of the region, and is also used. The reason to mention it under electricity is that if more geothermal is used for heating, it saves biomass for power, adding flexibility. Denmark[36], and again Iceland, are leading the field.

If geothermal heat is "under-dimensioned" and complemented with electric boilers, it can absorb "surplus" power from wind and solar and deliver that heat later, acting as a battery.

Ocean energy/Wave power

2014 share of NB8 electricity production: none.

Target for 2030: 5 TWh.

Solar, wind, hydro, geothermal and biopower may be enough to supply all the world's electricity needs, but the transition can be smoother and come sooner if still more sources can be developed.

The European Commission claims that Europe could get 350 TWh or 10 percent of its electricity from "ocean energy" in 2050. That includes wave power, tidal power, tidal stream power, ocean thermal energy and salinity gradient energy.

But if it can be done by 2050, it could be done much faster. Engineering problems are solved faster if you have more engineers, which means more money, especially long-term financing. Wave energy projects started 30–40 years ago, scattered over the world, have made progress, but not fast enough, and then lost funding. The teams have been scattered, expertise lost, the critical mass is not there anymore. The next project has then had to start from scratch.

Of the ocean energies, tidal power is promising and may soon be developed in the UK, which has higher tides than our countries. Ocean thermal energy conversion, if developed at all, will take place in tropical oceans, not here. Salinity gradient energy has the advantage of producing steady power, but may be both expensive and, on a large scale, carries biodiversity risks.

33 http://www.thinkgeoenergy.com/iceland-could-see-up-to-7-new-geothermal-projects-until-2035/

34 See for example http://www.unugtp.is/en/gallery/video/geothermal-kenya

35 www.nortonrosefulbright.com/knowledge/publications/147194/opportunities-geothermal-energy-in-germany

36 http://www.geotermi.dk/media/2156235/AllanMahlerNDT20141016-2.pdf

Our best bet seems to be wave power.

Wave power has an enormous global potential, estimated at 8,000–80,000 TWh by the IEA, so it is an enormous prize. It should not be controversial, if biodiversity issues are adequately addressed, as there are no neighbours. Like most renewables, it is modular and scalable.

However, there is no proven technology yet, and the economics are unknown.

Wave power is a complement to wind power, because the waves are built up by the wind, but with a delay. When the wind slows, the waves remain high for several hours. From a systems point of view this out-of-sync behaviour is valuable, here and in the rest of the world.

In January 2016 the first wave power installation was connected to the grid on Sweden's west coast, near Norway, with tens of millions of euros each from (Finnish) Fortum and the Swedish Energy Authority. Whether it will result in a commercial technology remains uncertain. But with a strong political will, there is a good chance that it could be done, or something similar.

Denmark did it with wind power in the 1990s. It was a high-risk, high-benefit effort, but paid off in two ways: it solved a global problem, and it created a blooming business. 25 years later, Vestas is the biggest wind power supplier in the world.

The UK did it with offshore wind in the years after 2010.

Norway did not do it with CCS, but maybe it was not a very good idea from the start. (Quite a few people said so at an early stage.)

With a strong effort, it is probable that the technology could be developed, demonstrated and scaled up to 5 TWh by 2030. But there is of course a risk that either no way forward is found at all, or that it can be done but will not meet the 2030 deadline. If either is found to be the case by say 2026, the gap can be filled by adding more wind, solar, biopower or efficiency measures. One starting point is that Fortum has given the technology a lot of attention[37] and money.

Imports and exports

"Net exports" (as defined below) 2014: 3.1 TWh.

Target for 2030: 30 TWh exported from the NB8 to other countries

Electricity is imported and exported all the time, except for Iceland which is not connected to other countries. The net result of trade over a year, if we sum up for all the countries, has been rather small, so far.

This net sum is not a very good measure, and does not reflect how much electricity flows in and out of the region. But it is important to achieve a balance. In 2007, there was a small net import; in 2014 a small net export. For 2030, a large

37 https://www.fortum.com/en/energy-production/wave-power/pages/default.aspx

net export is postulated, and is then assumed to represent a real net flow to Russia, Belarus, Poland, Germany, the Netherlands and the UK. The reason for the export is that it can compensate for some remaining CO_2 emissions in the NB8. This is also a likely development, since the countries mentioned will have greater difficulties than the NB8 to decarbonize their power.

The market forces point in the same direction, as most of those countries now have higher power prices than in the NB8. This will continue for quite a long time, because they must transform their power sector more, and in a more expensive way, than the NB8 – both because of policy and because of the need to shut down many old power plants. Germany will phase out all its nuclear power in a few years' time and most coal before 2030. NGOs have demanded a firm plan to phase out lignite and coal, and detailed how it could be done[38], and this seems now to be accepted by the CDU and Angela Merkel[39]. Poland has a large capacity of old coal power plants which cannot comply with coming EU legislation. The UK is now highly dependent on imports and will have to phase out most of its nuclear[40] power before or during 2030, more than the planned new reactors, if they materialize. The future politics of Russia and Belarus is anybody's guess, but if everybody else moves to cut their CO_2 emissions, they will have to move in the same direction. Beyond Germany, France plans to reduce its nuclear capacity from 75% to 50% by 2025, and to cut CO_2 emissions more. New power lines from the NB8 to Germany, the Netherlands and the UK will probably be used more for exports than imports.

net trade import/export, GWh		
	2007	**2014**
Denmark	-950	2855
Estonia	-2420	-2754
Finland	12557	17967
Iceland	0	0
Latvia	3000	2407
Lithuania	-1372	7623
Norway	-9945	-15585
Sweden	1316	-15623
NB8	2186	-3110

Note: Export is denoted with minus.

38 See for example http://www.airclim.org/acidnews/phase-out-plan-coal-europe andwww.greenpeace.de/sites/www.greenpeace.de/files/publications/20170628-greenpeace-studie-klimaschutz-kohleausstieg.pdf

39 http://www.sueddeutsche.de/politik/braunkohle-merkels-ausstieg-1.3591265

40 www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx retr 2017-06-14

Losses

2014 losses: 23.3 TWh, or 0.8% of production.

Target for 2030: 18 TWh.

All the electricity that is produced does not reach customers. Some is lost either through resistance or conduction.

Resistance loss is proportional to the square of the current, so it occurs mainly during winter peaks. With improved insulation of buildings, and improved demand management (moving and flattening peaks for an hour or so), the peaks caused by electric heating should be less steep, which would lead to decreasing losses.

The conduction loss, or corona loss, takes place during rain or when lines are covered with frost. This is localized. With a smarter grid and more power lines, affected lines could be bypassed, which should also cut losses.

More power lines are being built, with new lines to third countries (non-NB8) and within the NB8, which should also cut losses somewhat, especially as less electricity is produced and consumed.

The trend is already there.

Losses, GWh		
	2007	2014
Denmark	1,947	1,974
Estonia	1,354	842
Finland	3,043	2,772
Iceland	495	498
Latvia	798	465
Lithuania	1,118	815
Norway	10,111	8,586
Sweden	10,661	7,334
NB8	29,527	23,286

Electricity consumption

2014 consumption: 410 TWh

Target for 2030: 371 TWh

Electricity per capita consumption is very high in Norway, Iceland, Finland and Sweden, all of which have a tradition of cheap electricity for various political reasons. The "for comparison" entry shows some neighbouring countries with which we exchange or will exchange electricity.

kWh/capita		
	2007	2014
Denmark	6670	5862
Estonia	6284	6705
Finland	17157	15255
Iceland	37032	53394
Latvia	3168	3513
Lithuania	3567	3826
Norway	24947	22988
Sweden	15255	13475
NB8	13337	12608
for comparison		
Germany		7035
Poland		3972
United Kingdom		5130
Russia		6603
Belarus		3680
The Netherlands		6713

TWh electricity consumption (production+import-export-losses)			
	2007	2014	Change %
Denmark	36.42	33.06	-9.2
Estonia	8.42	8.85	5.1
Finland	90.76	83.29	-8.2
Iceland	11.48	17.62	53.5
Latvia	6.97	6.99	0.3
Lithuania	11.52	11.21	-2.7
Norway	117.5	118.16	0.6
Sweden	139.58	130.71	-6.4
NB8	422.65	409.89	-3.0

As can be seen in the table above, consumption has declined in most of the countries with high consumption. One reason is deregulation of the power market in the 1990s, initiated by the EU. Another is increasing cross-border trade. The 100-year-old model of government planning of power supply and grid does not work as before. The power companies can sell their electricity abroad for a better price than at home, and no one is stopping them.

Previously, new power stations were subsidized by old power stations. Hydropower, once built, is like a money printing press and could carry the construction costs of expensive new power stations. The power companies made small but reliable profits in the context of ever-increasing electricity consumption. They often built too much, and had to find fanciful ways to get rid of the surplus electricity, such as resistive electric heating on an absurd scale, electric heating for district heating, and extremely low prices for outdated industry.

In a more competitive market this does not work. The new construction of power plants stopped, except for politically ordered renewables. Meanwhile, some old plants have been decommissioned: four nuclear power plants in Sweden and several coal power plants in Denmark. Some industrial consumers of large amounts of electricity have also been shut down, notably extremely old and dirty aluminium plants in Norway and Sweden, along with some mechanical paper pulp mills.

This has led to greater price variability. Some of the worst profligacy has been squeezed out. Prices, though volatile, are still on average very low in the Nordic market. But in other parts of the world where prices are higher, new technology and new management techniques have been developed to cope with high prices. These techniques have been imported to the Nordic countries.

CFL lighting, which saves 75–80 percent of the electricity compared to incandescents, took off early in other parts of the world, but finally reached even Sweden and Norway. Much more efficient chargers for phones and other devices, copying machines, etc., have been developed elsewhere in the world and then been adopted by NB8 countries. Some of them are the result of the US Energy Star programme for efficiency or similar EU, UK, German, Japanese or Chinese efficiency programmes.

Technology moves both ways, especially policy-driven tech. Danish refrigerators, Swedish heat pumps and windows, Finnish high frequency drivers for lighting, Norwegian building codes[41] have all contributed to energy savings, domestically and in other countries. The unglamorous development of more efficient fans, pumps and industrial doors has created large potential for savings.

Only parts of the potential are realized automatically, such as LED TV sets instead of CRT TVs. Much depends on governments or companies demanding efficient tech, which is quite common in for example the construction sector, in real estate management, in engineering companies, and sometimes also in heavy industry. This is being done partly to project a modern and green image, and partly because it can save money.

Most companies sell their products and services on environmental credibility (to some extent), and it looks foolish if they cannot even get their own house in order.

41 http://www.oamk.fi/hankkeet/ieeb/final_symposium/materials/dahl.pdf

Systematic energy efficiency in an industry or an office block can save large sums of money. This is often done by performance contracting, where a company such as Siemens or Schneider Electric undertakes energy conservation measures (electricity, heat and fuels) and shares the money saved with the customer. At a Volvo plant, cooperation between a plant manager and Siemens resulted in an 86 percent saving for lighting; some of the saving came from switching from not-so-bad fluorescent tubes to LED fixtures, but most of it from occupancy and daylight control. Such solutions also spread spontaneously, or because saving energy is a simpler way to show environmental improvement than for example screening the whole supply chain. The big companies need to write something in their sustainability reports.

For companies that do screen the whole supply chain, energy efficiency at the supplier is a simple criterion to see who is acceptable, no matter where in the world. Perhaps 10,000 companies and organizations are certified to environmental management standard 14001, and the energy management system ISO 50001 is expanding fast in the world:

"In fact, nearly 12,000 organizations were already certified to the standard at the end of 2015 – up 77% from the previous year.

CEM analysis shows that implementation of the ISO 50001 standard across the commercial and industrial sectors globally could drive cumulative energy savings of approximately 62 exajoules by 2030, sparing nearly USD 600 billion in energy costs and avoiding 6,500 million metric tons of CO_2 emissions. The projected annual emissions savings are equivalent to removing 215 million passenger vehicles from the road."[42]

CEM is the Clean Energy Ministerial in Beijing, 8 June 2017.

The combined international political and commercial pressure to save energy is bound to increase. If the 2007–2014 trend continues, consumption will be about 380 TWh by 2030, not very far above the 371 TWh targeted.

It is conceivable that the target will be reached without any further action.

But low electricity prices and sudden investment growth in new industrial sectors (for example data servers or huge battery factories) can work the other way. Energy efficiency will need political attention, but it is well worth it, because it saves a lot of money and effort to be proactive rather than reactive. The saved kWh is the cheapest and cleanest kWh, and saved electricity is usually associated with better quality, safety, production reliability, better health at work and overall less resource use.

If electricity can be saved at a faster rate than projected, some of the investment in new power and infrastructure would not be needed, freeing land and money for other purposes.

42 https://www.iso.org/news/ref2193.html

Chapter 5

Balancing electricity: When the wind does not blow

A near 100 percent renewable future in the NB8 region means first a lot of hydropower, which already exists, and a lot of biomass, which is also in place. Second, it means a lot of wind and solar, to replace all the fossil and nuclear power, except for what can be saved by using electricity more efficiently.

This creates a problem, namely: how do we manage when the wind does not blow and the sun does not shine?

This problem may not be very demanding from a technical and economical point of view, but no self-preserving government is ready to take risks over the reliability of the power supply. They will play safe, meaning at least no more large-scale blackouts, no more frequency variations than today. There are unknowns for the future – regional climate change for starters – so aiming for unchanged power stability means improved stability.

Part of the problem of balancing has been around since the first electricity grids in the 1880s: production has to match consumption, to keep the frequency close to 50 Hz. Another old problem is to manage the expected or unexpected loss of a big power station or a power line. In the NB8 system, a scram in a big nuclear reactor represents the biggest short-term challenge. It takes just a few seconds from full power to zero power, and occurs roughly once a year per reactor. Usually, the system can handle this, and quickly restore the frequency. Other electricity producers can also fail, though they are usually smaller. Power line failures happen frequently and sometimes last for a long time.

A part of this problem is to avoid production exceeding consumption, which will lead first to a surge in frequency, then to damaged equipment and finally to the meltdown of transformers and power lines.

Balance can be restored in several ways. They are expressed here in physical terms, but with a well-functioning market, the market would kick in the measures in the optimal order.

a) With hydropower that can be ramped up or down in seconds, days and even years.
b) With thermal power from fossils or biomass, that can either be turned on and off or up and down. (Nuclear power can never be increased, and it cannot be turned down easily.)
c) With more exports during power surpluses and more imports during power deficits.
d) With storage, such as batteries, compressed air storage, flywheels, and pumped hydro.
e) With demand-side management, where customers are asked for, or paid for, or ordered to cut down consumption, or shift it in time.

Balancing wind and solar uses the same methods. The difference is quantitative, not qualitative. On top of these, there are some other options to consider.

The big worry, whether warranted or not, is however to meet peak demand, which in our countries takes place on weekday winter mornings.

Hydro

The NB-8 countries are fortunate in that we have a lot of hydro – about 56 percent of electricity consumption in 2014. This is much more than most other regions. This works well with wind. When the wind blows, hydro is used less, which means rising water levels. When the wind is low, more water runs through the turbines.

This in-built storage function is not without problems. Big permitted differences between the highest water level and lowest water level are good for storage, but bad for the fish (and in several other respects). High flow rates, if sustained over many hours, cause other costs for nature and society, for example through erosion of river banks. Increased nature protection is both desirable and likely, due to European legislation.

Prospective changes in water rights, such as maximum level, minimum level or flow rate, will not per se diminish energy output, but may reduce the storage function of dammed hydro.

The storage capacity is still very considerable, and is not used optimally at present, since wind power is new and solar power still insignificant.

Wind power is not useless during peaks

Wind power is variable, but it nevertheless can be relied on to deliver some power when needed.

Svenska Kraftnät, the Swedish power grid authority, has increased the "capacity value" for wind power from 6 to 11 percent of full capacity during demand peaks. This may be conservative (as indeed it should be). During the peak demand hour during winter 2016/2017, on 5 January between 17.00 and 18.00, wind power produced 1,141 MW, or 17.5 percent of its capacity. In the previous winter, wind power produced 1,950 MW during Sweden's peak hour (15 Jan 15, 8.00–9.00) or 32 percent of its capacity.

It is reasonable to assume that similar figures can be applied for other countries. More detailed data are important for planning and economics, and will no doubt come as wind power grows.

The probability of very low wind power when it is most needed is low, and it is likely to fall further with larger wind power turbines and more offshore wind.

If the worst happens – low wind during peak load – it is still not a disaster unless it coincides with events like loss of power lines, other power stations offline, partial loss of reserve power, failure of weather forecasts to predict both low temperatures and low winds, and lack of development of demand-side management.

It takes both extremely bad luck and and gross incompetence to let that happen.

Thermal power

In several of our countries, combined heat and power (CHP, or cogen) can be used as a damper. When winds are high, no power. When winds are low, full power.

For reserve and peak power purposes, it is a cheap option to keep some old fossil power plants. Sweden's grid operator Svenska Kraftnät purchases a capacity reserve through an auction each year, as insurance if the market should fail. An old oil power plant won the auction for the winter of 2016/2017 at a very low price. This emits large amounts of CO_2 per unit of energy, but if it is used for only a few hours per year, it makes no large contribution in absolute terms.

A lot of fossil power will need to be decommissioned before 2030 in the postulated scenario. If some of it is mothballed instead of being demolished, it will be a cheap way to allay (mainly unwarranted) fear of blackouts. These would mainly be fossil gas power plants, and some oil, as they can be started at short notice. Coal power is not suited for this purpose and should be closed for good as soon as possible.

Imports and exports

The capacities for importing and exporting power are huge. They have increased and will increase further, within the region and with interconnectors to neighbouring countries. Sweden and Lithuania were connected in 2016. Iceland will probably be connected to the European grid[43] by 2027 through the UK, and the UK will be connected to Norway by 2021.

Exports/imports can handle a lot of problems. If the wind is low in north Scandinavia, it may be sunny or windy in Germany and Poland or the UK, and vice versa. It is a hedge against failures of power lines. On cold winter days, when demand peaks in our countries, there can be surplus capacity in Russia or Germany.

Denmark has the highest wind energy share in the world, around 40 percent, and increasing. At a record peak, wind produced 140 percent of demand[44]. As Denmark has no hydro and no other storage, this demonstrates the strength of grid capacity. In other countries, "curtailment" of wind power happens now and then, meaning that wind power is operated at lower than full capacity, but not in Denmark.

43 http://www2.nationalgrid.com/About-us/European-business-development/Interconnectors/Iceland/

44 https://www.theguardian.com/environment/2015/jul/10/denmark-wind-windfarm-power-exceed-electricity-demand

Storage

Storage is expensive, and may have other drawbacks. Pumped hydro means that a hydro station is run in reverse when power is cheap and used as regular power station when power is expensive. Such stations were often built as a fast back-up for nuclear in case of scrams. In energy terms, it means a loss. The losses are around 25 percent, meaning that for every kWh stored, you get 0.75 kWh back. It is not meaningful to build such capacity unless power prices vary widely and often, typically over a day/night cycle. Hydro storage is expensive to build, and not pretty. In the Nordic countries, day/night prices do not differ very much, so pumped hydro has not been much of an option. There is a pumped hydro station in Krounis, Lithuania, which may be an asset if electricity price variation increases.

Batteries may be a great idea together with photovoltaics in countries that get a lot of sun and use a lot of air conditioning. They let you store electricity at noon and use it when the sun sets, every day. In our countries, peak demand is due to electric heating during cold winter days. It is not a good idea to store electricity from summer to winter, essentially using it once a year. Batteries are thus not much of an option to balance the high-voltage (around 400 kilovolts) grid, but they may be of importance at lower voltage levels for improving the quality of electricity (pure sine waves) and for increased uninterruptible power supply.

If electric cars become the big thing they are said to be, they represent a big sink for surplus/cheap electricity and a big source of electricity when electricity is scarce/expensive, if charging and discharging can take place at the right time and be controlled by the grid operator. The theoretical potential power is huge; a Tesla S has a peak output of 365 kW. If two million cars were used to supply power, that would mean a total of 730 gigawatts – about ten times the maximum output from all power stations in the NB8, so even if a small share of them were available for grid balancing when needed, it would be very significant.

But the economics do not look good. Batteries cost a lot of money and don't last forever, so there is a capital cost and a cost per use. If used EV batteries are used to supply power, the economics look a bit better, but such battery banks for a few gigawatts will be very big industrial complexes. They will need a lot of design work, environmental impact assessment including fire, safety etc. Really large-scale use can hardly be expected by 2030. Even if it is, the batteries would probably be of more use and give a better return in countries with more solar and less hydro than in the NB8.

If batteries, in cars or elsewhere, become sufficiently cheap, efficient and long-lasting, they may make a real contribution. The same goes for ultra-capacitators, flywheels, compressed air storage, and flow batteries. Flow battery technology can be used for large-scale storage, and there is a project that aims to power Berlin for one hour from such a battery[45] by 2023.

45 www.greentechmedia.com/articles/read/german-utility-plans-a-flow-battery-big-enough-to-power-berlin

It is possible that storage technology will be good enough, cheap enough and fast enough to add balancing power by 2030, but this is not a prerequisite for this scenario. If storage technologies do take off, it will be in areas with less hydro and less export/import capacity.

Hydrogen storage is not a great idea for electricity balancing alone, but hydrogen is interesting for two other uses: as a vehicle fuel (which is not discussed in this report, and as industrial fuel, more of which later under Industrial emissions.

Demand-side management

Demand-side management (DSM) is a very large and almost unused resource. The biggest items are electric heating and water heating. The customer does not notice if the heat is turned down for an hour, especially if it happens at home during working hours. Other options are to turn down pumps in water treatment plants or shop refrigerators for a short time. Conversely, electric heating can be turned up in the early morning, before the morning peak, and cooling can be turned up at non-peak time.

DSM can amount to a "virtual power plant", a demand reduction that makes a real power plant superfluous.

This can shave the peak, and can avoid large costs for society which will not have to dimension the whole power system (production, transport and distribution) for the highest peak. The technology is not very demanding in principle but there are either insufficient incentives or cultural barriers, as this practice hardly exists in our countries. It is different in the UK, where the balancing market is worth a billion pounds[46] (some 1.2 billion euros), and in the United States and Germany. In the US and Germany much attention is given to DSM at lower level, to match local production of wind and solar, so the community (rather than the national grid agency) can save money.

A more radical form of demand reduction can be agreed between supplier and customer. A house owner can get cheaper electricity bills if he or she accepts lower indoor temperature for say a maximum of 20 hours per year, during which an extra pullover may be needed.

A Norwegian study[47] claims that dynamic pricing and automation can save more than 28 percent of the peak consumption in an average Norwegian home by 2030. This means gigawatts can be saved, just by Norwegian homes. Applied to offices and industry all over the region, it may be more like ten gigawatts.

An aluminium smelter or a paper pulp grinder can accept, at a price, reduced capacity for a few hours per year under specified conditions. The Swedish grid

46 http://uk.reuters.com/article/uk-britain-electricity-aggregators-idUKKCN0YE0GU

47 http://publikasjoner.nve.no/rapport/2017/rapport2017_34.pdf (English)

operator Svenska Kraftnät[48] purchased 340 megawatts of demand reduction options from two pulp producers for the winter of 2015/2016.

DSM can also be used to reduce a surplus of wind power. If you have 1,000 megawatts of wind capacity, it produces on average 300 megawatts, which can drop close to zero or increase to almost 1,000 MW. The surplus problem is more dramatic. One way to handle it is to use the cheap electricity in electric boilers, to produce district heat.

While the potential for DSM is huge, clean, cheap and hardly noticeable, it is not necessarily simple to aggregate many small and big consumers to shed load when needed. The first DSM-compatible water heater may cost a lot of money to install to reduce the load by just a few kilowatts. There is clearly an economy of scale, and an initial threshold. It is a chicken and egg problem. This calls for political intervention, to create a market.

Cloudy days with sunny intervals create very variable solar power output and gusty winds create very variable wind output. DSM and hydropower can dampen this variation. DSM has a more limited potential to cut annual peaks. People can wait a few hours for the heat to be turned on, but not weeks.

Additional methods to meet variable renewables

While balancing is an old art, there are some new challenges and solutions.

In the new energy landscape, there will be fewer very large-scale production units, which decreases vulnerability. Without nuclear, we will get rid of several problems. One is the immediate loss of 1,400 megawatts or even 1,600 megawatts if Olkiluoto 3 is operational. A second is the risk for generic problems that could immediately shut down several reactors at the same time, as happened for five reactors in Sweden in 1992. Independent problems can also create a lot of variation in annual output. In Sweden, again, nuclear produced 75 TWh in 2004 but only 50 TWh in 2009. There is also the unpredictability of when reactors will start to operate (Olkiluoto 3) and when they will shut down. At the time of writing (July 2017) it is unknown if Sweden will have three or six reactors in 2021, because the operators have not made up their minds whether or not to invest in meeting new safety requirements.

On the other hand, most nuclear and fossil plants do operate during winter time. Solar power is next to useless during winter. Wind power is relatively predictable on an annual basis, though there was about 10 percent less wind energy in 2016 in Sweden and Denmark than in 2015. Over shorter time scales the variability is very high. For the seconds-to-weeks variability, hydro and DSM can handle that unpredictability.

48 www.svk.se/om-oss/press/forbrukningsreduktionsresurser-i-effektreserven-upphandlade-for-vintern-20152016-1965509/?_t_id=1B2M2Y8AsgTpgAmY7PhCfg%3d%3d&_t_q=effektreserv+f%C3%B6rbrukning+2016%2f2017&_t_tags=language%3asv%2c-siteid%3a40c776fe-7e5c-4838-841c-63d91e5a03c9&_t_ip=192.121.1.150&_t_hit.id=SVK_WebUI_Models_Pages_PressPage/_cc796d1c-65c7-405d-89b9-343c311e762c_sv&_t_hit.pos=7 (in Swedish)

Hydro can even out considerable variability, but there are limits. In an ideal situation, capacity can be increased or decreased a lot within a large range. But the water level is not allowed to exceed maximum and minimum levels, so a long period of high wind or a long period of low wind shrinks this range. The critical time seems to be about three weeks of calm, if it takes place in the cold season.

Interannual hydro variation used to be balanced with thermal power. In a dry or cold year, this could mean many million tonnes of CO_2 from coal and oil power stations, and is unacceptable. One option would be to build biomass condensing power plants, which would waste about 60 percent of the biomass energy, and have a low utilization rate and very high costs per unit of energy.

Unless such plants are built, we will be increasingly dependent on hydro, which has a substantial interannual variability.

Better weather prediction

Wind, solar and hydro and are uneven in the short run, but not exactly unpredictable. The meteorological forecasts for how windy, sunny and rainy (and cold) it is going to be over the next 24 hours and the next week are fairly good, but still need to be improved. This can be used for DSM, for CHP planning and for reserve power planning. If wave power becomes a significant energy source, it has a power profile similar to wind power, but with later peaks and troughs, so it has a modest stabilizing effect.

Better insulation of buildings

Buildings with improved insulation, better windows and more efficient ventilation use less energy per year. Their peak demand is also much lower. Good legislation for new buildings will be important. Near-zero-energy buildings, as required by the EU directive[49] should not take the easy way out and put some solar cells or collectors on the roof of a leaky house, because solar energy in the summer cannot compensate for high electricity consumption in the winter.

Standards and practices for renovating existing buildings are still more important. There are many examples of deep renovation that has cut energy use by 50 percent or more.

Buildings with high thermal integrity lose their heat more slowly, so they are also more DSM-compatible.

Wind + solar = better

Solar and wind show less variability together than each separately, to judge from German data[50]. This should be true in the southern parts of the NB8, too.

49 http://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:32010L0031&from=EN

50 https://www.ise.fraunhofer.de/content/dam/ise/en/documents/publications/studies/recent-facts-about-photovoltaics-in-germany.pdf p35

It is likely that more solar decreases the risk of a "dry year" with low hydro production. If it is sunny, it doesn't rain much, and vice versa.

Curtailment and spill

Most of the time the weather is not the same everywhere. Wind power turbines in different locations can back up each other. So can solar power, and anyway there is 2–3 hours' difference between the solar maxima in the west and east of the region, which permits electricity trading.

But it can happen that calm periods coincide over a large area, or strong winds and sunshine. There are limits for what the system can absorb.

With much more wind, it may at times be necessary to turn down some wind turbines. This option could be valuable, and up to a few percent lost energy is an acceptable cost. Modern wind power has this feature. Solar farms can do this too.

Curtailment of wind was 2–3 percent around 2014 in Germany, the UK and Ireland, less in Spain and Italy, and zero in Denmark and Portugal[51].

The need for curtailment can be diminished with better forecasts, improved grids and grid management, and more demand-side management.

It may even be needed to spill hydro at times, though this has been unusual for decades.

It should be noted that phasing out nuclear reduces the need for flexibility and curtailing. Nuclear power can[52] [53], technically, follow load but this is not common practice, and has safety and economic issues[54]. Nuclear plants prefer to run at maximal load, and unless there is a legal priority for wind and solar, nuclear plants will not supply any flexibility, and will instead consume flexibility. In normal base-load operation, nuclear power produces the same number of gigawatts during winter weekday morning and afternoon demand peaks as during low-demand periods such as summer weekend nights. This must be balanced, for example with hydro or imports/exports. If nuclear power is gone, this flexibility can be used by wind and solar.

The legal environment is also important for some other power plants. Combined heat and power can be inflexible or very flexible, depending on what they are required to do as well as on their technology.

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51 https://windeurope.org/wp-content/uploads/files/policy/position-papers/WindEurope-Priority-Dispatch-and-Curtailment.pdf

52 http://de.areva.com/customer/liblocal/docs/KUNDENPORTAL/PRODUKTBROSCHUEREN/Broschüren%20nach%20Nummer/340-Flexible%20Power%20Plant%20Operation_en-Web.pdf

53 https://www.oecd-nea.org/ndd/reports/2011/load-following-npp.pdf

54 Elforsk 12_71_rapport_screen.pdf Additional Costs for Load-following Nuclear Power Plants Experiences from Swedish, Finnish, German, and French nuclear power plants Outside the electricity sector

Balancing: conclusion

In the 2030 perspective it is not very difficult to balance 110 TWh of wind and 35 TWh of solar with known technology at reasonable costs, and to achieve a very good (but not 100 percent) security of supply for almost all contingencies.

There are some risks of over-dimensioning of balancing capacity and power lines but it may be a political necessity. Building too many power plants and power lines is not just a waste of money but also has a price for nature.

Chapter 6 Non-power emissions

Heat

If electricity is decarbonized, much of the district heating will automatically follow at combined heat and power plants. Emissions from district heat are not much of a problem. Coal, peat, gas and mixed waste can easily be replaced by biofuels, and by improved building efficiency. This is not a technical issue, and not much of an economic issue.

Oil heating of individual buildings has fallen rapidly, and will continue to do so, even without any new policy. It is hardly significant as a source of CO_2.

oil for heat, TJ			
	2007	2014	Change %
Denmark	4480	1154	-74.2
Estonia	1439	429	-70.2
Finland	14414	6228	-56.8
Iceland	38	0	-100.0
Latvia	856	43	-95.0
Lithuania	1855	894	-51.8
Norway	747	441	-41.0
Sweden	7137	3016	-57.7
NB8	30966	12205	-60.6

Gas heating for individual buildings is common in some countries, though not in most of Sweden, Finland and Norway. It can be replaced with heat pumps or biogas or hydrogen fed into the natural gas grid. The trend is already there. 99,000 TJ = 27.5 TWh and represents emissions of 5.5 Mton of CO_2.

natural gas, heat, TJ			
	2007	2014	% change
Denmark	35787	23469	-34.4
Estonia	14504	7072	-51.2
Finland	44965	30164	-32.9
Iceland	0	0	
Latvia	23157	17036	-26.4
Lithuania	30330	15611	-48.5
Norway	498	447	-10.2
Sweden	8197	5225	-36.3
NB8	157438	99024	-37.1

Manufacturing

Most of manufacturing industry is well decarbonized, if electricity and district heating is carbon-free. Emissions have halved since 1990.

Manufacturing industries and construction1, emissions, kiloton	1990	2015	% change
Denmark	5483	3917	-28.6
Estonia	2498	490	-80.4
Finland	13478	8287	-38.5
Iceland	243	68	-71.9
Latvia	3914	638	-83.7
Lithuania	6108	1172	-80.8
Norway	3987	3749	-6.0
Sweden	11190	7435	-33.6
NB8	46901	25756	-45.1

This can partly be explained by more efficient processes, as many old production units have been retired for a number of reasons. Another explanation is that many poorly insulated and draughty industrial premises were heated by oil or coal in 1990, but now have draught-proofing, are better insulated and are heated with district heating or heat pumps.

In manufacturing, the paper and pulp industry has reduced emissions even faster:

Paper, pulp and print, emissions CO_2, kton	1990	2015	% change
Denmark	330	68	-79
Estonia	0	14	
Finland	5330	2680	-50
Iceland	0	0	
Latvia	169	6	-97
Lithuania	255	22	-91
Norway	227	69	-70
Sweden	2187	710	-68
NB8	8498	3568	-58

The reason here is mainly switching fuels, from fossil fuels to biofuels such as bark, chips from branches etc.

This development will continue in many industries, but some are more problematic. The two major emitter groups are cement and steel.

Industrial emissions: cement and lime production

Cement is a globally significant source of CO_2, also in our region. CO_2 is emitted from the fuels used to heat the limestone, and from the limestone itself, through the reaction:

CaO3 => CaO + CO_2

The following table refers to the limestone emissions alone:

Cement emissions2 2014		
	Kton CO_2	
Denmark	935	
Estonia	224	
Iceland	623	
Finland	0	
Latvia	598	
Lithuania	451	
Norway	847	
Sweden	1247	
NB8	4924	

Globally, 2.1 billion tonnes of CO_2 were emitted from cement production[55] in 2014, almost 6 percent of total anthropogenic CO_2. (If fossil fuels are included it may amount to 8 percent). These emissions have increased fast – six-fold since

55 http://cdiac.ornl.gov/ftp/ndp030/global.1751_2014.ems

1975. Cement contributes much more to global warming than aviation, though it attracts much less political, technological and scientific attention and funding.

No politician would suggest stopping construction as a method to save the world.

There are however many methods to substantially cut, or even eliminate emissions.

The fuel for heating the limestone can be switched from coal to biomass or hydrogen, or even concentrated solar heat, but it is *almost* (see below) impossible to stop CO_2 from being emitted during the core process. Portland cement is produced in that way.

The fundamental function of cement is to make sand and rocks or pebbles stick together as concrete.

Alternatives to limestone include volcanic ash, fly-ash and slag. Volcanic ash was used in the Pantheon in Rome, and has withstood 2,000 years.

Modern concrete is reinforced with steel. If the steel oxidizes, it expands and cracks the concrete. This oxidation can be avoided or delayed by ensuring an alkaline environment, which lime can provide, but it can also be provided by ash or slag.

Cement producers understandably do not want to change their processes and feedstuff, because it costs them money. But if the customers require less CO_2, they can mix in more slag or ash. Cementa/Heidelberg Cement has achieved new mixes with about 30 percent less carbon emissions[56] . Thomas Concrete reported 34 per cent alternative binders in its ready-made concrete for 2017, and aims[57] for 50 per cent 2020.

Opportunities for reducing emissions also include improved, slimmer designs that use less concrete for the same or better strength, using less clinker in the cement, less cement in the concrete, and using stainless rebars. Cement and concrete are cheap bulk materials. The construction industry has not seen any problem until relatively recently.

Concrete is not the only construction material. Wood is sometimes an alternative, and has recently been used for eight-storey buildings[58], though wood is probably not an alternative for all buildings in the world.

There are non-lime cements, for example from magnesia[59]. The magnesium cement production does not emit CO_2, and it is more energy efficient because it needs lower temperatures, 650 instead of 1400 degrees. This is under development, but it is not yet a commercially available alternative to Portland cement.

56 https://www.heidelbergcement.com/en/sustainable-construction

57 http://thomasbetong.se/images/docs/Team%20Thomas_Sustainability%20Report_2017_180327_FINAL_www.pdf p22

58 http://folkhem.se/sv/massivtrahus

59 See http://pubs.acs.org/doi/pdf/10.1021/acs.chemrev.5b00463

The minerals are abundant. Magnesium oxide is widely used for boards in construction, though not yet as cement.

The market pressure is there, at long last. The construction companies, private and public housing companies, and other companies that rent their offices all want a smaller carbon footprint if the price is not too high.

The political pressure is hardly noticeable yet, but it will come, through public procurement and funding for research and development and other methods.

One such other method is to deny or restrict the rights of extraction companies to extract lime at their convenience. Nordkalk mines limestone on the Baltic island of Gotland, for lime (not cement). One of its quarries was shut down when the government declared the area a Natura 2000 reserve. The lime industry is similar to the cement industry and Cementa/Heidelberg, which also mines limestone on Gotland, will no doubt notice.

In June 2017, Vattenfall (owned by the Swedish government) and Cementa in Sweden set up the Zerocem[60] project to produce cement without CO_2 by 2030. It does not spell out how this is to be done, other than that electricity will be used. One possibility pointed out elsewhere[61] is that the carbonate is electrolyzed:

$$CaCO_3 + \text{energy} \Rightarrow CaO + C + O_2$$

The technical detail is foggy but the message is clear: the emissions are not necessary.

If Vattenfall and Cementa fail to deliver, someone else will. The present use of Portland cement is not part and parcel of our way of life.

Steel and hydrogen

Steel can be produced from scrap or ore. Scrap steel is not much of a problem for the climate, if the electricity comes from renewable sources.

Ore-based iron is a major emitter of CO_2, globally and in Scandinavia. The whole idea of steelmaking is to turn iron oxide into iron. The oxygen is removed in a blast furnace by a reducing agent, which is almost always coal or coke.

Because steel has to compete globally no company can afford to use a much more expensive reducing agent than its competitors. Biomass is not a practical option even if it were as cheap as coal.

SSAB in Sweden is the biggest producer of iron/steel in the NB8, with one blast furnace in the far north, in Luleå, near the mines of LKAB, and another south of Stockholm. Together with LKAB they emit about six million tonnes of CO_2 per year, about one-eighth of Sweden's total.

60 https://corporate.vattenfall.com/press-and-media/press-releases/2017/vattenfall-and-cementa-focusing-on-zero-emissions/

61 https://phys.org/news/2012-04-solar-thermal-cement-carbon-dioxide.html

SSAB, LKAB and Vattenfall have formed a joint venture[62] for fossil-free steel with hydrogen as the reducing agent.

They have taken a big step by saying it can be done. They are talking about a pilot plant in 2024 and a demo plant by 2035, but if it can be done, it can be done faster.

Hydrogen has been produced by electrolysis since the 1920s, for example in Norway. Electrolysis produces about 4 percent of the 85 Mton of hydrogen that is produced globally.

Gas reduction of iron oxide to iron, using a hydrogen-rich gas (reformed natural gas) as reducing agent, is also an established technology. Almost 70 million tonnes were produced[63] in 2015 with that technology, some of it by Höganäs in southern Sweden, which produces metal powder.

Other manufacturing

Some of the industrial bulk chemicals, for example plastics, can be produced either from biomass or from recycled plastics. There is also scope for reducing the use of these.

This depends largely on how transport decarbonization takes place, because the output of oil refineries is dominated by fuels. Out of the 4.4 billion tons of oil and 3.2 billion toe of natural gas extracted each year, some 322 million tons go into plastics[64], so it is much easier to replace petrochemistry with biomass chemistry than to replace petro-fuels with biofuels.

Aluminium production has climate issues, though the main problem has been PFCs rather than CO_2. The only three countries in the region with aluminium production are Norway, Sweden and Iceland, and they are the only significant PFC emitters in the NB8. PFCs are terrible greenhouse gases which stay in the atmosphere for many thousands of years. But that problem is essentially solved, as Norway and Sweden have phased out the primitive Söderberg process.

Emissions of PFCs, ktons of CO_2-equivalent

	1990	2015
Norway	3,895	146
Sweden	569	36
Iceland	495	104
	4,959	286

62 https://www.ssab.com/globaldata/news-center/2017/06/28/06/01/ssab-lkab-and-vattenfall-form-joint-venture-company-for-fossilfree-steel

63 https://www.worldsteel.org/en/dam/jcr:37ad1117-fefc-4df3-b84f-6295478ae460/Steel+Statistical+-Yearbook+2016.pdf

64 https://www.statista.com/statistics/282732/global-production-of-plastics-since-1950/

CO_2 is still emitted from the combustion of graphite electrodes. Norway is a major aluminium producer (#7 in the world), and the production process emits a million tons of CO_2.

One way to end CO_2 emissions is a new technology using inert anodes. The aluminium oxide is then turned into metal + oxygen gas. This technology has been researched for a long time, but not with enough urgency. Rusal, which owns the Swedish factory, is working on it[65]. So is the European Joint Research Centre[66]. But claims that it can be a commercially available technology by 2020 leads to the underwhelming conclusion that it can reduce emissions by 2050[67]. 2050!

65 http://www.rusal.ru/en/development/innovations/inert_anode/

66 http://publications.jrc.ec.europa.eu/repository/bitstream/JRC96680/ldna27335enn.pdf

67 http://aluminiuminsider.com/new-green-technologies-could-transform-the-european-aluminium-industry-by-2050/