Norwegian Energy Policy in Context of the Global Energy Situation

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Preface

H.M. King Harald V, flanked by Professor Nils Chr. Stenseth, President of The Norwegian Academy of Science and Letters (left), Professor Roy H. Gabrielsen, President of The Norwegian Academy of Technological Sciences, and Minister of Petroleum and Energy, Ola Borten Moe. Photo: Atle Abelsen.

This volume contains the written versions of the talks presented at a symposium with the title: 'Norwegian energy policy in context of the global energy situation', jointly organized by the Norwegian Academy of Science and Letters (DNVA) (www.dnva.no), the Norwegian Academy of Technological Sciences (NTVA) (www.ntva.no) and the Research Council of Norway (RCN) (www.rcn.no). The symposium was held in the House

of the Academy (DNVA) in Oslo on 1st February, 2012 and had 150 participants. His Majesty King Harald V attended the complete meeting.

Ola Borten Moe, Minister of Petroleum and Energy, gave the introductory talk. He was followed by CEO Helge Lund of Statoil and CEO Christian Rynning-Tønnesen of Statkraft. Experts invited by the learned societies contributed with talks on: the transition from conventional to renewable energy, the power-intensive metallurgical industry, and challenges in energy and climate policy. The volume includes a chapter on energy efficiency that has been added after the symposium.

The following participants contributed by discussion and comments to the talks: Oluf Ulseth (Energi Norge), Sverre Aam (Sintef Energi), Kjell Bendiksen (Institute for Energy Technology), Cecilie Mauritzen (met.no/Cicero), Tormod Schei (Statkraft), Per Håvard Kleven (Kongsberg Devotek AS), Thorvald Moe (Cicero), Knut Bjørlykke (University of Oslo), Olvar Bergland (Norwegian University of Life Sciences), Gunnar Buvik (Vestavind Offshore), Svein Richard Brandtzæg (Norsk Hydro ASA), and Hildegunn Blindheim (OLF).

Together, DNVA and NTVA represent the entire spectrum of the learned disciplines. RCN joined the organization of this year's symposium. By the organization of an annual symposium series like this, focusing on a subject of high political priority, the two academies and RCN want to develop this kind of science communication.

The scientific committee of this year's symposium included: Executive Director Anne Kjersti Fahlvik, RCN, Professor Roy Helge Gabrielsen, University of Oslo and President of NTVA, Professor John Grue, University of Oslo, and Chair, the Natural Sciences Division of DNVA, and Professor Signe Kjelstrup, the Norwegian University of Science and Technology.

Previous symposium in the series: Marine Transport in the High North, held on 19th October, 2010.

We acknowledge with gratitude the technical assistance by Eirik Lislerud and Erik Furu Baardsen of DNVA. The symposium was jointly funded by DNVA, NTVA and RCN.

Some words about the chapters of this book:

Ola Borten Moe, Minister of Petroleum and Energy, writes that climate and poverty are the two major challenges the world is facing today. The growing world population and the decline in poverty present an enormous demand for more energy. Regarding climate, a global price tag on greenhouse gas emissions would be the most effective policy instrument we can introduce. It is important that individual countries and regions take the initiative in introducing measures that lead to global emission reductions. More renewable energy sources should be developed. In Norway, we must manage the oil and gas resources in a perspective that spans generations. Fossil energy production should be as environment-friendly as possible, and with maximum energy efficiency. Research on carbon capture and storage (CCS) should be continued. The electricity certificate arrangement with Sweden introduces a paradigm shift when it comes to renewable energy in Norway. We will have more wind turbines and more small-scale power plants. Development of the electrical grid is essential in the transition to renewable energy. Production of bio-gas from source-separated food waste, climate-friendly energy production and district heating represent smarter and more efficient uses of energy. Norwegian hydropower may serve as a balancing power in combination with wind and solar energy, but Norwegian gas has better capacity in this respect.

Helge Lund, president and CEO of Statoil, writes that Statoil's strategy consists of three pillars, which are 1) to take out the full potential of the Norwegian Continental Shelf, 2) to exploit the company's offshore expertise to build international offshore positions, and 3) to enhance the positions of Statoil within the field of unconventional resources. Statoil has developed a sharper profile as a technology-focused upstream company. Statoil's analyses in a 30 years horizon anticipate an average annual growth in the global economy of 3 per cent accompanied by a growth in energy demand of 1.3 per cent. The latter will primarily be covered by gas and renewable energy sources, although oil will continue to be an important part of the energy mix. While the world's oil and gas reserves have risen by more than 100 per cent since 1980, major investments in new conventional and unconventional resources are required in order to maintain the world's oil and gas production. Stringent

requirements are set for Statoil's operations regarding safety, ethics, integrity and transparency. The climate, energy and economic growth dilemma is discussed.

Christian Rynning-Tønnesen, CEO of Statkraft, writes that the world may become 77 per cent renewable by 2050, up from 13 per cent at present. This is according to reports from the IPCC. Such a development requires substantial political backing. Renewable energy is becoming more competitive. Photovoltaic sun power in China is down to 15 US cents/kWh and onshore wind power down to 10 US cents/kWh. In Europe, there is a massive shift from fossil to renewable sources, mainly wind and solar. Annual wind power production may triple to 581 TWh by 2020 compared to today's level, matching the consumption of all households in France, Germany, Poland, Spain and the UK. The variable sources (wind, solar, waves, tidal) need backup from energy storage and balancing services. With half of Europe's hydropower storage capacity, this is an opportunity for Norway. The distributed production of new renewable energy will depend on an extended European grid.

Ånund Killingtveit of NTNU reviews IPCC's special report on renewable energy (RE) sources and climate change mitigation (SRREN); this report concludes, among other things, that the median values of all renewable energy sources range from 4-46 g CO_2 equivalents/kWh, while those of fossil fuels range from 469-1001 g CO_2 equivalents/kWh. He discusses the European strategy for transition from fossil to renewable energy including an energy road map for 2050, and expands on how Norwegian hydropower can be used as balancing power in the European grid, for combination with the highly intermittent energy from wind and sun. Parts of the Norwegian hydroelectric reservoir capacity, in combination with new pumped storage hydropower plants, are of sufficient volume to provide such an increasingly important back up in Europe.

Halvard Tveit and Vegar Andersen of Elkem write that the Norwegian production of silicon and metals represents some of the best use of our hydroelectrical energy regarding energy quality and efficiency. The electrical metallurgical process also produces a large amount of excess heat energy, which represents a possible source for energy recovery with

great potential for improving the energy situation in Norway. There are sufficient energy resources for both industrial and public use, but energy consumption in the public sector continues to rise in spite of ambitions for energy savings. This is a concern in a world where important resources may become scarce and challenge the supply-and-demand economy. The consequences for Norway should be addressed as part of a national energy strategy.

Arild Underdal of UiO addresses challenges in energy and climate policy, and writes that the most demanding challenges are found at the interface between what are commonly labelled as energy policies and policies aimed at mitigating the impact of human activities on the global system. He writes that policymakers must steer an increasingly energy hungry world towards sustainable and effective energy systems. Two main strategies that can be used to promote the required transition are examined. He recognises that both strategies will most likely bring about incremental change rather than fundamental transition, however. He continues by describing a few game-changing measures that can fundamentally reverse current development trajectories, including, 1) supply-side measures/ large-scale technological shifts towards low-carbon energy systems, 2) demand-side measures, including radical improvement of energy efficiency, and major changes in infrastructures and lifestyles, and 3) geo-engineering like carbon capture and storage (CCS) and ocean iron fertilization.

Signe Kjelstrup, Mari Voldsund and Marit Takla of NTNU write about the way towards a resource-efficient society, which is to reduce the amount of wasted energy. They introduce the concept of exergetic efficiency, which can be used to map the energy efficiency of a society. They talk about available exergy and the use of exergy. In Norway, hydroelectric power represents a large share of available exergy, which is also available from biomass, oil and gas. Use of exergy includes production, work, transport and heating. Exergy efficiency is the amount of exergy output divided by the amount of available exergy. For example, the transport sector has very low exergetic efficiency, mainly because of the low efficiency of the combustion engine. The authors show how exergetic efficiency has developed over 300

years, where the first steam engines were less than 1 per cent efficient, while today's combined cycle plants reach 55 per cent efficiency. The fuel cell – relevant for a replacement of the low efficiency combustion engine in cars – has currently the highest exergetic efficiency. Exergy streams and their improvement in Norwegian society are discussed.

In total, the conference presentations cover crucial aspects of the present and future energy situation as seen in the Norwegian and the global perspectives. The intention of the conference was indeed to address these perspectives. We do hope that this book will serve as a contribution in bringing the debate about this difficult and extremely important issue forward.

May 2012, the Editors

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Introduction – The Norwegian Energy System and the Global Perspective

Roy H. Gabrielsen and John Grue

The background for the energy demand

Earth is facing a dramatic human population growth in the 21st Century, most likely reaching 8.2 bn in 2050. A maximum estimate is even significantly higher (9 bn; IEA 2009). These scenarios are affiliated with severe constraints and risks (e.g. Rees 2003), one of the most serious being the global energy demand (Smalley 2005). The expectations related to the global energy availability rest on three premises, namely that

1) the escape from energy deficiency is a premise for the battle against poverty as reflected in that 1.5 bn people are lacking access to energy to fill the most elementary needs like heating and electric light, and that this figure is likely to remain high (1.3 bn in 2030 by the medium population scenario; IEA 2009),

2) energy supplies are extremely unevenly distributed, so that an average American or Norwegian individual consumes 10 - 20 times that of an average Indian citizen, although India is significantly more energy efficient in its production as mirrored in its BNP (Fig. 1),

3) the world seems to be balancing on the edge when it comes to filling the global energy need (Tertzakian 2006, IEA 2011), and

4) even the present level of global energy consumption seems to cause severe and perhaps unbearable environmental strains (IPCC 2007).

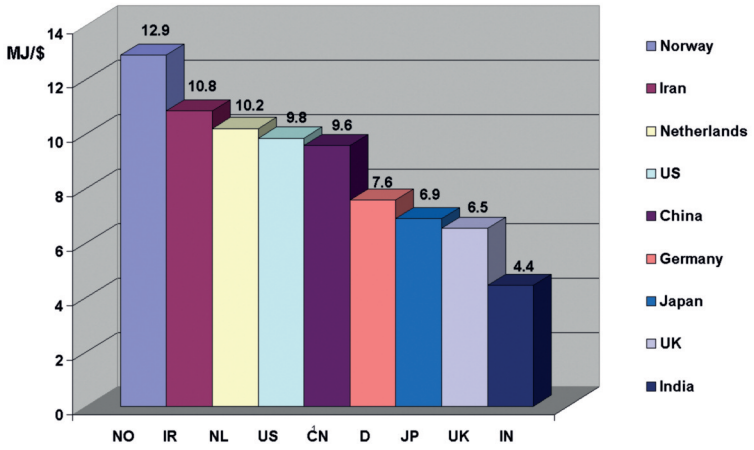

Figure 1: Global energy consumption per capita in kg oil equivalents. It illustrates energy efficiency for selected countries, displaying the energy consumed per financial unit in US$ related to BNP. Figure from IEA (2003).

This implies that in estimating the global energy demand and the possibility to fulfill this demand, the total energy system must be carefully evaluated. This includes the exploration for the total of energy resources and the technological ability to safely exploit and distribute these resources, but also the strategy and economic-political aspects behind the sharing of the energy resources (Fig. 2). All confirmed, exploitable and future types of energy need to be considered in this context, including fossil, nuclear and

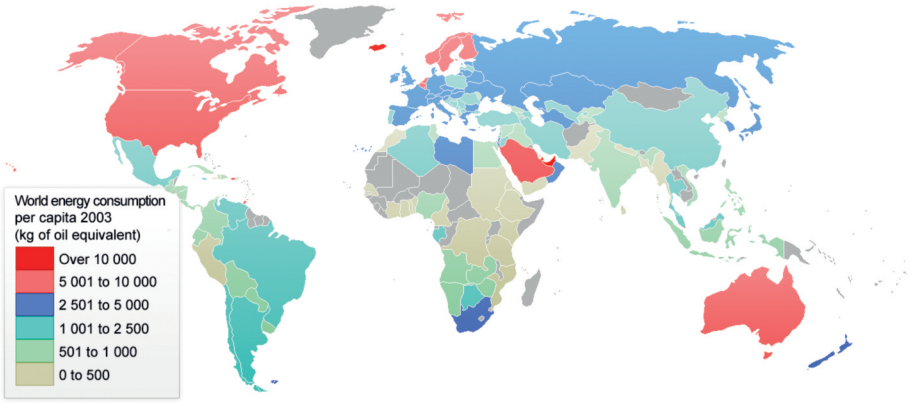

Figure 2: The world's energy consumption per capita in 2003. From IEA (2003).

renewable. But also potentially important new types of energy and all aspects of the total energy system need to be taken into consideration (e.g. Letcher 2008). Actually, global welfare and political stability lean heavily on our ability to solve these tasks (Rees 2003, Smalley 2005).

It goes without saying that the Norwegian energy resources must be seen in the global context, and not as a matter of Norwegian economy and industry alone. This is even more so because despite its small size, being the 118th largest nation when population is considered, and the 68th largest in area (Wikipedia 2011), Norway holds a much higher position in area when the continental shelf is included. Even more important, Norway is the world's 3rd largest exporter of crude oil and natural gas (IEA 2006), and we currently produce approximately the same amount of hydroelectric energy as Sweden and France together. In other words; when it comes to energy, Norway possesses resources giving the nation options, but also responsibilities, that outpace those reflected by its physical size and population alone.

When it comes to hydroelectric energy, Norway has enormous natural resources, along with tradition and technological knowledge that makes it a player of international dimensions. It also gives Norwegian society a significant advantage in that 98% of the electrical energy consumption is based on renewable and clean energy, and gives Norwegian industry an advantage through its access to this energy, as well as technological knowledge that is in demand on the international energy market.

The production of hydrocarbons from the Norwegian continental shelf has been, and is, a foundation for the modern Norwegian economy, presently (2010) providing 21% of the total Norwegian BNP, 26% of the total revenues of the Norwegian state, and 47% of the total exports of Norway (NPD 2011). Judging from the known resources as supported by recent discoveries on the Norwegian shelf and the increasing internationalization of the Norwegian petroleum industry, it is clear that Norway will be an important international producer of petroleum for the foreseeable future assuming that the international demand for petroleum does not decline. It is generally accepted that the North Sea became the global technological driving force already in the mid 1990s, also making Norway a significant exporter of petroleum technology. Within the framework of the petroleum

industry, the capacity for CO_2 storage and sequestration is also being developed, with Statoil and associated companies being forerunners by applying it to the offshore Sleipner and Snøhvit fields (e.g. Baines and Worden 2004, IPCC 2006). The importance of this technology has been escalated by the fact that important international players like Germany have declined further research on CCS for political and assumed safety reasons.

With respect to renewable energy technology, Norway is presently increasing its research and innovation capacity, but perhaps to a lesser degree than many expect. It seems obvious that Norway has a great potential at its disposal when it comes to offshore wind energy due to the combination of a long, windy coast and the very capable offshore industry. Although assumed to have less potential, energy plants related to waves and ocean currents are research and technological development goals of several minor Norwegian companies and research groups. It is noted however that research into renewable energy from offshore wind, wave power and tidal energy obtains higher priority in countries like Denmark and the UK, compared to Norway. This also concerns geothermal energy that should remain in focus; although the geothermal configurations onshore Norway remain less favourable compared to more geologically active environments like those seen in Iceland and the western US, advanced Norwegian drilling technology still makes this option attractive. When it comes to solar energy, Norwegian innovation groups played an important role during the infancy of the industry. As it moves into the production stage, however, other countries are extremely competitive on labour costs, most likely leaving Norway to compete in the future on the research and innovation front rather than production. Biofuels, hydrogen and battery technology will certainly continue to make their way as energy sources and carriers in the transport sector. It is questionable, however, as to whether Norway has the potential to play a leading role in these fields.

In the global perspective, a most recent report on renewable energy sources and climate change mitigation is IPCC's SRREN 2012 report.

The internationalization and commercialization of the energy market, and particularly in Europe, has indeed clarified the need for efficient energy distribution on all scales. This is becoming even more pressing since an

increasing proportion of the energy will be obtained from renewable sources that are characterized by variable production rates, as is the case for wind and photovoltaic energy sources (McKay 2009, EASAC 2011), generating a need for temporary storage of energy in e.g. hydropower magazines. This is to a large extent a complex, combined hardware/computer infrastructure, that in part exists already but needs to be connected and harmonized, and in part still remains to be developed. Moreover, the introduction of distributed production of electricity from new renewable energy resources demands a strong, new development of the electrical transmission grid. Developments are necessary in three main areas, namely in the 1) planning and development, including well-planned and optimized investments, 2) the physical and market aspects of the operation of the grid, and 3) the development of transmission technologies, including e.g. high voltage direct current technology (HVDC) for bulk power transmission (EASAC 2009).

Motivation for the seminar

The energy question remains one of the most important for humanity to solve. Indeed, it is probably not an exaggeration to state that the future of humanity depends on this. And the problem cannot be solved without intensified and focused research, development and innovation. It is our opinion that energy research must be performed on a global scale. Still, coordination is necessary to ensure that no branches of energy research are neglected. Not generating the necessary knowledge, and preventing essential innovation from prospering, the future cost can be unforeseeable. Which alternatives would there be, and what international consequences would result, if Japanese nuclear energy should remain inoperative for years after another tsunami? What are the consequences of failing to develop sustainable geological systems for storing CO_2? Although these are global issues, Norway is in a particular position to contribute to the energy problem solution, being a globally recognized exporter of energy and also having the financial and technological resources to contribute to its future solution.

Our question is therefore: Do we utilize the possibilities that Norway's position as a present and future energy exporter offer? And do we accept

the international responsibility in energy research and innovation that Norway's position demands?

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Norway's Energy Challenges

Ola Borten Moe
Minister of Petroleum and Energy

Energy and the global challenge

The world is facing two major challenges today: the climate challenge and the poverty challenge. Hence, there will be an enormous need for more energy in the years to come. Significant changes are required if we are to limit global warming to no more than two degrees by 2050. However, even in that scenario, energy consumption will have increased by more than 20% in 2035. Major reasons for the increase in energy demand are the growing world population and a decline in poverty. There is a close link between energy consumption and increasing prosperity. Norway is a prime example of this. Ever since the Middle Ages, our prosperity has been dependent on learning how to control nature and develop energy. This has been a prerequisite for development. But energy consumption is also closely linked with greenhouse gas emissions. If we are to handle the problems of poverty and the climate challenge in parallel, we must achieve economic growth without a corresponding increase in energy consumption.

Last year, the world's population passed the 7 billion mark. Never before have so many people, in relative or absolute terms, had such a good chance of achieving a good life. This is a positive and encouraging trend. Nevertheless, there are around 1.5 billion people without electricity and more than 1 billion who do not have enough to eat. This is one of the greatest challenges facing our world, not least in an ethical and moral

perspective. Historically, there is a clear parallel between economic growth and energy consumption. However, the IEA reports a reduction of slightly more than 1% in energy consumption per unit of growth in the period from 1985 to 2009. All scenarios in the World Energy Outlook indicate better global progress in the years to come, and that we have to accomplish twice as much if we are to achieve the two-degree goal. This should be possible. The task facing the world is formidable, but we have a moral obligation to succeed. I choose to be optimistic. Our grandparents and parents managed to send people to the moon and to bring about a peaceful conclusion to the cold war and imminent nuclear threat. In such a perspective, I don't think these challenges are insurmountable.

The Chinese example

China is an example of the enormous growth in energy supply and consumption that is taking place today. Twenty years have passed since China became an importer of oil. Today, China is the world's second largest importer of oil, consuming 10 million barrels per day in 2011, nearly 10% more than last year, and representing a growth that accounts for almost 40% of the increase in global oil consumption. 10 million barrels per day is about 5 times Norway's production. China's installed capacity for generating electricity increased by 80 gigawatts from 2007 to 2008, compared with Norway's installed capacity of 31 GW. In other words, it took China five months to build up what took us 120 years to achieve. Most of China's power production comes from coal-fired power plants. China consumes more coal than any other nation, and is responsible for almost 50% of the world's coal consumption. China became a net importer of coal three years ago, and is today the world's second largest importer, dominating development in global coal prices.

Consequences of the global energy demands

In Norway and the western world, sustainable economic and social growth came as a consequence of eliminating such factors that still affect a large

part of the world's population who lack electricity and sufficient food supplies. I believe that this is also necessary in the rest of the world. It is also a precondition for controlling climate change created by human activity. If you do not have access to food, light, heat and shelter, the global climate is probably not your primary concern. Therefore, it is positive that global energy consumption is increasing. Now it is up to us to work together to make sure that this progress becomes sustainable. Events in Norway are a good example. From 1990 to 2010, Norway's energy consumption grew by about 20%, while our economic growth in the same period was 67%. Figures from Statistics Norway show that the emission intensity for greenhouse gases relative to production has been cut almost by half during this period. This is significant progress, and the development continues.

A binding, international climate agreement would be an important step, as well as a global CO_2 price. A global price tag on greenhouse gas emissions would be the most effective policy instrument we can introduce. It can facilitate making a proactive climate policy good business policy as well, and it can contribute to realising global emission cuts. Not least, the development of carbon capture and storage will take on a whole new drive if we can put a global price tag on CO_2. The development that we see now is largely a result of the lack of consensus from the world society as regards a global price tag on CO_2. Along with setting the "right price" on both energy and emissions, we must remove fossil energy subsidies. According to the IEA, more than 400 billion dollars were spent on subsidising fossil energy consumption in 2010. This is more than seven times the amount spent on subsidies for renewable energy production in the same year.

At the same time, we must be realistic when it comes to the challenges countries face when adjustments are made. When diesel subsidies in Nigeria are cut, it means more expensive transport and more expensive goods for the people. One example of a country that has succeeded in implementing a programme to redistribute funds from fossil energy subsidies to the poorest segment of the population is Indonesia. Nigeria, for example, lacks a social structure and institutions that can ensure efficient redistribution of these funds to the poorest citizens.

We must acknowledge that we still have a long way to go before the world can put a global price tag on CO_2. Therefore, it is important that individual countries and regions take the lead and introduce policy instruments and measures that lead to global emission reductions. Durban was not enough. We must hope for, and work hard to ensure, that future processes will lead us to take bigger steps in the right direction.

With regard to the energy sector, it is quite clear that we have to do something about the way we produce and use energy – both in Norway and around the world. We must:

Use energy more efficiently – and smarter.

Use more renewable energy resources.

Also produce fossil energy in the most environmentally friendly way possible, and with maximum energy efficiency.

Consequences for Norway

For Norway, this means several things: We will continue to produce oil and gas for an energy-hungry world. As the world's second largest gas exporter and the world's sixth largest oil exporter, we have a large responsibility in the international energy markets. We will strive to make our production as clean as possible. We must develop new and more energy-efficient technologies for recovering petroleum. And we must continue our commitment to carbon capture and storage.

Many have predicted the demise of the Norwegian continental shelf; a prediction that has proven to be premature. My opinion is that we must manage the oil and gas resources in a perspective that spans generations. I am optimistic on the industry's behalf. The world's energy markets are essential for economic development. The changes we have experienced in recent years have been demanding, both for producers and consumers. Major price fluctuations create uncertainty, which erodes the preconditions for necessary investments in all parts of the value chain. We also note the

current tense market situation. Norway plays an important role as a large, reliable and transparent supplier. It is important to remember that substantial price fluctuations have the greatest consequences for those who have the least. Analyses from the IEA and The Intergovernmental Panel on Climate Change also illustrate the importance of a commitment to renewable energy. We must significantly increase production of renewable energy in the years to come.

There is a tendency to create antagonism between fossil and renewable energy sources in the Norwegian public debate. I believe this is a contrived conflict. We have to pursue both avenues at the same time. We will produce and deliver our petroleum resources to the world efficiently, and in the most environment-friendly way possible. At the same time, we will adapt our own society in an increasingly green and renewable direction. Therefore, we have ambitious goals for restructuring of energy consumption, energy efficiency and renewables, as well as greener and more climate-friendly petroleum production. We also have a huge commitment to development of technology, both in fossil and renewable sources, as well as in technology that can promote energy-efficient consumption.

Let me expand on this, starting with renewable energy. Anyone who claims that we do not have high ambitions for renewable energy hasn't been paying attention. I have claimed – and continue to claim – that we are facing a paradigm shift when it comes to renewable energy in Norway. The reason for this is the electricity certificate arrangement with Sweden. The Renewables Directive sets a renewables target for Norway of 67.5 per cent by 2020. This entails an increase of around 9.5 percentage points from 2005. Norway's share of renewables will thus amount to 2/3 of our energy consumption in 2020, which is much higher than any EU country. The most important policy instrument for achieving such an ambitious goal is the joint electricity certificate market with Sweden. This took effect 1 January this year and in practice represents an efficient support scheme for renewable electricity. The target is set: Norway and Sweden will have 26.4 terra watt hours of new production by 2020.

And let me say this: the targets are extremely ambitious. 26.4 terrawatt hours is equivalent to about 1/5 of Norway's current annual production.

As regulatory authorities, we have put the framework in place. Now it is up to the industry to get these projects started. In parallel, we are working to reinforce the electricity grid. We know that many of the new developments are coming in remote areas, far from the consumers. There is no point in developing more renewable electricity if we can't transport it to where it is needed. Obviously, such a strong commitment to renewable energy will be felt all over our country. We will have more wind turbines, more small-scale power plants and more power lines. It would be naive to think this will not be an important part of the public debate in the years to come.

I believe that the focus of our debate will change in the period ahead of us, and that we will see the focus shift from framework conditions to licensing policy. For generations, the balance between preserving and using nature has been one of the strongest conflicts in Norwegian politics. I believe this will continue – and it is certainly legitimate. Just before Christmas, we passed the final resolution giving the go-ahead for the new power line between Ørskog and Sogndal. This power line was crucial for realising a number of small-scale power projects in Western Norway. The same is true of a number of other power line projects, which Statnett is currently working on. All in all, this shows that there is quite a lot going on in the renewables area, much of which will be essential in the work to make Norwegian society even greener.

Another important element is the work to use energy in ways that are smarter and more efficient. Considerable activity is also underway in this area, and the role of the research and academic communities is key in developing new technology. We do not have to travel far to find good examples. The City of Oslo is currently building a biogas plant at Nes in Romerike. The plant will use source-separated food waste, in part to produce biogas. The Haraldrud heating plant in Oslo is another example. I visited the plant myself before Christmas last year. Hafslund district heating is in full swing to expand its production capacity with more climate-friendly energy. Anyone who is interested in the potential of pellets should come and see the new pellet boiler. 56 megawatts of installed capacity is a lot. The consumption in this pellet boiler alone is

estimated at more than one-third of total pellet consumption in Norway, equivalent to 100,000 cubic metres of timber! We have many examples like this, and Enova is an important resource in this work. I am pleased to see that the interest and enthusiasm in the market has been – and continues to be – substantial. Enova currently has a portfolio of more than 4,000 large and small projects in the fields of renewable energy and energy efficiency. Overall, these projects contribute to ensuring that Norway's energy supplies become greener, and more flexible.

Last year marked Enova's 10th anniversary. I believe that an important reason for Enova's success is the management model it employs. Enova is responsible for selecting these projects, not the politicians. As I mentioned in the beginning, it is a fact that the world needs more energy in the years to come – and all scenarios indicate that fossil energy carriers will continue to play an important role. How this fossil energy is produced is thus of great significance. We must combine Norway's role as a major petroleum producer and exporter with our ambition to lead the world in environmental and climate policy. Norway has been a pioneer in fields such as CO_2 pricing. The fact that the Norwegian petroleum industry must deal with a price tag on CO_2 as a consequence of quota obligations and the CO_2 tax, gives the industry incentives to continuously improve. This is good. We produce our petroleum resources in a way that is energy-efficient. The Norwegian petroleum sector is world-class in environment-friendly offshore petroleum production.

We will continue to set strict requirements for the industry, and further develop the Norwegian petroleum industry as described in the White Paper on Norway´s petroleum activities, adopted by the Norwegian parliament before Christmas. In contrast to what we often see in the media, the parliamentary debate revealed fairly comprehensive political agreement on petroleum policy. I believe it is important to look at the Norwegian oil and gas activities in a wider perspective. Gas production is particularly important for Europe, due to good supply security – but potentially also in connection with the substantial renewables ambitions.

The EU has pledged to increase its share of renewables to 20% by 2020. These targets are legally binding, and entail a massive commitment

to renewable energy in the years ahead. One of the challenges we face is the increased need for balancing power. If we are to exploit the sun and the wind, we need backup for days when sun and wind are in short supply.

It is in this context that we talk about Norwegian hydropower functioning as a "green battery" for the rest of Europe. Norway already has this function, to some extent, and I believe this can be further developed. Denmark's commitment to wind turbines is largely the result of Norwegian hydropower functioning as balancing power. However, this is also a question of proportions. While Norway does have a lot of hydropower, it is far from enough to function as balancing power for all of Europe. Gas, on the other hand, does have this potential. Another relevant point to remember in a climate context is that gas is the cleanest of all fossil energy sources. If the rest of Europe replaced coal with gas, it would achieve the target of a 20% cut in greenhouse gas emissions – by implementing this measure alone.

One of the most important things we can do is to promote technology. I would go so far as to say that Norway has a special responsibility in this field. At the same time, it is important that we don't just do things because we can afford it. We must consider how the solutions we develop can be used in other countries and other parts of the world. We must not end up with a situation where Norway implements measures simply because we can – this could actually be counter-productive.

Comprehensive work is underway in technological development, as regards making renewable and fossil energy production both less expensive and more efficient. Work is also being devoted to more environment-friendly use of fossil energy. Here I would particularly mention the work being done on carbon capture and storage, CCS. CCS will have to deliver up to 20 per cent of the necessary emission reductions in 2050. Norway is one of the pioneers in this area, with experience based on 15 years of carbon storage at Sleipner and the newer storage project at Snøhvit. At the Technology Centre Mongstad the goal is to create an arena for developing, testing and qualifying technology for carbon capture. The work at Mongstad is complex, and has proven to be even more complicated than we thought initially. Now, however, we will soon see the results of a long-term, vigorous

commitment. The technology centre will soon be commissioned, and I am looking forward to the opening in May of this year.

Conclusion

My primary message is that we must be able to pursue not just one or two, but many avenues at the same time. We will continue to produce oil and gas for a world that needs ever more energy. But we will strive to make our production as clean as possible. We must develop and apply new and more environment-friendly technologies for petroleum recovery and energy consumption. And we must continue our commitment to carbon capture and storage. At the same time, we will guide Norway in a greener direction through determined efforts to promote energy efficiency and renewable energy.

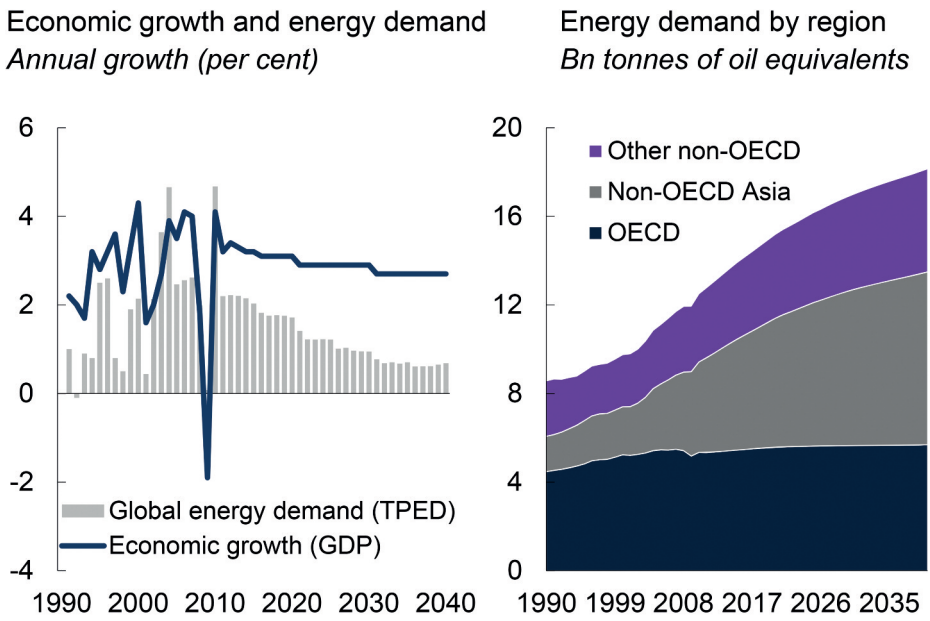
Energy Realities – Oil & Gas in the Future Energy Mix

Helge Lund
President and CEO, Statoil

Introduction

In recent decades several hundred million people in emerging economies have increased their standard of living considerably. More and more people – in more and more parts of the world – are finding their way out of poverty and are gaining access to goods and services that improve their quality of life. The implied elevation of living standards has been enabled by access to safe and efficient energy. Continued development, growth and affluence are conditional on people's access to the energy they can afford. Without electricity, there is no development. Without transport, there is no trade. Without energy, there is no future.

Even though there is considerable uncertainty in the short run, most factors indicate that the global economy will continue to grow in the long term. In Statoil we expect economic growth during the next 30 years to be in line with that of the past 30 years: an average growth of just about 3% per annum. With their 4.5-5% growth per annum, emerging economies will make the biggest contribution, while growth in the industrialised countries is expected to be more moderate, at perhaps <2%. With continued progress in energy efficiency, especially in industrialised countries, the implication is that almost all growth in energy demand will take place in emerging economies. Consequently, global energy demand is expected to rise by roughly 1.3% annually, adding some 45% to annual energy needs by 2040.



Source: Statoil (*Energy Perspectives 2011*).

Figure 1: Global economics and energy

Economic growth and energy demand
Annual growth (per cent)

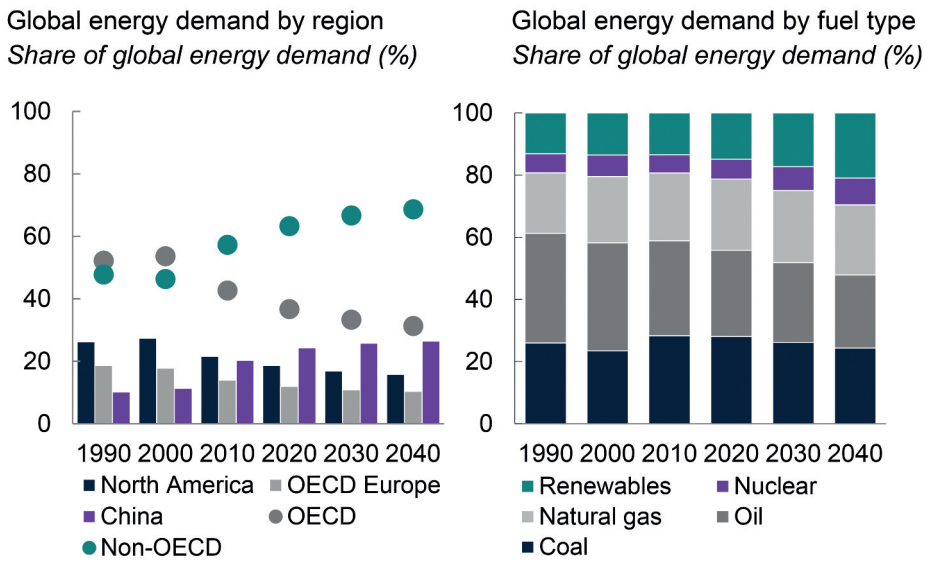
Energy demand by region
Bn tonnes of oil equivalents

The future energy mix

Oil will continue to be an important part of the energy mix. We have not yet reached the end of the oil age, even though the growth in energy demand will primarily be covered by gas and renewable energy sources. We envisage that global demand for oil will peak sometime after 2030. However, maintaining the world's oil production will require major investments in new resources and new acreage both in conventional oil and gas provinces, and in provinces dominated by emerging unconventional resources. With large legacy fields in decline, there is a substantial need for capital and new field developments to replace existing capacity, even in a world that will cut its greenhouse gas emissions heavily. International Energy Agency (IEA) statistics indicate that the world will

have to develop roughly 50 million barrels per day of new capacity by 2035 – even in a scenario where the global temperature increase is limited to 2 degrees Celsius. The required replacement of production capacity corresponds to a volume five times Saudi Arabia's current oil production.

Future oil supplies will be derived from what we currently regard as conventional oil resources as well as from resources that are currently classed as more unconventional. Across these resource types, Statoil and other oil companies must therefore invest in exploration, field development, and increased recovery in producing fields with new technological solutions, in order to secure continuing supplies of oil to the global market. And the key to success is our know-how and expertise.



Source: Statoil (*Energy Perspectives 2011*).

Figure 2: Global energy demand by region and fuel type

Global energy demand by region
Share of global energy demand (%)

Global energy demand by fuel type
Share of global energy demand (%)

Natural gas will play an increasingly important role in the global energy supply. Global gas resources are considerable, they are growing each year, and they are available in many countries. We expect that the growth in gas demand will outstrip overall energy demand in all markets. Gas is considerably more climate-friendly than coal. New gas power plants replacing old coal power stations reduce carbon emissions by up to 70%. Gas therefore holds the potential of providing the entire world with energy in a more sustainable way.

In the future we expect a growing share of electricity production to come from renewable sources, which is good. New renewable sources of energy, such as wind and solar, will grow by an average of roughly 8% during the next 30 years. That will mean a tenfold increase in annual supply of new renewable energy compared with the current level. Oil and gas will therefore account for 46% of global energy production in 2040, compared to just over 50% of the current, lower level of total production. Responsible and energy-efficient production – from the Norwegian continental shelf for example – will therefore be of great significance and value.

Within a two-degree target framework for global temperature increase, the International Energy Agency has shown that we will have to develop new gas capacity equivalent to 1,500 billion m^3 per annum in order to meet increased demand and to replace current production capacity. This is equivalent to approximately 15 times current gas production in Norway. As the second largest gas exporter to Europe, Statoil is well positioned to meet a favourable future for natural gas.

In the USA we are playing a growing role in the shale gas sector. In his State of the Union speech January 20th 2012, President Barack Obama said the following about shale gas: "My administration will take every possible action to safely develop this energy." Statoil has taken a significant position and aspires at an industrial role in this development.

Different energy sources have different advantages and disadvantages. The most important advantage of renewable energy sources is their low carbon emissions. Oil and gas are cost-efficient energy carriers that are both stable and flexible. The world needs to meet the increasing demand

for energy with a sustainable and balanced energy mix. And we need to develop policies, knowledge and technology to reduce or compensate for the disadvantages of the different sources.

For Statoil it is important to help make the production of oil and gas as environmentally friendly as possible. Our strong recommendation is therefore that the share held by gas is high at the expense of coal. In return we will make sure that we recover and deliver oil and gas in as energy efficient ways as possible, and that we research opportunities for carbon capture and storage. Historically Statoil has played a role in all these areas. We intend to continue doing so.

In the world today, we need a wide-reaching energy strategy. We need all the sources of energy and a balanced energy mix. That means both a more active development of renewable resources and the continued development of oil and gas.

So the question remains: Do we have the oil and gas resources needed to meet the growing demand? The short answer is yes: oil and gas have demonstrated a unique ability to constantly prolong their lifetime. Since 1980 the world's oil and gas reserves have risen by more than 100%[1] – so we have more than twice as much oil and gas available for development as we thought 30 years ago. The reason for this is the constant development of technology, new resources (deep water/unconventional resources, new acreage) at an ever lower cost. In addition comes the increase in the oil price over the last ten years, which has resulted in more favourable market conditions for oil and gas supply.

1. Different sources reach more or less the same conclusion, though precise estimates do vary. BP's Statistical Review of Energy 2011 concludes with the following: Since 1980 proven oil reserves globally have risen from 667 billion to almost 1400 billion barrels, i.e. by 107%. R/P, the number of years with remaining reserves given current production, was some 46 years in 2010. If the oil sands are added as well, the reserves according to BP amount to 1,526 billion barrels. In addition to this there is tight oil etc. Since 1980 the world's gas reserves have increased from 81,000 bcm to 187,100 bcm, i.e. by 131%. R/P for gas is almost 59 years.

The climate – energy dilemma

The interface between economic growth, energy consumption and climate problems represents perhaps the biggest dilemma for the modern world. The balance between growth and welfare considerations on the one hand and environmental and climate considerations on the other, is one of the greatest political challenges of our time. The core of the problem is that energy consumption and climate gas emissions have a cost to society that goes beyond the price paid by individual users. The cost to society of the over-consumption of common resources (i.e. the quality of our atmosphere) is therefore not reflected in the energy bills of individual consumers.

The UN has made 2012 the year of sustainable energy for everyone. It is eminently sensible of them to look at the challenge of energy provision to everybody in connection with the climate challenges, and to focus on the role that commerce and industry can play. Statoil is ready to make a constructive contribution to this process, although the political process itself is also an example of the complex challenges we face in our efforts.

Even though it is clear that the world needs a coordinated energy and climate policy, it is difficult to establish and ensure compliance with a coordinated approach to the energy and climate challenges. Statoil believes that carbon must be priced globally in a way that reflects its social emission costs. We therefore need political measures to stimulate private investments in the required technology development.

Technology development will be important. There is a great potential for innovation when it comes to reducing climate gas emissions. New technologies can improve efficiency, in both the production and consumption of different types of energy. A framework of global governing conditions with the proper incentives would accelerate technology development – but unfortunately there are few indications that such a regime can be established anytime soon.

Implications for Statoil

The oil and gas industry is fundamentally attractive. All credible analyses reveal that energy demand is increasing; the question is how much? And

the vast majority of analyses indicate that oil and gas will constitute a significant proportion of the energy mix for many decades to come. It is against the backdrop of this global energy outlook that Statoil formulates its strategies and plans.

In the course of its forty years history our company has undergone major changes, but our value basis has stood firm throughout the entire period. Safe and efficient operations are crucial to our business and to our general licence to operate. Expertise, technology and innovation have been, and are, perhaps our most important competitive advantages. And to develop – and deliver – a long-term growth strategy with Norway as the mainstay.

Statoil has moved on from being mainly a Norwegian player to becoming a global energy company. We are currently positioned in some of the most attractive areas of the world for our industry. We have significant operational organisations and operations in Houston, Rio de Janeiro, Calgary and Algeria in addition to extensive activities in Azerbaijan, Russia, Nigeria, Angola, Tanzania, Mozambique and Indonesia, among others. In 2011 we celebrated important milestones with the start-ups of two major international operatorships.

At the same time we have developed a sharper profile as a technology-focused upstream company. In its simplest form, Statoil's strategy consists of three pillars: Firstly, we will take out the full potential of the Norwegian continental shelf. Secondly, we exploit our offshore expertise to build international offshore positions. Finally, we will enhance our position within what we currently call unconventional resources.

We have set ourselves some ambitious plans. Up until 2020 we will maintain production on the Norwegian continental shelf at its current high level. Over the same period we will grow our international production by more than 100 per cent. The result is a boost to our production from just under 2 million barrels of oil equivalents per day (boepd) to over 2.5 million boepd. For the Norwegian continental shelf this will mean that we shall add roughly 600,000 new barrels of annual production in order to replace natural depletion towards 2020. And outside Norway we will more than double current production during the next eight years.

As a listed company and player in tough global competition we must balance our efforts against different expectations and requirements. We are a company and part of an industry that means a lot to many people. We hold a very special position in Norwegian society. We therefore understand and appreciate that there is an on-going discussion regarding the company's priorities and plans.

Our overall mandate is to create long-term values for our shareholders. We manage natural resources belonging to the countries in which we are working. We therefore honour the framework set by national and international authorities. However, our special role as resource manager sets particular requirements to the way we work, above and beyond the legal considerations/regulations.

A fundamental element of that responsibility is to maintain the vitality and competitiveness of our company - and to do this on a clear value basis. But at the same time this, by itself, is not sufficient. Our ambitions are therefore higher.

Our industry is thoroughly regulated. We meet formal requirements and expectations in our *modus operandi.* Stringent requirements are set to our operations, safety, ethics and integrity. These are absolutes in Statoil about which there is no discussion. We do not accept shortcuts. At the same time we have to acknowledge that the regulation of our industry is not complete. As we enter into new types of resources, deeper waters and more vulnerable and tougher climates, new requirements will be set for companies like Statoil. Moreover, we are also registering growing public interest in and informal expectations of the company.

There are different ways of relating to this. We can await new governing regulations and legislation for our operations. Or we can take our own initiatives so that society at large can feel confident that we are operating in an efficient and justifiable manner. We in the industry can claim a clearer leadership; developing standards and building confidence through openness and transparency. Thus we will also to a greater extent be self-regulated.

Our business is intrinsically dependent on people's trust. Authorities must be able to trust that we are running our business with integrity and within the predefined framework. But we also need society at large to feel

confident that the same authorities will give us opportunities to develop. Openness is a precondition for trust. We must therefore communicate openly, directly and factually regarding our business. At the same time we must be willing to discuss our approach to the dilemmas we encounter along the way. In the final analysis this is about protecting our operations and our values – thus boosting our competitiveness.

Over 40 years Norway has built up an oil and gas industry that is now competitive in a global arena when benchmarked against the best in our industry. This is not coincidental and is due to a number of factors. We have consistently cultivated expertise and know-how. Ever since first discovering oil it has been important for us to learn and to transfer our knowledge and experience. We work with complex resources in ever deeper waters and in ever tougher environments. The profitable recovery of oil and gas sets considerable requirements to innovation and technology development. And now the company, having become an international player operates more and more at the interface between politics, culture and religion. This also challenges our knowledge base. If we are to meet greater technological and societal challenges, we will need to increase our expertise and improve our skills in cooperating – with an increasing variety of specialist disciplines, across companies and between academia and industry.

Knowledge and experience will continue to play a decisive role in further developing and strengthening the Norwegian oil and gas industry. The resource situation is good and demand is growing. The industry therefore has a long and promising future, both in Norway and abroad.

Development of Renewable Energy Nationally and Internationally

Christian Rynning-Tønnesen
President and CEO, Statkraft

Demand for energy is increasing all over the world. The Organisation for Economic Cooperation and Development (OECD) and the International Energy Agency (IEA) are expecting a substantial increase and the megatrend is enormous coal and oil consumption, thereby producing large CO_2 emissions which will become significant challenges to reaching the two-degree target.

China and India alone are expected to represent half the growth in demand. In 2000 China's consumption of oil was less than half that of USA. The oil import of China will pass that of USA shortly after 2020 and they will probably be the world's largest oil consumer in 2030. According to World Energy Outlook (2011) China will consume 70 per cent more oil than USA by 2035. The rates of growth in energy consumption in India, Indonesia, Brazil and the Middle East are even faster than in China. At the same time the challenge of climate change and global warming following from carbon-intensive use of energy is increasing. Climate change is the most dire threat humanity has ever met.

Despite this rather dismal perspective, climate change represents large opportunities for both nations and companies that have traditions, resources, insight and expertise in renewable energy. Development and integration of renewable energy globally can be perceived as one of this

century's most pressing tasks – and challenges. Therefore climate change and climate policy are key drivers for energy policy and thus for the energy industry, and for Statkraft.

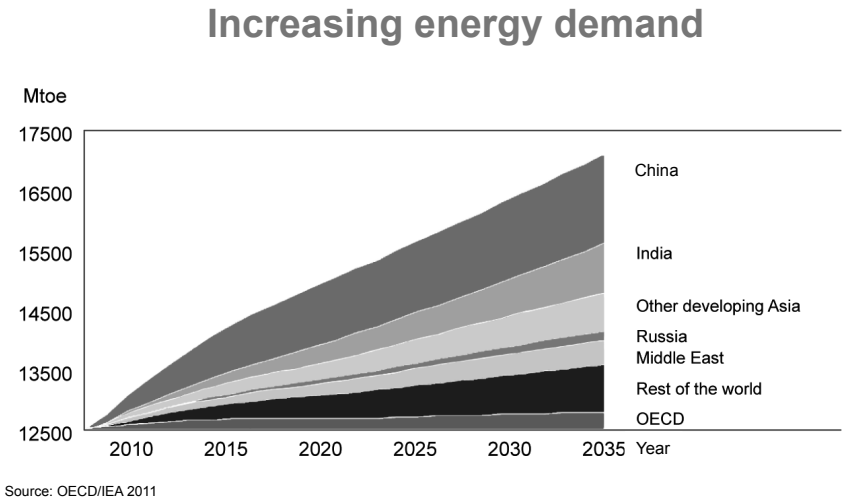


Figure 1: Increasing energy demand. Source: OECD. (IEA 2011)

Sharp increase in greenhouse gases

Emission of greenhouse gases (GHG) has increased substantially from the Industrial Revolution (1850s) until today. The concentration of greenhouse gases in the atmosphere is now at a level that makes it impossible to avoid the most serious consequence: global warming. At the Conference of the Parties (COP) in Copenhagen in 2009, and then at the COP meeting in Cancun, the two-degree target, aiming at limiting the mean global temperature to not increase beyond 2°C, was agreed upon and confirmed.

The Intergovernmental Panel on Climate Change (IPCC) says the two-degree target can be reached if concentrations of GHG in the atmosphere do not exceed 440-450 ppm. At higher concentrations, i.e. 600 ppm, IPCC fears that mean temperatures can increase by as much as 5 degrees Celsius. The amount of carbon in fossil fuel reserves and resources (unconventional oil and gas resources as well as abundant coal) not yet burned, has the potential to add very large quantities of CO_2 to the atmosphere. If

burned over the coming centuries, emissions will exceed the range of any considered scenario and will probably lead to atmospheric GHG concentrations far above 600 ppm, with a corresponding global mean temperature rise of 8°C or above (IPCC SRES 2000, IPCC AR4 2007, IPCC SRREN 2012).

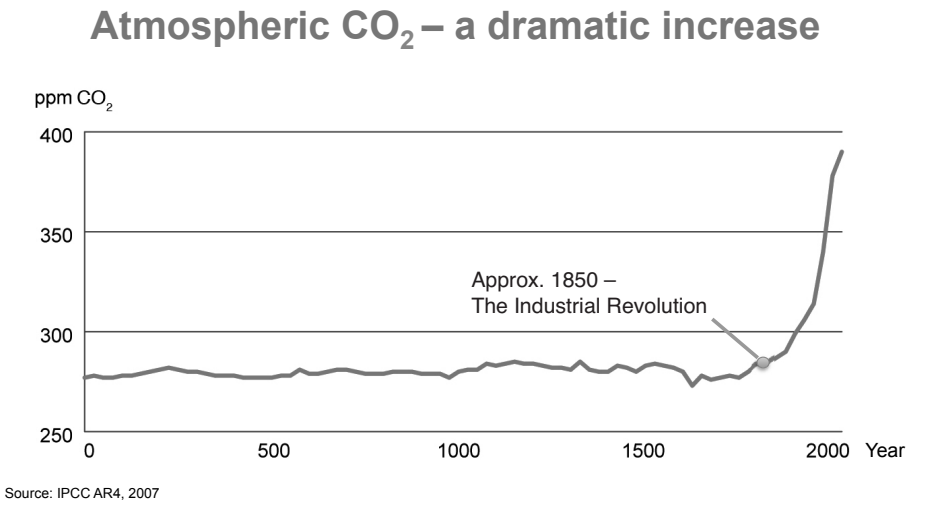


Figure 2: Atmospheric CO_2 – a dramatic increase. (IPCC AR 4 2007)

Sea level rise and more extreme weather

Most people are aware that global warming leads to sea level rise. Ocean water expands as it heats up (thermal expansion), and additional water flows into the oceans from the ice that melts on land. The future sea level is intensely debated by scientists. However, since 1870 the global sea level has risen by about 20 centimetres. These findings are based on data from tide gauges at coastal stations around the world. Since 1993, sea level has been accurately measured globally from satellites. These measurements show sea level is rising at 3.4 millimetres per year, which equates to six centimetres over the last 20 years. This is 80 per cent faster than projected by the IPCC models. Satellite and tide-gauge measurements show that the rate of sea level rise has accelerated and is tracking the upper range of IPCC projections from 1990. Recent research indicates that it is likely that

the range of sea level rise will reach 1 to 2 metres in the present century (The Copenhagen Diagnosis 2009).

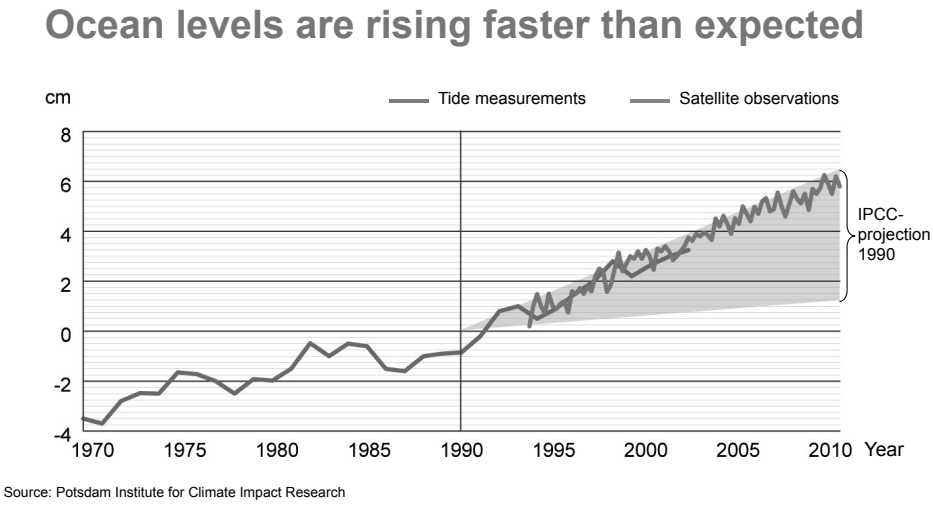


Figure 3: Ocean levels are rising faster than expected. Potsdam Institute for Climate Impact Research.

Climate change not only leads to increased temperatures but also changes in weather patterns. It is expected that some regions will have more precipitation, some less, and dry regions will be even drier (IPCC AR4 2007). The IPCC predicts that episodes with heavy rainfall will occur more often throughout this century in wet parts of the world, and likewise, droughts in drier parts. The weather pattern is slowly changing, posing major challenges for society (IPCC SREX 2011) – and also for energy production.

A shift in energy supply

World Energy Outlook (WEO 2011) states that we cannot delay further action to tackle climate change. Even in scenarios where some policies are implemented, WEO state that we are on our way to a 3.5°C increase in global mean temperature. If we do nothing, the IEA (WEO 2011) fears that we will move towards an increase of 6°C or more. It is self-evident

that energy demand increasingly must be met by renewable energy. IPCC (AR4 2007) found that fossil fuel combustion (and a smaller contribution from cement manufacturing) was responsible for 75 per cent of human-caused CO_2 emissions (land use change being responsible for the rest). In 2008 renewable energy sources had a share of 12.9 per cent of total energy supply. The IPCC has been looking at various options for mitigating climate change and has found that it is possible for the world to be as much as 77 per cent renewable in 2050, if this shift in energy supply is backed by the right enabling public policies. This could contribute towards the goal of holding the increase in global temperature below 2 degrees Celsius. This finding is based on an assessment of 164 different scenarios that predict how various renewable sources and technologies can contribute when increasingly ambitious carbon stabilisation policies are applied. The 77 per cent scenario is certainly the most ambitious, and very challenging, but also shows what is possible. The optimistic aspect of this is that we have a way to slow down and eventually stop global warming, if we want and if policies are ambitious enough. There are no technological limits, and the resource potential is more than sufficient (IPCC SRREN 2012).

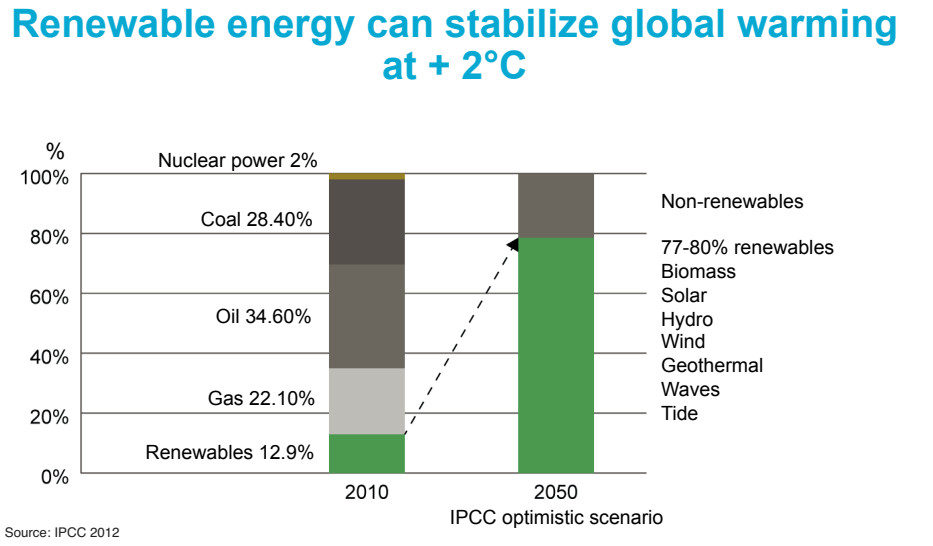


Figure 4: Renewable energy can stabilize global warming at + 2°C (IPCC SRREN 2012).

If we do nothing, IPCC has found that renewables will increase to about 15 per cent and GHG concentrations will very likely track WEO's (2011) predictions.

Renewable energy – increasingly more competitive

Significant advancement in renewable technologies and associated cost reductions have been demonstrated over the past decades. Further cost reductions are expected, resulting in greater potential for climate change mitigation and reducing the need for policy measures to ensure rapid deployment. Studies of levelized costs show that especially hydropower but also geothermal and biomass, can compete with the fossil sources. Also, onshore wind energy is now in many cases competitive, while for instance wave- and tidal power have a way to go before they will be profitable. In the US photovoltaic (PV) solar power went from 65 USD/W to 1.4 USD/W from 1976 to 2010 (IPCC SRREN 2012). In China PV is down to 15 US cents per kWh and cost reductions of 10-15 per cent per annum are expected. The cost of onshore wind power is now about 10 US cents per kWh.

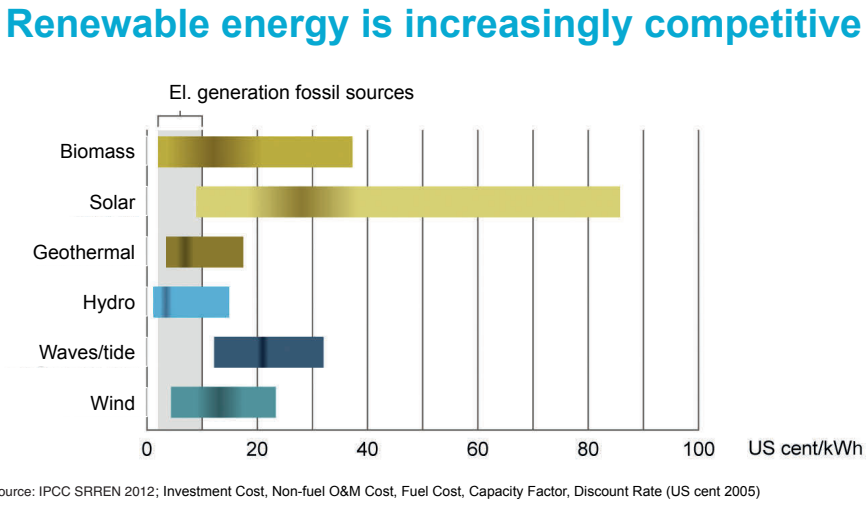


Figure 5: Renewable energy is increasingly competitive. Investment cost, Non-fuel O&M Cost, Fuel Cost, Capacity Factor, Discount Rate (US cent 2005) (IPCC SRREN 2012).

In a climate perspective the observation that many renewables now are competitive with coal, crude oil and gas gives cause for optimism. Several technologies have a way to go but the assessment by the IPCC shows that the evolution of renewables is moving in the right direction. Wind power is a good example. When His Majesty King Harald V opened Smøla Wind Farm in September 2002, the hub height was 70 m and installed capacity 2000 kW. Today hub height is closer to 100 m. The offshore turbines currently being erected by Statoil and Statkraft at Sheringham Shoal off the coast of Norfolk, England, have hub heights of 80 m and installed capacity of 3600 kW (per turbine). This is nearly twice the capacity of the Smøla turbines.

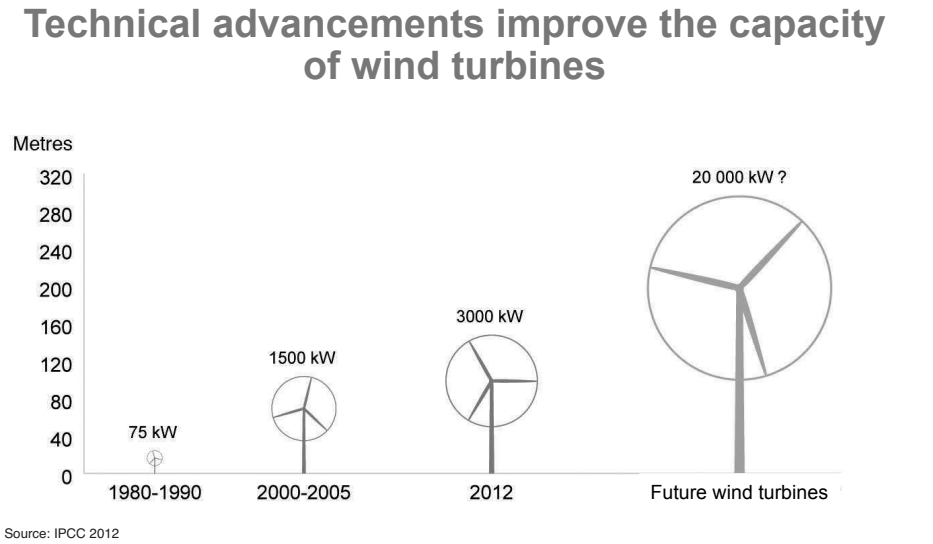


Figure 6: Technical advancements improve the capacity of wind turbines (IPCC 2012).

Research and Development (R&D) – a necessity

R&D is a key factor to enhance and further develop the performance of renewable technologies in order to increase production per unit and to make them more cost competitive. The development of wind turbines is an example of such a development. For Statkraft, innovation and R&D

also contribute to higher environmental standards and better mitigation measures with regard to nature and local communities. One example is our wind farm on Smøla where bird strikes are an issue. In recent years we have made an effort to develop technology that can help steer white-tailed sea eagles away from the turbine blades.

Though hydropower is a proven and well-advanced technology, there is still room for further improvement. For example, through optimisation of operations, mitigating or reducing environmental impacts, adapting to new social and environmental requirements and more robust and cost-effective technological solutions. In Eiriksdal, western Norway, three power plants from the 1930s and 1940s are in the process of being replaced by two new underground plants. R&D has contributed to the development of habitat models being implemented in the river and applied to optimise future operational rules, aiming to secure best possible conditions for the salmon stock. Old scars in the landscape will be restored, the river through the community of Høyanger will have more water, and at the same time future production in this system will increase by about 100 GWh. This is a win-win project where innovative planning and fruitful R&D come together and enhance sustainability performance.

Knowledge gained through several decades of research into environmental aspects of hydropower, innovative planning, construction and operation and certainly R&D related to these areas, are now part of our approach when we operate internationally. An example is the Theun Hinboun Expansion Project in Laos where Statkraft together with two partners develop 1600 GWh of new hydropower. About 10 per cent of investment costs, equivalent to NOK 400 million, was spent on mitigating environmental and social impacts. Norwegian experience and state-of-the-art competence is brought into the project. New villages, clean water, schools, electrification, new crops and income targets for affected families are central elements. Norwegian expertise on both “hard” and “soft” aspects of energy production makes it possible to create synergies between Statkraft and Norwegian research institutions on developments outside of Norway, making win-win situations a possibility and setting up competitive advantages.

Norway's 100 years of experience in hydropower is valuable and relevant in many international arenas and allows us to take part in processes where new frameworks are developed or where climate policy and energy policy will be set out. Recently, the IPCC (SRREN 2012) have looked closely into how renewable energy can mitigate climate change. In this process both our hydropower industry, with representation from Statkraft, and academia, represented by NTNU, contributed in exploring how the various aspects and properties of hydropower can make efficient contributions to the efforts against the on-going climate change.

The family of renewable technologies

Hydro, wind, solar, bio, geo and ocean power technologies comprise a rather heterogeneous class of technologies. One of them, geothermal energy, relies on heat in deep layers of the earth, the remaining rely on solar energy.

Various types of renewable energy sources can supply electricity, thermal energy and mechanical energy, as well as produce fuels that are able to satisfy multiple energy service needs. Some renewable technologies can be deployed at the point of use (decentralised) in rural and urban environments, whereas others are primarily deployed within large

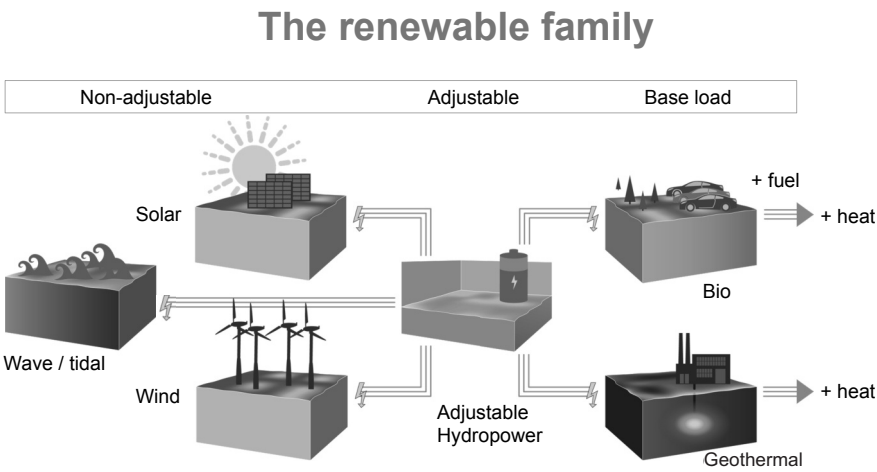


Figure 7: The renewable family (Statkraft).

(centralised) energy networks. Though a growing number of renewable technologies are technically mature and are being deployed at significant scale, others are in an earlier phase of technical maturity and commercial deployment or fill specialised niche markets. However, all the renewables have one thing in common: the source is renewable and their carbon footprints are extremely small.

The energy output of renewable technologies can be variable and to some degree, unpredictable over differing time scales (from minutes to years), in other cases the variability can be predictable, constant or controllable.

Wind, solar, wave, and to some extent tidal, energy sources are variable and often unpredictable, while bio- and geo-energy are the predictable sources. The variable sources need back-up and regulation. Too little wind or sun makes power production from other sources necessary, while much wind or sun may force other power plants to reduce their output. Wind power can also profit from energy storage (i.e. pumped storage) that can receive energy in periods with low demand, for instance during night-time. The more predictable sources such as bio and geo will have a steady output, a so-called base load, but have long lead times and are slow to respond when demand is peaking. In this context hydropower, with its flexibility, extremely short response time, ability to black start (start-up without help from the grid) and energy storage can enhance the performance of all the other renewables. Both bio- and geothermal plants can be kept at their optimum and thus at better efficiency. Variable sources like wind power may have a higher penetration in a given grid if operating in synergy with hydropower.

Therefore, it could be said that as a combined family of technologies, they may have a higher total output and reliability than the mere sum of each single technology when standing alone. In this context storage hydropower and to some extent pumped storage are key elements, acting as a "battery" which at very short notice can offer various services enhancing total output and increasing energy security.

In light of this it makes sense to utilise hydro resources when developing energy supply in emerging markets. Here hydropower can act both as a centralised and decentralised technology and at the same time secure a high utilisation of variable sources like wind and solar power.

European energy revolution

In Europe, there is a massive shift from fossil to renewable sources, mainly wind and solar. The European Wind Energy Association (EWEA) expects electricity production from wind power to be almost tripled in 2020, with an increase from today's approximate 180 TWh to 581 TWh per year. This is close to the combined consumption of all households in France, Germany, Poland, Spain and the UK. Ambitious European goals for renewable power generation will be achieved largely through the introduction of significant amounts of variable wind power into the European power system. An advisory group for the German government stated that a system with possibilities for energy storage and balancing services would enable a higher penetration of wind power in the system without compromising the security of supply (German Advisory Council on the Environment (SRU 2010)). Norway, which has half of Europe's hydropower storage capacity at its disposal, is mentioned by the German advisory group. This is an opportunity for Norway. Our flexible power production meeting peak demand in Europe may create large values, and at the same time increase energy security.

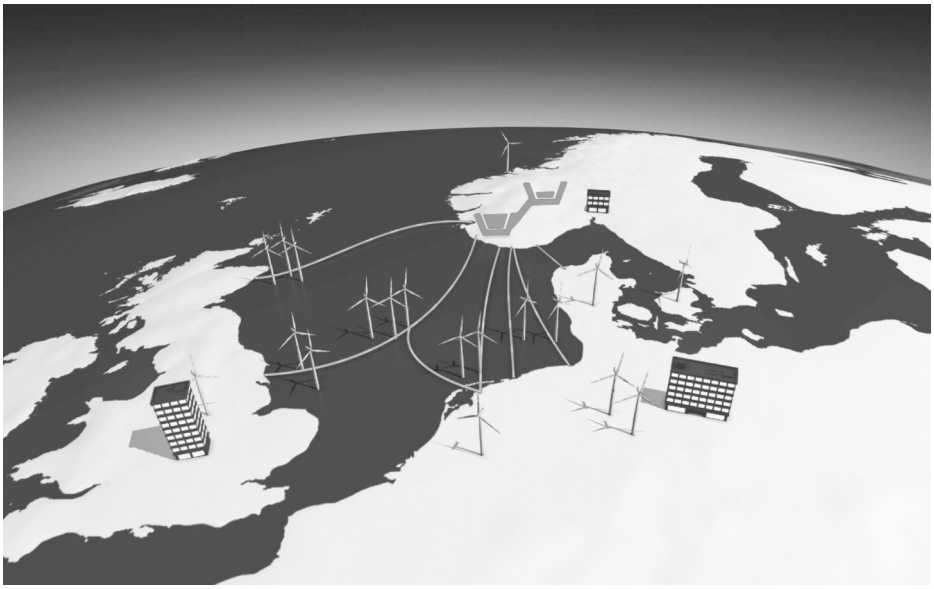


Figure 8: New renewable energy requires extension of the electrical network (Statkraft).

Several interest groups are looking at an even larger picture. Desertec is a concept for a European encompassing grid where cables to Scandinavia and even to Iceland take advantage of Nordic and Icelandic hydropower as the "battery", balancing wind and to some extent solar in Europe and even solar in the Sahara region. Since 2009 the Desertec Industrial Initiative (DII) has been developing the Desertec concept. Munich RE, one of the consortium members, claims that large economic losses due to natural catastrophes, possibly caused by climate change, are an incentive for a radical and large-scale change in energy supply.

The way forward

In spite of enhanced financial unrest EU maintains a high focus on climate change both in international climate negotiations and among member states. A global agreement on the other hand seems still not quite within reach. International climate conferences like the UN Framework Convention on Climate Change COP meetings are accused of failure. However, there are several positive trends. The Copenhagen and later Cancun COP meetings agreed on the two-degree target, and even asked for a move towards a 1.5°C temperature increase target, even if this currently seems a difficult goal. In Durban, in December 2011, governments decided to "adopt a universal legal agreement on climate change as soon as possible, but no later than 2015" and "for it to come into effect and be implemented from 2020".

On the national level, however, there is quite high activity. Bilateral agreements are set up between states and countries. For example, in the US several states have set up voluntary cap and trade regimes (RGGI). California has approved the first mandatory cap and trade scheme. Quebec has decided on a similar system that will be linked to California (Western Climate Initiative). Also, several states in the US are actively adapting to climate change and recent polls indicate that a majority of people in the USA now believes climate change is real. In Durban, China presented plans for a pilot on cap and trade aiming at reducing emissions nationally by 17 % within 2020, according to information from Chinese delegates. The pilot will operate until 2015 and will consist of 5 cities and 7 regions. If successful the pilot will become a nationwide system from the onset of the

next five year plan, in 2016. Australia has recently decided to implement carbon taxes until 2015 and thereafter a cap and trade system. Australian efforts to curb emissions will also affect the energy system and agriculture. All over the world investment in renewable energy is increasing.

IPCC (2012) has found that the number of countries that has a renewable energy policy increased substantially from 2004.

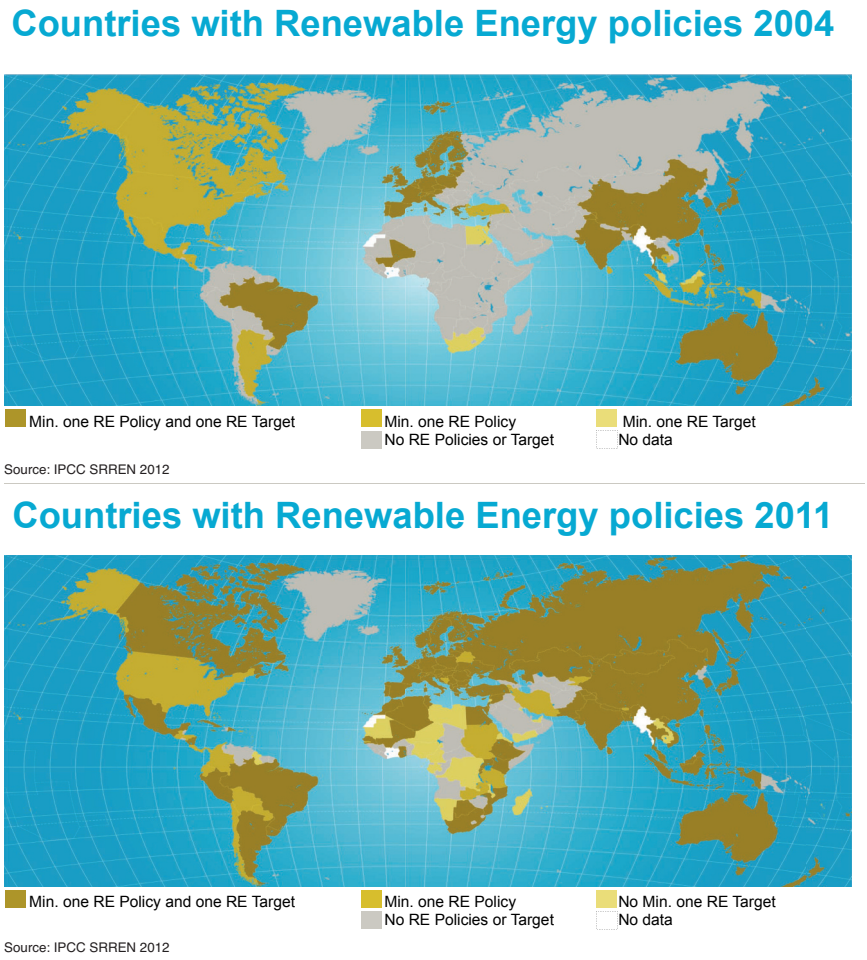


Figure 9: Countries with renewable energy policies 2204 and 2011 (IPCC SRREN 2012).

In the coming decades we will still need fossil fuels such as oil and gas. However, there is little doubt that a large-scale deployment of renewable energy is important as a means of curbing global warming at a tolerable level.

The scale of this shift in energy sources is probably staggering and will be challenging both for technology, economies and for the environment. At the same time Norway has utilised and addressed many aspects of renewable energy, first and foremost in the form of hydropower, for close to a century. The expertise and knowledge in the Norwegian energy industry and in our scientific, technical, economic institutions and clusters are substantial.

To solve the challenges of climate change, close cooperation between business, industry and science is required. Based on environmental competence, natural resources and a well-functioning society, Norway has all the necessary prerequisites to become a European leader in renewable energy and environment. And the best of all; renewable energy lasts forever!

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On the Transition from Fossil to Renewable Energy in Europe – How can Norway Contribute?

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Introduction

Norway is in a unique position as an energy nation. It is endowed with large fossil energy resources, oil, gas and coal, but also has considerable renewable energy resources, particularly hydropower and wind. The most important renewable energy resource so far is hydropower, which has been utilized for more than a hundred years, to supply both public use of electricity and energy for industrial development. Norway also has very large wind resources, probably among the best in Europe, and today there is a growing interest in developing these for electricity production. Existing and planned wind power development in Norway is presently mostly on land ("onshore sites"), but the really large potential lies in offshore wind. Extensive research is aimed at developing offshore, even floating, wind power plants. If the cost can be brought down to an acceptable level, this will open up for a major contribution to the European power system, some say in the order of hundreds of TWh.

The Norwegian hydropower system also offers another, and potentially even more important resource, that may become vital for the development of renewable energy from sun and wind in the rest of Europe: large scale

energy storage. As the hydropower system was developed during the previous century, it was necessary to build many large reservoirs in order to capture and store water during the spring and summer season, and then use this water during the winter. The total energy storage capacity in Norwegian hydropower reservoirs is 85 TWh, enough to supply electricity for 6-8 months during the winter, when natural inflow to the power plants is at a minimum. Utilizing even only a small part of this reservoir capacity, combined with new pumped storage hydropower plants, opens up a possibility to balance intermittent energy sources like solar and wind, without reducing the ability to handle seasonal storage. This type of use of the Norwegian hydropower system could become increasingly important as the amount of power from intermittent sources increases, providing an important service to the European electricity grid.

In this paper we will discuss several options for Norway's contribution to the development of renewable energy in Europe. This discussion will be based on knowledge about the present energy system, the characteristics of different types of renewable energy sources, prospects for technology development in the future, and last, but not least, energy policy in the EU for the near (2020) and more distant (2050) future. All this will be important for Norway's future role and could bring challenges but also new opportunities for Norway.

First, some background will be given to explain the reasons for the growing interest in the use of renewable energy, and how a change from fossil fuels to renewable energy can help to mitigate climate change.

The link between energy and climate change

Since about 1850, global use of fossil fuels (coal, oil, gas) has increased rapidly, and today about 85% of the global energy consumption is based on fossil fuels (Table 1). This has led to a corresponding rapid increase in carbon dioxide (CO_2) emissions, and also to an increase in the concentration of CO_2 in the atmosphere. There is a well established connection between CO_2 concentrations in the atmosphere and air temperature. Increasing concentration of CO_2 (and other greenhouse gases) leads to increasing

temperature in the atmosphere. The big change can be identified to be around 1800, the start of the Industrial Revolution, which was based on coal as energy source (ACIA, 2004). The IPCC Fourth Assessment Report (AR4) concluded that "*Most of the observed increase in global average temperature since the mid 20th century is very likely due to the observed increase in anthropogenic greenhouse gas concentrations*" (IPCC, 2007) (p. 39).

The major share of greenhouse gas (GHG) emissions can be linked to the burning of fossil fuels for energy generation. Other important GHG sources are land-use changes, deforestation and emission of methane (CH_4) and nitrous oxide (N_2O) (Table 2). In AR4 it was stated that *"Global increases in CO_2 concentrations are due primarily to fossil fuel use, with land-use change providing another significant but smaller contribution. It is very likely that the observed increase in CH_4 concentration is predominantly due to agriculture and fossil fuel use. The increase in N_2O concentration is primarily due to agriculture*" (IPCC, 2007) (p. 37).

It has been estimated that a doubling of the GHG concentrations from present levels at 390 ppm up to 780 ppm, could lead to an increase in global air temperature of 2-4°C or more during this century (IPCC, 2007). Based on this cause and effect model, the most important measure taken to mitigate climate change will be to reduce GHG emissions as soon and as much as possible. Here, energy generation and land use changes, especially deforestation, are the main candidates for action. One of the main contributions could be a change from fossil to renewable energy sources. There are multiple options for lowering GHG emissions from the energy system while still satisfying the global demand for energy services.

The importance of fossil fuels in the global energy mix is illustrated in Tables 1 and 3. Here we can see that nearly 85% of the global energy supply today is based on fossil fuels. For electricity the picture is similar, with a little lower share of fossil fuels (68%) and a higher share of "carbon-free" energy sources: nuclear (13.6%) and renewables (18.5%). The dominating source of renewable electricity production is hydropower (15.9%) followed by wind power (1.1%) and bio-energy (1.1%). Other renewables had minor shares, less than 0.5%.

Fossil			**85.1 %**
	Oil	34.6 %	
	Gas	22.1 %	
	Coal	28.4 %	
Nuclear			**2.0 %**
Renewables			**12.9 %**
	Bioenergy	10.2 %	
	Hydropower	2.3 %	
	Wind	0.2 %	
	Geothermal	0.1 %	
	Solar	0.1 %	
	Ocean energy	0.002 %	
			100 %

Table 1. Shares of energy sources in the global energy mix in 2008 (IPCC, 2012).

CO_2 fossil fuel use	56.6 %		CH_4	14.3 %
CO_2 other	2.8 %		N_2O	7.9 %
CO_2 deforestation etc.	17.3 %		F-gases	1.1 %
Sum CO_2	**76.7 %**		**Sum other GHG**	**23.3 %**

Table 2. Sources of GHG emissions (IPCC, 2012).

Fossil			**68.0 %**
	Oil	5.5 %	
	Gas	21.4 %	
	Coal	41.1 %	
Nuclear			**13.6 %**
Renewables			**18.5 %**
	Bioenergy	1.1 %	
	Hydropower	15.9 %	
	Wind	1.1 %	
	Geothermal	0.3 %	
	Solar	0.065 %	
	Ocean energy	0.005 %	
			100 %

Table 3. Shares of energy sources in global electricity supply in 2008 (IPCC, 2012).

Special Report on Renewable Energy Sources and Climate Change Mitigation (SRREN)

In 2008 IPCC decided to prepare a special report in order to provide a comprehensive review of how much renewable energy could contribute to climate change mitigation. Important topics to be covered were renewable energy sources and technologies for extraction, relevant cost and benefits, environmental effects, sustainability issues and the realistic deployment of various renewable energies. The report was finished in 2011 and published as a book in 2012 (IPCC, 2012).

The results presented are based on an extensive assessment of scientific literature but also an aggregate across studies analyzed for broader conclusions. The report combines information on technology-specific studies with results of large-scale integrated models, and provides policy-relevant (but not policy-prescriptive) information to decision makers on the characteristics and technical potential of different resources; the historic development of the technologies; the challenge of their integration; social and environmental impacts of their use; as well as a comparison in levelized cost of energy for commercially available renewable technologies with non-renewable energy costs. Further, the role of renewable energy sources in pursuing GHG concentration stabilization levels is discussed. The SRREN consists of three categories of chapters:

Chapter 1 is an introductory chapter designed to place renewable energy technologies within a broader framework of climate change mitigation options and to identify characteristics common to all renewable energy technologies.

Chapters 2 to 7 cover the following renewable energy technologies: bio-energy; solar energy; geothermal energy; hydropower; ocean energy; wind energy. These six technology chapters provide information on the available resource potential, the state of technological and market development, issues regarding integration into broader energy systems, social and environmental impacts, prospects for technology improvement and innovation, cost trends and potential future deployment. For hydro-power the additional topic of integrated water and energy management is

also discussed, including multipurpose use of reservoirs and regulated rivers, regional cooperation and sustainable watershed management.

Then follow four so-called integrative chapters (8-11) covering issues across technologies: Integration of renewable energy into present and future energy systems; renewable energy in the context of sustainable development; mitigation potential and costs; policy, financing and implementation.

The total report covers 1070 pages and contains a wealth of information about all the important renewable energy technologies. A few conclusions and highlights given in the summary for policymakers can be mentioned, having special relevance for the later discussion regarding transition to renewable energy in Europe and the problem of integrating renewable energy into the current energy system.

Are there sufficient renewable energy sources to replace fossil fuels in the energy mix? The report states very clearly that "*The global technical potential of renewable energy sources will not limit continued growth in the use of renewable energy. A wide range of estimates are provided in the literature, but studies have consistently found that the global technical potential for renewable energy is substantially higher than global energy demand*" (Summary for Policymakers (SPM) p. 10).

But even if enough renewable energy resources are available "*Factors such as sustainability concerns, public acceptance, system integration and infrastructure constraints, or economic factors may limit deployment of renewable energy technologies*" (SPM p. 11).

One general conclusion that is drawn is that even if there are no fundamental barriers towards integrating renewable energy into existing systems, there will be many challenges to overcome, especially for the integration of highly intermittent sources like wind and solar. "*The cost and challenges of integrating increased shares of renewable energy into an existing energy supply system depends on the current share of renewable energy, the availability and characteristics of renewable energy resources, the system characteristics, and how the system evolves and develops in the future". "Wind, solar photo-voltaic energy and concentrated solar power without storage can be more difficult to integrate than dispatchable hydro-power, bioenergy, concentrated solar power with storage and geothermal*

energy. As the penetration of variable renewable energy increases, maintaining system reliability may become more challenging and costly. Having a portfolio of complementary renewable energy technologies is one solution to reduce the risks and costs of renewable energy integration. Other solutions include the development of complementary flexible generation and the more flexible operation of existing schemes; improved short-term forecasting, system operation and planning tools; electricity demand that can respond in relation to supply availability; energy storage technologies (including storage-based hydropower) and modified institutional arrangements. Electricity network transmission (including interconnectors between systems) and/or distribution infrastructure may need to be strengthened and extended, partly because of the geographical distribution and fixed remote location of many renewable energy resources" (SPM p. 15-16).

Here, the two main solutions needed in order to facilitate large-scale renewable energy integration into the energy system, will be extensive development of grid and storage capacity. Grid development because most renewable energy sources tend to be located far away from demand areas, more storage to even out an intermittent supply and make it possible to meet the demand profile and secure high reliability and safety of supply. The integration problems seem to increase with increasing share of intermittent renewable in the energy system, some studies conclude that there may be a practical limit of 20%, at least for integration into the existing system (Castelvecchi, 2012). Others are more optimistic, as long as grid and storage are developed appropriately.

The report contains detailed estimates of GHG emissions from various types of renewable and non-renewable energy resources, and concludes that "*Lifecycle assessments (LCA) for electricity generation indicate that GHG emissions from renewable energy technologies are, in general, significantly lower than those associated with fossil fuel options, and in a range of conditions, less than fossil fuels employing CCS. The median values for all renewable energy range from 4 to 46 g CO_2 eq/kWh while those for fossil fuels range from 469 to 1001 g CO_2 eq/kWh* " (SPM p. 18). It demonstrates that a transition from fossil to renewable energy (and/or nuclear energy) will lead to a very substantial reduction in GHG emissions.

The cost is probably the most critical parameter. In order to replace fossil fuels with renewable energy the cost of renewable energy must be brought down to or below the cost of energy from fossil fuels. Table 4 contains a summary of estimated levelized cost of energy for different types of renewable energy. The range of cost is due to different technologies within each main category, uncertainty in cost estimates, and varying discount rates (from 3% up to 10%). It is concluded that "*The levelized cost of energy for many renewable energy technologies is currently higher than existing energy prices, though in various settings renewable energy is already economically competitive*". "*Some renewable energy technologies are broadly competitive with existing market energy prices. Many of the other renewable energy technologies can provide competitive energy services in certain circumstances, for example, in regions with favorable resource conditions or that lack the infrastructure for other low-cost energy supplies. In most regions of the world, policy measures are still required to ensure rapid deployment of many renewable energy sources*" (SPM p. 13).

Resource	Technology	Investment cost (US$/kW)	Capacity factor (%)	Economic design lifetime (years)	Levelized cost of energy (LCOE) (US c/kWh)
Bioenergy	Biopower	2600-4200	70-80	20	5.1 - 17
	Cofire	430-900	70-80	20	2.0 - 7.1
	Combustion	4100-9800	55-68	20	6.2 - 37
	Gasification	1800-2100	55-68	20	2.1 - 14
Direct solar	PV (Rooftop)	3500 -7300	12 - 20	20 - 30	11 - 92
	PV (Utility scale)	2700 - 5000	15 - 27	20 - 30	7.4 - 50
	CSP	6000 - 7300	35 - 42	20 - 30	11 - 30
Geothermal	Condensing	1800 - 3600	60 - 90	25 - 30	3.1 - 13
	Binary cycle	2100 - 5200	60 - 90	25 - 30	3.3 - 17
Hydropower	All	1000 - 3000	30 - 60	40 - 80	1.1 - 15
Ocean energy	Tidal	5000 - 5500	22.5 - 28.5	40	13 - 34
Wind	Onshore - Large	1200 - 2100	20 - 40	20	3.5 - 17
	Offshore - Large	3200 - 5000	35 - 45	20	7.5 - 23
Non-Renewables	For comparison - Typical cost of Non-Renewable energy				2.5 - 10

Table 4. Electricity production cost from different types of renewable energy sources Data from (IPCC, 2012) - Appendix III. (2008 and 2009 price level.) Cost range typically covers mid 80% of values found in literature.

In the analysis of potential deployment, data for resource availability is combined with cost estimates into supply curves which are then used in regional and global models in order to compute the deployment of different renewable energy technologies, assuming the most economic technologies are implemented first up to the resource limits.

European strategy for transition from fossil to renewable energy

The European policy on energy and climate is based on accepting as a fact that climate change is real, that it is caused by increasing level of CO_2 in the atmosphere, and that a major part of this is coming from the use of fossil fuels for energy production. In a communication from the Commission to the Council and the European Parliament (EU, 2005) (p. 5) this view is stated very clearly: "*Climate Change is happening*", "*The overwhelming scientific consensus is that the cause is emissions of greenhouse gases from human activity*", "*Climate Change needs to be slowed down and eventually halted*". One of the main elements in proposed actions from the EU is the change from the present fossil-dominated to renewable energy production.

Policy for promotion of renewable energy 1997 to 2011

Already in 1997 the EU formally recognized the need to handle the Climate Change issue, and formulated a "White Paper for a Community Strategy and Action Plan" on the use of renewable energy sources (EU, 1997). This White Paper was a part of the preparation for the Kyoto meeting later the same year. In the White Paper the Commission outlined a strategy for increased electricity production from renewable energy sources (RES-E) in order to reduce "carbon intensity" and CO_2 emissions. In 2001, a "Directive on the promotion of electricity produced from renewable sources in the internal electricity market" (RES-Directive) was adopted by the European Parliament and the Council of the European Union (EU, 2001). Here, a renewable target of 12% for gross energy

consumption and 22.1% for electricity production in 2010 was stated. In 2005 it was decided that the RES-Directive should become part of the EEA agreement, and consequently also implemented by Norway later on.

In 2007 the European Commission presented a new White Paper on the energy policy for Europe. The document (EU, 2007) laid out the so-called 20/20/20 targets for the EU Member states to be reached by 2020. It stated that the EU as a whole should increase its share of renewable energy in primary energy consumption to 20% by 2020. It also required the EU to become 20% more energy efficient and cut CO_2 emissions by 20%, all compared to the 2005 levels.

A new and updated RES Directive (EU, 2009) was drafted as a part of the so-called "Climate and Energy Package" which was adopted by the European Parliament and the Council and entered into force in 2009.

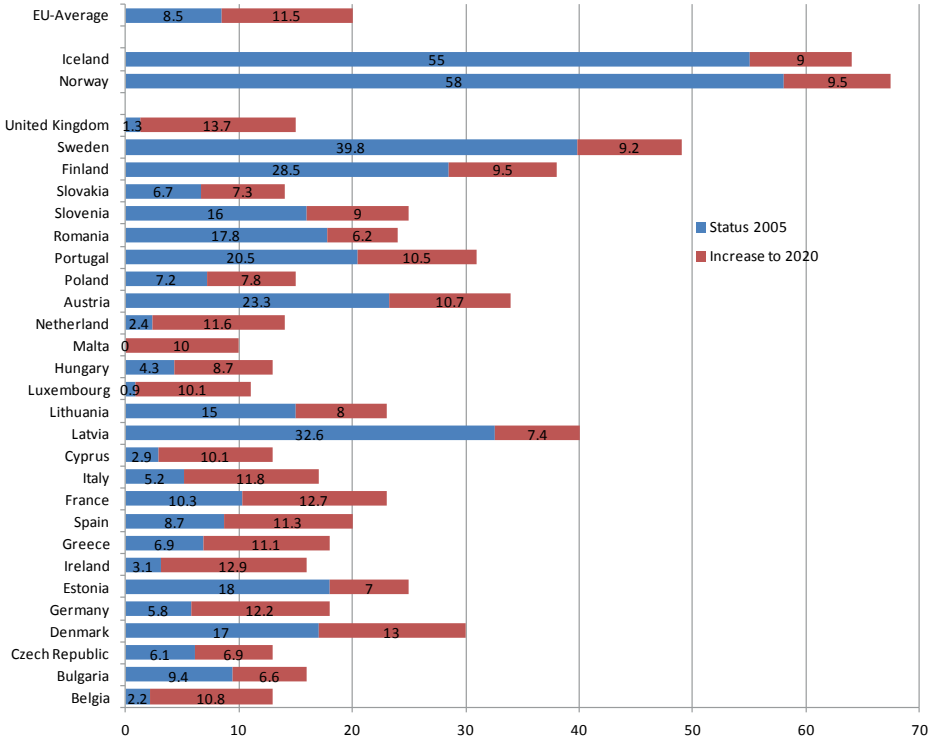

Figure 1. RES share in 2005 (%) and increase to reach targets for 2020 (%)
Source: (EU, 2009) Annex I.

Here the EU member states agreed on a "burden sharing" methodology, so that the Union as a whole would reach the 20/20/20 goals as defined in the 2007 White Paper. The European Economic Area (EEA) States (Norway, Iceland and Lichtenstein) were not part of this burden sharing, but agreed to join in later. (This happened in 2011 for Norway and Iceland.)

Before the incorporation of the RES Directive, Norway had a higher share of renewable energy than any other European state (58% in 2005). In December 2011 the EEA Joint Committee decided to incorporate the RES Directive into the EEA agreement, with a target of 67.5% renewable energy for Norway by 2020, an increase of nearly 10% from 2005. By comparison, the EU-average was 8.5% in 2005, increasing by 11.5% to 20% in 2020. The RES Directive formally entered into force in Norway 20 December 2011.

The allocation of renewable energy shares between electricity, heating and cooling, and transport, is the responsibility of the individual member states. The overall target for electrical energy (RES-E) is 21% in 2010 increasing to between 34.2 and 42.8% in 2020 according to different scenarios (Nicolosi & Fuersch, 2009).

The RES Directive addresses various subjects related to the development of renewable energies in the European Member States, among others the legally binding share of renewable energy in gross final energy consumption. In Article 4 of the Directive, each Member State is requested to provide a National Renewable Energy Action Plan (NREAP) by 30 June 2010. Each Member State has completed a set of tables on how it expects to meet its 2020 target, including the technology mix and the trajectory to reach it. The recently published report (Nicolosi & Fuersch, 2009) contains a summary of RES share in 2005 and projected values from all NREAPs. A summary for all EU-27 States is given in Figure 1. The highest RES share of EU-27 states in 2020 will be Sweden with 49%. For comparison, Norway has agreed on a RES share of 67.5% in 2020, nearly 20% more than Sweden. The other Nordic countries also will have high RES shares in 2020: Denmark 30%, Finland 38% and Iceland 64%.

Projected energy system development in the EU up to 2030

Based on data for the existing power system, binding plans up to 2020 (Beurskens, Hekkenberg & Vethman, 2011) and projections for further development up to 2030 (EU, 2010b), (EWEA, 2011b), it is possible to present the main characteristics of existing and future power systems in the EU. The projections up to 2020 are based on legally binding plans, while the projections towards 2030 are more uncertain and described as possible scenarios. Two main scenarios were developed (EU, 2010b), a

Electrical energy generation in EU-27 Reference Scenario (EU, 2010) - Appendix 2B							EREC 2010 100% Renewable vision		
RES (TWh/Year)	2 005	2010	2015	2020	2025	2030	2020	2030	2050
Ocean energy	0	0	1	7	10	14	5	18	158
Geothermal	5	7	8	12	17	22	31	169	601
Biomass/Waste	84	120	171	261	275	286	250	292	496
Solar (PV/CSP)	1	17	32	62	77	94	223	697	1732
Wind - Offshore	2	14	81	177	224	287	3)	3)	3)
Wind - Onshore	68	147	243	348	381	407	477	833	1552
Hydropower 1)	307	323	333	341	350	358	384	398	448
Sum RES	**467**	**628**	**869**	**1208**	**1334**	**1468**	**1370**	**2407**	**4987**
Non-RES (TWh/Year)	2005	2010	2015	2020	2025	2030			
Nuclear	997	926	933	885	914	982			
Coal/lignite	981	911	910	844	877	857			
Petroleum	133	74	70	48	47	40			
Gas	694	766	749	722	757	724			
Sum Non-RES	2805	2677	2662	2499	2595	2603			
Sum electricity	**3272**	**3305**	**3531**	**3707**	**3929**	**4071**	**3493**	**3702**	**4987**
							2)	2)	2)
%-RES	**14.3**	**19.0**	**24.6**	**32.6**	**34.0**	**36.1**	**39.2**	**65.0**	**100.0**
%-Non storage RES	2.2	5.4	10.1	15.8	17.4	19.4	20.0	41.3	65.9
%-Wind	2.1	4.9	9.2	14.2	15.4	17.0	13.7	22.5	31.1
%-Solar	0.0	0.5	0.9	1.7	2.0	2.3	6.4	18.8	34.7
%-Bio&Waste	2.6	3.6	4.8	7.0	7.0	7.0	7.2	7.9	9.9
%-Hydro	9.4	9.8	9.4	9.2	8.9	8.8	11.0	10.8	9.0
%-non RES	85.7	81.0	75.4	67.4	66.0	63.9			
%-Nuclear	35.5	34.6	35.0	35.4	35.2	37.7			
%-Fossil fuel	55.3	53.0	49.0	43.5	42.8	39.8			

1) Excluding Pumped Storage

2) Highest of two scenarios
3) Included in onshore wind

Table 5. Electrical generation in Europe (EU-27) up to 2030 and 2050
Based on reference scenario (Appendix B) in (EU, 2010b) and (EREC, 2010).

baseline scenario and a reference scenario. Table 5 contains a summary of observed and predicted data for the electrical generation system for the reference scenario, up to 2030.

In this projection the share of renewable energy sources will increase from 19% in 2010 to 32.6% in 2020 and 36.1% in 2030. But the system still contains a large share of thermal power from nuclear (37.7% in 2030) and fossil fuels (39.8% in 2030). The general trend is clear, however, renewable energy sources are increasing steadily up to 2030, first and foremost by adding wind (to 17% in 2030) and solar (to 2.3% in 2030). Hydropower, the dominating RES now (9.8% in 2010), will continue to have about the same share in the period up to 2030.

The large share of nuclear is somewhat surprising. Even if the German decision of closing down all nuclear plants by 2022 has been included in the reference scenario, the total nuclear capacity in EU is predicted to be at about the same level as now for EU-27 as a whole.

A view towards 2050 - The SET-Plan

The future energy strategy for the EU must balance sustainable development, competitiveness and security of supply. A Green Paper presented in 2006 (EU, 2006) puts forward suggestions and options that could form the basis for a new comprehensive European energy policy.

The European Strategic Energy Technology Plan (SET-plan), based on the ideas formulated in this Green Paper was adopted by the European Union in 2008. The SET-plan is considered as a first step towards establishing an energy technology policy for Europe, as the principle decision-making support tool for the European energy policy. The SET-Plan has two main timelines, one for 2020 and a second for 2050 (EU, 2007).

For 2020 the SET-Plan provides a framework for the development and deployment of low-carbon technologies needed to meet the 20-20-20 goals. Some of the main technology challenges identified in order to meet the 20-20-20 targets are: competitive second generation bio-fuels include CO_2 capture and storage; larger offshore wind-turbines; large-scale photo-

voltaic; concentrated solar power; and a single smart European grid (EU, 2007).

For 2050 the SET-Plan is targeted at limiting climate change to a global temperature rise of no more than +2ºC. To achieve this target, it is considered necessary to reduce GHG emissions in the EU by 80-95% (EU, 2009a), (EU, 2011). Some of the key technology challenges for the next 10 years in order to meet the 2050 target are: breakthrough in cost-effective storage technologies; hydrogen fuel cell vehicles; a new generation nuclear (fission) reactors; a trans-European energy network; improved energy efficiency.

The need for storage and grid development up to 2020 is also underlined in (EU, 2009), (EU, 2009a) and (EU, 2010a) where the Commission states that it will launch four new large-scale projects. One of these (Priority 4, Action 2) is a European initiative on linking the whole electricity system, another is on "*Re-establishing Europe's leadership on electricity storage (both large-scale and vehicles)*". Here, hydro storage is mentioned as one of three types of storage that will have special focus. The two other projects are about biofuel and energy-saving technology.

An Energy Roadmap for 2050

From 2030 to 2050 there will have to be a "*... revolution in energy systems ...*" in order to meet the target of 80-95% reduction in GHG emissions by 2050 (EU, 2011a) (p. 1).

In the Energy Roadmap 2050 (EU, 2011) the EU Commission explores the challenges posed by meeting the ambitions of a 80-95% reduction in GHG emissions in 2050, while at the same time ensuring security of energy supply and competitiveness. The measures taken towards 2020 will reduce emissions in 2050 by about 40%, but additional measures will be needed beyond 2020. Today, no detailed plan exists for measures to be taken between 2020 and 2050, but the work on this topic has started, first by developing and simulating different scenarios for the energy system up to 2050 (EU, 2011). One important conclusion for all scenarios is that the share of renewable energy resources will rise substantially, achieving at least 55% of gross final energy

consumption in 2050, up by 45% from the current level of 10%. The share of renewable energy sources in electricity production reaches up to 97% in the High Renewables Scenario, a scenario that includes significant electricity storage to accommodate varying renewable energy sources supply even at times of low demand. "*Renewables will move to the centre of the energy mix in Europe, from technology development to mass production and deployment, from small-scale to larger-scale, integrating local and more remote sources, from subsidized to competitive*" (EU, 2011) (p. 10).

In the roadmap it is strongly emphasized that increasing use of renewables depends on increasing storage capacity and better transmission: "*Storage technologies remain critical*" (p. 10) and "*Further interconnection with Norway and Switzerland will also continue to be critical*" (p. 11). One of the 10 main conclusions in the document is "*(7) A new sense of urgency and collective responsibility must be brought to bear on the development of new infrastructure and storage capacities across Europe and with neighbours*" (p. 20).

Gas is planned to have a key role in the transition in the short to medium term (up to 2030-2035) by substituting coal and oil with gas in the power generation. In some scenarios gas-fired power generation will account for roughly 800 TWh in 2050, slightly higher than today. It is assumed that carbon capture and storage (CCS) will have to be applied to all fossil fuels from c. 2030 in order to meet the 2050 goals of decarbonisation. Without CCS the long-term role of gas may be limited to flexible back-up and balancing capacity (EU, 2011).

The next step in the EU now is to work out a 2030 policy framework, building on the 2020 policy and pointing towards the 2050 goals. This policy is under development, but not yet finished. More detailed sectoral roadmaps and a "Roadmap to a Resource Efficient Europe" are under preparation (EU, 2011a).

An indication of how the electrical production system may look in 2050, once the goals for 2020 and visions for 2050 (80-95% reduction in GHG emissions) have been achieved, can be found in a recent study from the European Renewable Energy Council (EREC, 2010). Since emission reduction is more difficult in sectors such as transport and agriculture, it

will be necessary to reach zero carbon emissions for the power sector well before 2050. Some of the main results from this study are shown in Table 5, right column. The difference between the two scenarios is small in 2020 but is increasing towards 2030, reflecting the much more aggressive deployment of renewable energy sources in the EREC study, first of all wind and solar. The EREC scenario has a very high share of solar (photovoltaic and concentrated solar power) and wind power, with a total share reaching 65.6% in 2050. Such a high share of highly intermittent (non-storage) power will present a huge challenge for the operation of the grid, and require large storage capacity for load balancing. In the report, geothermal plants, electric vehicles and a "super grid" are assumed to supply load-balancing services, but further details are lacking.

An interesting observation is that in order to have zero emissions from the power sector at or before 2050, no new fossil fuel plants (gas, oil or coal) should be built after 2015, since the typical lifetime of such plants are 30-35 years for gas and 35-45 years for coal. Existing fossil fuel plants will all reach their lifetime and be decommissioned before 2050 (EWEA, 2011b).

The renewable electricity system in Norway

Electricity production in Norway has been based on hydropower from the very start more than a century ago, and has always been nearly 100% renewable. This is the main explanation for the high renewable energy share in Norway's total energy use (c. 60% today). In recent years a few wind power plants have been deployed. Even though the potential is large most potential projects are still on the drawing board, in the application pipeline or simply put on hold waiting for grid development or for better economic incentives.

Hydropower

Installed capacity in hydropower reached 30 140 MW in 2011. A total of c. 1250 hydropower plants were in operation, most of these small. c. 920 plants are <10 MW, with a total capacity of c. 1400 MW and a total energy output

of c. 6 TWh. 253 plants are between 10 and 100 MW and have a total capacity of c. 9200 MW and an energy output of c. 41 TWh. Finally, 78 large plants (>100 MW) have a total capacity of 18 400 MW and an average annual energy output of 74.3 TWh (OED, 2008), (NVE, 2011a). The largest three hydropower plants in Norway are Kvilldal in Rogaland (1240 MW), Sima in Hardanger (1120 MW) and Tonstad in Vest-Agder (960 MW).

Hydropower production varies during the year and from year to year, depending on hydrological conditions. The average production capacity in Norway is 124.4 TWh/year (per 1/1-2011). This amounts to 60% of the total potential, which has been estimated at 206 TWh (at cost c. <3 NOK/kWh; Figure 2). Since 48.6 TWh (24%) is protected, the remaining, so far unused potential, amounts to 33 TWh (16%). It is important to realize that more hydropower could be developed at a higher cost (c. >3 NOK/kWh), but still at a much lower cost than other renewable electricity sources. The exact amount is not known, as the resource mapping for hydropower has traditionally only focused on the low-cost projects.

An important characteristic of the Norwegian hydropower system is its high capacity of energy storage, c. 85 TWh (62 000 mill. m^3). This storage capacity amounts to nearly 70% of annual inflow in Norway (124.4 TWh), and to nearly 50% of all hydroelectric energy storage capacity in Europe (NVE, 2011b). Storage was previously developed as an integrated part of most hydropower projects in Norway, because of the very large seasonal variation in flow, and because there was no thermal backup in the system. Low costs for reservoirs due to favourable natural conditions made storage construction economically feasible. Most of the hydropower development and nearly all of the storage was constructed before 1995. In later years, mainly small hydropower without storage has been put in operation, mostly caused by increasing social and environmental protests against large hydro developments. The largest reservoirs in Norway ranked by energy storage capacity are: Blåsjø (7759 GWh), Storglomvatn (4589 GWh), Svartevatn (2923 GWh) and Møsvatn (2270 GWh) (NVE, 2011). Together, the largest ten reservoirs have energy storage capacity of 25 400 GWh. The rest of the storage is distributed over nearly 800 reservoirs located all over the country.

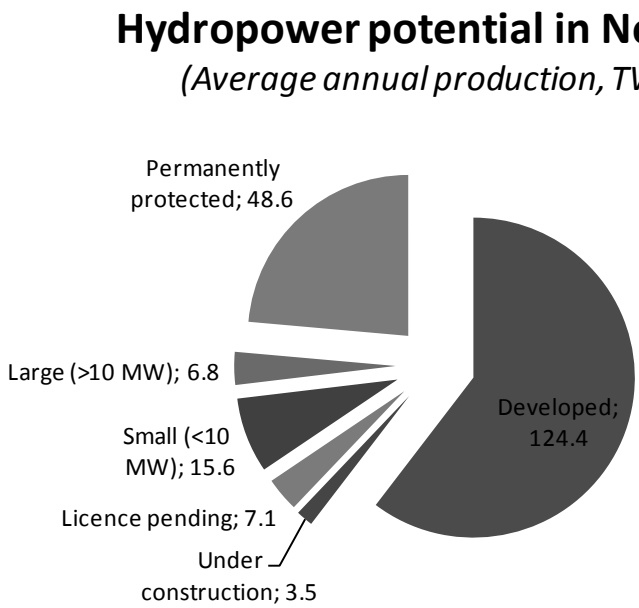

Figure 2. Hydropower potential in Norway 1/1-2011. Source: (NVE, 2011a).

The storage capacity was mainly designed for seasonal storage of water. In Norway the largest inflow usually occurs during spring and summer, when electrical energy consumption is at its lowest. In the winter the inflow

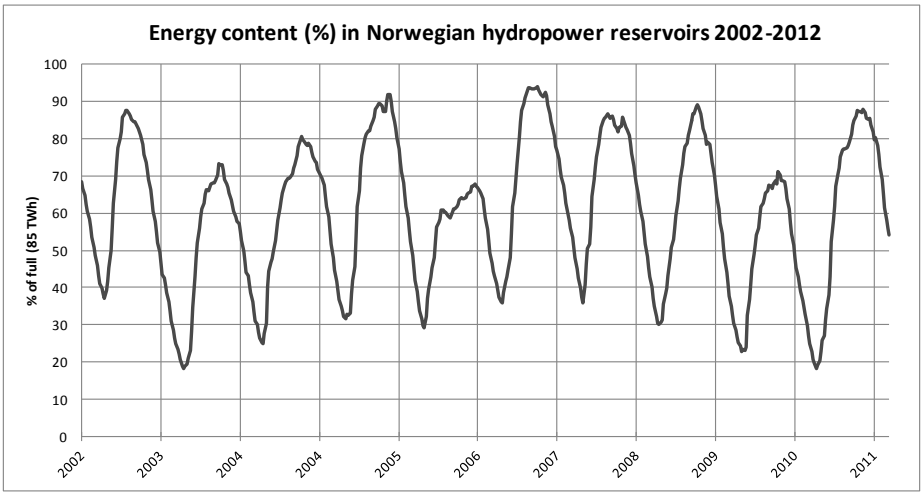

Figure 3. Energy stored in Norwegian hydropower reservoirs. (Data from NVE).

is very low, while the electrical energy consumption is at its highest. The reservoir capacity will usually be large enough to store all the energy needed during the next winter, except in exceptionally dry years. This is illustrated by Figure 3 which shows the actual energy content in Norwegian hydropower reservoirs during the last 10 years. The seasonal variation is evident, with a maximum in late summer and a minimum at the end of the winter. But it also shows that the reservoirs nearly always have some free capacity, not only during autumn and winter but also during summer and early autumn when reservoirs are usually at their highest levels.

Wind power

Wind power is so far not much developed in Norway. In the years since 2002 installed capacity increased from c. 100 MW to c. 510 MW, with energy production increasing from c. 40 GWh in 2002 to c. 900 GWh in 2010 (NVE, 2011a). The total resource potential for wind in Norway is, however, much greater. A study from 2009 found a theoretical annual potential of 1636 TWh for onshore wind, most of this in Mid-Norway and in the North (NVE, 2009). For offshore wind the theoretical potential is far larger, up to 14 000 TWh (Enova, 2007). The realistic technical and economic potential for both onshore and offshore wind power is believed to be much less, both because of high costs and lack of transmission capacity.

Renewable energy development in Norway towards 2020, 2030 and 2050

Electrical energy consumption in Norway is expected to grow from its present level (131 TWh/year in 2010) to between 153 and 179 TWh in 2050 (NOU, 2012). Norway is committed by the RES-Directive to increase its renewable energy share from 58% in 2005 to 67.5% by 2020, therefore additional renewable energy has to be developed in Norway.

Norway and Sweden recently (January 2012) agreed on a joint electricity certificate scheme ("green certificates") to promote development of more

renewable energy, in order to meet the RES-Directive target for 2020. The agreement specifies the development of 26.4 TWh renewable energy in both countries combined, and it is believed that most of this will be as wind-, hydro- and bio-energy. If 50% of this (13.2 TWh) is deployed in Norway, it will increase annual electricity production capacity here to nearly 140 TWh in 2020. Based on information on cost structure, it is assumed that most of this will be hydropower in Norway, while Sweden will probably develop more wind and bio-energy (NOU, 2012). Having reached 140 TWh in 2020, it will still be possible to develop the additional 13-39 TWh needed up to 2050, from remaining hydro and/or wind resources in Norway.

Electrification of the offshore oil and gas installations

The Norwegian offshore oil and gas exploitation is using approximately 5 TWh/y in its operations. Most of the installations use gas for their power supply, and only a few of the installations (Troll A, Ormen Lange, Valhall, Gjøa) use electricity supplied from the mainland. For Norway, to reach the ambitions in reducing CO_2 emissions also from the energy sector, it is very likely that the use of electricity from the mainland in offshore oil and gas industry will increase. It may be very costly and difficult for some of the existing installations, but it is likely that electricity from the mainland will be the selected option for power supply for new projects.

The role of Norway in the Nordic and European power system from 2020 to 2050

For Norway, the changes in the energy system in EU from 2020 to 2050, will give new possibilities but also new challenges. Most countries in the region plan to develop increasing amounts of wind power in order to meet the RES-Directive goals, leading to a very high share of wind in the region (Table 5). For example, Denmark must replace coal power plants with offshore wind, Sweden may have to replace nuclear plants

with wind from c. 2035, Germany wants to close down both nuclear plants (by 2022) and all fossil plants (starting from 2020), UK plans to close down old coal and gas plants and replace them with renewable. If Norway wants to contribute to this transition (in addition to own inland use) three different main strategies can be used, alone or in combination:

A. Develop more renewable energy in Norway for export to Europe (e.g. as hydro and wind).

B. Develop renewable energy technology for use in Europe (e.g. offshore wind).

C. Supply balancing power services (e.g. for UK and Germany).

Strategy 1: Develop more renewable energy in Norway for export to Europe (e.g. as hydro and wind)

Up towards 2050 Norway will probably have developed a major share of the remaining hydro-power potential for its own use, since this is the most cost-effective way to meet the renewable energy source obligations up to 2020, and also for increased consumption further to 2050. Any significant power export must therefore probably be based on wind, preferably offshore wind. But the cost of this will be very high, and it is unclear if significant amounts of more wind power will be developed, once the period of approval for new "green certificates" is over by 2020. Europe will by then already have a very large share of intermittent power in the grid, so the benefit of even more wind power from Norway may be limited or uncertain. It is therefore not realistic to assume that Norway will be exporting significant amounts of renewable energy to Europe in the future.

Strategy 2: Develop renewable energy technology for use in Europe (e.g. offshore wind)

There is a huge need to develop more cost-effective renewable energy technology, in order to make possible the change to renewable energy sources in Europe (EU, 2009). Since the most abundant renewable energy resource for most countries in Northern Europe is wind, and in particular offshore wind, the technology development should first of all focus on offshore wind and more specifically floating offshore wind plants. If the cost of floating offshore wind plants can be brought down to an acceptable level, it will open up for really large-scale electricity generation and thereby also help to avoid an increasing public resistance against land-based wind power plants.

Here, Norway can contribute with leading-edge technology developed in offshore oil and gas exploration and, since most of the offshore wind plants will be deployed in the North Sea, Norway will also be in a strategic position for construction, maintenance and operation of these. Important contributions to the development of offshore wind are in particular coming from the two research centres NOWITECH (www.nowitech.no) and NORCOWE (www.norcowe.no).

But it seems less likely that Norway will develop its own large-scale offshore wind projects for energy export, since the cost will probably remain higher than the market price for electricity for a very long time (Table 4).

Strategy 3: Supply balancing services (e.g. for UK and Germany)

With the policy that has been formulated for the EU and EEA in the RES-Directive up to 2020 and visions towards 2050, the share of renewable energy sources in electricity production in Europe could reach 30-40% by 2020, 40-60% by 2030 and come close to 100% by 2050 (Table 5). Even if the most optimistic goals are not reached, there will certainly be a very rapidly increasing share of renewable energy sources in Europe, and most of it will be intermittent (solar and wind). At the same time, the share of thermal

(nuclear, coal and gas) plants will be reduced as a result of safety concerns and the de-carbonization policy. These are the plants that traditionally have contributed most to firm power supply in the system. As discussed before in this paper, such a high share of intermittent renewable energy sources could create huge challenges for the operation of the power system, and require very large investments in grid infrastructure and large-scale (bulk) storage, in order to balance all the intermittent renewable energy sources.

The amount of energy storage needed could be very large, since variability in wind may have cycles of days or even weeks in extreme cases, from nearly calm to stormy conditions. In some cases, solar power production and load curves will fit in with the variations in wind power production to a certain extent, but in many cases this will not be enough to give a balance in production and consumption.

Figure 4 gives an illustration of the typical variation in wind power production. It shows simulated daily average power output from a hypothetical wind power system in the North Sea, with total installed capacity of 94 000 MW. From an average winter output of around 45 000 MW, we can see both rapid and more long-term variability in power output. During two calm periods in February and March, the power output was down to only c. 15 000 and 25 000 MW as average for an entire week. In another one-week period in early February (above upper arrow) the output was around 80 000 MW for one full week. In some extreme cases the total output can be well below 10 000 MW for a few days and as low as below 2000 MW for several hours. In order to balance this system and maintain a steady supply, of for example 45 000 MW, one will need a technology that can provide 30 000 MW extra for a full week, or create a demand of 30 000 MW another week. The energy storage needed for this balancing will be in the order of 5000 GWh (5 TWh) for each event of one week.

The only known carbon-free technology today that could provide balancing on this scale is pumped storage hydropower. The main problem is the volume of storage needed. The typical storage capacity in existing pumped storage hydropower is in the order of 5-10 GWh, since the plants are designed for daily peaking only. The total storage capacity in all European pumped storage hydropower today is in the order of 30 GWh,

less than 1% of what is needed for the example above. This is where Norway could give a very significant contribution, by allowing some of the large existing hydropower reservoirs to be used for wind power balancing. In the winter months, when the need for wind power balancing is largest, the hydropower reservoirs will have a large free capacity (Figure 3) that could be used for storing large amounts of excess wind power, even quantities as demonstrated by Figure 4.

In order to establish a pumped storage hydropower one needs *both* an upper and a lower reservoir reasonably close to each other, with a large head difference. The amount of energy that can be stored will be determined by the product of the regulation volume of the smallest of the two reservoirs and head difference between them. In Norway, there are more than 100 such potential sites with existing reservoirs. Twenty of these have a storage capacity of more than 100 mill. m^3 (NVE, 2011c).

A preliminary study (Solvang, Harby & Killingtveit, 2011) has identified a number of sites where the total capacity of pumped storage hydropower and ordinary peaking hydropower production could provide up to 20 000 MW of capacity, and large storage volumes for energy. The potential new

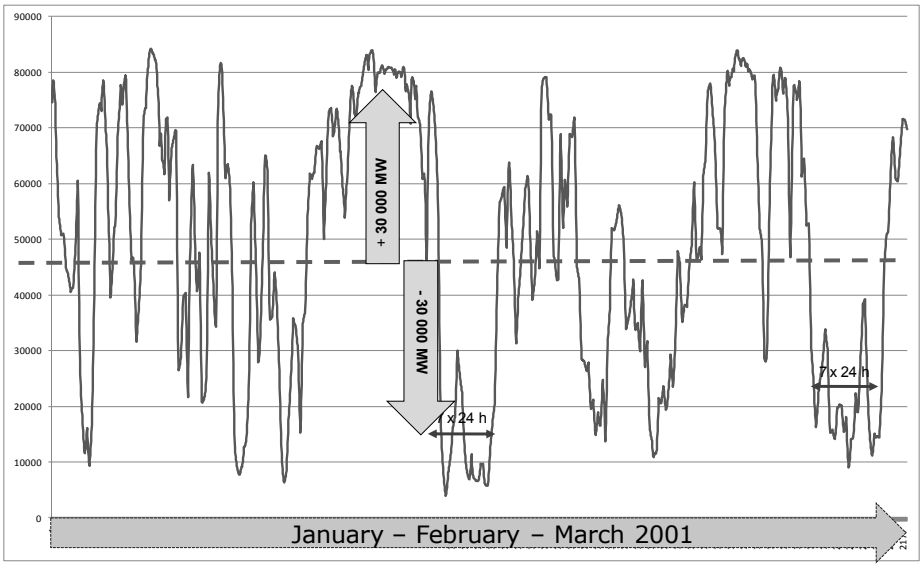

Figure 4. Simulated total output (MW) from a North Sea based wind power system with total capacity of 94 000 MW. Source CEDREN.

sites are all located in parallel or close to existing power plants, and they may all be constructed in underground caverns. The reservoirs selected will be operated within the same limits of upper and lower reservoir levels. As these reservoirs also need to be used for conventional energy production in Norway in parallel, there may be some limitations to their use for long-term and large-scale balancing of wind power. However, the CEDREN study has shown that even with quite strong restrictions in drawdown speed of reservoirs (14 cm/h) and respecting the national operation of the system, Norway can deliver 20 000 MW of new capacity and a large volume for storage for European flexible use. More detailed studies need to be performed in order to sort out technical, economical, social and environmental effects of such new projects, and to find the best design. There is also a need to develop new regulations and new market solutions.

Summary and recommendations

The threat of climate change has triggered very comprehensive research internationally to find possible mitigation methods. The most promising mitigation method today seems to be to reduce emissions of GHG into the atmosphere by switching from fossil to renewable energy sources. Recent studies by IPCC (the SRREN report) confirm that sufficient quantities of renewable energy exist, and that a large-scale integration of renewable energy into the present energy system is feasible, but also that a number of challenges have to be met and solved. Two of the most important topics that have been identified are the need for an extensive development of the electricity grid (since renewable energy sources tend to be located far away from consumption centres) and the need for construction of large volumes of energy storage (since most renewable energy tends to be intermittent and needs to be balanced).

In Europe, both EU and EEA countries agree on the climate change threat, and have agreed on a policy (the RES-Directive) to increase the use of renewable energy to 20% by 2020, thereby reducing use of fossil fuels and GHG emissions. Further on, towards 2050, the GHG emissions should be reduced by 80-95%, by converting the present fossil fuel based energy

system into a low-carbon renewable energy based energy system. This transformation will be guided by a strategic energy technology plan (SET-plan) which is still under development. The most important renewable energy technologies will be wind power and solar power. This will lead to a massive growth in highly intermittent energy sources, with wind dominating in the northwestern part of the North Sea basin and solar energy in Southern Europe. Based on existing plans (up to 2020) and visions towards 2050, it is predicted that wind plus solar could contribute >15% of total electrical energy in 2020, increasing to 20-40% in 2030 and to >60% in 2050. The remaining part will be supplied by other renewable (hydropower and bio-energy), by nuclear and by some thermal power, in particular from gas.

Norway already supplies 60% of its energy consumption from renewable sources, mostly from hydropower. This will increase to 67.5% by 2020, probably by more hydropower and some wind power. But the Norwegian hydropower system could be developed into an even more valuable resource in the total European renewable energy system by providing pumped storage and peaking hydropower for balancing the intermittent renewable energy sources in the rest of the European system. Preliminary studies at CEDREN and by others have revealed a technical potential of >20 000 MW (pumped storage and peaking hydropower) together with large volumes of storage (in the order of several TWh) in the hydropower reservoirs, without the need for construction of new reservoirs. Here, excess wind and solar power could be stored and later produced to supply demand during periods with low wind or low insolation.

This new use of the hydropower system could benefit both Norway and Europe and become an important contribution to the de-carbonization of the energy system and help achieve the planned reduction of GHG emissions in Europe. Since no other country in Europe has a similar potential for high volume (bulk) energy storage and load balancing, it can be argued that it places a special responsibility but also creates a unique opportunity for Norway. Therefore, this topic should be given very high priority in future research both in Norway and in EU research programmes.

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The Norwegian Power-intensive Metallurgical Industry and its Role in the Global Household

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Summary
The Norwegian metallurgical industry has a strong global position, both in terms of technology and market. In some fields, such as basic process understanding and HES (Health, Environment and Safety) knowledge, the Norwegian metallurgical industry is a global leader. Ever since its beginnings, the industry has continuously developed itself and moved into new markets. Today, the Norwegian plants are more specialized and market oriented than before.

To gain access to this knowledge and in order to secure production volume, major international companies have invested in this Norwegian industry. This situation is in principle not a problem, but the need for an appropriate national strategy for energy and industry will increase.

There is a growing focus on access to resources – in some countries more than others. The coming scarcity of energy and commodities due to depletion and increased human resource consumption may challenge the supply-and-demand economics. The leap in the price of important commodities around 2005 may indicate a new paradigm – and may suggest that even more focus has to be concentrated on strategic, long-term use of resources such as energy.

The concept of energy *quality* should be introduced as a part of national energy strategy, as well as energy saving. The industry should be more integrated as an energy system in the community at large. The prospect for improved energy savings is better now with the Enova support and the focus on energy saving – but still the results do not show up in real savings. A continued and unnecessary increase in the public and private use of energy in Norway may create moral questions in a world with energy scarcity. Both industry and the political society have an obligation to mitigate the trend towards wasting energy.

Land-based industry is not very visible in the media – and then too often the news is problematic or negative. Industry is (rightly) critisised for not taking their responsibility to engage in the national strategic discussions and work. The motivation to write this article is to give some background and reflection about the history, the current situation and the challenges and opportunities that lie ahead.

Continued development of the material and metallurgical production in Norway is one good way to make the world a better place for human beings.

I. OVERVIEW OF THE NORWEGIAN METALLURGICAL INDUSTRY

Some history

107 years ago, in 1905, Norway became an independent country – and Prince Carl of Denmark was asked to become the king of Norway. He took the old royal name King Haakon VII.

At that time, Norway was one of the less industrially developed countries in Europe and had a modest economy /1/. Farming, the paper industry and shipping were the basis for the economy. But there was great optimism regarding the use of hydroelectric energy which was abundant in Norway.

The introduction of the use of electrical energy gave a new paradigm in the production of metals and other energy-intensive products. However, the production of metals already had a long history in Norway, dating back to the days of the Vikings. In the 17th century, copper, silver, gold and iron were mined and there was some production of metallurgical goods. Most

famous in Norway is the silver mine and works at Kongsberg and the copper mining and smelting at the city of Røros. Røros was added to the UNESCO list of World Heritage Sites in 1980. The hardship of former days has been described by Johan Falkberget, who lived and worked in Røros. The first effective iron blast furnace was erected in 1622 at Bærums Verk, west of Oslo.

Already in the second part of the 19th century, the usefulness of electricity to produce different iron alloys and carbides was tested. Calcium carbide was an important material for producing acetylene, which was used for light. The market need for these new products combined with many exploitable waterfalls fuelled the important early industrial development in Norway. One of the first plants established was "Meraker Brug og Carbidfabrik" at Kopperå, Meråker in central Norway. The plant started with only calcium carbide production – but later also produced special ferrosilicon alloys and silicon in combination with high-quality microsilica. The need for calcium carbide also motivated the start of AS Bjølvefossen in 1905 and Odda Smelteverk in 1906. Odda Smelteverk was one of the largest plants in the world at the time.

Meanwhile, the Norwegian entrepreneur Sam Eyde became increasingly interested in the utilization of the electrothermic metallurgical possibilities and other applications for electrical energy, and eventually started the company "Elektrokemisk" (later Elkem) in 1904. A major part of the Norwegian metallurgical industry as well as Norsk Hydro may be traced back to Sam Eyde's work in the beginning of the 20th century /2/.

In 1917 "Elektrokemisk" bought a plant at Fiskaa near Kristiansand in the very south of Norway. A critical component of the reduction furnaces was the electrode which had to be replaced regularly and created stops and low electrode utilization. The electrode was also a strategic commodity, and during WWI constraints from the German suppliers made the electrode even less available. Hence, there was a need to develop a different electrode system. Carl Wilhelm Søderberg had performed a small set of tests while working at the Jøssingfjord Manufacturing Company. He continued this work, first at Lysaker, and then at the Fiskaa plant, resulting in the now famous Søderberg electrode. It was the idea of Søderberg, combined with

Position	Plant name when started	Year	Products at start	Plant name today	Products today	Comments
1	Christiania Spigerverk	1853	Iron		Closed 1989	Elkem 1972, Jernverket 1984
2	Meraker	1898	CaC_2		Closed 2006	Owners: Union Carbide and Elkem
3	Hafslund	1899	CaC_2 (1899-1967) FeSi (1908 - 2002)		Closed 2002	
4	Bjølvefossen Ålvik	1905	CaC_2, later FeSi and FeCr	Elkem Bjølvefossen	FeSi and Foundry Products	Elkem from 1986
5	Odda Smelteverk	1906 (1924)	CaC_2		Closed 2002	British Oxygen Company from 1937
6	Fiskaa Verk (1917)	1907	Fertilizers	Elkem Solar	Solar Silicon, Carbon	Rebuilt 2005-2008
7	Vennesla	1908	Aluminium	Hydro Vennesla	Aluminium	Hydro Aluminium
8	Kristiansands Nikkelraffineringsverk A/S	1910	Nickel	Xstrata Nikkelverk AS	Nickel, Copper Cathodes, Cobolt, (Gold, Silver)	Falconbridge Nikkelverk A/S (1929), Xstrata (2006)
9	Arendal SiC	1912	SiC	Saint-Gobain	From 2005 only processing SiC	
10	Eydehavn	1912	Aluminium		Closed 1975	
11	Sulitjelma Smeltehytte	1912	Copper		Closed 1991	
12	Pea Porsgrunn	1913	FeMn/SiMn	Eramet PEA	FeMn	Eramet
13	Electric Furnace Products Company	1915	Manganese	Eramet Sauda	FeMn, SiMn	Union Carbide to 1981, Elkem 1981-99, Eramet from 1999
14	Tinfoss Jernverk AS	1916	Iron		Closed 1987	FeSi, SiMn and Silicon
15	Tyssedal	1916	Aluminium	Eramet Tyssedal	Ilmenite	Convertion from Al to Ti in 1988
16	Elkem Bremanger	1917	Iron	Elkem Bremanger	FeSi, Silgrain	
17	Det Norske Zinkkompani A/S	1924	Zinc	Boliden Odda As	Zinc/AlF	Outokumpu to 2003
18	Lilleby Smelteverk	1927	FeSi		Closed 2002	
19	AS Tafjord Smelteverk	1930	FeSi		Closed 1962	
20	Orkla Metall	1931	Copper & Sulphur, FeSi from 1964	Elkem Thamshavn	Silicon + Microsilica	Orkla, from 1986 Elkem
21	Norsk Jernverk	1946	Iron/Steel	Norsk Jernverk Vale Fesil	Steel, FeMn, FeSi	Started 1955, Restructured 1988
22	Årdal	1948	Aluminium	Hydro Aluminium AS Årdal	Aluminium	Hydro Aluminium
23	Sunndal	1954	Aluminium	Sunndal Primary Production	Aluminium	Hydro Aluminium
24	Mosal Mosjøen	1958	Aluminium	Alcoa Mosjøen	Aluminium, Carbon	Elkem/Alcoa, Alcoa from 2009
25	Fesil Nord	1960	FeSi	Finnfjord Smelteverk	FeSi	Finnfjord Smelteverk from 1983
26	Holla Verk	1962	FeSi	Wacker Chemicals Norway As Holla Metall	Silicon	FESIL sold to Wacker 2010
27	Husnes	1962	Aluminium	Sør-Norge Aluminium AS	Aluminium	Rio Tinto / Hydro
28	Orkla Exelon	1962	SiC	Washington Mills AS.	SiC	Washington Mills 2004
29	Hydro Karmøy	1963	Aluminium	Karmøy Primary Production	Aluminium	Hydro Aluminium
30	Elkem Salten	1967	FeSi	Elkem Salten	Silicon, FeSi	
31	Elkem Lista	1971	Aluminium	Alcoa Lista	Aluminium	Elkem/Alcoa, Alcoa from 2009
32	Tinfoss Øye	1974	SiMn	Eramet Øye	SiMn	Eramet from 2008

Table 1: shows the history of the Norwegian electricity based metallurgical industry /3/.

the practical experience of Jens Westly, that gave birth to this revolutionary invention.

The Søderberg electrode was tested for different processes in the following years such as calcium carbide, iron, ferrosilicon, ilmenite and ferrochrome. One of the most important applications came with the development of Søderberg electrodes for aluminium electrolysis. This process was industrialized already in 1927.

The technical platform for a successful Norwegian industry development had been made, and the establishment of new metallurgical industries followed. At that time, it was access to hydroelectrical energy that decided where the plants were located – and most new industries were built near power stations. Another criterion for establishment was direct access to harbour facilities. The value of the latter is shown in the fact that all the metallurgical plants without access to the sea have been decommissioned. With only 3 exceptions, Tafjord Verk, Eydehavn and Odda Smelteverk, all the plants with their own harbour are still in operation today.

Use and application of Norwegian metallurgical products

The history of human development has been strongly linked to the availability of materials. Norwegian metallurgical products have three main areas of use, as shown in Table 2 below.

Category of use	Material
Construction materials	Aluminium (Al), Iron and Steel (Fe)
Alloys and ferroalloys	Ferrosilicon (FeSi), Aluminium (Al), Manganese alloys (SiMn and FeMn), Ferronickel (FeNi) and Silicon (Si)
Functional materials	Silicon (Si), Silicon Carbide (SiC), Titanium dioxide (TiO_2) and Zinc (Zn)

Table 2: shows the principal uses of metals and materials made in Norway.

Construction and engineering materials are probably the most well known, with major and wide-ranging applications for buildings, infrastructure and transport, as well as for consumer products such as cars and kitchen equipment.

Alloy materials form a non-visible, but important part of a construction. They are crucial to give the steel and aluminium the necessary quality according to today's standards. One example is the addition of manganese alloys in steel which provides the strength to the excavator bucket. Without the manganese, resistance to wear would be much poorer.

The functional materials make use of special qualities of the materials. Zinc is used to avoid corrosion of ships and equipment in the sea. The special usages of silicon are presented as an example below.

The silicon story

The Swedish chemist Jöns Jacob Berzelius is generally credited with the discovery of silicon in 1824. The general increase in chemical and technical understanding, like the periodic table of elements presented in 1869 by Russian scientist Dmitri Mendeleev, established the necessary foundation for industrial production of many metals. There was, however, no practical way to produce silicon alloys in significant quantity.

Silicon is a chemical element with atomic number 14. Silicon has many metallic properties but is a semi-metal due to the lack of free electrons in its pure state. The atomic structure enables silicon to form very stable molecules such as silicones. If other elements such as phosphor or boron are added to silicon, the electrical properties will change. This quality is used in silicon-based electronics such as computer processors and solar cells.

The first electric arc furnaces were developed by French Paul Héroult, and the first commercial plant was established in the United States in 1907. Although the main use for the electric arc furnace was to make steel – soon this novel technology was tested for the production of other elements and metals.

The development of the Søderberg electrode combined with the electric arc furnace enabled the industrial production of ferrosilicon. Silicon has

strong deoxidation properties which is favourable for improving steel qualities and improving yield for traditional steel qualities. These properties combined with increasing steel production created a growing market for ferrosilicon. Ferrosilicon for steel also became an important part of the production of stainless steel that was developed around 1920.

Ferrosilicon became very much attached to the production of iron and steel. Steel is the most widely used construction metal with a yearly consumption of 1.4 billion tons. Increasing amounts of ferrosilicon with special qualities are developed to meet specific requirements for the final products. An example of this is low-titanium ferrosilicon (High Purity FeSi) that is used for the production of electrical steel. The low titanium content in the electrical steel reduces the loss of energy in transformers by reducing magnetic field loss. The effect of this "detail" in reducing energy consumption globally is huge.

Another special quality ferrosilicon is FSM (FerroSiliconMagnesium). FSM is used in the production of nodular cast iron to achieve much higher tensile strength than grey cast iron; therefore, toughness and elongation are great advantages of nodular cast iron. The ferrosilicon acts mainly as a carrier for the magnesium.

These are just two examples of the results of a long period of continuous development in applications for ferrosilicon. Meanwhile, pure silicon has achieved a higher star status. The reasons for that are its applications in electronics and silicones and in particular the connection to "Silicon Valley". As shown in Figure 1 there are 3 major usages for metallurgical grade silicon; 1) as an alloy to castable aluminium, 2) as the main component in silicones and 3) in electronics and solar cells. All of these usages were mainly developed after the WWII and they still have high growth rates.

Castable aluminium alloyed with silicon is mainly used in machinery and the automotive industry. The silicon allows the casting of complex aluminium products and the benefits are easy production and weight saving.

In the 1930s the first silicones were produced in small quantities. WWII created an urgency to find better sealing for aircraft and submarines. The merger of the chemical company Dow and the metallurgical producer Corning created a company with the technical and economical strength that enabled a rapid development of silicone. It was the young

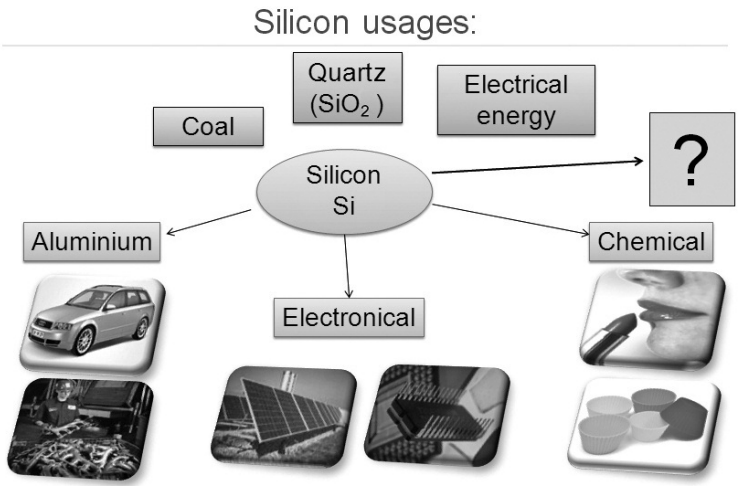


Figure 1: shows the 3 main usages of silicon. The question mark indicates potential future uses of silicon in the human household /4/.

scientist Dr. Eugene Rochow who developed the direct method for synthesizing silicones on an industrial scale.

After WWII, the development continued with civil usages of silicon – and today silicone products are in everyday use and are an important part of our life standard. Figure 2 shows the usage of silicone in the human body. Some of the applications may be questionable – but most of them are medical and for human wellbeing.

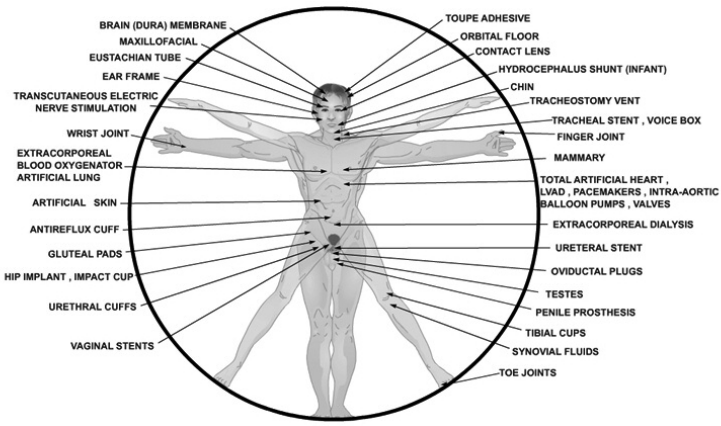


Figure 2 shows the main uses of silicone in the human body /4/.

Silicon and electronics

Computational theory was developed and written without the present knowledge of electronic use of silicon. It was the war economy and development surge during WWII that created the first usable computers. The invention of the transistor around 1950 and the development of the use of the semiconductor silicon made way for the silicon age. In 1971 the name Silicon Valley was used for the first time and the silicon-based microprocessor was invented by Intel Company. The PC came around 1981 – and other major electronically based developments followed. In the 1990s the internet and the small mobile phone were introduced. In the new millennium we have seen the take-off of silicon-based solar cells, the use of GPS, personal electronics in cameras, smartphones and players and much more.

This development created a market potential for metallurgical grade silicon. As shown in Table 1 there are seven Norwegian plants that have produced metallurgical grade silicon. Today five of the plants are still in operation producing different silicon qualities, in addition to three plants producing different grades of ferrosilicon.

The huge change from this use of silicon in our everyday life is unprecedented in human history.

The competence base

The first mining institute in Norway was founded in 1757 (Kongsberg Sølvverks Bergseminar). The Bergseminar was an important factor in the founding of the University in Christiania in 1811 (later the University of Oslo). When the Norwegian University of Science and Technology (NTNU) was founded in Trondheim in 1910, mining and metallurgy were continued there as a significant part of the education and the research. The continued growth of the silicon, ferroalloy and aluminium industries after WWII created a need for greater understanding both of the processes and product development.

The combination of education and research together with the development in the industry created a unique competence base in

Norway. One example is the Norwegian FerroAlloy Industry Research Association (FFF) where the industry, together with NTNU and SINTEF, carry out long-term research and education. Today, many programmes and projects have a clear HES focus.

Norwegian industry competence and knowhow has gained global recognition and is one reason why the silicon and ferrosilicon industry was bought by major international companies. Knowledge may be exported – but the unique base for knowledge creation in this special field cannot easily be created elsewhere. One prerequisite condition for continuing this contribution to the global household is to continue the metallurgical production in Norway as the engine for the competence programmes.

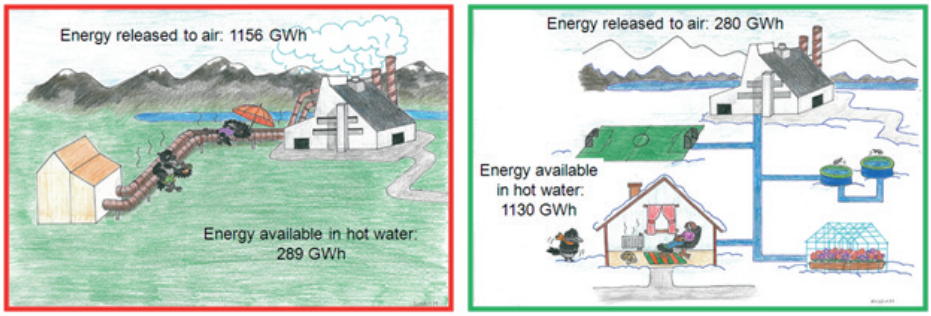
Today, the silicon and ferroalloy industry has four international owners – Vale, Wacker, BlueStar and Eramet. All have demonstrated interest in the Norwegian competence and willingness to continue long-term development.

II. THE ENERGY DIMENSION

Energy savings

There is no alternative energy source to electricity to produce most of the materials shown in Table 2. The metallurgical reason is the need to control the endothermic (energy consuming) reactions. The use of electrical energy is the only way to reach high enough temperatures to do this. For some of the processes there is also a need for a reducing agent – normally carbon – that represents an extra addition of energy.

Almost all of these processes produce large amounts of excess heat – even with the best available technology. This heat energy represents a possible source for energy recovery, which would improve the energy standard of the process. This is one way of improving the energy situation in Norway. Figure 3a shows the principal situation for many plants today.



Figures 3a and 3b show the energy situation for a large silicon plant without energy recovery (left) and with an optimized use of heat energy (right). The problem is to find an energy recipient that can make use of large amounts of available thermal energy.

Although the potential for energy saving is large, there is too much energy that is wasted, as shown in Figure 3a. The main reasons for that are:

- No external infrastructure for heat energy utilization – most plants are situated far from city centres and other possible customers for huge amounts of heat energy.
- Some of the earlier investments have demonstrated technical and economical risks.
- Capital limitations – such investments do not have a financially favourable alternative – and long-term depreciation is needed.
- The price structure of the electrical energy did not encourage such investment – the marginal electricity cost that was the basis for calculation was uncertain and variable – and the investment horizon too short.

Today, there is a range of interesting projects being realized that will improve the technical standard for the plants. The Finnfjord plant is now building an energy recovery system at a total cost of 700 MNOK and with a yearly energy production of 340 GWh /5/. The Elkem Thamshavn plant has recently finalized a 200 MNOK upgrading of the existing energy recovery plant that will increase production of recovered energy from 120 GWh/year to 180 GWh/year. Both projects are supported by Enova.

According to Enova, the aluminium and ferroalloy industry has a potential for energy recovery totalling 11.7 TWh/year if an infrastructure for heat energy use could be established /6/. This will be a challenge for both industry and society and will require long-term planning.

The Norwegian electrical energy use is presented in Figure 4a /7/. Even with a clear ambition for energy saving, electrical energy use in both the private and public sectors is increasing. Figure 4a shows that the public and private electrical energy consumption has increased by 15% from 1998 to 2010 and there is no clear sign of abatement. The figure also shows the structure change in the ferroalloy industry presented in Table 1 – especially the reduction of electrical energy in the silicon and ferroalloy industries.

This development is not very positive for the long-term industry outlook. Capital-intensive industry needs a perspective of at least 10-20 years, as this is what R&D, the development of raw material sources and major investments require before becoming profitable. Frequent calls to shut down the metallurgical industry coming from leading economists /8/ are not helpful to the long-term thinking of this industry.

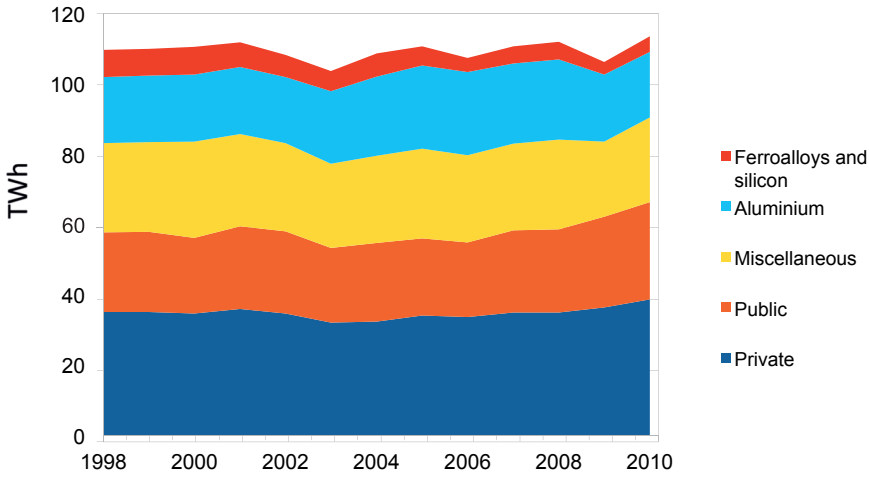


Figure 4a shows the use of electrical energy in Norway from 1998 to 2010. The 15% increase in the private and the public use of energy may in the long term discourage the metallurgical use if this development continues /7/.

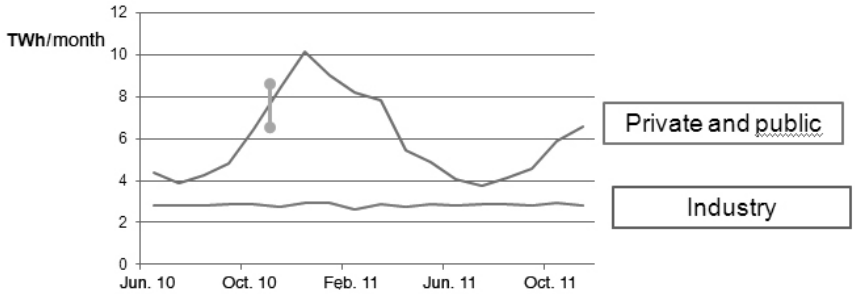


Figure 4b shows the use of electrical energy from June 2010 to October 2011. Note the variation of the private and public use over the year, and indication of variation over one day. The industry is a more reliable customer and the electric energy prices to the metallurgical industry are not directly comparable to the price to other uses /7/.

The cost of electricity is partly due to its production and partly to maintaining capacity. As shown in Figure 4b, the industry has very little variation during the day and during the year. The cost of the electrical energy to the private and public customers is much higher due to the variation in consumption. The huge difference in how the energy is used does not generally seem to be fully understood and recognized /8/.

Exergy – the importance of energy quality

Energy is in part easy to comprehend – and in part complicated. We all use energy every day – inside and outside. There are two laws of thermodynamics. The first law states that energy cannot be created or disappear, only change form. The energy we use today is mostly direct or indirect energy from the sun – with the exception of nuclear and geothermal energy.

The second law of thermodynamics is more difficult to explain, but it describes very well how we use energy. The law is about the energy quality and the tendency for energy to end up as heat energy. An example is how easy it is to use electrical energy to make warm water. However, the second law of thermodynamics states that the heating of water is not reversible and it is theoretically (and even more practically) impossible to transform the energy in the warm water back to the same amount of electrical energy.

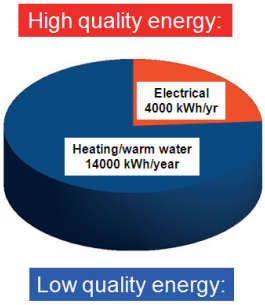


Figure 5 shows the energy use in a flat where heating and warm water is a part of the Trondheim district heating system. The major part of the energy used could use low-quality thermal energy, instead of electrical energy. Moreover, even more reduction in the use of electricity for light may be achieved with the new light systems such as LED. Finally, total energy use may be reduced with improved building standards.

THE ENERGY QUALITY */9/. It is simple to understand the concept of* ***energy.*** *We use the amount of energy when we talk of kWh electrical energy or litre of gaz. The concept of* ***exergy*** *is not so commonly used and is more difficult to comprehend. The exergy is shortly defined as the energy available to the maximum useful work possible during a process that brings the system into equilibrium with a heat reservoir. Energy is never lost – exergy is always destroyed in human activities.*

The exergy values for human activity using this information can be useful for comparing policy alternatives based on the efficiency of utilizing natural resources to perform work. It is the combination of the energy and the exergy usage that shows the impact of the energy use on the environment.

Exergy analyses for Norway are not favourably seen from a global perspective. The exergy analysis shows that the same goods and services in theory could be obtained with 25% of the energy that is used today. The main reason for that is the use of high quality energy (electrical) where low quality energy (heat) is sufficient. /9/

The production of silicon and metals represents some of the best uses of the Norwegian hydroelectrical energy regarding exergy and the right use of energy quality.

If all countries had abundant access to hydro electrical energy the Norwegian use of energy would be good. But in a world with energy constraints the Norwegian use is not very impressive seen from a global point of view.

The need for a change in the Norwegian energy strategy

There seems to be increasing competition for energy and other commodities. One example is the 90% price reduction of iron ore from 1885 to 2005 which has almost been reversed to the 1885 price since 2005.

As shown in Figure 6 there seemed to be a jump in some important commodities around the year 2005.

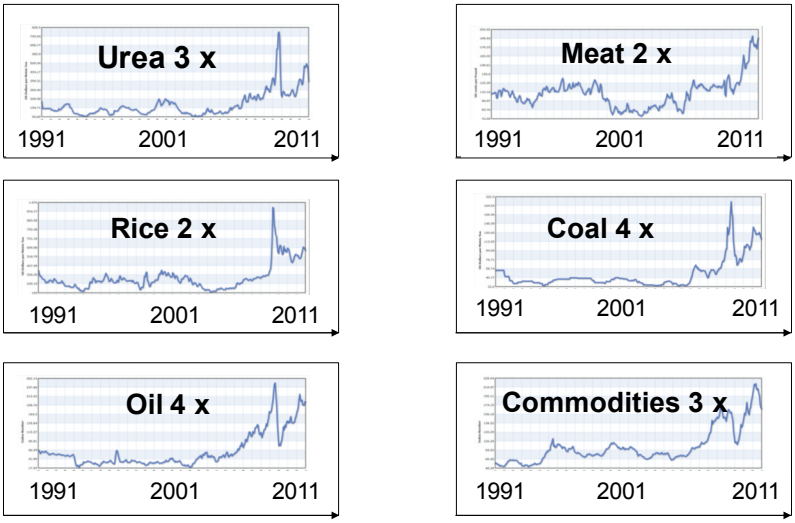


Figure 6 shows the price for some important commodities the last 20 years. Note the almost simultaneous leap in the price after year 2005. The last figure is inflation corrected price for a large number of fuel and non-fuel commodities /12/.

Does Figure 6 indicate a new historical paradigm with limited resources? Maybe not – some professionals blame speculants or temporary high economic activity for this increase. But some countries prepare for the possibility of scarcity of important commodities and raw materials. *"The Chinese elite see the world in terms of brutal competition for limited resources. And it has no truck with Western ideas about relying on the market" /10/.*

Besides the increase in the world population and the increase in living standard for many, there are other factors that may increase prices of vital commodities in the future. Some of the business now is directly controlled by states to secure their own population or is done by barter:

"Recently Russia announced the country would stop all wheat exports Aug. 15 because of widespread drought and fires …….The world's wheat market got a harsh reminder of supply-and-demand economic theory recently, with Russia's announcement Aug. 5 that it will stop exporting wheat and other grains starting Aug. 15 until Dec. 31. Severe drought, a record-breaking heat wave, and wildfires have taken 20 per cent of

Russia's wheat crop. And to prevent a rise in domestic food prices the country has decided it's time for an export ban" /11/.

History shows there is an irrevocable relationship between resources and the possibility for a good life for human beings. This is indicated in Figure 7. The ultimate resource is energy, which Norway fortunately is blessed with and has utilized wisely for many years.

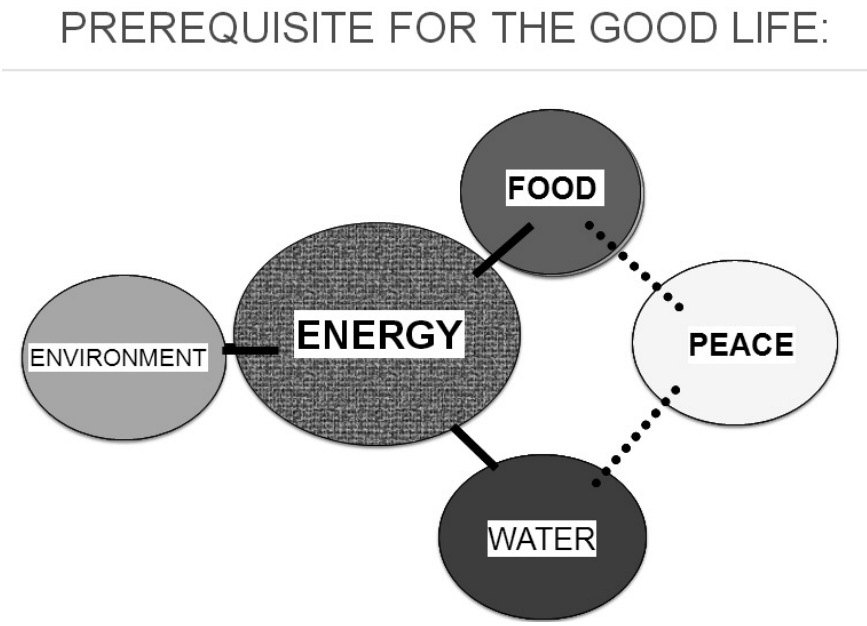


Figure 7 shows the prerequisite for the good life. Contrary to most of human history this has fortunately been the life for most of the Norwegians living today.

If the examples above indicate a possibility for global scarcity of energy and important commodities – what should be the logical consequences for the use of the Norwegian resources? From a moral standpoint, we should as a nation try to use these resources better. This requires an even more powerful national energy strategy to mitigate the negative trend shown in Figure 4a.

As a nation, Norway has many a time demonstrated an ability and willingness to achieve national goals. During the Winter Olympic Games

at Lillehammer in 1994 – only 18 years ago – we gave the World a fabulous global party.

If we look 18 years ahead to the year 2030 there are some clear challenges the anticipated 8.4 billion global citizens will face at that time.

Energy may become one of the major challenges by then. Utilizing the Norwegian energy resources – directly, by metal production and by setting good energy standards – will be helpful to the global energy situation.

Better use of our energy resources is the next "party" we should give the World.

Conclusion

In this article, we have looked at the history of the Norwegian metallurgical industry and the importance of the development of materials for the global household. Norway's main contributions to this are the production of important materials and as a knowledge base. The long history and tradition combined with the industrial concentration in combination with long-term academic and industrial R&D has contributed to this unique situation.

There are sufficient energy resources for both industry and public use in Norway. The energy use in the public sector is still increasing in spite of ambitions for energy savings. We like to be looked upon as a nation with high environmental and energy standards. The reality may not be so glamorous. This raises moral questions in a world with ever more limited resources.

Important resources may become scarce in the future and challenge the supply-and-demand economy. There are already examples of more selfish strategies. The consequences for Norway should be discussed and addressed as part of a national energy strategy.

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Challenges in International Climate and Energy Policy

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1. Purpose and scope

I begin my three-step analysis by exploring energy and climate policy challenges at the global level, and argue that the most demanding of these challenges are found at the interface between what are commonly labelled 'energy' policies and policies aimed at mitigating the impact of human activities on the global climate system. Essentially, policymakers must steer an increasingly energy-hungry world towards sustainable and effective energy systems. This is a formidable task. I then examine two main strategies that can be used to promote the transition required. One is holistic in the sense that it conceives of the challenge as systemic in scope and assumes that complex systemic problems call for integrated global solutions. The negotiations organized under the UN Framework Convention on Climate Change (UNFCCC) aim at establishing a regime that responds to this call. The other strategy is premised on the observation that the human impact on the climate system can be traced to multiple systems of activities. These systems differ widely in important respects and can – some argue – therefore most effectively be governed in small clusters or even one by one. The overall result will be a loosely connected patchwork of measures. Although not in a strict sense mutually exclusive options, these strategies are premised on

different assumptions and prescribe different cures. Recognising that both strategies will more likely bring about incremental change than fundamental transition, I devote the third and final section to briefly exploring what might be called 'game changers', that is, measures that can fundamentally reverse current development trajectories.

2. The Challenges

'Energy policy' – understood as a distinct domain – deals with energy supply, distribution, and consumption. Much of the discussion within this domain is framed in terms of effectiveness (of supply), efficiency (in use), and fairness (in distribution). In my analysis here, three global challenges of 'energy' policy are particularly important. One is to satisfy the basic needs of about two billion people who today suffer badly from insufficient access to energy. Another is to meet the increasing demand for energy worldwide, particularly in rapidly growing economies. The third is to manage increasing risks of severe environmental damage caused by prevailing patterns of energy production, distribution, and consumption.

These challenges differ in important respects. Because basic needs are involved, the first challenge is the most important and urgent assessed by ethical standards. The poor's needs are, however, also those least effectively translated into purchasing power or political influence. However, while the poor may be insignificant as customers they are just as significant as human beings. The second challenge – meeting increasing demand worldwide – generates more drive in energy markets than either of the other two, and probably also more 'political energy'. Since the poor are more vulnerable to high prices than the rich are, supply-enhancing measures sufficient to reduce energy prices in important markets can improve living conditions also for the poor. The effect is likely to be marginal, though, and targeted local support measures can be much more valuable to the world's poor than any increase in, say, Norwegian energy production. The third challenge – managing increasing risk of severe environmental damage – has become more significant over the past two decades. Certainly, energy production, distribution and consumption have caused multiple environmental problems also in

earlier times. Until recently, however, most such problems have been confined to limited geographical areas and to local or regional communities. Substantial growth in fossil-fuel consumption – and prospects of further increases driven by a combination of population growth and rising income levels – has added new risks of human-induced changes in the climate system at large, potentially affecting billions of people. Once again, the poor tend to be more vulnerable than the rich are (UNFCCC 2007).[1] Consequently, energy policy is today inextricably linked to growing concerns over potentially severe side effects of prevailing patterns of energy production, distribution, and consumption.

While 'energy' policy is an established domain, 'climate' policy is a newcomer on domestic as well as international political agendas. As commonly understood, climate policy has two main components: mitigation and adaptation. *Mitigation* is proactive damage prevention. IPCC's Fourth Assessment Report (2007) indicates that effective mitigation of human-induced climate change will require cuts in aggregate GHG emission levels of 50–80% over the first half of the 21st century. To allow for improvement in the poor's living conditions, the reduction targets for the rich industrialised countries must be very close to this range's upper limit. Meeting such targets would essentially amount to reversing current trends. *Adaptation* concerns making the best of the changes that in fact occur. Most policymakers will probably consider adaption a less demanding option than mitigation, for three main reasons. First, whereas mitigation policies, by definition, must be proactive, at least some types of adaptation measures can wait until consequences materialise. Second, emission cuts of 80% seem a daunting task even to people who accept that current trajectories are non-sustainable. By comparison, a wide range of adaptation measures will – at least considered one by one – appear as feasible incremental adjustments. Third, while adaptation measures will be taken primarily by those who are most directly affected, the main responsibility for developing and implementing effective mitigation policies will, at least early on, fall to the rich industrialised countries that

1. Vulnerability is, though, affected also by a number of other factors, including population growth and low quality of governance (see Maplecroft 2012).

seem less vulnerable to (incremental) climate change. Taken together, these differences have profound implications for incentive structures and power configurations.

Climate change mitigation combines several features that make it an *extremely demanding* governance challenge. One such feature is *very long time lags* – in some cases extending well beyond one human generation – between mitigation measures (commonly perceived as 'costs') and effects on the climate system (perceived as 'benefits'). Most profoundly, such long time lags leave important future stakeholders unable to voice their concerns and to influence decision-making about mitigation policies. We are, in other words, faced with an extreme temporal asymmetry in participation and political power. To make things worse, long time lags also generate important asymmetries for present generations that *can* participate. Other things being equal, uncertainty tends to increase the farther into the future we look. By implication, long-term benefits of mitigation policies will be more uncertain than their short-term costs. The political significance of this asymmetry is amplified by a common tendency to react more strongly to the prospects of a certain loss than to the prospects of an equally large gain (Kahneman and Tversky 1979). These and other features interact synergistically to make ambitious mitigation policies very difficult to adopt and even more difficult to implement.

Second, mitigation policies intervene in highly complex systems that are not fully understood. The global climate system fits this description well and so do many systems of human activities, including (global) markets and political processes. High complexity makes governance more demanding and leaves sceptics and opponents with stronger arguments for proceeding slowly.

Third, international climate change negotiations are embedded in a broader context of deep cleavages and high-stakes competition. Huge gaps in economic welfare and human living conditions lead to widely divergent concerns and priorities. Any global agreement on mitigation measures must differentiate contribution according to widely accepted norms of distributional fairness (see section 3.1 below). Moreover, as negotiators struggle to devise such a scheme, major shifts are under way in the world

economy and in world politics. Rapidly growing economies such as China, India, and Brazil challenge the 'hegemonic' positions of the United States and other major Western powers. As a number of Western firms and industries lose ground, governments, companies, and trade unions become more reluctant to accept policy measures that can further strengthen the competitive edge of emerging powers. Also measures undertaken to mitigate climate change can be vulnerable to this kind of criticism. Consequently, participants in the UNFCCC negotiations face the task of establishing an international regime that can substantially reduce GHG emissions and do so in ways that (a) serve the basic needs of the poor of the world, and (b) accommodate major players' competing interests in international trade, finance and politics. This is a tall order indeed.

Fourth, the search for a global deal that can meet these requirements is further constrained by the fact that incentives and capabilities seem to be negatively correlated. At the global scale, stark asymmetries exist between 'guilt' for causing the problem and capacity to alleviate it, on the one hand, and socio-ecological vulnerability to climate change on the other. As far as mitigation measures are concerned, the most likely victims are heavily dependent on the largest polluters.

Finally, climate change mitigation essentially attempts to avoid or reduce a global collective 'bad' to which many human activities contribute. Unless cost-sharing arrangements are made, those making the mitigation efforts will shoulder the burden while most of the environmental benefits will be shared by all. As a consequence, incentives to undertake *unilateral* mitigation measures will be weak unless these measures have some positive side effects for the party which instigates them. Moreover, at least currently, mitigation on a scale that can effectively respond to the IPCC's problem diagnosis exceeds the reach of any 'single best effort solution' (Barrett 2007).[2] Even the largest emitters (China and the United States) each controls only about one fifth of world GHG emissions.

2. Barrett uses this label for measures that a single initiative taker – notably one that financially is particularly well-endowed – has the incentives and the resources to implement alone (should others not be willing to join).

When we 'feed' a challenge that has all these characteristics into mainstream political science models of international cooperation, we get a sombre prediction: lacking some major exogenous shock(s), negotiations will fail – by a wide margin – to deliver a global mitigation programme that effectively responds to IPCC's description and diagnosis of the problem. Predictions for *adaptation* policies would be significantly more optimistic, indicating a likely shift in priorities as frustration with the more ambitious and demanding mitigation project increases. The ways that decision-makers frame the challenge and organise efforts can, however, make a non-trivial difference. To indicate how, I will briefly outline two strategies for developing and implementing mitigation policies and practices.

3. Two main strategies

One of these strategies is premised on understanding climate change as a *systemic* (global) problem that calls for an equally holistic solution. The other approach builds on the observation that mitigation concerns intervening in human activities rather than in the climate system, and proceeds to argue that since these activities differ widely in important respects, more can be achieved by searching for measures that 'fit' one particular activity or a smaller cluster of activities.

3.1 Global problem ➛ global solution

Natural science – particularly what is often referred to as Earth System science – regards climate change as a *systemic* (global) challenge that calls for a response that is equally comprehensive in scope. If we combine this understanding of the challenge with a notion of good governance as involving broad stakeholder participation in democratic processes, a simple and clear procedural recipe emerges: a major effort that will affect people worldwide should be developed and implemented by the global community. With some modifications, the UNFCCC negotiations pursue this 'global problem ➛ global solution' approach.

This strategy builds on two sets of pillars, one ideational, the other institutional. Beginning with the ideational pillars, we may first note that

global agreement on a common cure requires broad consensus regarding the description and diagnosis of the 'disease'. In this area, substantial progress has been made over the past twenty years, thanks largely to the IPCC's work. Second, the strategy also requires broad agreement on likely effects of alternative cures. Here, too, significant progress has been made, but since major participants diverge when it comes to assigning relative weights to different consequences, no common platform exists at this time. Third, a global regime requires broad agreement on responsibilities and duties – ideally an agreed formula for determining who shall contribute how much ('burden-sharing'). Consensus has been achieved on the vague notion of 'common but differentiated responsibilities'. Moreover, at least three principles of distributional fairness (equity) are frequently invoked and rarely disputed (Ringius et al. 2002). One of these principles prescribes that the costs of undertaking mitigation measures be shared in proportion to the 'guilt' in causing the damage. This is a version of the 'polluter pays' principle. Another interpretation of equity calls for costs to be distributed in proportion to the capacity to undertake a particular measure. This is, in essence, the reasoning behind progressive taxation. A third principle prescribes that benefits be distributed in proportion to need, consistent with social welfare ideals. All these notions of fairness place the main responsibility for mitigation with the rich industrialised countries. Most if not all such countries seem to accept this implication. However, interest-based disagreement persists over the application of fairness principles to this particular case. For example, because the rapid growth of several major emerging economies (such as China, India, and Brazil) changes the distribution of 'guilt' as well as the relative capacities to undertake mitigation measures, the actual distribution of responsibilities prescribed by these norms will depend significantly on the time perspective adopted in calculating shares.

Similarly, at least three institutional pillars can be identified. One is the existence of a global forum broadly accepted as *the* appropriate negotiating arena. Most states have signed on to the UNFCCC framework, but as negotiations drag on, an increasing number of parties turn to other arenas, at least as supplementary tools. A second pillar is the existence of legitimate and effective mechanisms for aggregating and integrating

preferences. Most developing and many small industrialised countries continue to prefer consensus-based global diplomacy. For major players, however, club-like institutions such as the G-8 and the G-20 are becoming increasingly important. Consequently, overall support for the UNFCCC framework now seems to be strongest among its least powerful members. Third, prospects for developing effective international regimes can be enhanced by the support of an international organisation capable of providing independent inputs into the negotiation process and of amplifying agreements reached. IPCC clearly aspires to a high score for contributing science-based inputs, but otherwise IO capacity within the UNFCCC framework is low. In particular, the enforcement mechanisms established so far are very weak.

What can global conference diplomacy be expected to achieve? The *good* news is that it can be an effective tool for (a) setting political agendas and focusing governments and stakeholders' attention worldwide; (b) providing an institutional framework for building consensual science-based knowledge; (c) providing arenas for learning about effective policies and good practices; and (d) generating for many involved people positive stakes in its own success. The *bad* news is that when faced with demanding challenges, global conference diplomacy becomes highly vulnerable to (a) deadlock over basic principles (pertaining, for example, to responsibilities and duties); (b) internal coalition dynamics that enhance polarisation; (c) obstinate veto players, taking advantage of the consensus requirement to thereby exert greater influence; (d) strains of global competition over wealth and power, enhancing participants' concern with *relative* gains and losses; and (e) the burden of overwhelming complexity. Adding up all these, we may conclude that global conference diplomacy can deliver – and has in fact already delivered – some significant achievements, particularly regarding agenda setting and learning. Faced with the very demanding challenge of climate change mitigation, however, its mechanisms for aggregating and integrating divergent interests and amplifying agreements will likely prove too weak to steer the world towards a low-carbon energy future.

3.2 'Clumsy solutions for a complex world': a differential approach

I have borrowed this headline from Verweij et al. (2006) and use it here as a label for a pragmatic strategy that seeks mitigation measures that are effective *and politically feasible*, that is, measures that a critical mass of participants will be willing and capable of undertaking themselves (see Victor 2011).[3] It differs from the global problem → global solution approach in at least four respects. First, it focuses directly on the human activities to be governed rather than on the climate system. Second, given that the human impact on the climate system can be traced to a wide range of activities involving participants with different interests and resources, it argues that a differentiated approach designing measures to 'fit' particular activities can be more effective in mobilizing existing incentives and resources for mitigation. Third, it claims that many measures that can contribute to mitigation will be attractive (also) for other reasons. For example, closing primitive coal burners can cut GHG emissions and simultaneously reduce the amount of soot and other particles that cause health problems. Where expected climate change mitigation benefits are not considered sufficient to warrant investment in cleaner energy options, positive side effects on human health (and, indirectly, on productivity and economic growth) may tip the scales. A 'clumsy solution' approach searches for such win-win measures. Finally, instead of near-universal participation, it takes critical mass of contributions as the appropriate standard for cooperative arrangements. Few if any mitigation measures require universal participation; so, it makes sense to focus the search for solutions primarily on measures that some smaller group may be willing and capable of undertaking themselves (Victor 2011).

Efforts to build such coalitions of the willing sometimes involve hard bargaining, and agreement can never be taken for granted. Successful coalitions will often include 'Bootleggers' (~those taking advantage of regulation to pursue their own interests) as well as 'Baptists' (~those motivated primarily by broader environmental concerns) (DeSombre 1995). The stratospheric ozone depletion case clearly illustrates such

3. In a follow-up book, Verveij (2011) replaced the label 'complex' with 'wicked'. For my purpose, however, 'complex' is more appropriate.

situations; the *joint* support of a few transnational companies (driven primarily by prospects of new markets) and government agencies and environmental NGOs concerned with human health and the environment made effective international regulation politically feasible (Benedick 1991). Climate change mitigation is much more challenging. Thus, more will be required to accomplish an equivalent breakthrough in this area. Nevertheless, multiple opportunities exist for activating similar mechanisms also in climate politics. The 'clumsy solutions' approach advises us to search for such opportunities and exploit them. The aggregate result will certainly not be a coherent, well-integrated global programme. However, in dealing with highly complex and politically malignant challenges, a 'clumsy' patchwork of measures involving different groups of participants can – some argue – be more effective in mobilising existing ideas, incentives, and resources.

This differential approach builds on the same types of ideational and institutional pillars as the global problem → global solutions strategy does. The main difference is that the burden on these pillars is reduced to serving particular measures undertaken by smaller groups. Beginning with ideational foundations, we first note that effective mitigation still requires widespread concern with the impact of human activities on the climate system and common understanding of primary causal mechanisms. A differential approach assumes, however, that each participant will be concerned primarily with expected consequences for itself. These consequences will differ and so will demands for mitigation measures. Similarly, accurate and reliable assessments of alternative mitigation measures' effects are as important here as in the search for global solutions. However, since countries differ widely regarding economic and technological development, industry structures, natural resource endowments, and several other important characteristics, their cost-benefit assessments of particular mitigation measures will likely diverge. Certain patterns will nevertheless likely emerge, and they may be used to bring together like-minded countries. Finally, recognizing responsibilities and duties remains an important pillar of mitigation policies. A differential approach will, however, build on existing notions of responsibilities and

duties (divergent as they will be) and will not invest much energy in negotiating 'burden-sharing' formulas.

Similarly, the three institutional pillars of international cooperation described above – generally accepted arenas for negotiations, legitimate and effective mechanisms for aggregating and integrating preferences, and organisational capacity to support negotiations and amplify agreements – are important also to a differential approach. Arguably, however, the burden on these pillars should mostly be lighter and the institutional capacity for collective action higher. The burden should be lighter because negotiations will deal mostly with measures limited in scope and involving small to medium-size groups of participants. The institutional capacity should mostly be higher because a differential approach extensively uses existing regional and functional organisations and networks strengthened from decades of work. Admittedly, such organisations' decision rules and their secretariats' mandates and resources vary widely, but some have acquired significantly higher capacity for initiating and managing collective action than has the secretariat serving the global climate-change regime. The European Union stands out as a unique case, but some narrowly specialized IOs (such as the International Maritime Organization and the World Health Organization) have developed fairly effective procedures for integrating and aggregating preferences, and have built up secretariats and other bodies with significant capacity to support negotiations and to enhance compliance with agreements.

Mitigation measures that make sense by environmental and economic criteria, and that a critical mass of willing and capable participants can undertake, are found at different levels – ranging from local communities to international coalitions, and from broadly defined economic sectors to specific technologies. At domestic and subnational levels, widely varied plans and programmes already exist – some involving real change, many confined to expressions of good intent. The EU has made significant achievements regionally. This development is consistent with the proposition that institutional capacity built up for other purposes can be useful in developing and implementing mitigation policies as well, but since no other region has an equally well-developed institutional infra-

structure, we cannot expect the EU's achievements to be replicated. Some initial steps have been taken by, inter alia, the Asia Pacific Economic Cooperation (APEC) summit in 2011. Moreover, several inter-regional forums have been established to foster dialogue and cooperation (e.g., The Africa-EU Climate Change Partnership). This partnership has developed a joint action plan, but so far, the results of most such initiatives are meagre. The potential for using functionally specialized IOs to negotiate mitigation agreements for specific sectors seems largest in sectors that (a) are only moderately exposed to competition from other sectors, and (b) rely on a common technological base. Maritime transport is a sector that aspires to a relatively high score on both dimensions, and work to develop energy efficiency standards for ships are in fact progressing under IMO auspices. Similar opportunities seem to exist in some other sectors, but progress transforming them into significant material change has been slow.

To summarise, advocates of the 'clumsy solutions' approach seem correct in claiming that a wide range of mitigation measures can in fact be undertaken by a critical mass of willing and capable participants. Most such measures would, however, be limited in scope and/or participation. The critical question thus becomes whether multiple small and loosely coordinated steps can – and, more importantly, in fact *will* – add up to substantial change. Optimists will focus on *potential* gains and answer yes. Pessimists will estimate *actual* achievements and answer no.

4. 'Game changers?'

If the pessimists are right – and in a short-term perspective, evidence seems to tilt in their favour – can we identify one or more 'game changers', that is, feasible measures that can bring about transformation that is sufficiently profound to qualify as an effective response to the energy–climate change challenges as these are described above?

At least three main categories of potential game changers can be identified. One involves *supply-side* measures, more precisely large-scale technological shifts towards low-carbon energy systems. This partly involves technological innovation and investments to support R&D, and

partly involves orchestrating large-scale conversion of energy supply *systems*. In economic and political terms, the latter challenge may well be more demanding than the former. The other category of potential game changers consists of *demand-side* measures. Two of the three principal drivers of human impact on the environment – population size and income levels – are not easily controlled.[4] This constraint leaves us with two other types of demand-side measures: radical improvement in energy efficiency and major changes in infrastructures and lifestyles. Significant improvements in energy efficiency are being accomplished, and more can be expected. These gains are, however, largely offset by increasing demand generated by rising income levels and growing populations. Lifestyles – and even more so, physical infrastructure systems – are 'slow' variables; therefore, major changes will in many instances take decades. The third category includes measures known under the label of *geo-engineering*. Such measures come in two main versions – one aimed at removing carbon dioxide either through direct capture (CCS) or through indirect means such as ocean iron fertilization, the other aimed at controlling incoming solar radiation. The knowledge base of some of the geo-engineering options is still weak. Therefore, consequences – particularly side effects – cannot presently be confidently predicted. Moreover, prospects of unilateral or mini-lateral efforts will likely generate fear and demands for strict international control. Yet, should a climate change emergency occur, geo-engineering options will likely be included in the toolbox of climate change policy (Victor 2011).

More generally, policy measures of the format required to qualify as game changers will likely need powerful triggers. Exogenous shocks in the form of, for example, extreme weather events may indeed change perspectives and incentives. Unfortunately, if dramatic damage is required to trigger policies that can effectively reverse current trajectories, the overall project of mitigation – the proactive *avoidance* of damage – will have failed.

4. The third variable, in Ehrlich and Ehrlich's (1981) well-known formula, is *technology*. Technology can, however, enter the equation on both sides – as part of the problem and as part of the solution.

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Towards a more Resource-efficient Society – The Concept of Exergy

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Introduction

According to the International Energy Agency (2011), it is necessary to increase the energy efficiency in society at large, in order to avoid a two degree rise in average global temperature within 2050 and damaging climate changes. This work addresses some measures that need be taken to realise a substantial increase in the energy efficiency world wide.

There is first a need for consensus on how the energy efficiency should be measured, as several definitions are presently in use. We propose to use systematically the concept of the *exergetic efficiency*, which measures the use of available work. Exergetic efficiencies can be used to map efficiencies in a society at large. We shall present such a map for Norway, and discuss how it can be used to foster a development towards more *resource-efficient* technologies. With reference to the situation in Norway, we discuss whether we can expect significant improvements in the way that we produce or consume power. Examples from the offshore-industry and the metallurgical industry are used to illustrate the possibility.

A development towards a more resource-efficient society depends on the availability of highly competent persons in several sectors of the

society. Universities should be granted training programmes for this purpose.

Defining the energy efficiency

All energy conversion is ruled by the laws of thermodynamics. The first law says that energy is conserved. It is therefore paradoxical to speak of energy consumption. The second law of thermodynamics gives a quality scale for energy, with electric and chemical energy being higher on the scale than thermal energy. By quality we mean the potential to do work. This varies largely among the energy forms. The potential to do work is a quantity known by several names, e.g. *ideal* or *available work,* or *exergy*. We shall use the term exergy, (for terminology, see Tsatsaronis, 2007). Exergy can be used to evaluate materials as well as electric power, cf. exergy analysis (Kotas, 1995).

Broadly speaking, we divide definitions of energy efficiency in to two categories; those based on the first law of thermodynamics only, and those using both laws of thermodynamics. The definitions related to the first law of thermodynamics consider all energy forms on the same footing. The efficiency measures the useful output energy over the input energy. An efficiency, which does not account for energy quality can be misleading about the potential for improvement. Consider as an example the heating of water by the use of electric power (as in an electric kettle). This process has a large first law efficiency, because nearly all the electrical energy is used to heat the water. But the high quality electric energy, used for simple heating purposes, could have been used to do work.

An efficiency defined from the first and second laws of thermodynamics measures the work output with respect to the highest possible work theoretically obtainable, see Kjelstrup et al. (2010a). The real process is now compared with an ideal process. In the real process, the exergy leaving a process is always less than the exergy entering a process. This enables one to rank different power producing and consuming technologies by their exergetic efficiency. Work and power have absolute values. They are not conserved quantities like energy. Thus, we can speak of using power.

The difference between the exergy entering and leaving a process is called the lost exergy. To reduce the amount of lost exergy is the way towards a resource-efficient society. The exergetic efficiency is the ratio between the exergy output and the exergy input of a process.

A map showing the exergy input and output and the lost exergy, is called a Grassman diagram.

The potential for increasing sector energy efficiencies in Norway

An exergy analysis of Norwegian society in 1995 was carried out by Ertesvåg and Mielniek (2000), see Fig.1. Exergy streams in the Norwegian society are shown. Similar studies have been done for Sweden, Italy and other countries. Supply and use of exergy have changed since 1995, but the figure is still relevant. The left hand side of the figure gives an overview of the available exergy. Waterfalls represent a large share of the total exergy. Exergy is also available from biomass, oil and gas. Offshore gas- and oil activities are not included. Except for water power, renewable power sources were few in 1995. Wind turbines were only in the planning stage.

The relative contribution of hydroelectric power and oil/gas has since then changed and so have the plans for their use. The large areas of power consumption are shown to the right in the figure. This is what we use the exergy for; production of products from wood, food, light, mechanical work, aluminium and other metals, chemicals, transport or logistics and heating of houses/rooms. The interesting information for each sector is the exergetic efficiency, the ratio between the exergy input and the exergy output, cf. the definition above. We notice large exergy losses. Parts of this exergy could have been used for other purposes.

The figure gives immediately a perspective on where efforts are needed. The transport sector and the domestic sector stand out by having rather low efficiencies. The first case can be explained by the low efficiency of the combustion engine. The second case is special for Norway; it is due to our use of high quality electric power to heat houses. Much effort has been devoted to increase the efficiency in the transport sector world-wide, but it is still not large. Some effort has been made to improve the way we heat

houses in Norway. The government has via Enova given support to increase the use of heat pumps. Heating by water from incinerators is also a step in the right direction. The research centre on Zero Emissions Buildings, funded by the Research Council of Norway, is also an answer to this challenge.

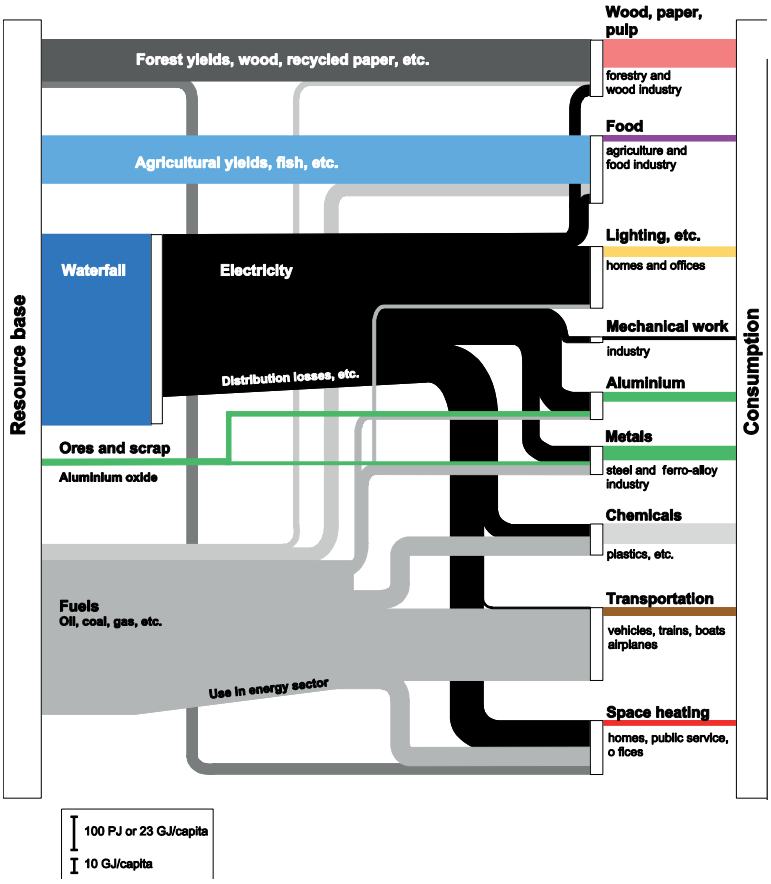

Figure 1. Grassman diagram for the Norwegian society in 1995. Offshore gas- and oil activities are not included (Ertesvåg and Mielnik, 2000).

In the perspective of the Grassman diagram in Fig. 1, the industry is not an inefficient user of exergy. The sector can however also improve, and exergy calculations can help explain how and by how much. The two examples below illustrate the use of exergy calculations in industry. For other examples, see Rian and Ertesvåg (2011, 2012).

Consider first the operation of a typical offshore platform. In 2008, offshore gas turbines and diesel engines were responsible for 21 % of Norway's total CO_2 emissions (Statistics Norway, 2010). The exergetic efficiency of oil platforms depends on the mode of operation (Voldsund et al., 2012). The oil and gas separation at a North Sea oil platform was studied for a typical production day in 2011. Parts of the process equipment were designed for a larger volume of gas. In order to deal with this, gas was constantly recycled around several gas compressors. By removing the recycling, the exergetic efficiency increased from 0.32 to 0.38, and the power consumption sank by 3.6 MW (Table 1). The large improvement requires update of some equipment. The results in Table 1 can be used to find out when the update is beneficial.

	Case 1: With gas recycling	Case 2: Without gas recycling
Power consumption / MW	23.9	20.3
Destructed exergy / MW	16.1	12.6
Specific power consumption / kWh/Sm^3 oil	180	154
Exergetic efficiency	0.32	0.38

Table 1. Power consumption, destructed exergy, specific power consumption and exergetic efficiency for oil and gas processing at a North Sea platform for a typical production day in 2011 according to Voldsund et al. (2012). Results are given with and without recycling of gas.

Exergy calculations can be used to set standards by companies or governments. The exergetic efficiencies for the North Sea process can be compared with efficiencies for production of hydrocarbons from unconventional sources; from Canadian shale fields or from gas hydrates. Consider next the operation of a typical Norwegian silicon smelter, which has an exergetic efficiency of 0.31 for typical operating conditions. Table 2 shows that installation of a power-producing boiler and steam turbine in the gas outlet section of the furnace can increase the exergetic efficiency from 0.31 to 0.39. This is a substantial improvement (Takla et al., 2012). The numbers can be used to argue that installation of such equipment is

	Case 1: No power recovery	Case 2: With power recovery
Exergy in / MW	22.1	22.1
Lost exergy / MW	15.3	13.5
Specific power consumption / kWh/kg Si	11.7	9.6
Exergetic efficiency	0.31	0.39

Table 2. Exergy input, lost exergy, specific power consumption and exergetic efficiency in the cases of no recovery, and recovery, of thermal exergy from the furnace off-gas for one furnace operating at a silicon plant in Norway, according to Takla et al. (2012). The numbers are scaled to one hour of production in a 10 MW furnace. The product includes silicon metal as well as electric power delivered from the energy recovery system. In Case 2, the recovered exergy is used to power the process. The specific power consumption is the power that has to be used beyond this.

important, not only for the single plant, but for all plants. The government can promote development in the direction of better efficiencies in several ways, rewarding such changes, or punishing less optimal behaviour.
In the context of these examples, it is interesting to see a proposal by Sauar (1998) to tax the *excess* lost work. Such a proposal cannot be realised without knowledge of reasonable values of lost work, however. The theoretical upper limit of the exergetic efficiency is unity, but in practice lower limits apply. The practical limit is specific for each technology, given the operating conditions of the equipment used and the demanded rate of production. Who should define the practical limit? We propose that the industry itself should not do that alone. Each user should have to defend their use of quality resources.

Industries are now required in their annual report to give all facts related to their production. With a public demand for quantitative information on the use of exergy sources, also each sector of society may need to document their exergetic efficiency. Such documentation may not only be used to justify the needs of each sector, they may lead to stable long-term framework agreements. The more facts we have on exergy and its use, the more options we have to foster a development towards more environmentally-friendly technologies. To understand the optimal operation and the potential for improvements is crucial.

We propose that the Grassman diagram of 1995 for Norway should be updated to increase awareness of these matters. As we study the various needs for exergy, as illustrated in Fig. 1, we understand that an overall increase in exergetic efficiency must come, not just from one exergy source, but rather from all possible sources and uses. The future will see a variety of exergy sources, all tailored for special purposes and needs, and taking advantage of local conditions. The potential of ocean power in terms of salt power plants and tidal plants is not yet explored beyond the test stage (Veerman et al., 2009).

A knowledge-based development

The development described above is knowledge-dependent. It requires insight and competence on the highest level, to further develop the most sophisticated parts of our society. In this context, one might first ask: given that we already are so advanced, is there any room for improvement? We can answer this question in detail by studying the single process, but also in a broad manner by looking at the curve in Fig. 2 calculated by Beretta

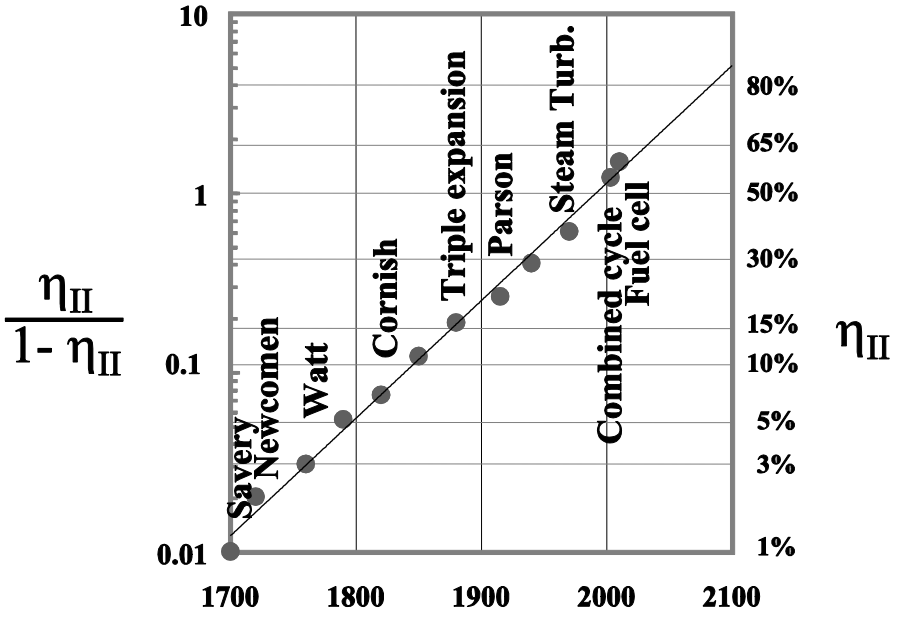

Fig. 2. *Development of the exergetic efficiency, η_{II}, over time according to Beretta (2007).*

(2007). The curve shows how exergetic efficiency has developed during the last 300 years. The first steam engines at the dawn of the Industrial Revolution were <1% efficient. Today's combined cycle plants reach 55% efficiency. The ratio between the efficiency over one minus the efficiency is plotted on a logarithmic scale. The linear variation in this ratio with time is typical of many learning processes.

The last point on the curve is, for the time being, the fuel cell. This cell is relevant for a replacement of the combustion engine in cars, to make the transport sector more energy efficient and environmentally friendly. Famous scientists have contributed to the field of thermodynamics, making this curve possible. Lars Onsager, a Nobel Prize winner of Norwegian descent, made his discovery of the rules of energy conversion in non-equilibrium thermodynamics in 1931. Improved design of fuel cells may benefit from his theory (Kjelstrup et al., 2010b).

What is particularly encouraging with the curve is that we have not reached its end point. A limit exists, as there is no process possible without some losses when the process must run in a finite time. Nevertheless, it seems that we can continue to work in this field and learn important new things for quite some time. New power generators can be more dedicated, smaller machines, of electrochemical or optical nature. The field of thermodynamics is now moving to be able to describe smaller and smaller systems on shorter and shorter time-scales. The laws for energy conversion under such conditions are not yet formulated. It is believed that such knowledge can contribute to the variety and specificity that is needed for all the power producing and consuming units that the future will need. The number of PhDs trained at Norwegian universities is not excessive in this context, rather the contrary. In order to foster development of a multitude of solutions, universities should have an increase in their allotment of PhD positions, to be competed for by the many motivated candidates who want to contribute to this development.

Conclusions and perspectives

We have argued above that the Grassman diagram illustrating exergy

consumption in the Norwegian society should be updated, on the national scale, and on smaller scales, for each sector involved. By making maps for the unit or plant level, one can foster a development towards technologies with higher efficiencies, by increased awareness of the single technology and by transfer of knowledge between similar activities and plants.

An exergy map for the Norwegian society can be used to indicate targets for research where a relatively large potential for improvements exists, like for instance the domestic sector. Several definitions of the concept "energy efficiency" exist. We have recommended to use more systematically the exergetic efficiency. Discussions referring to these efficiencies will be more informed, and help politicians and others to make difficult trade-offs. We have given two examples from central Norwegian activities to illustrate possibilities.

To foster the development of a multitude of solutions to increase the resource efficiency in the society at large, the universities should be given an increase in PhD positions, for research groups to pursue their ideas with young investigators. A multitude of solutions must be sought.

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