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874

NINA Report

Renewable energy respecting nature

A synthesis of knowledge on environmental impacts of renewable energy financed by the Research Council of Norway

Roel May
Kjetil Bevanger
Jiska van Dijk
Zlatko Petrin
Hege Brende

Norwegian Institute for Nature Research

Cooperation and expertise for a sustainable future

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874

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CONTACT DETAILS

NINA head office
Postboks 5685 Sluppen
NO-7485 Trondheim
Norway
Phone: +47 73 80 14 00
Fax: +47 73 80 14 01

NINA Oslo
Gaustadalléen 21
NO-0349 Oslo
Norway
Phone: +47 73 80 14 00
Fax: +47 73 80 14 01

NINA Tromsø
Framsenteret
NO-9296 Tromsø
Norway
Phone: +47 77 75 04 00
Fax: +47 77 75 04 01

NINA Lillehammer
Fakkelgården
NO-2624 Lillehammer
Norway
Phone: +47 73 80 14 00
Fax: +47 61 22 22 15

www.nina.no

Executive summary

May, R., Bevanger, K., van Dijk, J., Petrin, Z., & Brende, H. 2012. Renewable energy respecting nature. A synthesis of knowledge on environmental impacts of renewable energy financed by the Research Council of Norway. – NINA Report 874. 53 pp.

Renewable energy production is seen as a key factor for reduction of climate emissions; however further development of landscapes and seascapes may impact the environment on top of existing pressures. Norway has committed to reduce emissions, and major efforts are put into technological and environmental research to provide knowledge and solutions to meet these challenges. This report synthesizes the knowledge on environmental impacts of renewable energy acquired through the EFFEN, EFFEKT and RENERGI programmes run by the Research Council of Norway; especially from the Centre for Environmental Design of Renewable Energy (CEDREN), as one of the centres for environmental-friendly energy research (CEER).

Due to extensive water resources Norway was among the first countries to base its energy system on hydropower; already from the late 19th century. Today, approximately 62% of Norway's energy supply comes from hydropower. Norway has ratified EU's Renewables Directive and committed to a target of generating 67.5% from renewable sources. Because the majority of the large river systems were already regulated in the 1960s, wind power is expected to grow extensively to reach this target. With the current development of onshore and offshore wind power and the extension of associated power transmission, environmental considerations will evolve rapidly.

Research on environmental impacts of hydropower production prioritized the Atlantic salmon for many years, also due to its value for recreation and tourism. Currently Norway is at the very front of generating knowledge on salmon, empirical studies and development of mitigation measures. Research on hydropower production in regulated rivers has revealed major bottlenecks for salmon production and survival, with varying impacts at different life stages. Research results from EnviDORR and EnviPEAK have provided solutions to ensure production of salmon despite hydropower development. This shows the possibility of reconciling societal and ecological interests, ensuring both socio-economic interests and ecological considerations.

Research on environmental impacts of onshore wind power focused on the Smøla wind-power plant in Central Norway, which has received much attention regarding the extent of the conflicts especially with white-tailed eagles and the scope of consequent research (BirdWind). Although the white-tailed eagle population is stable, collisions with wind turbines account for more than half of detectable adult mortality. Much important knowledge was gained by utilising an advanced mix of methods and tools such as fatality searches using dogs, mobile avian radar, GPS telemetry and GIS modelling. The research has led to substantial advances for future development of mitigation measures; including micro-siting of turbines, bird-friendly turbine designs and real-time bird collision risk forewarning.

CEDREN investigates both socio-economic impacts (SusGrid) and ecological impacts (OPTIPOL) of overhead power-lines. These may pose a potential risk to birds both through collisions and electrocution, which are highly site-, seasonal- and species-specific. Conversely, electrocution of birds represents an outage risk for the operator. Understanding landscape and design features related to these risks are important for new expansions and retrofitting solutions. Effects on ungulates and game birds related to power-line corridors are important; consequently also for outdoor activities including hunting. To take into account various stakeholders' perspectives, OPTIPOL has developed a least-cost-path analysis-tool to aid complex decision-making in routing of power lines.

The ambition of the RENERGI programme to provide applicable knowledge and solutions for industry and policy-makers has so far increased the knowledge base on the impacts from renewable energy production. This has resulted in method development, disposed of existing misconceptions, and specific solutions for implementation and commercialisation. In EnviDORR ecologists, hydrologists, engineers, industry and management joined forces to find solutions for both salmon population and hydropower production. Novel modelling tools demonstrate that adaptive hydropower operation secures habitat conditions and salmon survival. To prevent turbine-induced mortality in juvenile fish, a solution with strobe lights and optimal diversion of water in the bypass section was developed. BirdWind has mastered using avian radar technology, including supporting database analysis tools, to monitoring bird movement patterns in space and time. A GIS-based micro-siting tool was developed for turbine placement that considers terrain properties that enhance collision risk. OPTIPOL has procured knowledge for environmentally-friendly design solutions. To mitigate eagle owl electrocution, an innovative elevated perch structure was designed which is adopted by the industry. The RENERGI programme and CEDREN are on-going and planned for continuation; provision of the innovation potential and implementation for the industry is still on the way. Still, the cross-disciplinary collaboration of research institutions, industry and public funding spurs innovation in the development of renewable energy production.

So far, research has shed important light on the ecological challenges of renewable energy production. However, future development of renewable energy production will increase the pressure on natural resources and the convergence of societal needs, climate goals and biodiversity preservation demands new methods and integrated decision support. Overall spatial planning can here contribute to improved legitimacy and acceptance for balancing ambitious renewable energy targets and biodiversity conservation. Sustainable management of natural resources require research to follow the cross-disciplinary approach of CEDREN to aid sound strategic decisions for planning and development of future energy systems beyond 2020.

<table>
<tr><th>Regulated ecosystems (EnviPEAK)</th><th>Where eagles dare (BirdWind)</th></tr>
<tr><td>New operation regimes, increased flexibility and so-called “hydro-peaking” of Norwegian hydropower plants causes frequent and rapid changes in water levels in rivers, lakes and fjords. This may change the living conditions for ecosystem components in regulated rivers, including hydrology and icing, invertebrates and fish, birds and mammals.</td><td>To aid authorities and industry to plan, construct and operate onshore wind-power plants, new knowledge and tools to minimize impacts on birds is required. Conflicts with white-tailed eagles has provided insight into flight behaviour, collision risk and population dynamics. Appropriate technological and methodological tools for studying avian-turbine interactions have been further developed, such as GPS-telemetry, DNA monitoring and GIS modelling and mobile avian radar.</td></tr>
<tr><td></td><td></td></tr>
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Roel May, Kjetil Bevanger, Jiska van Dijk, Zlatko Petrin, Hege Brende, Norwegian Institute for Nature Research, P.O. Box 5685 Sluppen, NO-7485 Trondheim, Norway, roel.may@nina.no

Sammendrag

May, R., Bevanger, K., van Dijk, J., Petrin, Z. & Brende, H. 2012. Renewable energy respecting nature. A synthesis of knowledge on environmental impacts of renewable energy financed by the Research Council of Norway. – NINA Rapport 874. 53 s.

Fornybar energiproduksjon er betraktet som en sentral faktor for reduksjon av klimautslipp. Men videre utbygging av landskap og havområder vil gi ytterligere miljømessige og samfunnsmessige virkninger ut over det vi ser i dag. Norge har forpliktet seg til å redusere utslippene, og en stor innsats er igangsatt innenfor teknologisk og miljøbasert forskning for å gi mer kunnskap og nye løsninger for å møte disse utfordringene. Denne rapporten syntetiserer kunnskapen om miljøeffekter av fornybar energi ervervet gjennom EFFEN, EFFEKT og RENERGI i regi av Norges forskningsråd, med spesielt fokus på CEDREN, som ett av sentre for miljøvennlig energiforskning (FME).

Norge har tilgang til omfattende vannressurser, og på slutten av 1800 tallet var Norge et av de første landene til å basere energisystemet på elektrisk vannkraftproduksjon. I dag kommer nesten 99 % av Norges elektrisitetsforsyning fra vannkraft. Norge har ratifisert EUs fornybardirektiv og forpliktet seg til målet om å generere 67,5 % av sin energiproduksjon fra fornybare kilder. Selv om de fleste av de store vassdragene allerede er regulert er det forventet at vindkraft må vokse mye for å nå dette målet. Med dagens utbygging av land- og havbasert vindkraft, samt utvidelse av tilhørende kraftoverføringslinjer, vil krav og hensyn til miljø komme på agendaen med behov for ny kunnskap og nye verktøy og løsninger.

Forskning på miljøeffekter av vannkraftproduksjon har i stor grad vært fokusert på villaks, ikke minst på grunn av sin verdi for rekreasjon og turisme. Foreløpig er Norge helt i front med grunnleggende kunnskap, empiriske studier og utvikling av tiltak fro å ivareta laksehabitat og -bestander. Forskning på vannkraftproduksjon i lakseførende regulerte vassdrag har avdekket store flaskehalser for utvikling og overlevelse, med en rekke effekter på ulike livsstadier for fisken. I prosjektene EnviDORR og EnviPEAK er det utviklet forskningsbaserte løsninger som sikrer produksjonen av laks til tross vannkraftutbygging. Dette viser at man kan komme frem til nye løsninger som forener både økonomiske interesser og økologiske hensyn, til felles samfunnsmessig nytte.

Forskning på miljøeffekter av landbasert vindkraft er tilknyttet Smøla vindkraftverk i Midt-Norge, og har fått mye oppmerksomhet om omfanget av konfliktene – særlig havørn – og omfanget av påfølgende forskningen (BirdWind). Selv om havørnbestanden er stabil, utgjør kollisjoner med vindturbiner mer enn halvparten av påviselig voksendødelighet. Mye viktig kunnskap er oppnådd gjennom å anvende en avansert sammensetning av metoder og verktøy, herunder søk etter kollisjonsofre ved hjelp av hunder, mobil fugleradar, GPS telemetri og GIS modellering. Forskningen har ført til betydelige fremskritt for kommende utvikling av spesifikke tiltak, som mikro-lokalisering av turbiner, fuglevennlig turbindesign og real-time forvarsel for fuglekollisjonsrisiko.

I CEDREN undersøkes både sosioøkonomiske virkninger (SusGrid) og økologiske påvirkninger (OPTIPOL) av kraftledninger. Disse utgjør en potensiell risiko for fugler både gjennom kollisjoner og elektrokusjon, som igjen er svært steds-, sesongs- og artsspesifikk. For nettoperatøren representerer elektrokusjon av fugler en risiko for strømbrudd. Å forstå hvordan landskaps- og designmessige egenskaper på kraftlinjene innvirker på disse risikoene er sentralt for nye utbygginger og avbøtende tiltak. Effekter av kraftgater på hjortevilt og fuglevilt er også viktig å forstå, blant annet med hensyn til aktiviteter som jakt. For å ta hensyn til ulike interessentenes perspektiver, har OPTIPOL utviklet et “least-cost-path” analyseverktøy for å hjelpe komplekse beslutninger i trasévalg av kraftledninger.

Ambisjonen av RENERGI for å gi anvendbar kunnskap og løsninger for industri og politikere har så langt økt kunnskapsgrunnlaget om miljøeffekter av fornybar energiproduksjon. Dette har resultert i ny metodeutvikling, kvittet seg med eksisterende misforståelser, og gitt spesifikke løsninger for implementering og kommersialisering. I EnviDORR har økologer, hydrologer, ingeniører, industri og forvaltning slått seg sammen for å finne løsninger for både laksebestand og vannkraftproduksjon. Nye modelleringsverktøy viser at adaptiv vannkraftsdrift sikrer habitatforhold og lakseoverlevelse. For å hindre turbinindusert dødelighet av unglaks ble det utviklet en løsning med strobelys og optimal vannslipp forbi kraftverket. BirdWind har utnyttet fugleradarteknologi, inkludert databaserte analyseverktøy, til overvåking av fuglebevegelser i rom og tid. Det er utviklet et geografisk verktøy (GIS) for mikro-plassering av turbiner som tar hensyn til egenskaper i terrenget som øker kollisjonsfare. OPTIPOL har fremskaffet kunnskap for miljøvennlige designløsninger. For å forhindre elektrokusjon av hubro, ble en innovativ sittepinne utviklet som er allerede kommersialisert og anvendt av industrien. RENERGI-programmet og CEDREN er pågående og planlagt for videreført; fremskaffelsen av innovasjonspotensialet og implementeringen for næringen er dermed fortsatt underveis. Likevel fremmer tverrfaglig samarbeid mellom forskning, næringsliv og forvaltning innovativ og anvendbar miljødesign på fornybar energiproduksjon.

Så langt har forskningsinnsatsen kastet viktig lys over de miljømessige utfordringene av fornybar energiproduksjon. Imidlertid vil framtidig utbygging av fornybar energiproduksjon øke presset på naturressurser og arealer. Økt tilpasning til samfunnets energibehov, klimamål og bevaring av biologisk mangfold vil kreve ny kunnskap for integrert beslutningsstøtte. Samlet system- og arealplanlegging vil kunne gi økt legitimitet og aksept for å balansere ambisiøse mål for fornybar energi med bevaring av biologisk mangfold. Fremtidig bærekraftig forvaltning av naturressursene krever forskning som følger den tverrfaglige tilnærmingen av CEDREN for å håndtere strategiske beslutninger for planlegging og utvikling av fremtidens energisystemer fram mot 2020.

Regulerte økosystemer (EnviPEAK)	Hvor ørnene våger (BirdWind)
Nye driftsmønster, økt fleksibilitet og såkalt "effektkjøring" av norske vannkraftverk fører til hyppigere og raskere vannføringsendringer i elver, innsjøer og fjorder. Dette kan endre levekårene for økosystem komponentene i regulerte elver, inkludert hydrologi og ising, virvelløse dyr og fisk, fugler og pattedyr.	For å hjelpe myndigheter og næringslivet til å planlegge, bygge og drive landbasert vindkraftverk, er ny kunnskap og verktøy for å minimere påvirkningen på fugler nødvendig. Konflikter med havørn har gitt innsikt i fluktatferd, kollisjonsrisiko og populasjons-dynamikk. Egnede teknologiske og metodiske verktøy for å studere fugl-turbin interaksjoner har blitt videreutviklet; som GPS-telemetri, DNA overvåking, GIS-modellering og mobil fugleradar.
	
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Roel May, Kjetil Bevanger, Jiska van Dijk, Zlatko Petrin, Hege Brende, Norsk institutt for naturforskning, Postboks 5685 Sluppen, 7485 Trondheim, roel.may@nina.no

Contents

Foreword

The problems caused by climate change and its environmental impacts are well known and recognised. Renewable energy production is seen as an important measure to reduce the adverse effects of climate change; however, further land-use and the development of the seascape may impact the environment on top of already existing pressures. Norway has committed to specific emission reduction goals, and major efforts are put into technological and environmental research in order to provide the necessary knowledge and solutions to meet these goals. A shift towards renewable energy production is identified as a key factor for emissions reduction. However, expansive development of renewable energy comes at an environmental cost.

In 2011 the Research Council of Norway announced with the conclusion of the RENERGI Programme they wished to synthesize long-term progresses in renewable energy research. This synthesis report aims to assess the importance of public R&D money in obtaining the present knowledge base on environmental impacts of renewable energy production. The report synthesizes the knowledge on environmental impacts of renewable energy acquired through the EFFEN, EFFEKT and RENERGI programmes run by the Research Council of Norway. In addition it describes the historical development on how the R&D institutions have evolved and interacted with such research programs. We have also exemplified where and when new innovations have been adopted by the industry and feedback from the users on advantages by new methods and technologies. Within this scope the report focuses especially on the projects executed as part of the Centre for Environmental Design of Renewable Energy (CEDREN), one of eleven Centres for Environment-friendly Energy Research (CEER). CEDREN executes interdisciplinary technological, ecological and societal research on environmental impacts of renewable energy and develops environmental design-solutions to mitigate these impacts. The results from CEDREN contribute to a sustainable and optimal utilisation of renewable energy resources, with special regard to hydropower, onshore wind power and associated power transmission. The report structure and content is based on our interpretation of the Research Council of Norway wishes behind making these synthesis reports, and we want to thank Birgit Hernes at the Research Council of Norway for a constructive cooperation.

08.10.2012 Roel May

1 Balancing climate change, renewable energy and biodiversity

Global climate change is probably a major threat to human development and welfare in the coming decades. During the UN Climate Conferences in Copenhagen, Cancún and Durban in 2009 – 2011, a continuation of the Kyoto Protocol commitments was agreed upon by over 140 countries towards 2020. Norway has committed itself to reduce greenhouse gas emissions by 30% relative to the 1990-levels and become carbon neutral by 2050 (Meld.St. 21 (2011-2012)). The impact global climate change has on sustainable development (Millennium Ecosystem Assessment 2005) has been acknowledged, and pathways towards a green economy have been presented (UNEP 2011). The UN Convention on Climate Change and the IPCC scenarios (Pachauri & Reisinger 2007) have boosted the innovation, development and application of renewable energy sources worldwide, as more than 100 countries have adopted a global warming limit ≤ 2°C as a guiding principle for mitigation efforts to reduce the risks of climate change (UNFCCC 2010). The ambitious EU goals in the UN climate agreement indicate an increase of renewable energy production to 20% by 2020 (EU 2020 goals as spelled out in the Renewables Directive 2009/28/EC). To meet the climate challenges, by 2020 two thirds of all energy production in Norway must be renewable. Currently, circa 62% of all energy production, and nearly all electricity production, is from renewable sources (mainly hydropower). Although renewable energy production from water, wind and biomass will be needed to reach Norway's ambitious climate targets, we must at the same time realize that any development affects ecosystems and biodiversity through land use/seascape impacts.

All energy generation therefore has environmental costs; a challenge to be met by the Norwegian Government, as it has committed itself to the Convention on Biological Diversity goals (www.cbd.int). The main driver for biodiversity loss is anthropogenic habitat alterations, and all renewable energy systems imply land use change, affecting species through changes in habitat quality, fragmentation etc. The Convention on Migratory Species (Bonn Convention) has recognized that "*measures aimed at curbing climate change, such as renewable energy, biofuel production and geo-engineering, are thought to have the most immediate negative impacts on migratory species today compared to the direct impact of climate change*" (Resolution 10.19 on Migratory Species Conservation in the Light of Climate Change, COP10 2012). In addition, the Convention on the conservation of European wildlife and natural habitats (Bern Convention) is actively used to ensure protection of species and their habitats from untoward development, such as renewable energy. In addition, concern about the electrocution (and collision) hazard for birds has been raised by the Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention) (Resolution 7.4 – Electrocution of migratory birds) and the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention) (cf. Recommendation No. 110) (Bern Convention 2004). The environmental challenges tied to resident and migratory species and their habitats with regard to renewable energy development, stresses the need for increased knowledge not in the least to uphold the international responsibilities that Norway has (Bonn, Bern and OSPAR Conventions). The Norwegian climate policy is, among others, guided by sustainability, ecosystem thresholds and the precautionary approach (Meld.St. 21 (2011-2012); cf. Ot.prp. nr. 52 (2008-2009) *Naturmangfoldloven*). Here, lack of knowledge and scientific uncertainty should be credited to nature.

The EU Biodiversity Strategy 2020 indicates that conservation of biodiversity should be viewed in the context of both human use of nature (ecological footprint) and adaptation to climate change (ecosystem service). While maintenance of biodiversity is important in its own rights, ecosystems also provide services that sustain and fulfil human life (e.g. provision of biomass, wind and water resources for energy). Renewable energy systems may simultaneously affect other ecosystem services (e.g. food supply) (Tallis & Kareiva 2006). To make ecosystem services an integral part of key political decisions is increasingly important (Reid 2006; Ruhl et al. 2007). It is thereby clear that climate change and biodiversity are interconnected.

Biodiversity is affected by climate change and its mitigation measures, which may lead to negative consequences for human well-being. However, biodiversity, through the ecosystem services it supports, also makes an important contribution to both climate-change mitigation and adaptation (e.g. towards a green economy). Technology innovation (R&D), together with proactive efforts to mitigate and manage social and environmental concerns, is therefore crucial and is simultaneously expected to lead to incremental cost reductions for renewable energy (IPCC 2011). Appropriate planning and siting procedures can reduce the impact of renewable energy development on ecosystems and local communities, and techniques for assessing, minimizing and mitigating the remaining concerns could be further improved. As a follow-up of the political agreement on climate policy in 2008 (Klimaforliket) the Norwegian Government established two R&D fora; one for climate research (Klima21) and one specifically for the energy sector (Energi21). The latter forum has resulted in, among others, the establishment of eight Centres for Environment-friendly Energy Research (FME) and increased allocations to the Research Council's RENERGI-programme.

The EU's collective target of generating 20% of its energy from renewable sources by 2020 has brought forward plans for renewable energy (electricity) that project a doubling of the totally installed wind-energy and biomass capacities to 214GW and 44GW, respectively, and a total hydropower capacity of 140GW (Beurskens et al. 2011). In 2010, Norway had an installed capacity of 30GW hydropower and 435MW wind power (www.fornybar.no). The vision of the national R&D forum Energi21 is that Norway will be Europe's leading energy and environment-conscious nation – from a national energy balance to green energy exports – using its vast hydropower resources and extensive wind resources along the long Norwegian coast. However, maybe the greatest bottleneck to further development of renewable energy is power transmission. Rapid and large scale renewable-energy development challenges our ability to anticipate (and subsequently verify) the combined impacts of numerous power plants and their associated infrastructure (e.g. transmission lines) on nature and our own livelihood. In this context, decision-makers and industry require improved methods and tools for thorough (strategic) environmental impact assessments and standardized monitoring approaches to guide them in balancing ambitious renewable energy targets and biodiversity conservation. Biodiversity impacts from renewable-energy development are usually addressed in the permitting process through the "avoid - minimize – compensate" mitigation hierarchy (Langston & Pullan 2003). It also requires a thorough pre-construction spatial siting selection to avoid the most conflict-ridden areas, with respect to ecology, technology, economics, aesthetics and existing land use. Although renewable energy is essential for society it is important to understand the species-, site- and season-specific ecological impacts, and to identify technologies and methods to reduce (minimize) these impacts. Here, new approaches and technologies are essential to reduce environmental impacts and offer solutions ("eco-innovation") for future renewable energy development. It is important to emphasize that at the end of the mitigation hierarchy there will always remain a net-impact which may be offset through compensation activities.

These views indicate that renewable energy research is very much an emerging field, which requires interdisciplinary collaboration and integrated Research and Development (R&D) strategies. A long-term perspective here is essential. Regardless of technological, socio-economic and environmental challenges, there should be a balance in how we use ecosystem services irrespective of short-term profitability: biodiversity and resources as natural capital for the future.

2 Environmental considerations in renewable energy production

2.1 Historical development of renewable energy in Norway

Due to the extensive hydropower resources, Norway was among the first countries to transform it into electricity. Already in the late 19th century cities were lit by electricity from hydropower, and in 1920 65-70% of the Norwegian households had access to electricity based on hydropower. After World War II hydropower development boosted and electrochemical and electro-metallurgical industries together with aluminium production became an important part of the Norwegian industry and wealth creation for the country.

The second hydropower development period took place in 1960-1985 when several large hydropower plants were constructed. It was followed by increased focus on the environmental effects of the inundation of extensive land areas, tunnels, construction roads, rock deposits and dry riverbeds. An important issue then was the barrier effect of the hydropower reservoirs for migratory species like reindeer and salmon. Only later the range of possible negative impacts hydroelectric development may have on surrounding terrestrial and aquatic ecosystems were addressed, as further elaborated on in this report.

Today, Norway generates approximately 99% of its electricity mainly from hydropower (32.5 GW), representing approximately 62% of its total energy production (i.e. in addition to oil and gas). This sets the country in a special situation in the view of the climate change scenarios and the need for more energy without climate gas emission. Following the EU Renewable Directive (2009/28/EC) Norway has accepted that renewable energy will amount to 67.5% of our energy needs by 2020 (cf. Meld. St. 21 (2011-2012). However, already in the late 1990s the Norwegian Government decided that Norway should further increase its renewable energy production (St.meld.nr. 29 (1998-99)). As the majority of the large rivers were already developed, one of the remaining options was wind power. The first two wind-power plants in Norway became operational in 1998 (5.4 MW), and in 2005 the Smøla wind-power plant in Central Norway was finished being the largest in Norway so far with 68 turbines (150 MW). Today circa 20 wind-power plants are operational in Norway (512 MW) and more are expected to be developed in the near future.

2.2 Chronology of nature considerations in renewable energy development

2.2.1 Early environmental considerations (1900 – 1970)

Already in the late 1890s, the Norwegian Trekking Association (DNT) and the Norwegian Society for the Conservation of Nature (Naturvernforbundet) proposed protection for specific riverine systems from hydropower development and other encroachments (e.g. Berntsen 1977). In the 1920s a debate on the possibility to reverse a resolution on two protected objects (Skjeggedalsfossen and Tyssestrengene) became highly debated and ended in Parliament. The environmentalists lost and the case became a symbol for those claiming that there are values being more important than energy and economy and that hydropower development not should take place in favour of economic benefits. Even though in 1954 the Nature Conservation Act passed the Parliament – replacing the Nature Protection Act of 1910 – the majority of applications for hydropower development were still consented.

The environmental impacts of hydropower development were given minor attention until the 1960s, as hydropower development was regarded as the best way to secure economic growth and prosperity both by national as well as local politicians and authorities. Although the consenting authorities were obliged to weigh negative and positive impacts from the hydropower development against each other, there were very few examples where consents were rejected. Thus, it was not until the “hydropower era” was well beyond its peak that environmental impacts received attention; and then mainly concerning negative impacts to freshwater salmon fisheries.

During the 1960s several countries in Europe and other continents experienced a diversity of environmental problems arising from the rapid growth in industrial development. A special committee with responsibility for conservation issues in the European Council decided that 1970 should be a so-called European Conservation Year. Norwegian politicians were highly involved and dedicated to this idea and one of them, Olav Gjærevoll, stressed in his speech at the opening conference in Strasbourg that ecology should be given attention on an equal basis as technology and economy. The Nature Conservation Act of 1970 first stressed that “*intervention in nature should only be carried out from a long-term and comprehensive allocation of resources, taking into account the nature of the future preserved as a basis for human activity, health and well-being*”. In May 1972 the Norwegian Parliament decided that Norway should have a separate ministry for environmental issues, and Gjærevoll became the first Secretary of State for the Ministry of Environment (MD).

2.2.2 A turning point in environmental considerations (1970 – 1990)

The new and modern Nature Conservation Act which was adopted by the Parliament in 1970 stated among other things that nature encroachments only should take place based on long-term and comprehensive resource priorities emphasizing to keep the nature as a basis for future human activities, health and prosperity. The 1970s became a very important decennium for environmental issues; not only in Norway but Europe in general as many wake up calls were given by authors and movements like the Rome Club’s “The limits to growth”. The conflicts the increased hydropower development activities during the 1950s and 1960s had generated and the fact that each river system was handled separately by the consenting and political authorities became an import issue and the demand for a national framework plan became increasingly voiced.

In 1969 the so-called Sperstad Panel (Sperstadutvalget) was appointed; led by Hans P. Sperstad, the Director General of the Norwegian Water Resources and Energy Administration (NVE). The Panel was appointed by the Parliament with the authority to prepare a Protection Plan for Norwegian Watercourses (verneplan for vassdrag), i.e. rivers suggested to be protected against future hydropower development. Based on the assessments by the Sperstad Panel and by the Gabrielsen Committee (Gabrielsenkomiteen, 1960-63), the Norwegian Parliament adopted the first Protection Plan in 1973; protecting 95 watercourses together with 51 watercourses which were protected for 10 years. However, 35 watercourses were finally excluded of the protection plan. The Parliament decided at the same time that the work on protection plans should continue and that the Sperstad Panel should continue its work. This resulted in the adoption of the second Protection Plan in 1980 presenting a list on 51 more watercourses that should be protected, in addition to 11 that received temporary protection.

During the processes with the Protection Plans, discussion evolved on the necessity of a holistic evaluation of the conservation interests in each separate watercourse. Energy companies argued that the assessment of conservation values was the responsibility of the Ministry of Environment (MD), while the consenting application only required an environmental impact assessment (EIA). The role played by MD was seemingly inconsequent at the time. Baseline studies lacked consistency with regard to extent and methodology. Not until the 10-year protected watercourses became a focal issue, was formal cooperation among the different professional institutions established. This cooperation led to significant efforts being made to agree on standardized methods to be used in all watercourses (Gjessing 1980; NOU 1983: 42).

In 1974 NVE issued the *Guidelines Regarding Hydropower Development* ("Retningslinjer. Konsesjonssøknader vedr. vassdragsreguleringer. Rundskriv nr. 36"). These guidelines became important regarding the extent an EIA should have, and the topics to be included. Although the guidelines were not very specific, they opened up for a rather extensive baseline data collection in connection to a consent application and formed the legal basis for environmental issues like flora and fauna to be included. However, the interpretation of the extent of baseline data collection became a recurring question. An important conflicting issue has been that the consenting authorities not have been persistent with respect to new data collection, but accepted to take decisions based on existing knowledge and thus invited the developer not to spend money on too extensive and expensive EIAs. This is still common practise in Norway, nearly 40 years later.

The environmental status of the temporary protected watercourses became thoroughly evaluated in the period 1976-1982, comprising among others fisheries, wildlife, geology, outdoor and recreational interests and cultural interests. The data collected during these years still has relevance and no project in the following years have had the same extensive focus on baseline data collection. At the same time EIA baseline studies were carried out in several watercourses with mature hydropower developing plans such as Hellemo, Kobbelv and Eiteråga (e.g. Bevanger 1978, 1979, 1980). During the period 1976-1982 several conferences/symposia were arranged focusing on scientific assessments in connection to hydropower development, of which five have been made public through proceedings (Gjessing 1977; Gunnerød & Mellquist 1979; Gjessing 1980; Kjos-Hanssen et al. 1980; Brørby et al. 1982). Based on the evaluation of the temporary protected watercourses their conservation status was decided on in the third Protection Plan (St.prp. nr. 89 (1984-1985) "Verneplan for vassdrag 3") adopted in 1986 (NOU 1983: 41). A fourth Protection Plan was decided on by the Parliament in 1993, as well as a supplement to the Protection Plans in 2005. Now 375 watercourses are protected for hydropower development.

In 1982 the Ministry of Environment commissioned the development of a report assessing environmental issues in connection to hydropower development planning. This report should be part of the "Project on Environmental Impact Assessments" (cf. Halvorsen 1983, Faugli 1984), and aimed to contribute to a professional and administrative coordination and increased effectiveness on EIA (including pre- and post-construction studies) and a better professional evidence basis for consenting applicants and consultants to reduce the need for additional investigations.

2.2.3 Towards modern environmental considerations (1990 – 2012)

In 1993 the Master Plan on Watercourses (Samlet Plan for vassdrag; Miljøverndepartementet 1984) was finalized after three White Papers (St.meld.nr. 63 (1984-85), St.meld.nr. 53 (1986-87) and St.meld.nr. 60 (1991-92)). This was a comprehensive national framework plan regarding the management of rivers worked out by the Ministry of Environment together with the Ministry of Oil and Energy, NVE and other authorities. The documentation of the scientific and conservation importance was, however, a very heterogeneous chapter, and was partly highly insufficient for several watercourses. However, the intention of the Master Plan was not to replace the consenting process, and the decision on a possible development of a river should still take place in accordance with current routines (Miljøverndepartementet 1984).

In 1991 the Energy Act came into force and provides the current framework for the organization of electricity supply in Norway. It contains an aggregate of guidelines previously spread over a large number of laws. The law provides guidelines concerning among others energy-related construction licenses. In 2001 the Water Resources Act replaced the former Water Resources Act of 1940. The Act aims to ensure a socially responsible use and management of water bodies and groundwater. It contains guidelines on, among other things, consenting practice, protected watercourses, preventing and compensation for damages, groundwater, and other sanctions and transitional provisions. The Watercourse Act (1917) is a side-law to the Water Resources Act and applies to all watercourses which purpose it is to change the watercourse flow. These Acts are still in place today.

In 2005 the *Regulation on Environmental Impact Assessment* (Forskrift om konsekvensutredninger) was adopted by the Parliament. The regulation was revised in connection to the adoption of the revised Planning and Building Act in 2009. The regulation specifies and complements the provisions on environmental impact assessments (EIA) of the Planning and Building Act. The purpose of which was to ensure that the environment and society were taken into account during the preparation of plans or actions, and when deciding whether and on what terms, plans or measures can be implemented. The Planning and Building Act (Plan- og bygningsloven) contains regulations for land use planning in Norway and is therefore central to environmental management. Although laws on building issues have existed since 1274, it wasn't until 1986 that the first Planning and Building Act was adopted which set more focus on the planning processes. The aim of this Act is to promote sustainable development for the benefit of the individual, society and future generations. It has today become a powerful tool, together with the Nature Diversity Act (Naturmangfoldloven) to ensure sustainable development. In 2009 the Nature Diversity Act replaced the Nature Conservation Act from 1970, and parts of the Wildlife Act and Salmon and Freshwater fish Act. Contrary to the previous acts, the Nature Diversity Act encompasses both conservation and sustainable use of nature. The Act has therefore a much wider scope than before, including among others recognizing the intrinsic value of nature and a binding duty to assess mitigation measures when nature is affected. The Act adopts three key principles as guidelines for management of biodiversity: the precautionary principle, the user-pays principle and the principle that any pressure on an ecosystem shall be assessed on the basis of the cumulative environmental effects on the ecosystem, now or in the future. The Act is now the most central tool for nature management, enabling also the conservation of unprotected natural values. Most of these, and other, laws have been worked out in specific regulations. Among the regulations relevant for the development of renewable energy tied to other laws is the *Regulation on Physical Interventions in Watercourses* (Forskrift om fysiske tiltak i vassdrag) from 2004. This regulation falls under the Salmon and Inland Fish Act from 1993 (Lakse- og innlandsfiskeloven; revised in 2009). Small interventions that do not require licensing by e.g. the Water Resources Act, may still need permission through this regulation. This may affect revisions of existing licenses and concessions of new small-scale hydropower development (<10MW). The EU Water Framework Directive (see next paragraph) was transposed into the Norwegian *Regulation on a Framework for Water Management* (Vannforskriften) in 2007. This regulation has a legal base in the Planning and Building Act, the Water Resources Act and the Pollution Control Act. The regulation follows the Water Framework Directive, and aims to (1) provide a framework for setting environmental objectives that ensure integrated protection and sustainable use of the water bodies, and (2) ensure the preparation and adoption of River Basin Management Plans with corresponding Programs of Measures, aiming at reaching the environmental objectives, and ensuring that the necessary knowledge base is provided. This regulation will affect future revisions of existing licences and new concessions, as it requires "good potential" environmental targets adapted to the societal benefits of renewable energy production. Appendix 1 gives the existing relevant legislations in chronological order in which they came into force. Figure 1 visualizes the timeline in the adoption of national and international regulations with respect to the development in hydropower and wind power in Norway.

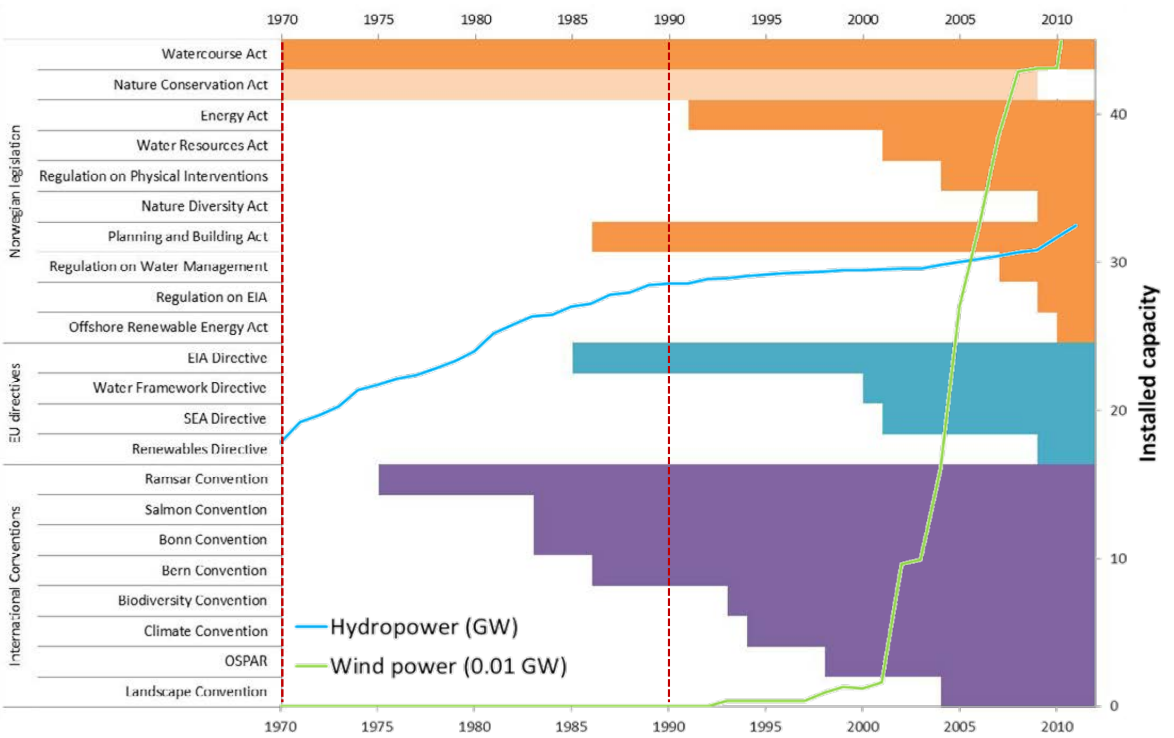

Figure 1. *Timeline of national and international regulations with regard to renewable energy and biodiversity. The red dotted lines indicate an époque change (see § 2.2). The blue and green lines indicate the development in installed capacity for hydropower and wind power, respectively (source: NVE/SSB).*

Norway has, partially through the European Economic Area Agreement, ratified several EU directives relevant to renewable energy (Fig. 1; Appendix 2). The two most important directives are the Renewables Directive (2009/28/EC) and the Water Framework Directive (2000/60/EC). The Renewables Directives aims at promoting the development of renewable energy – 20% the total energy production in the EU by 2020 – to meet the climate challenges. The Water Framework Directive is one of the EU's most comprehensive, cross-sectorial and ambitious environmental directives. Its main purpose is to ensure the protection and sustainable use of the water environment, and if necessary, initiate preventive or improving environmental measures to ensure environmental conditions in freshwater, groundwater and coastal waters. The Water Framework Directive was transposed into the Norwegian *Regulation on a Framework for Water Management* (Vannforskriften) in 2007. Norway also ratified the Impact Assessment Directive (97/11/EC) and the Strategic Impact Assessment Directive (2001/42/EC). These have been incorporated in Norwegian legislation including the requirement for environmental impact assessments of plans and the establishment of thematic county plans such as for small hydropower and wind-power plants (May 2011). Two important directives for the protection of nature – the Habitats Directive (92/43/EEC) and the Birds Directive (2009/147/EC) – are however not ratified by Norway. In addition, international conventions and agreements with direct relevance to renewable energy and biodiversity in Norway are the Bern, Bonn and OSPAR Conventions (Fig. 1; Appendix 3). Both the Bern and Bonn Convention have established specific recommendations regarding impacts of renewable energy on biodiversity in several resolutions (see also § 1.1). The OSPAR Commission has prepared specific guidelines on environmental considerations for offshore wind-power plant development (OSPAR Commission 2008c). Also, they have reviewed the environmental impacts of offshore wind-energy (OSPAR Commission 2004, 2006b, 2008a) and other offshore renewable-energy development (OSPAR Commission 2006a), including associated cables (OSPAR Commission 2008b). Other agreements that may in some cases set limits to the development of renewable energy through habitat protection are the Ramsar, NASCO and Landscape Conventions (see Appendix 3).

In order to streamline the consenting practice, including pre-construction EIAs and post-construction environmental monitoring, various guidelines and instructions have been developed by the Norwegian Water Resources and Energy Directorate (NVE) and the Norwegian Directorate for Nature management (DN) with regard to small-scale hydropower development (Norconsult & NVE 2003 (revised in 2010), Brodtkorb & Selboe 2004 (revised in 2007 and 2009); Hamarsland 2005; OED 2007). Especially two of them set clear requirements for the extent and standardization of environmental themes pre- and post-construction: *Mapping and documentation of biological diversity with regard to hydropower development (1-10 MW)* (Korbøl et al. 2009) and *Guidelines environmental supervision at hydropower plants* (Hamarsland 2005). For larger scale hydropower development a separate instruction has been developed (Jensen et al. 2010; revision from 1998).

Until the 1990s utilization of renewable resources only concerned hydropower. However, from the late 1990s onwards the extensive wind resources began to be developed. In the White Paper on Energy Policy (St.meld.nr. 29 (1998-99)) set a goal to build wind-power plants which produce 3 TWh annually by 2010. This has stimulated the development of wind-power plants since. In order to ensure that wind-power plant development occurs after holistic and long-term assessments to minimize (piecemeal) conflicts with other considerations, two documents have been developed to aid the consenting process. The *Directive for planning and placement of wind-power plants* (MD & OED 2007) defines important environmental and societal considerations to take into account. To discourage piecemeal development the Directive proposed the preparation of regional plans for wind power (i.e. Fylkesdelplan for vindkraft). The Ministry of Environment and the Ministry of Petroleum and Energy produced guidelines to aid County administration to prepare these regional plans (MD & OED 2007). In 2002 Norway was reported to the Bern Convention by BirdLife International on behalf of the Norwegian Ornithological Association (NOF) for the mortality of white-tailed eagle at the Smøla wind-power plant. This resulted in recommendations for improved EIA procedures and the demand for a strategic environmental assessment (SEA) nationally. As a result of these recommendations, the regional plans were evaluated to see whether they jointly could function as a SEA for onshore wind-power development in Norway (May 2011). In the meantime, the Norwegian Directorate for Nature Management had – given the rapid development of wind power in Norway – become apprehensive for the potential cumulative environmental impacts of multiple wind-power plants, both onshore and offshore. To be able to assess cumulative impacts in the future they promoted standardization among pre-construction studies, foremost on birds (May et al. 2010).

While debating the White Paper on Norwegian Climate Policy (St.meld.nr. 34 (2006-2007)) the government and a majority of Parliament agreed to prepare a national strategy for electricity production from offshore wind power and other marine renewable sources. This resulted in the Offshore Renewable Energy Act (Ot.prp.nr. 107 (2008-2009)) adopted in 2010 (Prop. 8 L (2009-2010)). Consequently, the Norwegian water Resources and Energy Directorate, together with the Norwegian Directorate for Nature Management, the Directorate of Fisheries, the Norwegian Coastal Administration and the Norwegian Petroleum Directorate started a strategic environmental assessment (SEA) to assess possible areas suitable for the development of offshore wind power (Drivenes et al. 2010). Within this SEA, which is still on-going, all possible considerations are assessed thoroughly. The Directorate group actively involved the Centres for Environment-friendly Energy Research focusing on wind power (i.e. CEDREN, NORCOWE and NOWITECH).

Although not a renewable resource by themselves, power transmission is inextricably connected to the development of renewables. Already as part of the White Paper on Energy Policy (St.meld.nr. 29 (1998-1999)), the Parliament recognized that a well-dimensioned transmission grid would be required to meet the ambitious goals for increased electricity production from renewables. In the White Papers *Relating to Amendments to the Energy Act* (Ot.prp.nr. 62 (2008-2009)) and *We build Norway – on Development of the Electricity*

Transmission Grid (Nettmeldingen; Meld.St. 14 (2011-2012)) extensive expansions of the central transmission grid are proposed to be able to secure power supply and to support the expected development of especially renewables in the future. To aid concession applicants the Norwegian Water Resources and Energy Directorate has prepared guidelines clarifying the requirements for construction licenses. While a description of expected consequences for the environment suffices for transmission of electricity under 22kV within a limited area (NVE 2008), for higher voltages each transmission route requires a separate EIA (NVE 2011). Still, the construction of transmission lines is exempt of the Planning- and Building Act.

To stimulate the development of renewable energy further the Act on Electricity Certificates was adopted by the Parliament in 2011. This agreement enables trade in renewable electricity certificates in Norway and Sweden – which already had this arrangement since 2003 – to increase the profitability of renewable energy by subsidizing its development.

2.3 Environmental impact assessment and research bodies

In 1972 the Hydropower Development Team (Reguleringsutvalget) at the Directorate for Wildlife and Freshwater Fisheries (DVF) (the present Norwegian Directorate for Nature Management (DN)) was established at the initiative of the Norwegian Hydropower Developers Union (Reguleringsforeningens Landssammenslutning). The Hydropower Development Team undertook pre-construction studies on wildlife – at first mainly game species – and freshwater fisheries in connection to various hydropower development plans (Kjos-Hanssen 1975, 1976; Aabakken & Myrberget 1975; Gravem et al. 1976; Pedersen 1976). The Norwegian Hydropower Developers Union also established the Laboratories for Freshwater Ecology and Inland Fisheries (Laboratoriene for ferskvannsøkologi og innlandsfisk (LFI)) connected to the zoological museums in Trondheim, Oslo and Bergen; institutions that are still operational today. In the 1980s the Hydropower Development Team also took responsibility for all EIA wildlife baseline studies (Tømmeraas & Barikmo 1983; Tømmeraas 1984; Reitan & Jordhøy 1985). This implied a new tradition where the management authorities took responsibility for investigations earlier handled by the universities.

The use of private consultants by NVE and MD in the early 1970s led in some cases to decreased confidence in EIA quality, and the question of what a professional reasonable level should be became an important topic. Moreover, several energy companies hired consultants known to make less critical conclusions than the universities and the independent research institutions. An important event from an ecological point of view was the establishment of the National Contact Forum (Nasjonale Kontaktutvalg) in 1976 (Faugli 1984) as it improved the methodological consistency and scientific scope of EIAs. The National Contact Forum – connected to the universities – became responsible for the professional, multidisciplinary scientific evaluations following the consenting application, and became an advisory body for NVE. In 1985 the duties handled by the National Contact Forum were further secured through the research programme Vassdragsforsk when the Ministry of Environment, the Ministry of Culture and Science and the Ministry of Oil and Energy signed an agreement with the Research Council for Science and the Humanities.

In the late 1960s and early 1970s it became increasingly common that universities undertook multidisciplinary pre-construction studies for hydropower consenting applicants (e.g. Moksnes 1973, 1980). Especially at the Natural History Museums (DKNVS) such commissioned research connected to hydropower development plans advanced rapidly, and included botany, ornithology, small game, freshwater biology, recipient and freshwater fisheries.

In the late 1970s and early 1980s the Parliament decided to separate research and management activities, and a more centralized managed system taking care of commissioned research. In 1984 this stemmed in the founding of Økoforsk, as an unspecified research program for applied ecology established by the Research Council for Science and the

Humanities; from 1986 Vassdragsforsk was incorporated into Økoforsk. Økoforsk had several projects connected to hydropower development and published several reports highly relevant for the management authorities (e.g. Andersen & Fremstad 1986, Bevanger & Thingstgad 1986, 1988, Geelmuyden & Berg 1986, Moen 1986, Nøst et al. 1986, Bevanger 1988c, Hvoslef 1988, Melby 1988). In 1986 the Norwegian Institute for Water Research (NIVA), established in 1958 under the Norwegian Research Council for Scientific and Technical Research, was reformed into an independent foundation.

After extensive discussion the Parliament decided that the Norwegian Institute for Nature Research (NINA) should be established as an independent foundation in 1988 (Gunnerød 1999); encompassing the Hydropower Development Team, the Fisheries and Wildlife Research Divisions in DN and Økoforsk. NINA became a national institution for applied ecology research with a staff covering a broad spectrum within natural science able to serve the environmental and other authorities with data and facts necessary to take knowledge-based management decisions. During the nearly 25 years since it was established, NINA has carried out numerous EIAs in connection to hydropower development projects, and from the end of the 1990s also wind power projects. However, the important difference compared to the pre-NINA period has been that NINA has had the opportunity, partly due to the funding of Strategic Institute Programs from the Research Council of Norway (Norges Forskningsråd (NFR)), to carry out basic research on different aspects of the impacts generation of renewable energy inevitably causes. This, combined with funding from several relevant NFR Programs, NINA has had the opportunity to focus how to mitigate problems created by energy generation, and to find solutions to minimize the negative impacts.

In 1988 an international evaluation committee found that research on terrestrial ecology and systematics in Norway was largely lacking. This and other weaknesses identified by several evaluation panels scrutinizing the development of Norwegian research, resulted in debates at the end of the 1980s and early 1990s how Norway should organize its future research (e.g. NOU 1991: 24 Organisering for helhet og mangfold i norsk forskning). One of the outcomes of this debate was the establishment of the Research Council of Norway in 1993 (St.meld. nr. 43 (1991-1992). This has been characterized as the most important research-political event during the 1990s (St.meld nr. 39 (1998-1999)). Earlier Norway had four research councils – NAVF (the Research Council for Science and the Humanities), NTNF (the Norwegian Research Council for Scientific and Technical Research), NLVF (the Norwegian Agricultural Research Council) and NFFR (the Norwegian Research Council for Fisheries). Since its foundation NFR has launched several research programs focusing environmental impacts of energy generation (e.g. EFFEN, EFFEKT, RENERGI), of which one of the most important decisions probably was de establishment of eleven research centres for renewable energy (CEER) in 2009. Some of the most important lessons learned from nearly 50 years of research connected to renewable energy generation are that to take the knowledge a significant step forward the work has to be carried out within extensive, multidisciplinary research teams, such as the CEERs.

3 Environmental impacts of renewable energy

3.1 Impacts of renewable energy on biodiversity

The environmental impacts of renewable energy encompass both direct effects through mortality or behavioural changes and indirect effects through changes in area use and effects on demography (Langston & Pullan 2003; Ugedal et al. 2008). Mortality can take different forms; including collisions with wind turbines (Drewitt & Langston 2008) and overhead wires (Bevanger 1994b,1998), injury and mortality to species that pass through hydroelectric turbines (Cada 1990, 2001), electrocution at transmission pylons (Bevanger 1994b,1998) and barotrauma of bats near wind-turbine rotor blades (Baerwald et al. 2008). Behavioural responses such as avoidance can occur as a result of general scepticism to the structures or due to altered hydrological conditions (Kraabøl et al. 2008), but also due to e.g. noise (Tougaard et al. 2009) and electro-magnetic fields (Gill et al. 2005). Indirect effects may include loss and degradation of habitat in the built-up area, clear-cut corridors and regulated river sections (Englund & Malmqvist 1996; Johnsen et al. 2011); barrier effects and fragmentation of wind-power plants, power-line rights-of-way and hydropower plants for migrating and non-migrating species (Nilsson et al. 2005; Kraabøl et al. 2009); displacement from the impacted areas (e.g. Garvin et al. 2011). These indirect effects may in turn lead to reduced reproductive success (e.g. Dahl et al. 2012) and reduced survival (Finstad et al. 2009).

However, not in all cases will negative environmental impacts occur. Species-specific responses may vary not only in time – be that daily, seasonal or among years – impacts are also very much site-specific (Tougaard et al. 2009; Finstad et al. 2009). Whether renewable energy structures will have an impact may depend, among others, on the surroundings within which it is placed. For example, harbour porpoises (*Phocoena phocoena*) avoided Nysted offshore wind-power plant (Tougaard et al. 2009), seemed indifferent to Horns Rev offshore wind-power plant during operation (only avoidance during pile driving; Tougaard et al. 2009), and were attracted to OWEZ offshore wind-power plant (Lindeboom et al. 2011). As can be perceived from the last example, when the situation is right also positive environmental impacts may occur. At OWEZ, the wind-power plant actually functioned as a refugium to the harbour porpoises from heavy fishing and boating activities (e.g. marine-protected areas). The construction of renewable energy structures may lead to changes to the local habitat and changes in the species communities, thus creating novel ecosystems. Novel ecosystems, such as artificial reefs and fish aggregation devices (FAD), may develop through the introduction of new hard substratum of e.g. monopiles and scouring protection in offshore wind-power plants (e.g. Wilhelmsson et al. 2006; Inger et al. 2009; Lindeboom et al. 2011). Also, changes in the hydrodynamic conditions (e.g. upwelling, water flows, temperature) may affect local communities (Wilson & Elliot 2009). While birds are generally seen as being vulnerable to renewable energy development, some species may benefit from the presence of wind turbines or transmission pylons as resting posts, and the utilizing the wind-power plant area or rights-of-way corridor as feeding habitat (Takatsuki 1992; Drewitt & Langston 2006). Although short-term flow regulation generally adversely affects benthic macro-invertebrate and riparian communities (van Looy et al. 2007; Marty et al. 2009), some organisms may in fact benefit. For instance, short-term flow regulation has been shown to benefit larval blackflies due to the exclusion of invertebrate predators (Meissner et al. 2002). Increased production of biting midges including blackflies may not be perceived as positive by most citizens. However, the consequences of increased production of blackfly larvae for water filtration and hence the ecosystem's water cleansing capacity has not been examined and may, or may not, entail positive surprises also from a societal perspective. However, increased production of salmonid fish often is perceived as positive. Even if river regulation generally adversely affects fish production (Johnsen et al. 2011), higher winter flows and increased phosphorous concentrations at Orkla have been shown to increase the production of juvenile salmon (Hvidsten et al. 2004). Yet, the consequences of enhanced fish production for water cleansing and other ecosystem-level ecological processes have not been examined yet. Above examples suggest that the ecological effects of the development of renewable energy sources may be fairly complex with some ecosystem components benefiting and others being adversely affected. The ultimate consequences for society are hence difficult to predict.

Environmental impacts may also have an economic component. The project "*Miljøkostnader av vindkraft i Norge*" financed through the RENERGI programme (2001-2004) found that people are more willing to pay for environmentally-friendly renewable energy (Navrud 2007). Transmission lines may have an ecological impact on birds through collisions and electrocution; whereby the latter may e.g. result in power outages and thus also have an economic impact (cf. review in Bevanger 1994b). Power-line corridors (rights-of-way), which constitute an economic problem tying up huge land areas e.g. for the forestry sector, may at the same time constitute habitat which could benefit some species (e.g. browsing habitat for ungulates, hunting habitat for edge-tolerant carnivores) where others may suffer (barrier for e.g. forest-dwelling species) (Nellemann et al. 2003; Frid & Dill 2002). In addition to the link between impacts and economic costs; environmental impacts may also be used to channel opposition and concern to developments (e.g. Solli 2010). The projects "*Not in my nature? The controversies and politics of environmentalism and public planning in localizing wind farms*" (RENERGI, 2004-2012) and "*Sustainable grid development (SUSGRID)*" (RENERGI, 2011-2014), both financed by the Research Council of Norway, are investigating such conflicts. These links between environmental impacts and socio-economic impacts have resulted in stronger interest and requirements for technological solutions to mitigate these impacts.

3.2 Environmental design for renewable energy

Meeting the global challenges of climate change through increased development of renewable energy should not comprise habitats and biodiversity locally. Finding the right balance is rather complex and diverse, which relies on acquiring adequate knowledge on environmental impacts. However, knowledge is not going to be the only requirement; promising solutions should also be adopted and implemented. A key issue is how to operate and develop hydropower and wind-power plants in a sustainable way by balancing the protection of local ecosystems and the utilisation of natural resources. At the same time, avoiding additional stress on already impacted organisms and ecosystems by other land use activities necessitates taking appropriate mitigating actions. To enhance the efficiency of energy production this requires the reconciliation of the increased share of renewables in our energy portfolio with mitigation of negative environmental impacts of power production; matched with the political ambitions to implement more sustainable interactions between energy production and environment.

The Research Council of Norway established eleven Centres for Environment-friendly Energy Research (CEER); among them the Centre for Environmental Design of Renewable Energy (CEDREN, www.cedren.no). CEDREN aims to develop and demonstrate innovative design solutions for renewable energy production at the national and international level actively communicating solutions to environmental and political authorities, to the industry and to the general public. To address the identified problems, we know that we have to change and develop our energy system to match future needs. We also know that the natural environment around existing and planned hydropower plants, wind-power plants and transmission lines is vulnerable. We have to implement environmental design in new and old renewable energy projects. Environmental design means that planning, building and operation have to include technical, economic, environmental and social aspects from the beginning. This is the only way to develop future hydropower plants, wind-power plants and transmission lines in a sustainable manner. The solutions often require a trans-disciplinary approach necessitating close cooperation and integration of the know-how and skills from researchers from all research disciplines and relevant stakeholders. Therefore, CEDREN – the only centre with a distinct trans-disciplinary and environmental profile – is actively coordinating their research with two other CEER's focusing on technological challenges with regard to offshore wind energy: NOWITECH (www.nowitech.no) and NORCOWE (www.norcowe.no). In the following three chapters, knowledge and solutions from different CEDREN projects are presented. The subsequent chapters focus on hydropower, onshore wind power and power transmission. So far, no research has been funded by the Research Council of Norway on the environmental impacts of offshore wind energy production. The Bioenergy Innovation Centre (CenBio, www.cenbio.no), another CEER, sets focus on, among others, ecological management with respect to biomass as a renewable energy resource.

4 Hydropower: knowledge status and solutions for environmental impacts

The knowledge that we rely on today about the environmental impacts of river regulation and hydropower production in Norway is partly based on the Research Council of Norway programmes EFFEN[1] (Efficient Energy Systems; 1992-1996), EFFEKT[2] (1995-2005) and its successor RENERGI[3] (Clean Energy for the Future; 2004-2012). Within the EFFEN and EFFEKT programmes, the Research Council of Norway co-financed projects together with NVE (Norwegian Water Resources and Energy Directorate), DN (Norwegian Directorate for Nature Management), EnFO (now: Energy Norway) and Statkraft SF (now: Statkraft AS). Different power companies have also contributed to funding the RENERGI programme.

EFFEN and EFFEKT mainly aimed at increasing our knowledge pertaining to technological developments with regard to renewable energy production and power transmission. Within both programmes, research on the environmental impact assessments of increased energy demand and supply was financed under two overarching projects: "*Efficient and environmental friendly use of river systems*" within the discipline MILJØ[4] of the EFFEN programme, and "*The environmental impact of diurnal peaked regulation and mitigation measures"* under the EFFEKT programme (see Table 1 for original Norwegian titles and their translation).

Table 1. *Overarching projects within the EFFEN and EFFEKT programmes of the Research Council of Norway focusing on the environmental impacts of hydropower production.*

Norwegian title	English title	Program (period)
Effektiv og miljøpasset bruk av vassdragsressursene	Efficient and environmental-friendly use of river systems	EFFEN (1992-1996)
Effektregulering – Miljøvirkninger og konfliktreduserende tiltak	The environmental impact of diurnal peaked regulation and mitigation measures	EFFEKT (1995-2005)

In general, the objective of the two overarching projects under EFFEN and EFFEKT was to investigate the environmental impacts of river regulation and diurnal peaked regulation and to develop mitigation measures to reduce or even eliminate negative impacts. The RENERGI programme continued with funding research on the ecological effects of the development of sustainable energy sources and enabled further acquisition of knowledge on the ecological effects of hydropower production.

In addition to the NFR programmes, especially the "*Environmental-based water discharge*" programmes I and II by NVE ("*Miljøbasert vannføring I og II*"; 2002-2006 and 2007-2011, respectively) resulted in improved knowledge-based management of regulated rivers while accounting for the elimination or reduction of environmental impacts.

[1] The EFFEN programme was divided into four sub-programmes: MARKED, MILJØ, NETT, PRODUKSJON and SYSTEMDRIFT.
[2] EFFEKT was one of three sub-programmes under the programme for the energy sector; the other being NYTEK and Naturgass. EFFEKT was maintained as part of the Innovation Programme Energy, Environment, Building and Construction (EMBa).
[3] RENERGI represents a confluence of three existing programmes: (1) Energy for the future, (2) SAMSTEMT and (3) the Innovation Programme Energy, Environment, Building and Construction (EMBa).
[4] Within the sub-programme MILJØ "*Efficient and environmental friendly use of river systems*" was the only project focusing on environmental impacts of hydropower production. The other three projects within MILJØ were "*Efficient and environmental friendly transmission of energy*", "*Environmental friendly energy planning"* and "*Information and knowledge transfer"*.

4.1 Knowledge on environmental impacts

4.1.1 Efficient and environmental-friendly use of river systems

Within the overarching project – Efficient and environmental-friendly use of river systems – under the EFFEN programme, four projects were carried out during 1992-1996: "*River systems biology"*, "*Effects of minimum water flow regimes"*, "*Measures for improving the population of wild salmon"*, and "*Development of a river system simulator"* (Norges Forskningsråd 1997).

River systems biology
Within this project, a model tool to simulate different fish habitats was developed at the rivers Stjørdalselva and Gjenegedalselva. In addition, experiments were carried out with lighting, temperature regulation, salinization and different treatments to see under which conditions the biology of juvenile fishes – i.e. survival and growth rate – could be optimized in-situ to increase survival following releases at different sites to compensate for river regulation. Research at the rivers Orkla and Ingdalselva facilitated our understanding of securing natural fish recruitment and selecting necessary fish stocks for compensation releases. These fish stocks could then be taken out to use for in-situ breeding purposes and compensation releases afterwards. Research at the river Otra showed that sedimentation as a result of the operation of the Hekni power station had a positive effect on fish stocks because sedimentation caused improved water quality. In addition, two other studies resulted in the development and tests of methods for labelling fish (in-situ and ex-situ) with radio senders. With the radio-marked fish it was possible to collect information on activity levels, survival rates and temperature.

Effects of minimum water flow regime
The aims of this project were to define measures to compensate for negative effects on biodiversity and how to increase the population size of Atlantic salmon (*Salmo salar*). In addition, a dialogue process was set up comprising an expert group. Different stakeholder groups and the stakeholders' interests were mapped; based on the experience and expertise of the expert group, a proposal for a minimum water release regime was set up. This process was implemented for four relevant river systems. The aim of this overarching project was to develop methods or procedures to be used in decision making processes with regard to issuing licences for building and operating hydropower plants.

Measures for improving the population of wild salmon
This project suggested that when fluctuations in discharge were limited to 3% per hour, fish did not strand. Also, when discharge of water was reduced in spring and early summer, water temperature increased, which in turn positively influenced the growing conditions for young salmon. High increases of water discharge in spring had a negative impact on young fish because organic material and benthic fauna were then washed away. Better hiding places yielded higher fish densities. Released parr (young salmon) tended to migrate relatively late and were smaller compared to wild-born salmon. Only a small fraction of the released fish returned to their home river. The overarching project resulted in better cooperation between environmental and river management, local stakeholders, hydro power companies and researchers.

Development of a simulator for river systems
This project resulted in the development of a simulator for river systems which modelled how river systems were affected by different forms of water regulation. The simulator monitored environmental impacts of simulated flooding, the effects of measures aiming at fish conservation, or the effects of measures aiming at the reduction of harmful sedimentation, for example. The simulator worked very well especially for use in environmental impact assessments before the construction of hydro power plants. However, there was a huge complexity of models, and the simulator was not yet user friendly at that time. It was also argued that good data was still needed as input data to adequately interpret model results.

4.1.2 Environmental impacts of diurnal peaked regulation and mitigation measures

The overarching EFFEKT project "*The environmental impact of diurnal peaked regulation and mitigation measures*", implemented in the period 1996 to 2001 (Førde & Brodtkorb 2001), used the Vinjevatn reservoir in Telemark County as trial location and a stretch of the river Drammen for erosion experiments. The project focussed on the environmental (i.e. erosion, sedimentation, ice formation, frost fogs, temperature fluctuations, aquatic vegetation, benthic fauna and fish) impacts of hydropower plant operation. The project demonstrated that diurnal peaked regulation can result in increased erosion and turbidity in reservoirs with the deposition of fine sediments in the littoral zone and at sites characterized by a constant supply of sediment from the catchment. The magnitude of the water level fluctuations, alterations in the processes of erosion, sedimentation and in the water flow all affected biological conditions. Trials with different discharge regimes in Vinjevatn resulted in plankton drift, reduction biomass of benthic fauna and phytoplankton in the littoral zone and increased stranding of littoral fish.

Furthermore, it became apparent that stranding risk was highest for young fishes using littoral habitats. Stranding risk was significantly reduced when water levels didn't change by more than 13 cm per hour. Stranding risk was also higher during the day than during night in winter. During summer, stranding risk at night was about the same as stranding risk during the day. However, both young salmon and young trout seemed to be able to quickly adapt to new environmental conditions as long as river beds remained wetted. Benthic fauna communities on the other hand needed much longer to recover after a period with disturbances followed by a period with stable water discharge.

4.1.3 Balancing hydropower and the environment through mitigation

The main projects under the RENERGI programme which focused on biodiversity impacts of renewable energy production, included "*Increased power and salmon production*" (EnviDORR, 2007-2011), "*Effects of rapid and frequent flow changes*" (EnviPEAK, 2009-2013) and a project entitled "*Can nuisance growth of the aquatic macrophyte* Juncus bulbosus *be related to elevated nitrogen deposition as well as hydropower regulations?*" (2007-2011). EnviDORR and EnviPEAK are affiliated with CEDREN. Further projects have addressed the effects of the development of renewable energy sources on abiotic factors and processes including temperature conditions, ice formation, sedimentation, discharge, flow fluctuations and flow periodicity in both rivers and lakes and with respect to climate change. Relevant projects include for instance HydroPEAK, VAKLE (Tjomsland 2004) and a project entailing modelling of deltas in reservoirs. In the latter project, the hydrological effects of aquatic vegetation have also been considered, but not the ecological effects of the hydrology. Abiotic processes have also been researched in the projects considered here, for instance in the EnviPEAK project, but the corresponding findings are beyond the scope of the present report.

Increased power and salmon production

A major feature of EnviDORR was the exploration of the possibility for reconciliation between hydropower development and power production on the one hand and the production of Atlantic salmon on the other hand. Most of the research pertained to the salmon's autecology, life history, population dynamics, conservation biology and secondary production, one of the many components of ecosystem services. Therefore, the effects of hydropower development and production on the salmon's different life stages have been examined in detail (Barlaup et al. 2008, Teichert et al. 2010, 2011). One finding of the project was that in principle salmon production does not need to occur at the cost of reduced power production. Salmon fry constitute a relatively robust stage capable for compensating for regulation-induced, altered water temperatures through the reallocation of resources. Nevertheless, groundwater inflow has proved beneficial for salmon fry. For parr, shelter availability has proven the most significant factor affecting growth in addition to fish densities that reflect the spatial distribution of spawning locations. Discharge, however, proved to be of limited importance. The salmon carrying capacity is determined by the total wetted area and spatial distribution of spawning areas and shelters. However, the findings also imply that sea trout may be competitively stronger than Atlantic salmon in cold water. Hence, regulation that brings about lower water temperatures may favour trout at the cost of salmon production. Another potential conflict point is smolt entering turbines causing increased mortality rates. At sea, smolt survival is related to body size. Modelling of the effects of different climate scenarios for selected rivers including selected locations suggests that salmon as well as power production may both benefit from the consequences of climate change given that most climate change scenarios for Norway predict increased precipitation and hence increased runoff.

Effects of rapid and frequent flow changes
EnviPEAK is an on-going project addressing the environmental effects of hydro-peaking hydrological regimes, that is, the effects of rapid fluctuations in flow and water levels and their periodicity. The ultimate goal is to balance different interests including economic, technical, environmental and social issues. More specific goals include the exploration of the changes in both physical processes such as dewatering and wetting, hydromorphology, water temperature and ice formation as well as the biological impacts on salmonid fish, on macro-invertebrates including insects and mussels and also on mammals and birds using natural and semi-natural watercourses, experimental flumes, laboratory facilities and numerical models in order to develop the knowledge necessary to reach the overall objectives. Hydro-peaking may also affect for instance temperature, substrate composition and other abiotic factors in addition to resource supply rates, which may interact with, for instance, fish spawning behaviour. Hence, in EnviPEAK, the interactions between biotic and abiotic components are also addressed. As the project has not been finalized yet, the summary of the findings is preliminary and the conclusions may be subject to change. An early finding is that salmonid fish may tolerate rapid flow fluctuations better than anticipated. Consequently, adapting the operational regime may optimize energy production without sacrificing on the conservation of fluvial ecosystems. In an experimental context, the effects of hydro-peaking have proven stronger during summer than during winter, although the effects were overall weaker than expected. Verification of the preliminary results through field observations is on-going. The effects on stranding have not been addressed in the experiments, although negative effects of stranding are expected. For instance, it remains unclear what the long-term population effects on the stranded survivors are. Also, the importance of stranded fish for mammalian and avian predators remains as yet unclear. Hydro-peaked river stretches seem less attractive for otters (*Lutra lutra*) due to the strong water flow fluctuations, consequent habitat alterations and reduced connectivity across dams. Preliminary data analysis suggests that hydro-peaking may cause decreased macro-invertebrate abundance and decreased species richness. Also, hydro-peaking appears to affect species composition. To this end, only preliminary, contingent data are available. An important limitation of the project is the fact that the set of study sites is non-random given the operators’ interest in particular watercourses. Consequently, general conclusions cannot easily be drawn.

Nuisance growth of Juncus bulbosus
In the scope of the project on excessive growth of *Juncus bulbosus*, a PhD thesis has recently been completed (Moe 2012). Excessive growth has mainly been observed in oligotrophic lakes. The findings suggest that the plant is characterized by high C:N and C:P ratios compared to other plant species suggesting that *Juncus bulbosus* may be highly competitive in nutrient-poor habitats and at the same time comprise a low-quality food resource for herbivores. Research also suggests that different factors may prompt excessive growth in river and lake plants: ammonia may be an important cause of excessive growth of *Juncus bulbosus* in rivers, whereas carbon dioxide may cause excessive growth in lakes. Although a final answer to the question what may cause excessive growth of *Juncus bulbosus* in Norwegian freshwater ecosystems has not been found, several hypothesized explanations could be excluded including eutrophication and genetic differences. The study provides no direct evidence for the effects of hydropower development on excessive growth in *Juncus bulbosus*.

However, the relationships between hydropower development and water chemistry including oxygen and carbon dioxide solubility have hitherto received very little attention. Hence, whether there may be indirect effects of hydropower development on excessive growth in *Juncus bulbosus* for instance via potential effects of hydropower on water chemistry and unexplored routes presently remain unclear.

4.2 Solutions for environmental impacts

Mitigation measures came forward especially under the EFFEKT and the RENERGI programmes and not so much under the EFFEN programme. The best measure to avoid negative environmental impacts from rapid changes in water discharge, which has repeatedly come forward in various projects, is to change the flow slowly so that organisms are able to adapt to the new flow conditions. If possible, it may also be useful to increase or decrease the flow very slowly first, like a warning signal, indicating that a change in flow is coming soon (Atle Harby, pers. comm.).

Another mitigation measure is to reduce flow only after dark to reduce stranding risk, especially during winter (at water temperatures below 8 degrees Celsius) when fish are less mobile and often hiding in the substrate during daytime. Decreasing flow rates by less than 13 cm per hour may reduce the risk of stranding of juvenile salmonids, although stranding may still occur at locations with high water velocities, coarse substrate with low abundance of suitable hiding space and on side slopes with a grade less than 5 per cent. Furthermore, it is important to maintain a minimum residual flow to ensure survival of the benthic fauna in the river that is subject to rapid water discharge (Atle Harby, pers. comm.). In addition to these mitigation measures, it was suggested to protect vulnerable stretches against erosion and avoid rapid changes in water discharge during autumn and spring when the ecosystems are most vulnerable.

Within EnviDORR it became apparent that for selected fluvial ecosystems suitable spawning habitats can be designed to compensate for the loss of suitable habitat due to river regulation. This may be necessary because the availability of spawning habitat has been identified as a bottleneck at least in some fluvial ecosystems. At the same time, modification of the regulation regime should be possible to allow for sustainable salmon production without significantly compromising power production. Strobes and the spill regime may favour bypass migration increasing the proportion of outgoing adults. The improved design of fish ladders and also the positive effects of weir removal may support homing salmon. The success of restoration measures has been demonstrated at Nidelva.

In addition to the NFR programmes, the NVE programmes "*Environmental-based water discharge*" programmes I and II focussed on minimum acceptable discharge levels and other mitigation measures such as fish traps and limited water releases to forewarn fish of upcoming water discharges.

5 Wind power: knowledge status and solutions for environmental impacts

The EFFEKT programme from the Research Council of Norway funded the REIN project (1998-2001) which studied the effects on noise from power lines (see also chapter 6) and wind turbines on semi-domestic reindeer (*Rangifer tarandus*) (Flydal et al. 2002).

The RENERGI programme from the Research Council of Norway financed one research project focusing wind power and environmental impacts: "*Pre- and post-construction studies of conflicts between birds and wind turbines in coastal Norway*" (BirdWind; 2007-2010). The project was finalized with an international conference synthesizing the current knowledge base on wind energy and wildlife (May & Bevanger 2011). The main project objective of this project was twofold: (1) study species-, site- and season-specific bird mortality due to wind turbines, and (2) develop methodologies and technical tools for data collection and mitigating measures. The obtained knowledge base may improve the design of future wind-power plants both during the pre- and post-construction phase. Below salient knowledge acquired in this project are summarized, and solutions to mitigate impacts are proposed. If not indicated otherwise, all information given refers to Bevanger et al. (2010).

5.1 Knowledge on environmental impacts

5.1.1 Impacts of wind turbines on semi-domestic reindeer

Results from the REIN project indicated that noise from operating wind turbines was clearly audible to reindeer. Still, enclosure experiments (control areas versus areas <450m from wind turbines) did not indicate that increasing wind-turbine-related noise levels affected reindeer behaviour. Space use in the enclosed reindeer was not influenced by the wind-turbines. Reindeer that were exposed to a wind turbine with or without moving rotor blades did not have higher rates of activity; neither did they show any clear behavioural responses to the wind turbines; not even in strong winds and increased noise levels. The REIN project (Flydal et al. 2002) did not assess the effect of different types of wind turbines on reindeer behaviour. Mitigation measures proposed include placement of wind turbines in the landscape if they have a negative effect on free-ranging reindeer. Construction work should if possible be carried out in a time of year when reindeer are not in that area.

5.1.2 Wind turbines and bird mortality

On several occasions energy and environmental management authorities, as well as the energy industry, have stressed the need for additional knowledge on environmental impacts of wind-power development, and how birds and animals respond to related man-made structures (e.g. NVE et al. 2003). Research on how wind turbines affect birds (and bats) has been conducted elsewhere for 10-20 years, but the results have been inconsistent, with differing results regarding number of fatalities and species-specific vulnerability. A limited number of studies have reported wind turbines to be less harmful than other structures including those connected to energy production (Nelson & Curry 1995, Osborn et al. 1998, Garthe & Hüppop 2004). Conversely, other studies have reported a significant number of birds being killed by wind-turbine constructions (Orloff & Flannery 1992, Hunt et al. 1998). The problem of bird mortality related to wind turbines has gained increasing international attention as the number of installations has increased, including (among other developments) the convening of an international conference on the problem in Leicester, April 2005 (Langston et al. 2006).

The construction of the Smøla wind-power plant (Norway's first large-scale wind-power plant encompassing 68 turbines (150 MW)) initiated an interesting debate regarding the economic responsibility for obtaining environmental impact data. As wind-power generation was quite a new activity in Norway only ten years ago, no one had thoroughly defined the content of "good or best practice" in connection to it. Vague guidelines, together with absence of national experience regarding how a wind-power plant could affect the Norwegian environment, generated an interesting debate among the actors – the energy industry and the energy and environmental authorities. The industry claimed that it was the responsibility of the public authorities to obtain basic data, and to pay for basic research to make a better platform for how to design an EIA study as well as pre- and post-construction studies.

As it was known from international studies that bird mortality has been a major problem associated with some wind-power plants, the ornithological impacts became a focal issue. Avian problems associated with wind-power generation were rarely debated in Norway until 2005. However, during the period October 2005 – May 2006 nine dead white-tailed eagles (*Haliaeetus albicilla*) (and some other birds) were found killed in connection to wind turbines on Smøla. When NINA in 2006 designed the BirdWind application to the RENERGI programme, it was welcomed and supported by both the energy industry and the management authorities.

During the course of the BirdWind project (August 2005 – December 2010; but still on-going) wind-turbine induced bird mortality was documented through weekly searches for dead birds using especially trained dogs. Documentation of collision victims help identify species-specific factors triggering high collision risk, possible causes of death and estimating species-specific collision rates. More than 25 species have been recorded; of which willow ptarmigan (*Lagopus lagopus variegatus*), white-tailed eagle, common snipe (*Gallinago gallinago*), golden plover (*Pluvialis apricaria*) and hooded crow (*Corvus cornix*) were the most common collision victims.

Impacts on willow ptarmigan, breeding waders and smaller passerines
During 2005-2010 remains of 74 willow ptarmigan have been identified within the wind-power plant area, including birds found dead during the regular turbine-related searches. Between 10 and 15 individuals were found each year, the majority in March-June (42; 57%), but also in November-January (20; 27%). About half the willow ptarmigan victims were found within 50 m of the turbine base. No difference in density was found between the wind-power plant area and the control area, although chick production was reasonably good compared to other willow ptarmigan populations. The annual mortality of radio-tagged birds was much higher than in inland willow ptarmigan populations (>70% vs. 50%), and the mortality pattern is different from the pattern found in inland populations. Heavy winter mortality of radio-tagged birds seems to be mainly caused by natural mortality from migrating and wintering raptors.

A survey was done on the breeding populations of waders and small passerines to assess any evidence for effects on bird distribution in relation to wind turbines. The field work was carried out at the Smøla wind-power plant in 2007, in a planned wind-power plant area on Andmyran in 2008, and in connection to a planned extension of the Hitra wind-power plant in 2009. There is evidence that several species of small birds and waders avoided the vicinity of wind turbines on Smøla. Although all of these species were common, the precautionary principle would suggest avoiding building wind-power installations in areas inhabited by similar but rarer species.

Impacts on white-tailed eagles
During the period 2005-2010, 39 white-tailed eagle collision victims were recorded, on average 7.8 eagles annually (0.11 eagles/turbine/year). The exact causes of death were based on necropsies, and overall the x-ray pictures show a pattern of violent impacts inflicting massive damage to the skeleton, with a broad spectrum of fracture, although some specimens had only minor damages. Because of the recorded mortality and the fact that the white-tailed eagle until recently was on the Norwegian Red List, it was obvious that the species should receive particular attention within the BirdWind Project. Different aspects of the species have been

studied, e.g. flight behaviour inside and outside the wind-power plant area. The overall conclusion from this was that the eagles did not seem to respond to the presence of the wind turbines by modifying their flight behaviour. Assuming these observations are representative, this clearly imposes constraints on mitigating measures to decrease the white-tailed eagle collision risk.

More than 50 ready-to-fledge white-tailed eagle nestlings were equipped with satellite telemetry backpacks to acquire information on white-tailed eagle movements and data for collision risk assessments. GPS satellite telemetry on juvenile/sub-adult white-tailed eagles has provided detailed insight into their behaviour within and outside the wind-power plant. Collision risk modelling has shown that white-tailed eagles are most prone to collide during spring (May et al. 2010, 2011). A novel developed model led to improved insight into diurnal and seasonal effects in collision risk, but also enables the delineation of specific areas or specific turbines with increased risk. The sub-adults show a cyclic movement pattern, involving dispersal during summer, mainly to the north, and a return movement to the area they were born in the spring, with a new movement away during the next spring (Nygård et al. 2010). Over years, they seem to be more and more attached to their region of birth. Their movements along the coast involves visiting many potential future sites for wind-power development, which illustrates the possible nation-wide scale of cumulative effects; any young white-tailed eagle born along the coast has a potential chance of entering any planned and existing wind-power plant along the Norwegian coast.

Possible changes in the white-tailed eagle breeding population on Smøla were monitored to assess whether the wind-power plant has had any short- or long-term effect on the eagles' reproduction and breeding success. So far the conclusion is that the overall population on Smøla is stable. The decrease of the population inside the wind-power plant area is due to mortality and displacement (Dahl et al. 2012). The number of young eagles born on Smøla overall increased throughout the study period (2002-2010), as did the reproductive success. DNA studies were applied to estimate adult mortality among breeders in, or close to, the wind-power plant. DNA sampling of moulted feathers has proven to be a cost-effective method for estimating the number of active territories accurately. A simple survey of nesting sites may overestimate the number of breeding pairs on Smøla by approximately 10-15%. This has important implications for the evaluation of the vulnerability of white-tailed eagle populations. Development and optimization of the DNA methods used herein have given significant data making it easier to address similar questions also for other birds of prey. Preliminary results indicate that the wind-power plant constitutes an important mortality factor for the white-tailed eagle population on Smøla, accounting for more than 50% of the detectable adult mortality. In particular, birds breeding within or close to the wind-power plant seem to be vulnerable.

Technological tools for wind-power impact assessments
The BirdWind project has also assessed the current knowledge on the effectiveness of tools and technology best suitable to study avian wind-turbine impacts. Such tools and technology may also help reduce bird mortality in connection to wind-power plants by suggesting concrete mitigating actions. The technologies assessed encompassed dog-searches, GPS-telemetry, avian radar, geographical information systems (GIS), and video cameras. Although outcome on technological tools has not entirely met its initial expectations, the findings and the increased understanding of the complexity provides a basis for further work on these challenges at a later stage.

Since April 2008 a MERLIN mobile avian radar system (DeTect, Inc.), placed in the centre of the wind-power plant, has monitored bird activity continuously. The radar was set to cover the relatively large area of the Smøla wind-power plant, and was operated 24 hours a day all year round at all types of weather conditions, which is a task impossible to achieve with the use of human observers alone. At the same time the radar offers means for continuously recording of the radar images which provides documentation of the activities in the surveillance area. This is the first time avian radar has been deployed for this kind of research in Norway. To gain general experience using radar as a research instrument validation experiments were employed and the necessary methods for filtering large amounts of data were developed. Practical methods/tools to aid radar personnel to ease localisation, set-up and calibration of radar equipment, as well as provide protocols to handle data analysis have been developed. Avian radar may provide many new insights into bird behaviour, not in the least connected to possible effects of wind-power development – both in the pre- and post-construction phase. Analyses from Smøla visualize, for example, fluxes of spring/autumn migration, species-specific bird behaviour; possible collision tracks and provides improved ways to analyse avoidance behaviour at a fine spatial scale.

Most of the GIS efforts have focused on terrain modelling, line-of-sight studies and ground-clutter modelling. Using GIS-modelling and high precision elevation data to perform line-of-sight studies and ground-clutter modelling have made important contributions, in order to optimize the avian radar localisation and tagging of potential false tracks inside the theoretical land clutter areas stored in the MERLIN Horizontal database. The models are flexible and easy to perform. The land clutter mask is currently implemented in the MERLIN Horizontal database. Every track identified inside the land clutter mask is automatically tagged as a potential false track. The land clutter seems to correlate well with the clutter areas identified with the static clutter map detected by MERLIN.

5.2 Solutions for environmental impacts

Progress on developing mitigating measures to reduce the collision hazards require increased species-specific knowledge of how the behaviour is determined by their vision (including colour and movement sensibility), and at what distance their visual stimuli are triggered. Without this knowledge it is difficult to assess how for example a white-tailed eagle views and understands the movements of the rotor blades and other wind-turbine associated structures. Increased knowledge on how birds are using their biomechanics and aerodynamic skills, to cope with the turbulence and vortices in the vicinity of the wind turbines is also needed.

Important remaining questions relate to the fact that avian radar can provide near real-time information on bird activity. This may be used to identify periods and/or areas with increased risk for collisions. What remains to be done is to develop a collision risk model based on these data; rendering insight into higher levels of bird activity at rotor-swept height at each turbine at any given time. If this model proves to have predictive power, when verifying with recorded casualties, it may potentially be utilized to warn wind-power plant personnel to idle turbines (i.e. curtailment). Comparing bird activity patterns with correlates between recorded casualties and weather parameters (especially wind speed) may form the basis to define mitigation measures such as idling turbines in given pre-defined situations while minimizing loss of energy production. The MERLIN avian radar deployed at the Smøla wind- power plant only provides insight into local patterns of bird activity. As part of the allocation of research infrastructure to the Centres of Environmental-friendly Energy Research, CEDREN was granted a ROBIN 3D Flex Avian Radar System built-in a small van by the Research Council of Norway in 2010. This mobile avian radar can be employed to monitor resident and migratory bird activity. Utilizing the large-scale 3D radar systems, employed by the Royal Norwegian Air Force and the Norwegian Meteorological Institute, to extract birds from their signals enables the mapping of large-scale migration routes. Especially for wind-power plants along the Norwegian coast, improved knowledge on migration will be important to identify high-risk sites and forewarn operators. Currently, however, our limited knowledge on bird migration routes is largely based on recoveries of ring-marked birds.

6 Power lines: knowledge status and solutions for environmental impacts

The EFFEKT programme from the Research Council of Norway funded the REIN project (1998-2001) which studied the effects on noise from power lines and wind turbines (see also chapter 5) on semi-domestic reindeer (Flydal et al. 2002).

In 2009 the Research Council of Norway – through the RENERGI programme – funded the project "*Optimal design and routing of power lines; ecological, technical and economic perspectives*" (OPTIPOL; 2009-2013), and it was affiliated with CEDREN. The OPTIPOL rationale is based on the belief that the negative effects of electricity transmission and distribution can be reduced with respect to birds and mammals. Many aspects of the project require a close co-operation between ecologists and engineers, dealing with electricity transmission. Supporting structures for power lines and a diversity of specific constructions found within the Norwegian grid system must be considered carefully in order to safeguard the stability of energy supply to the consumer and/or violate safety regulations. Below salient knowledge acquired in this project are summarized, and solutions to mitigate impacts are proposed. If not indicated otherwise, all information given refers to Bevanger et al. (2011).

6.1 Knowledge on environmental impacts

6.1.1 Impacts of power transmission lines on semi-domestic reindeer

Knowledge on how power lines may affect ungulates is in general lacking until the late 1990s. In 1996 Statnett took initiative to discussions on how to improve the situation. After a workshop arranged by Statnett in early 1997, it was decided to make a pilot study. The study concluded that it has been more or less a standstill in the knowledge gain on the topic since the last review was made in the mid-1980s. It was also pinpointed that some specific topic should be given priority in future research activities. A main question should be to assess local effects of scaring stimuli as well as regional avoidance in connection to power lines, but also wind turbines.

The REIN Project, funded through the EFFEKT programme, made some interesting findings regarding power line impacts on semi-domestic reindeer. It turned out that corona discharge noise from the power lines is audible for reindeer, but not necessarily disturbing, and that direct exposure to power-line constructions has a limited effect to the local behaviour of the reindeer. Moreover, it was evident that the construction phase has the strongest, short term disturbing effect, but limited long term effect Flydal et al. 2002).

One the other hand it turned out that reindeer avoided power lines, reducing their area use up to several kilometres from the power line corridor. It was also evident that females with calves were most vulnerable to these disturbances, though there were seasonal differences in the disturbance effect. There are also differences in the degree to which different populations of domestic and wild reindeer and caribou tolerate disturbances. The fact that local disturbances like corona discharge noise do not necessarily act as a scaring device, also explain several observations of reindeer grazing below power lines. However, there are also observations of reindeer herds stopping and turning around when approaching a power-line corridor. The debate on local scaring effects or regional avoidance effects with respect to reindeer is still going on, and research on human induced disturbance impacts on reindeer has become a main focus for researchers in NINA (e.g. Strand et al. 2011; Panzacchi et al. 2011) and the University of Oslo (e.g. Reimers et al. 2007; Flydal et al. 2009).

6.1.2 Wildlife impacts of power transmission lines

In April 1980 the Norwegian Directorate for Nature Management (DN) and the Norwegian Water Resources and Energy Directorate (NVE) arranged a symposium focusing wildlife impact from hydropower development. This was the first attempt in Norway for making a status on the existing biological knowledge covering hydropower reservoirs, regulated rivers, power lines, access roads and pre-construction studies (Kjos-Hanssen et al. 1980). The power-line session was covered by four presentations (Folkestad 1980; Kjos-Hanssen 1980; Lund-Tangen 1980; Strømsøe 1980).

During the Økoforsk Research Programme in the mid-1980s research on power lines as mortality factor for birds was initiated. Focus on birds and power lines became a main research task for the unit located at the Natural History Museum in Trondheim (Bevanger 1984, 1987, 1988a,b; Bevanger & Thingstad 1988). In September 1988 Økoforsk bacamse part of NINA, and the research activities on birds and power lines continued, financed both from the NINA basic funding (Bevanger 1990b,c,d,e,f, 1991, 1993a,b,c,d,e,f; Bevanger & Sandaker 1993), and directly from energy companies as part of environmental impact assessments (Bevanger 1993a, 1994a; Bevanger & Henriksen 1993). The following years several findings on birds and power lines were published in international journals (Bevanger 1994a,b,c, 1995a,b, 1997, 1998, 1999; Bevanger & Overskaug 1998; Bevanger & Brøseth 2001, 2004). Some of the main conclusions from the Økoforsk and NINA projects on birds and power lines were that this is a species, site and seasonal specific problem (Bevanger 1990e, 1993e, 1994b,c, 1998) and that gallinaceous birds in particular suffer a high mortality in Norway from colliding with the overhead wires (Bevanger 1995a). Moreover, power lines seem to be a main mortality factor for some vulnerable and red listed species like the eagle owl, mainly due to electrocution (Bevanger & Overskaug 1998).

Although the OPTIPOL project, funded through the RENERGI programme, is not finalized several interesting results are emerging. Possible negative (i.e. barrier) and positive (i.e. browsing) effects of power line corridors on moose (*Alces alces*) movement and habitat selection are studied using extensive GPS telemetry data analyses. The effects of public roads, for which the body of published knowledge is extensive, are analysed simultaneously for comparisons. Possible population effects on capercaillie (*Tetrao urogallus*) and black grouse (*Tetrao tetrix*) population due to the mortality caused by collisions with the power lines are also studied. DNA-sampling and line-transect sampling of the important game birds the capercaillie and black grouse form the basic data for population mortality estimates. During the patrols along the seven km long power line section a total of 38 bird fatalities have been recorded so far. In order to provide authorities and developers a tool for “optimal” routing power lines, a Least Cost Path (LCP) modelling tool is developed. The Klæbu-Viklandet transmission line (built in 2002) was chosen as a pilot case study, in agreement with NVE and Statnett, to test the LCP methodology. A first version of the pilot was released at the first workshop in April 2012 (Thomassen et al. 2012). Subjects and criteria from technical, economical, ecological and social perspectives are identified, and the work ahead will focus on validating and mapping them. Eagle owls (*Bubo bubo*) are known to be susceptible for electrocution, and are classified as endangered on the Norwegian Red List (Kålås et al. 2010). On the island of Sleneset in Lurøy municipality, where one of Norway’s highest density of eagle owls exist, OPTIPOL concentrates both on possible population impacts and on mitigating this electrocution hazard.

6.2 Solutions for environmental impacts

To achieve European-level policy goals on climate change challenges, as well securing the electricity supply within Norway, it will be necessary to increase power-line construction efforts significantly, as well as to upgrade the existing grid. Statnett have estimated an approximately 40 billion NOK investment over the next 10 years will be required for the central grid. Although this is a huge investment, the length of the new transmission lines constructed will only comprise a small part of the Norwegian grid. Of approximately 193 000 km of overhead power lines in Norway the distribution grid (i.e. up to 24 kV) comprises 85% of the total Norwegian grid system.

All overhead wires pose a potential risk to flying birds; however, the risk increases with the number of lines and wire length per unit of land area. The central and regional grid, in general, represents no electrocution threat, as the distances between the phase conductors and/or the distance between a phase conductor and an earthed device is rather wide. Thus the electrocution problem is a distribution grid specific problem.

Both the collision and the electrocution risk are highly species-specific problems. Over the last years several research projects have collected data enabling an identification of the bird species and bird species groups facing a particular risk. However, there is still a lack of knowledge in several respects, for example why the number of collisions is not evenly distributed along a power line section, but is frequently concentrated at a few spots. This type of knowledge is crucial to contribute to the selection of as environmentally friendly power line routing as possible when new power lines are constructed. These problems are addressed in the on-going OPTIPOL project.

Earlier solution to the electrocution problem has been focusing on e.g. covering the wires in their suspension points. This has, however, resulted in increased corrosion problems. Corrosion of power line equipment is a major problem in Norway, particularly in coastal areas with a high marine corrosion index. A solution used in the US has been to construct perching structures on the top of the pylons, i.e. above the insulators and the cross-arm. In principle this is a fine construction, however, in some environments it has some obvious disadvantages as bird excrements left on the pylons may serve as a conductor for electricity and increase the electrocution hazard.

In connection to the eagle owl subproject in OPTIPOL a new elevated perch construction in cooperation with Eltjeneste AS is designed (Bevanger et al. 2011). The grid owner at Sleneset, Rødøy-Lurøy Kraftverk, has installed these alternative perching structures at a selection of 12 pylons. At the same time perching avoidance structures (racks of sharp plastic spikes) have been fixed to the cross-arm, preventing the eagle owl to rest on the dangerous parts of it. So far the results have been very promising, and the surveillance cameras have confirmed that the eagle owl actually is using the new perching alternative.

With respect to both upgrading, and to new power line constructions, underground cabling should be used to a much greater extent. This is also stressed in the new Energy Act of 2009. This will significantly reduce the extent of bird mortality due to collision and electrocution. A cost-benefit evaluation indicates that underground cabling is the best method to reduce the extent of conflict.

7 Towards future development of renewable and sustainable energy production

To make the sustainable transition to resource-efficient, low-carbon societies there is a need for collaboration and system approach between technology, markets, society and the environment. When the first Energi21 strategy was launched in 2008, it was the first time that energy stakeholders in Norway were unified behind a collective research, development and demonstration (RD&D) strategy in the energy sphere (Energi21 2011). This laid a foundation for intensive RD&D activities to realize the substantial potential for value creation under an energy regime with clearly-articulated climate targets, strong focus on environmental considerations and requirements for effective resource management. This report has presented some of the main research outcomes that have emerged from the increased focus on R&D on environmental impacts in the last decade. Renewable energy has been perceived as “environmentally-friendly”, but future large scale development of natural renewable resources will arrive with several impacts and issues attached; many of them not yet solved. To ensure that reaching the climate goals is optimized towards environmental, economic and political ambitions, specific research for good environmental design is vital for the coming period.

The EU’s collective target of generating 20% of its energy from renewable sources by 2020 has pushed forward plans for renewable electricity that project an doubling of the totally installed capacity in EU to 492 GW (Beurskens et al. 2011). In Norway we have ratified to undertake a 67.5% renewable target within the same period as laid down in the Climate and Energy package (20/20/20 targets). At the same time Norway is obliged to serve the European Biodiversity and Sustainability Strategies[5] and international conventions on protection of species and habitats. These co-lateral objectives are directly reflected in three central reports delivered by the Norwegian government lately: *Energiutredningen*, *Klimameldingen* and *Nettmeldingen*. These reports describe status, main challenges and the future strategic needs for accomplishing the renewable goals in Norway in interaction with the European energy system.

Many of the projects described in this report have already contributed to the knowledge needed to draw relevant conclusions in these national reports. The following will attempt to further outline some important research questions in alignment with these strategies, and hopefully point towards R&D efforts that will provide the industry, government and end-users with the best solutions for future energy development.

7.1 Handling expansion and complexity

In 2012 the Norwegian Ministry of Petroleum and Energy released the White Paper on the *Assessment of future energy development in Norway towards 2030 and 2050* (NOU 2012:9 Energiutredningen). This White Paper identifies important research needs; many of which are addressing the uncertainties of future scale and complexity of the energy system. As we are heading towards renewable expansion and fully integrated energy markets in Scandinavia and Europe numerous potential challenges arise. How will cumulative impacts of increased development manifest? What is the environmental cost of energy in a life-cycle assessment

[5]
- Commission Communication 'A Sustainable Europe for a Better World: A European Union Strategy for Sustainable Development', COM(2001) 264 final of 15.5.2001.
- Commission Communication 'Our life insurance, our natural capital: an EU biodiversity strategy to 2020', COM(2011) 244 final of 3.5.2011.
- http://ec.europa.eu/clima/policies/package/index_en.htm
- Commission Communication 'A Roadmap for moving to a competitive low carbon economy in 2050', COM(2011) 112 final of 8.3.2011.
- Commission Communication 'Roadmap to a Resource-Efficient Europe', COM(2011) 0571 final of 20.9.2011.

perspective? How can the actual effects of climate gains be obtained without loss of ecological value? How can we secure a holistic approach across planning, construction and operation?

7.1.1 Balancing and flexibility towards intermittent energy sources

The expected expansion of renewable energy in the coming decades challenges our ability in balancing the ambitious renewable energy targets and biodiversity conservation. Phasing in large scales of intermittent renewables, such as wind and solar energy, creates an increased need for balancing power. Norway has potential to become Europe's "green battery" by utilizing its extensive hydropower storage capacity: Norway's reservoir storage capacity is the equivalent to half of the total capacity in Europe (Catrinu-Renström & Knudsen 2011). Increased pumped storage capacity in Norway could be a significant solution, where production variability may be equalized by pumping water up in upstream reservoirs, and releasing it to downstream reservoirs when required. This simultaneously necessitates, however, a closer connection between intermittent renewables and hydropower by establishing a "super-grid" for electricity transmission across the North Sea. Likewise, a large part of Norway's hydropower system has a highly flexible hydro-peaking capacity, being able to regulate production from standstill to full load within minutes. However, pumped storage and hydro-peaking has potentially severe impacts on respectively reservoirs and river systems in regards to organisms and ecosystems. As the socio-economic value can be huge, this brings up complex scenarios to be answered. To meet the challenges it is imperative to guide government and industry decision-makers through these possible pathway-scenarios that secure that impacts will remain within acceptable levels.

Through scenarios, actual projections of solutions and consequences can be derived using multi-criteria tools that incorporate key economic, technological, social and ecological criteria identified through stakeholder dialogue. Such projections may then be used to assess whether renewable energy targets can be reached, within certain ecological and socially acceptable thresholds. Examples of such contrasting scenarios might encompass a preference for sites away from human settlements versus development close to consumption hotspots; regional self-sufficiency of energy production/consumption versus production/consumption within a world market. While the first example would require balancing not-in-my-backyard (NIMBY) conflicts with impacts on the environment; the latter would result in more or less clustering of development regions.

7.1.2 Cumulative impacts

To address the climate change effects and its impacts ecosystems, a total overview of processes and uncertainty across disciplines and technologies is vital. More knowledge on climate sensitivity, tipping points and thresholds is essential for sustainable and valid decision-making.

It has been suggested that the impacts of renewable energy are small relative to other factors (Erickson et al. 2001; Rydell et al. 2011). However, rapid and large-scale utilisation of renewable energy resources challenges our ability to anticipate (and subsequently verify) the accumulated impacts on biodiversity from power plants and their related infrastructure over large geographical regions. Because most impact studies have primarily focused on species-specific impacts associated with single power plants, cumulative impacts on the environment at large are generally ignored or at least underestimated. Existing and on-going renewable projects have so far been able to avoid the most conflict-ridden sites, but as the "good-quality" projects are deployed, the opportunities for future avoidance will inevitably diminish and projects of higher risk will accumulate. Good, overall spatial planning will in this context be decisive for legitimacy and acceptance for concession approvals. In addition, environmental design ('eco-innovation') could help reduce impacts enabling development at new sites allowing for improved utilization of renewable resources. Decision-makers will require improved tools and methods to guide them in balancing ambitious renewable energy targets and biodiversity conservation. Internationally and nationally, a growing need has been identified to establish common standards and methods concerning how issues related to the cumulative effects can be integrated in future research and monitoring practice (Erikstad et al. 2009; May et al. 2010; May 2011).

7.1.3 The cost of energy, ecosystem services and ecological footprints

While “no-net loss” of biodiversity can be seen as an ideal – or a benchmark – against which to evaluate alternative scenarios, some amount of loss is inevitable over time in order to fulfil societal and technical requirements of renewable energy development. It will be relevant to measure acceptable losses of biodiversity in order to sustain climate targets. Identification of these acceptable thresholds (e.g. willingness-to-pay; Breffle & Rowe 2002), can be compared against factual ecological tipping points. This is one major focus in Norway’s approach towards grid development and operation; how to balance safety of supply, social economics and environmental requirements (Nettmeldingen; Meld.St. 14 (2011-2012)).

Climate change and sustainability in an international perspective are key drivers for future development of Norway’s energy system, and the White Paper on *Norwegian Climate Policy* (Klimameldingen – Norsk klimapolitikk; St.Meld. 21 (2011-2012)) addresses some important challenges in this process. There are several biophysical factors that can drive or reduce emissions and global warming, and the system for pricing of climate impacts from energy development depends upon complex quantitative and qualitative factors. A range of conditions are at play when assessing socio-economic benefits of renewable energy development, and *Klimameldingen* refers to the concept ecosystem services (ESS), and the need for reliable methodology and data in order to support complex decision making across technologies, systems and value chains. Although compensatory principles are incorporated in other sectors; further development of the compensation scheme should be better addressed in the energy sector. Pricing of natural resources is a complex and conflicted issue, and there is explicit need to improve guiding principles and methodologies for financially offsetting non-monetary environmental impacts (see Quétier & Lavorel 2012). The UN initiative, *The Economics of Ecosystems and Biodiversity* (TEEB) has completed a large international study on framework, strategy and approaches on ecosystem services. Similarly, the Norwegian Ministry of the Environment has established an expert group that shall deliver a report on this issue in 2013.

Methods aimed at designing and quantifying offsets in an ecosystem services (ESS) approach will identify the extent to which damaged resources (e.g. biodiversity) provide services that contribute to human welfare, and then to select compensations that offset both impacts and loss of benefits. Yet another perspective is the impact of renewable energy on the ecosystem as a whole (structure and function). From an ecosystem perspective, some vulnerable species may be negatively impacted; some may be relatively unaffected while others may benefit. However, given that all species within an ecosystem are connected, impacts on one species may in turn indirectly affect other species, presenting new and complex impacts to be handled. Assessments of the total ecosystem load across species and projects, and implementing this into an ecosystem service-logic, presents new research challenges. Although such approaches may be challenging to realize given the complexity of ecosystem components to take into account, modelling exercises could enhance our understanding of impacts of renewable energy on ecosystems at higher hierarchical levels and at larger spatial and temporal scales.

Life Cycle Assessments (LCA) have been used to assess all the energy used and related emissions, to compare different energy production technologies (Gagnon et al. 2002; Pehnt 2006). This may be important especially in the case of renewable technologies, where it often is argued that the energy used to produce the technology is not paid back during the lifetime of the technology (Schleisner 2000). However, LCA models are to a large extent simplistic and not optimized towards renewable energy and environmental ecosystem logics. As long as LCAs are not able to assess the actual impacts on the natural environment as part of the total life-cycle load of renewable energy, the methodology must be improved and further developed in order to be applicable towards renewable energy development and valid policy-making.

Renewable energy projects demands large proportions of land use, often in conflict with other societal interests (recreation, other industry, primary production) and of course environmental impacts and sustainability. An approach that has been followed to evaluate sustainable development is the “ecological footprint” (Wackernagel & Rees 1996). The ecological footprint is an indicator that can evaluate the effects of society’s actions (e.g. renewable energy production) on the environment, by the amount of land use required for keeping up its current lifestyle. The ecological footprint methodology may then be employed to define the trade-off between increased “land-use footprint” (i.e. the actual infrastructure and post-construction environmental impacts) and reduced “climatic footprint” (i.e. carbon-neutral electricity production), both over time for different forms of renewable energy sources, and at varying capacities. The World Wide Fund for Nature (WFF) has extended the ecological footprint methodology by including biodiversity indicators in their Living Planet index (Pollard et al. 2010). In this setting renewable energy takes a special place. While renewable energy may lower our dependence on fossil fuels and help reduce carbon emissions to the benefit to both society and biodiversity, simultaneous it may enhance land use impacts.

A comparison of the benefits of renewable energy in meeting the global climate challenges versus the impacts on our natural environment is a necessity. While often the global contribution of renewable energy with regard to “combatting the climate crisis” is put forward; possible impacts on the environment are usually indicated to be of more local character. Eliminating this global-local mismatch is essential to avoid ambiguity in cost-benefit discussions in order to make the right strategic decisions for planning and development of future energy systems beyond 2020.

7.2 Closing remark

Both internationally and in Norway a focused and recognised effort is invested in research on renewable energy and its impacts and implications on the environment and society. The complexity of energy system is increasing as different disciplines converge in order to handle this. We must keep on increasing our basic knowledge, secure applications and actual innovations and work closely with industry and government to implement the optimal solutions. This report is a direct documentation of some of the central achievements and knowledge produced through focused work on these issues. The Research Council of Norway has through the programmes EFFEN, EFFEKT, RENERGI and the CEERs so far produced a unique portfolio of projects, and just as important, established a research network that is tuned directly onto the challenges that must be addressed. This has largely been done in collaboration with industry partners and governments, creating a unique value chain from knowledge production to innovation and implementation of solutions. In the future, these research-based networks and collaborations will enable the development of new technology, management and policies needed for sustainable development of renewable energy production and climate change mitigation.

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Appendix 1. Norwegian legislations with relevance to renewable energy and biodiversity

Legislations are given in chronological order in which they came into force.

Original Norwegian title (acronym)	English title	Entered into force	Rationale
Lov om vassdrags-reguleringer (vassdragsregu-leringsloven)	Watercourse Act	1917	The Watercourse Act applies to all watercourses which purpose it is to change the watercourse flow. The law is a side-law to the Water Resources Act and contains rules on licensing and application, reversion, license fees, licensing, revision of terms and expropriation.
Naturvernloven	Nature Conservation Act	1954 (1970)	While the Nature Protection Act of 1910 and the Nature Conservation Act of 1954 only ensured protection of natural areas; the 1970 act became important for modern environmental conservation. The Act defined nature as a national asset that must be protected, and provided rules on the protection of special natural areas and natural resources. It also stated that “intervention in nature should only be carried out from a long-term and comprehensive allocation of resources, taking into account the nature of the future preserved as a basis for human activity, health and well-being”.
Lov om planlegging og byggesaks-behandling (plan- og bygningsloven)	Planning and Building Act	1986 (2009)	The Planning and Building Act ensures sustainable development for the benefit of the individual, society and future generations. It should help to coordinate state, regional and municipal tasks and provides a basis for decisions about the use and protection of resources. Construction of procedure under the Planning and Building Act shall ensure that measures are in accordance with laws, regulations and planning decisions. The act also ensures transparency, predictability and participation of all interested parties and authorities. Emphasis will be placed on long-term solutions, and consequences for the environment and society will be taken into account.
Lov om produksjon, omforming, overføring, omsetning, fordeling og bruk av energi m.m. (energiloven)	Energy Act	1991	The Energy Act provides the framework for the organization of electricity supply in Norway. It provides a unified set of rules that were previously spread across a large number of laws. The Act laid the foundation for a market-based production and sale of power. The Act includes rules relating to the construction, site and sales licensing and license for district heating plants. Furthermore, the law includes regulations on case management, emergency response, sanctions, etc.
Lov om vassdrag og grunnvann (vannressursloven)	Water Resources Act	2001	Water Resources Act ensures a socially responsible use and management of waterways and groundwater. The Act replaces the previous Water Resources Act (Vassdragsloven) of 1940. The act consists of regulations for licenses, joint actions, protected rivers, protection from damage, the closure of water systems, groundwater, compensation for damage, expropriation, audits, order corrective action and other sanctions and transitional provisions.
Forskrift om fysiske tiltak i vassdrag	Regulation on Physical Interventions in Watercourses	2004	This regulation falls under the Salmon and Inland Fish Act from 1993 (Lakse- og innlandsfiskeloven; revised in 2009). Small interventions that do not require licensing by e.g. the Water Resources Act, may still need permission through this regulation.
Forskrift om konse-kvensutredninger	Regulation on Environmental Impact Assessment	2005 (2009)	The regulation specifies and complements the provisions on environmental impact assessment (EIA) of the Planning and Building Act. The purpose of which is to ensure that the environment and society are taken into

			account during the preparation of plans or actions, and when deciding whether and on what terms, plans or measures can be implemented.
Forskrift om rammer for vannforvaltningen (vannforskriften)	Regulation on a Framework for Water Management	2007	The Water Framework Directive was transposed into the Norwegian Regulation on a Framework for Water Management. This regulation has a legal base in the Planning and Building Act, the Water Resources Act and the Pollution Control Act. The regulation follows the Water Framework Directive, and aims to (1) provide a framework for setting environmental objectives that ensure integrated protection and sustainable use of the water bodies, and (2) ensure the preparation and adoption of River Basin Management Plans with corresponding Programs of Measures, aiming at reaching the environmental objectives, and ensuring that the necessary knowledge base is provided.
Lov om forvaltning av naturens mangfold (naturmangfoldloven)	Nature Diversity Act	2009	The Nature Diversity Act ensures that biological, geological and landscape diversity and its ecological processes are taken care of through sustainable use and conservation. This to provide a basis for human activity, culture in general and the Sami culture in particular, human health and wellbeing for now and in the future.
Lov om fornybar energiproduksjon til havs (havenergilova)	Offshore Renewable Energy Act	2010	This Act facilitates the utilization of renewable energy resources at sea in accordance with social objectives, such that energy facilities are planned, built, and utilized while safeguarding the environment, human safety, commercial activities and other interests.
Lov om elsertifikater	Act on Electricity Certificates	2011	The purpose of this Act is to contribute to the production of electricity from renewable energy sources through the creation of a common market in Norway and Sweden for the exchange of renewable electricity certificates. This trade is to stimulate increased production of electricity from renewable sources.

Appendix 2. EU directives ratified by Norway with relevance to renewable energy and biodiversity

Directives are given in chronological order in which they came into force.

English title	Reference	Entered into force	Rationale
Environmental Impact Assessment Directive (EIA)	85/337/EEC	1985	The common principle of the Directive is to ensure that projects likely to have significant effects on the environment are made subject to an environmental assessment, prior to their approval or authorisation.
Water Framework Directive	2000/60/EC	2000	The Water Framework Directive aims to achieve good qualitative and quantitative status of all water bodies (including marine waters up to one nautical mile from shore) by 2015. One important aspect is the introduction of River Basin Districts, which have been designated, not according to administrative or political boundaries, but rather according to the river basin (the spatial catchment area of the river) as a natural geographical and hydrological unit.
Strategic Environmental Assessment Directive (SEA)	2001/42/EC	2001	The common principle of the Directive is to ensure that public plans and programmes likely to have significant effects on the environment are made subject to an environmental assessment, prior to their approval or authorisation.
Renewables Directive	2009/28/EC	2009	The Directive on renewable energy aims at a 20% share of energy from renewable sources within the EU by 2020. It also improves the legal framework for promoting renewable electricity and establishing pathways for the development of renewable energy sources.

Appendix 3. International conventions and agreements with relevance to renewable energy and biodiversity

Conventions and agreements are given in chronological order in which they came into force.

English title (acronym)	Under auspices of	Entered into force	Rationale
Convention on Wetlands of International Importance (Ramsar Convention)	United Nations	1975	The Ramsar Convention is an intergovernmental treaty that provides the framework for national action and international cooperation for the conservation and wise use of wetlands and their resources. It aims to protect wetlands especially as habitat for waterfowl, but now extended with the inclusion of flora and fauna protection and as nature resource for people.
Convention for the Conservation Of Salmon in the North Atlantic Ocean (NASCO)	Inter-governmental (CA, DK, EU, NO, RU, USA)	1983	NASCO's objective is to conserve, restore, enhance and rationally manage wild Atlantic salmon. It adopts and applies a Precautionary Approach to the conservation, management and exploitation of salmon in order to protect the resource and preserve the environments in which it lives. One key issue is to maintain and, where possible, increase the current productive capacity of Atlantic salmon habitat through habitat protection and restoration.
Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention)	United Nations	1983	The Bonn Convention aims to conserve terrestrial, aquatic and avian migratory species throughout their range. It acts as a framework Convention specialized in the global conservation of migratory species, their habitats and migration routes.
Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention)	Council of Europe	1986	The Bern Convention is a binding international legal instrument in the field of nature conservation, which covers most of the natural heritage of the European continent and extends to some States of Africa. Its aims are to conserve wild flora and fauna and their natural habitats and to promote European co-operation in that field. The Convention places a particular importance on the need to protect endangered natural habitats and endangered vulnerable species, including migratory species.
Convention on Biological Diversity (CBD)	United Nations	1993	Signed by 150 government leaders at the 1992 Rio Earth Summit, the Convention on Biological Diversity is dedicated to promoting sustainable development. CBD has three main objectives: (1) the conservation of biological diversity,(2) the sustainable use of the components of biological diversity, and (3) the fair and equitable sharing of the benefits arising out of the utilization of genetic resources.
United Nations Framework Convention on Climate Change (Climate Convention)	United Nations	1994	UNFCCC is the central framework for international cooperation to combat climate change and prepare for adaptation to climate change. The Kyoto Protocol (2005) is a follow-up of the Climate Convention in that it sets binding and quantified emission reduction commitments for industrialized countries. The goal is to reduce industrialized countries' emissions of greenhouse gases by at least five percent compared to 1990 levels over the period 2008-2012.

The Convention for the Protection of the marine Environment of the North-East Atlantic (OSPAR)	15 contracting European governments and EU	1998	The OSPAR Convention is the current legal instrument guiding international cooperation on the protection of the marine environment of the North-East Atlantic. OSPAR is implementing a five thematic strategies to address the main threats (the Biodiversity and Ecosystem Strategy, the Eutrophication Strategy, the Hazardous Substances Strategy, the Offshore Industry Strategy and the Radioactive Substances Strategy), together with a Strategy for the Joint Assessment and Monitoring Programme. These six strategies fit together to underpin the ecosystem approach, among others resulting in Marine Protected Areas.
European Landscape Convention	Council of Europe	2004	The European Landscape Convention promotes the protection, management and planning of European landscapes and organizes European co-operation on landscape issues.

874

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Norwegian Instutute for Nature Research
NINA head office
Postal address: P.O. Box 5685 Sluppen, NO-7485 Trondheim, NORWAY
Visiting address: Tungasletta 2, NO-7047
Phone: +47 73 80 14 00, Telefax: +47 73 80 14 01
E-mail: firmapost@nina.no
Organization Number: 9500 37 687

http://www.nina.no

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