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ASSESSING ENVIRONMENTAL IMPACTS OF RENEWABLE POWER

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INTRODUCTION

Electrical power systems based on renewable energy sources are often intuitively perceived as environmentally benign. This may be true at least for comparisons between electricity generated by combustion of fossil fuels and non-combustion-based renewable sources, at least in terms of contributions to greenhouse gas (GHG) emissions (Chapter 7) and other air polluting gases. However, there exists no system generating electric power for applications on commercially relevant scales that is completely without unwanted environmental side effects; it is more a question of which environmental effects and their severity. Given the serious implications of climate change, the motivation to find substitutes for fossil-based energy systems is strong, but it is likewise important to not solve one environmental problem by creating another, although of a different type. In order to prevent that, systematic investigations and assessments of the environmental performance of different renewable electricity sources become crucially important.

The methods applied for environmental assessments of renewable energy sources need to be applicable to a number of fundamentally different energy systems, spanning from the construction of offshore wind power farms to hydroelectric power dams. These different energy sources provide a set of very different environmental impacts occurring in many different ecosystems. The challenge of the environmental assessment methods is to deliver assessment results that are fair and encompass the various significant environmental impacts under different

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conditions. Particularly when seen from a life-cycle perspective, encompassing the raw material extraction, production and use of the energy, a number of environmental impacts in terms of both resource extraction and emissions become apparent, even for renewable energy systems. Therefore, careful consideration of environmental impacts of renewable energy systems along the entire life-cycle of the energy systems is important to avoid serious environmental repercussions (see also Chapter 8).

In addition, based on earlier experiences, it is apparent that the specific design, location and scale of e.g. hydro and wind power installations are factors that to a large extent determine their environmental impacts (see also Chapter 9). A smaller installation will often result in less environmental impact than a large-scale. These factors are so-called site-dependent and cannot easily be assessed in a standardised manner, which calls for flexible and adjustable assessment methods that can be adapted to the specific case. An unfortunate location of a hydropower dam does not mean that the entire technology carry unacceptable environmental impacts, just that the specific location or design in the specific case is unfortunate.

This chapter aims at a general description of the challenges posed when trying to assess environmental impacts of renewable energy technologies and to, with limited technical detail, introduce the ways environmental impacts are assessed. Furthermore, a few specific examples will be employed to exemplify environmental impacts of renewable power systems.

HOW TO ASSESS ENVIRONMENTAL IMPACTS?

The most important aspect of the environmental assessment methods is to allow for comparisons. The driver of comparisons of alternatives regarding renewables is to provide arguments underpinning the choice of (1) energy technologies, (2) their design of specific installations, and even (3) the long-term development of large energy systems. The challenge is to cover the many different renewable energy sources, their construction, operation and decommissioning phases, and the different kinds of environmental impacts associated.

In general, environmental assessment is a matter of linking the human activities related to the (renewable) energy source under consideration with the environmental impacts of concern. This idea is illustrated in Table 6.1.

The framework in Table 6.1 illustrates the linking of human activities during the life-cycle stages of the energy infrastructure to identified environmental endpoints of concern. Stressors are factors, external to an organism, which will restrict its availability of resources, growth or reproduction. The outcomes of exposure to stressors are changed ecosystem structure or functions. In order to indicate these, environmental indicators can be applied.

Environmental indicators can directly indicate effects on endpoints, or along the pathway of stressors from source to endpoint. Pressure-state-impact (PSI) type of indicators was described in OECD-reports[1] and further developed into the

1 See e.g. OECD (1993) *Environment Monographs no.83 - Core Set of Indicators for Environmental Performance Reviews, A Synthesis Report by the Group on the State of the Environment.* Paris, France: OECD (OCDE/GD(93)179).

European driving forces-pressures-states-impact-response (DPSIR) framework.[2] Several hundreds of indicators related to environmental pressures, states and impacts have been identified and likewise the number of ecologically relevant endpoints is very large.

Table 6.1 Framework that combine life-cycle thinking and an ecological risk assessment approach with examples of stressors, endpoints and environmental indicators. PSI stands for pressure-state-impact.

Life-cycle stage of renewable power technology	Stressors	Environmental indicators along pathways or for effects on environmental endpoints (PSI-indicators)	Endpoints
Production of raw materials & manufacturing of power generating infrastructure	Resource extraction, emissions from mining, emissions from power production for manufacturing	Emitted amount of specific substance like copper emitted from mining (ton/year)	Atmospheric energy balance, nutrient status of sea water
Installation	Habitat destruction or disturbance	Area occupied by installations (ha)	Specific species, or biodiversity in general
Operation and maintenance	Emissions from operations	Emitted amount of specific substance, like greenhouse gas emissions (ton/year), collisions caused by moving turbines (no. of individuals of specific specie)	Atmospheric energy balance, nutrient status of sea water, specific species, or biodiversity in general
Decommissioning & waste handling	Toxic emissions from waste handling	Emitted amount of specific toxic substance, like leakage of lead from landfills (ton/year)	Specific species, or biodiversity in general

In addition to the description and comparison of environmental impacts, trade-offs between technologies, designs, costs and, accordingly, between different environmental impacts are of great importance. So beside direct comparisons within the same category of impacts, there is a wish to perform trade-offs between environmental impacts. Trade-offs are unavoidable when decisions are taken, and when dealing with collective decisions, trade-offs should involve a conscious weigthing of perceived positive ("gains") and negative ("losses") consequences of different energy systems. This ideal is, however, seldom pursued in real world situations.

The idea of linking causes to effects, illustrated in Figure 6.1, is at the core of the different environmental assessment methods. These include retrospective, prospective and product-related, process-related and project-related methods.[3] Despite their differences, both the process- and project-related types of

2 Smeets, E. and Weterings, R. (1999) *Environmental indicators: Typology and overview*. Copenhagen, Denmark: European Environment Agency (Technical report No 25).

3 As identified by Ness, B. et al. (2007) Categorising tools for sustainability assessment. *Ecological Economics,* 60(3):498-508.

environmental assessment (e.g. Environmental Impact Assessment, EIA, Strategic Environmental Assessment, SEA, and Ecological Risk Assessment, ERA) and the product-related, non-site specific, type of assessment methods (e.g life-cycle assessment, LCA) maintain the same basic idea. The differences between assessment methods lie more in how the various methods are designed and organised with regards to stressors, indicators and endpoints.

Life-cycle assessment (LCA) has from its inception as a product design support method developed to an excellent mean for quantitative comparisons of the environmental performance of products.[4] The way LCA is standardised for application on products with long and complex product chains has made it a popular method of choice.[5] However, the standardisation of impacts assessment within LCA makes site-independent and more specific spatial considerations difficult, if not impossible, to include. Within LCA, the comparability issue has been high on the agenda from the very beginning. Making trade-offs within LCA is also possible in the voluntary normalisation and weighting steps. These methods are, however, much dependent on subjective values.

Inclusion of spatial differences are on the other side the strength of EIA, which is also flexible regarding contents and open for information from various other environmental assessment methods. Many EIAs have, on the other hand, been less clear when it comes to structured and systematic comparisons of alternatives. This shortcoming has been improved in the development of EIA into the SEA procedure, in which the formulation of alternatives to assess together with the establishment of base-line conditions, environmental indicators and recurring monitoring are important tenets.[6] Furthermore, trade-offs has not been focused enough in EIA, since much practice in the field has been done in order just to fulfil legal requirements.[7]

The procedures and rules for trading-off is a key issue that has got specific attention in sustainability assessments since the various social and ecological aspects of sustainability require radically different approaches for trade-off than earlier recognised.[8] Furthermore, trade-offs are needed to be performed *under* the core criteria for sustainability assessment, which among other aspects include maintenance and enhancement of socio-ecological system integrity; resource maintenance and efficiency; and precaution and adaptation. These rules and criteria await their application in assessments of renewable energy sources, and clearly go beyond only environmental considerations.

The recent developments within sustainability assessments may be of specific interest for environmental assessments of renewable energy technologies. This

4 See e.g. Baumann, H. and Tillman, A.-M. (2004) *The Hitch Hiker´s Guide to LCA - An orientation in life cycle assessment methodology and application.* Lund, Sweden: Studentlitteratur.

5 ISO (2006) *Environmental management – Life cycle assessment – Principles and framework.* Geneva, Switzerland: International Organisation for Standardisation (ISO 14040:2006).

6 Therivél, R. (2004) *Strategic Environmental Assessment in Action.* 2nd edition. London, UK: EarthScan Ltd.

7 Runhaar, H. et el. (2013) Environmental assessment in The Netherlands: Effectively governing environmental protection? A discourse analysis. *Environmental Impact Assessment Review,* 39:13-25.

8 Gibson, R. B. (2006) Sustainability assessment: basic components of a practical approach. *Impact Assessment and Project Appraisal,* 24(3):170-182; Morrison-Saunders, A. and Pope, J. (2013) Conceptualising and managing trade-offs in sustainability assessment. *Environmental Impact Assessment Review,* 38:54-63.

since the problem of comparing renewable energy technologies from an environmental point of view brings about a number of complicated, or even wicked, problems to handle.[9] The wickedness is due to the fact there will be no simple formal set of criteria for evaluating the environmental performance. Despite the recommendations of Gibson[8] and Morrison-Saunders and Pope[8], further specifications may be required, and as often shown - the devil is in the details. Low emission of GHGs per kWh of wind power will not easily convince antagonists claiming that wind power is ugly, breaking the horizon line of their sea views, or bird watchers worrying for birds colliding with the turbines. The trouble is in the incommensurable units of GHG emission on the one hand and the preferences related to the appreciation of an unbroken horizon, or birds, on the other. The complication becomes especially obvious as the groups and individuals involved often do not communicate making the bridging of these types of controversies difficult. If the trade-off rules of Gibson[7] can overcome this kind of troubles remains to be demonstrated in further studies.

Under the wide umbrellas of assessment procedures such as EIA, SEA and sustainability assessment, a number of more specific assessment methods can be used. Ness and colleagues identified in their review of methods for sustainability assessment at least 30 families of methods, of which about half are fully or partly applicable for environmental assessments of renewable energy systems including tools for handling comparison and trade-offs.[10]

WHAT ENVIRONMENTAL IMPACTS TO ASSESS?

The questions of which environmental assessment method to apply and how to perform trade-offs need to be handled in parallel with considerations of what environmental impacts to assess. As pointed out, there are different kinds of impacts and the renewable energy sources differ in terms of which environmental impacts they cause. Therefore, performing an environmental assessment of renewable energy sources is a matter of reducing the complexity and to establish boundaries for the assessment based on the initial considerations of comparability and trade-off.

Given the many and complex interactions in ecosystems, simplification of environmental impact is a challenging task. Ecological Risk Assessment, ERA, has developed into a useful method also for the assessment of renewable energy sources.[11] The ERA framework has the ability to inform tailored, detailed and site-specific assessments. The basic idea is to make quantitative assessments of the impacts of stressors on selected endpoints. Therefore, one of the most crucial aspects is the selection of endpoints for the ERA.

What are the ecological effects in focus? A large number of interlinked physico-chemical and biological parameters can be identified in an ecosystem and pointing out particular species such as the peregrine falcon, or a physico-chemical

9 Rittel, H. W. J. and Webber, M. M. (1973) Dilemmas in a General Theory of Planning. *Policy Sciences,* 4(2):155-169.

10 Ness, B. et al. (2007) Categorising tools for sustainability assessment. *Ecological Economics,* 60(3):498-508

11 Efroymson, R. A. (2009) Wind Energy: The Next Frontier for Ecological Risk Assessment. *Human and Ecological Risk Assessment,* 15(3):419-422; Hammar, L., Wikström, A. & Molander, S. (2014) Assessing ecological risks of offshore wind power on Kattegat cod. *Renewable Energy,* 66:414-424.

parameter like water turbidity, to be the focal point of an assessment cannot be done in one way only. Individuals, including environmental scientists, have different preferences regarding object of protection and the "best" way to reduce the complexity of the ecosystem down to some few selected parameters in focus. There are many, potentially crucial, abiotic and biotic parameters in an ecosystem that can be observed. Wind power may cause fatalities to birds due to collisions if inappropriately located, some turbines can leak oil from bearings under unfortunate conditions, and noise can disturb. Hydropower may rely on dams hindering migrating fish, and dams can generate methane from inundated rotting biomass.

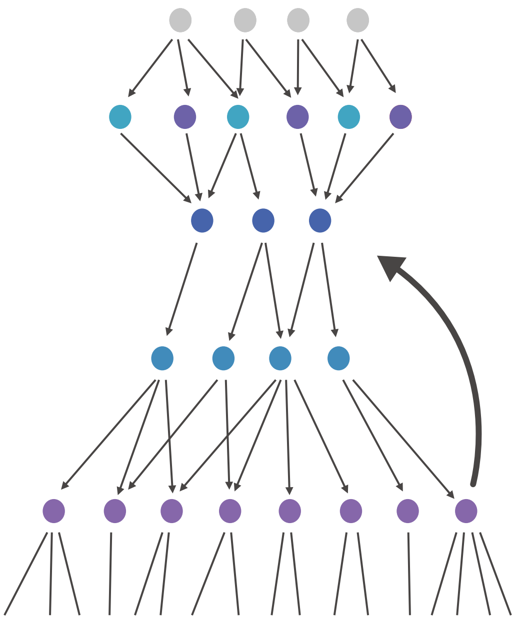

Figure 6.1 The ecological cause-effect cascade that follows the introduction of a stressor in an ecosystem is a consequence of the linkages mainly in the food-web. Due to links and feedback loops within the ecosystem, impacts will not be limited to the first order, or direct, effects observable close to the stressor source. However, biotic and abiotic negative feedback regulation within the system will often dampen effects to stay within a given range until a sudden shift may force the system into another relatively stable range under a new set of negative feedbacks. Nyström, M. et al. (2012).

The identification of endpoints, or objects of protection, is therefore a specific challenge of ERA and other environmental assessment methods. Different approaches such as checklists, expert judgment and participatory approaches for identification of endpoints have been suggested in order to address this challenge.[12] In LCA, the endpoints, called areas of protection, are pre-defined to be human health, the natural environment (with a number of more or less specified end-points) and natural resources.[13]

It is also possible to use political goals for the identification of endpoints. In a Swedish study, the Swedish National Environmental Objectives (SNEOs) were used in a stepwise procedure to identify more specific endpoints, and indicators,

12 US EPA (1998) *Guidelines for Ecological Risk Assessment.* Washington, DC, USA: U.S. Environmental Protection Agency (EPA/630/R-95/002F).; Burgman, M. A. (2005) *Risks and Decicions for Conservation and Environmental Management,* Cambridge, UK: Cambidge University Press.
13 Baumann, H. and Tillman, A.-M. (2004) *The Hitch Hiker's Guide to LCA - An orientation in life cycle assessment methodology and application.* Lund, Sweden: Studentlitteratur.

connected to the more vaguely formulated SNEOs.[14] The procedure therefore relied on a deconstruction and specification of the SNEOs down to endpoints, and related environmental indicators, representing the SNEOs and linking these indicators to stressors from various life-cycle stages of renewable energy sources (see example in Figure 6.2).

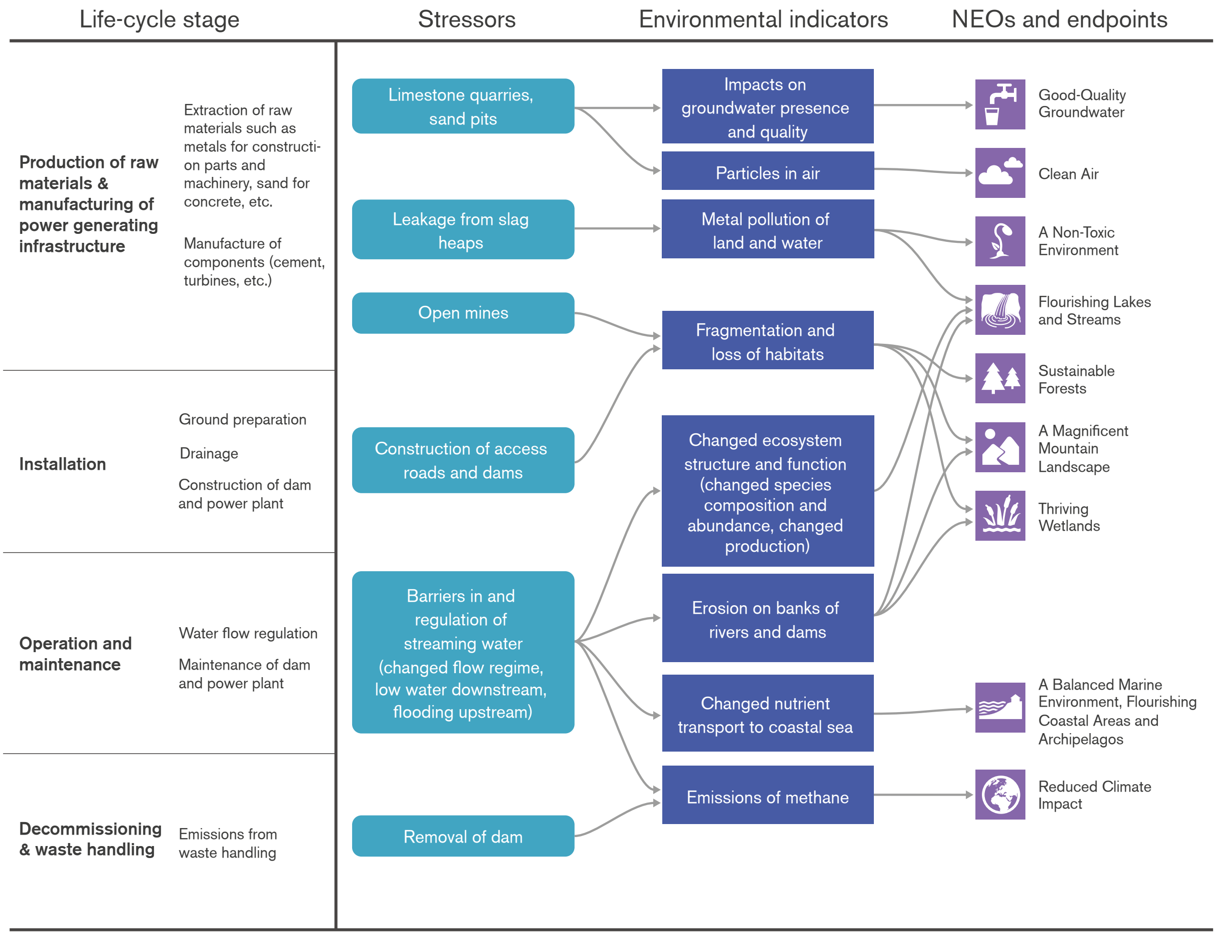

Figure 6.2 The direct links between Swedish National Environmental Goals (SNEOs) and stressors emerging from hydropower production systems. Indirect links of the prominent background systems that contain e.g. energy production's and transports' contribution to the total environmental impact were not included in the assessment. The direction of arrows indicates the material influences in the cause-effect chain from release or occurrence of stressors to effects on endpoints. The procedure for establishing links works in the opposite direction starting with the SNEOs and their specification into indicators and linking to human activities along the life-cycle stages of the energy system.

THE CASE OF HYDROPOWER

Hydropower provided globally 3700 TWh in 2012, which was approximately 2% of the total primary energy supply.[15] In the last decade, output has grown by 100 TWh/year annually, and the potential provision is estimated at 8 000-16 000 TWh/yr (Chapter 3-4).

In Sweden, 67 TWh, (or 43%, annual means) of the electrical energy generated stems from hydropower.[16] The main operator Vattenfall AB, contribute 32 TWh

14 Molander, S., et al. (2010) *Förnybara energikällors inverkan på de svenska miljömålen*. Stockholm, Sweden: Swedish Environmental Protection Agency (Report 6391).

15 IEA Statistics (2013). [online]

16 Swedish Energy Agency Energy Statistics *Energy commodity balance* in *2011* (2014) [online].

(48%) and has performed environmental assessments for their operations of hydropower in accordance with the Environmental Performance Declarations (EPD).[17] These assessments of hydropower cover 13 Swedish installations or about 15% of all Swedish hydropower, representatively spread across the country. The report includes stringently performed LCAs according to documents of the International EPD Consortium (IEC).[18] The assessments have also included environmental information based on other methods for impacts on biodiversity, land-use and environmental risks in accordance with the Product Category Rules (PCR) of IEC.

The LCA reported by Vattenfall covered installation (including the release of GHG due to inundation of land in reservoirs), operation and maintenance, and distribution.[16] The LCA inventory is extensive and includes 25 used resources, 10 types of energy inputs, 25 emitted substances with impacts on global warming, ozone-depletion, acidification, eutrophication or ground level ozone, and 17 emitted toxic, radioactive or otherwise environmentally significant substances (e.g. ammonia, arsenic, oil and polyaromatic hydrocarbons). The depletion of phosphorus due to deposition in sediments of water reservoirs is furthermore included, together with 11 waste streams.

The methods employed for the additional environmental information regards impacts on land-use change, specifically on biodiversity, and environmental risks in a broad sense. The estimation of impacts on biodiversity applies a method specifically developed by Vattenfall. The so called Biotope Method is based on a categorisation of land into four different biotope categories and land-use change caused by the construction of hydropower plants and the huge reservoirs.[19] The Biotope Method is regarded as admittedly coarse by Vattenfall and does not cover fragmentation and barrier effects or effects due to the changed flow regime.[16] These effects are known to contribute significantly to the environmental impacts, but also differ much due to the specific design, size and location of the installations.[20]

A further comparison of the endpoints covered by the EPD-report's combination of LCA and other methods and data underlying Figure 6.2 shows mostly overlapping categories where the Vattenfall EPD reports many, and detailed, environmental flows for the LCA-case, which is far beyond the coverage of the SNEOs and their related indicators. The EPD report covers many environmental aspects and the coverage is much better than ordinary EIAs or LCAs due to the combination of assessment methods.

This is clearly a benefit, but still many significant effects are not covered, such as the impacts on biodiversity along the rivers due to the altered flooding regime or the altered nutrient transport to the Baltic Sea. Furthermore many of the installations included were constructed in the period prior to modern legislation. EIAs

17 Vattenfall (2011) *Certified Environmental Product Declaration EPD of Electricity from Vattenfall's Nordic Hydropower*. Stockholm, Sweden: Vattenfall AB.
18 Vattenfall (2011).
19 Kyläkorpi, L. et al. (2005) *The Biotope Method 2005 - A method to assess the impact of land use on biodiversity*. Stockhom, Sweden: Vattenfall AB.
20 WCD (2000). *Dams and Development - a new framework for decision-making*. London and Sterling, VA, USA: Earthscan Publications.

were never performed,[21] making stringent comparisons to real baseline conditions impossible, and without that only comparisons to other, non-exploited, sites of similar ecosystems can be performed leaving room for some uncertainty. However, major impacts, such as impacts on fish migration, can be indirectly inferred.

A notable difference between the different installations concerns the land-use change caused by the inundation upstream dams. Expressed as loss of critical biotope per energy gained the results spans a range of around 100 between the least and the most biotope damaging among the studied Swedish hydropower plants (from around -15 ha/GWh electricity to -1500 ha/GWh). This is in accordance with the wide span of the ratio of reservoir area to annual mean power production, which is from 0.2 to 47 ha/GWh. A similar wide span, but on a global scale, has been reported for GHG emissions from hydro power reservoirs and a geometric mean emission of methane among some 150 reservoirs of 0.6 gCH_4/kWh, with a geometric standard deviation equal to 46 was found. This corresponds to a span from about 10 µg to 1 kg CH_4/kWh. Hertwich points out that it is likely that for maybe up to 10% of hydropower installations the biogenic GHG contribution reach levels comparable with electricity generation from natural gas combined cycle power plants, which are among the low-GHG-emitting fossil fuel systems.[22]

It is clear that the local conditions and the specific design of hydropower installations strongly influence the environmental performance, both regarding impact on biodiversity and GHG.

THE CASE OF WIND POWER

Wind power is globally increasing at a fast rate and the installed capacity was 280 GW in 2012, with a total production estimated at around 500 TWh in the same year. The global potential might be of the same order of magnitude as current global primary energy supply (Chapter 3).

In Sweden, wind power supplied 7 TWh in 2012, up from 1 TWh in 2006. The production in 2012 corresponds to 4% of total power supply.[23] Wind power is rapidly expanding despite an extensive debate on various impacts - environmental, social and technical (see also Chapter 9, 11 and 13-15).

Vattenfall AB is also involved in Swedish wind power and owns, and operates, 11 wind farms, 8 onshore and 3 offshore, with 129 turbines. In 2011, the installed capacity was 0.2 GW and the electricity production reached 0.7 TWh. Also for wind power Vattenfall has performed an environmental assessment in accordance with the Environmental Performance Declarations (EPD).[24] The assessment cover four Swedish installations or about 80% of Vattenfall's Swedish wind power (or 9% of all Swedish wind power), representatively spread across the country. As

21 Nizami, A. S. et al. (2011) Comparative analysis using EIA for developed and developing countries: Case studies of hydroelectric power plants in Pakistan, Norway and Sweden. *International Journal of Sustainable Development and World Ecology,* 18(2):134-142, and references therein.

22 Hertwich, E. G. (2013) Addressing Biogenic Greenhouse Gas Emissions from Hydropower in LCA. *Environmental Science & Technology,* 47(17):9604-9611.

23 Swedish Energy Agency Energy Statistics *Energy Commodity Balance 2012* (2014).

24 Vattenfall (2011) *Certified Environmental Product Declaration EPD of Electricity from Vattenfall's Nordic Hydropower.* Stockholm, Sweden: Vattenfall AB.

for the hydropower assessment the environmental assessment of wind power followed the EPD-guidelines and included impacts on biodiversity, land-use and environmental risks.

As for the hydropower LCA, the wind power LCA inventory is extensive and includes 26 used resources, 10 types of energy inputs, 25 emitted substances impacting on global warming, ozone-depletion, acidification, eutrophication or ground level ozone, and 17 emitted toxic, radioactive or otherwise environmentally significant substances (e.g. ammonia, arsenic, oil and polyaromatic hydrocarbons), together with 11 waste streams.

As in the case of hydropower, a set of complementary methods provides valuable insights on land-use, biodiversity, environmental risks (mostly leakage of oils and fluids related to accidents with transports during maintenance), electromagnetic fields, noise and visual impacts. The assessed wind power plants were constructed in the time period from 1998 to 2010, during which base line conditions have been examined giving, in contrast to hydropower, the possibility to monitor changes caused by the installations. This has been of particular interest regarding impacts caused by the offshore wind farms on the marine benthic ecosystems where effects are clear, but often considered positive since biodiversity increase due to the introduction of hard substrata in soft-bottom dominated areas and due to shelter from fishery (see also Chapter 8).[25]

Collisions between turbines and birds and bats have attracted considerable interest, but the Vattenfall report, in agreement with most studies, consider collision risk to be low and only important in exceptional cases of badly located wind farms.[26]

Another risk, that has attracted much less interest, is related to spills of lubricants from the operation (including accidents) of wind turbines. The risk is mentioned in the Vattenfall report and a report has found that such risks need further observations in order to be estimated and uncertainties reduced.[27]

As for hydropower a notable difference between the different installations concerns the land-use change caused by the installations. Expressed as loss of biotope per energy gained the results indicate a difference of about 200 times between the less area efficient on-shore and the off-shore wind farms (Table 6.2). However, a comparison between the on-shore wind power case and the large scale hydropower of the huge installations in the Lule River indicates that generation of electricity is about half as area efficient as land-based wind power, but very much less area efficient in comparison to the off-shore wind power case of Lillgrund.

25 Molander, S., et al. (2010) *Förnybara energikällors inverkan på de svenska miljömålen*. Stockholm, Sweden: Swedish Environmental Agency (Report 6391).; Wilhelmsson, D. and Malm, T. (2008) Fouling assemblages on offshore wind power plants and adjacent substrata. *Estuarine Coastal and Shelf Science,* 79(3). pp. 459-466.; Reubens et al. (2014) The ecology of benthopelagic fishes at offshore wind farms: a synthesis of 4 years of research. *Hydrobiologia,* 727(1):121-136.
26 Eichhorn et al. (2012) Model-Based Estimation of Collision Risks of Predatory Birds with Wind Turbines. *Ecology and Society,* 17(2), art.1.; Bright et al. (2008) Map of bird sensitivities to wind farms in Scotland: A tool to aid planning and conservation. *Biological Conservation,* 141(9):2342-2356.
27 Arvidsson, R. and Molander, S. (2012) *Screening Environmental Risk Assessment of Grease and Oil Emissions from Off-Shore Wind Power Plants*. Göteborg, Sweden: Chalmers University of Technology.

Table 6.2 Examples of land appropriation for renewable power production comparing on-shore and off-shore wind power and large scale hydropower using an indicator for land-use change related to net electricity production. Source: Adapted from Swedish Energy Agency Energy Statistics (2014) and Vattenfall (2013), along with specific data for the Lule River power plants from Vattenfall (2014).

	Mean annual net production (GWh)	Annual mean net electricity production per appropriated area (GWh/ha)	Biotope categories	Area before installations (ha)	Area after installations (ha)	Change of biotope category (ha)	Change of biotope per annually generated electricity (ha/GWh)
Wind farm - on-shore	**240**	**4.3**	Critical biotope	5.4	0	-5.4	-1.2
Stor-Rotliden			Rare biotope	21	0	-20.7	-4.8
(Northern Norrland)			General biotope	39	10	-29.4	-6.8
			Technotope	5.7	61	55.5	12.8
Wind farm - off-shore	**320**	**1400**	Critical biotope	1.8	1.8	-0.03	$-1.9 \cdot 10^{-05}$
Lillgrund			Rare biotope	2.3	2.3	-0.06	$-3.9 \cdot 10^{-05}$
(Öresund)			General biotope	2.9	2.8	-0.15	$-1.1 \cdot 10^{-04}$
			Technotope	0.18	0.41	0.23	$1.6 \cdot 10^{-04}$
Hydro power	**13800**	**2.0**	Critical biotope	5870	0	-5870	-2920
Lule River			Rare biotope	863	35	-829	-413
(Northern Norrland)			General biotope	3650	3500	-157	-78
			Technotope	110	6960	6850	3410

CONCLUDING DISCUSSION

In some aspects, impacts from renewables are very different from the ones caused by the fossil fuel based systems. Particularly land-use, and subsequent environmental impacts, is an example of such impacts. Other impacts, such as air pollution from biomass combustion (while not included in this book), resemble to large extent air pollution from fossil fuel combustion. Such combinations of differences and similarities provide difficulties when comparing and relates to the question of what in fact is compared.

Comparisons may be on the level of technologies or relate to specific designs (see also Chapter 7-8). The comparisons can also deal with specific installations. For this last category, site-specific conditions will determine the direct environmental consequences to a large extent. To reach further, the combination of LCA and other environmental assessment methods seem to be a way forward that has been applied to a certain extent in the EPD approach. Wide differences in environmental impact are demonstrated within the technologies of hydro and wind power, as are described above. These differences need to be considered along with average differences between technologies. The scale of the installations is also of importance since the relationship to environmental impact is not always linear. The extensive coverage of flows in LCA studies makes detailed comparisons across technologies possible. However, the normalisation of the flows to a certain base for comparison - one functional unit - will disregard differences in scale and site-specific factors.

It may be fair to state that simple between-technologies-comparisons can only be done for some specific parameters, see e.g. Table 6.2. It is also possible to compare LCA-based estimates of contributions to global warming from GHG emissions (Chapter 7). However, even that turns out to be a less straightforward exercise, e.g. regarding the biogenic carbon dioxide emissions of large hydro-power installations.

There are also severe difficulties related to incommensurable effects. It is not easy to compare widely different types of impact. It is even difficult to compare different impacts on biodiversity between e.g. wind power, where collisions of birds and bats occur, and hydropower where fish are injured or killed when passing turbines, dams are hindering fish migration and flooding regimes are disturbed. Experiences point to a practice where novel suggestions regarding trade-offs need to be considered.

Notwithstanding the mentioned difficulties, environmental assessments can and need to be performed. To define the questions regarding what to assess, and how to do it, broader and more consistent approaches can be a way forward.

Finally, there are no energy systems without some environmental repercussions. A transition to renewable power will not eradicate the benefits of reducing energy demand, and strategies aiming at efficient use of energy will remain crucial to limit the environmental impact of power production.