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Development of small versus large hydropower in Norway– comparison of environmental impacts

Tor Haakon Bakken[a*], Håkon Sundt[b], Audun Ruud[a] & Atle Harby[b]

a SINTEF Energy Research, Forskningsveien 3B, Pb 124 Blindern, 0314 Oslo, Norway
b SINTEF Energy Research, Sem Sælands vei 11, Pb. 4761 Sluppen, NO-7465 Trondheim, Norway

Abstract

This study has compared the accumulated environmental impacts from 27 small-scale hydropower plants with 3 large hydropower projects. The results show a slight tendency that large hydropower has a lower degree of impacts than many small-scale projects, but lack of precision in the data and weak methodological foundation introduces uncertainty in the results. Taking into account other benefits such as the provision of regulated power, it is reasonable to assume that a few large hydropower projects will produce electricity to a lower environmental cost compared to many small projects, which should be considered when realizing renewable energy policy objectives.

Keywords: small-scale hydropower, large hydropower, environmental impacts, accumulated impacts, comparison

1. Introduction

1.1. Point of departure

It is pertinent to reconsider the strategy of new hydropower developments when Norway is pursuing ways of implementing the political objectives related to the promotion of renewable energy. Currently Norway is specifying its National Renewable Energy Action Plan (NREAP) in accordance with the commitment of the Renewable Energy Sources (RES) Directive. One of the major initiatives recently approved, is the joint certificate market with Sweden which will stimulate renewable electricity

* Corresponding author. *E-mail address*: tor.haakon.bakken@sintef.no

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production of 26.4 TWh in Norway and Sweden – including hydropower. During the last 10 years, there has been a boom in the development of small-scale hydropower (< 10 MW). At the same time, the development of large hydropower has been very limited. The reason for this situation is due to political priorities given for the development of small-scale hydropower. We believe there is a tendency in the public opinion that 'small-scale hydropower is considered green and beautiful', while large-scale hydropower projects have a reputation to cause dramatic and negative impacts to the environment. More lately, the issue concerning fragmentation of untouched nature by many small projects, however, has been raised by scientists, e.g. (Erikstad *et al.*, 2009), and environmental concerns related to the massive development of small-scale hydropower have also been expressed in the public media (http://www.tu.no/energi/article292839.ece) (accessed February 24th, 2012). At the same time, research has continuously been pursued to identify good design-solutions balancing the need for electricity production while protecting the environment for large projects, including mitigation options, downstream flows and environmental flows in bypass sections. A number of the potential new large-scale hydropower projects are in already regulated river basins, meaning that 'the environmental damage is already made' and extensions of the production capacity in such projects can probably be made with limited additional environmental impacts. Further, it may also be possible to identify and develop large projects actually improving the environmental standard in rivers already extensively regulated, so-called 'win-win solutions' (Thaulow *et al.*, 2008). This same flexibility is not apparent when we refer to small-scale projects – particularly those located in virgin, not previously exploited cathments. Hence, with respect to minimizing the environmental impacts from hydropower development, we should question whether a large number of small hydropower projects are better than one or a few large projects.

1.2. Legislative framework

A number of legal acts and regulations apply to different stages of initiating, planning, licensing and revision of hydropower projects. The most essential are the Industrial Concession Act, the Watercourse Regulations Act and the Water Resources Act. In contrast to licences granted by the Water Resources Act, the Watercourse Regulation as well as the Industrial Concession Act prescribes a revision of the specific licences. Those granted before 1992 can be revised after 50 years, while the newer ones can be granted after 30 years. In addition, the Planning and Building Act (PBA) applies for the localisation of the hydropower plants above a certain size level measured in MW, as well as additional installations and infrastructure. The Energy Act regulates the technical installations related to hydropower production, including the connection to the grid. In addition to the role played by the energy regulator NVE (Norwegian Water Resources and Energy Directorate) and other public authorities at the national level, both the municipalities and counties are provided with the mandate of managing overall objectives and principles for affected areas and the relevant land-use within their jurisdictions. Regional and local assessments substantially influence the potential for existing and future hydropower projects.

The Water Regulation Act ('Vannforskriften') (Miljøverndepartementet, 2006) was adopted in late 2006 as Norway's main follow-up instrument of the EU Water Framework Directive (WFD) (OJEC, 2000), and entered into force on January 1st, 2007. Norwegian authorities selected 29 pilot areas with the common EU implementation, thereby being able to participate in the 'common European learning process' (http://www.vannportalen.no/enkel.aspx?m=40354) (accessed February 24th, 2012). This initial phase is, however, not part of Norway's formal follow-up, which is constituted by the next planning phase to be coordinated with the second phase of the WFD implementation (Knudsen and Ruud, 2011). A complete picture of the effect of the WFD in Norway will not be available before 2015.

Still, the legislative framework is being challenged due to the implementation of the WFD. The National Association of Hydropower Municipalities (LVK), together with other NGOs representing environmental and recreational interests, have complained to the EFTA Surveillance Authority (ESA) about Norway's implementation of the WFD in the pilot phase (http://www.lundogco.no/Documents/lvk/LVK%20revisjon/110310_esa_complaint.pdf) (accessed February, 24th, 2012). They claim that the Government's decision to set environmental standards for hydropower through the licensing process, rather than as environmental objectives within river-basin management plans runs counter to the main rules of the directive. If ESA finds that LVK and others have a good case, Norwegian authorities may alter this approach and upgrade the status of the WFD-related environmental objectives. This will have significant impact to the large number of licences that will be subject to revision during the coming years.

1.3. Clarification of the terms – small versus large hydropower & environmental impacts

According to the Norwegian legislation system, small-scale hydropower is defined as hydropower installations with an installed capacity less than 10 MW (NVE, 2010). The definition of small-scale hydropower differs between countries (Edenhofer *et al.*, 2011) and is made due to administrative and legislative reasons, typically with the aim of providing priority to development of small-scale hydropower (e.g. by subsidies). The concept of classifying hydropower into small-scale versus large has been criticised as this classification does not seem to apply to their environmental impacts (Edenhofer *et al.*, 2011). Given size-dependent thresholds can act as a barrier for further development of the better hydropower projects. Despite the critique, we use these categories to investigate if such thresholds are scientifically sound from an environmental point of view or if it acts is an undesired barrier for the future development of hydropower (Edenhofer *et al.*, 2011).

It is also worthwhile reflecting around the term 'environment', as environment is a multi-facetted term described by a number of physical, chemical and biological qualities, which can be exemplified by how the EU WFD is made operational (DN, 2011). Guidelines for development of environmental impact assessment (EIA) related to hydropower projects also recognises the wide understanding of the environment, as a large number of environmental topics are defined to be analysed when developing an Environmental Impact Assessments (EIAs) (NVE-Vassdragsavdelingen, 1998), (NVE, 2010), (Korbøl *et al.*, 2009), (Jensen *et al.*, 2010). Determining the environmental impacts from a given project means that a large number of impacts, which can be both dependent and independent of each other, must be analysed simultaneously and some sort of weighting or prioritisation must be carried out in order to compare the overall impacts of different alternative development strategies for hydropower.

2. Method and datasets

2.1. Approach for comparison

The basis for comparison of environmental impacts was that a similar volume of energy should be produced from one large hydropower plant and from a group of small-scale hydropower plants. The comparison would, however, be very sensitive to the selection of the single large plant. For this reason, 3 different large plants were selected, hence increasing the robustness of the analysis, and the *average* environmental impacts from the large hydropower projects were compared with the *accumulated impacts* of the small-scale hydropower plants. The case studies have to the extent possible been selected from the same region with similar bio-geographical characteristics. This would ensure that identified environmental impacts would not differ due to large differences in topography, climate or types of ecosystems.

EIAs were used as the basis for comparison of the environmental impacts, except for Trollheim (set in operation more than 40 years ago) where a set of relevant research reports were used as the basis. EIAs provide a complete overview of impacts and they are more or less standardized analyses according to (NVE, 2010), (OED, 2007) and (Jensen *et al.*, 2010). Investigations of environmental impacts from small-scale hydropower plants that are already set in operation are scarce (L'Abée-Lund, 2005), (Erikstad *et al.*, 2009), (Wendelbo, 2010), (Kubecka *et al.*, 1997) and investigations from large plants in operation are often focused on specific problems of concern not covering the whole range of impacts from constructing the hydropower system. Using EIAs for comparison provides analysis of the *predicted* impacts, and the real environmental impacts might be different than those given in the EIA.

Two of the large projects can be considered as upgrading/extensions of existing hydropower regulations, meaning that the new energy production is developed in river systems that are already exploited for hydropower production. The additional production makes benefit of the already developed infrastructure, and the environmental impacts are to some extent already made due to the existing hydropower production.

In order to compare a number of small-scale hydropower projects with one large project, aggregation and accumulation of the environmental impacts from each of the smaller plants is necessary. The method used for accumulating the environmental impacts from the small hydropower group in this study, is simply by adding and counting the number of impacts, and then by expert judgement classifying these according to impact categories (Vegvesen, 2006). These accumulated impacts are then directly compared with the impacts given for the large projects.

We have compared the environmental impacts by comparing the degree of impact in a nine-level scale, ranging from very large positive impact to very large negative impact, for each of the environmental topics to be analysed (Vegvesen, 2006). The impact categories are set based on the *value* and the *extent* of the impact for the various topics. This way of presenting the impacts from a project was originally developed within the road sector (Vegvesen, 2006), but has been adopted by many other sectors in Norway, including the hydropower sector. It is also worthwhile mentioning the approach used by the national Water Resources Master Plan from 1986-1993 where a combination of economical profitability and level of impacts categorised the hydropower projects into classes, by then giving priority to those hydropower development projects with the better economic and lower impacts.

It should be stated that this comparison includes only environmental impacts from development of hydropower, and not social impacts. For this reason, the topics like 'Society' and 'Tourism', which should be investigated as part of the EIA (NVE, 2010), (OED, 2007) and (Jensen *et al.*, 2010), are not included and accounted for in this study.

2.2. Dataset on small hydropower

The county of Sogn og Fjordane on the Western coast of Norway was selected as the region for the small-scale hydropower projects, as Sogn og Fjordane is a county with both a large number of existing small-scale hydropower plants and many new projects are under development. We also have good access to planning documents and environmental impacts assessments from this region. All the selected small-scale hydropower plants in this study have an installed capacity between 1 MW and 10 MW. Hydropower plants smaller 1 MW are exempted from the standard licencing procedure, thus not preparing a standardized EIA. All small-scale hydropower plants used in this study are given a licence to operate, but the final concession agreement might be different than proposed in the application (including EIA) from the developer (pers. comm. Lars Midtthun, NVE). This means that environmental impacts might be different than predicted in the EIA due to changes from the application (e.g. different minimum flow requirements), thus affecting also the impacts from the projects.

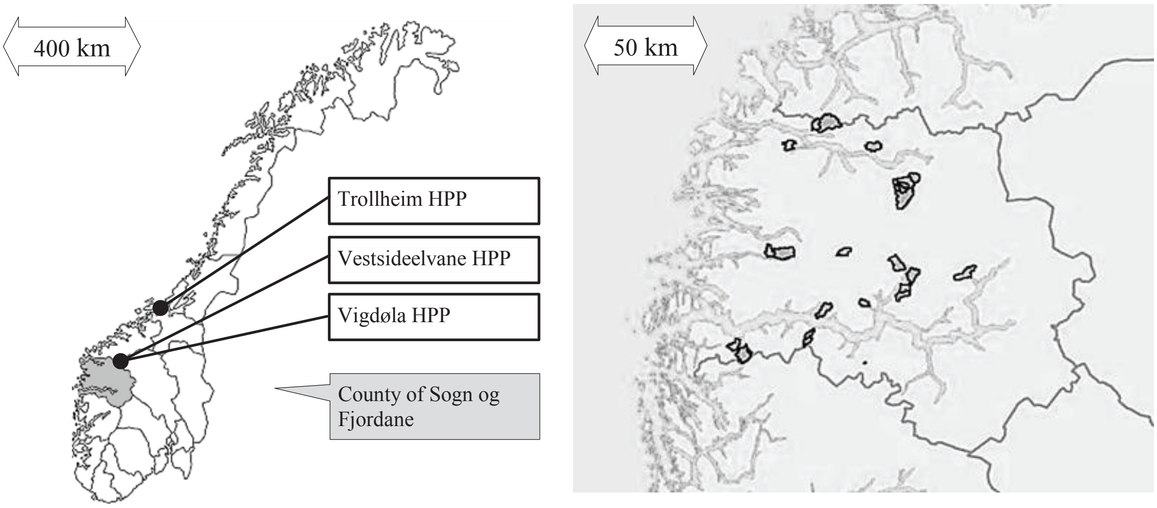

Fig. 1. The map to the left shows Norway and the location of hydropower projects used in this study. The larger black bullets point to the location of the large projects, while the area in grey indicates Sogn og Fjordane, the county of the selected small-scale hydropower plants. The map to the right shows the location of the small-scale hydropower plants within Sogn og Fjordane. The selected 27 plants are located within the small catchments indicated by the areas in darker grey.

All the EIAs have been available either from the Web-site of the consultant developing the EIAs (MFU, 2011) (accessed February 24th, 2012) and/or the national authorities (NVE, 2011) (accessed February 24th, 2012). Figure 1 shows the location of all hydropower plants used in this study. Table 1 presents basic physical characteristics of the 27 small-scale hydropower plants used in the study.

Table 1. The selected 27 small-scale hydropower projects in Sogn og Fjordane and selected characteristics. Empty cells in the column to the very right 'River distance with reduced flow [km]' indicate that the information is not provided for the given project.

Small-scale hydropower project	Annual production [GWh]	Max production [MW]	Max capacity [l/s]	Mean flow [l/s]	Min. flow winter [l/s]	Catchment [km^2]	River dist. red. flow [km]
Bjåstad	38.2	9.3	3220	2010	50	20.1	
Duvedalen	11.1	3.3	1500	750	60	5.1	
Eitreelvi	11.0	3.6	800	400	25	0.4	0.6
Eitreneselvi	9.4	3.0	720	414	30	5.7	
Engeseteelva	10.1	3.0	1200	566	40	3.8	
Hatlestad	13.4	3.2	850	420	25	4.4	
Holsen	24.5	9.2	2550	1420	50	14.0	
Hopland	17.0	5.5	2000	1300	50	17.4	3.0
Jordal	20.1	4.8	2900	1450	60	15.9	
Kjørstad	8.0	2.5	1400	760	30	7.8	1.8
Kvamselva	9.2	2.4	1150	740	40	6.7	1.3
Kvernhuselva	11.5	3.6	1200	580	50	4.4	
Lidal	20.8	5.7	1500	750	15/30	8.1	
Mjølsvik	13.0	4.0	1260	790	100	7.6	
Romøyri	27.9	8.5	1940	970	50	12.0	
Røneid	14.7	4.3	1040	520	50	10.3	2.2
Sandalselva	8.4	2.5	4940	2800	250	33.9	
Selselva	18.4	5.0	1040	669	30	4.5	1.8

Senneset	5.3	1.8	1000	500	20	7.2	2.2
Storelva kraft	11.0	3.2	1153	563	50	4.5	
Storelva	10.8	3.7	6500	3300	260	24.5	
Strupen	6.8	1.8	2760	1840	100	16.7	1.3
Sætredalen	26.2	4.5	1450	1200	25	9.5	
Timbra	8.3	2.5	873	582	20	1.2	
Torvikelva	4.9	1.0	1250	920	100	13.6	
Ygleelvi	14.0	4.6	900	490	30	5.1	
Øyni	16.0	6.0	2700	1380	50	33.6	0.8
Sum all projects	**390.0**	**112.4**	**49796**	**28084**	**1645**	**296.8**	
Average	**14.4**	**4.16**	**1844**	**1040**	**61**	**11.0**	**1.7**

2.3. Dataset on large hydropower

Three large hydropower projects were selected for comparison with the group of small-scale hydropower projects. They are all located in the same region of Norway as the large ones with similar landscape characteristics, climate, hydrology, flora and fauna. Basic information about the three large hydropower projects and the catchments they are located within are provided in table 2.

Table 2. Basic characteristics of the three large hydropower projects used in the study. Sources: (Statkraft, 2011c), (Statkraft, 2011b), (Statkraft, 2011a) (accessed February 24th, 2012).

Large hydropower project	Vestsideelvane (extension)[b]	Vigdøla	Trollheim[c] (Trollheim HPP / Gråsjø HPP)
Catchment size [km^2]	52	47	575/379
Installed effect capacity [MW]	None	16	130/15
Average numbers of hours annually, full production [hours per year]	1070	3000	6192
Capacity, flow [m^3/s]	None	3.2	38.5/27
Number of turbines	None	1	1/1
Average annual production [GWh] – Total	125	48	805/72
Average annual production [GWh] – Summer		38	369
Average annual production [GWh] – Winter		10	436
Storage volume lake/reservoir [mill m^3]	31	0,012	384
Lowest/Highest regulated water level		605/607	375/420-T 430/483-G

[b] Vestsideelvane-project does not represent any additional mechanical installations, just adding more water to the existing system and by this increasing the number of hours per year with full production.

[c] Constitute of 2 plants - Trollheim HPP and Gråsjø HPP. The summer and winter production is given for Trollheim HPP. T: the reservoir of Trollheim HPP (Follsjøen) and G: the reservoir of Gråsjø HPP (Gråsjø).

3. Identified, aggregated and compared environmental impacts - Results

3.1. Environmental impacts of the small-scale hydropower projects

From the EIAs of the small-scale hydropower projects, all the identified environmental impacts for all the individual plants have been extracted and organised in a consistent way. Table 3 presents those impacts considered most important and most frequently reported in the EIAs. The table provides thus not a complete list of all identified impacts. It is worthwhile noting that the impacts are given typically as yes/no (present/not present) without any description of severity. Table 4 presents all the environmental impacts identified in the EIAs from the 27 small-scale hydropower plants. The impacts are listed by how frequent they are reported in the EIAs, and not explicitely linked to the individual plants.

Table 3. List of the most important and most frequently reported environmental impacts in the selected group of small-scale hydropower plants. Empty cells indicate that the information is not provided for the given project.

Identified impact / Small-scale hydropower project	Areas with no prior & major encroachments (INON)	Area protected due to landscape values	Anadromous fish present	Fish fauna affected	Withdrawn water anadromous river stretch	Changed water quality	Cultural heritage affected	Changed water temp.
Bjåstad	Yes	No	No	Yes	No		Yes	
Duvedalen	Yes	No	No	No	No	No	No	
Eitreelvi	Yes	No	Yes	Yes	No		No	
Eitreneselvi	Yes	No	No	No	No		No	
Engeseteelva	Yes	No	Yes	Yes	No	No	Yes	
Hatlestad	Yes	No	No	No	No		Yes	
Holsen	Yes	No	No	Yes	No		Yes	Yes
Hopland	No	No	No	No	No	No	Yes	
Jordal	No	No	Yes	Yes	No		Yes	
Kjørstad	No	No	Yes	Yes	Yes	Yes[d]	No	Yes
Kvamselva	No	No	Yes	Yes	Yes	No		
Kvernhuselva	Yes	No	Yes	Yes	No		Yes	
Lidal	Yes	No	Yes	Yes	No		Yes	
Mjølsvik	Yes	No	Yes	Yes	No			
Romøyri	Yes	No	No	No	No		Yes	
Røneid	No	No	Yes	Yes	Yes	No	No	
Sandalselva	No	No	No	No	No		No	
Selselva	Yes	Yes	Yes	Yes	No	Yes[e]	No	
Senneset	No	No	Yes	Yes	No	No	No	
Storelva kraft	Yes	No	No	Yes	No		No	
Storelva	No	No	Yes	Yes	No		No	
Strupen	Yes	Yes		Yes	No		Yes	
Sætredalen	Yes	No	No	Yes	No		Yes	
Timbra	Yes	No	No	Yes	No		No	
Torvikelva	No	No	Yes	Yes	No		Yes	
Ygleelvi	Yes	No	Yes	Yes	No		No	
Øyni	Yes	No	Yes	Yes	Yes	Yes	No	

[d] Possible conflict with water supply (route) and undesired drainage of marsh land.
[e] Possible conflict with water supply (water allocation problem).

Table 4. All reported environmental impacts from the 27 small-scale hydropower plants and how often (in %) the various impacts are reported.

Type of environmental impact	% of cases impact reported
Reduction in water flow	100 %
Fish fauna affected by the project	78 %
Areas with no prior & major encroachments (INON)	67 %
Anadromous fish present in affected part of river (not only bypassed stretches)	56 %
Cultural heritage sites affected	44 %
Aadromous fish present on bypassed river stretches (reduced flow)	15 %
Pipe lines causing landscape encroachment/impacts	11 %
Changed water quality	11 %
Organisms living in or close to water/cryptogams by water falls negatively affected due to reduced flows	7 %
Reduced production of invertebrates reducing habitat qualities water ouzel (cinclus cinclus) and fish negatively	7 %
Area protected due to landscape values	7 %
Changed water temperature	7 %
Nature with local value negatively affected	4 %
Locations with valuable deciduous forest negatively affected	4 %
Marsh areas negatively affected	4 %
Reduced humidity affecting mosses negatively	4 %

It is worthwhile noting that impacts caused by establishing infrastructure (permanent and temporarily roads, landfills electric grid lines, etc.) are to a limited extent reported in the EIAs from the small-scale hydropower plants, while the infrastructure can often introduce considerable landscape impacts (Erikstad *et al.*, 2009), (Frilund, 2010).

3.2. Environmental impacts of large hydropower and comparison with the sum of the small

This section presents the impacts identified for the three large hydropower projects (table 5) and compares them with the accumulated impacts from the small plants. The impacts are classified in impact categories, varying from 'Very large negative impact' to 'Very large positive impact', according to (Vegvesen, 2006). The type of environmental topics used as basis for comparison are to a very large extent based on the categories given by the guidelines for developing EIAs for hydropower projects; (NVE, 2010), (OED, 2007) and (Jensen *et al.*, 2010), but to some exstent adapted to match the available data of this study. The impacts for Vestsideelvane and Vigdøla are taken directly from the EIAs, where the categorization has been made by consultants, while impact categories for Trollheim hydropower development project have been assessed and set by the authors of this paper. The 'average large HP project' (table 5, column no. 5) represents the 'averaged impacts' of the projects Vestsideelvane, Vigdøla and Trollheim and is estimated by the authors. The environmental impacts of the 27 small-scale hydropower plants have been summed by the authors (expert judgement) and categorised according to (Vegvesen, 2006), as the large projects, in order to provide a uniform basis for comparison.

Table 5. Key technical information and impacts for the three large projects, the average of the large projects, and the accumulated impacts from 27 small-scale hydropower projects, classified according to (Vegvesen, 2006). Sources for setting impact categories of the large projects are in addition to those sources given in table 2; (Sundt *et al.*, 2006), (Alfredsen *et al.*, 2006) and (Forseth, 2009).

Type of environmental impact (energy production/ effect)	Vestsideelvane	Vigdøla	Trollheim (Trollheim HPP / Gråsjø HPP)	Average large HP-project	Sum of 27 small
Effect [MW]	*0*	*16*	*145*	*54*	*112 (SUM)*
Energy production [GWh]	*125*	*48*	*877*	*350*	*390 (SUM)*
Water temperature	Medium -	Small -	Large -	Medium -	Small -
Ice cond./Local climate	Insignificant	Insignificant	Small -	Insignificant	Small -
Sediment transport/Erosion	Medium -	Insignificant	Small -	Small -	Medium -
Landscape	Medium -	Small -	Medium -	Medium -	Medium -
Recreation	Small/Medium -	Small -	Small -	Small -	Medium -
Nature and environment	Large -	Small -	Small -	Medium -	Medium -
Hunting	Small -	Small -	Insignificant	Small -	Insignificant
Fish	Small -	Small -	Medium -	Small -	Medium -
Cultural heritage	Small -	Small -	Insignificant	Small -	Small -
Nature resources	Medium +	Small +	Insignificant	Small +	Insignificant
Water quality, water supply and water pollution	Small -	Small -	Small -	Small -	Small -

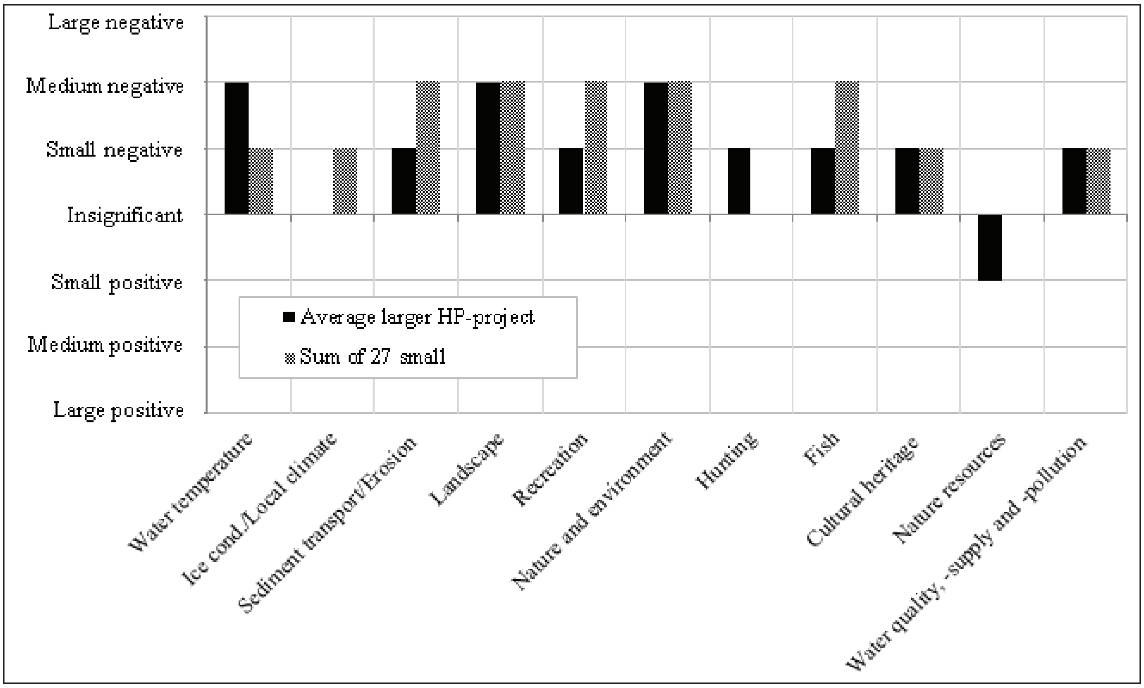

Fig. 2. Categorized impacts from the average of the large-scale projects and the sum of the small-scale hydropower projects, based on table 5. The impact categories 'Very large negative' and 'Very large positive' are excluded from the visualisation of the results as none of the assessed environmental topics fall into these categories.

It could be questioned whether the topics 'Recreation', 'Hunting' and 'Cultural heritage' can be classified as strictly environmental topics, as they could also be classified as 'Social impacts' from hydropower regulations. We believe, however, that these topics are so closely linked to environmental qualities/services provided by the catchments that they are included in the analysis.

4. Discussion

4.1. Environmental issues

The comparison of the impacts from 27 small-scale hydropower plants and large hydropower development involves several steps of processing and aggregating data to the basis for comparison, which are categorized impacts according to (Vegvesen, 2006). Some of these steps are problematic and involves a large degree of subjective expert judgements. Precision and details are lost in the steps from description of impacts of each small-scale hydropower plants to the aggregated sum of impacts by the use of impact categories. Similarily for Trollheim, one of the large projects, precision and details are also lost when going from the semi-quantitative description of the impacts to impact categories, as well as when averaging the impact categories from the three large projects. Translating semi-quantitative descriptions of the impacts into impact categories is a general problem related to development of EIAs and not specific to this study. It can also be questioned if similar impact categories for the same environmental topic indicate the same severity in small and large projects. The impact category comes out of a combination of value and extent, but it is not clear how well the extent reflects the size of the projects. This implies also that averaging projects and their impact categories is problematic, which introduces uncertainty in the results from this study. Furthermore, it is also relevant to raise the question about the predictability (precision), completeness and quality of the EIAs. An EIA is a prediction of the most likely impacts of a given project, and the predicted impact might differ from the actual impact.

Looking into the basic data of the study before aggregating them into impact categories, it can be seen that the identified impacts are partly overlapping, but also partly different. The environmental impacts predicted in the EIAs from the small-scale hydropower plants are different than those from the large projects. The basic data for the large projects are not provided in this paper, but available from the following sources: (Statkraft, 2011c), (Statkraft, 2011b), (Statkraft, 2011a) (accessed February 24th, 2012), (Sundt *et al.*, 2006), (Alfredsen *et al.*, 2006) and (Forseth, 2009). Typical impacts from the small projects are reduction in water flow, impacts on the fish fauna (including anadromous fish), reduction in remaining areas with no prior or major encroachments (INON-areas) and fragmentation, loss and reduction of qualities of cultural heritage sites, loss of selected species dependent on water or humidity (biodiversity) and loss of specific types of nature. The environmental impacts vary among the large projects, but the fish fauna is typically negatively impacted, both due to changes in water flow and water temperature, and impacts on landscape qualities. Changes in landscape are, in particular, seen in the Trollheim-case where the reservoir introduced damming of an area with no prior lake or reservoir. Changes in water quality are also identified in the large projects as an impact, but the ecological impact of this is not described.

In this study the environmental topics are given equal weight, which may be arguable. Some impacts could be considered less important than others, as impacts on salmonid fish are often considered more important than impacts on other aquatic species, due to their level of conflict. At the same time, one and the same impact, e.g. impacts on salmonid fish, can be more acceptable in one river than the other, depending on the status of the fish population and the interest for game fishing. Furthermore, some environmental impacts can be counted for twice as they are investigated as a separate topic (e.g. water temperature), while the main reason for assessing the particular topic could be that it has an effect on a different environmental topic (e.g. fish population). In order to weight the impacts, individual and subjective judgements are introduced, or political and/or management priorities. It is impossible to say, on general and objective basis, that one environmental impact is more important/severe than the other or opposite. Based in this, it is also difficult, without subjective perceptions, to say that one strategy causing one set of impacts is better than another strategy causing a different set of impacts. Multi-criteria analysis offer a systematic framework for assessing and weighting of non-commensurable variables in order to support decision-making, e.g. (Catrinu, 2006) and (Sparrevik *et al.*, 2011) and could be a useful tool in analysis comparing different strategies for hydropower development.

The methodology to assess accumulated impacts from several small hydropower projects is generally weak. According to (Lohani *et al.*, 1997) (page 343) after (Canter, 1996) the cumulative impacts are 'the impacts on the environment that result from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions'. It is further underlined that the term cumulative effect is one of the most confusing of all EIA concepts. Cumulative effects are difficult to analyse and there are few agreed upon methods for their assessment. This can also explain why there is no clear and consistent methodology following the definition. The Norwegian Act on Biodiversity and (OED, 2007) also underline the importance of analysing the cumulative impacts, but as the methodology is unclear, the management practice seems to be to handle this specific issue on a case-by-case basis without clear guidelines on methodology. In cases with two or more applications for hydropower development within the same region are handled (by NVE), the authorities aim at co-ordinating the applications and assess the accumulated impacts (pers. comm. Jan Sørensen, NVE). A few studies and approaches that are relevant to mention is the review done by (Smit and Spaling, 1995) and the GIS-based approach tested out by (Erikstad *et al.*, 2009). EIA from development of large hydropower project sometimes include a section about cumulative impacts, for instance (THXP, 2008). The EIAs from small-scale hydropower development normally does not include assessment of cumulative impacts, and this is considered being the responsibility of the regional management authorities and not the developer to analyse.

Drawing general conclusions about the environmental impacts from development of small-scale hydropower based on this study and published literature is difficult, also due to the fact that there are limited studies carried out. The published studies are neither consistent in their conclusions. It has been an understanding in Norway that a major impact from small-scale hydropower development is the loss of biodiversity (Korbøl *et al.*, 2009), while other underlines the problem of fragmentation (Erikstad *et al.*, 2009). The attention has also been drawn to selective loss of certain types of nature (water falls, gorges, rapids) (Erikstad *et al.*, 2009) as well as reduction of remaining areas with no encroachment (INON-areas). (L'Abée-Lund, 2005) found limited impacts on the fish fauna from studies in two counties of Norway (Rogaland and Telemark), which was supported by (Wendelbo, 2010). This is in contrast to the findings of this study and by (Kubecka *et al.*, 1997) and (Frilund, 2010), the latter from the smallest small-scale plants. (Egre and Milewski, 2002) argues that the environmental impacts from small-scale hydropower development are negligible, as they can simply be estimated as a function of dammed areas. This seems, however, to be a too simplistic approximation.

The environmental topics covered by the EIAs are to a large extent determined by the guidance documents and regulations for EIAs issued by the authorities and the stakeholders' involvement prior to defining the EIA-program (for large projects). Related to the development of small-scale hydropower it has been argued that there is too little focus on impacts from development of the infrastructure (e.g. Erikstad, 2009) and (Frilund, 2010), which is probably due to little focus on these impacts in the guidance documents. Along the same line, if the guidance documents focus on specific problems, the EIAs will most likely also give more focus to these problems, which could be the case for impacts on biodiversity

(Korbøl *et al.*, 2009) from small-scale hydropower development. This might lead to an imbalance between the different environmental topics, which has also been confirmed in other aspects related to development of hydropower (Egeland and Jacobsen, 2012) and (Knudsen and Ruud, 2011).

4.2. Technical issues relevant for the comparison

We would also like to mention other aspects to keep in mind when comparing environmental impacts and benefits of small-scale hydropower developments with large projects. Some of them are not affecting the environmental performance of the projects directly, but could have indirect positive or negative effects on the projects, or have environmental effects outside the area directly impacted by the hydropower projects.

- It is reasonable to believe that large hydropower developers tend to be more professional in planning, design, operation and carrying out mitigating measures of their hydropower projects compared to the local entrepreneurs developing small-scale hydropower, due to the access to competence and many years of experience. They are probably, in general, also more concerned about their corporate responsibilities (CR) which also would lead to better environmental performance in their projects.
- Large projects gain more attention from the general public, NGOs and the authorities, probably ensuring that the project get a better environmental design than those with less public interest.
- Large projects are followed-up more closely than smaller projects in their operating phase, probably leading to fewer violations of their permits. A review of plants smaller than 1 MW (those not following the standard licencing procedure) discovered discouraging findings (http://www.nve.no/no/Nyhetsarkiv-/Pressemeldinger/Nedslaende-resultater-fra-kontroll-med-smakraftverk/) (accessed February 24th, 2012) of operational practice.
- Projects that can be identified in rivers already regulated, or with limited new regulations, will often provide substantial amounts of electricity without new large impacts. Upgrading/extensions of existing hydropower systems are very relevant when discussion development of new hydropower production.
- Small-scale hydropower plants must be considered non-regulated power production, as only a few of them have storage capacity. This means that the majority of the production is during periods with high inflow, and not necessarily in the periods of high electricity consumption (e.g. during the winter).
- Large-scale hydropower with significant storage possibility provides services like energy storage, water supply and flood control in addition to instant power production.
- Small-scale hydropower development can be important business activities in the rural areas, giving important economical income to farmers, etc.
- Small-scale hydropower development may be an important solution in remote areas without access to the central grid (e.g. in countries with low level of electrification), by this supplying/securing electricity supply locally without large grid development.

4.3. Governance and administrative issues

It is a general challenge for Norwegian hydropower governance that bureaucratic procedures are very project and case specific (Knudsen and Ruud, 2011). Such an approach is needed to secure adequate knowledge and documentation to balance different, often contradictory interests. However, it creates challenges for the fulfilment of national targets both related to renewable energy as well as environmental protection. This will be further challenged when Norway is implementing the Water Framework Directive.

As part of the national planning for hydropower, Water Resources Master Plan was developed in 1986 (Angell and Brekke, 2011). The objective of the Water Resources Master Plan was to provide a mapping and assessment of all potential hydropower projects and stipulate priorities vis-à-vis further development and actual realisation. From 1993, updates and consideration of new projects, however, are only treated administratively. The Parliament decided in 1993 to introduce a revision clause every 4 – 6 years, with a specific view to the energy balance, but this has so far not been followed up (Knudsen & Ruud 2011).

In 2005 the Norwegian Parliament urged regional counties and local municipalities to develop regional and local small hydropower plans. At the same time, they decided that hydropower projects below 10 MW should not be included in the national Water Resources Master Plan. Other national planning tools do not exist. Currently there are no procedures enabling an overall assessment of hydropower.

Regional plans to identify potentials for small hydro are valid and useful. More comprehensive planning could be pursued – also with respect to the implementation of the Water Framework Directive. However, only a few counties such as Nordland and Hordaland have so far been granted approval by the Government (http://www.vannportalen.no/enkel.aspx?m=56932&amid=3386120) (accessed February 24th, 2012), but plans are under development in all counties. The county of Sogn og Fjordane has expressed a profound commitment to realize small-scale hydropower production, but the final approval is still pending. When the county council discussed the plan on March 23rd 2011, they underlined the need to document the accumulated impacts of small power development more systematically. We can read the following: 'we thus argue that the central authorities must stimulate more research enabling better knowledge on total, accumulated impacts of hydropower development' from Sogn og Fjordane county (2010) (page 91). This paper is aimed at filling some of the knowledge gaps expressed by the county council of Sogn og Fjordane.

5. Conclusions

Our results show a small tendency that large hydropower development has fewer and slightly less severe impacts than many small-scale hydropower project, given similar volume of energy production. The summed impacts from 27 small-scale hydropower projects basically give a slightly higher degree of impacts than the average of three large hydropower projects, assuming that all selected environmental topics are given an equal weight. The average large hydropower plant scores a more severe impact category on the topics 'Water temperature' and 'Hunting', but attains lower degree of impact on 'Ice conditions and local climate', 'Sediment transport and erosion', 'Recreation' and 'Fish'. These results must be considered marginal in the favour of large hydropower. The reader should be aware of the methodological challenges in aggregating/accumulating the impacts for the basis of comparison and the lack of precision/detail in the data available for this study. The selection of projects and plants may also affect the outcome. The empirical study can hence not form a basis for a conclusion with a high degree of certainty, and a generalization beyond the case study is problematic.

Taking into account other aspects and benefits of large hydropower projects, i.e. that they normally provide regulating services, that larger developers tend to be more professional in planning, design and operation of their plants and larger projects are generally closer monitored by the authorities and the general public, it is reasonable to assume that a few large hydropower projects will produce electricity to a lower environmental cost compared to many small projects.

The study raises also a more fundamental question on valuation of environmental qualities as the study reveals that the impacts identified in this study to some extent are different. Such a valuation can be based on individual preferences or political and management priorities. Without specific regulation or guidelines, it is problematic to decide which priority is genuinely more important than the other, and the value setting of the authors can not be considered more appropriate than others. In this study the environmental topics were all given equal weight. It is, however, not clear if the impacts to some extent are different due to differences in size of the projects (small versus large), difference in the requirements and qualities of the EIAs or differences due to the selection of cases in the study.

The EU Water Framework Directive has so far not caused significant changes on Norwegian hydropower governance. The formal implementation of the planning procedures from 2015 onwards, however, may trigger changes in the current governance structures. Development of regional water management plans may also produce stronger and more specific requirements for documenting environmental impacts of hydropower development. The knowledge base must be widened. It seems clear that there is weak methodology available in the assessment of the accumulated impacts from several projects. If such methodology and ultimately knowledge is in place, a better basis for a comparative assessment of small-scale versus large-scale hydropower development can be made, enabling a better reconciliation of energy and environmental policy goals.

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