Increased generation from upgrading and extension projects

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Recent research suggests that the increased generation which could result from upgrading and extending existing hydro plants in Norway could be considerably higher than previously estimated. This was based on a study of 20 projects with different characteristics, which have been upgraded over the last 15 years.

Hydropower has been the backbone in Norway's electricity system for more than 100 years, and today more than 1500 hydro plants with an installed capacity of 32 000 MW are in operation. Many of the older (pre-1950) powerplants and even a few built since 1950, have been upgraded. The recent upgrading and extension of hydropower projects has resulted in an increase of between 6 and 60 per cent in energy generation in cases where minor and major extensions have been approved.

The magnitude of the extensions varies, and they have been achieved both by adding additional water from new catchments, and by increasing storage, efficiency, capacity and flexibility in the powerplant itself. The study shows how an extension in one part of a project (that is, additional water or additional capacity) produces benefits through the upgrading of existing structures and installations in the hydro project. This current study proves that the upgrading potential is in the range of 6 to 60 per cent, based on former electricity production when civil structures are redesigned. This huge potential must be taken into account when investment strategies among different renewable energy sources are being established. If no extensions are allowed, the potential for increased production is limited to possible increases in efficiency of the turbines and reduced head loss, normally in the range of 2 to 3 per cent. In the worst case, this upgrading will not be profitable and may never occur.

1. Background

1.1 Hydropower development in Norway

Hydro development in Norway began in the 1890s and it quickly became the most important source of electricity generation, both for public supply and industrial development [Hveding, 1992[1]]. Generation capacity increased gradually, at a rate of 60 MW annually up to 1950, when installed capacity reached 3000 MW. During the next four decades, the capacity increased rapidly and reached 27 000 MW in 1990, representing an annual increase of 600 MW/year. In the years since 1990, an additional 5000 MW has been added, mostly from the upgrading and extension of existing powerplants, and from small hydro, see Fig. 1. The graph shows that the largest share (70 per cent) of hydropower plants was built between 1950 and 1990, so these plants now have reached an age of 25-65 years.

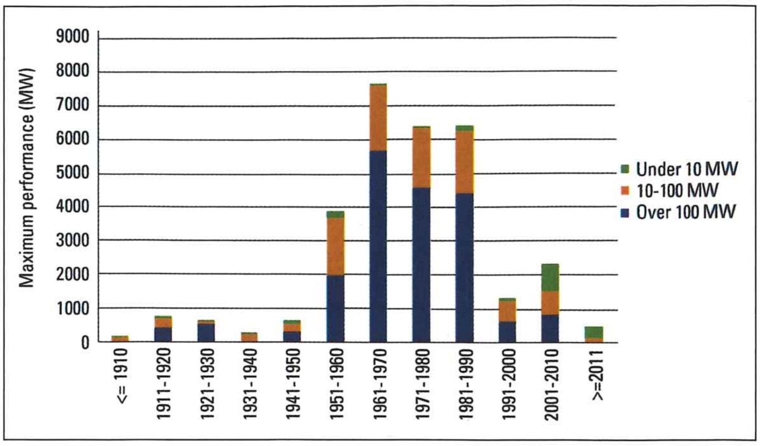

Fig. 1. Hydropower development in Norway according to year of commissioning [NVE, 2017[6]].

Currently, the hydropower capacity is 32 000 MW with an annual generation of 136 TWh; in addition there is 2.3 TWh/year under construction and 4.7 TWh/year at projects that have been approved for construction. Including approved licences for wind power, a total of 17 TWh of renewable energy is currently approved for construction in Norway.

(a) Tunnelling work at the 370 MW Lysebotn upgrading project. Photo: Lyse.

1.2 Further renewable energy development in Norway

As a result of various national initiatives [Lia *et al*, 2015[2]] and the EU RES-Directive for renewable energy [EU, 2005[3]], it has been decided to increase the share of renewable energy generation in Europe to reduce greenhouse gas emissions and help to combat climate change. Sweden and Norway have together committed to increase the renewable electricity generation by 26.4 TWh by 2020, which is equivalent to a 10 per cent increase in the total electricity production in the two countries combined; this is mainly to be generated from hydropower, wind power, bio energy and solar power. In Norway, hydro is the least cost alternative [OED, 2016[4]] with possible contributions from small hydro, upgrading and extension projects and some new projects in undeveloped rivers.

As described by Lia *et al* [2015[2]] there is currently a peak in development in small hydro in Norway, triggered by this renewable energy initiative. From an environmental point of view, however, upgrading of existing hydro plants is probably the best way of achieving this increase in production, because of the very limited environmental impact. The total potential for upgrading and extension projects is estimated to be 6.9 TWh [OED, 2016[4]] but the authors think this may be an under-estimate, as this paper will demonstrate.

1.2 Project development framework

All investments in energy production are made in a context regulated by authorities, investors, market and international conditions. The investments must fit with current and future frameworks for investments, and the most common framework is based on:

- estimated energy prices;
- political framework of laws and regulations;
- technological development;
- current and future environmental regulations;
- expected industrial development in other businesses; and,
- taxes and operational expenses.

Within this framework, estimated values of future investments must be calculated and the optimum investment strategy must be chosen. Before the strategy for the further development of renewable energy production can be decided, a full overview of the real potential and consequences of upgrading and extension needs to be ascertained. This paper highlights this and other general findings from the detailed study of 20 recent upgrading and extension projects in Norway.

Recorded upgrading potential of 20 projects

Project		Power generation (GWh/year)		Generation increase	
	Name	Before	After	GWh/yr	Per cent
1	Fløyrli	192	252	60	31
2	Leirfossene	150	193	43	29
3	Nedre Vinstra	972	1197	225	23
4	Follafoss	140	180	40	29
5	Funna	60	73	13	22
6	Blåfalli Vik	585	710	125	21
7	Skjerka (new plant)	492	622	130	26
8	Skjerka (higher dam)	622	665	43	7
9	Skjerka (new catchment)	665	820	155	23
10	Meråker and Tevla	150	512	362	241
11	Tyin and Holsbru	1180	1662	482	41
12	Sauda	1146	1850	704	61
13	Brokke North and South	1565	1740	175	11
14	Nedre Røssåga (lower)	1853	2053	200	11
15	Øvre Røssåga (upper)	890	940	50	6
16	Embretsfoss	215	335	120	56
17	Lysebotn	1320	1500	180	14
18	Gausbu, Åmdal and Skree	153	238	85	56
19	Framruste and Øyberget	-	650	650	-
20	Breidalsoverføringen	650	775	125	19
Total		13 000	16 967	3967	31
Total (excluding 10 and 19)		12 850	15 805	2955	23

2. Results of the recent upgrade projects in Norway

Previous studies have found a typical increase in production of 2 to 3 per cent by increasing the efficiency of turbines and generators, and this is often quoted as the 'upgrading potential'. In most upgrading projects, however, one can also see many other improvements: increased capacity leading to lower flood spill, increased tunnel and penstock cross-sections reducing head losses, increased dam height and storage volumes, diversion of new catchments, and increased inflow. An NTNU study [Aas, 2015[5]] shows that when all these factors are taken into account, the potential increase in energy generation could be much larger than the 2-3 per cent from increased turbine efficiency. A summary of the findings from this study is given in the rest of this section.

2.1 Selection of typical projects

The study [Aas, 2015[5]] includes 20 hydro plants which have been upgraded within the last 15 years. The selection of projects for the study is a mixture of randomly chosen plants and plants with a high possibility of obtaining data. All the projects are different in nature and design, and it is not possible to identify a group of 'average' ones. They are well distributed all over the country representing various natural conditions. Details are presented in the Table and Fig. 2.

In the Table, generation from the plants is shown before and after the upgrading work. Project 10, Meråker and Tevla, shows a 240 per cent increase in generation, while project 19, Framruste and Øyberget, provides 650 GWh/year of new generation since both stations in 19 are new, using previously untapped inflow. Both these projects are in a somewhat different category, as they mostly have new catchment areas (but are on previously developed rivers). The results demonstrate remarkable further gains in electricity production in previously developed areas. The summary in the Table shows that the

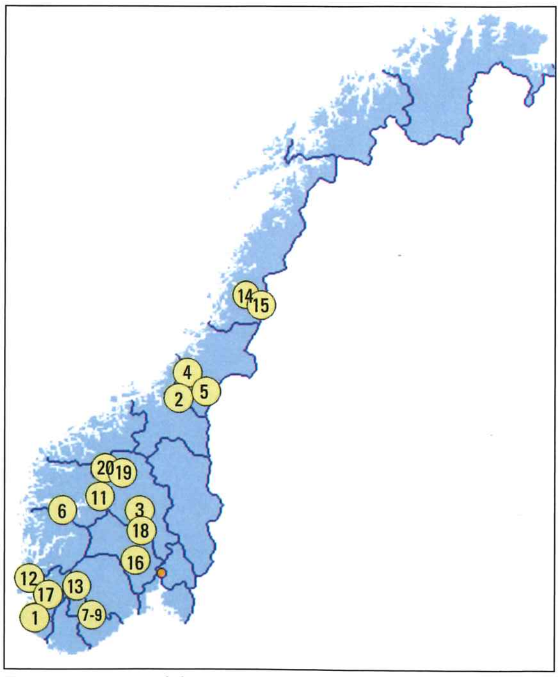

Fig. 2. Location of the 20 projects listed in the Table.

total increased production for the 20 upgrade projects is close to 4 TWh/year, or 31 per cent. If we exclude projects 10 and 19, the increase is still 3 TWh/year or 23 per cent. None of the upgrade projects has an increase of less than 6 per cent. For some of the most recent projects, there are only a limited number of years of monitoring of the new electricity production, and this may influence the computed increase slightly, but will probably not change the conclusion significantly.

2.2 Age before upgrading

It is likely that the age of a specific powerplant will influence its potential for upgrading. Since the construction of the old plant, new technology may have been implemented; also better design tools, optimized operational practice and other measures may have become available. This opens up opportunities for the use of improved design and alternative solutions, which were not available in the past. New markets for electric power can also influence the potential. If the age before upgrading is analysed, together with the potential for increased energy production, a relationship emerges. Fig. 3 illustrates this relationship and shows that most of the projects were upgraded between 50 to 70 years after construction. The average age at the time of upgrading for the projects was 60 years. The powerplants in project 2, Leirfossene (Upper Leirfoss and Lower Leirfoss) were in a class of their own, with more than 100 years between construction and upgrading. The age of the plant will never be the only criterion for upgrading potential, and it is not expected that we will see new groundbreaking technology which will totally turn the design principles upside down.

2.3 Increase in installed capacity

Increased capacity (MW) leads to increased energy production as a result of reduced spilling of water and other improvements, for example reduced head loss. Fig. 4 shows a direct relationship between the capacity increase and the relative increase in energy production for the 20 projects.

If the increase in energy production is compared with the capacity of the plant, no significant relationship can be found. Fig. 5 shows an average of 26 per cent increased production independent of installed capacity.

These findings indicate that the upgrading potential is not particularly dependent on the size of the powerplant.

2.4 Relevance of data

It is always important to question how representative such data are. One may argue that the selected projects were highly suitable for upgrading, and that the next 20 projects will be less suitable and will therefore have much less potential for increased production. To explore this idea, a further study of two new projects, Brokke and Aura, were carried out and this indicates that this is not a correct theory alone. Political and protection issues are very important and will influence the electricity production strategy more than the cost-benefit principle, but the cost-benefit analysis is important to take into account. One current project is the 225 MW extension at Lower Røssåga; installation of the draft tube in the new 225 MW powerhouse can be seen in Photo (b).

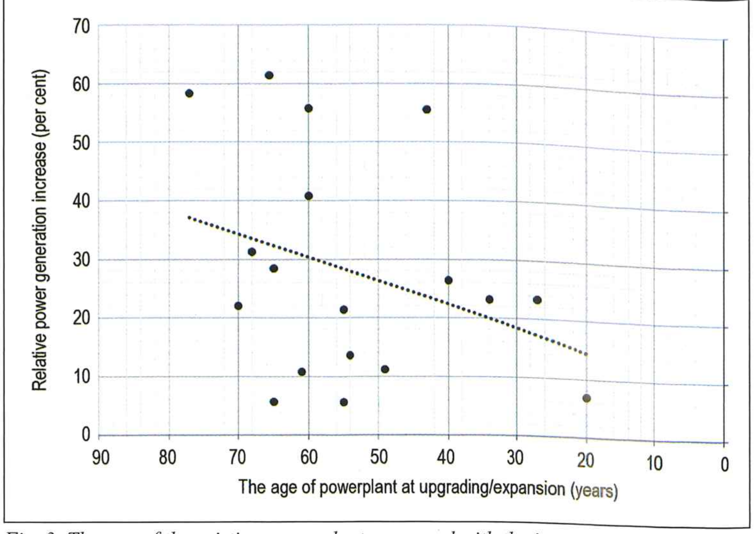

Fig. 3. The age of the existing powerplant compared with the increase in power generation [Aas, 2015[5]].

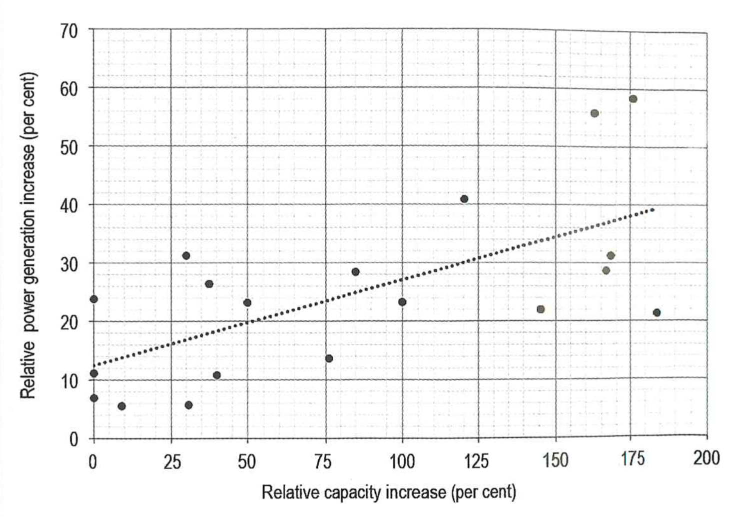

Fig. 4. The relative capacity increase compared with the increase in power generation [Aas, 2015[5]].

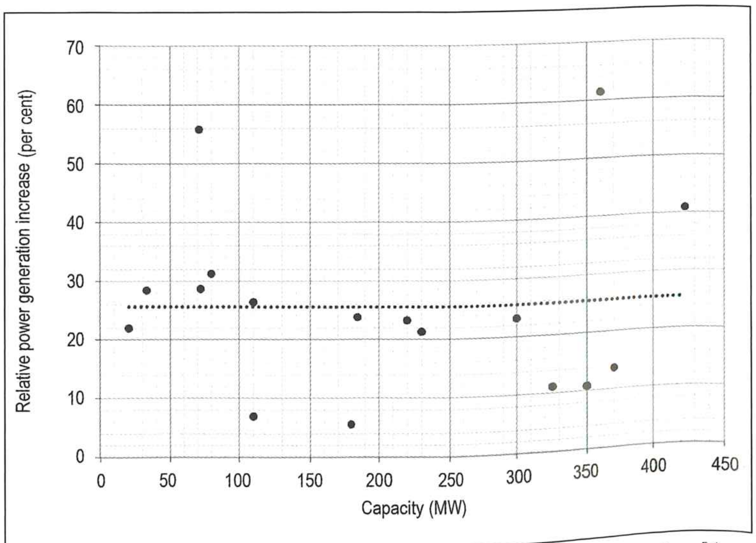

Fig. 5. The capacity of the powerplant compared with the increase in generation [Aas, 2015[5]].

(b) New powerhouse extension at the Lower Røssåga powerplant. Photo: Statkraft.

One other large upgrading project under construction is Lysebotn (370 MW). Iveland (44 MW) and Matre (180 MW) have been commissioned recently. All of them will increase the total energy output significantly.

3. Conclusion

This study shows a very significant increase in power production for all 20 projects studied. For 18 typical upgrading and extension projects, the increased electricity production was 6 to 60 per cent, with an average of 23 per cent (26 per cent if all projects are included). All the projects are different, in that they can be categorized by: new catchment, merged waterfalls, increased dam heights, increased capacity and different use of the available head. From the study it is clear that projects including new catchments have a significantly higher potential (37 per cent) compared with the potential for projects based on the same annual discharge (15 per cent). The potential is higher in the case of older existing powerplants. This is reasonable from two points of view:

- the oldest projects were the first choice for upgrading; and,
- the improved technology at the more recent projects reduces the potential for upgrading.

More detailed studies show the similarity between the market price for electrical energy and the potential for upgrading. If the price in the short-term market increases, this also opens up the potential for profitable upgrading projects from reducing head losses.

Based on the recorded potential at the 20 projects studied and the relationship between age and potential in Fig. 3, the total potential for upgrading for all existing projects in Norway can be calculated. Based on this theory, the current upgrading potential in the country is between 22 and 30 TWh/year. Political and environmental issues are, however, expected to reduce this figure. Nevertheless, it is important to know that through redesign it is possible to achieve a much higher increase in energy production than the 2 to 3 per cent commonly quoted as the potential for upgrading projects. ◊

(c) New parallel TBM tunnel at the Lower Røssåga powerplant. Photo: Leif Lia.

References

1. **Hveding, V.**, "Hydropower Development in Norway", Norwegian Institute of Technology (NTH); 1992.
2. **Lia, L, Jensen, T., Stensby K.E., Midttømme, G.H. and Ruud, A.M.**, "The current status of hydropower and dam construction in Norway", *Hydropower & Dams*, Issue 3, 2015.
3. **EU**, "Directive on Electricity Production from Renewable Energy Sources" EU Directive 2001/77/EC, 2005.
4. **OED**, Energimeldingen, Ministry of Oil and Energy (in Norwegian); 2016.
5. **Aas, M.N.**, "Upgrading and extension of hydropower (O/U) – Potential", NTNU Master's thesis; 2015.
6. **NVE**, "Facts of Energy"; available at www.nve.no; 2017.

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