Østfoldforskning

Memo SUSTAINABLE INNOVATION

To:	The LCA Case Group within the Project Energy Trading and Environment 2020
Report no:	AR 04.12 (commissioned by NFR in the Energy Trading and Environment 2020 project).
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Date:	10.11.2010

Categorising of Norwegian Hydro Power According to Physical Parameters and Related GHG Emissions

Version 2

At the Project LCA Case Meeting the 27th of May 2010, it was decided to investigate the possibilities for categorising Norwegian Hydropower into different category groups according to related GHG emissions. The work should be based on the existing LCA data of Norwegian Hydro Power from the report "Inventory of Life Cycle Data for Hydroelectricity Produced and Distributed in Norway'' (Vold et al., 1998).

The deliveries from the work should answer the following questions:

1. Are the existing LCA data of Norwegian Hydro Power representative for Norwegian Hydro Power?
2. Is it possible to categorise the different hydro power plants according to various physical parameters (e.g. annual production, height of head) and related GHG emissions?

At the Partner Meeting the 28th of October it was decided that the GHG results for the Norwegian hydropower cases (Vold et al., 1998) should, for the infrastructure phase, be further separated into the different life cycle activities (building of tunnels, dam, construction of turbines etc.). The results are included in this second version of this memo, see chapter 2 Results presented for different life cycle stages.

1 Representativeness of the existing LCA data

To analyse whether the existing LCA data are representative for Norwegian hydro power, the analysed generation units are sorted according to NVE's database and parameters (NVE 2009), such as annual power production [GWh], installed capacity [MW], height of head [m], tunnel length (km), reservoir volume [mill. m3], and total inflow [mill. m3/year]. The analysed generation units are highlighted by read bars in the figures below to demonstrate "their position", according to the total Norwegian hydro power generation units.

Figure 1 and Figure 2 show the Norwegian generation units sorted according to mean annual production and gross head, respectively, divided into reservoir and run-of-river units (data from NVE's database, (NVE 2009)).

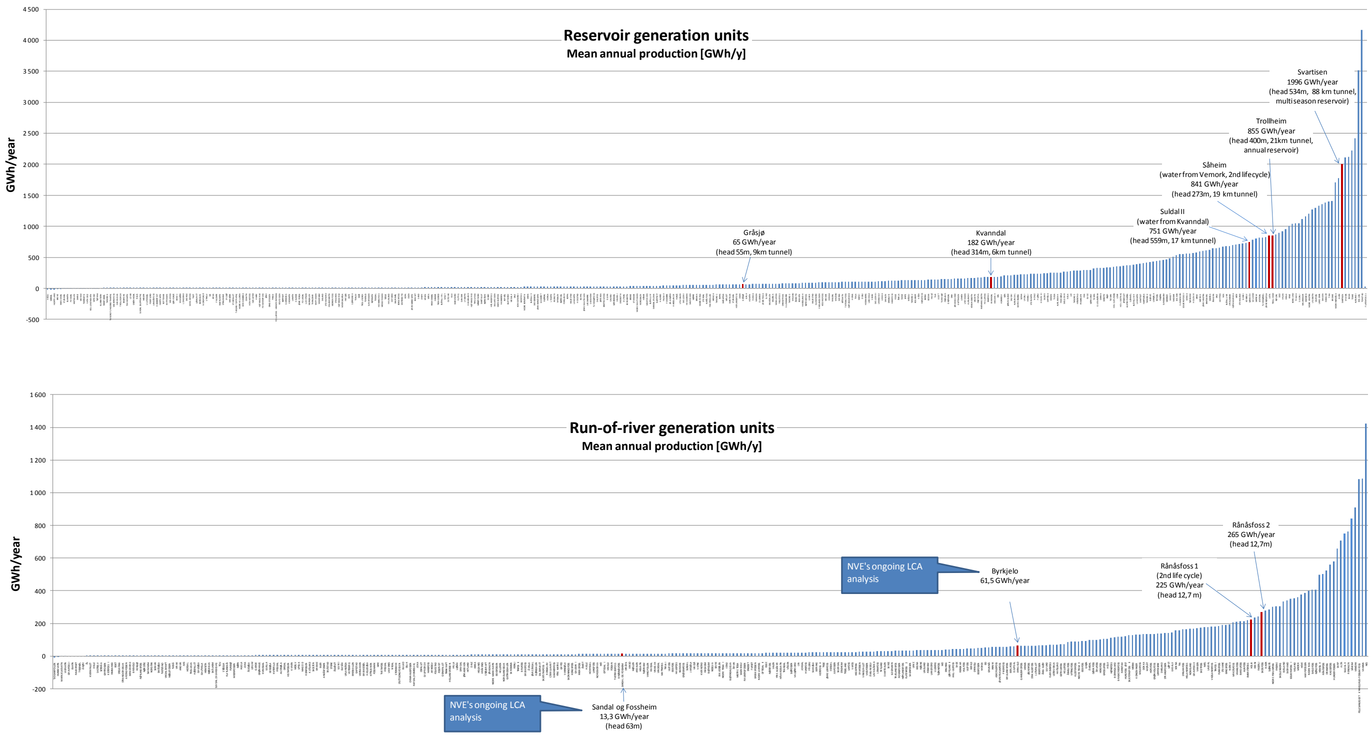

Figure 1: Norwegian reservoir and run-of-river generation units, sorted according to mean annual production [GWh/year].

Figure 1 shows that the analysed reservoir generation units (Vold et al., 1998) represent Norwegian reservoir generation units quite well, according to mean annual production, as these cases cover both "small", "medium" and "large" generation units.

When it comes to run-of-river plants, only two units are analysed in (Vold et al., 1998). However, these two units seems to represent a weighted average of the Norwegian generation units according to mean annual production as they seem to be "located" approximately in the middle of the area covered by the columns. NVE is currently working on life cycle assessments (LCAs) of the run-of-river units "Byrkjelo" and "Sandal og Fossheim" (shown in Figure 2), but they are not finished yet. When finished, these studies will complete the picture.

From Figure 1 it seems like (Vold et al., 1998) does not include the largest run-of-river units, but as ''Suldal II'' and ''Såheim'' were modelled as reservoir generation units due to the fact that the water comes from reservoirs and does have a certain head (but without having regulation options), they are presented as reservoir generation units in Figure 1. These two lie in the upper end of the annual production scale of run-of-river generation units in Figure 1. Still, removing them from the reservoir figure to the run-of-river figure would not have ruined the representativeness of the reservoir studies in (Vold et al., 1998).

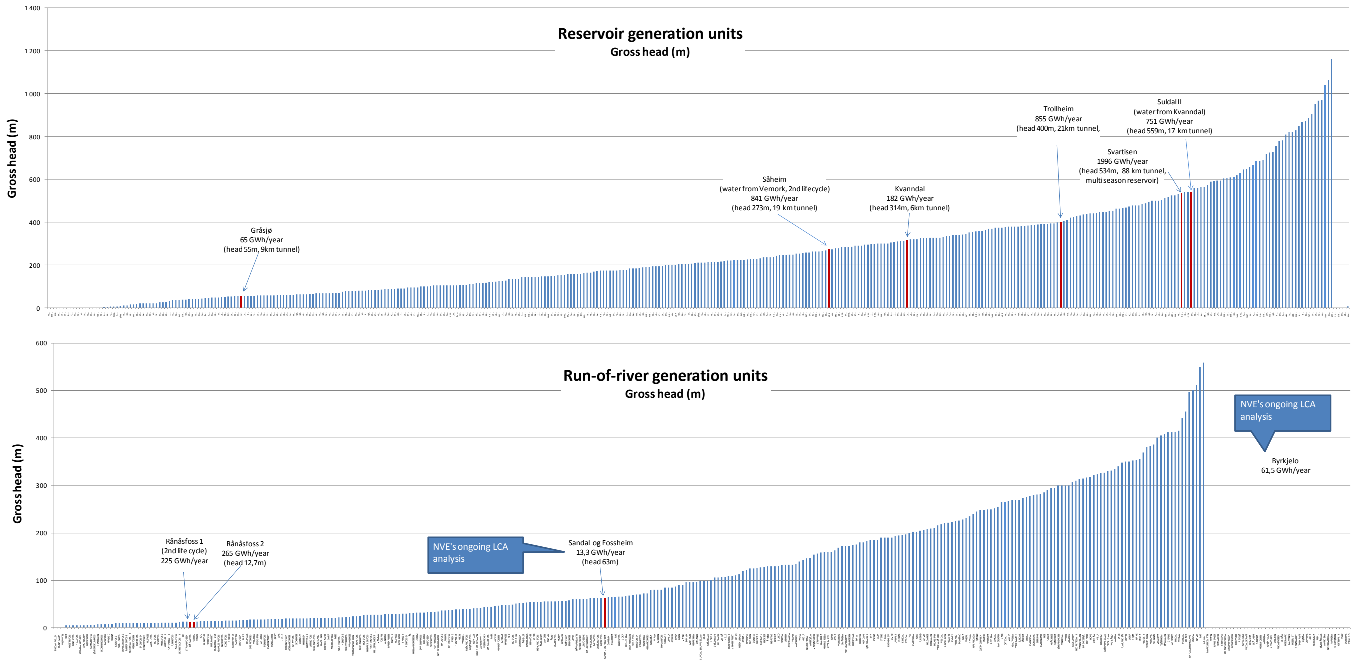

Figure 2: Norwegian reservoir and run-of-river plants, sorted according to gross head [m].

Figure 2 shows that the analysed reservoir generation units (highlighted with red bars) represent Norwegian reservoir generation units quite well, also according to gross head, as they cover both “small”, “medium” and “large” generation units.

At the same way as for the parameter annual production (Figure 1), only two cases are analysed representing run-of-river units. Figure 2 shows that these two cases represent units with relatively small gross head. However, the same categorisation issue apply here as for mean annual production; it seems like (Vold et al., 1998) does not include the run-of-river plants with largest head, but as ''Suldal II'' and ''Såheim'' were modelled as reservoir generation units due to the fact that the water comes from reservoirs (but without having regulation options), they are presented as reservoir generation units in Figure 2. These two, and especially ''Suldal II'', lie in the very upper end of the gross head scale of run-of-river generation units in Figure 2. Still, removing them from the reservoir figure to the run-of-river figure would not have ruined the representativeness of the reservoir studies in (Vold et al., 1998).

As seen in Figure 2, one of the two units that currently are analysed by NVE (“Sandal og Fossheim”) represents a larger gross head than the two run-of-river generation units included in (Vold et al., 1998), while gross head for the other plant (“Byrkjelo”) is not given.

In Appendix 1, similar figures for the parameters local inflow [mill m3/year] and total reservoir volume [mill m3] are given, showing corresponding results as the above shown figures.

Having in mind that the LCA study in (Vold et al., 1998) includes eight hydro power generation units, the conclusion is that this study seems to represent Norwegian hydro power generation units, as they cover a spectre of different plants within the analysed parameters.

2 Results presented for different life cycle stages

The existing LCA results from the report "Inventory of Life Cycle Data for Hydroelectricity Produced and Distributed in Norway (Vold et al., 1998) are presented as Global Warming Potential[1] (GWP, expressed as CO_2-equivalents per kWh). The data have been particularly checked, which has resulted in some small adjustments. The final adjusted data, which have been used in this analysis, are presented in Table 1.

Generation Unit	**GWP (g CO_2-equiv./kWh)**
Gråsjø (reservoir)	2,12
Kvanndal (reservoir)	1,01
Svartisen (reservoir)	0,89
Suldal II (reservoir/water from Kvanndal)	0,75
Rånåsfoss 2 (run-of-river)	0,74
Trollheim (reservoir)	0,72
Rånåsfoss 1 (run-of-river, 2nd life cycle)	0,32
Såheim (reservoir, 2nd life cycle)	0,15

Table 1: GWP for the different generation units based on the existing LCA data (Vold et al., 1998, adjusted august 2010).

As seen from the table, the variation in GWP is quite small, varying from 0.15 to 2.12 g CO_2-equivalents per kWh. It should be noted that the two units with smallest GHG emissions represent generation units which are calculated for their 2nd life cycle, thus they have less impacts from the infrastructure stage included (as these impacts have been allocated to the first life cycle of the generation unit).

The GWP for all the generation units are presented in Figure 3 separated into all the different infrastructure activities in addition to the operation life cycle stage (shown as "Use and Maintenance").

[1] To compare GHG emissions from different sources, the gases are indexed according to their global warming potential (GWP) per unit of weight. GWP is the ability of a GHG to trap heat in the atmosphere relative to an equal amount of carbon dioxide. According to the Intergovernmental Panel on Climate Change (IPCC), over a 100-year time span, carbon dioxide (CO_2) assumes the value of 1. The two other GHGs of importance in these analyses are methane (CH_4) and nitrous oxide (N_2O) which, according to a re-evaluation of the IPCC in 2007, take a value of 25 and 298, respectively.

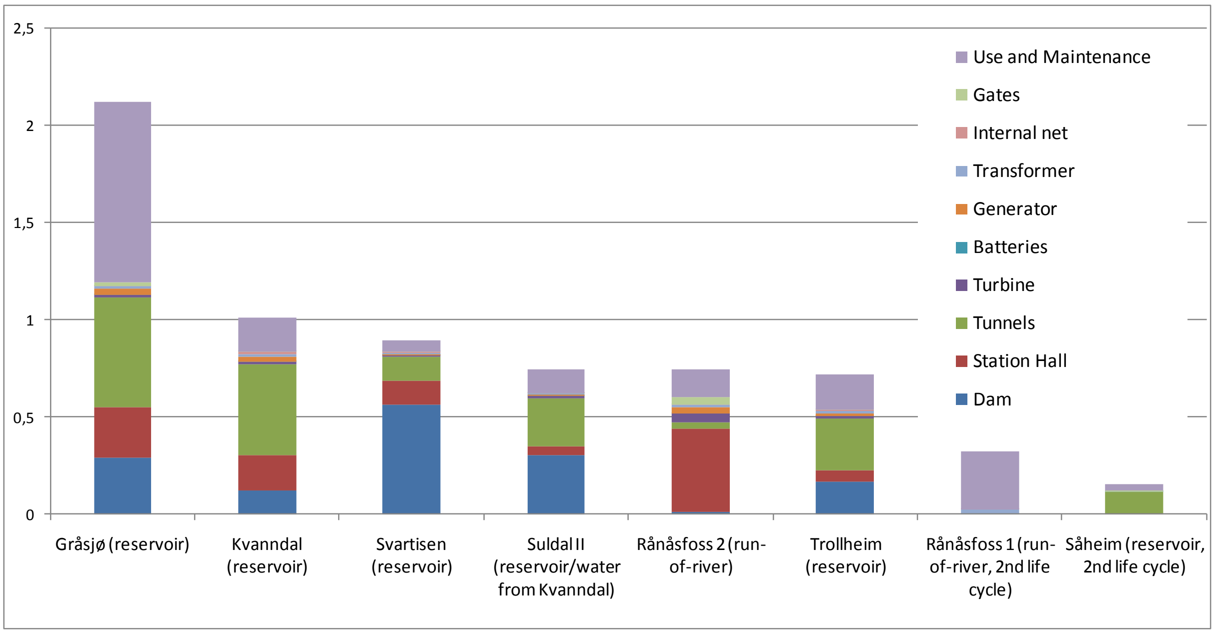

Figure 3: Global Warming Potential (g CO_2-equivalents/kWh) according to mean annual production (GWh/year).

As seen from the figure, the infrastructure life cycle phases are the main contributors to the overall GWP for all the 1st life cycle generation units. The exception is Gråsjø, having a contribution from the operation stage in the same order as the sum of the infrastructure stages. The main activities from the infrastructure stages are tunnels, dams and station halls.

For the 2nd life cycle generation units, the main contributing activities are the operation stage (Rånosfoss 1) and infrastructure by the tunnels (Såheim).

3 Categorising the hydro power plants related to Greenhouse Gas (GHG) Emissions (GWP)

As described above, the project wanted to investigate the possibility of categorising the plants according to different category groups and related GHG emissions. The work has been based on the calculated Global Warming Potential (GWP, expressed as CO_2-equivalents per kWh) for the analysed generation units and the corresponding parameters for the same plants, according to NVE's database. For each parameter, the analysed units' GWP are plotted with the corresponding parameter. Based on the plots, the corresponding trend lines were calculated. The GWP results are presented according to the parameters annual power production [GWh], installed capacity [MW], height of head [m], tunnel length [km], reservoir volume [mill. m3], and total inflow [mill. m3/year] to investigate if some interesting coherences are found.

It should be noted that the two 2nd life cycle cases have been excluded from these analyses to avoid "disturbing" results, as we know that these cases result in smaller GHG emissions due to less infrastructure burdens. It should also be noted that both reservoir and run-of-river plants are presented in the same figures to obtain as many relevant cases as possible.

Figure 4 shows the plot of the calculated GWP for each case according to mean annual electricity production.

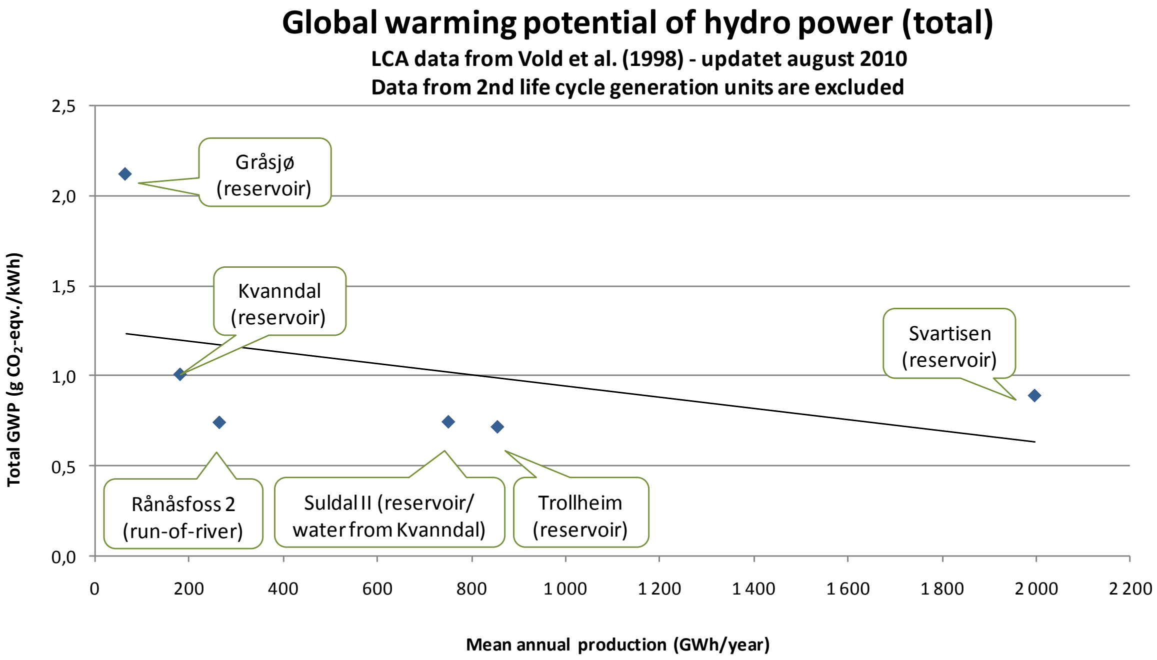

Figure 4: Global Warming Potential (g CO_2-equivalents/kWh) according to mean annual production (GWh/year).

From the corresponding trend curve a slight coherence can be observed, showing that the larger power production, the lower GWP. However, the number of cases is small, as well as the variation in GWP.

The Gråsjø generation unit seems to be an outlier representing considerably higher GWP than the others with the main difference coming from the life cycle stage “Operation and Maintenance”. If this case is excluded, the line would appear almost horizontal, showing no variation in GWP according to annual electricity production as the other cases result in GWP’s between 0.7 and 1.0 g CO2-equivalents per kWh. However, without any deeper investigation of the large “Operation and Maintenance” contribution, there is no reason to exclude Gråsjø just because it results in higher GWP.

Figure 5 shows the plot of the calculated GWP for each case according to installed capacity.

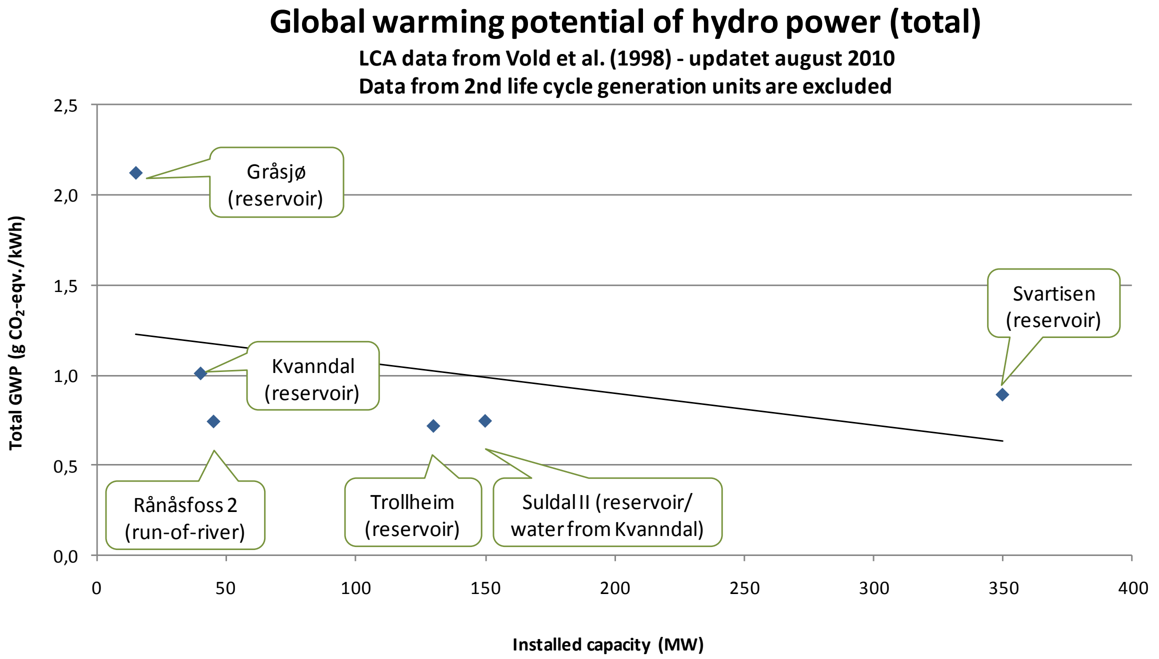

Figure 5: Global Warming Potential (g CO_2-equivalents/kWh) according to installed capacity (MW).

Not surprisingly, this figure shows almost the same result as Figure 4, as installed capacity should be expected to indicate the amount of annual production. The calculated trend curve for GWP in Figure 5 also slightly declines as the installed capacity increases.

However, if excluding the case "Gråsjø", the trend curve would also for this parameter be almost horizontal.

Figure 6 shows the plot of the calculated GWP for each case according to gross head.

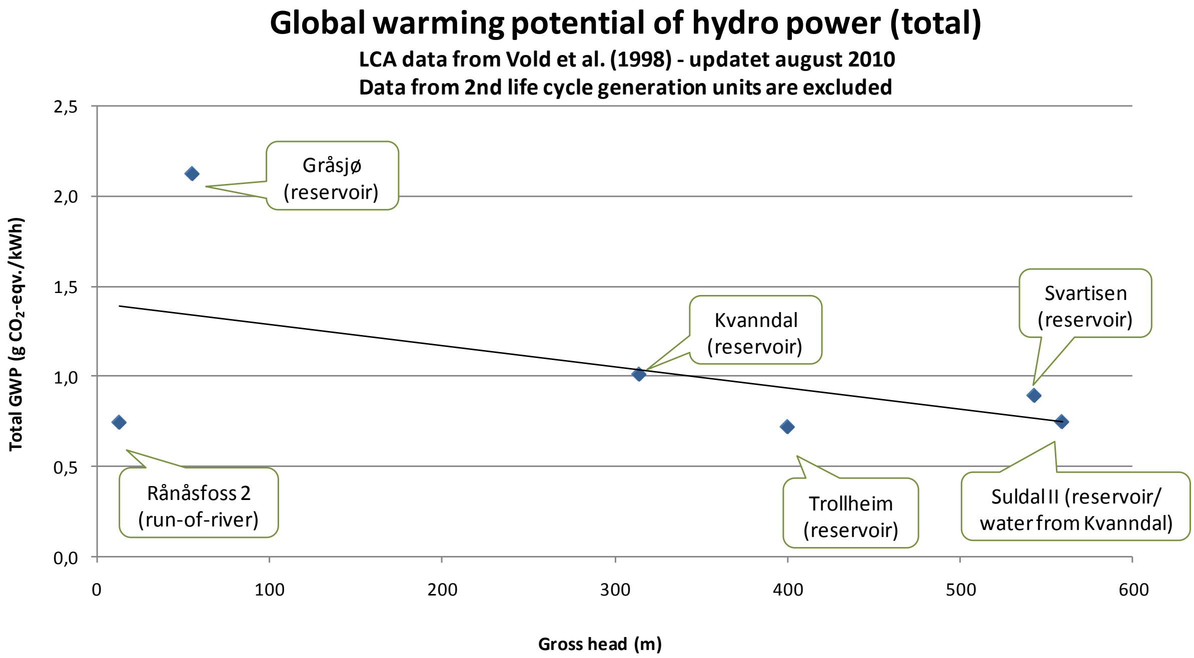

Figure 6: Global Warming Potential (g CO_2-equivalents/kWh) according to gross head (m).

Figure 6 also shows a slight coherence between the parameter “Gross head” and GWP, as the calculated trend curve for GWP slightly decreases with increased gross head. However, if excluding the Gråsjø case, also this curve would appear almost horizontal.

Figure 7 shows the plot of the calculated GWP for each case according to tunnel length.

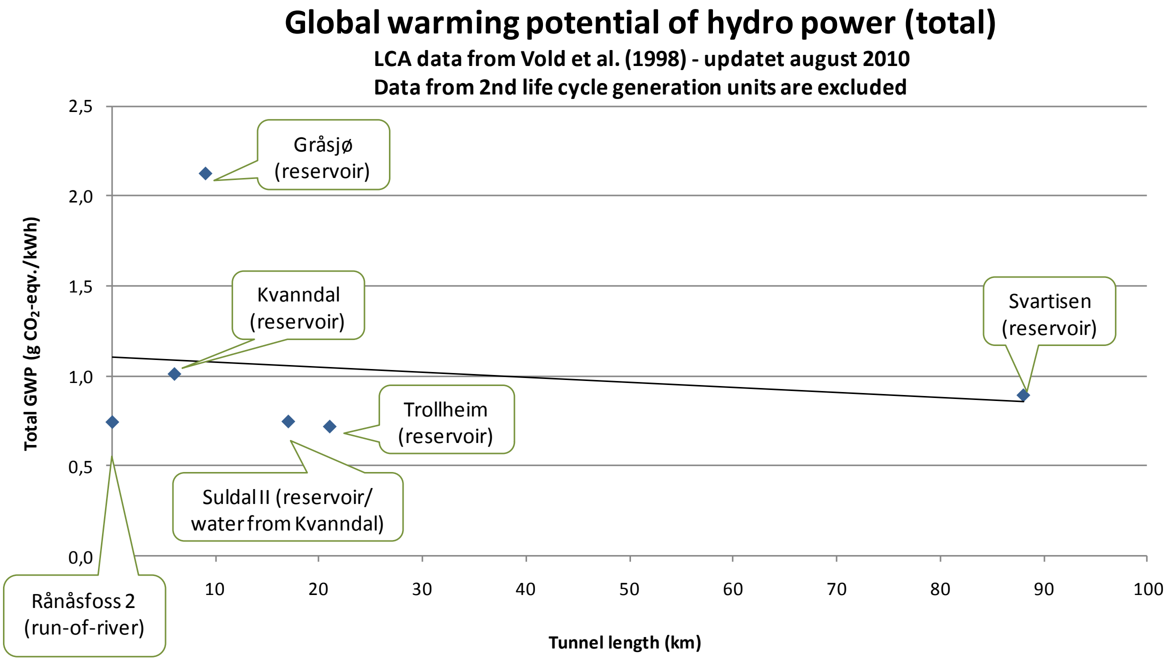

Figure 7: Global Warming Potential (g CO_2-equivalents/kWh) according to tunnel length (km).

The results show the same trend as the other presented figures. However, one would maybe have expected the opposite situation for this case: the larger tunnel length the larger GHG emissions, which does not seem to be the case according to the results.

Figure 8 and Figure 9 show the plot of the calculated GWP for each case according to total inflow and reservoir volume, respectively. It should be noted that the generation unit “Rånåsfoss 2” is excluded in both these figures as the data representing “Rånåsfoss 1” and “Rånåsfoss 2” are presented as one dataset in NVE’s database. The reason why “Rånåsfoss 2” is represented in Figure 4 to Figure 7 above is that the representative parameters have been available in the report (Vold et al., 1998).

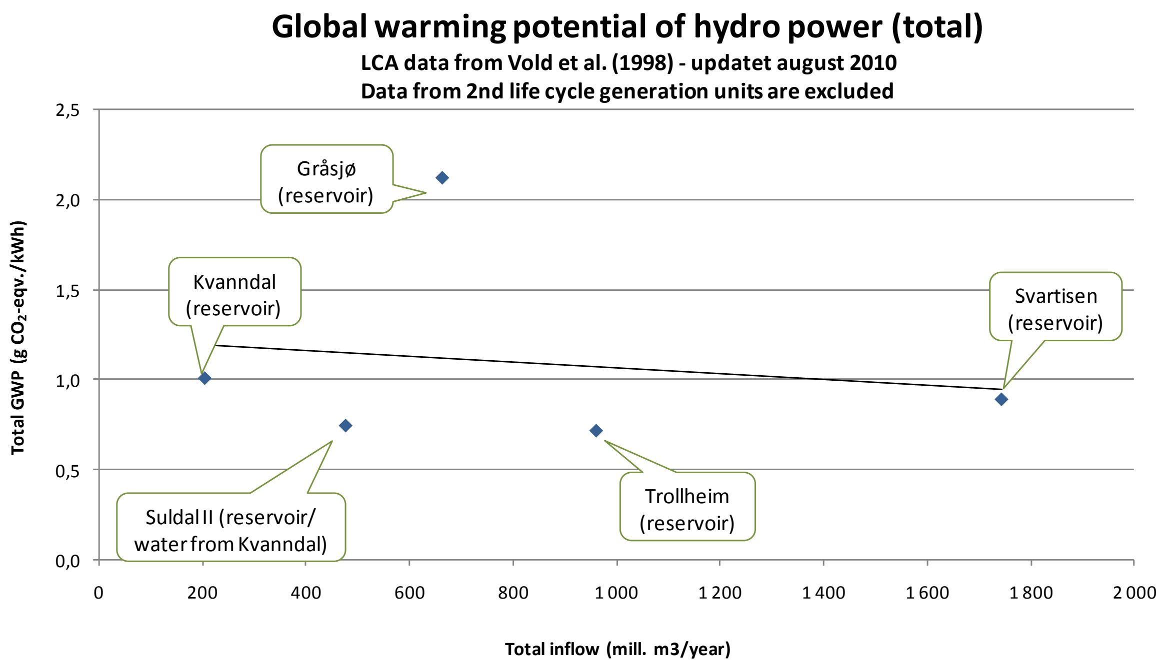

Figure 8: Global Warming Potential (g CO_2-equivalents/kWh) according to total inflow (mill m3/year).

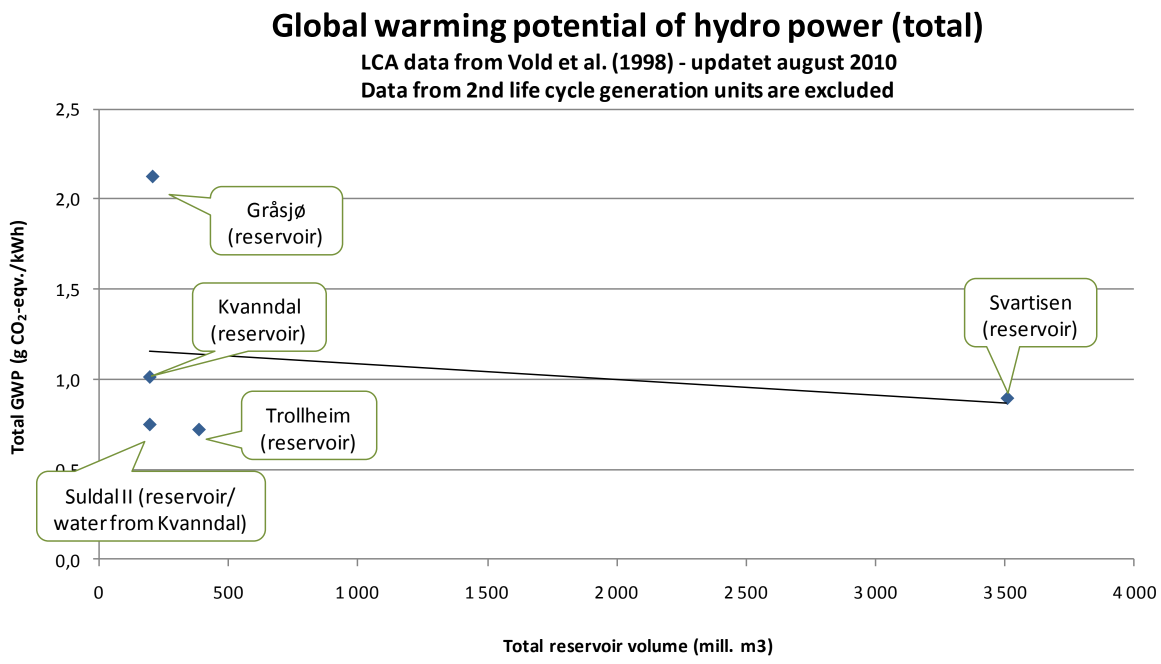

Figure 9: Global Warming Potential (g CO_2-equivalents/kWh) according to reservoir volume (mill m3).

Both Figure 8 and Figure 9 show the same trend as the other presented figures; a slight coherence between the analysed parameters and GWP, as the calculated trend curve for GWP slightly decreases with increased total inflow and reservoir volume, respectively.

4 Discussion and Conclusion

When sorting the LCA analyses of the eight Norwegian hydro power generation units (Vold et al., 1998), according to NVE's database (NVE 2009), the conclusion is that the studies seem to represent Norwegian hydro power generation units, as they cover a spectre of different plants within the analysed parameters.

The infrastructure life cycle phases are the main contributors to the overall GWP for all the 1st life cycle generation units. The only exception is Gråsjø, having a contribution from the operation stage in the same order as the infrastructure stages. The main activities from the infrastructure stages are construction of tunnels, dams and station halls.

The analyses of different physical parameters (according to NVE's database) and related GHG emissions show that there seem to be intuitive, logical coherences between the parameters and corresponding GHG emissions. However, the coherences are weak, the number of cases which the analyses are based on is small, and the variations in corresponding GHG emissions from the analysed cases are small. A categorisation of Norwegian hydro power according to physical parameters and related GHG emissions thus seems to be difficult.

One of the cases seems to be an outlier resulting in relatively higher GHG emissions compared to the others, based on larger contribution from the life cycle stage "Operation and Maintenance". However, why this larger contribution appears has been hard to investigate, which means that we have no good reasons to exclude the case from the analyses. A further investigation of the basis data for the Gråsjø generation unit should be made, to understand the reason why this generation unit differs from the others regarding GHG emissions.

It is important to note that the calculated GHG emissions from the LCA cases vary from 0.15 to 2.04 g CO_2-eqvivalents per kWh. Compared to electricity generation from other energy sources these GHG emissions are extremely small, as illustrated in Figure 10.

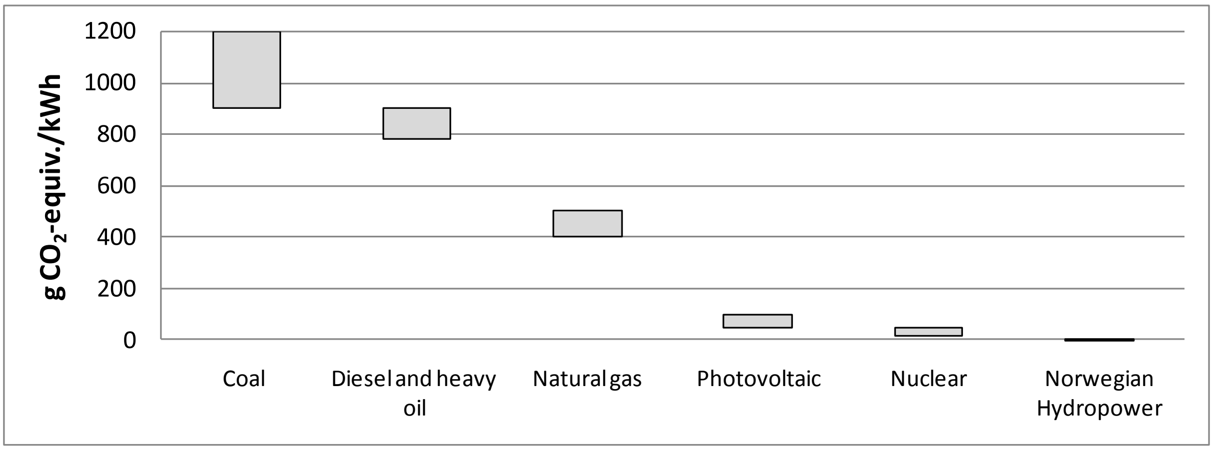

Figure 10: Life cycle GHG emissions from wind and hydro power compared to other electricity generation systems (based on literature data from (Ardente et al., 2008)).

Recommendations

Based on the results from these analyses, we recommend that the project agree on calculating an average Norwegian Hydro Power plant's typical GHG emissions, based on the adjusted existing data, complemented with the data from NVE's LCAs when finished. The variations within the different plants are evaluated to be too small for making it reasonable to categorise Norwegian Hydro power according to different physical parameters and related GHG emissions. The current (Vold et al., 1998) average of Norwegian hydropower (which has to be adjusted and complemented) is calculated to 1.2 g CO_2-eqvivalents per kWh.

5 References

Ardente, M. Beccali, M. Cellura, and V. Lo Brano, 2008. Energy performances and life cycle assessment of an Italian wind farm. *Renewable and Sustainable Energy Reviews*, 12(1), 200-217.

NVE, 2009. Database of Norwegian Hydro Power units and related parameters.

Vold, M., Askham, C. & Borchsenius, C., 1998. *Inventory of Life Cycle Data for Hydroelectricity Produced and Distributed in Norway.*, Ostfold Research.

Appendix 1

Figure A1 and A2 show the Norwegian generation units sorted according to local inflow [mill m3/year] and total reservoir volume [mill m3], respectively, divided into reservoir and run-of-river units (according to NVE's database).

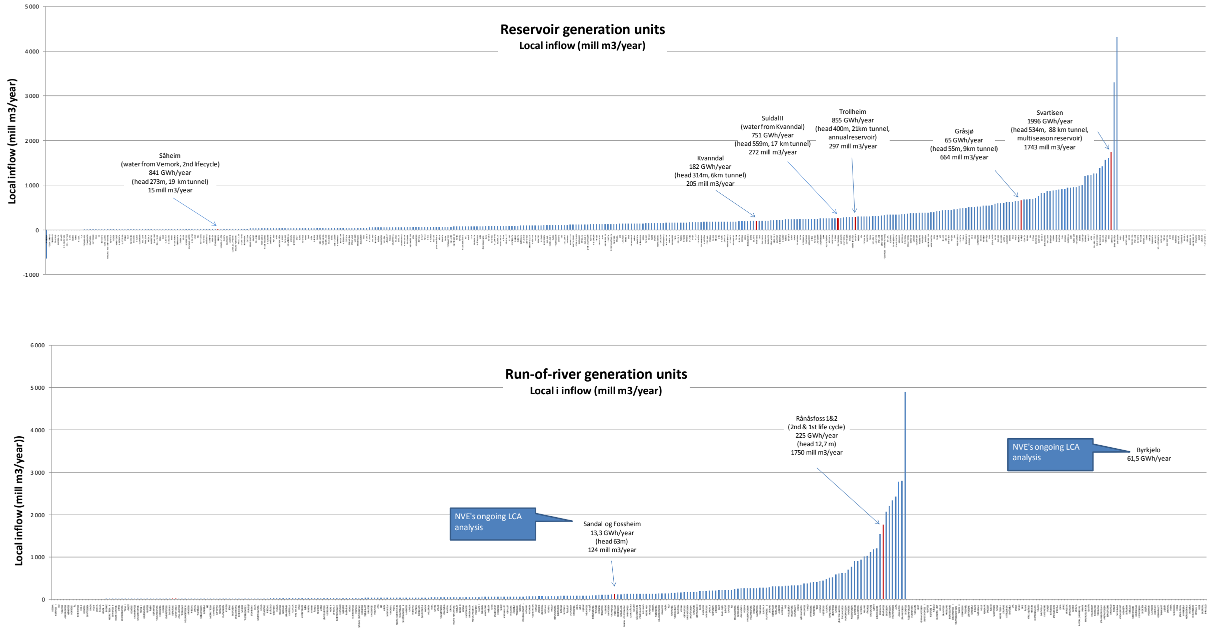

Figure A.1: Norwegian reservoir and run-of-river plants, sorted according to local inflow [mill m^3/year].

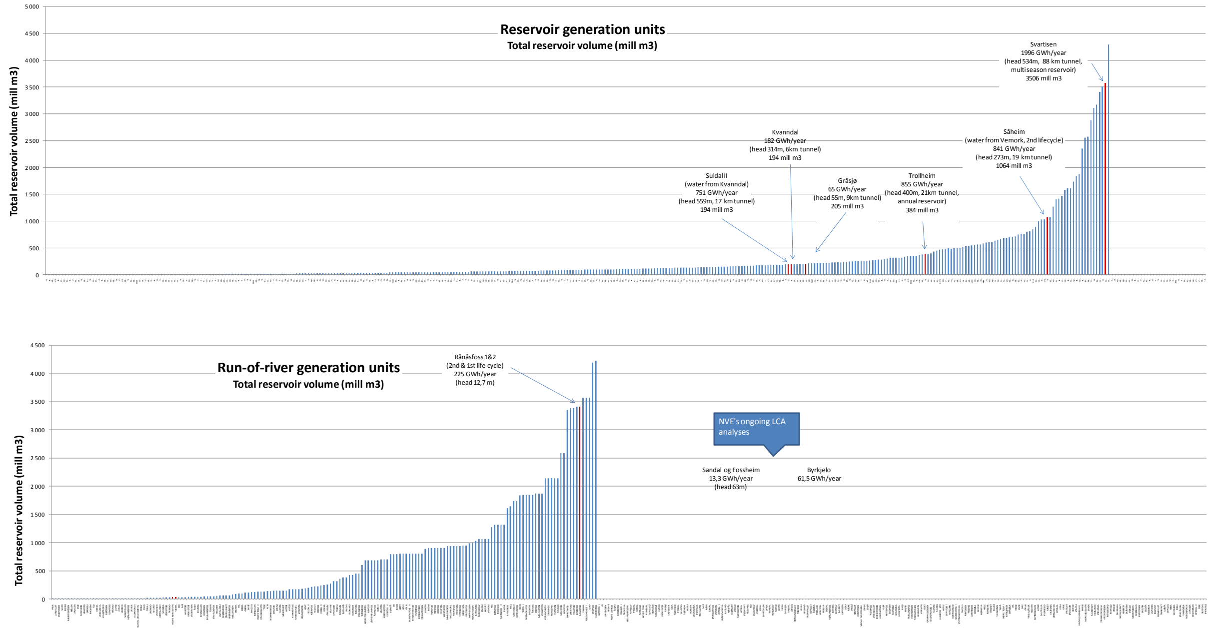

Figure A.2: Norwegian reservoir and run-of-river plants, sorted according to total reservoir volume [mill m^3].