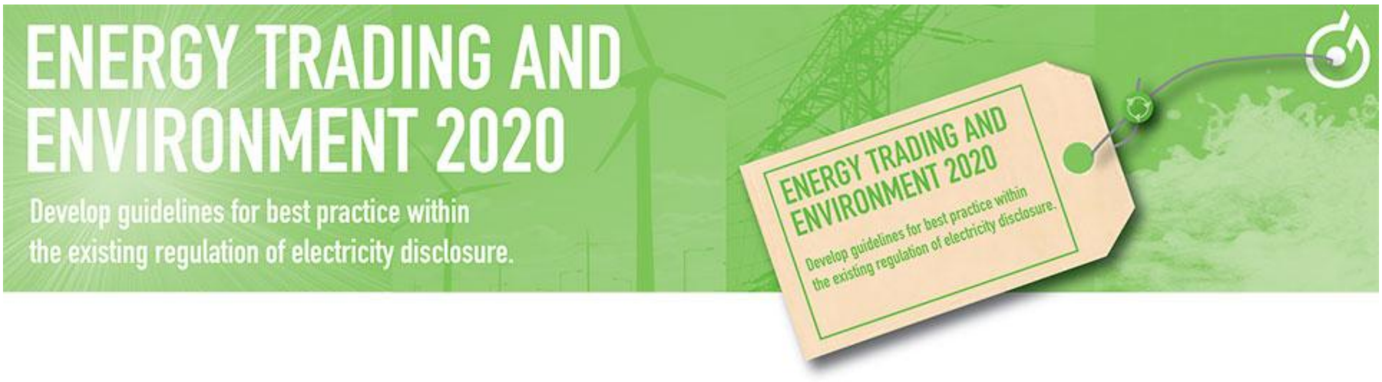
Østfoldforskning

Report SUSTAINABLE INNOVATION

Author(s):	Kaja Henny Engebrigtsen, Silje Arnøy
Report no.:	AR.04.11
ISBN:	-
ISSN:	0803-6659



Energy Trading and the Environment 2020

Work Report: Updating the dataset from “Inventory and Life Cycle Data for Hydroelectricity, produced and distributed in Norway”

Report no.:	AR.04.11	**ISBN no.:**	-	**Report type:**	
		ISBN no.:	-	Commissioned report	
		ISSN no.:	0803-6659		

Report title:

Energy Trading and the Environment

Work Report: Updating the dataset from “Inventory and Life Cycle Data for Hydroelectricity, produced and distributed in Norway”

Author(s): Kaja Henny Engebrigtsen and Silje Arnøy

Project number:	12887	**Project title:**	Energy Trading and the Environment 2020 / Energihandel 2020 (EH2020)

Commissioned by:	**Company contact:**
Ostfold Research	Hanne Lerche Raadal and Ingunn Saur Modahl

Keywords:	**Confidentiality:**	**Number of pages:**
• Hydroelectricity • LCA update • CSV-files • Lifetime adjustment	Open	29

Approved:
Date: 06.09.2011

Project Manager	**Research Manager**
(Sign)	(Sign)

Contents

Summary

In 1998 Ostfold Research published a report on the Inventory and Life Cycle Data for produced and distributed Norwegian Hydroelectricity. This work report is part of the current project “Energy Trading and the Environment 2020”, where the dataset from the 1998 report is updated and adjusted for new data and information. The new dataset is part of a cradle to gate Life Cycle Assessment; hence it does not contain data on electricity distribution.

“Energy trading and the Environment 2020” sets out to enhance consumer information on electricity. This work report describes the procedure in which the dataset was updated and adjusted. Furthermore it presents figures and tables illustrating the results obtained in SimaPro analysis of the dataset.

1 Introduction

As students attending the master program in Renewable Energies at the University for Life Sciences, we completed a course on Life Cycle Assessment (LCA). Through this course we learnt to know Ole Jørgen Hanssen and subsequently about Ostfold Research – a research institute with a strong emphasis on LCA. As summer approached we were informed that there were possibilities of summer internships at Ostfold Research. We were hired to assist on the project Energy Trading and the Environment 2020. Energy Trading and the Environment 2020 is a project where Ostfold Research and other research institutions together with industrial partners set out to enhance the consumer information available on electricity through:

- Helping consumers compare electricity from different sources in a transparent and trustworthy way.
- Helping suppliers use a harmonized electricity disclosure as a tool for informing energy consumers about the origin of electricity.
- Helping producers show the environmental footprint from renewable energy production.(Ostfold Research)

As part of the summer internship we were asked to edit and update an existing dataset from the 1998 report: “Inventory and Life Cycle Data for Hydroelectricity, produced and distributed in Norway”.

This document describes the procedure in which we conducted our work.

2 Life Cycle Assessment of generation of Hydropower.

All energy systems emit Green House Gases (GHG) and though Hydropower is defined as “renewable energy” the generation of hydropower contributes to emissions of GHG and effects from land use change.
Life cycle assessments of hydropower generation seek to analyze all upstream and downstream processes pertaining to a specific power plant. To perform a comprehensive analysis it is necessary to obtain data from all the components in the power plant and from the generation of hydropower.

The results from 39 LCAs published between 1990 and 2010 shows that the major sources of emissions from the generation of hydropower are activities related to the construction of the power plant and emissions from flooded land (Raadal mfl. 2011). There is a large variation in emissions from different types of power plants. Reservoir power plants tend to have higher emissions of GHG than run-of-river plants. This can be explained by the emissions from decomposition of biomass from flooded land.
It is consequently important to include emissions from flooded land in the LCA.

3 Updating the data set.

3.1 Organizing the original dataset from ‘Inventory and Life Cycle Data for Hydroelectricity, produced and distributed in Norway’.

- We organized the data in the original Excel files by removing some of the components without emission data.
- Arranged the data alphabetically under the relevant category equal to the setup in “input/output” data in the material process for the power stations in SimaPro.
- Cross checked the dataset

3.2 Importing/Exporting

- We transferred the updated dataset to SimaPro. This was done for 8 power stations, all with 9 lifecycle stages:
    - Power Stations:
        - Gråsjø
        - Suldal II
        - Trollheim
        - Svartisen
        - Kvanndal
        - Rånåfoss 1
        - Rånåfoss
        - Såheim
    - Lifecycle Stages:
        - Dam
        - Tunnels
        - Station hall
        - Internal net
        - Transformers
        - Generators
        - Gates
        - Batteries
        - Inundation of land

- We exported empty CSV files from SimaPro prepared with the relevant categories;
    - Input to nature
    - Emissions to air
    - Emissions to water
    - Final waste flows resource

- We transferred data from the updated Excel files to the CSV files.

- We imported the dataset (new CSV-file) to SimaPro.

3.3 Manual postings

Due to the fact that some values were missing in the original dataset and some values needed to be corrected, we posted the following manually in SimaPro. Values representing losses should not be adjusted for lifetime and were therefore corrected by a parameter manually in SimaPro.

3.3.1 Intrinsic Energy

- We posted 1 kWh intrinsic energy per kWh produced and placed it in the dam process. Text given in the ‘comment’-field in the actual process:

> *Intrinsic energy not included in OR 58.98. Included here to account for the potential energy needed to produce the FU (1 kWh). Value 1 according to the definition. Discussed by HLR and ISM 26/5-11.*
>
> *Added manually and should NOT be altered if the lifetime is changed (FU), hence this expression is used to eliminate the FU correction. By Kaja and Silje (20/6-11).*

3.3.2 Losses

- We posted potential energy losses in the generator, turbines, and tunnels. Text given in the ‘comment’-field in the actual processes:

> *Given as Hydro power [kWh, el] (r) [g], which means resource use in the form of potential energy which is lost in generator/transformator (according to inkl. i OR 58.98).*
>
> *Added manually and should NOT be altered if the lifetime is changed (FU), hence this expression is used to eliminate the FU correction. By Kaja and Silje (20/6-11).*

> *Given as Hydro power, t [kWh, mech] (r) [g], which means resource use in the form of potential energy which is lost in turbine (according to inkl. i OR 58.98).*
>
> *Added manually and should NOT be altered if the lifetime is changed (FU), hence this expression is used to eliminate the FU correction. By Kaja and Silje (20/6-11).*

> *Given as Hydro power, v [kWh, mech] (r) [g], which means resource use in the form of potential energy which is lost in the watersystem/tunnels (according to inkl. i OR 58.98).*
>
> *Added manually and should NOT be altered if the lifetime is changed (FU), hence this expression is used to eliminate the FU correction. By Kaja oig Silje (20/6-11).*

3.3.3 Land use (transformation into industrial area)

- This value was added manually and the emissions were included in the dam process. Text given in the ‘comment’-field in the actual process:

> *Given as Land use (m2). Added manually and should NOT be altered if the lifetime is changed (FU), hence this expression is used to eliminate the FU correction. By Kaja og*

3.3.4 Lifetime Parameters

- We created lifetime parameters for all life cycle stages. This was done to enable simple lifetime adjustment. (The base value is 60 years for all lifetime stages).

3.3.5 Corrections

- In the power station “Kvanndal”, the lifecycle stage “tunnel” is corrected by a factor 4,654 to adjust for the values in the original dataset for the “mining underground” activity being ten times too high. Text given in the ‘comment’-field in the actual process:

> *The 'tunnel' burden in the LCA Inventory Tool LCI was 4.654 times to high, according to investigations by HLR and ISM winter/spring 2011. This ratio is based on calculatios of Trollheim EPD 'tunnel' numbers, and is hence an assumption. To reduce the burden by 4.654, the FU is instead increased by 4.654 (ISM, 15/6-11). The result should be close to 0.4644 g CO2-eqv./kWh (analysing 15/6-11 gives the result 0.464 which is correct).*

- The adjustment of emissions (by correcting the FU) from the “mining underground” activity in the “Kvanndal” power station led to a correction in the manually posted numbers in “loss in tunnels”. Text given in the ‘comment’-field in the actual process:

> *Since this loss was NOT affected by the 'mining underground' fault, the number shall NOT be corrected (factor 4,654 in the FU), hence the factor 4,654 is used here to eliminate the FU correction. By ISM (17/6-11).*

3.3.6 Inundation of land

- For all the power stations the life cycle process “inundation of land” is included but these process cards are temporarily empty due to lack of data.

3.4 Analyzing the data in SimaPro.

- For each power station we linked together the process cards for the nine different life cycle stages to make the process card “Electricity from ‘power station’”.
- We used the Ostfold Research SimaPro method “Østfoldforskning Method LCA/EPD 2010 July(11-4-11)” to analyze the data.
- We exported the SimaPro results to Excel where we organized them according to their impact category, and made figures and tables for illustration purposes.

3.4.1 Norwegian Hydroelectricity

- After analyzing all the power stations individually, we linked them together to create a process card named “Norwegian Hydroelectricity”.
- The power stations were linked together in accordance with the weighting factor used in the 1998 report: “Inventory and Life Cycle Data for Hydroelectricity, produced and distributed in Norway”:

Gråsjø	9 %
Suldal II	9,5 %
Trollheim	9,5 %
Svartisen	36 %
Kvanndal	17 %
Rånåfoss II	10 %
Såheim	5 %
Rånåfoss I	4 %

3.5 Lifetime adjustment

We adjusted the lifetime for the life cycle stages ‘dam’ and ‘tunnel’ from the base value of 60 years to a 100 years. This gave us a new set of results for all the power stations following the same procedure as described above.

4 Results

This section shows the results obtained using SimaPro. How the analysis was conducted is described in section 3.4. We analyzed the dataset two times. One where lifetime equaled the original 60 years, and one scenario where we prolonged the lifetime for the lifecycle stages 'dam' and 'tunnel' to 100 years.

4.1 60 years lifetime of all infrastructure

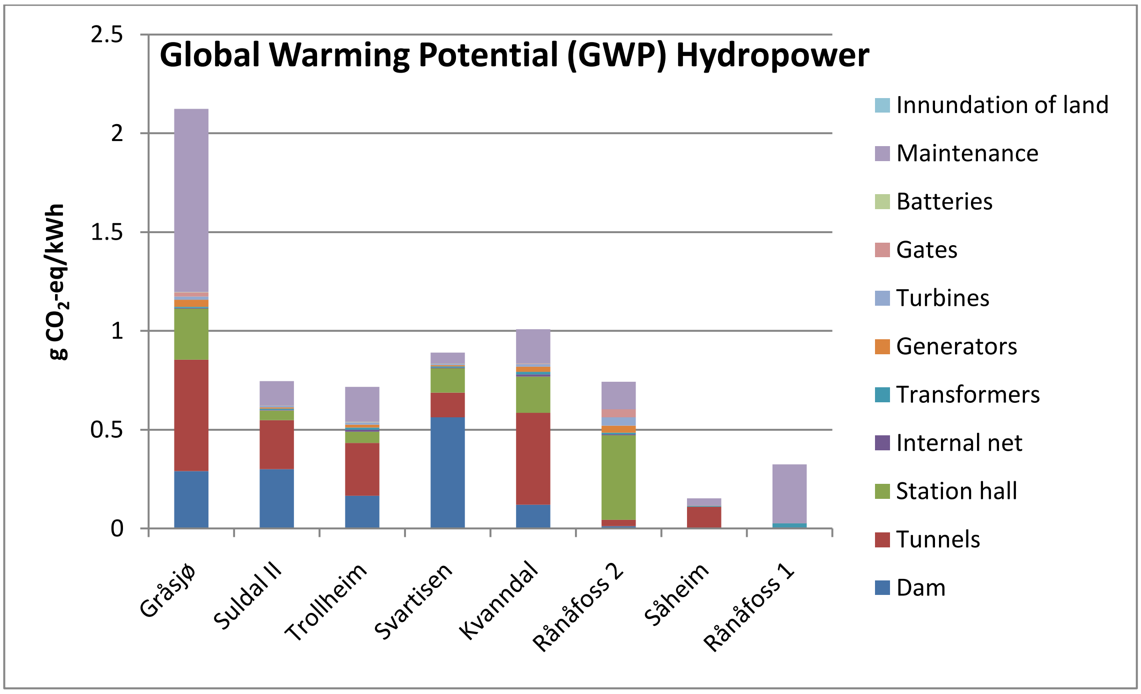


Figure 4.1.1: Global Warming Potential

Figure 4.1.1 shows the Global Warming Potential (GWP) from the individual power stations, divided into life cycle stages. There are three stations that significantly differ from an observed 'average'. These are Gråsjø, Såheim, and Rånåfoss 1. Gråsjø has significantly higher values connected to the life cycle "Maintenance" compared to the other power stations, and this constitutes most of the difference in GWP. This may mean that the values from the original dataset were skewed. Såheim and Rånåfoss 1 are in their second life cycle; hence we attribute the lower observed GWP to this fact.

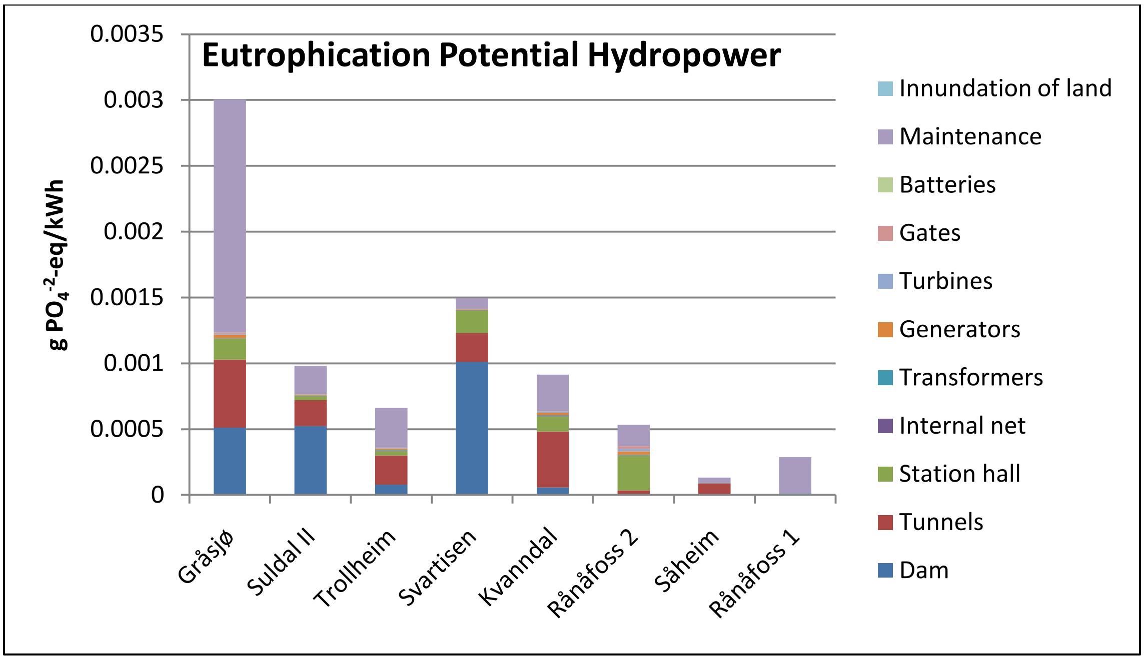


Figure 4.1.2: Eutrophication Potential

Figure 4.1.2 shows the Eutrophication Potential from the individual power stations, divided into life cycle stages. Also for this impact category Gråsjø, Såheim, and Rånåfoss 1 differ from an observed 'average'. The same observations made for GWP are also valid here. Gråsjø has significantly higher values connected to the life cycle "Maintenance" compared to the other power stations, and this constitutes most of the difference in the Eutrophication potential. This may mean that the values from the original dataset were skewed. Såheim and Rånåfoss 1 are in their second life cycle; hence we attribute the lower observed values to this fact.

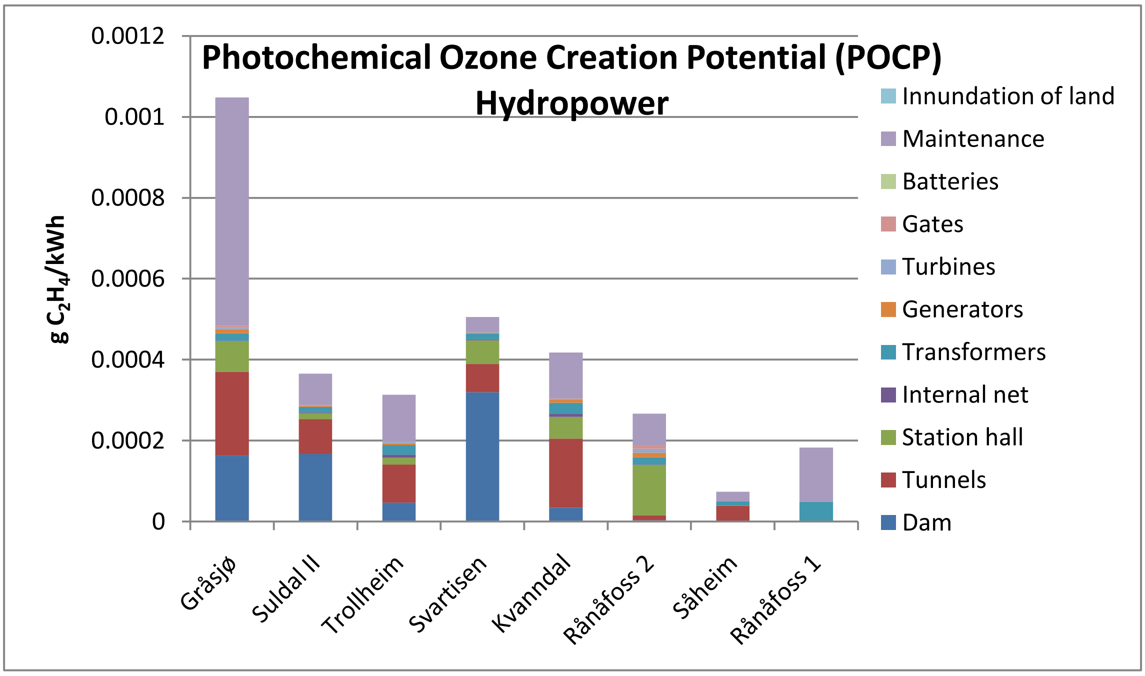


Figure 4.1.3: Photochemical Ozone Creation Potential

Figure 4.1.3 shows the Photochemical Ozone Creation Potential (POCP) from the individual power stations, divided into life cycle stages. Also for this impact category Gråsjø, Såheim, and Rånåfoss 1 differ from an observed ‘average’. The same observations made for GWP and Eutrophication are also valid here. “Gråsjø” has significantly higher values connected to the life cycle “Maintenance” compared to the other power stations, and this constitutes most of the difference in the POCP. This may mean that the values from the original dataset were skewed (wrong). Såheim and Rånåfoss 1 are in their second life cycle; hence we attribute the lower observed values to this fact.

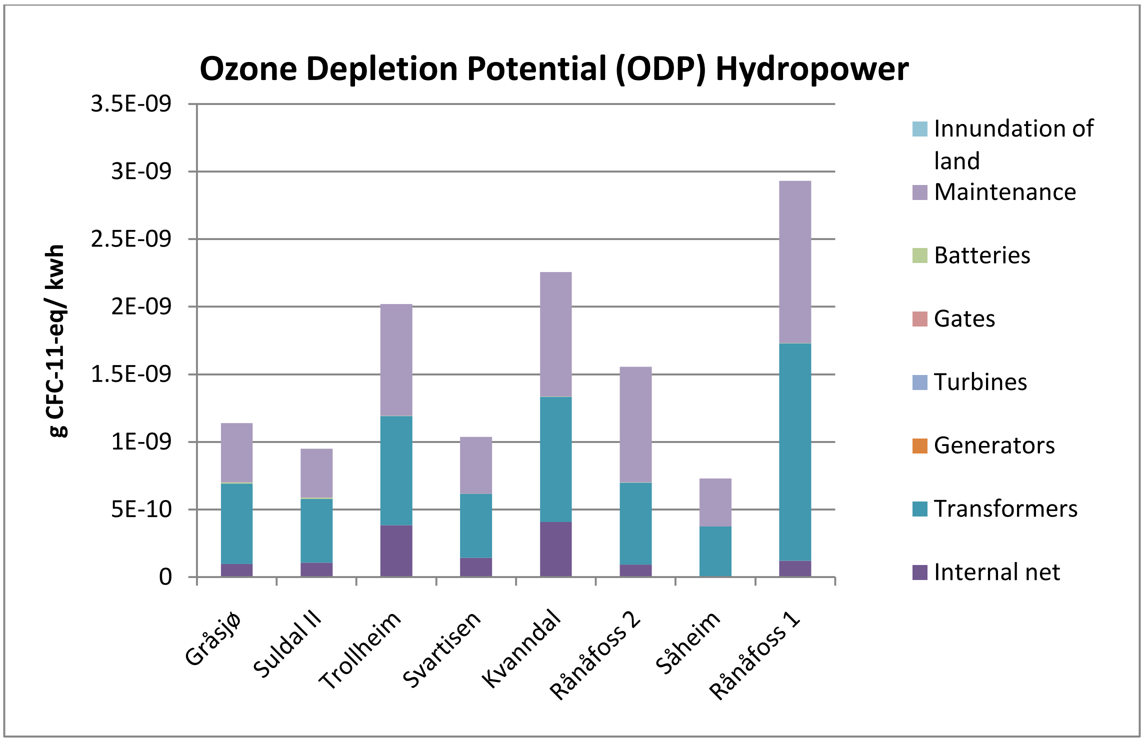


Figure 4.1.4: Ozone Depletion Potential

Figure 4.1.4 shows the Ozone Depletion Potential (ODP) from the individual power stations, divided into life cycle stages. The distribution differs from the other above impact categories.

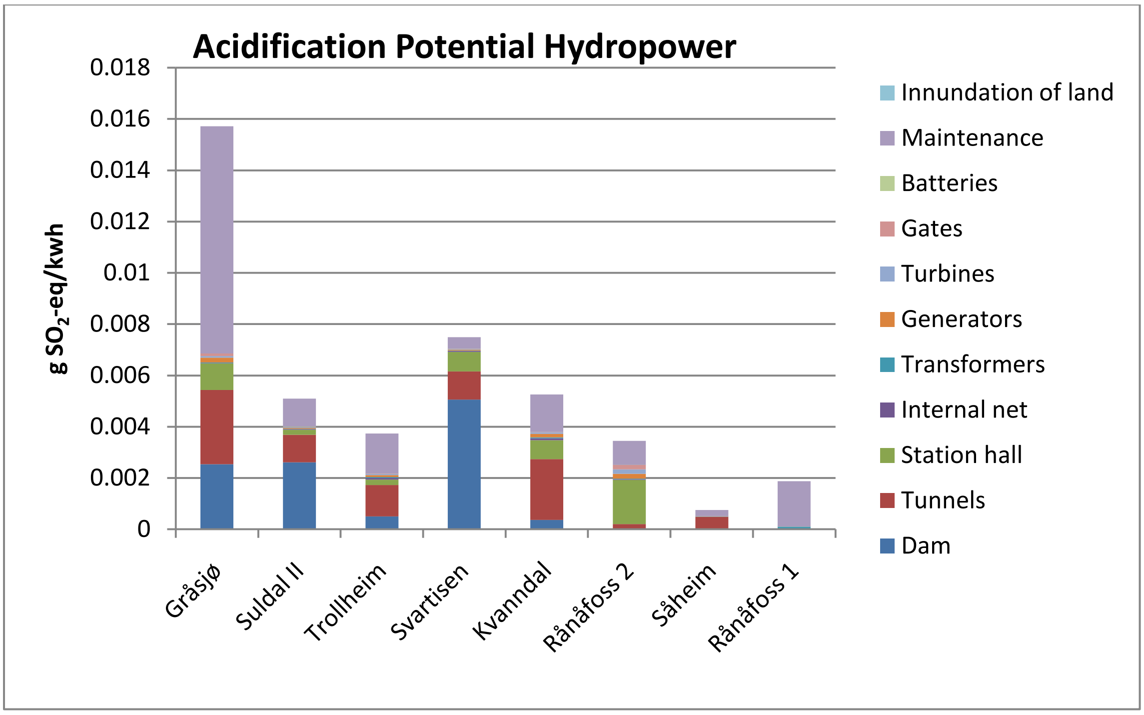


Figure 4.1.5: Acidification Potential

Figure 4.1.5 shows the Acidification Potential from the individual power stations, divided into life cycle stages. Again we observe that for this impact category Gråsjø, Såheim, and Rånåfoss 1 differ from an observed 'average'. Gråsjø has significantly higher values connected to the life cycle "Maintenance" compared to the other power stations, and this constitutes most of the difference in the Acidification potential. This may mean that the values from the original dataset were skewed (wrong). Såheim and Rånåfoss 1 are in their second life cycle; hence we attribute the lower observed values to this fact.

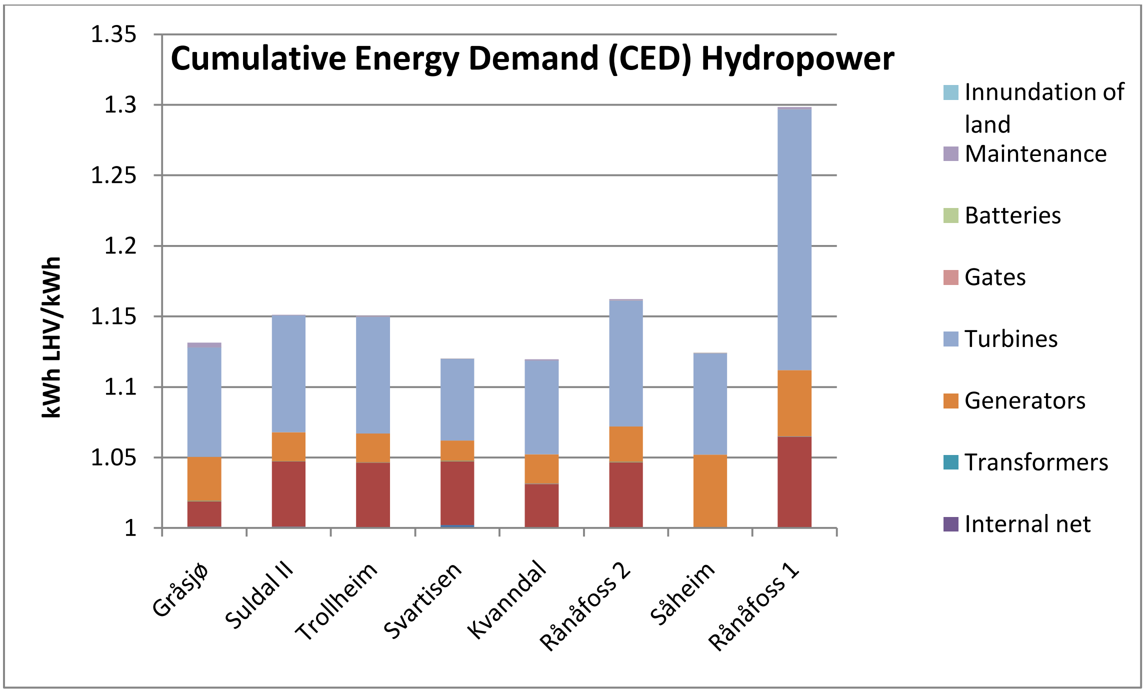


Figure 4.1.6: Cumulative Energy Demand

Figure 4.1.6 shows the Cumulative Energy Demand (CED) from the individual power stations, divided into life cycle stages. The y-axis min value starts from 1. This is because of the 1 kWh we manually posted as intrinsic energy (section 3.3.1). The CED tells us how much energy is needed to produce 1 kWh. We observe that the values for Rånåfoss 1 are significantly higher than for the other power stations.

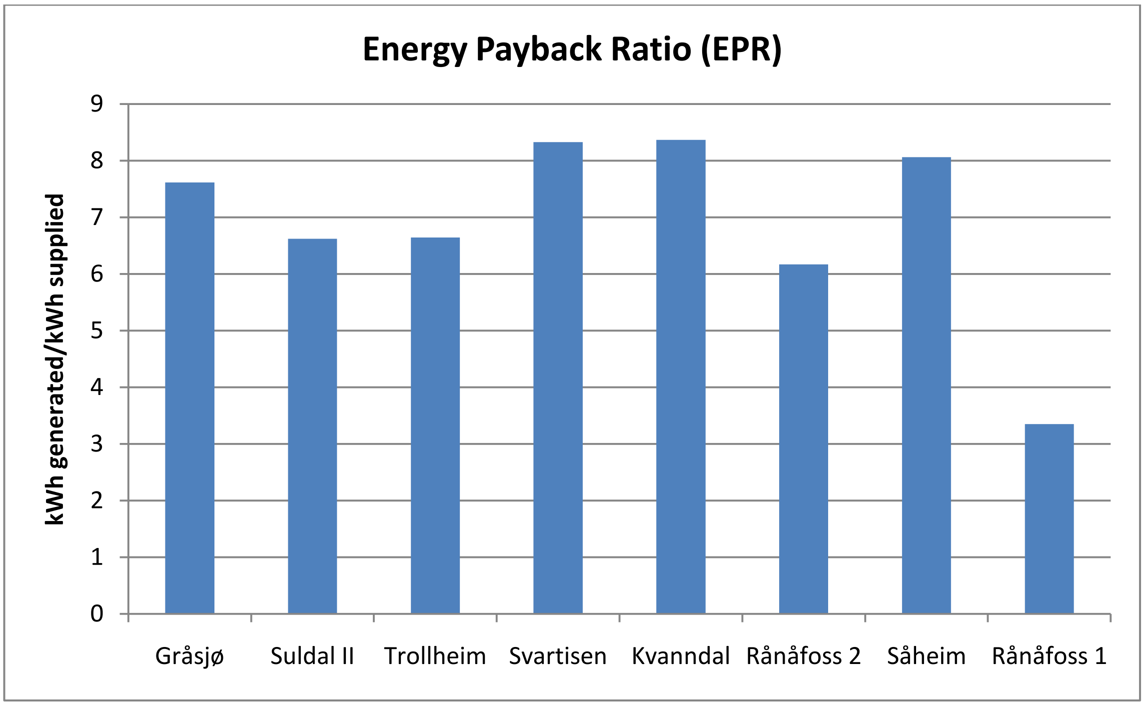


Figure 4.1.7: Energy Payback Ratio

Figure 4.1.7 shows the Energy Payback Ration (EPR) for the individual power stations. The EPR is “…the ratio of total energy produced during a system’s normal lifespan, divided by the energy required to build, maintain and fuel it...”(Hydro Quebec) We observe that all the power stations have relative high EPRs. This indicates high payback ratios and thus good environmental performance.

Impact category	Unit	Total	Dam	Tunnels	Station hall	Internal net	Transformers	Generators	Turbines	Gates	Batteries	Maintenance	Innundation of Land
Global Warming (GWP100)	kg CO_2-eq	9,2E-04	2,9E-04	2,3E-04	1,5E-04	5,3E-06	8,6E-06	1,6E-05	1,2E-05	7,7E-06	2,4E-07	1,9E-04	0
Ozone Layer Depletion (ODP)	kg CFC-11-eq	1,5E-12	0	0	0	1,9E-13	6,5E-13	0	0	0	3,1E-15	6,1E-13	0
Photochemical Oxidation	kg C_2H_4	4,5E-07	1,6E-07	9,3E-08	5,2E-08	3,5E-09	1,9E-08	4,6E-09	2,7E-09	1,9E-09	7,4E-11	1,2E-07	0
Acidification	kg SO_2-eq	6,3E-06	2,4E-06	1,3E-06	7,1E-07	3,5E-08	2,9E-08	8,0E-08	4,9E-08	3,5E-08	1,6E-09	1,6E-06	0
Eutrophi-cation	kg PO_4^{-2}-eq	1,2E-06	4,8E-07	2,4E-07	1,3E-07	3,0E-09	3,6E-09	1,2E-08	5,7E-09	3,8E-09	9,1E-11	3,2E-07	0
Cumulative Energy Demand	kWh LHV	1,1E+00	1,0E+00	3,9E-02	2,7E-04	3,2E-05	3,2E-05	2,2E-02	7,5E-02	3,0E-05	8,2E-07	7,4E-04	0

Table 4.1: Norwegian Hydroelecricity

Table 4.1 shows the emissions from an average Norwegian kWh hydroelectricity, divided into the different impact categories, divided into the nine different life cycle stages.

4.2 100 years lifetime of ‘dam’ and ‘tunnel’.

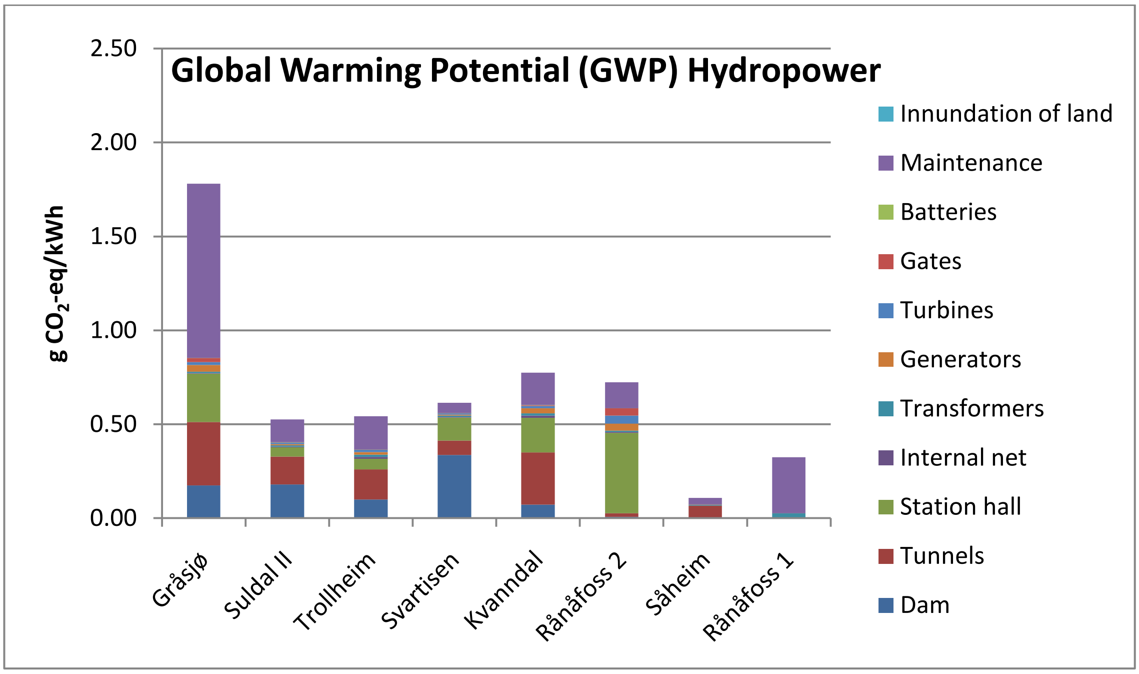


Figure 4.2.1: Global Warming Potential

Figure 4.2.1 shows the Global Warming Potential (GWP) from the individual power stations, divided into life cycle stages. The GWP-values are distributed similarly to the 60 years result, but for all of the power stations, except Rånåfoss 1, the GWP has decreased. This is due to the prolonged lifetime of the ‘dam’ and ‘tunnel’ life stages. Rånåfoss 1 had no emissions connected to these life stages and thus its GWP remains the same.

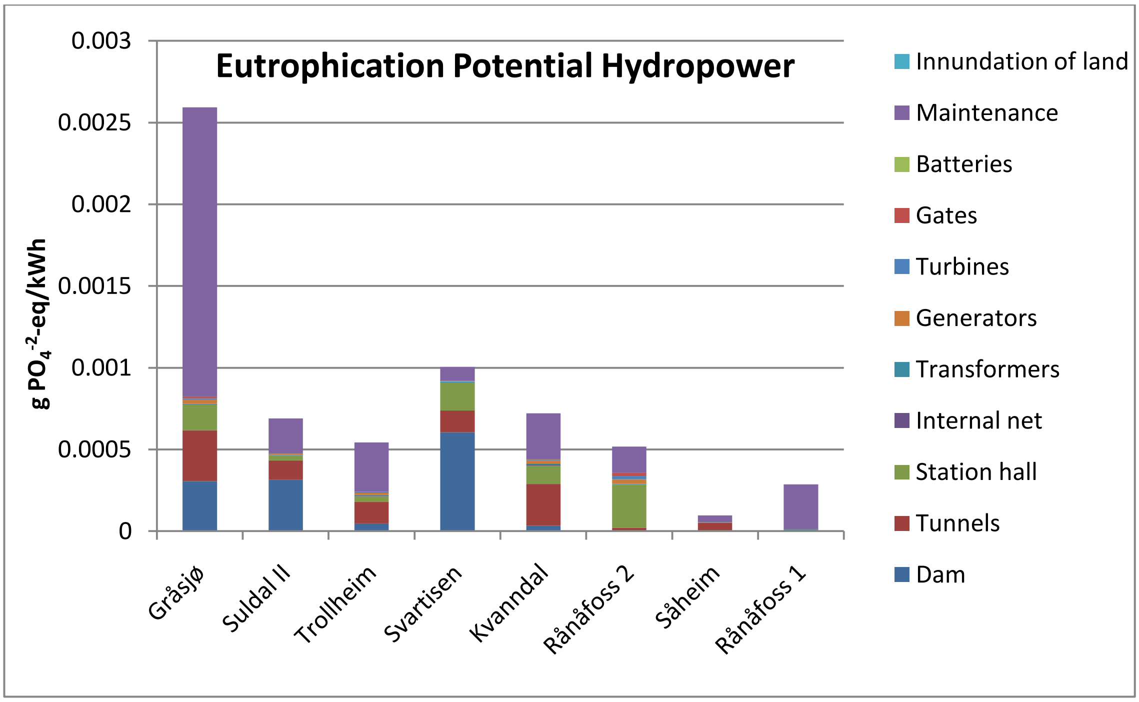


Table 4.2.2: Eutrophication Potential

Figure 4.2.2 shows the Eutrophication potential from the individual power stations, divided into life cycle stages. The Eutophication potential-values are distributed similarly to the 60 years result, but for all of the power stations, except Rånåfoss 1, the Eutrophication potential has decreased. This is due to the prolonged lifetime of the ‘dam’ and ‘tunnel’ life stages. Rånåfoss 1 had no emissions connected to these life stages and thus its eutriphication potential remains the same.

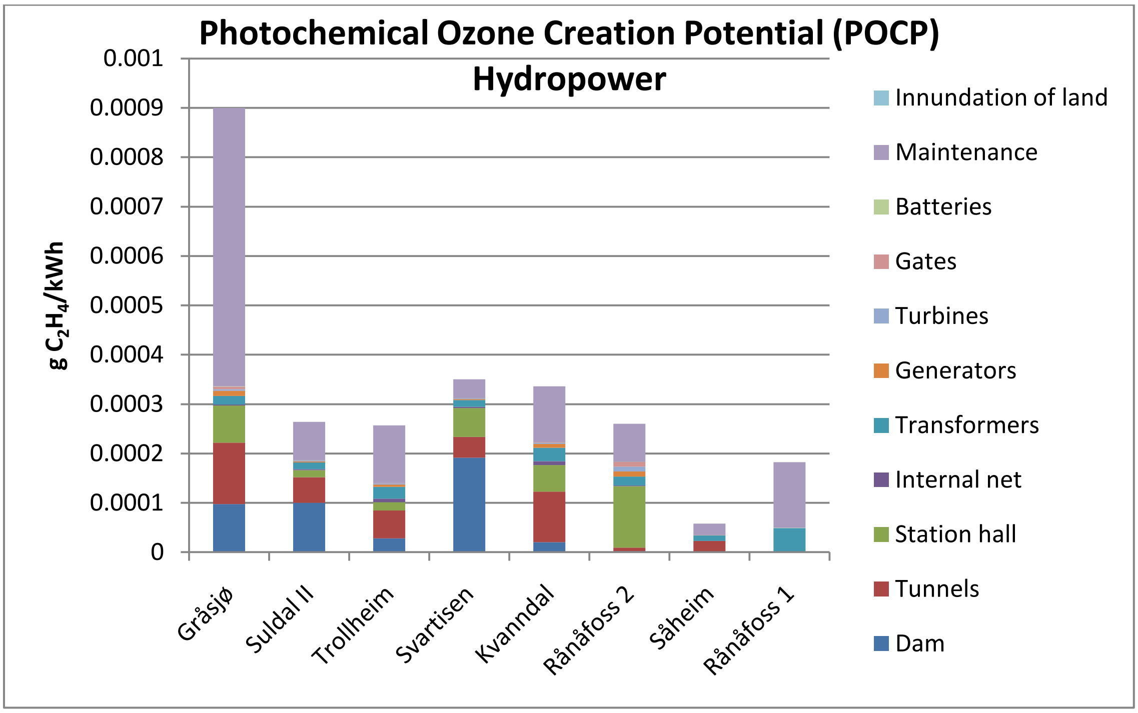


Figure 4.2.3: Photochemical Ozone Creation Potential

Figure 4.2.3 shows the Photochemical Ozone Creation Potential (POCP) from the individual power stations, divided into life cycle stages. The POCP-values are distributed similarly to the 60 years result, but for all of the power stations, except Rånåfoss 1, the POCP has decreased. This is due to the prolonged lifetime of the ‘dam’ and ‘tunnel’ life stages. Rånåfoss 1 had no emissions connected to these life stages and thus its POCP remains the same.

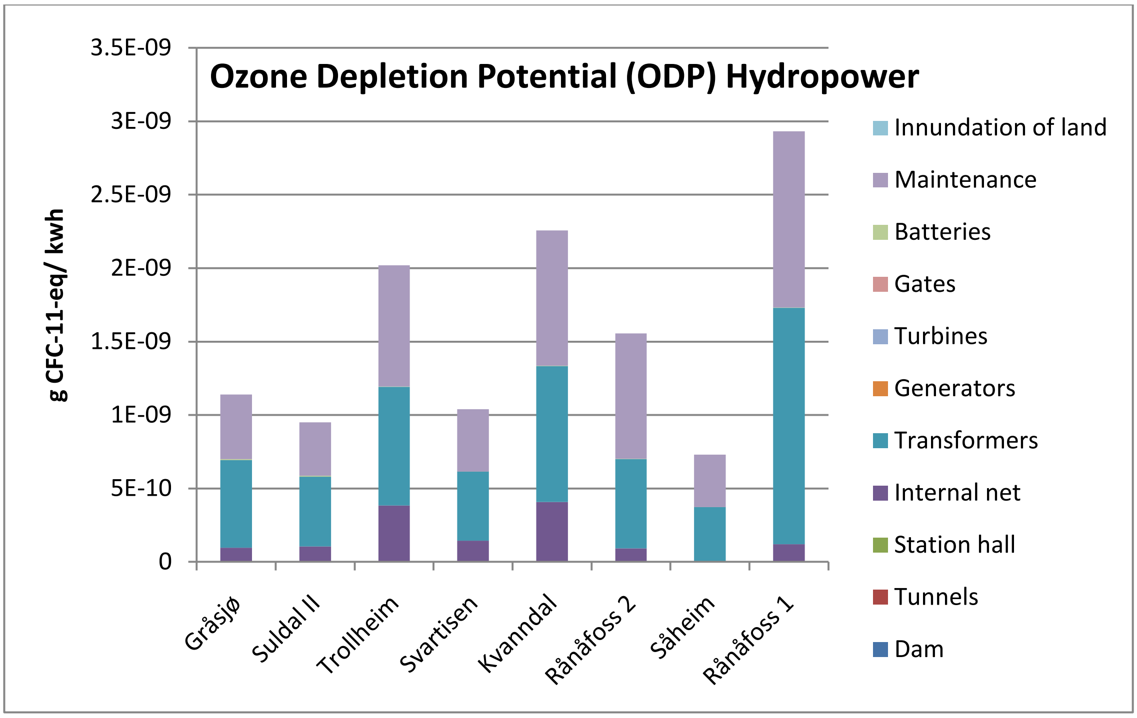


Figure 4.2.4: Ozone Depletion Potential

Figure 4.2.4 shows the Ozone Depletion Potential (ODP) from the individual power stations, divided into life cycle stages. The ODP-values are distributed equally to the 60 years result, as none of the power stations has emissions connected to the 'dam' and 'tunnel' life stages.

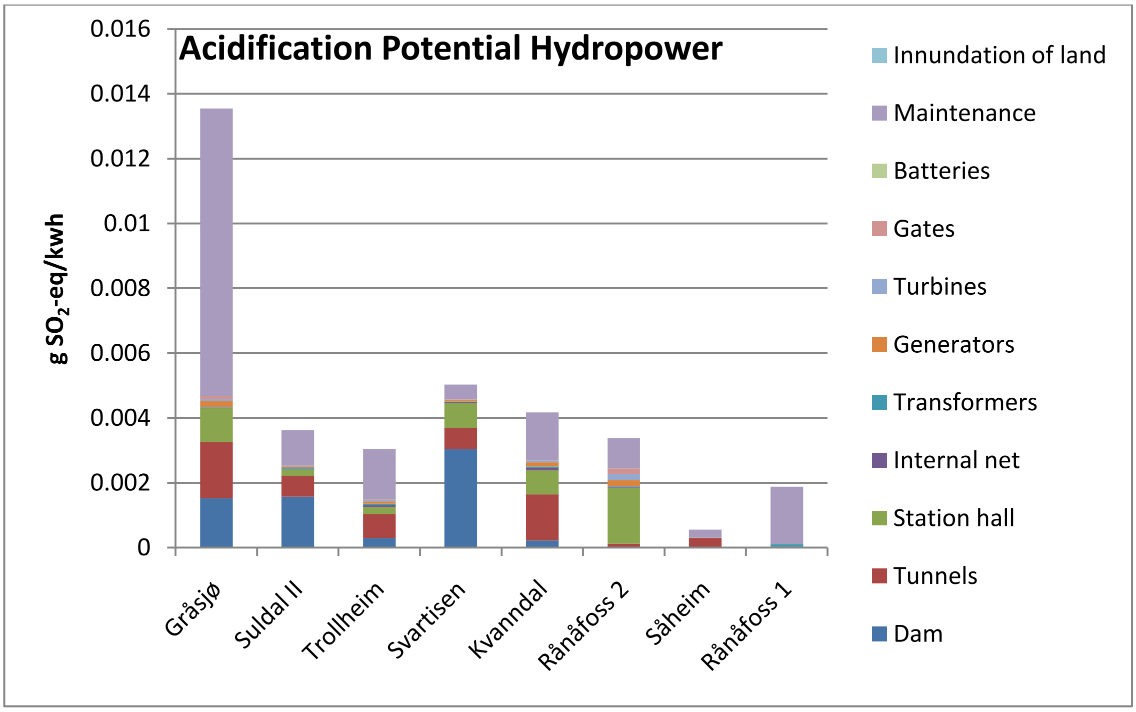


Figure 4.2.5: Acidification Potential

Figure 4.2.5 shows the Acidification Potential from the individual power stations, divided into life cycle stages. The acidification-values are distributed similarly to the 60 years result, but for all of the power stations, except Rånåfoss 1, the acidification potential has decreased. This is due to the prolonged lifetime of the ‘dam’ and ‘tunnel’ life stages. Rånåfoss 1 had no emissions connected to these life stages and thus its acidification potential remains the same.

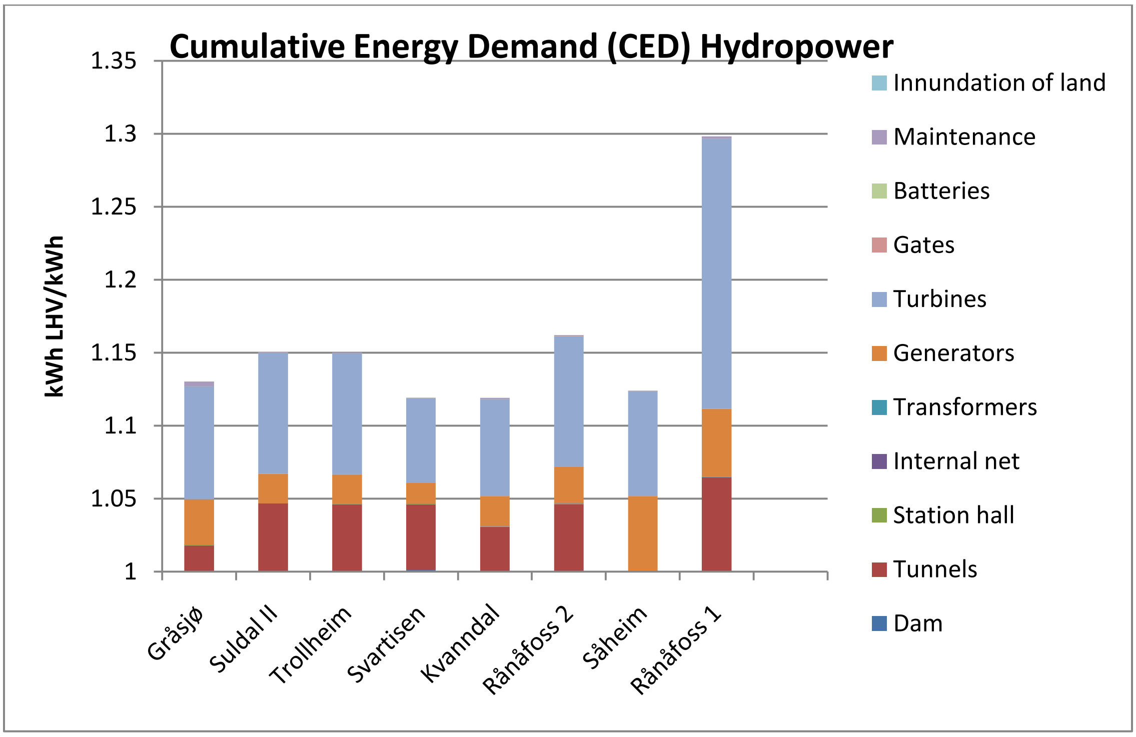


Figure 4.2.6: Cumulative Energy Demand

Figure 4.2.6 shows the Cumulative Energy Demand (CED) from the individual power stations, divided into life cycle stages. The y-axis min value starts from 1. This is because of the 1 kWh we manually posted as intrinsic energy (section 3.3.1). The CED tells us how much energy is needed to produce 1 kWh. The scenario results do not differ greatly from the 60 year results. We observe that the values for Rånåfoss 1are significantly higher than for the other power stations.

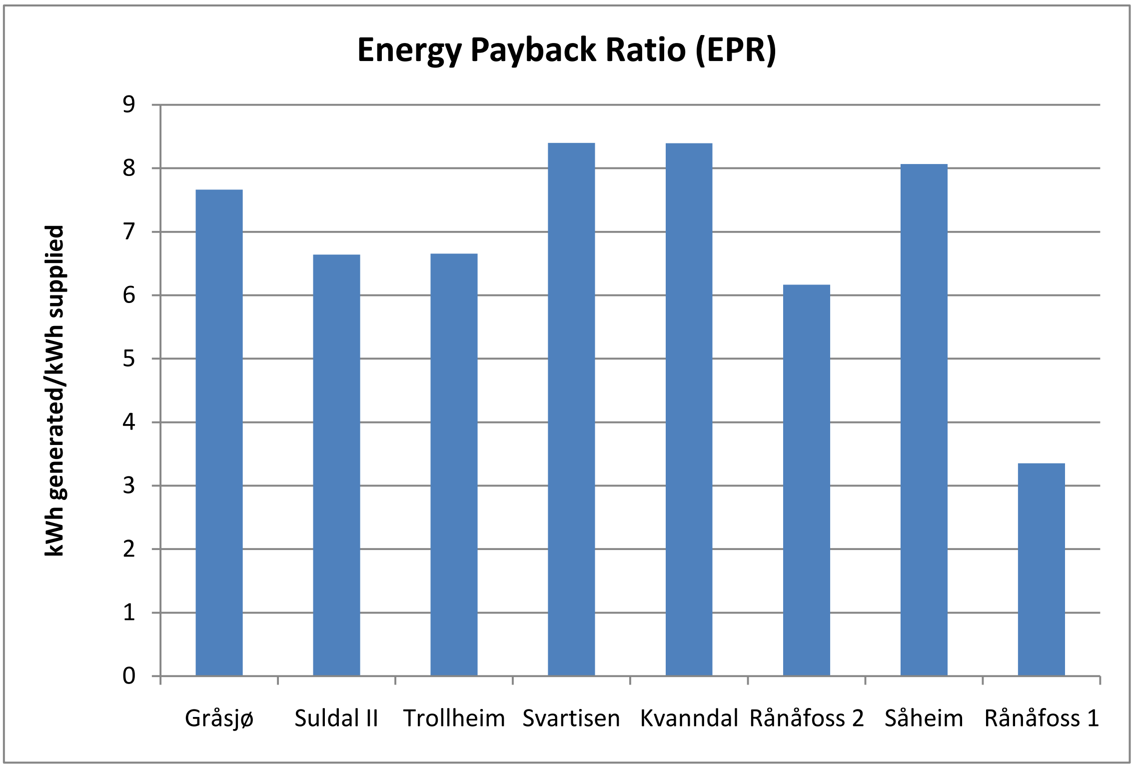


Figure 4.2.7: Energy Payback Ratio

Figure 4.2.7 shows the Energy Payback Ration (EPR) for the individual power stations. The EPR is “…the ratio of total energy produced during a system’s normal lifespan, divided by the energy required to build, maintain and fuel it...”(Hydro Quebec) We observe that all the power stations have relative high EPRs. This indicates high payback ratios and thus good environmental performance. The scenario results do not differ greatly from the 60 year results.

Impact category	Unit	Total	Dam	Tunnels	Station hall	Internal net	Transformers	Generators	Turbines	Gates	Batteries	Maintenance	Innundation of Land
Global Warming (GWP100)	kg CO_2-eq	7,1E-04	1,8E-04	1,4E-04	1,5E-04	5,3E-06	8,6E-06	1,6E-05	1,2E-05	7,7E-06	2,4E-07	1,9E-04	0
Ozone Layer Depletion (ODP)	kg CFC-11-eq	1,5E-12	0	0	0	1,9E-13	6,5E-13	0	0	0	3,1E-15	6,1E-13	0
Photochemical Oxidation	kg C_2H_4	3,5E-07	9,4E-08	5,6E-08	5,2E-08	3,5E-09	1,9E-08	4,6E-09	2,7E-09	1,9E-09	7,4E-11	1,2E-07	0
Acidification	kg SO_2-eq	4,8E-06	1,4E-06	7,9E-07	7,1E-07	3,5E-08	2,9E-08	8,0E-08	4,9E-08	3,5E-08	1,6E-09	1,6E-06	0
Eutrophication	kg PO_4^{-2}-eq	9,0E-07	2,9E-07	1,5E-07	1,3E-07	3,0E-09	3,6E-09	1,2E-08	5,7E-09	3,8E-09	9,1E-11	3,2E-07	0
Cumulative Energy Demand	kWh LHV	1,1E+00	1,0E+00	3,9E-02	2,7E-04	3,2E-05	3,2E-05	2,2E-02	7,5E-02	3,0E-05	8,2E-07	7,4E-04	0

Table 4.2: Norwegian Hydroelectricy

Table 4.2 shows the emissions from an average Norwegian kWh hydroelectricity, divided into the different impact categories, divided into the nine different life cycle stages.

5 References

Anon, Energy Trading and the Environment 2020. Available at: http://ostfoldforskning.no/prosjektsider/49/energy-trading-and-the-environment-2020.aspx [Åpnet juli 26, 2011a].

Anon, rendement_investissement.pdf. Available at: http://www.hydroquebec.com/sustainable-development/documentation/pdf/options_energetiques/rendement_investissement.pdf [Åpnet juli 26, 2011b].

Raadal, H.L. mfl., 2011. Life cycle greenhouse gas (GHG) emissions from the generation of wind and hydro power. *Renewable and Sustainable Energy Reviews*, 15(7), s.3417-3422. Available at: [Åpnet juli 26, 2011].

Gamle Beddingvei 2B
N-1671 Kråkerøy
Telephone: +47 69 35 11 00
Fax: +47 69 34 24 94
firmapost@ostfoldforskning.no
www.ostfoldforskning.no

Reports can be obtained by contacting us,
or by downloading them from our website: www.ostfoldforskning.no