

Environmental sustainability assessment of hydropower plant in Europe using life cycle assessment

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Abstract. Hydropower is the oldest and most common type of renewable source of electricity available on this planet. The end of life process of hydropower plant have significant environmental impacts, which needs to be identified and minimized to ensure an environment friendly power generation. However, identifying the environmental impacts and health hazards are very little explored in the hydropower processing routes despite a significant quantity of production worldwide. This paper highlight the life-cycle environmental impact assessment of the reservoir based hydropower generation system located in alpine and non-alpine region of Europe, addressing their ecological effects by the ReCiPe and CML methods under several impact-assessment categories such as human health, ecosystems, global warming potential, acidification potential, etc. The Australasian life-cycle inventory database and SimaPro software are utilized to accumulate life-cycle inventory dataset and to evaluate the impacts. The results reveal that plants of alpine region offer superior environmental performance for couple of considered categories: global warming and photochemical oxidation, whilst in the other cases the outcomes are almost similar. Results obtained from this study will take part an important role in promoting sustainable generation of hydropower, and thus towards environment friendly energy production.

1. Introduction

In this modern era, world has experienced rising economic growth and increasing energy demands that make happen detrimental effects on the environment [1]. These environmental effects, the outcome of the improper practice of available assets, have a worldwide level in few circumstances; for instance global warming, climate change and so on. The major consequences of global warming are temperature increase and ocean's surface escalation. Human activities, such as deforestation, land use changes, agriculture and combustion of fossil fuels [2]. The combustion of coals or gases for power production and transportation induce release of carbon dioxide (CO₂), nitrous oxides and greenhouse gases (GHG) like chlorofluorocarbons (CFCs) and methane, which are the primary providers to the greenhouse effect. The development of environment friendly, sustainable hydropower generation system is gaining substantial attention due to its unrivalled potential for extensive renewable energy production and GHG release diminution.

Considering the noteworthy role that hydropower production technology has to take part in meeting today's power crisis, researchers require to assess the environmental life cycle impact analysis considering different stages of hydroelectricity production technology. The life cycle assessment (LCA) technology assists to assess the total GHG emissions causing from the consumption of hydropower as a source of energy. LCA is a systematic approach which gives an evaluation of the net environment-related effects of the products from a cradle-to-grave schemes employing the



comprehensive life cycle input elements and output emissions which work under the specific life cycle inventory (LCI) [3-6].

Though water itself is not lethal, the electricity production process involves many stages, which creates environmental issues. Furthermore, the transportation medium of these elements to the plant location releases hazardous particles i.e., carbon monoxide, dust and carcinogenic particles. As Europe has the largest resource of renewable energy generation through hydropower, it is quite expected that both alpine and non-alpine regions of Europe is facing the environmental impacts and health effects caused by the hydropower generation process.

All the hydropower generation based LCA research until now have addressed on the assessment of the GHG releases. No prior LCA-based researches [7-9] assessed and compared the total environmental impacts by hydropower production technologies in Europe. This work purposes to fill this research gap by executing a complete environmental LCA of hydropower production technologies in Europe. This research paper, will highlight the environmental threats associated with hydropower production by a systematic LCA method considering whole life period of the plant. We also compare the environmental impacts for two different cases of hydropower plants in Europe under various assessing categories. The environmental impacts of hydropower generation process in alpine and non-alpine regions of Europe through LCA by comparing their generation stages are addressed and the outcomes at different assessing categories are analyzed. Section 2 provides a comprehensive outline of the environmental life cycle impact assessment methods. Section 3 highlights the LCA outcomes under the ecological effect assessment categories, using the ReCiPe technique and the CML technique, thus recommends the environmental-effect reduction methods for selected processes.

2. Methodology

Hydropower generation take place harvesting mechanical energy from the flowing water using a turbine or rotor. The main elements which assist to produce energy by hydropower plants are the alternator, the hydraulic turbine, the transformers, and the reservoir [3]. A turbine constitutes of several blades joined to a moving shaft. The speedy contact between turbine blades and flowing water create a movement of the shaft. Then the alternator transforms the mechanical power from the moving shaft to electricity. The transformers work as a connecting route between the alternator and consumer through wires. The reservoirs hoard water prior to the flow via blades.

The aim of the study is to analyze the environmental impact of two different hydropower plant located in alpine and non-alpine regions of Europe, and compare their environmental impacts under several impact categories. The environmental impact calculation is the sub-section of a LCA analysis in which the outcome for the life cycle inventory (LCI), the general flows of each step, are converted into LCA category indicator outcomes [2]. This is done using characterization simulations. The characterization simulations included in the CML-IA (baseline) methodology [10, 2] were utilized in this research work. Six different life cycle impact categories were measured: abiotic depletion, global warming, ozone layer depletion, photochemical oxidation, acidification and eutrophication. Simapro 8.4 [11] software package was used to perform the life cycle inventory and impact assessment calculations [2]. The scope datasets of this research work are gathered from Australian Life Cycle Inventory (AusLCI) database.

The investigation approaches are selected as the ReCiPe technique and the CML technique, which are generally applied to electricity generation technology-based environmental impact evaluations. The approach of ecological effect assessment of hydropower generation system is cradle-to-grave. These datasets are renewable energy technology related where the major emissions are distributed among electricity generation parts. Table 1 shows the comparative input and output datasets of the reservoir based hydropower plant process at alpine and non-alpine regions. It highlights that the input rates are same for both alpine and non-alpine location based hydropower plants at all the categories. It also shows that the hazardous waste incineration associated with production activities such as mineral oil disposal and biogenic methane. Although mineral oil disposal is same for both systems but non-alpine region power plants shows higher biogenic methane emission compared to alpine region plants

Table 1. Life-cycle inputs and outputs of hydropower plant at alpine and non-alpine regions in Europe

Inputs and Outputs	Amount		Unit
	Electricity, hydropower, at reservoir power plant, alpine region/RER U/AusSD U	Electricity, hydro-power, at reservoir power plant, non alpine regions/RER U/AusSD U	
Inputs			
Transformation, from unknown	0.000023	0.000023	m ²
Transformation, to water bodies, artificial	0.0000228	0.0000228	m ²
Transformation, to industrial area, built up	0.00000023	0.00000023	m ²
Occupation, water bodies, artificial	0.0035	0.0035	m ² a
Volume occupied, reservoir	0.15	0.15	m ³ y
Water, turbine use, unspecified natural origin	0.81	0.81	m ³
Energy, potential (in hydropower reservoir), converted	3.79	3.79	MJ
Lubricating oil, at plant/RER U/AusSD U	0.000007	0.000007	kg
Reservoir hydropower plant, alpine region/RER/I U/AusSD U	3.90E ⁻¹³	3.90E ⁻¹³	p
Outputs			
Methane, biogenic	0.000014	0.000286	kg
Disposal, used mineral oil, 10% water, to hazardous waste incineration/CH U/AusSD U	0.000007	0.000007	kg

3. Results and Discussion

The outcomes are represented at impact evaluation aspect. As it is a relative analysis, the finding for every impact type for the system with the maximum effects are counted 100 percent and the outcome for another system is counted as the corresponding ratio.

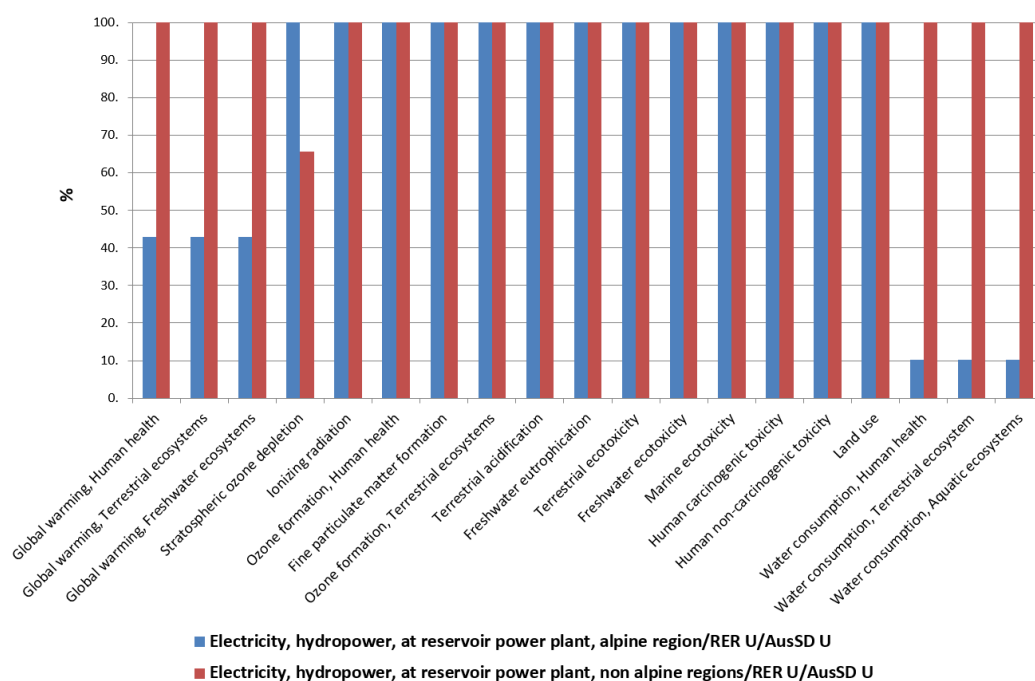


Figure 1. Impact comparison using ReCiPe 2016 Endpoint methodology.

Figures 1 to 3 illustrate the comparative environmental impacts caused by hydropower plant technologies at alpine and non-alpine regions in Europe. Figure 1 shows the environmental impact comparison applying ReCiPe 2016 Endpoint methodology. It is transparent that plants of alpine region perform better environmentally than non-alpine region except in one impact category, stratospheric ozone depletion. The endpoint comparison after weighing, using ReCiPe 2016 methodology is represented at Figure 2. As shown, hydropower plant in non-alpine regions results in more damage compared to alpine regions.

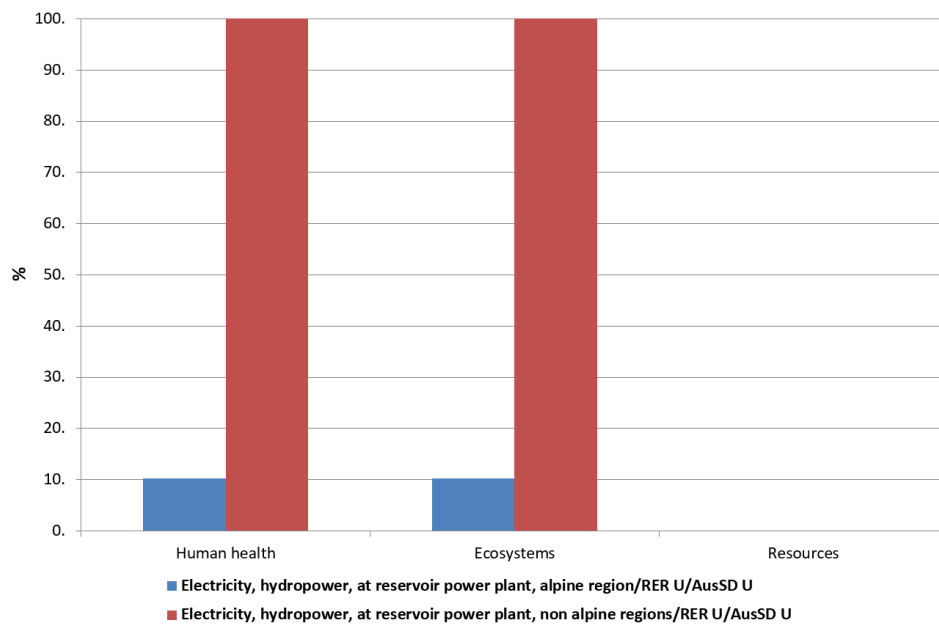
**Figure 2.** Endpoint comparison after weighing, using ReCiPe method.

Figure 3 illustrates the comparative LCA-based environmental effect evaluation of hydropower plant in alpine and non-alpine regions of Europe using CML method. The results indicate that plants of alpine region offer superior action for couple of studied impact groups: global warming and photochemical oxidation. Although in the other cases the outcomes are almost similar. This analysis highlight the LCA-based environmental influences caused by the hydropower plant systems in Europe, to get the queries arising from ecological threats.

Table 2. Life-cycle impact assessment outcomes-ReCiPe method.

Impact category	Electricity, hydropower, at reservoir power plant, alpine region/RER U/AusSD U	Electricity, hydro-power, at reservoir power plant, non-alpine regions/RER U/AusSD U	Unit
Global warming, Human health	1.7838999 E-9	4.1655307 E-9	DALY
Global warming, Terrestrial ecosystems	5.3818149 E-12	1.2556865 E-11	species.yr
Global warming, Freshwater ecosystems	1.4702874 E-16	3.4298551 E-16	species.yr
Stratospheric ozone depletion	3.6271486 E-13	2.3780375 E-13	DALY
Ionizing radiation	1.0769103 E-13	1.0769103 E-13	DALY
Ozone formation, Human health	4.8714449 E-12	4.8714448 E-12	DALY
Fine particulate matter formation	1.2586791 E-9	1.258679 E-9	DALY

Ozone formation, Terrestrial ecosystems	7.0163971 E-13	7.016397 E-13	species.yr
Terrestrial acidification	1.1623602 E-12	1.1623602 E-12	species.yr
Freshwater eutrophication	3.762101 E-14	3.762101 E-14	species.yr
Terrestrial ecotoxicity	5.5926631 E-14	5.592663 E-14	species.yr
Freshwater ecotoxicity	1.4610729 E-15	1.4610729 E-15	species.yr
Marine ecotoxicity	5.143076 E-16	5.143076 E-16	species.yr
Human carcinogenic toxicity	5.2830406 E-10	5.2830405 E-10	DALY
Human non-carcinogenic toxicity	2.499131 E-11	2.4991309 E-11	DALY
Land use	3.7055138 E-13	3.7055138 E-13	species.yr
Water consumption, Human health	5.0869534 E-7	5.0041953 E-6	DALY
Water consumption, Terrestrial ecosystem	3.0934176 E-9	3.0430917 E-8	species.yr
Water consumption, Aquatic ecosystems	1.3840179 E-13	1.3615018 E-12	species.yr

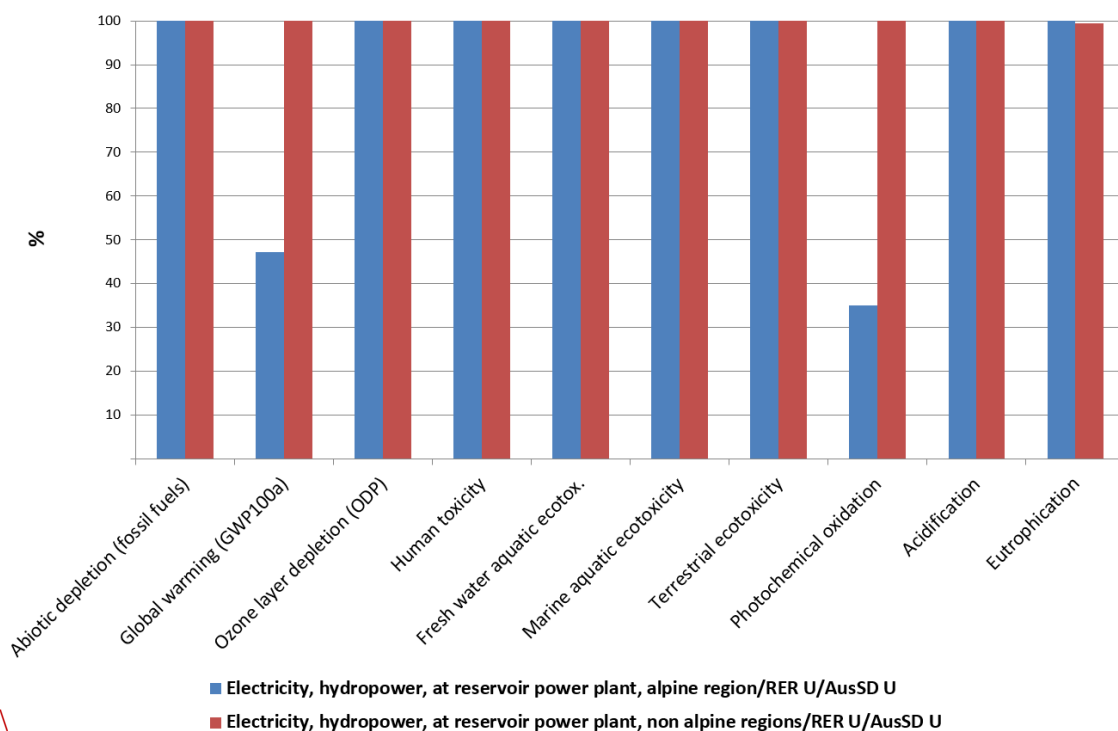


Figure 3. Comparative ecological influence evaluation of hydropower plant in alpine and non-alpine regions of Europe using CML method.

The assessment is performed utilising the ReCiPe technique and the CML technique considering various ecological influence groups which could be generally categorized as – global warming, ozone formation, acidification, eutrophication, ecotoxicity, human toxicity, water consumption, stratospheric ozone depletion, ionizing radiation, land use, etc [10]. Among the key impact groups which are exemplified at tables 2 and 3, the whole outcomes show that a substantial ecological influence is occurred by the non-alpine region plants over the alpine region plants. The reason behind this is that the long distance transportation of raw materials in non-alpine region hydropower plants due to unavailability at nearby locations where raw materials of the alpine based plants is available at nearby locations.

Table 3. Life-cycle impact assessment outcomes-CML method.

Impact category	Electricity, hydropower, at reservoir power plant, alpine region/RER U/AusSD U (%)	Electricity, hydropower, at reservoir power plant, non alpine regions/RER U/AusSD U (%)
Abiotic depletion (fossil fuels)	100	100
Global warming (GWP100a)	47.2216	100
Ozone layer depletion (ODP)	100	100
Human toxicity	100	100
Fresh water aquatic ecotox.	100	100
Marine aquatic ecotoxicity	100	100
Terrestrial ecotoxicity	100	100
Photochemical oxidation	35.0314	100
Acidification	100	100
Eutrophication	100	99.4055

Table 4 shows the contrast per impact type, by addition of each effects, using Ecoindicator 2016 methodology. It is transparent that plants of alpine region perform better environmentally than non-alpine region plants. The comparative ecological influence evaluation of hydropower plants in alpine and non-alpine regions of Europe using Ecoindicator approach is represented at Figure 4.

Table 4. Life-cycle impact assessment results by Ecoindicator approach

Impact category	Electricity, hydro-power, at reservoir power plant, alpine region/RER U/AusSD U	Electricity, hydro-power, at reservoir power plant, non-alpine regions/RER U/AusSD U	Unit
Human non-carcinogenic toxicity	2.499131 E-11	2.4991309 E-11	DALY
Human carcinogenic toxicity	5.2830406 E-10	5.2830405 E-10	DALY
Fine particulate matter formation	1.2586791 E-9	1.258679 E-9	DALY
Ionizing radiation	1.0769103 E-13	1.0769103 E-13	DALY
Stratospheric ozone depletion	3.6271486 E-13	2.3780375 E-13	DALY
Freshwater eutrophication	3.762101 E-14	3.762101 E-14	species.yr
Terrestrial acidification	1.1623602 E-12	1.1623602 E-12	species.yr
Land use	3.7055138 E-13	3.7055138 E-13	species.yr

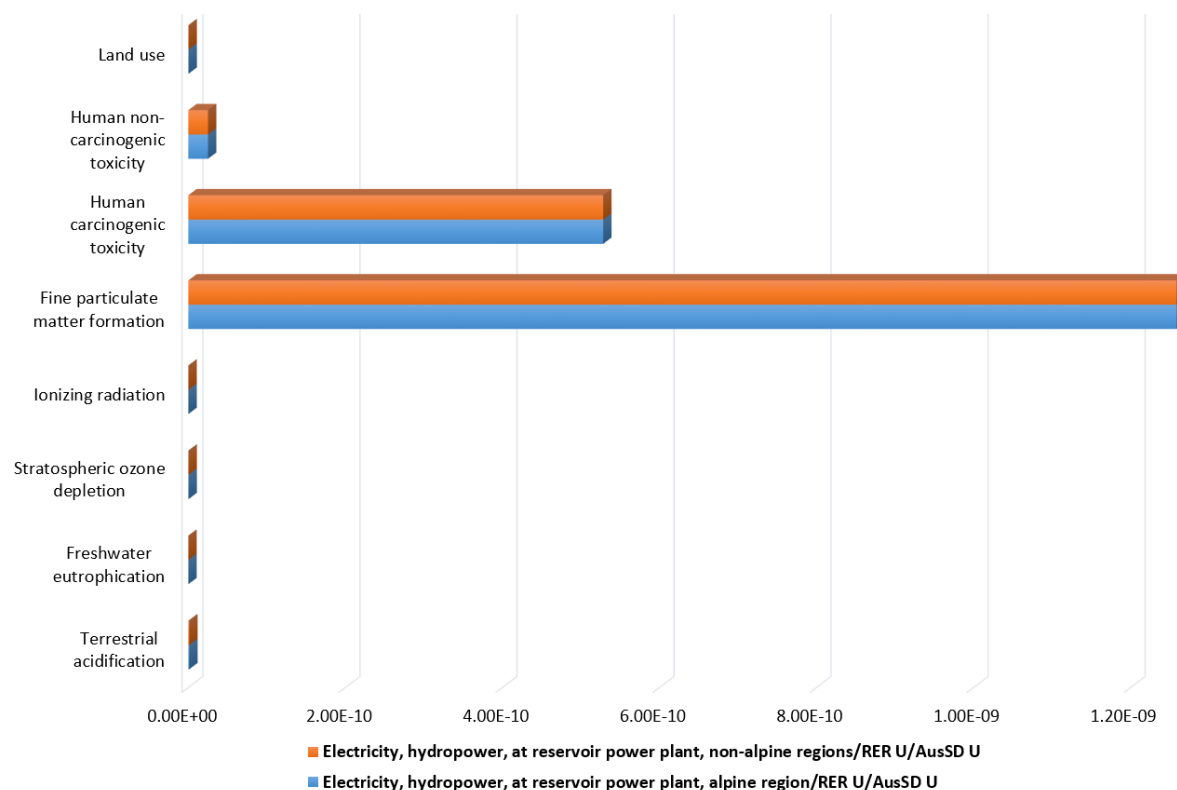


Figure 4. Comparative ecological influence evaluation of hydropower plant in alpine and non-alpine regions of Europe using Ecoindicator method.

The results reveal that the maximum impact is occurred at fine particulate matter formation impact category. Whilst the minimum is obtained freshwater eutrophication category by both types of hydropower plants. The reason behind these impacts is the amount of toxic materials present as constituent of plant structure and its electricity production steps.

On the whole, the outcomes obtained from this comparative analysis show that a substantial ecological danger is generated from the hydropower plants in Europe, which will be greater in the upcoming days due to reduction of quality raw materials. Thus will release higher toxic elements to the environment, which are required to be controlled to save the earth and its creatures.

4. Conclusion

Europe has the abundant source of a hydropower plant, the biggest in the entire world. By providing environmental sustainability, Europe could generate additional hydropower from now onwards, which could further reduce the ever-growing energy demand. To generate energy in an environmentally-safe procedure, attention should be given in making the raw material extraction systems optimized and sustainable. In this paper, we highlight the comparative environmental impact of hydropower plants located in alpine and non-alpine region of Europe using the CML and ReCiPe methods utilizing AusLCI database and SimaPro software. The results indicate that plants of alpine region have a better performance over non-alpine cases. This research outcome will play a vital role in promoting environment friendly and sustainable generation of hydropower.

5. References

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