ECOS 2023: Environmental life cycle assessment of a hydropower plant in Bolivia

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Abstract:

Hydropower technologies are usually related to low-carbon emissions; however, detail discussion of a different number of environmental concerns is not properly done at the moment especially considering the lifetime phases. There is also a lack of evaluations when comparing with conventional technologies and when comparing with traditional Environmental Impact Assessments (EIA). In this context, this paper explored the environmental impacts using the LCA methodology of a hydropower plant to identify which lifetime phases damage more in health, ecosystems and resource areas of protection. A comparison between the impacts with the grid conventional electricity generation and a comparison with the results of the conventional EIA method are also presented. A database of a cascade hydropower in the tropical region is built using as a case study, the Bolivian project named “Ivirizu” with 290.21 MW of power capacity. Reservoir hydropower plant, campsite and road are analyzed. Data collection considered materials transportation, grave production, construction, maintenance, operation and disposal step. Data was obtained directly from the Governmental energy corporations and Ecoinvent database. Biogenic emissions were determined using the model proposed by Hertwich, 2013. ReCiPe 2016 method was employed to calculate the mid-point and end-points environmental impacts. The construction phase was found to impact most. This phase impacts on the resources depletion by 98.16%. This due to diesel is mainly required during the construction phase. This phase also impacts in 71.17% in human health mainly. The operation has 34.31% of contribution of impacts in ecosystems. This is due to high levels of water consumption during electric generation. The damage on resources is reduced in 63.32 % while hydropower lifetime is increased up to 150 years. Hydropower electricity has more than 79.00% less impacts compared with grid electricity. LCA results could contribute significantly in traditional EIA by providing quantitative information.

Keywords:

Hydropower; LCA; Reservoir; Run of River; Renewable Energy

1. Introduction

According to International Renewable Energy Agency (IRENA), the electricity generated by renewables was 7468 TWh in the world in 2020, where hydroelectricity represented almost 60.00% of the total [1]. Hydropower is growing up in the last years and some countries like Brazil rely almost entirely on this. However, other countries have not investment in this kind of infrastructure to generate electricity [2]. Global hydropower installed capacity increases in 1.90% in 2021 in comparison to 2020; however, an increase of more than 2% is expected to contribute to the reduction of climate change impacts [3].

Bolivia is a country located in the middle of South America where the base for the electricity generation are thermoelectric centrals. Due to the installation, operation and construction time is lower than for hydropower plants. The natural gas is also subsidized (Cost around 1,3 US$/MPC) representing a problem for the national economy and rapid depletion of gas reservoirs [4]. Bolivia has an Energy Development Plan (PDE) where they proposed the implementation of different alternatives like wind, photovoltaic, and hydropower centrals to cover the energy demand in all the country [5]. According an evaluation made by OLADE, the estimated hydropower potential is 39857 MW, but just the 1.2% was exploited in the country [6]. The majority of this potential are located in Pando, Beni, Tarija, La Paz and part of Cochabamba [7]. The overall effective power capacity at the beginning of 2023 in the country was 3626.27 MW, where 20.24% comes from hydroelectric, 68.17% from thermoelectric, 3.62% from eolic, 1.15% from solar and 3.38% from biomass [8]. Bolivia planned 28 hydroelectric projects, one of them is Ivirizu, located in the tropical region of Cochabamba with 290.21 MW of installed power capacity. This is a hydropower unit in cascade, shaped for two hydropower plants Sehuencas (198.66 MW) and Juntas (91.55MW) [9,10].

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Hydroelectric projects bring negative and positive environmental impacts which depends of different variables like, the type of hydroelectric, the materials used during construction among others included the possible socioeconomic local impacts [4].Usually, a hydropower plant is considered a low-carbon option. This represents an attractive option to different governments to cover the electricity demand if they have the potential hydric resources [2]. However, hydropower plants produce greenhouse gases (GHGs) and different emissions to air, water and soil due to different materials, energy, and equipment are employed during the construction and operation stages [11]. Many studies have been focused only on the evaluation of environmental impacts during the electricity generation (i.e. operation phase), in the different types of hydropower plants (reservoir, run of river, and pumped) employing a life cycle assessment; however, the different phases during the lifetime of the plant and a comparison with traditional environmental impact assessment has been rarely done [12].

The life cycle assessment (LCA) is an analytical method to identify the resources flows and different environmental impacts associated with the products and services during their entire lifetime[12,13]. This methodology considers products and technologies from a "cradle to grave". It can contemplate the raw materials extraction, processing, manufacturing, and use to final disposal [15]. This methodology is one of the most actual tools to carry out environmental impact evaluation and analysis for many process, system and products. This also can help to take decision in organization, industries and governments [16]. It is standardized by ISO 14040 [16–18]

Actually, few LCA studies evaluate hydropower plants focused in a reservoir [11]. In South America most of the analysis are located in Brazil focused on large hydropower plants [18,19]. This current study considers LCA methodology and RECIPE 2016 method applied in Ivirizu project which is a cascade hydropower plant that combines a reservoir and run of river plants. This is located in a tropical region in Bolivia. The main objective to determinate the environmental impacts during 1 KWh electric energy generation and create a detailed life cycle inventory (LCI) with the aim of having the real conditions, inputs and outputs flows. A comparison between the impacts with the grid conventional electricity generation and a comparison with the results of the conventional Environmental Impact Assessment method are also presented.

2. Materials and method

2.1. System description

Ivirizu hydropower project is located in the tropical region of Cochabamba, inside the limits of National Park Carrasco, in Bolivia. The power capacity installed is 290.21 MW. This plant is a cascade model. It is shaped for two plants, Sehuencas (reservoir plant) and Juntas (run of river plant). Figure 1 shows where the different parts of Ivirizu project are planned. The main purpose of this project is to generate electricity and it is still in the construction phase.

Sehuencas is the first plant, it is a reservoir plant with a dam to form a reservoir with a volume of 29.48 Hm^3. The water is transported 5.98 km through a concrete-lined tunnel and reaches a balance chimney with a height of 95.45 m, which balances the air pressure between the plant and the atmosphere. This is connected to a penstock with a length of 1.51 km that leads to the power house, where three hydro turbines, generators, and machines are located. The electricity generated is then transported to a substation. The second run of river plant, Juntas, is located 10 km from Sehuencas and it has an intake structure located in the Ivirizu river. It features elements such as a gravity diversion weir, right bank intake and drain, sediment traps with a flow of 6 m^3/s, a flow regulation float with a capacity of 40000 m^3, and a tunnel intake. To this intake structure also is transported the turbines water from Sehuencas through a discharge canal. The water flow is transported inside a tunnel that it is armored in the final part and then connected to a balance chimney and penstock, which transport the water flow to the power house where two Francis turbines are located. Both power plants have a substation where the electric generation tension of 11.50 kV is increased to the transport tension of 230 kV before being transported to Mizque substation and then to the International System Transmission [9]. The technical details of the Ivirizu hydropower plant are listed in Table 1.

Table 1. Description of Ivirizu Hydropower plant

Characteristics	UN	Sehuencas	Juntas
Installed Capacity	MW	198.66	91.55
Type of Plant		Reservoir	Run-of-river
Turbines	UN	3	2
Type of turbine		Pelton	Francis
Annual Power Production	GWh	805.29	355.6
Design flow rate	m^3/s	26.50	32.50
Heigh	m.a.s.l	1340	1009
Water head	m	843	326

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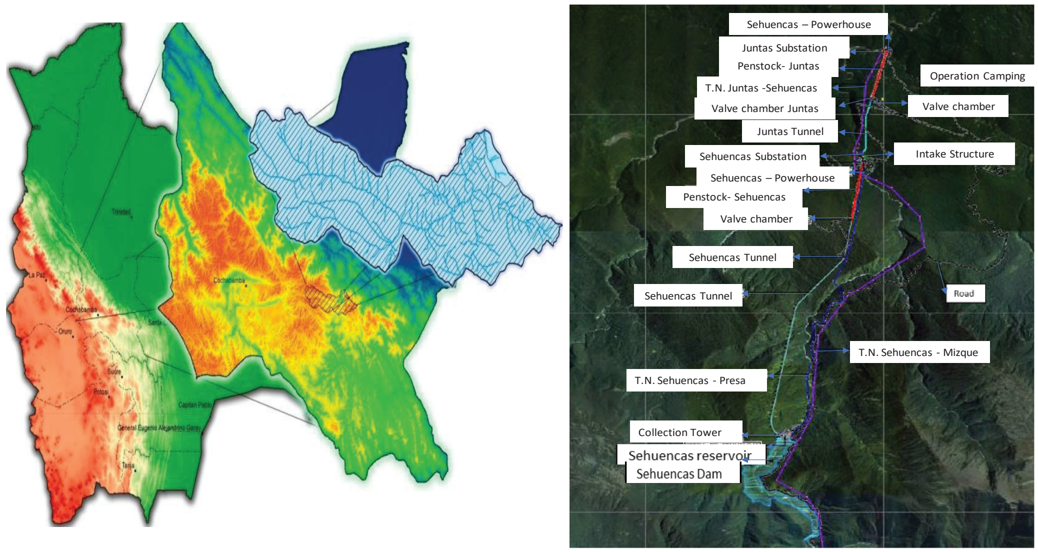

Figure. 1. Geographical location of Ivirizu hydropower plant in Bolivia [9]

2.2. Goal and scope definition

The primary objective of the study was to assess the environmental impacts associated with the generation of 1 KWh of electric energy in a hydropower plant located in Bolivia, using a cradle-to-grave approach and Life Cycle Assessment (LCA) methodology in accordance with ISO 14040 guidelines [18]. This research also aims to create a comprehensive life cycle inventory data, considering all the materials, equipment, transportation, and energy used throughout the entire life cycle. The emissions generated because of decomposition of biomass in the flooded area were also analyzed. All these factors were calculated based on 1 KWh generated defined as the functional unit.

2.3. System boundaries

The overall system boundary is presented in Figure 2. The system boundary includes five phases: construction (buildings, camp, equipment installation, gravel and sad extraction, roads and transmission network), operation, maintenance, transportation and disposal step. The preconstruction activities like deforestation for infrastructure development, materials, energy use from land preparation, materials extraction were part of the construction phase. Operation covers energy and materials require in this step, the emission caused for the biomass decomposition was also determined. The maintenance phase covered the materials throughout the lifespan of the hydroelectric plant. The lifespan of this plant is 50 years according to ENDE Corporation [9]. For the disposal phase was just considered the transport of recyclable materials, equipment and waste to a treatment place.

2.4. Life cycle Inventory Analysis (LCI)

The life cycle inventory (LCI) collect physical information of input and output flows such resources, materials, semi-products, products and the output of emissions [20]. Two kind of data are usually considered; one is the information obtained from the companies that design the plants. The second one is data acquired from different international database and adapted to study case like Ecoinvent [13]. In this study, the inventory considers both type of data and it is described for the five steps to generate 1 KWh of electric energy. Assumptions and limitations are described for each step and all data is presented in Table 2.

Construction: This phase includes the building work, equipment installation, road and camping building. Land preparation using explosives, raw material extraction in the place were considered in this stage. The building work contemplated the dam, penstock, powerhouse, balance chimney, substation, transmission network, waterway canal, etc. of both plants that make up Ivirizu. A diesel generator was considered to provide the required electricity for the equipment used in the construction zones. Ecoinvent data was considered for the diesel generator inventory. Different equipment and components used such generators, turbines, bridge crane, dampers, valves, etc. were discomposed in materials such steel. The description of each building works, materials, electromechanical and hydromechanical equipment were obtained from the final design study of Ivirizu, proportioned for ENDE Corporation.

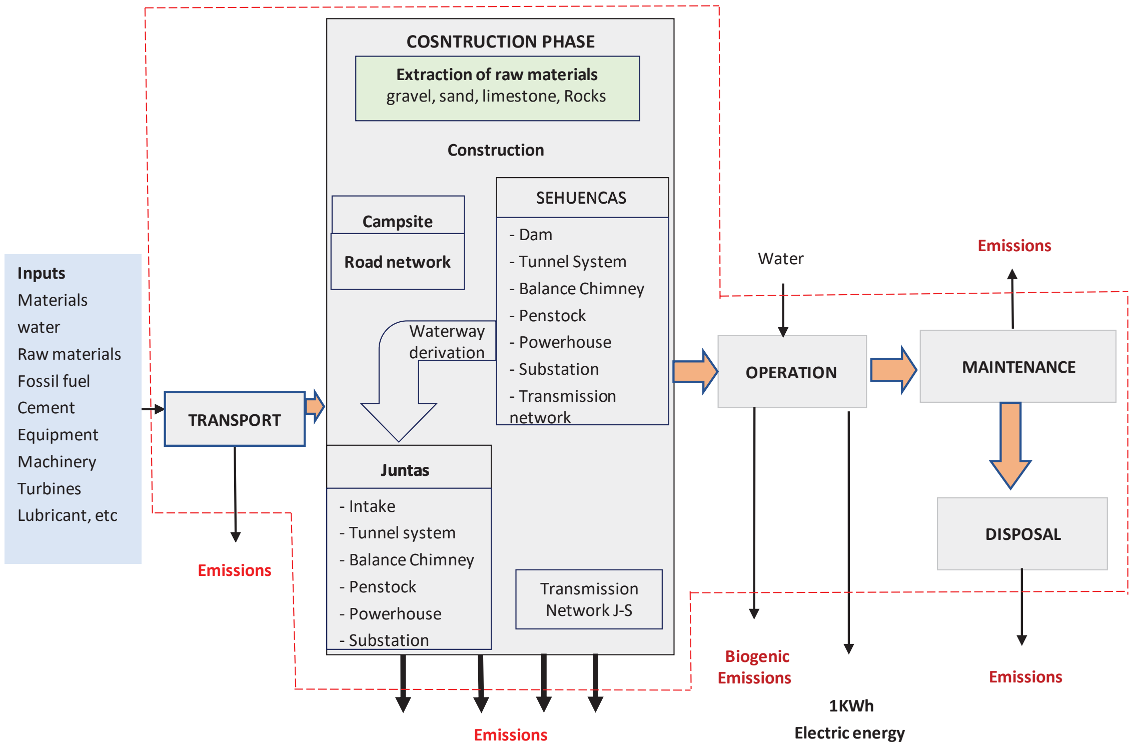

Figure. 2. System boundaries

Operation: This step requires just water flows for electricity generation; the value was achieved from the final design of Ivirizu project proportioned by ENDE corporation. The biogenic emission that are generate due to the degradation of biogenic carbon in reservoirs was included. This is produced by oxidation of organic carbon from biomass, organic carbon matter in soil, or sediments [21]. These were estimated using the methodology presented by Hertwich [21] in the Eq. (1), this model calculates biogenic carbon dioxide and methane emission per 1 kWh.

$$log\, E = const + B_{Land\ use} \times log(Land\ use) + B_{Age} \times Age + B_{NPP} \times log\,(NPP) \tag{1}$$

Where E represents the emission estimated (CO_2 or CH_4), land use is referring to reservoir flooded area, age is the reservoir lifetime, NPP is the net primary production. Const, $B_{Land\ use}$, B_{Age}, and B_{NPP} are constants for CO_2 an CH_4 described in [21]. The age is 50 years, and land use is 8.67E-4 m^2 calculated for 1 kWh. Both data were obtained from Ivirizu final project. NPP is 40000 gC/m2y, employed by Villarroel et.al map [22]

Maintenance: The lubricant oil necessary to perform a good operation for the equipment was considered. The replacement of turbines or generators was not included. The life time for this equipment were assumed to be the same as the hydropower plant. The lubricant data for this step was used from Ecoinvent.

Disposal: This step refers to the recollection of waste mineral oil and the transport to a treatment place, which is considered in this case to be Cochabamba city. After the lifetime of hydropower plant, the infrastructure is assumed to be abandoned but after the siltation of the lake and the dams. The adit systems will not be transported or demolished. The disposal of gravel, cement and reinforced steel were assumed from Ecoinvent data.

Transportation: This includes the transport of different materials used during the construction, maintenance, disposal and the transport of equipment to the plant site considered a freight lorry. The international transportation was not considered because this information is not available and therefore all the materials were assumed that were located in Cochabamba city, at the distance of 140 km. The transport process was employed from Ecoinvent database.

2.4. Life cycle Impact assessment (LCIA)

In this step the purpose was to quantify the environmental impacts of all inventory data recovering in the LCI [16] using the RECIPE 2016 method that evaluates 18 midpoints and 3 endpoint levels [23]. Characterization factors at the midpoint level are located somewhere along the cause-impact pathway, usually at the point after which the environmental mechanism is identical for each environmental flow assigned to that impact category.

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The endpoint level reflect damage at one of three areas of protection which are human health, ecosystem quality and resource scarcity [24]. The computation of the environmental impacts was done in the SimaPro Version 9.4.0.2 software [25].

Table 2. LCI data for Ivirizu hydropower plant on 1 kWh of electricity for 50 years lifetime

Variable	Unit	Sehuencas	Juntas	Ivirizu	Total per 1 KWh
Construction					
Volume occupied, reservoir	m3	2.95E+05		2.95E+05	5.08E-04
Land use	m2	4.90E+06	1.8E+06	5.41E+06	9.32E-05
Explosive	kg	2.83E+04	1.25E+04	4.09E+04	7.04E-07
Water	kg	1.97E+08	8.70E+07	2.84E+08	4.89E-03
Sand	kg	3.06E+08	1.36E+08	4.42E+08	7.62E-03
Grave	kg	4.89E+08	2.17E+08	7.07E+08	1.22E-02
Stone	kg	2.60E+07	1.16E+07	3.76E+07	6.47E-04
Cement	kg	1.78E+08	7.97E+07	2.57E+08	4.44E-03
Reinforcing Steel	kg	1.53E+07	6.83E+06	2.21E+07	3.81E-04
Steel low alloyed	kg	8.07E+05	3.61E+05	1.17E+06	2.01E-05
Steel - equipment	kg	4.86E+05	4.36E+04	5.30E+05	9.13E-06
Diesel	kg	3.37E+07	1.49E+07	4.86E+07	8.37E-04
Lubricant	kg	1.25E+05	5.51E+04	1.80E+05	3.10E-06
Emissions					
Particulates, < 2.5 um	kg	5.92E+04	2.62E+04	8.54E+04	1.47E-06
Particulates, > 10 um	kg	6.85E+05	3.03E+05	9.88E+05	1.70E-05
Particulates, 2.5 -10um	kg	2.60E+05	1.15E+05	3.75E+05	6.46E-06
Water	m3	1.66E+05	7.35E+04	2.40E+05	4.13E-06
Emissions to Water	m3	1.67E+05	7.39E+04	2.41E+05	4.16E-06
Carbon Dioxide	kg	1.05E+08	4.64E+07	1.51E+08	2.61E-03
Carbon monoxide	kg	9.02E+05	3.98E+05	1.30E+06	2.24E-05
Nitrogen oxides	kg	1.90E+06	8.38E+05	2.73E+06	4.71E-05
Operation					
Water flow	m3	1.93E+10	2.27E+10	4.21E+10	7.21E-01
Emisions					
Carbon dioxide, biogenic	kg	4.35E+08		4.35E+08	7.49E-03
Methane, biogenic	kg	2.38E+05		2.38E+05	4.10E-06
Water/m3	m3	1.18E+09		1.18E+09	2.03E-02
Emissions to water	m3	1.82E+10	2.277E+10	4.09E+10	7.04E-01
Maintenance					
Lubricant	kg	3.04E+05	1.34E+05	4.39E+05	7.56E-06
Disposal					
Waste reinforced concrete	kg	2.60E+09	1.15E+09	3.74E+09	6.45E-02
Waste mineral oil	kg	5.15E+05	2.27E+05	7.42E+05	1.28E-05
Transportation					
Truck transport	Tkm	1.25E+09	5.50E+08	1.80E+09	3.10E-02
Diesel	Kg	8.92E+05	3.94E+05	1.29E+06	2.21E-05
Emissions					
Carbon dioxide, fossil	kg	7.79E+07	3.44E+07	1.12E+08	1.93E-03
Carbon monoxide, fossil	kg	1.20E+05	5.30E+04	1.73E+05	2.98E-06
Nitrogen oxides	kg	6.33E+05	2.79E+05	9.12E+05	1.57E-05
Sulfur dioxide	kg	3.98E+02	1.75E+02	5.73E+02	9.87E-09

3. Results and discussion

3.1. Life Cycle Interpretation

This is the last stage of LCA, where results are summarized and discussed according to ISO 14043 [26].

- Midpoints impacts

The average midpoint impact contribution of life cycle phases of Ivirizu hydropower plant is presented in Figure 3. The construction was the mayor contributor on seventeen environmental impacts with more than 98% in each one. This was due to the use of different materials required like diesel for electric generation, for the machinery used and for the raw material extraction.

The operation step had 99.73% of contribution in the water consumption equivalent to 2.03 E-02 m^3 per 1 KWh. The construction step just increased the water consumption in 5.42E-05 m^3 per 1 KWh. The construction phase contributed with 98.00% to the global warming and the operation phase with 0.97%. Those are due to the diesel used for machinery and for the electricity generation in the construction step and the biogenic emission during the operation step. The value of CO_2 in the global warming midpoint impact is similar to other hydroelectric plants quantification [27]

The mayor impacts in the maintenance phase were the Ionizing radiation and Fossil resource scarcity due to amount of the lubricant use in different equipment. For the transportation step, the mayor impact was the terrestrial ecotoxicity because of diesel employed during material transportation. The disposal was the step with the minor impact contribution, because it is just the recollection of materials to a treatment place.

Comparing the results with other authors in [11,28,13,29] construction phase was the mayor contributor to the environmental impacts and the second one was the operation even considering than in those studies the lifetime was among 50 to 100 years. Ecoinvent database for all hydropower plants assume 150 years of lifetime. Therefore, a sensitivity analysis for different lifetime years is presented below.

Figure. 3. Midpoints impacts results of 1 kWh hydropower electricity in Ivirizu

- Endpoint impacts

The endpoint results are presented in the Figure 4. The construction and operation phases had mayor damage in human health with 71.17% and 28.28%, respectively. The first one increased de problems in respiratory diseases and different kind of cancer with 2.81E-08 DALY due to the type of materials employed. The operation increased human health damage in 1.11E-08 DALY due to the biogenic emissions which change the water characteristics.

The damage in the ecosystems was 65.10% for the construction phase and 34.31 % for operation phase, this last was equal to 3.13E-11 species.yr induce for the water use and biogenic emission origins damage the freshwater, terrestrial and marine species during the electricity generation.

The construction phase had the mayor contribution in damage to resources availability with 98.16%. This increases the cost in mineral extraction, oil, gas, coal and energy in 8.52E-04 USD2 013 due to this phase uses many and different materials including the raw materials extraction.

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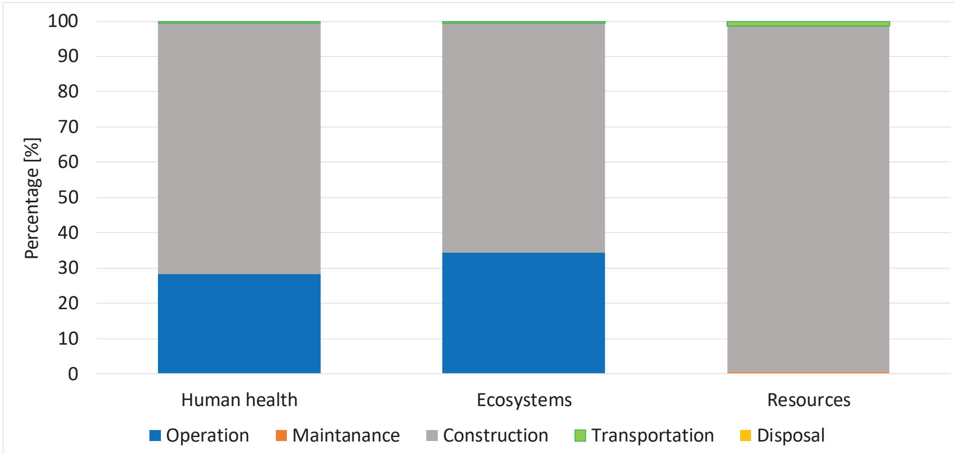

Figure. 4. Endpoints impacts results of 1 kWh in Ivirizu

- Construction

The results presented before shows that the construction phase had mayor impacts during the electricity generation. Due to the large amount and type of materials used and building process. Figure 5 presents the midpoints impacts for construction steps and materials. The mayor impacts were produced for diesel employed to generate electricity to satisfy the demand during the construction phase where Stratospheric ozone depletion had 1.51E+02 kgCFC11eq, Ozone formation Human health had 2.46E+06kgNOx eq and Ozone Formation Terrestrial ecosystems had 2.48E+06 kgNOxeq. The first two increases the damage to human health and the last one increases the damage in ecosystems in 36.57% and 37.74 %, respectively. But, the mayor effect was presented in the damage to resources which increases the cost in 43.15% during the 50 years because of minerals and fossil scarcity.

Water consumption impact increased more due to grave use; this was because the raw materials extraction was considered to be in the same place.

The impacts due to fabrication had more impact in the land use with a 7.31E+7 m^2a crop eq, this is due to activities the construction area.

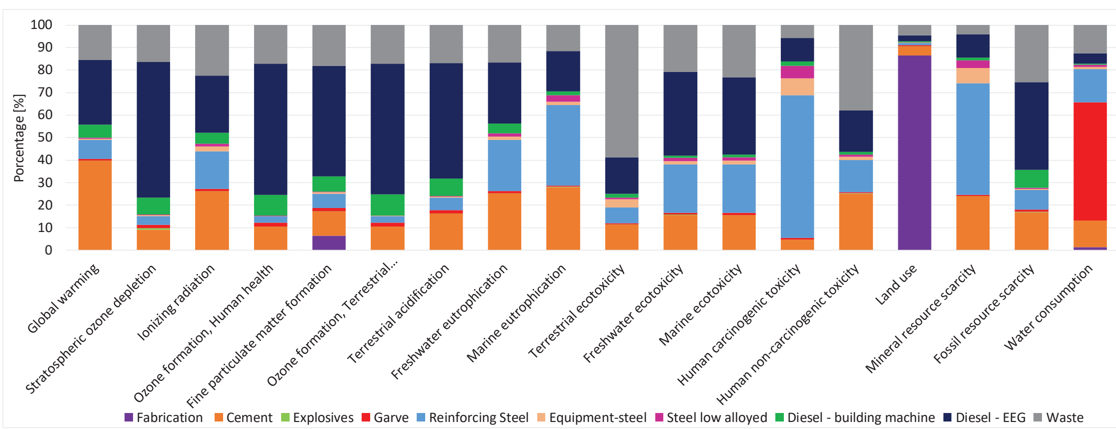

Figure. 5. Midpoints impacts results for Ivirizu hydropower plant construction

3.2. Sensitivity analysis

- Hydropower Lifetime

According the final design of Ivirizu project, the lifetime is 50 years. This value in Ecoinvent database for different hydropower is 150 years and other studies consider 100 years. It depends of each hydropower plant information. Therefore, the endpoint impacts for different lifetimes were evaluated. The results presented in Figure 6 show the decrease of environmental impacts with a mayor lifetime. The mayor reduction in comparison with the 50 years lifetime was for the damage to resources in 37.30%, 49.74% and 66.32 % in comparison to the lifetimes of 80, 100 and 150 years, respectively. For damage to human health and ecosystems, the decrease for the lifetime of 150 years is 55.59% and 54.23%, respectively. These results show that environmental impacts for the electricity generation in the hydropower plants can be reduced when the lifetime is increased due to the impacts are distributed during these years.

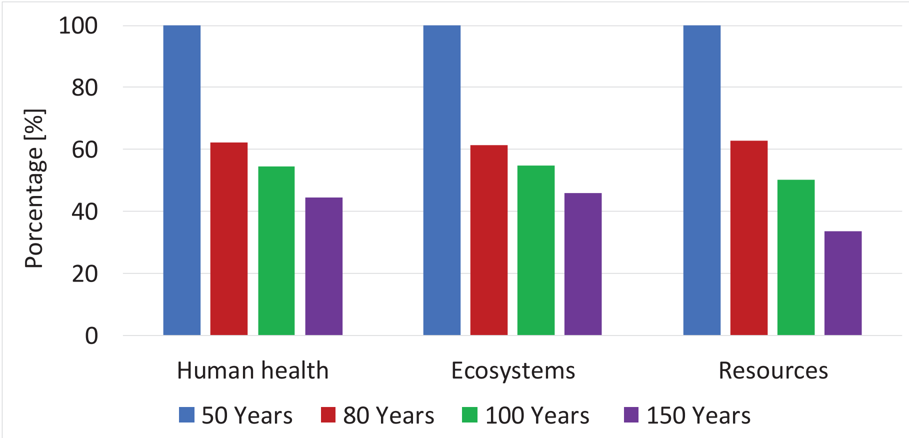

Figure. 6. Endpoint impacts 50, 80,100 and 150 years of lifetime

3.3. Comparison between hydroelectricity Vs Grid electricity generation

The electricity generated in Ivirizu during the operation phase is compared with the conventional grid electricity options in this section. Ecoinvent database for a conventional natural gas and an oil-based power plants were used. The results presented in Figure 7 shows the environmental impacts for 1 KWh. In most of the midpoint impacts, natural gas and oil power plants were higher than the hydropower plant but the water consumption. This is due to water was the principal flow inside the hydropower plant for the electricity generation.

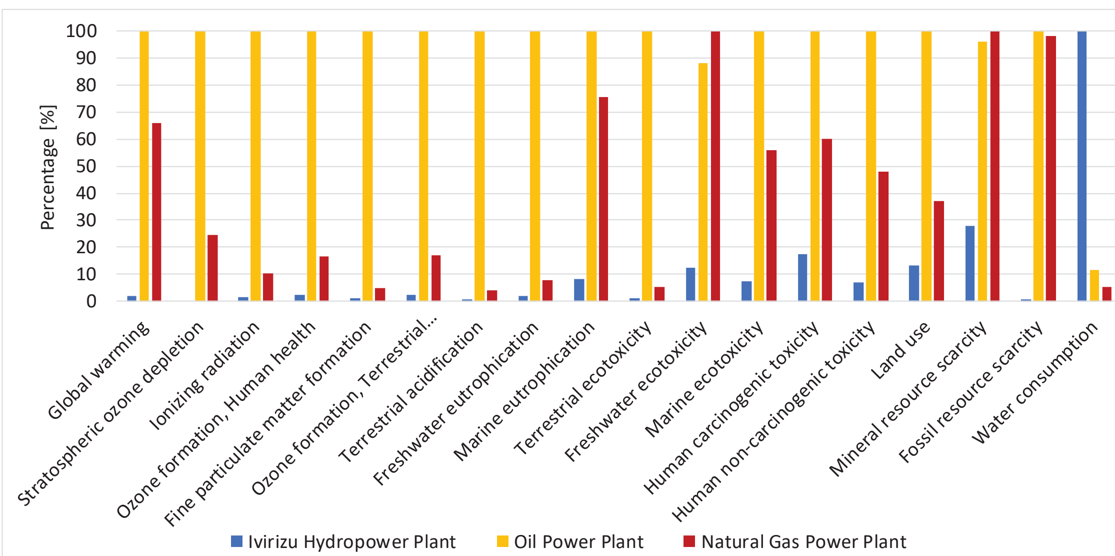

Figure. 7. Comparation between Hydroelectricity vs grid electricity generation

3.4. LCA vs EIA

The results of the traditional environmental impact assessment (EIA) of Ivirizu and the LCA performed in this study were analyzed in this section. The EIA of Ivirizu hydropower plant project includes the identification and assessment of the foreseeable effects on the socio-environmental aspects inventoried in the baseline, taking the area of influence as a reference [30]. Table 3 presents the results of the EIA where the environmental importance is describing according to the following scale:

- Less than 25 are **irrelevant or compatible** with the environment.
- Between 25 and 50 are **moderate** impacts.
- Between 50 and 75 are **severe**.

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- More than 75 are **critical.**

According the results show in Table 3, the EIA considers four steps: 1) construction, 2) operation and maintenance, 3) abandon and 4) induced future. Where the construction and abandon step have several impacts in terrestrial flora, fauna, and ecosystems. LCA considers also the same steps except the induced future.

Table 3. Ivirizu Environmental Impact Assessment (EIA)

Environment	Attributes	Construction	Operation and maintenance	Abandon	Induced Future
PHYSICAL	Particulate Matter	32	22	32	24
	Combustion gases	26	20	26	24
	Noise	25	38	25	24
	Erosion	36	24		
	Instability of slopes	32			
	Soil contamination	37	32	37	
	Compaction	34	24	34	23
	Change in morphology	23	24		
	Sedimentation	23	24		
	Flow rate variation	30	39	30	
	Surface water quality	32		32	
BIOLOGICAL	Loss of vegetation cover	35			
	Aquatic flora	36	36	36	
	Terrestrial flora	66		48	20
	Birds	26	25		
	Terrestrial fauna	58	28	58	20
	Aquatic fauna	48	46	48	20
	Ecosystems and landscape	66	32	42	
SOCIO-ECONOMIC	Affectation of public and private properties	18			
	Health and safety (population)	33	20	24	
	Industrial Safety and Occupational Health	33	30	33	22
	Current land use	47			
	Job creation	32		32	25
	Tourism and recreation potential	19			28
	Archeology and cultural heritage	32	21	32	
	Improvement of the local economy	26	24		

Table 4 presents an identification of the major impacts using both methodologies. By applying EIA, several impacts on terrestrial flora, fauna and ecosystem in the construction step were identified to impact with more than 50 points. Those were related to have more impact on the biological environment. While by applying a LCA, the mayor damage was on human health; where 51.42% was due to contribution of global warming and 31.64% was due to contribution of fine particulate matter formation. But, when comparing the results of both methodologies, the particulate matter formation had a moderate punctuation in the EIA, this impact, according to the quantitative data provided by the LCA, should have a severe punctuation because in one of the mayor contributors. The damage on the resources due to fuel scarcity that can increase the cost in 98.12 % of the fuels and it is significant but this aspect is not evaluated in the EIA. The damage on ecosystems were 55.34% for global warming that affect the terrestrial ecosystem. This impact had also a severe punctuation in the EIA. The operation and maintenance step according to the EIA had severe impacts in aquatic fauna. While for LCA shows a mayor damage on ecosystems due to water consumption and global warming impacts. Those are related with EIA because of the impact on the water have effects on the aquatic fauna. The Abandon step according EIA have severe impacts on terrestrial fauna but according to the LCA, this step contributes less to the impacts and trigger more impact in the damage to resources. In this step, LCA analysis is considered as the recollection of materials to the treatment place and EIA considers the demolition of the central.

EIA considers social and economic variables like neighborhood disturbances or economic benefits which are very important for the public acceptability of projects [31]. But, it is limited for the objectives or the study. Global impacts are not considered during the evaluation while LCA considers that [32] EIA also presents qualitative results that depends on the judgment of an expertise while LCA not [31] Both methodologies can be complementary tools [32,33] and provide more information for decision making.

Table 4. EIA and LCA results comparison

Phases	EIA Identification of main local pressures/concerns (qualitative):	LCA Quantification of the impacts
Construction	Terrestrial quality Impacts on flora, fauna, ecosystems and landscape	- Climate change - Fine particulate matter formation - Fossil resource scarcity
Operation and maintenance	Impact Aquatic fauna	- Water consumption - Global warming - Fossil resource scarcity
Abandon	Terrestrial fauna	- Global warming - Fossil resource scarcity - Fine particulate matter formation

4. Conclusion

The LCA presented in this study, demonstrated that the construction phase of a hydropower plant has the largest impact in most of the mid-point environmental indicators. The contribution to global warming was, for this phase, of around 98% while for the operation phase was 0.97%. Fine particulate matter formation, water consumption and global warming are the main impact categories contributing the largest to human health damage. The last two of the midpoint indicators mentioned are also the mayor providers in the damage on ecosystems. Fossil resource scarcity is the mayor contributor in the damage on resources due to the large amount of diesel requirements in the construction step. The environmental impacts of the hydropower plant case decreases with a mayor lifetime. The damage on resources decreases of about 66.32 % when considering a lifetime of 150 years compared with 50 years showing that for this stage the impacts are distributed along the lifetime. The damage in human health and ecosystems reduce in 55.59% and 54.23%, respectively, for the same comparison of lifetime years. The impacts when comparing a hydropower plant with conventional fossil fuels plants are decreased in all the categories but the water consumption due being used for the electricity generation. The use of LCA as a complementary tool for traditional environmental assessment could provide quantitative relevant data.

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