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Environmental Damage Cost of Renewable Electricity Production: Hydroelectricity.

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Master in Economics (Environmental and Resource Economics)

Master Thesis

Norwegian University of Life Sciences
Faculty of Social Science
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Environmental Damage Cost of Renewable Electricity Production: Hydro-Electricity.

MASTER THESIS

Title of the study: Environmental Damage Cost of Renewable Electricity Production: Hydro-Electricity

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Abstract

Environmental damage and its costs have been given priority in modern production pattern in the rapid global climate change circumstances. As a key input factor, electricity (energy) and its increasing demand boost up its excessive production to meet the increasing demand all over the world.

Having scarcity in input factors of producing electricity (non-renewable sources) and its increasing trends of price, renewable sources (hydroelectricity, wind energy, solar energy, Bio-thermal and nuclear energy production) have been given priority for research and development and finding out the way of its lucrative production and distribution by the most developed and developing countries at the present world.

To keep pace with the excessive demand shifting from non-renewable sources to renewable sources, measuring and inclusion of environmental damage costs in the production pattern is appeared as a core concern for the Environmental Economists. To set-up the caps and trades of these sources of energy production, a policy maker needs to know its production pattern, land use, damages of human and wild life, nature of emission to the water and air (both in long and short term) to make sure that all impact costs of environment due to this production are well defined and included into the main CBA analysis of any project of this sector.

In this changing scenario of electricity production, my concern of this study is to find out the costs of Environmental Resource and Ecosystem damage costs due to the renewable electricity production, particularly hydroelectricity as it is considered as the matured, reliable and cost-effective source of renewable electricity production (Brown 2011).

The measurement process as well as the methodologies which are widely used in this cases are not adequate to explain all probable damages and their associated costs arise from the production of electricity using the renewable resources. It is now a huge debate among the environmental economists that it’s high time to study more about highly environmentally sensitive projects like hydroelectricity generation, to make sure that all the associated costs can be reflected properly in the Cost-Benefit Analysis of this project to avoid any serious environmental damage and its remedial processes to safe our environment for the better future world.

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1. Introduction:

Hydropower is a renewable energy source based on the natural water cycle. Hydropower is the most mature, reliable and cost-effective renewable power generation technology available in different alternatives (Brown, 2011).

Hydropower is the largest renewable energy source and it produces around 19% of the world's total electricity production and over four-fifths of the world's renewable electricity (IEA, 2010). At present world, more than 25 countries are highly dependent on hydropower for 90% of their total electricity supplies and 12 countries are 100% reliant on hydroelectricity, which is 99.3% in Norway. Hydro produces the bulk of electricity in 65 countries and plays vital role in more than 150 countries (IEA, 2010). Countries like Canada, China and the United States, which have the largest hydropower generation capacity right now (Sources: IPCC, 2011; REN21, 2011; IRENA, 2012 and IHA, 2011).

Not only that, "two-thirds of the economically feasible hydropower potential remains undeveloped. The World Environment Commission (WEC) estimates that in order to exploit this potentiality, 20,000 new hydropower plants with a total capacity of 1400 GW would have to be built, at a cost of US $1500 billion (WEC, 2004; current price)." So, it's a sector of huge potentiality and economic attraction due to the quick energy demand shifting from non-renewable to the renewable sector.

The aim of this study is to estimate the environmental, human and ecosystem damage cost based on the Life Cycle Assessment Approach (LCA), Life Cycle Impact Assessment Approach (LCIA) and the Contingent Valuation Method (CV) on the mitigation of world's increasing and changing energy demands. As it is a huge topic for a master thesis based on the duration of time and lack of other facilities, I´ve selected only one source of renewable energy generation for my study, which is hydroelectricity.

From the very beginning of my study I´ve started to design the main problem of this topic at section 2 and specify it correctly which has been elaborated and discussed in details step by step later on.

I´ve started by literature reading of some handful research papers and articles of the same topic, which have been considered the core part of this study. Literature gives a huge idea and mixed results about the environmental cost of hydroelectricity, which have been designed based on the scientific and mathematical analysis using practical evidences.

After that, I´ve elaborate the main methods of my study and discussed them to get some clear idea and calculating process of the environmental and ecosystem damage costs due to the hydroelectricity production. As the main methodology of my study, I´ve considered the LCA method (Life Cycle Assessment methodology), LCIA (Life Cycle Impact Assessment Approach), LCOE (Levelised Cost of Electricity generation) as well as the CV (Contingent valuation) method to determine and calculate the costs.

After this stage of my study, I´ve discussed the preceding methodologies elaborately; their probable cost patterns, main tools, calculating processes and cost figures. Some existing data sets for LCIA calculations have been considered so far and for the other cases I had to rely on the CV analysis (Contingent Valuation) and choice Modeling (Revealed/stated Preference), as some of the environmental damage costing are ambiguous and difficult to find their market values. For an example- the effect on fish life due to building a hydropower plant on a river near an urban village. It's quiet hard to get any amount of cost due to a hydropower plant on a river where the villagers used to catch fish (for their own consumption) before building that power plant. So, in some cases I´d to use the secondary data available (for LCA) and in the other cases on the CV methods.

Then, I´ve done the data analysis and calculation part based on- LCA for the global impact and CV analysis for the local impact. Here I've designed a table of all available cost tables for different types of emissions from hydropower plant to the air, water, human and wild lives. Cost of one unit emission of carbon to the air by a hydropower plant is possible to get from any reliable sources (IRENA or from IEA, for an example) but lost of wild life shelter or water species is impossible to get here in this particular case to include their impacts. Due to the lack of time and money it was not possible to go for a survey for CV analysis for this study and include, but a clear and mathematical process or guideline have been designed and developed for any project implementation body to take a good care of the environmental damages and its associated costs to reflect on their main Cost-Benefit Analysis (CBA) of hydroelectricity power plant.

Based on all methodologies and calculations as well as the findings I´ve written the conclusion of my study at the end part and have given some relevant economic forecast for the future research. One thing which was really surprised me while going through all my literature as well as the whole journey of this study, a huge scope and necessity is required for research work to determine the water species damage cost due to building a water dam on the river or water reservoir on any flowing lakes. The truth is, due to building a dam on a run-of-river, the life style of water species as well as the water quality is completely changed and thousands of water species lost their lives, disappear forever or died which is usually neglected by the project implemented body when calculate the CBA of their projects.

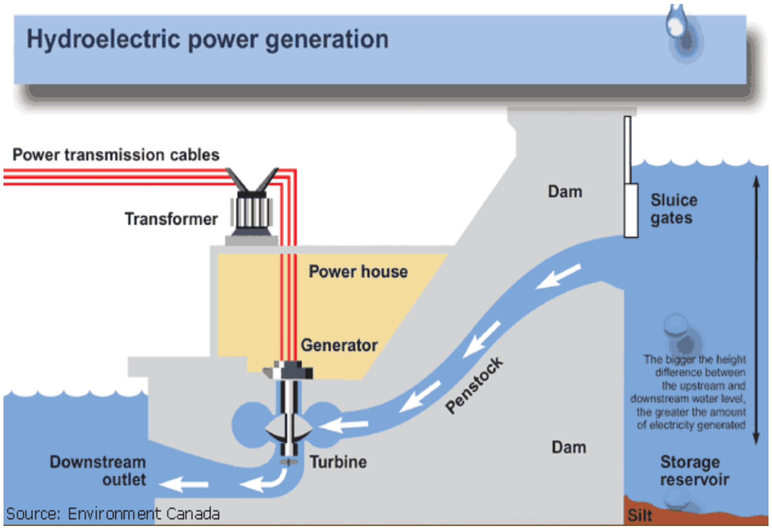
All useful data sources, reference lists including the lacking of my study, shortcomings of the methodologies as well as all elaboration of the abbreviations, which are mentioned or included have been well mentioned at the end part of this study.

Before any other discussions I want to specify the problem of this study, discuss literatures, associated methodologies, useful data and their analysis so that I can reach my a conclusion about the external effects and their associated environmental costs for this study which is actually the objective of it. So, lets start the discussion about the origin of hydroelectricity and its production procedure to specify the problem.

2. Specification of the Problem:

2.1) Historical Background of Hydroelectricity:

‘Hydro’ comes from the Greek word hydra, whose meaning is water. Hydro electricity is the electricity produced from the energy contained in the downhill flow of water from rivers, dams and lakes. Hydropower provides about 19% (2,650 TWh/yr) of the world’s electricity supply, which is about 99% in Norway (The highest rate in the world) (IEA, 2010).



Source: Environment Canada

Figure 1: Hydroelectric power generation; Water Resources of the United States: USGS (Environment Canada)

Hydro-electricity is the hundred years of proven way of producing electricity. In early ages, the ancient Greeks used the wooden water wheels about 2000 years ago. But at years of 1882 USA first built the hydroelectricity power plant to produce electricity using turbines based on fast flowing river as a sources of energy. After some years they started to build the water dams on rivers to store the river current and control the water flow by massive turbines to produce electric energy commercially.

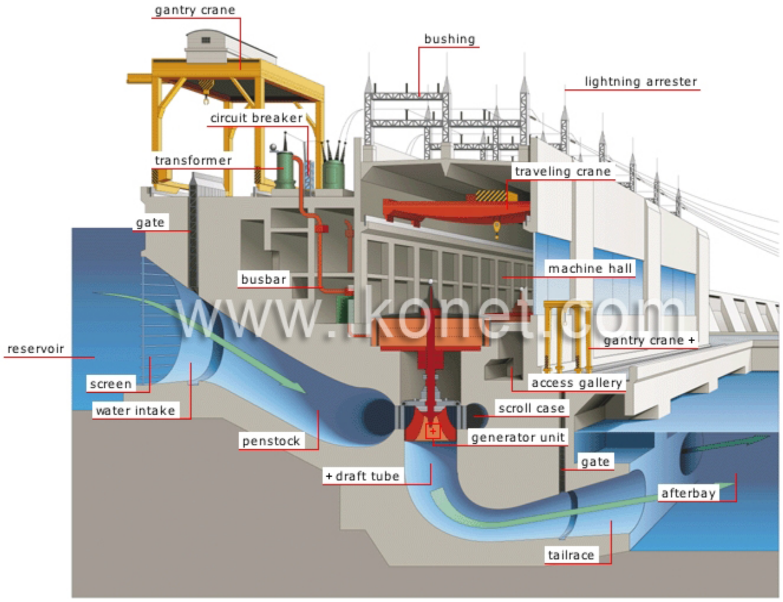


Figure 2: Modern Hydroelectricity power generation; Source: Australian Institute of Energy; Fact Sheet-6: Hydroelectricity

Small Hydroeletricty power plant at early of nineteenth century

Figure 3: TES- Small Hydro Generator; Susasca, Switzerland.

Originally those initial hydroelectricity power plants were small in size, built on water current on the hilly areas as well as near to the city so that the electricity can easily be transported to the city because it was not possible to transport electricity far away from one city to another as it was highly expensive and under-developed gridding system which they used to transfer electricity as well as it was impossible to store the produced energy at that time. But now-a-days, due to the development of technology it becomes easier to transport electricity even some thousands of miles by highly developed gridding system even though it's still a bit expensive.

Figure 4: Small Hydro-power plant at initial stage of nineteenth century. Source: hydropower in New-York; NYS department of Environmental conservation.

2.2) Environmental Concern:

[Figure 5: A recently taken image of an under construction Hydropower plant at Alaknanda Hydroelectricity project, Uttarakhand, India; after building a water dam and storage the river water the downstream area dried out and looks like small desert, there is almost no trees and plants around a couples of kilometers after the construction of this dam completed]

From the above-originated story of producing hydroelectricity a must needed couple of things are required to build and produce hydroelectricity:

a) Water Current or b) Water dam (can be both natural and artificial) or c) Lake (huge amount of water sources in a place and which are used to make sure that the water can fall from a certain level of height).

So, the alteration of water quality and blockage of water flow are happening to produce hydroelectricity. So, there is some obvious environmental and eco-system damage from a hydroelectricity power plant and its production on human life, animal life and bio-diversity, which is unavoidable. Because from this above discussion and figures it is cleared that to produce hydroelectricity one must change/protect the water flow from its natural trends which has some obvious natural impacts on environment (any alteration of natural water flow has some environmental effects.

As an easy and certain source of electricity production and from the excessive demand of world total electricity consumption as well as the scarcity of non-renewable sources make the renewable sources more trustworthy, reliable and popular sources of electricity production and the world total production of electricity is shifting towards the renewable sector in a quick. Considering this fact and practical evidences environmental and ecosystem damage due to the renewable sources is required more attention for the policy makers as well as project implementation bodies with environmental scientists to study more and calculate the actual environmental damage and its cost and make sure that these costs are well defined and reflected on the actual cost functions highly environmentally sensitive electricity productions.

Here we can see that the alteration effect of water flow on a reservoir. The upper stream area has been flooded and the downstream area has been dried. These types of alteration are very common and obvious for building water dam on the run-of-river or on a lake for hydroelectricity, which has massive and serious environmental negative impacts.

Figure 6: Dam building effect on environment; Environment of Canada.

Let's have a look one more similar case (effect) of dam building on the run-of-river water flow alteration and its impact on local circumstances. Here on this graph, it is clearly understandable that a huge amount of water has been stored on the upstream area while the downstream area is nearly dried. Flooding upstream and drying the downstream area by any artificial alteration of natural flow of water and water current has a huge impacts on local species lives, human habitats as well as the change of global climate (Jonathon & Kleinman; 2010).

Figure 7: Dam Building effects on downstream area of hydroelectric dam; Water Resources of the United States; USGS.

It is clearly understandable from this simple figure, how a hydroelectric dam on a run-of-river changes the entire river flow, flooding the lands on upstream area and reduces water flow on the downstream area. A huge difference is made, even if the dam is built on the hilly areas and this impacts area even destructive and fatal on a comparatively plain land dam area. On a comparative plain land dam on a running river current changes the whole water quality of that river, flood a huge area of upstream region, makes desert on the downstream area.

Figure 8: Grand Inga Dam on comparatively plain land, Congo; Africa. Source: IEA Research paper.

After the discussion of this sector it is cleared that any alteration of natural water flow has some obvious environmental and ecosystem damages which should definitely be studied and calculated so that the damage cost can be minimized for making sure the optimum use of water resource in the safest way.

In this changing scenario of electricity production, there is no doubt about the issue that the environmental impact-cost measurements, calculation as well as its inclusion into the main cost function of hydroelectricity power project deserves similar importance as it is the technical and related all other costs calculations. So, it is obviously a concern to protect our surroundings and environment as well as use the natural resources in the safe and healthy way so that the environment can sustain and continue to support human and animal life for some thousand years.

To define and calculate those environmental and ecosystem damage cost which can be raised of hydropower generation using water flow of river and reservoir this study is designed as a triumph to find out all probable environmental impacts and their associated cost of hydroelectricity power plants on both run-of-river and water reservoir.

3. Literature Review:

Global energy demand is growing faster with the speed of global population growth, but the production of non-renewable electricity generation is not growing fast to keep pace with such speed to mitigate the world excessive demand of total electricity production because the resource of non-renewable sources are running out quickly (IEA, 2010 & IRENA, 2012). As a result, it becomes obvious phenomenon to find out a new means of electricity production, to meet the excess demand of this sector from the beginning of the nineteenth century. A source of electricity production which can be reliable, less expensive as well as environmentally friendly, which is hydropower production. At the year of 1880s, USA first started to generate electricity from the water current (Hydro-electricity) by a small electric turbine to meet the household energy need (IRENA; 2012). Around 19% of world total electricity production is coming from hydropower plants (IRENA, 2013 & IEA, 2012) where 51 countries of the present world meet their 70% of total domestic electricity demand by their hydroelectricity production where countries like Sweden and Norway meet almost 100% of their total electricity demand by hydropower (IREA-2013 & IEA; 2012; Annex: 1, 2 & 3). It is said that from the soviet era countries like Iceland, Norway, Sweden, and Finland as well as the Baltic countries are highly dependent on their hydroelectric power to generate electricity from the era of 1st world war (Jonathon & Kleinman; 2010).

Besides producing electricity for ideological agendas to fulfill much political purpose, a huge number of dams have been started to build after 2nd world war, which brought into the environmental concerns as well as ecosystem savings. Because the whole procedure of building a dam on a river current up to the stage of its production and maintenance there is a huge impact on ecosystems, biodiversity as well as on the human and wild lives (Jonathon & Kleinman; 2010). Because of building dams many people displaced from their home and even from homeland together with animal lives and water species. Not only that, it has a massive negative impact on local and regional environment. According to a Swedish research, almost 60% of length of world's large river systems are shared or portioned by inter linking transfer of water by artificial channels or by withdrawing water from the rivers and lakes for irrigation or other production purposes. So, hydropower generation, building dams for it, or any transfer of water from the rivers and lakes have a huge environmental, social and economic impact (Jonathon & Kleinman; 2010) because any alteration of natural flow of river has a massive negative impact on environment (IRENA 2012 & IEA 2010, 2012 and Annex: 1, 2, 3 as well as Frischknecht & Müller-Lemans, 1996 and Karen Flurry & Frischnecht, 2012). Based on the structure & functions of dams, Jonathon & Kleinman; (2010) divided the sources of hydropower into two sections: storage water plant or reservoir and run-of-river dam hydroelectricity generation by circulating turbines.

Hydropower becomes more and more popular because it's safe, low production cost, environmentally friendly than other sources of renewable electricity production and the projects life is usually very long as well as it is financially cheaper than any other renewable power generation which are used at this present world (Brown, 2010). Having these attractive facilities and availability of huge number of river current and lakes all over the world (water resources), at some countries of the world, hydropower became the main sources of electricity production like Norway, Sweden, Vietnam, South America and so on. But it's now really a matter of concern that the CBA analysis of most of the hydropower projects, countries did not calculate the actual environmental and social costs associated their projects which are caused a serious environmental and social damage for that territory for some decades on human and wild lives (Green ID, 2013).

I read some numbers of good research papers for this study, subjected the environmental costs and fatalities on human and wild lives but at my literature review section I want to highlight a paper designed a similar scenario by Green ID (2013) in the Vietnam hydropower project on Song Tranh river as an example of severe environmental and ecosystem damages and its impacts on human and wild lives due to building hydropower dams on a run-of-river. Hundreds of hydropower plants like it, can be found at present world, where the environmental damages were so fatal that after building a hydropower plant some regions of human civilization were needed to transfer from the project area to other places and its impacts on wild life were vast. Green ID (2013) have studied the hydropower plants, its potentialities in the future as well as its environmental impacts on human and their displacement and the measurement of cost of losing houses due to Hydropower project. Its social risks on environment, gaps in resettlement cost, forest loses, impacts on biodiversity, dam safeties, gaps in EIA requirements and some other recommendations.

To fulfill rapidly growing electricity demand, hydropower is one of the best options in Vietnam. But it is true that hydropower has a massive negative impact on environment in Vietnam just like many more other countries. During 70s to 90s some numbers of hydropower projects have been built where the project implementing body did not care about the environmental damages and its actual costs in their CBA analysis. The actual social & environmental risks and its associated costs were neglected in most of the projects (Green ID, 2013). It is difficult to measure the costs appeared from hydropower projects because resettlement of displaced people, forest lost and overall negative impacts of biodiversity are such factors that the market price of most of them are not found in the market (Green ID, 2013).

Now, if we look at the cost-gap regarding resettlement, we can also see some problem and misguided cost calculations here. Sometimes hydropower projects do not want to spend enough cost for resettlement because of the budget scarcity (Green ID, 2013). Sometimes people who are going to be displaced by the project from project area where they were not ready to leave their own land. The problem is that, project investors sometimes cannot really afford the amount of money for the resettlement. Green ID (2013) shows by their own survey, hydropower investors cannot afford and pay much compensation for the resettlement of this alteration because sometimes the affected area of the project are really large. So, it is clear that, some cost-gap in hydropower project where the value of resettlement is not counted sometimes as a cost (Green ID, 2013).

In those Vietnam cases survey also gives evidences that during the hydropower project development and resettlement process, many farmers got less land that they actually had.

Sometimes the quality of those lands is not as good as the land they previously had which has a negative impact on their less agricultural production. They cannot produce the same amount of product as before. So, the less fertile and less area of agricultural land is also a big problem for both the farmers and the investors. 79% of resettled people got less land and on the other hand, 77% of people got less quality land (less fertile) than they previously had after the resettlement of Vietnam Hydropower Plant (Green ID; 2013).

Another big environmental issue came into light of Green ID paper, which is the loss of forestland due to building the water dam for hydroelectricity, as most of the hydropower projects are located in a large forest area in Vietnam. To make a reservoir and to construct dam structure it's also destroy a huge forest area. According to Ministry Of Agriculture and Development during the year 2006-2012, 19,792 hectare of forestland in 29 provinces and cities has been chopped down where 160 hydropower projects started using 3,060 hectares of special use production forest (Green ID; 2013).

Central authority needs to assign the forest ownership rights to compensate forest owners for the loss of forest trees, its growth and loss of areas. Unfortunately, in most hydropower projects of Vietnam, the costs of losing forest and deforestation were not calculated properly in the final cost of projects (CBA). Some obvious negative environmental impacts and climate change are unavoidable due to the loss of forest area, trees as well as its destructions. All types of GHG can be stored at greater amount than before due to this loss. Not only that- serious floods, droughts in downstream area can happen due to the lack of sufficient forestland. Forest dependent economic activities are also hampered in a greater scale because of this loss.

Varieties of wild animal and birds lost is highly connected with the loss of forest land due to building hydropower project, this impact on biodiversity is also unavoidable. Building water dams on river flow blocks the normal water flow and thousands of water lives and other related species are lost due to the uneven flow and sediment storage from the mountain to the upstream area. Water quality changes the water to be in toxic due to the sediment storing at up stream area and all water lives as well as other animals that drinks this water can die. In Vietnam, before the year 2010 there was no specific laws and regulations to protect animal and wild lives. There were no specific statistics about their actual amount/number of losses. So, the loss of these impacts on biodiversity were in dark and never been calculated for CBA into hydropower generation cost.

Dam safety is another issue during construction of hydropower projects in Vietnam. During the construction of dams, human as well as animal lives should be given priority for their safety that can be in danger because of this construction. Because of earthquakes, the safety matters failed in Vietnam, which damages hundreds of human & animal lives as well as their houses. Many dams are still threat for them. Lack of financial and developed dam building technology; lack of experienced investors, owners and builders of hydropower plants are responsible for it. Laws and regulations are still not sufficient for safety issue there (Green ID, 2013).

Another issue they have discussed here as the lack of dam building which is the gaps in EIA (Energy Information Administration) requirements. Approval of EIA is a legal condition to build up a hydropower projects. But EIA has many diffficulties on environmental and social effects of these projects. Many requirements are not enough and enforcement is also not so strict. So, process of hydropower projects is still risky in Vietnam.

It's not very easy to calculate external cost. Climate change is the outcome of electricity production project and climate change is interrelated with many factors. Such as emission of CO_2, air pollution with different gases etc. Human health is also related with environment. High emission of greenhouse gas from fossil fuel based power supply is also related with environmental pollution (EEA; European Environment Agency; 2005).

External cost for hydroelectricity is one of the biggest problem that usually don't reflect as the cost of the project, which has exactly the equal impact for every country of the world. Because there is no border of world climate and the change of one country's weather easily affect the others. So, the global climate change and its associated effect on human and animals should be seriously treated as the global environmental concern and take into account for project implementation of hydropower generation because if one man can suffer by the activities of others, he needs to pay for it (EEA; European Environment Agency; 2005).

According to United Nations dam building statistics, canals are made in almost 60% of the world's 227 largest rivers. When a dam is built, environment & ecosystem of its surroundings are badly damaged which is turned into a social problem. Because the affected group by this project, especially poor people and people who lives depending on the river water and other water resources suffer a lot due to the flow alteration, habitat alteration as well as the restricted activities on dam areas (EEA; European Environment Agency; 2005).

Government policies or Government environmental monitors body should take/run surveys for selecting suitable/environmentally friendly hydropower plant areas. Good site selection is another important factor for hydropower plant. Negative impacts from the outset should be minimized through the proper site selection. It should keep in mind that ecosystem should not be hampered by the wrong site selection. A proper monitoring system should ensure that wildlife is not under threat due to build a hydropower project (EEA; 2005).

From the Green ID (2013) paper along with all other literature here, some points can be considered as standard environmental and ecosystem damages by a hydropower production as- 1) alteration/blocking of water flow will be happened; 2) Land on upstream will be inundated (loss of forest & agricultural land); 3) Deforestation will happen on the downstream area (lack of sufficient water flow); 4) Thousands of habitat alteration can happen due to building water dam; 5) Blocking water species forever; 6) Water gets in toxic due to the prohibition of water current which is the cause of thousands of water species death; 7) More carbon will create and emit to the air due to storing a large amount of water and deforestation; 8) Fishing and cultivation will be permanently blocked due to building water dam on running river. From this Green ID (2013), most of these environmental obvious impact cost were neglected and under calculated in the main CBA analysis of Vietnam Hydropower Projects. This is not only the case of Vietnam Hydropower plants; it is also true for most of the Asian (China, India and so on), South America (most of the countries) and African courtiers (IEA 2010, Green ID, 2013 & IRENA, 2012). The external fatalities from hydropower plants in Europe & North America is less than Asia, Africa and South America because of developed technologies for dam building, environmental consciousness as well as geographical advantages (have rocky mountains and less plain lands).(IEA 2010, Green ID, 2013 & IRENA, 2012).

Now-a-days global climate change is the issue of global concern. It is important to find out cost and benefit of hydropower projects before its start to implement. When a dam is built on water current to make hydropower plant, human and water lives hamper a lot. All water species get block while blocking the river current. Many species also killed because of sharp blades of turbines while some species get serious injured and eventually died. Sometimes, some species disappeared from some specific area forever. Biodiversity are hampered a lot because of hydropower projects. It’s really a matter of concern if authority gives emphasize on hydro power electricity and all its impact cost of environmental damages, balancing of these two factors and minimize the cost of environmental damages, hydropower production can be the best environmentally as well as ecosystem-friendly means of electricity production which can save a huge amount of other resources of electricity production to mitigate the world total electricity demand (Maria Steinmetz & Nathalie Sundqvist; 2014).

Hydropower plants seems more eco-friendly than any other energy production as they are not responsible for increasing a large amount of greenhouse gas comparing with others and it is environmentally friendly as well as sustainable type of energy sources depending on its proper use by saving the environmental damages. Having huge potentiality hydropower sources should be used at its optimum level by ensuring the proper dam design & construction by balancing between economic, social and environmental consideration (Ute Collier; 2004).

4. Methodology of Study; LCA Approach:

4.1) Addressing the Life Cycle Assessment Approach (LCA):

Life Cycle Assessment, shortly LCA which is also known as the Life-Cycle Analysis, Eco-Balance and Cradle-to-Grave Analysis, is a technique to assess the environmental impacts associated with every stages of product (from its raw form to the finished/final form) life, like processing, manufacturing, distribution, repair or recycling and their all waste dumping to the air, water and land to make sure that all associated environmental & Eco-system damage costs are included and reflects in the main cost function and budget on the projects (IEA Research paper: Environmental & Health Impacts on Electricity Generation). From IEA (2002) & Green ID (2013) research, they found most of the highly environmental related projects do not care about the accurate environmental & Eco-system damage costs in their project evaluation and cost calculations which they have considered as the main concern from the excessive demand shifting of electricity production from non-renewable to the renewable sectors. They also mentioned that still two-third of the world total possible Hydro-electricity is not yet under the production processes, which can be possible in the near future.

In the year 2006, Life-Cycle Assessment (LCA) approach has been addressed and used for the first time to calculate a product's life time (from primary stage to final stage) environmental damage cost for the highly environmentally risky projects. It has been designed to assist the decision makers and stakeholders to figure out the actual measures to reduce the environmental burdens through the calculation of detailed track of the flow of all materials and energy used from the very early to final stages of the production of a particular product life.

LCA plays a vital role for the decision makers and stakeholders in identifying the actual measures to reduce the environmental damages and disturbances by taking into account the step-by-step damage cost to make sure that all probable environmental, human life and ecosystem damage costs are included and well defined into the cost function to reduce the best possible environmental damage in the large scale manufacturing plants, particularly electricity energy plants where we have some unavoidable environmental damage and ecosystem disturbances.

There is an international standard called ISO (International Organization for Standardization, 1998) that describes the major principals of LCA under ISO-14040. A standard LCA should include the mapping of resources use and the environmental impact of equipment such as boilers, turbines, condensers, feed water pumps, pipes, as well as the auxiliary all other electric equipment. According to the ISO-14040 standard LCA framework requires the goal and scope of the LCA be clearly defined which is also required the Life-Cycle Inventory Analysis (LCI) is performed by data collection and calculations to find the exact physical result related to the functional unit as well as the allocation of flows and the releases of water.

International Standardized Organization; ISO 14040 describes the principles for conducting and reporting LCA studies. The ISO 14040 LCA framework requires: 1) definition of goal and scope, 2) inventory analysis, 3) impact assessment and 4) interpretation of results which is shown on the diagram 1.

[Source: "Environmental and Health Impacts on Electricity Generation, A Comparison of the Environmental Impacts of Hydropower with those of Other Generation Technologies" IEA; 2002]

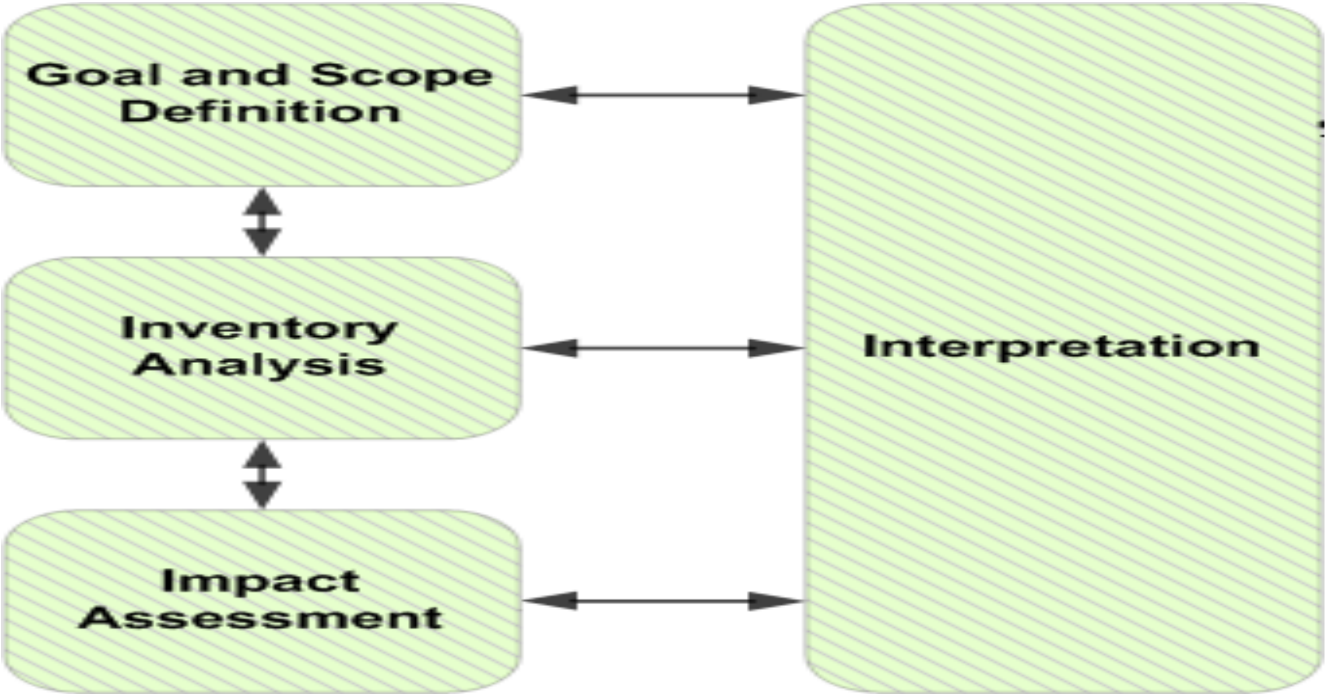
So, the LCA should follow the rules of flows and releases of LCI, which is standardized, with the ISO-14040. So, setting a standard for LCI according to the ISO-14040 is a core concern. So, let's have a look the main framework of LCA and we will proceed towards the LCI afterwards-

4.1.1) LCA Framework- Main Approach:

The Life-Cycle Assessment technique for impact analysis becomes popular for assessing the environmental aspects and potentials, other impacts associated with a particular product for its unique technique based on criteria and practical calculations. Because it's iterative in nature and many related and useful studies also consider under it for the several iteration cycles of that particular product. Inventory data collections and calculation are considered to get the impact assessment results.

The main frame follows by the LCA procedures of analyzing data for assessing the interpretation and approaching towards a suitable decision, the main steps, which are considered under it, are as follows-

Life-Cycle Assessment (LCA) Framework (ISO-14041-14043 standard):



(Diagram 1: LCA model in graph; Source: - "Environmental and Health Impacts on Electricity Generation, A Comparison of the Environmental Impacts of Hydropower with those of Other Generation Technologies" IEA; 2002).

Direct applications associated with the LCA impact assessment analysis are as follows-

- Product development and improvement
- Strategic planning
- Public policy making
- Marketing and
- Others

Goal and scope definition, Inventory analysis, Impact assessment, Interpretation assessment, economic rates of return, technical feasibility, etc., are the Main framework of Life-Cycle Framework. Out of them, the goal and scope identifies the specific work aiming the LCA phases. Some more following steps must be considered as part of the LCA framework:

►The functions of the product system
►The functional unit
►The product system to be studied
►The product system boundaries
►Allocation procedures
►Types of impact and the impact assessment methodology
►Data requirements
►Assumptions
►Limitations

►Initial data quality requirements
►Type of critical review, if any and the
►Type and format of the report required for the study

In this framework of LCA my concern and motive is to concentrate on the third point of LCA framework, which is the Impact Assessment (LCIA) of environment and ecosystem damages. So, after consideration of Goal & scope and inventory analysis LCA's another main iterative part- the impact assessment (LCIA) will be assessed here through LCI method to look at the environmental impacts.

[Source: This part has been executed from the main research paper of IEA- International Energy Agency; Title- "ENVIRONMENTAL AND HEALTH IMPACTS OF ELECTRICITY GENERATION, A Comparison of the Environmental Impacts of Hydropower with those of Other Generation Technologies" IEA; 2002].

As we have already know now the life cycle inventory analysis (LCI) is concerned with the data collection and calculation procedures for quantifying relevant inputs and outputs of a product system which includes the resources and the environmental burdens for the land, air and water pollution associated with production system.

The following input-output example table can explain more about it-

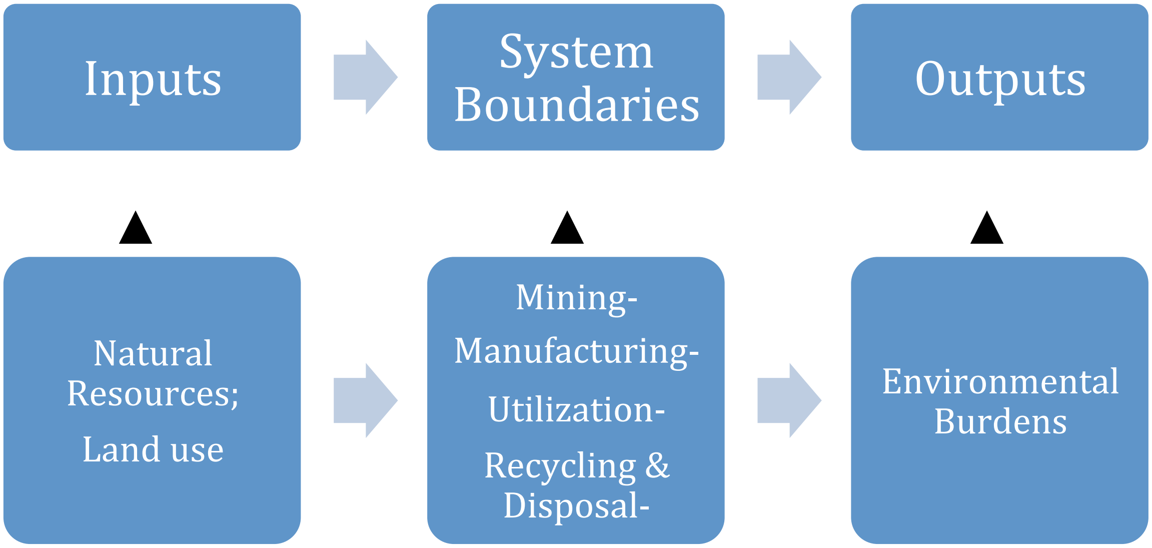


Diagram 2: Framework of Life Cycle Inventory Analysis (LCI); IEA; 2002

From the first stage to the finished level of the product, it's actually an analysis of a chain of all associated inputs, their costs and final outputs including the environmental burdens where all capital goods as well as environmental inputs are considered as the main instruments of LCI framework (IEA; 2002).

Inputs including the natural resources and lands are used for the 2nd stage of production, which is called here the system boundaries where Mining, manufacturing, Utilization, Recycling and disposal process have been followed. At the output level where all environmental burdens have been included to make sure that the damage cost of environment due to this production have been reflected in this project.

So, under the LCA, specifically LCI I get now the procedures and methods of any environmental impacts assessment from the hydropower generation but before going to the probable cost analysis lets have a look two more methods of study the costs associated hydropower production.

4.2) LCOE (Levelised Cost of Electricity Generation) method to calculate the standard life-time cost of a Renewable electricity Production:

Now my plan is to present a standard cost calculation method of a renewable electricity production plant which has been widely used to calculate the life-cycle cost of project's life (International Renewable Energy Agency (IRENA, 2013): Renewable energy technologies: cost analysis: series-1). I want to elaborate the method of Levelised Cost of Electricity generation, LCOE here in details. Here from this graph we can define this method as-

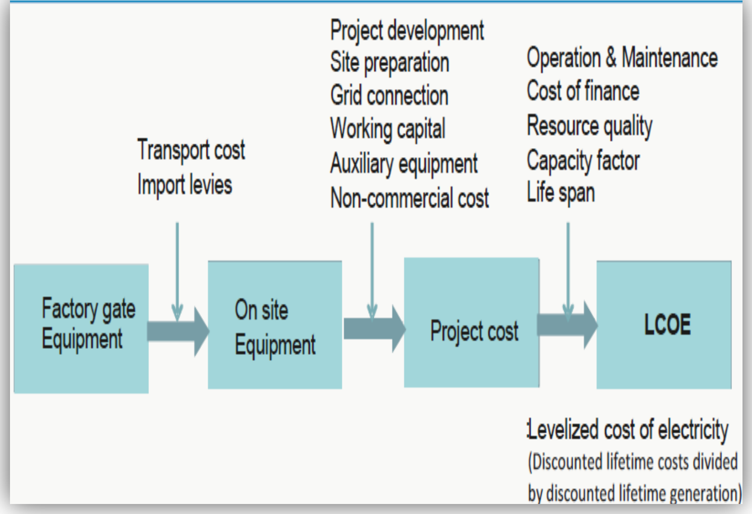


Diagram 3: Main framework of Levelised Cost of Electricity Generation; IEA (2002)

LCOE= Discounted lifetime cost divided by discounted lifetime generation.

Which means all the costs associated with the projects and its lifetime is already been discounted considering the inflation of the market. From the very beginning of the projects life to the end or final stage of the project, all probable physical costs have been taken into account under this method. Most of the big renewable electricity power plants of the world use this method to calculate their physical costs of the lifetime projects evaluation and make the projects meaningful in the practical sense.

The approach under this method are widely used is called the discounted cash flow (DCF) following the approach discounting financial flow based on the data annually, monthly or even quarterly or even the whole life time of the project. Here the Weighted Average Cost of Capital (WACC) also refers the discounted rate. A huge number of potential trade-offs have taken into account when developing the modeling approach for LCOE. The formula used for calculating Levelised Cost of Electricity Generation of renewable energy technologies is as follows-

$$\text{LCOE} = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where, LCOE = the average life-time levelised cost of electricity generation,

I_t = Investment expenditure at time t.

M_t = Operations & maintenance expenditures at time t.

F_t = Fuel expenditures at time t.

E_t = Electricity generation at time t.

r = discounted rate at time t.

n = Economic Life of the system at time t and finally

t = total life time (duration) of the project.

Levelised Cost of Electricity Generation (LCOE) has been widely used to calculate the physical cost of a renewable electricity production but not use to calculate the external and environmental cost of CBA analysis of a project. So, let's have a look the last two methods which are also relevant for my study. *[Source: International Renewable Energy Agency: Renewable energy technologies: cost analysis series-1; IRENA-2012].*

4.3) Contingent Valuation Approach/Method:

Contingent valuation method or the non-market benefit/loss approach refer to the method where the market price of any externalities (both the positive & negative) is calculated based on the man-to-man questionnaire based surveys on the particular externalities (Richard G. Walsh, Donn M. Johnson, and John R. McKean; 1989).

For an example- the cost of losing the opportunity of fishing (can be both personal consumption as well as the commercial fishing) on particular river by the villagers due building a hydro-power plant on that river and has been restricted by the authority for fish cultivation and preservation on that particular river (or some areas of it). The market price of this opportunity loss of fishing for the life span of building this water dam is not present. To include this opportunity loss or negative externality for the villagers as well as the fishermen in this project's Cost-Benefit analysis, policy maker can run a survey by man-to-man free question asking process and can collect data from every single villagers and fishermen and can include the discounted average of all individual observations. This cost calculating process is widely used for calculating the non-market product cost (Richard G. Walsh, Donn M. Johnson, and John R. McKean; 1989). Similarly, cost calculations by the similar way of sound effect of construction of water dam on local people, the dust emissions to the air and local roads damages due to building a hydropower plant on the village areas (negative externalities), the beautiful view after building a hydropower dam on a run-of-river (positive externality) can be more example of CV method (Richard G. Walsh, Donn M. Johnson, and John R. McKean; 1989).

Richard G. Walsh, Donn M. Johnson, and John R. McKean, (1989) calculated the recreational price of visiting a park in USA and they have used the CV method based on Sorg & Loomis (1985; which was all about the price calculation of wild-life preservation valuation where they used the non-market valuation approach) to get the non-market price based on the visitors willingness to pay for continuing to visit the park. They have analyzed the demand criteria of the park as a recreational media for US people and survey by man-to-man demand and willingness to pay for that particular park.

Here in my study on some particular cases I've to rely on the CV approach to get some cost idea about some particular externalities (cost side only) associated with the hydropower generation.

4.4) Choice Modeling (Revealed Preference/Stated Preference):

Choice modeling attempts to model the individual choices based on their utility preferences via revealed preference or stated preference. For any particular good/service (or any externality) an individual revealed her preference based on her personal interest/utility (what she gets or what she needs to loose) and makes her decision. This method is widely used to calculate the values of non-market goods and services (or any types of externalities arise by any third party). This method is also called the qualitative analysis. It’s a part and technique of consumer utility analysis where economists try to calculate the values of external effects by a third party on general consumer where the market price of those external effects is absent.

The preceding CV method as well as this Choice Modeling has been considered here to calculate the cost of external effects by a hydroelectricity power plant where the local environmental damage costs are absent at market price. All the qualitative analysis of LCA cost components will be suggested to calculate by using CV and Choice modeling.

LCI and LCIA, which are two main components of LCA method, have been considered as the main method to calculate the global environmental emission cost of hydroelectricity because it is one of the most accurate and popular cost valuation methods where the cost is calculated from very first level to the very last. The step-by-step environmental cost calculation for the whole life span of a project is the main objective of my study, which is possible to calculate by using LCA approach. The cost of 1 unit carbon emission to the air has its lifetime effects on the global climate change, which has also the equal level of effect on all countries of the world. So, I need to know the actual lifetime environmental cost of 1 unit of carbon from hydropower production, which is possible by LCA approach. LCOE is the method to calculate mostly the physical cost of a project, so it is not relevant for me here to discuss more in details. I´ve mentioned it here only because of some knowledge that how to include the physical cost into the CBA study of any hydropower plant.

And for the local impact cost calculation of life time effect of a hydropower plant I need to apply the methods to find out the cost of non-market values like water quality change effect on local water species or the effects on fishermen and their socio-economy from fishing restrictions and cultivation due to building a water dam on run-of-river. These types of loss/effect cost are not available in the market. So, contingent valuation approach, choice modeling approach as well as consumer utility analysis can be better option to find some local effect cost of building hydroelectricity. One thing is more important that the local impact cost can be completely different from project to project as well as from country to country. But their global effects will be exactly the same for all projects and places.

So, I can set a per-unit cost of global emission for all projects and for all countries. For an example- to emit 1 ton of carbon to the air, $10 will be the cost/tax for every hydropower plant. But for the local impact cost of environmental damage I need to go through CV, Choice Modeling and consumer utility theory and calculate the cost for a particular hydropower project.

Now, I want to discuss the affected environmental factors by a hydropower plant (both the global and local factors) and the suggested methodologies by which I can figure out the actual lifetime effect costs for producing a particular amount of electricity (for an example- 1 Giga Watt Hour).

5. Cost Analysis of Hydropower Production:

5.1) Affected Factors & Methods of Cost Analysis:

By help of those three major categories of LCA method- a) Goal and scope definition; b) Inventory analysis and c) The impact analysis, The Life Cycle Impact Assessment (LCIA) method is usually used to assess the environmental impacts. Under this assessment the data usually been used are generally in good quality. Under the LCIA, some factors have more influence on overall results than the others, such as life expectancy, for any hydroelectric dam, the true life expectancy duration is rarely known but it has a huge impacts on decision making and cost analysis of the project. At the same time, water current as well as the flooding of the reservoir constitute are the most significant structure in terms of the resource use and the environmental impacts which means that a small changes of the longevity of the project has a huge impacts on the cost pattern as well as the overall environmental impacts.

There is one more problem that we need to consider and given priority to resolve in future LCA analysis for the hydroelectricity power plant, which is the differential emissions of air pollutants and their different retention of times. This problem should also be specifically addressed in relation to the methane gas emissions to the air from some tropical hydro reservoirs (Rosa & Schaeffer- 1995). For the further consideration and elaboration, the emission of radionuclides and their potential health impacts need to be specified and include under any CBA of hydroelectricity power plant for better environmental Impact analysis.

IEA suggests the following methods to assess the environmental cost of using different types of natural resources:

Use of resources	**Methods of Assessment**
Land-	LCIA (for whole life span of the project)
Water-	LCIA (for whole life span of the project)
Global environmental impact	
Greenhouse effect-	LCIA (life time climate change effect of emitting 1 unit of carbon)
Ozone layer depletion-	LCIA (life time climate change effect of emitting 1 unit of carbon)
Local/regional environmental impact	
Acidification-	LCIA
Eutrophication-	LCIA
Photochemical oxidant formation-	LCIA
Eco-toxic impact-	LCIA
Habitat alteration-	qualitative
Impact on biodiversity-	qualitative, based on LCA’s

Accidents-	Quantitative Risk Assessment (QRA)
Impact on human & wild lives	**Methods of Assessment**
Health risks-	QRA
Social and socio-economic impact-	qualitative
Risk perception-	qualitative; Risk perception studies.
Aesthetic impact-	qualitative analysis.

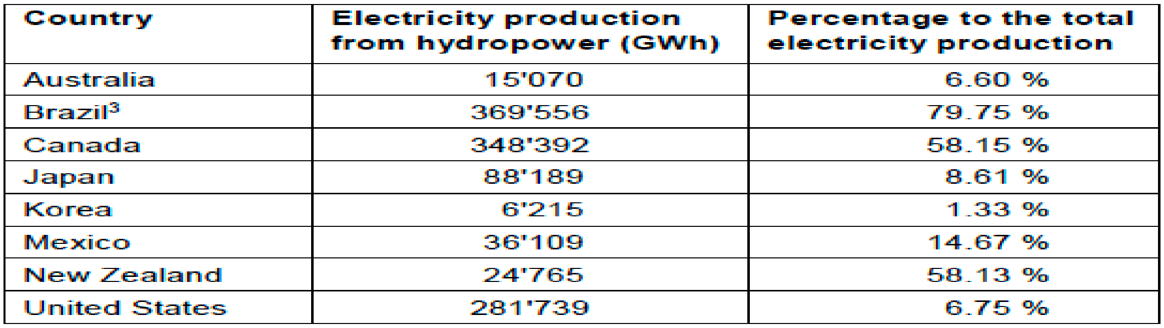
Fourteen environmental cost factors associated with renewable energy production are based on the LCIA and qualitative analysis means the physical or mathematical analysis is not possible for all of the environmental cost criteria and there are also some cases where the data of these factors is near impossible to figure out. International Energy Agency (IEA) suggests to take into account the Contingent Valuation Approach which is also known as the willingness-to-pay Approach (CVA- A valuation approach where external effects from a production is not existed on market, in this case the willingness to pay by the externally affected people can be a good measure to get some ideas about their costs and effects on human and animal life; for an example- if a water dam is built on a village area river water current where the villagers use to catch fish for their own consumption as well as it has been considered as one of their recreational medium and they are not allowed to catch fish anymore from the upstream and downstream area about a kilometer, the cost of their opportunity lost will not be available on the market to evaluate their loss of catching fish and recreation. In this case, the CV approach can be a very good approach to ask by man to man through a random survey and an average opportunity loss cost can be consider to include this cost into the original cost function to build up the dam on that particular liver current) as well as consumer behavioral analysis (Revealed/stated preference) can be two good alternatives to get some cost figures to valuate those factors at market prices. (More in details about CV method is on section no. 4.3)

[Source: This part is also executed from the main research paper of IEA- International Energy Agency; Paper title: - *"ENVIRONMENTAL AND HEALTH IMPACTS OF ELECTRICITY GENERATION, A Comparison of the Environmental Impacts of Hydropower with those of Other Generation Technologies" 2002*].

5.2) Cost of Hydroelectricity Power Plant; Environmental Case Study:

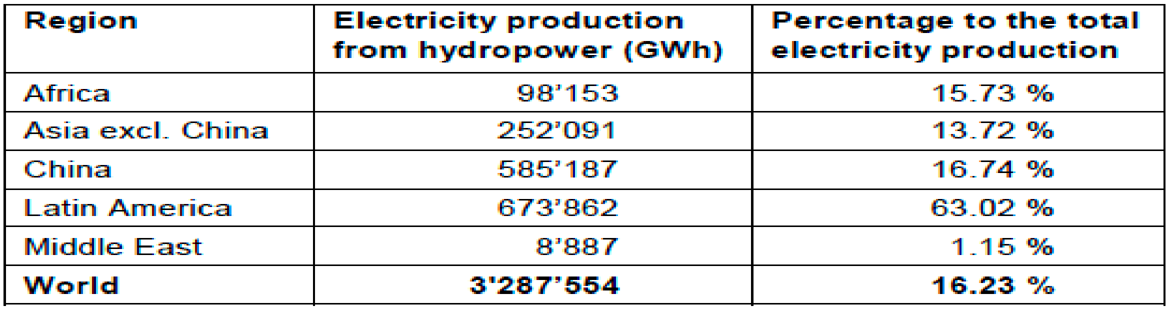
Hydroelectricity is one of the most potential, proven and environmentally friendly renewable sources of electricity production that efficiently transform the potential hydro energy via kinetic energy to electric energy where to produce 1 kilo watt hour electricity it is required 1.28 kilo watt of potential energy (ETH-Study) where the transformation rate is 78% and 23.7 tons of water is required to generate this amount of electric energy but it varies on different settings of geographical structures (IEA, 2002). Let's have a look the world total hydroelectricity production of percentage of their total production by two different tables here.

Table 1: Country based hydroelectricity production and the percentage of total electricity production. Source: IEA (2002).



Country	**Electricity production from hydropower (GWh)**	**Percentage to the total electricity production**
Australia	15'070	6.60 %
Brazil[3]	369'556	79.75 %
Canada	348'392	58.15 %
Japan	88'189	8.61 %
Korea	6'215	1.33 %
Mexico	36'109	14.67 %
New Zealand	24'765	58.13 %
United States	281'739	6.75 %

Table 2: Regional/continental based hydroelectricity production and the percentage of total electricity production. Source: IEA (2002).



Region	**Electricity production from hydropower (GWh)**	**Percentage to the total electricity production**
Africa	98'153	15.73 %
Asia excl. China	252'091	13.72 %
China	585'187	16.74 %
Latin America	673'862	63.02 %
Middle East	8'887	1.15 %
World	**3'287'554**	**16.23 %**

This statistics are from the year of 1995, now the world total hydroelectricity production share is 19% (IEA, 2010).

Usually two types of hydroelectricity power plants are widely used to produce the hydroelectricity- a) Run-of-River and b) Water Reservoir but both types of hydroelectricity power plants require a huge amount of water available, hilly and cool areas where there is a certain amount of height is available to make the water fall from a certain level height with a huge force to turn the turbines where there is less chances to loss the water due to the heat from the sun.

North Pole, South Pole as well as mountainous and hilly areas (Alps, Himalayas) are suitable for the hydroelectricity. For this reason we can see the most of the hydropower plants are situated on northern countries as well as countries with vast area of mountains; like- Russia, Sweden, Norway, China, India, North America and South American countries.

50% of total electricity production of Sweden (Brannstrom-Nordberg et al. 1995) comes from Hydroelectricity where Norway produces its 97.1% of total electricity from Hydro-sources (World Bank and IEA 2002). The total electricity production from hydropower sector can be double if all the possible hydropower plant can come under it production.

Following the Life-Cycle Impact Assessment cost criteria and its suggested methods of calculation at this part of my study I feel to elaborate every single probable environmental impacts and their associated costs on environment, impacts on bio-diversity as well as the human health. Let's have a start from the very first input factor for hydroelectricity (from section 5.1 resource list) production which is land (here we need to remember that only the environmental cost of Hydroelectricity power plant will be considered in this study).

5.2.1) Land:

The very first factor of the list mentioned in the section 5.1 of producing energy from hydroelectricity is the land, which will be the first input factor to be used. One way suggested by ETH to calculate the price of land is going to be used for this product is definitely be well defined and try to get the actual price of it. ETH divided four quality classes of land based on the UCPTE countries (UCPTE: European Network of Transmission System Operators for Electricity) by the following ways-

►Class 1: natural (human activities have very less effect than species on it; forest land and unused fallow areas)
►Class 2: modified (human activities has more effects than the species on it; forest land but uncultivated)
►Class 3: cultivated (human activities have great effect than the species on it; mostly cultivated, useful agricultural and fuel forests)
►Class 4: built (dominated by buildings, infrastructures, roads, cultural heritages, parks etc.) (IEA, 2002 & Annex-1,2,3)

Land prices are assessed based on these four categories and their changed states. The formula is used to calculate its prices following the formula m^2a (annual appropriation of a unit area) considering the average time of use and time needed to re-cultivate a particular category to another. For an example- if a building is built on the third category of above list of land it can be turned into the fourth category of land and its price will more (bigger) than the third but to build a budding infrastructure on it, a particular time duration and for sure some amount of money is needed. ETH assured that 5 years of time is needed for land category three to turn into category four, 50 years of time is needed for land category two to turn into category three and 100 years of time is needed for the land category one to turn into the category two. Land price varies a lot based on the categories mentioned here (above four type). ETH claims on their UCPTE studies that the type-1 land on UCPTE regions has hardly any environmental effect cost due to the development of Hydropower plants as its usually situated on the remote area of forestland or barren and highly un-useful and they are situated on the valleys of the fallow mountainous or hilly areas but this value changes a lot when it turns into other form of categories like category 2, 3 & 4 (ETH-study of UCPTE land valuation).

Let's see the shifts of average land use by a table based on UCPTE regions:-

Table 3: Use of land, its unit based on their type of use; Source: IEA 2002; here the expression $m^2a.kWh^{-1}$ is the annual appropriation of per kilowatt of electricity production.

Land use type	Unit	Area
River-bed area: type 2-3	$m^2a.kWh^{-1}$	1.99×10^{-5}
River-bed area: type 2-4	$m^2a.kWh^{-1}$	2.05×10^{-6}
River-bed area: type 3-4	$m^2a.kWh^{-1}$	0.00
Land area: type 2-3	$m^2a.kWh^{-1}$	4.68×10^{-3}
Land area: type 2-4	$m^2a.kWh^{-1}$	9.79×10^{-5}
Land area: type 3-4	$m^2a.kWh^{-1}$	1.50×10^{-5}
Land area: type 4-4	$m^2a.kWh^{-1}$	1.12×10^{-7}
Average land acquisition	$m^2a.kWh^{-1}$	**4.82×10^{-3}**

According to the ETH study, most of the land use changes brought by hydropower development from type 2 to 3 due to the building of water dam and filling the water reservoir. The UCPTE average land use/acquisition they found is 4.82×10^{-3} of annual appropriation of per kilowatt of electricity production ($m^2a.kWh^{-1}$), which is more or less same for all countries in the UCPTE regions. They also found the maximum and the minimum values here-

- Minimum is on Germany: 4.75×10^{-3} $m^2a\times kWh^{-1}$ and for the
- Maximum is on Italy which is: 4.86×10^{-3} $m2a.kWh^{-1}$

Which two are very close and the difference are not too much significant.

(The effects on water lives and its cost is highly contradictory topic in this purpose and the determination of its cost is not yet completely studied and calculated, a huge research study is still required to get the actual LCA of water lives from hydropower generation; therefore some calculation and discussion has been done at the later part of this section)

5.2.2) Global Environmental Impacts (Greenhouse Effect):

Greenhouse gas emissions or specifically the carbon emissions from power plants (both from renewable and non-renewable sources) are widely debated topic of current world. Though CO_2 is attributable in the case of hydropower plants but some gases of CO_2 emissions from it is unavoidable. The emission of CO_2 gas is very low from the run-of-river hydro-plants but in the case of reservoir different studies claims that on an average range 4g to 410g of CO_2 gas emits per kilo watt hour of electricity production (Gagnon & van De Vate, 1997). Emissions are also very low from the manufacturing and construction phases, gases are mainly emit during the manufacturing of constructions as well as the transportation of the building materials, for these reason, countries like Norway, Sweden emit lower amount of CO_2 during the construction phases as most of the lands are made of rocks and hard ground soils. In addition the run-of river has also lower carbon emissions as it requires a lower amount of construction work (Brannstrom-Nordberg et al. 1995).

Let's have a look a couple of tables here of three Swedish hydropower plants and a Japanese power plants and their carbon emission amounts:

A Swedish case:

Table 4: Three Swedish hydro-power plants and their associated estimated emission of carbon dioxide to the air; Source: Brannstrom-Nordberg et al. 1995.

Name of the plant	Emitting Substances	Units	Manufacturing & Construction	Operational works & maintenance	Total amounts
Seitevare	CO_2 (carbon-dioxide) emission	$g.kWh^{-1}$	4.47×10^{-1}	1.02×10^{-1}	5.76×10^{-1}
Harspræget	CO_2 (carbon-dioxide) emission	$g.kWh^{-1}$	6.89×10^{-1}	0.56×10^{-1}	7.45×10^{-1}
Boden	CO_2 (carbon-dioxide) emission	$g.kWh^{-1}$	7.24×10^{-1}	0.63×10^{-1}	$\mathbf{7.87 \times 10^{-1}}$

A Japanese case:

Table 5: Japanese hydro-power plants and their associated estimated emission of carbon dioxide to the air; Source: Uchiyama, 1995.

Substances	Units	Manufacturing & Construction	Operational works & maintenance	Total amounts
CO_2 carbon-di-oxide	$g.kWh^{-1}$	17.0	0.26	17.26
CH_4 methane gas	$g.kWh^{-1}$	0.40	0	0.40
Total	$g.kWh^{-1}$	17.4	0.26	**17.66**

But the emission amount is very low, found on the other study made for Norwegian case and the rate of emission is 0.2 $g.kWh^{-1}$ in the case of manufacturing and constructions and 1.25 $g.kWh^{-1}$ in the case of operation and maintenance (Sandgren & Sorteberg, 1994).

Some recent studies found that lake water usually acts as the sources of carbon dioxide emitted to the atmosphere (Cole et al. 1994). Cole, in his study described the process as- when anaerobic conditions arise, by the decomposition of organic matter in the situation of stratified and eutrophic lakes and reservoirs forms the methane gas which Greenhouse gas potentials of 25 times than of CO_2 gas. This calculation and practical studies proves that hydropower sometimes causes an atmospheric load on greenhouse gases which is even stronger than the CO_2 effects from fossil-fueled power plants (Rosenberg et al, 2000 & Galy-Lacaux et al, 1999) but another study claims that no actual account is correct so far in the case of measuring lake water methane formation and its effects on greenhouse gas but it has of course some methane formation and effects on greenhouse gas (Gagnon & Chamberland, 1993).

IEA-2002 (Main source: Frischknecht & Muller-Lemans-1996) calculated the actual emission of greenhouse gases in the UCPTE regions from lake water reservoir which are follows:-

Table 6: Lake-water hydropower plants in UCPTE region and their associated estimated emission of greenhouse gases; Source: IEA, 2002. (CF_4 = Tetrafluoromethane and N_2O = Nitrous Oxide.

Substances	Units	Emissions	GWh 100 years of CO_2-equivalents/g	CO_2 Equivalents
CF_4p	$g.kWh^{-1}$	8.82×10^{-7}	6500	5.72×10^{-3}
CH_4 methane p	$g.kWh^{-1}$	8.53×10^{-3}	21	1.79×10^{-1}
CH_4 methane s	$g.kWh^{-1}$	1.44×10^{-2}	21	3.02×10^{-1}
CO_2 carbon monoxide p	$g.kWh^{-1}$	8.28×10^{-3}	3	2.48×10^{-2}
CO_2 carbon monoxide s	$g.kWh^{-1}$	1.23×10^{-2}	3	3.71×10^{-2}
CO_2 carbon dioxide m	$g.kWh^{-1}$	1.07×10^{-1}	1	1.07×10^{-2}
CO_2 carbon dioxide p	$g.kWh^{-1}$	1.26	1	1.26
CO_2 carbon dioxide s	$g.kWh^{-1}$	2.39	1	2.39
N_2O p	$g.kWh^{-1}$	2.79×10^{-5}	310	8.64×10^{-3}
N_2O s	$g.kWh^{-1}$	2.13×10^{-5}	310	6.62×10^{-3}
Total	$g.kWh^{-1}$			$\mathbf{4.03\times10^{-3}}$

In this table, m indicates the emissions from transport; p indicates the process specific emissions, such as- diffuse, leakage, evaporation etc. and s indicates the stationary emissions, such as- combustion, flue gases etc.

From this table, comparatively low amounts of organic matter are available for decomposition following the reservoir flooding as well as the low temperature in UCPTE regions are also causes to increase the dissolved oxygen and reduce the low amount of methane gas which has comparatively weaker effect on GHG increase. The total amount of emitted carbons during a 100 years of range is only $3.71 g.kWh^{-1}$ in the UCPTE regions (average) which can be varied in the other regions of world, like- India, due to high temperature the methane emission is higher than cool areas like Norway (Varun, Prakash & Bhatt, 2010). But still in comparison with other sources of electricity production, this amount is still very low.

The range of CO_2-equivalent emission from the UCPTE countries are, the minimum is in Switzerland which is $3.96 g.kWh^{-1}$ and the maximum is in the Italy which is $4.43 g.kWh^{-1}$

[this statistics has been done for the UCPTE regions where the 52.1% hydroelectricity is produced from run-of-river and 47.9% of them is produced from reservoir sources as well as most of the reservoir is situated on the high altitudes where the temperature is normally very low]. On other hand, in the case of tropical reservoir and run-of-river hydropower plants, a huge amounts of biomass can be flooded which can cause to increase the greater amount of methane as well as the GHG but it is still will never reach the level of the amount of GHG emissions from fossil fuel electricity plants (McCully, 1996).

5.2.3) Ozone Layer Depletion:

Now, let's have a look on the ozone Layer depletion potentials (ODP) scenario due to the hydroelectricity production. As we have already seen from our previous section that the water reservoir increase the greenhouse gas through the methane gas creation which has some obvious effects on the ozone layer. Let's have a look on another table here about the Ozone layer Depletion Potentials shortly ODP from water reservoir due to the hydropower generation.

The table has only the effects of substances, which has at least 0.1% of effects on it.

Table 7: Emission of ozone layer depletion from UCPTE countries; source: Source: IEA, 2002. FCKW = Fluorchlorkohlenwasserstoffe; in English: fluorochlorohydrocarbon.

Substances	Unit	Emissions	Best Estimate ODP factor(g CFC-11 equivalent/g)	CFC-11 equivalent
H 1301 halon	$g.kWh^{-1}$	1.04×10^{-7}	16	1.67×10^{-6}
R11 FCKW	$g.kWh^{-1}$	5.11×10^{-9}	1	5.11×10^{-9}
R114 FCKW	$g.kWh^{-1}$	1.35×10^{-7}	0.8	1.08×10^{-7}
Tetrachlormethane	$g.kWh^{-1}$	4.93×10^{-9}	1.08	5.33×10^{-9}
Total	$g.kWh^{-1}$			**1.79×10^{-6}**

So, the total ODP contribution of CFC gas to the ozone layer from Hydropower water reservoir in the UCPTE region is 1.79×10^{-6} $g.kWh^{-1}$ (unit) where the contribution of Halon is not too much. And the maximum contribution in UCPTE region is found so far is 1.85×10^{-6} $g.kWh^{-1}$ unit in Switzerland and the minimum is found in Germany which is 1.65×10^{-6} $g.kWh^{-1}$ unit.

5.2.4) Local & Regional Environmental Impact:

Acidification:

Now let's have a look on some other chemical compounds which generates by the effects on building hydropower and water reservoir which has some diverse effects on human and environment surrounded by the hydropower plants on the UCPTE regions. Effects of substances which has less than 0.1% are omitted from this calculations. Let's have a look here one more table about the acidification effects by hydropower plants:

Table 8: Emissions of acidifying substances from hydropower in UCPTE regions; here m indicates the emission from transport; p indicates the process specific emissions, like diffuse, leakage, evaporation etc.; s indicates the stationary emissions from combustion, flue gases etc. and the f indicates the fresh water; Source: IEA, 2002.

Substances	Units	Emissions	Max. factor (g SO_2-equivaletns/g)	Max. AP (SO_2-equivalents)
HCI	$g.kWh^{-1}$	2.46×10^{-5}	0.88	2.16×10^{-5}
HCI_s	$g.kWh^{-1}$	1.56×10^{-4}	0.88	1.38×10^{-4}
NH_3p	$g.kWh^{-1}$	1.88×10^{-5}	1.88	3.53×10^{-5}
NO_xasNO_2m	$g.kWh^{-1}$	1.36×10^{-3}	0.7	9.54×10^{-4}
NO_xasNO_2p	$g.kWh^{-1}$	3.85×10^{-4}	0.7	2.70×10^{-4}
NO_xasNO_2s	$g.kWh^{-1}$	9.76×10^{-3}	0.7	6.84×10^{-3}
SO_xasSO_2m	$g.kWh^{-1}$	1.22×10^{-3}	1	1.22×10^{-3}
SO_xasSO_2p	$g.kWh^{-1}$	3.48×10^{-3}	1	3.48×10^{-3}
SO_xasSO_2s	$g.kWh^{-1}$	5.62×10^{-3}	1	5.62×10^{-3}
Ammonium as NF	$g.kWh^{-1}$	3.38×10^{-5}	1.88	6.37×10^{-5}
Total	$g.kWh^{-1}$			**1.86×10^{-2}**

Here we can see the total Life-Cycle acidification potential (AP) of hydropower is recorded as 1.86×10^{-2} $g.kWh^{-1}$ units where the maximum emission of AP is coming from two main sources SO_x and NO_x which are stemming from the construction and material production works. Meaning that, once the hydropower plant is built the AP emission reduces a significant level and AP emission from all other sources is not significantly high. The maximum AP has been recorded in UCPTE region as 1.90×10^{-2} $g.kWh^{-1}$ for Italy and the minimum is recorded as 1.59×10^{-2} $g.kWh^{-1}$ for Switzerland.

Let's have a look one more table for AP from Norway (Sandgren & Sorteberg; 1994):

Table 9: Acidification potentials of Norwegian Hydropower plants; Source: Sandgren & Sorteberg; 1994; the total AP of Norway is bit higher than the UCPTE region.

Substances	Units	Emission from Building	Emission from Operational works	Total Emission	Total (SO_2-Equivalents)
NO_x	$g.kWh^{-1}$	2×10^{-3}	1×10^{-5}	2×10^{-3}	1.4×10^{-3}
SO_x	$g.kWh^{-1}$	2.5×10^{-3}	2×10^{-6}	2.5×10^{-3}	2.5×10^{-3}
Total	$g.kWh^{-1}$				**3.9×10^{-3}**

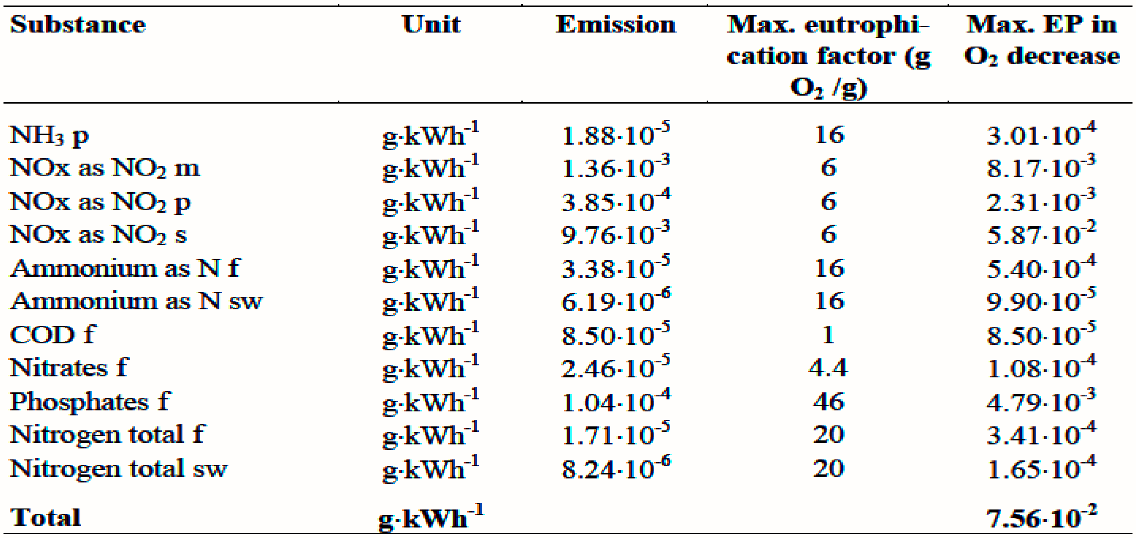
Eutrophication Potential (EP):

One more substance emits from hydropower plants is Eutrophication, which has been calculated in *IEA 2002* research paper. The results they found:-

They found the maximum EP decrease for the UCPTE region for a hydropower plat life cycle is 7.56×10^{-2} g.kWh^{-1} unit of producing per Kilo Watt Hour of electricity. Where the maximum is recorded as 7.81×10^{-2} g.kWh^{-1} for Germany and for the minimum EP has recorded as the 7.06×10^{-2} g.kWh^{-1} for Switzerland.

*[**Eutrophication** or more pricisely hypertrophication is the nutrients of water body which helps the plants and algae due to the bimass growth. Reducing eutrophication may cause the reduction of plants and algae growth]*

Table 10: Eutrophication potentials (EP) emission calculation results of UCPTE region. Source: IEA, 2002.



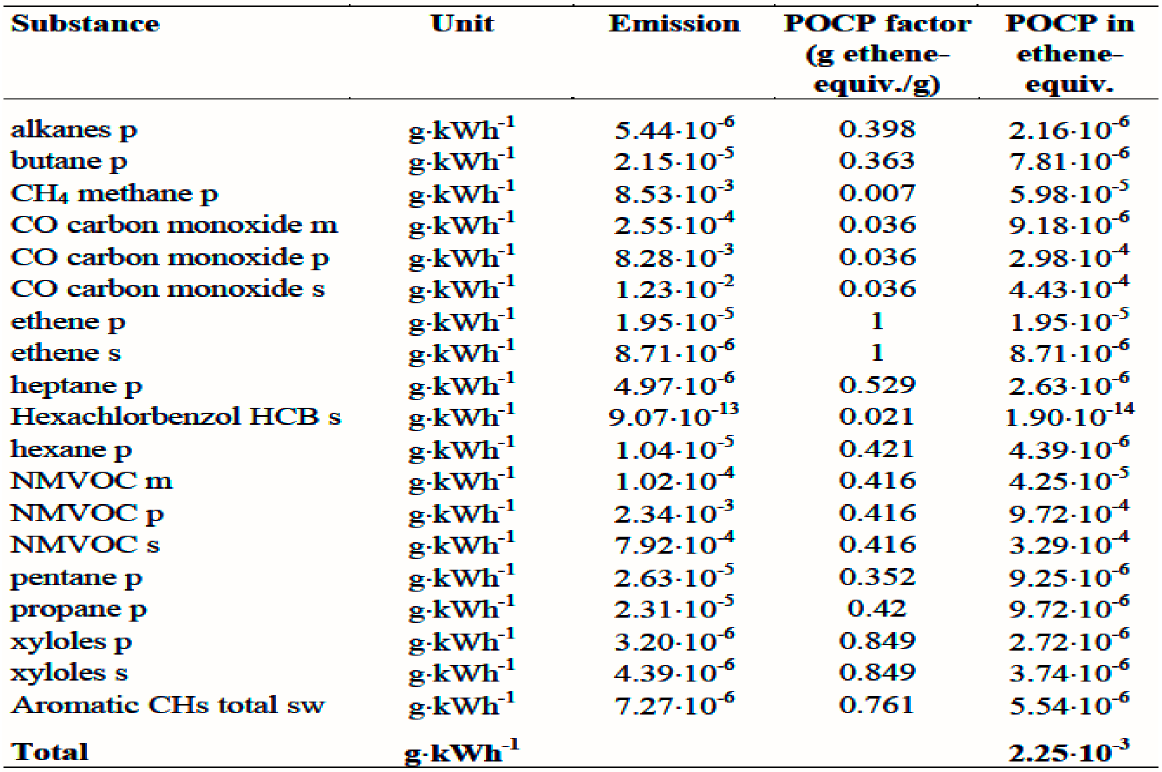
Substance	**Unit**	**Emission**	**Max. eutrophi-cation factor (g O_2 /g)**	**Max. EP in O_2 decrease**
NH_3 p	g·kWh^{-1}	$1.88\cdot10^{-5}$	16	$3.01\cdot10^{-4}$
NOx as NO_2 m	g·kWh^{-1}	$1.36\cdot10^{-3}$	6	$8.17\cdot10^{-3}$
NOx as NO_2 p	g·kWh^{-1}	$3.85\cdot10^{-4}$	6	$2.31\cdot10^{-3}$
NOx as NO_2 s	g·kWh^{-1}	$9.76\cdot10^{-3}$	6	$5.87\cdot10^{-2}$
Ammonium as N f	g·kWh^{-1}	$3.38\cdot10^{-5}$	16	$5.40\cdot10^{-4}$
Ammonium as N sw	g·kWh^{-1}	$6.19\cdot10^{-6}$	16	$9.90\cdot10^{-5}$
COD f	g·kWh^{-1}	$8.50\cdot10^{-5}$	1	$8.50\cdot10^{-5}$
Nitrates f	g·kWh^{-1}	$2.46\cdot10^{-5}$	4.4	$1.08\cdot10^{-4}$
Phosphates f	g·kWh^{-1}	$1.04\cdot10^{-4}$	46	$4.79\cdot10^{-3}$
Nitrogen total f	g·kWh^{-1}	$1.71\cdot10^{-5}$	20	$3.41\cdot10^{-4}$
Nitrogen total sw	g·kWh^{-1}	$8.24\cdot10^{-6}$	20	$1.65\cdot10^{-4}$
Total	**g·kWh^{-1}**			**$7.56\cdot10^{-2}$**

Photochemical Oxidant Formation:

Photochemical ozone creation potentials or POCP also need to calculate for a life cycle time duration for a hydropower plant. IEA, 2002 calculated the followings:-

For UCPTE region LCA average total they have got which is 2.25×10^{-3} g.kWh^{-1} unit of ethane equivalent for per Kilowatt Hour of Hydroelectricity production where the most contributors are the non-methane volatile organic compounds as well as the carbon monoxide emissions. The maximum was in Germany and the minimum was in Switzerland. Let's see here one more table-

Table 11: Photochemical ozone creation potentials or POCP in the UCPTE region; Source: IEA, 2002



Substance	Unit	Emission	POCP factor (g ethene-equiv./g)	POCP in ethene-equiv.
alkanes p	$g\cdot kWh^{-1}$	$5.44\cdot10^{-6}$	0.398	$2.16\cdot10^{-6}$
butane p	$g\cdot kWh^{-1}$	$2.15\cdot10^{-5}$	0.363	$7.81\cdot10^{-6}$
CH_4 methane p	$g\cdot kWh^{-1}$	$8.53\cdot10^{-3}$	0.007	$5.98\cdot10^{-5}$
CO carbon monoxide m	$g\cdot kWh^{-1}$	$2.55\cdot10^{-4}$	0.036	$9.18\cdot10^{-6}$
CO carbon monoxide p	$g\cdot kWh^{-1}$	$8.28\cdot10^{-3}$	0.036	$2.98\cdot10^{-4}$
CO carbon monoxide s	$g\cdot kWh^{-1}$	$1.23\cdot10^{-2}$	0.036	$4.43\cdot10^{-4}$
ethene p	$g\cdot kWh^{-1}$	$1.95\cdot10^{-5}$	1	$1.95\cdot10^{-5}$
ethene s	$g\cdot kWh^{-1}$	$8.71\cdot10^{-6}$	1	$8.71\cdot10^{-6}$
heptane p	$g\cdot kWh^{-1}$	$4.97\cdot10^{-6}$	0.529	$2.63\cdot10^{-6}$
Hexachlorbenzol HCB s	$g\cdot kWh^{-1}$	$9.07\cdot10^{-13}$	0.021	$1.90\cdot10^{-14}$
hexane p	$g\cdot kWh^{-1}$	$1.04\cdot10^{-5}$	0.421	$4.39\cdot10^{-6}$
NMVOC m	$g\cdot kWh^{-1}$	$1.02\cdot10^{-4}$	0.416	$4.25\cdot10^{-5}$
NMVOC p	$g\cdot kWh^{-1}$	$2.34\cdot10^{-3}$	0.416	$9.72\cdot10^{-4}$
NMVOC s	$g\cdot kWh^{-1}$	$7.92\cdot10^{-4}$	0.416	$3.29\cdot10^{-4}$
pentane p	$g\cdot kWh^{-1}$	$2.63\cdot10^{-5}$	0.352	$9.25\cdot10^{-6}$
propane p	$g\cdot kWh^{-1}$	$2.31\cdot10^{-5}$	0.42	$9.72\cdot10^{-6}$
xyloles p	$g\cdot kWh^{-1}$	$3.20\cdot10^{-6}$	0.849	$2.72\cdot10^{-6}$
xyloles s	$g\cdot kWh^{-1}$	$4.39\cdot10^{-6}$	0.849	$3.74\cdot10^{-6}$
Aromatic CHs total sw	$g\cdot kWh^{-1}$	$7.27\cdot10^{-6}$	0.761	$5.54\cdot10^{-6}$
Total	$g\cdot kWh^{-1}$			$2.25\cdot10^{-3}$

Eco-toxic Impacts (Water & Soil Contamination):

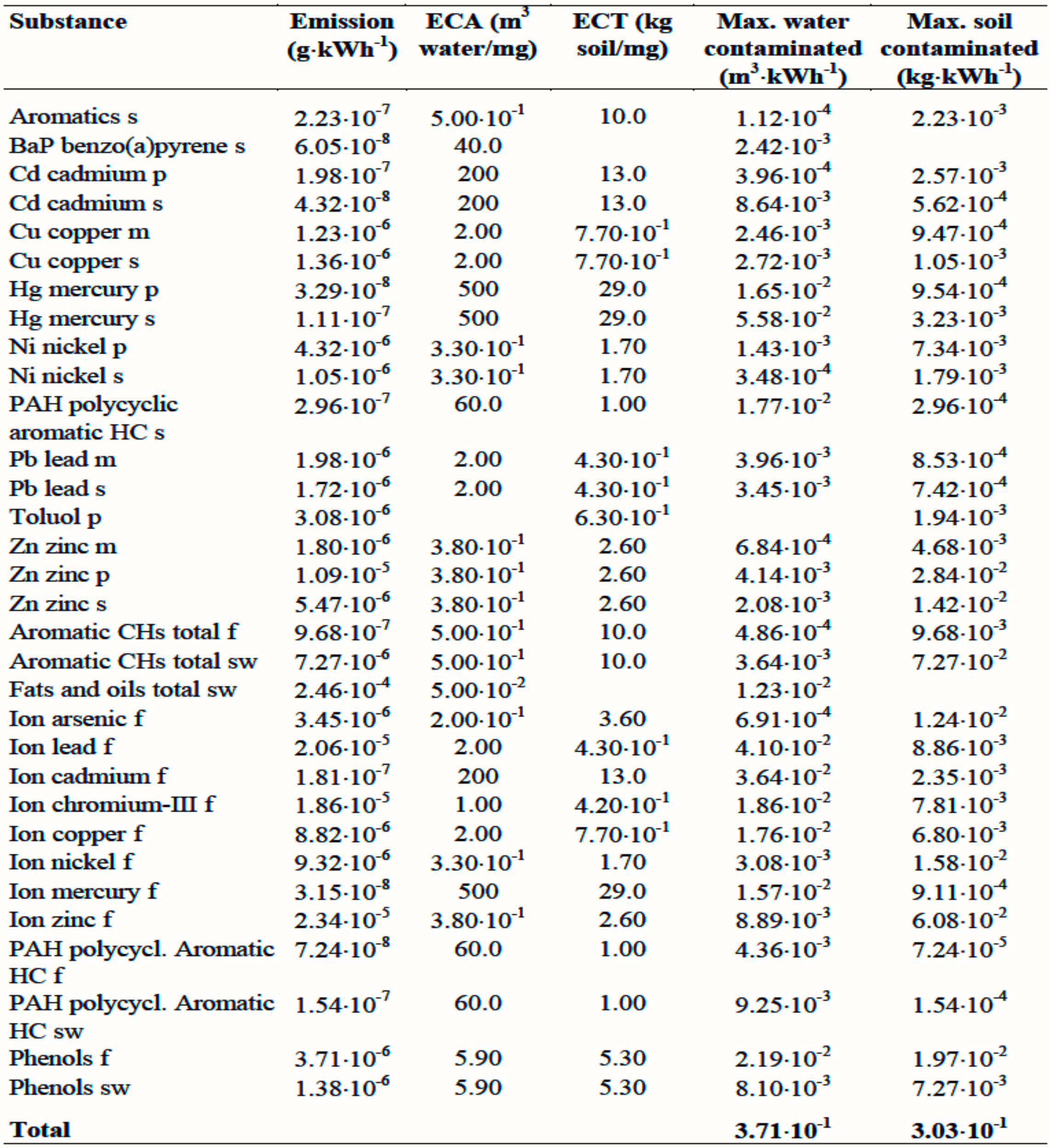
The contamination potentials of soil and water due to the hydropower plant I find in the same paper by IEA (2002), where they have calculated the followings:

The table of next page shows the emissions of Eco-toxic substances from Life-Cycle hydropower plants in UCPTE region (IEA, 2002) where m indicates the emission from transport; p indicates the process specific emissions, like diffuse, leakage, evaporation etc.; s indicates the stationary emissions from combustion, flue gases etc. the f indicates the fresh water and the s indicates the sea.

To produce 1 kilo watt hour of hydroelectricity the Life-cycle contamination of water has recorded as 3.71×10^{-1} qubic meter (m^3) aswq well as for the soil contamination has recorded as 3.03×10^{-1} kilogram of soil. As we can see on this table that diferent types of substances have been calculated differently. The highest amount of ecotoxic substance released by a Life-Cycle hydropower plant are mercury, nickel, cadamin & Ion lead for the water and zinc & aromatic hydrocarbonsfor the soil.

The calculated valuse more or less the same for the investigated countries (UCPTEs) which are recorded as- Minimum for water is 3.43×10^{-1} m^3 for Germany and maximum for water is 3.43×10^{-1} m^3 for Italy. And for the soil, the minimum is recorded as 2.88×10^{-1}kg for Switzerland and for maximum for soil is 3.11×10^{-1}kg for Italy (IEA, 2002).

Table 12: Eco-Toxic (water and soil contamination) impacts of hydropower plant in the UCPTE regions; Sources. IEA, 2002



Substance	Emission ($g\cdot kWh^{-1}$)	ECA (m^3 water/mg)	ECT (kg soil/mg)	Max. water contaminated ($m^3\cdot kWh^{-1}$)	Max. soil contaminated ($kg\cdot kWh^{-1}$)
Aromatics s	$2.23\cdot10^{-7}$	$5.00\cdot10^{-1}$	10.0	$1.12\cdot10^{-4}$	$2.23\cdot10^{-3}$
BaP benzo(a)pyrene s	$6.05\cdot10^{-8}$	40.0		$2.42\cdot10^{-3}$	
Cd cadmium p	$1.98\cdot10^{-7}$	200	13.0	$3.96\cdot10^{-4}$	$2.57\cdot10^{-3}$
Cd cadmium s	$4.32\cdot10^{-8}$	200	13.0	$8.64\cdot10^{-3}$	$5.62\cdot10^{-4}$
Cu copper m	$1.23\cdot10^{-6}$	2.00	$7.70\cdot10^{-1}$	$2.46\cdot10^{-3}$	$9.47\cdot10^{-4}$
Cu copper s	$1.36\cdot10^{-6}$	2.00	$7.70\cdot10^{-1}$	$2.72\cdot10^{-3}$	$1.05\cdot10^{-3}$
Hg mercury p	$3.29\cdot10^{-8}$	500	29.0	$1.65\cdot10^{-2}$	$9.54\cdot10^{-4}$
Hg mercury s	$1.11\cdot10^{-7}$	500	29.0	$5.58\cdot10^{-2}$	$3.23\cdot10^{-3}$
Ni nickel p	$4.32\cdot10^{-6}$	$3.30\cdot10^{-1}$	1.70	$1.43\cdot10^{-3}$	$7.34\cdot10^{-3}$
Ni nickel s	$1.05\cdot10^{-6}$	$3.30\cdot10^{-1}$	1.70	$3.48\cdot10^{-4}$	$1.79\cdot10^{-3}$
PAH polycyclic aromatic HC s	$2.96\cdot10^{-7}$	60.0	1.00	$1.77\cdot10^{-2}$	$2.96\cdot10^{-4}$
Pb lead m	$1.98\cdot10^{-6}$	2.00	$4.30\cdot10^{-1}$	$3.96\cdot10^{-3}$	$8.53\cdot10^{-4}$
Pb lead s	$1.72\cdot10^{-6}$	2.00	$4.30\cdot10^{-1}$	$3.45\cdot10^{-3}$	$7.42\cdot10^{-4}$
Toluol p	$3.08\cdot10^{-6}$		$6.30\cdot10^{-1}$		$1.94\cdot10^{-3}$
Zn zinc m	$1.80\cdot10^{-6}$	$3.80\cdot10^{-1}$	2.60	$6.84\cdot10^{-4}$	$4.68\cdot10^{-3}$
Zn zinc p	$1.09\cdot10^{-5}$	$3.80\cdot10^{-1}$	2.60	$4.14\cdot10^{-3}$	$2.84\cdot10^{-2}$
Zn zinc s	$5.47\cdot10^{-6}$	$3.80\cdot10^{-1}$	2.60	$2.08\cdot10^{-3}$	$1.42\cdot10^{-2}$
Aromatic CHs total f	$9.68\cdot10^{-7}$	$5.00\cdot10^{-1}$	10.0	$4.86\cdot10^{-4}$	$9.68\cdot10^{-3}$
Aromatic CHs total sw	$7.27\cdot10^{-6}$	$5.00\cdot10^{-1}$	10.0	$3.64\cdot10^{-3}$	$7.27\cdot10^{-2}$
Fats and oils total sw	$2.46\cdot10^{-4}$	$5.00\cdot10^{-2}$		$1.23\cdot10^{-2}$	
Ion arsenic f	$3.45\cdot10^{-6}$	$2.00\cdot10^{-1}$	3.60	$6.91\cdot10^{-4}$	$1.24\cdot10^{-2}$
Ion lead f	$2.06\cdot10^{-5}$	2.00	$4.30\cdot10^{-1}$	$4.10\cdot10^{-2}$	$8.86\cdot10^{-3}$
Ion cadmium f	$1.81\cdot10^{-7}$	200	13.0	$3.64\cdot10^{-2}$	$2.35\cdot10^{-3}$
Ion chromium-III f	$1.86\cdot10^{-5}$	1.00	$4.20\cdot10^{-1}$	$1.86\cdot10^{-2}$	$7.81\cdot10^{-3}$
Ion copper f	$8.82\cdot10^{-6}$	2.00	$7.70\cdot10^{-1}$	$1.76\cdot10^{-2}$	$6.80\cdot10^{-3}$
Ion nickel f	$9.32\cdot10^{-6}$	$3.30\cdot10^{-1}$	1.70	$3.08\cdot10^{-3}$	$1.58\cdot10^{-2}$
Ion mercury f	$3.15\cdot10^{-8}$	500	29.0	$1.57\cdot10^{-2}$	$9.11\cdot10^{-4}$
Ion zinc f	$2.34\cdot10^{-5}$	$3.80\cdot10^{-1}$	2.60	$8.89\cdot10^{-3}$	$6.08\cdot10^{-2}$
PAH polycycl. Aromatic HC f	$7.24\cdot10^{-8}$	60.0	1.00	$4.36\cdot10^{-3}$	$7.24\cdot10^{-5}$
PAH polycycl. Aromatic HC sw	$1.54\cdot10^{-7}$	60.0	1.00	$9.25\cdot10^{-3}$	$1.54\cdot10^{-4}$
Phenols f	$3.71\cdot10^{-6}$	5.90	5.30	$2.19\cdot10^{-2}$	$1.97\cdot10^{-2}$
Phenols sw	$1.38\cdot10^{-6}$	5.90	5.30	$8.10\cdot10^{-3}$	$7.27\cdot10^{-3}$
Total				$\mathbf{3.71\cdot10^{-1}}$	$\mathbf{3.03\cdot10^{-1}}$

Habitat Alteration:

Man-made hydropower plant or reservoir has diverse impacts on the local climate change. It increases the humidity as well as the water evaporation in the air around the reservoir areas. In tropical region case, reservoir may decrease the could cover, on the other hand in temperature regions when the temperature decreases near freezing level excessive fog can form over the reservoir water along the shore (Moreira and Poole, 1993).

Geophysical Impacts:

Due to the build of hydropower dam and reservoir on a run-of-river, the rapid water fluctuation increases, which leads to increase the soil erosion to the downstream area as well as the delta formation system affects. In the upstream area the flow of sedimentation of solid substances increase because of the reduced water flow of the river which can cause a reservoir “silt up” in the is absence of adequate mitigation measures.

A large size of dam has adverse influence of seismic activities, which is very difficult to measure and predict (Vladut, 1993), but environmentally friendly as well as careful dam design can reduce some risk of it. In the region of the low rate of tectonic activities this risk is naturally low and can be mastered by using proper design of dams.

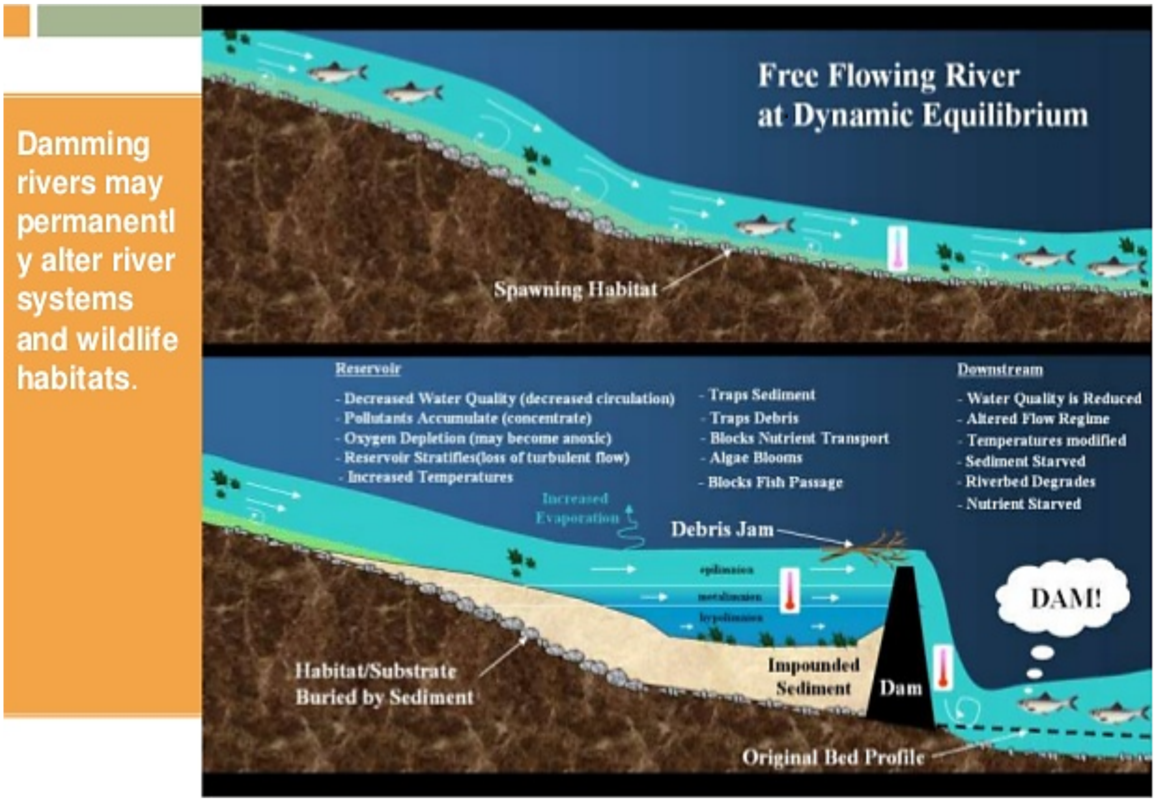
Earthquake may cause near the reservoir & dam areas due to reserve a huge amount of water on it, which is the cause of increased seismic activities because the friction of tectonic plates causes the earthquakes fundamentally as they move against each other. Two earthquakes near water reservoir have been considered as the cause of building hydropower plants are-

a) In the year 1967 an earthquake with 6.3 Richter scale happened on Koyna dam in India where approximately 180 people were killed with a huge household damages.
b) Another earthquake occurred near Vainot water dam in Italy in the year 1962 where 2600 people were killed, a huge number of injured with a destruction of vast amount of other resources.

So, it has been suggested to the dam project planners and designers to have initial trigger on the dam-induced seismic activities and proper geographical risk studies (IEA; 2002; & Annex- 1, 2, 3).

Aquatic Impacts:

The natural flow of a river is changed for building the dam on it for hydroelectricity power production due to the change of normal water flow on it. Both the upstream and downstream life of water species is affected due to this tremendous change of normal water flow as well as the natural flooding of the river is also changed. As a result, the life of thousands of habitats lost their shelters as well as the nutrients of aquatic biota (source of food of those habitats).



[Figure 9: Serious environmental effect on the fish and water lives due to building a river dam on a flowing river current. Free moving scenario before the dam has been built and blocking their moves when the dam is built. All water species get block from moving towards upstream and a huge number of (uncounted species have been killed and lost their lives forever) water habitat buried by sediment from the effect of blocking the water current. This image has been taken from an original research paper of International Energy Agency- IEA; 2002 & Annex-1, 2, 3].

Reduced water flow on the dam building river (down-stream) can cause the damages of urban pollution. Usually highly flowing rivers are used to dump the urban pollution which will also be blocked due to the lack of sufficient water flow but the most likely environmental effect will definitely fore-seen on the water lives and different water habitants which is unavoidable.

Thermal stratification occurs when water flow is regulated. It creates where warm water accumulate on the top of the cold water on the bottom and it’s really a problem in the tropical and sub-tropical regions where small seasonal changes appear in air temperature because it leads sometimes the permanent oxygen deficiency below the level of thermocline.

Usually the water intake to the turbine is located in the bottom part of the dams, so the low content of oxygen can create the unhealthy water condition for the water species even for a long distance. There is one more problem arise in the bottom layer of the dams. From this unhealthy and reducing oxygen condition the available Sulphur compounds will be transformed to the hydrogen sulphide (H_2S), which is also toxic for the living organisms and corrosive to steel.

This decomposition of the substances will deplete the oxygen level even worse in bottom level, which may cause the water species death of thousands in numbers.

Discussion of this part about the environmental and water habitat damage is not sufficient to determine the cost and harmful effect from dam building on a flowing river. The list is even longer and the damage cost is even bigger. It's just a small scenario of complex nature of habitat alteration due to blocking a river current. LCA of this part is not sufficient to illustrate the actual damage of environment and affected species, large amount of research is highly recommended to get the actual figure of affected biodiversity.

Figure 10: It shows the effects of dam building and thousands of fish died lack of oxygen and increase of toxic substances on down-stream area. Source: Water Resources of the United States; USGS.

5.2.5) Accidents and its Environmental Damage Costs:

From the historical background, accident of building and operating the hydropower plants is also considered one of the most treats for the environmental and ecosystem damage. The most severe risk of hydropower plant is the risk of dam failure where 40% of cases is from overtopping and 30% of cases is the foundation collapse causes those accidents (IREA; Volume 1). World-wide, the collapse of dams has caused more immediate environmental and biodiversity causalities than any other means of power generation options (McCully, 1996) and long term socio-economic losses from such disasters can also be severe in this case (Toberts & Ball; 1996). Let's have a look at some of the world-wide scenario of hydropower plants accidents:-

Table 13: Hydropower plants accident history and its fatalities; Source: McCully, 1996; Toberts & Ball; 1996 and Hirschberg & Spiekerman, 1996.

Period of study	Number of Events	Fatalities/Events	Total immediate fatalities	Total late fatalities	Energy Produced per GWa	Fatalities /GWa
1969-1986(A)	8	11-2500	3839		2700	1.41
1969-1992(B)						0.90
1969-1995(C)	19	14-230,000	88,444	145,000	4900	48

The data shows that the most of the accidents happened in fill dams in compared with concrete dams as well as the majority of failure also happened during the first 5 years of dam's buildings (European Commission, 1995).

If we look at the fatalities/GWa ratio the hydropower accidents are bit controversial because most of the hydropower dams are built to control the severe natural flood and make the water supply more frequent based on the use of water for agricultural irrigation as well as the other production purpose on the downstream area. Still some of the historical evidence indicates the serious weaknesses of dam construction and planning. For an example- the Hennan catastrophe in the year 1975 which was kept secret by the Chinese government destroyed some hundreds of thousands people and some villages has been completely destroyed (IEA, 2002; & Annex-1,2,3). Another example of hydropower plant collapse of Banqiao reservoir overtopping made approximately 30 more dams collapse and about 85,000 people were killed immediately and 145,000 more people died due to the flood (Si, 1998).

Another table of severe dam's accidents and its fatalities on human and environments can be shown here; (Jones & Freeman, 2000):

Table 14: Hydropower plants accident history and its fatalities; some particular accidents and their associated fatalities. Source: McCully, 1996; Toberts & Ball; 1996 and Hirschberg & Spiekerman, 1996.

Years	No. of lives lost	Property damage
1911	Hundreds of thousands	Inundated an area which size is equal to New York state. Submerged more than 3 million hectares of farm land and destroyed 108 million of houses.
1931	145,000	
1935	142,000	Inundated 48 million hectares of farm land and affected 18million people. An additional 18.88 million more people suffered from the flood created by it. Operation of Beijing-Guangzou railway was suspended for more than 100 days.
1954	30,000	
1996	No info got here	Affected the lives of 290 million people. 5 million houses destroyed. 21.8 million hectares of farm land submerged. Total economics cost was calculated as 30 million dollars.
1998	3,656	

For the overtopping and dam collapse of Hennan hydroelectricity and flood control dam created some severe flood in the other Chinese river connected with Yellow River. Among them Yangtze was one of them and there were approximately 100,000 people died during the twentieth century. Though the fatality of dam collapse is severe and highly costly for human and environment but it's still far better than the natural and untimely natural flood.

5.2.6) Impacts on Biodiversity:

Impact on biodiversity due to building hydropower plants on run-of-river or from the reservoir has a huge controversial phenomenon. Effects on biodiversity takes place when the man-made changes of natural process get stuck and any alteration set-up is created to their natural movements and growth. Several mechanisms associated with hydropower development projects can be taken into accounts as the reasons of these changes.

"If the energy crop plantations replace, natural ecosystems and the overall impacts will be negative" (Christian et al. 1998), means any alteration of land use which was previously been used as open farmland the biodiversity effects of this alteration is negative. A recent study from North America shows that the birds and other small mammals use the plantations and trees on the riverbanks and seashores and they permanently lost their lives due to the change of these land uses. Hydropower production has strong negative impacts on small animals and birds due to the permanent changes of land on rivers as well as the logging trees. Some species can resettlement on the new structures of changing lands but others dis-appeared forever. "The composition of mammal communities are similar for energy crop plantations and for agricultural land, yet rabbits, hares and tree squirrels make very little use of biofuel plantations in the wintertime (Christian et al., 1998)."

Global Impacts:

The effects of emitting gases like- GHG, CFC, Methane, CO_2, and Carbon Monoxide etc. have equal impact on every countries of the world. One unit extra emission of GHG on the air means one unit addition of carbon on the ozone layer and its impact on global climate change is exactly the same for all countries, even that extra unit of gas emits from Norway or from India its dost not a matter because this effect works on global village (air has no boundary) So, the environmental cost of one unit extra gas emission to the air by any power-unit will be exactly the same for all countries Daniel Weisser (2007).

But as global environmental threats hydropower is near negligible based on its impacts on the global environmental arena. There is some GHG emissions from it but in compare with other means of power generation its comparatively far less and can be negligible. In the case of tropical hydropower projects this effects is also very less than mid regions (IEA, 2002; Annex: 1,2,3).

Local/Regional Impacts:

Hydropower plant has massive local/regional environmental impacts based on the changes of water habitat and alteration effects on its life. There are also some other reasons which makes this effect more severe on it, Flora & Fauna in rivers used for hydropower are affected due to some related factors alteration, such as- extension &

frequency of flooding; drought condition below the diversion points; stresses from the rapid changes in water level; water quality changes; changes in groundwater conditions etc. changes are more visible in this purpose (IEA; 2002, & Annex-1,2,3).

A huge change takes place due to these changes of water level, quality, and blocking as well as some complete alteration of the river. Some species disappeared for ever, some lost their lives forever and some other can be affected by blocking from one area from other, like fishes cannot move from downstream to the upstream because of the dam, bottom layer species like snails, oyster etc. can be covered by the sediment stored on the bottom surface on the upstream of the dam, huge number of fish get hurt, injured and killed by the fans of turbines while they try to move from upstream to the downstream through the penstock whole. Fishing by the mass people can be permanently stopped by the dam building on this river where the villages and visitors used to catch fish for their own means of consumption.

These changes as well as the local effect and their associated environmental cost is not equal for al countries rather it varies a lot from one country to others, based on their sizes inside the same countries, based on their positions etc. For an example the environmental cost of a hydropower plant of South America and Europe (UCPTE countries) are not the same. Similarly the sound of dumping water from the large dam is louder than a small dam. The construction period pollutions are not the same for big and small dam, a big dam construction period is usually longer than a small dam, so the associated local impact costs will be more for a big dam than a small one (A.K. Akella, R.P. Saini, M.P. Sharma; 2009).

5.2.7) Impacts on Human Life and Health:

Excluding the major accidents of the hydropower dams collapse each stage of Life Cycle process of a dam has human health risk. Let's have a look on most of them-

Table 15: Human health risk associated every single stages of the hydropower plant (general case study) construction excluding major accidents. Source: Thohne & Kallenbach, 1988.

Materials Provision	Acute occupational, occupational disease, transport related risk, public disease from pollution.
Plant Construction	Acute occupational
Plant operation	Occupational risk, public risks from change in water quality, increased pollution & increase of water borne diseases.
Waste Disposal	Acute occupational
Dismantling	Acute occupational

Two German studies have found so far where the writer calculated the human health risk from both of the run-of-river water dam as well as the reservoirs. Let's have a look at them first:-

Table 16: Human heralth risk associated every single stages of the hydropower plant (water reservoir) construction excluding major accidents. Source: Thohne & Kallenbach, 1988.

Acute occupational fatalities per GWa	0.15-0.26
Occupational diseases and injuries in missed days of work per GWa	630-1110
Public fatalities per GWa	0.01
Public diseases and injuries in cases per GWa	0.61

Table 17: Human heralth risk associated every single stages of the hydropower plant (run-of-river) construction excluding major accidents. Source: Thohne & Kallenbach, 1988.

Acute occupational risk per GWa	0.2-2.7
Late occupational risk per GWa	n.a
Acute public risk per GWa	n.a
Late public risk per GWa	n.a

Roberts & Ball (1996) calculated the health risks from tidal hydropower plants which they suggest to compare with other hydropower plants as they have the same characteristics because both are renewable sources, leaking emissions from operations, main risks are prevailed under construction works as well as the similar kind of construction they require. Their study suggest based on their estimation that the acute occupational risks at 0.1-0.2 fatalities per GWa due to plant construction where all other risks are below 0.1 fatalities. There is also some other health risks and their corresponding data are not available which can be observed on the following ways-

*The reduced water flow on the downstream area can boost up the mosquito production on the stagnated river and can spread out diseases like malaria etc.
*Ground water flow will definitely affected by the hydropower plant which will affect the water quality of well water.
*Reduced water flow of downstream area will definitely create scarcity of water for other species of downstream regions.

5.2.8) Socio-Economic Impacts:

From a survey by World Commission in the year 2000, some updated information they mentioned about socio-economics impacts of hydropower plants where some important elements of socio-economic impacts have come into account for the LCA of a hydropower plant. A multi-purpose hydropower project has immediate positive impacts on the local socio-economic life and a hydropower plant is more profitable for both the social & environmental economic life by means of electricity production than any other sources. Let's have a look on some socio-economic impact factors mentioned by the World Commission by their research paper (2000):

Inundated Land:

Building a dam or reservoir on water (land) creates some higher level of water reservation that can flooded some more agricultural, forest or recreational land which further creates the losses of agricultural production, forest losses, loss of pastures and inundation effect of cultural heritages. Goodland made a survey of 180 projects based on World Bank database reveals that there is no significant relationship between the sizes of the projects in associated with the size of inundated land but some land definitely affected or inundated by altering the rivers flow.

Figure 11: Inundated land effect of building a dam non flowing river current; Shasta Dam; Northern California; Source: California Department of Water; USA. .

Let's see here one more figure of the inundated land effect due to building a hydroelectricity dam by India and its effect on the upstream river areas:

It's clearly visible here the difference between two years 1987 (when there was no dams on the river) and 2006 (when there is dam on it). The and on the upstream area flooded a huge area of land as well as the forest areas. At the same time lack of proper and sufficient water flow the downstream area have been dried and become barren land. It has huge effects on the upstream and downstream species, wild lives as well as the forestlands.

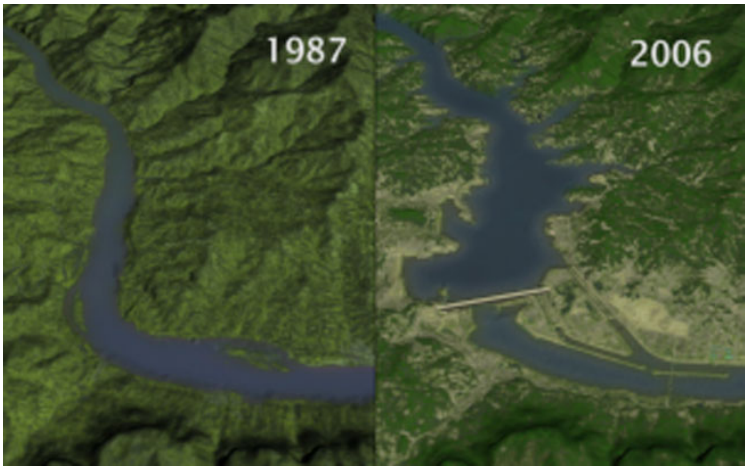


Figure 12: Inundated land effect of building a dam non flowing river current; Indian academy of Environment and Research.

Fishing Restrictions:

Any alteration of river flow creates some restriction of fish life, practicing fisheries, catching fishes etc. Some people can lose their earnings because this restrictions those who used to cultivate fishes, catching and selling them to the market. But on the other hand, a permanent water reservoir can create better chances to the fishing communities than it was before (Costa-Pierce; 1997).

Cultural Changes:

Hydropower projects bring some obvious economic and cultural changes on the local communities. The roads, highways, new buildings, schools, colleges etc. are built up on the project area but it has some negative impacts on some groups of local people. If the local people are indigenous, it is required to manage the project with some particular sensitivity in order to avoid those negative effects on them.

One more thing, if the project is on the archeological area it can inundate the archeological interest. The project implementation body needs to be careful about the archeological interest and need to be waiting until it is done or the project can be stopped forever to preserve important historical buildings or areas.

Aesthetic Impacts (Visual):

It is very important to preserve the wonderful visual natural sceneries like high waterfall as well as long and beautiful natural views. The projects implementation body need to be very careful to tale care it. One example can be here the Onterio (USA) Hydropower plant where the overall natural scenario becomes more attractive and natural heritage after building the water dam on it. Building too much construction works on the natural lakes can destroy the natural looks/views of it, this thing need to carefully handle and preserve.

Figure 13: Change of natural views due to the hydroelectricity project on a beautiful river view, Onterio Power-plant, Source: Water Resources of the United States; USGS.

Acoustic Impacts (Noise Creation):

Usually hydropower plant has some noise of releasing water through the electric turbine but not too much area affects by this sound but during the construction work a huge noise can disturb a lot for the local inhabitants. Still there is some debate that silent rivers can become too much noisy due to building the water dam on it.

6. Discussion of Findings:

I want to start by a summary table based on different types of environmental impact associated costs and biodiversity effects due to build hydroelectricity dam and reservoir on lakes or run-of-rivers from the section 5.

Land:

Based on the data from section 5 and its estimated emission amount I've prepared two summary table here (17 &18), I've calculated the life cycle cost of land use (in hectare) for per Giga watt-hour of electricity production (based on the suggested land tax per hectare by IEA (2002) for UCPTE region; on section 5.2.1), which is a range of **$2559.75 to $7744.75 per hectare land use.** This amount is calculated on the base price of 2000 as well as discounted from the standard suggested price for land use set by Environmental Agency, UK-2015. (Land unit square meter has been converted into hectare and electricity unit kilowatt-hours have been converted into Giga watt-hour to get some bigger amount of cost because the cost amount for kilowatt-hour is too small). Cost figures are on table no. 18. For hydroelectricity generation plant only the land category 1 and 2 are widely used (land classification by IEA (2010) is on the section 5.1. which has comparatively less land use cost than other two (category 3 & 4) categories.

Green House Effect:

One unit extra emission of Green House Gas (GHG) has exactly the same effect to every corner of the world, so the cost of emitting one extra unit of GHG can be equal for everybody. Here I took a standard price set by Intergovernmental Panel on Climate Change (IPCC) study group-3 suggested price for emission cost of per metric ton of GHG (IEA; 2002 suggested price/tax; section 5.2.2). The data has been transformed into metric tons from per Giga Watt-hour to get the bigger mathematical figure for better discussion. Here I get a range of **\$0.036- \$0.789/GWh**$^{-1}$ per metric ton of emitting GHG for the hydroelectricity production.

Ozone Layer Depletion:

For some particular substance emissions from hydropower plant, I took the tax price set by US Environment Protection Agency (US EPA) for south California air pollution taxation where they imposed some taxes for the air pollution production firms, which have further effect on GHG increase as well as ozone layer depletion. From one Giga Watt-hour production of hydroelectricity there is effect of amount 0.00000179 metric ton on ozone layer depletion (IEA; 2002 calculated amount on section 5.2.3), and the associated cost can be equal to **\$0.00079/GWh**$^{-1}$ (US EPA standard tax price for 99/00 financial year). This price is suggested and set for all other gasses, which have further effect on ozone layer depletion (US EPA).

Table 17: Life Cycle environmental impacts and their associated costs from hydroelectricity based on the section 9 of this paper. Substances, its units, estimated amount as well as their calculation methodology have been prepared following IEA (2002), (2010) & IRENA (2012) research paper and their associated cost have calculated based on IPCC, EA and EPA emission taxes and suggested prices for emissions. (Next page).

Impact Factors			Measurement Unit	LCA Hydro-energy Unit	Total Average LCA Damage	Methods of Calculation/ Study	Standard and suggested cost range
Land			$m^2a.kWh^{-1}$	1 kWh	4.82×10^{-3} (area)	LCIA	£2000-£6000/hectare,(Environment Agency, 2015)
Global Environmental Impacts	Greenhouse effects		$g.kWh^{-1}$	1 kWh	4.03×10^{-3} (grams, CO_2 equivalents)	LCIA	\$9 to \$197/t CO_2 at 2000 prices (IPCC scale).
	Ozone Layer Depletion		$g.kWh^{-1}$	1 kWh	1.79×10^{-6} (CFC-11 Equivalents)	LCIA	\$441/t of CFC-11 equivalents (EPA tax price for 99/00).
Local & Regional Environmental Impacts	Acidification		$g.kWh^{-1}$	1 kWh	1.86×10^{-2} (SO_2-Sulpher-dioxide Equivalents)	LCIA	\$0.92/t of SO_2 equivalent gas. (EPA tax price for 99/00)
	Eutrophication		$g.kWh^{-1}$	1 kWh	7.56×10^{-2} (O_2 Equivalent)	LCIA	NA; reduction of oxygen has not found.
	Photochemical oxidant formation		$g.kWh^{-1}$	1 kWh	2.25×10^{-3} POCP equivalent	LCIA	\$5.28/t in Maine for POCP equivalents (EPA for 99/00)
	Eco-toxic impacts	Water	m^3kWh^{-1}	1 kWh	3.71×10^{-1} ECA(m^3 water/mg)	LCIA	Data for water & soil contamination is not available.
		Soil	$Kg.kWh^{-1}$	1 kWh	3.03×10^{-1} ECT(kg soil/mg)	LCIA	
	Habitat Alteration		Not Available	1 kWh	n.a	Qualitative/ CV	Most of the local effects and their associated costs are different from one place to other, it also varies for different sizes.
	Impacts on Biodiversity		Not Available	1 kWh	n.a	Qualitative/ CV	
	Costs of Accidents		Fatalities/GWa	1 kWh	48 (1969-1995)	Quantitative Risk Assessment (QRA)	Cost of accidents from hydropower plants are highly and their real cost is nearly impossible to calculate (its long run effect is vast & fatal)
Impacts on Human & Wild lives	Health Risk		Some Results which have found so far is on section 5.2.7	1 kWh	Not Available (Contingent valuation approach can be applied)	Qualitative/ CV	Not Available (Contingent valuation approach can be applied).
	Socio-economic impacts			1 kWh		Qualitative/ CV	
	Risk Perception			1 kWh		Qualitative/ Risk Perception Studies (RPS)	
	Aesthetic Impacts			1 kWh		Qualitative/ CV	

Table 18: Name of Emissions, LCA amount of emission per Kilo watt hours as well as Giga Watt hours, their suggested cost and Life Cycle Cost of them. Costs, emission taxes have calculated based on the prices suggested by IPCC, EA and EPA for those particular emissions. Costs of emissions based on the availability of data have been included here. CV/Qualitative analysis methods for local impacts are not included.

Name of emission	Emission/kWh^{-1} of power production (UCPTE region)	Emission per GWh^{-1} (to get some big amount)	Average total LCA/GWh^{-1} emission per Unit.	Price range of Emission per Unit.	Life Cycle Cost (\$) per GWh^{-1} (converted & discounted)
Land	4.82×10^{-3} m^{2}.a	4820 m^{2}a/GWh^{-1} (1GWh=10,00000kWh)	0.482 hectares (1 hectare= 10,000 m^{2}a)	£2000-£6000/h (EA-2015 price)	**\$2559.75-\$7744.75/hectare** (converted & discounted at 2000 prices; EA-2015)
Green House Effect	4.03×10^{-3} g/kWh^{-1}	4030 g/ GWh^{-1}(1GWh=10,00000kWh)	0.004003 metric ton (1mt=1000000 grams)	\$9/t- \$197/t CO$_2$ (IPCC prices scale)	**\$0.036-\$0.789/GWh^{-1}** (IPCC price scale for 2000-2020)
Ozone layer Depletion	1.79×10^{-6} (CFC-11 Equivalents); g/kWh^{-1}	1.79 g/GWh^{-1} (1mt=1000000 grams)	0.00000179 metric ton/GWh (1 ton= 1000000 grams)	\$441/t of CFC-11 equivalents	**\$0.00079/GWh^{-1}** (EPA tax price for 99/00 financial year)
Acidification	1.86×10^{-2} SO$_2$ g/kWh^{-1}	18600g/GWh^{-1} (1mt=1000000 grams)	0.186 metric m.t/GWh^{-1} (1 mt=1000000 grams)	\$0.92/t of SO$_2$ equivalent gas.	**\$0.0171/GWh^{-1}** production (EPA tax price for 99/00 FY.
Eutrophication	7.56×10^{-2} (O$_2$ Equivalent) g/kWh^{-1}	75600 g/GWh^{-1} (1mt=1000000 grams)	0.0756 metric ton/GWh^{-1}(1 mt=1000000 grams)	Cost of Reduction of Oxygen in air is not available	Cost of Reduction of Oxygen in air is not available
Photochemical oxidant formation effect	2.25×10^{-3} POCP equivalent	2250g/GWh^{-1} (1mt=1000000 grams)	0.00225 m. ton/GWh^{-1} (1mt=1000000 grams)	\$5.28/t in Maine for POCP equivalents (EPA for 99/00)	**\$0.01188/GWh^{-1}** (EPA; in Maine for POCP equivalent emission tax for 99/00)
Water Contamination	3.71×10^{-1} ECA(m^{3} water/kWh^{-1})	N/A	N/A	N/A	Data for water & soil contamination was not available.
Soil Contamination	3.03×10^{-1} ECT(kg soil/kWh^{-1})	N/A	N/A	N/A	

Acidification:

From US EPA I got the suggested tax price set by US EPA for acidification on section 5.2.4, which is equivalent to the Sulfur Dioxide (SO_2) from all types of production units that emit SO_2 equivalent gasses to the air. US EPA suggested \$0.92 (current price of year 1999/2000) per ton of all gasses equivalent SO_2. In my cases I calculated based on the data from section 5.2.4 and got **\$0.0171 per GWh^{-1}** production of hydroelectricity (EPA tax price for 99/00 Fiscal Year).

Eutrophication:

Another gas emits from the hydropower plant that in a particular process reduces the amount of oxygen in the air and water is Eutrophication. Some amount I got from my calculation from hydropower generation was not possible to figure out its exact cost or tax due to the unavailability of its market price. So, at this case my suggestion to go through CV analysis to get some values of this effect.

Photochemical Oxidant Formation Effect:

Photochemical ozone creation potentials or POCP is formation of gas from hydropower generation, which increases GHG on the ozone layer, is also important to measure the effect and cost of CBA of hydropower projects. From US EPA standard of taxation on this gas emission (based on the section 5.2.4) and effects I got **\$0.01188** (EPA; in Maine for POCP equivalent emission tax for 99/00) for per Giga Watt hour of Electricity production from Hydropower plant.

Data of water and soil contamination as well as the reduction of oxygen in the air due to the hydropower plant was not found. So, their effects on environment and associated costs were not possible to present here.

Some local effects from hydropower generation and its impact on local environment as well as biodiversity were not possible to calculate. Most of the affected elements and their possible way to calculating the cost directed to the qualitative analysis and Contingent valuation. The local impacts on environment and their associated cost from a big project and a small are not the same; it may vary for the same size of projects, which are located, one at the South Pole and another one on the North Pole. It also may vary two different projects on two different countries, which can even vary inside the same country for the same size of power plant. Impact cost of particle emission from a power plant close to Oslo city (for an example) where the place is crowded and a coastal area where there are no habitats, can be completely different. Near Oslo city the impact can be very high but for the coastal area power plant the particle can be unaffected due to the air blow and sufficient amount of trees and plants. So, for a particular hydropower project, a particular or specified CV analysis is highly required to figure out the exact cost of local environmental and ecosystem damage. More clearly for a different hydropower project, different CV analysis is required to find out that particular case.

Due to the lack of sufficient time and other facilities it was not possible for me to collect data for CV analysis to determine all probable external costs for local impacts at this time but a huge amount of study is highly required in this sector to make sure that all probable external costs can be included in the future. A huge amount of research work can give a path to find out the exact amount of all external environmental impacts from hydropower plant and to find out all associated costs from its effect on local environments and habitat alterations, particularly the water and wild species to make sure that all probable and obvious environmental damage costs are well defined and reflected on the main Cost-Benefit Analysis (CBA) of a highly environmentally sensitive projects like hydropower plant.

Table of US EPA suggested price/tax of different gas emissions, which has further effects on Ozone layer through GHG, increase have been attach here for the data evidences of this calculation sector.

Table 19: EPA emission permit frees for emitting gases based on the South Coast Air Quality Management District (SAQMD); Annual emission from 4 tons and above; Southern District of California; USA. Fiscal Year 1999/2000; US Dollars per ton.

Annual Emission	Organic cases	Nitrogen Oxides	Carbon Monoxides	Sulfur Dioxide	Particular Matter
4-25 tons	292.80	171.30		203.10	223.90
25-75 tons	475.40	272.10		320.30	362.80
75-100 tons	711.60	409.60		492.90	543.20
100 or more	n.a	n.a	3.50	n.a	n.a

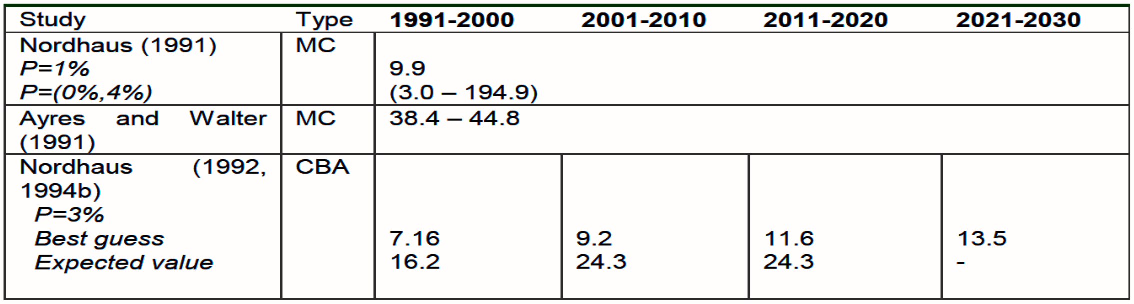
One more table of tax/price list by US EPA for air pollution by emitting different gases.

Table 20: EPA emission permit fees for emitting gases base on the South Coast Air Quality Management District (SAQMD); emission price per-pound; Southern District of California; USA.

Pollution Substances	Cost in dollars per-pound		
	FY96-97	FY98-99	FY99-00
Asbestos, Cadmium	2.17	3.00	3.40
Benzene, carbon tetrachlonde, ethylene di-bromide, ethylene dicholoride, ethylene oxide	0.90	1.00	1.13
Methylene chloride	0.05	0.05	0.06
Hexavalent chromium	2.67	4.00	4.53
Chlorinated dioxins & dibenzofurans	3.17	5.00	5.66
Nickel	1.67	2.00	2.26
1.3-Butadiene, inorganic arsenic, beryllium, poly-nuclear aromatic hydrocarbons (PAH)	1.50	3.00	3.40
Lead, vinyl chloride	0.50	1.00	1.13
1.4-dioxane	0.11	0.21	0.23
Formaldehyde, perchlorethylene	0.21	0.21	0.23
Chlorofluorocarbons (CFC)	0.18	0.18	0.20
1.1.1-trichloroethane	0.038	0.04	0.04

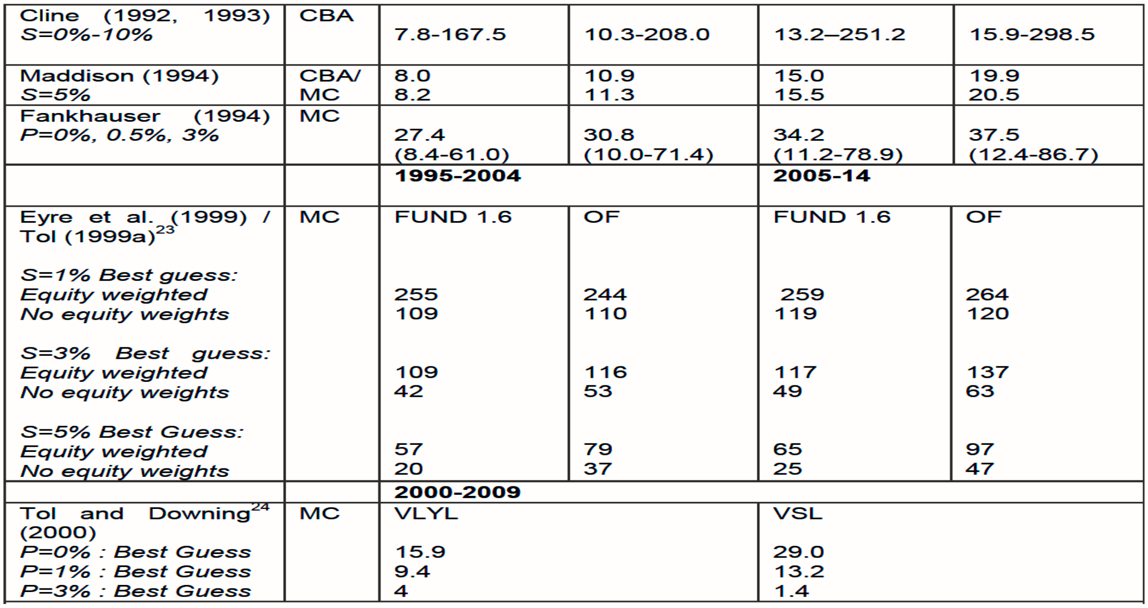
Table 17 & 18 has been calculated and developed based on the price/tax list of US EPA (table 19 & 20 here) for South California states air pollutions for the fiscal year 1999/2000 in association with IPCC carbon price and Environmental Agency, UK suggested standard land use price for using land (LCA) for the whole life span of the project. Clarson and Deyes (2002), calculated for a better comparison with IPCC carbon price with some suggested carbon prices by different scholars. Table 21 & 22 are the charts of those other carbon prices than IPCC.

Table 21; Costs of carbons in different decades; Sources: Clarkson & Deyes, (2002).



Study	Type	1991-2000	2001-2010	2011-2020	2021-2030
Nordhaus (1991)	MC				
P=1%		9.9			
P=(0%,4%)		(3.0 – 194.9)			
Ayres and Walter (1991)	MC	38.4 – 44.8			
Nordhaus (1992, 1994b) *P=3%*	CBA				
Best guess		7.16	9.2	11.6	13.5
Expected value		16.2	24.3	24.3	-

Table 22: Cost of carbon in different decades; Source: Clarkson & Deyes, (2002).

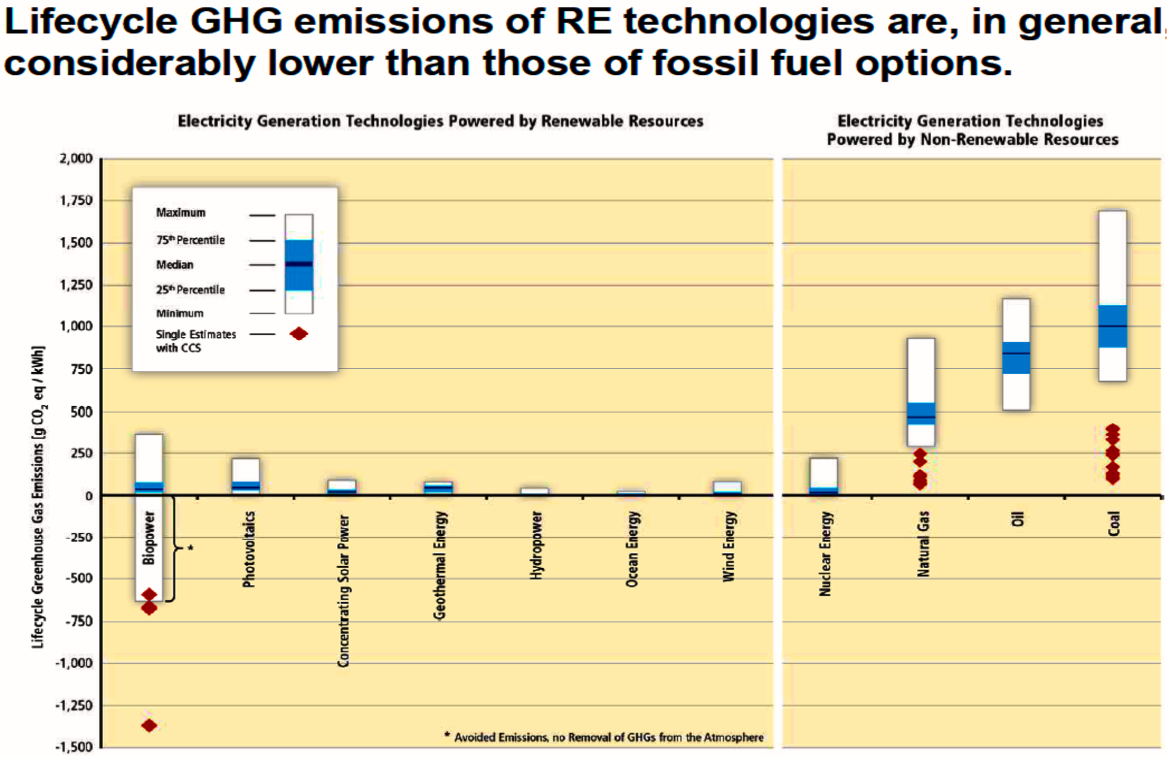


Cline (1992, 1993) *S=0%-10%*	CBA	7.8-167.5	10.3-208.0	13.2–251.2	15.9-298.5
Maddison (1994) *S=5%*	CBA/MC	8.0 8.2	10.9 11.3	15.0 15.5	19.9 20.5
Fankhauser (1994) *P=0%, 0.5%, 3%*	MC	27.4 (8.4-61.0)	30.8 (10.0-71.4)	34.2 (11.2-78.9)	37.5 (12.4-86.7)
		1995-2004		**2005-14**	
Eyre et al. (1999) / Tol (1999a)[23]	MC	FUND 1.6	OF	FUND 1.6	OF
S=1% Best guess: Equity weighted		255	244	259	264
No equity weights		109	110	119	120
S=3% Best guess: Equity weighted		109	116	117	137
No equity weights		42	53	49	63
S=5% Best Guess: Equity weighted		57	79	65	97
No equity weights		20	37	25	47
		2000-2009			
Tol and Downing[24] (2000)	MC	VLYL		VSL	
P=0% : Best Guess		15.9		29.0	
P=1% : Best Guess		9.4		13.2	
P=3% : Best Guess		4		1.4	

[CBA= Shadow value in a cost-benefit analysis; MC= Marginal Cost Study; S= Social rate of time preference; P= Pure rate of time preference; Most of the prices calculated at the base price of 1990 and to convert them into 2000 price an inflation factor 1.35 is used]

Due to some obvious risks and probable fatalities of environmental damages from hydropower projects, some production regulations with other particular environmental safety studies like- risk of local health impact assessment, impacts on local species assessment, impacts on global warming due to the GHG gas emissions, better suitable replacement of affected human and wild lives as well as finding their all associated costs can be made mandatory for the CBA analysis of any projects like hydropower plant with other standard physical construction of dam buildings or reservoirs.

Better construction quality with all probable environmentally friendly measures as well as mass awareness can reduce environmental damages and fatalities on human and wild lives. Having economies of scale and low production cost facilities (have economies of scale and average cost is very low) with huge availability of water sources (its main input of production) hydropower generation became very popular and useful for the territories where a huge amount of mountain water streams are located (IPCC, 2011). Not only that in compare with all other means of electricity production it is still has a very low environmental damage possibilities just after ocean energy production based on the GHG emissions (IPCC, 2011). Lets have a look on a graph of emission level from different types of renewable energy production here (IPCC, 2011)-



(Diagram 4: GHG emission scenario of probable renewable energy production alternatives. Source: IPCC, 2011)

Diagram 4 shows the emission scenario of GHG from hydropower production. It is clearly understandable that hydropower generation still emits a very low amount of GHG in compare with all other renewable energy production alternatives.

At the section 5 and 6, I´ve discussed both the global and local environmental emissions factors, amount of emissions from hydroelectricity and some suggested prices for the global factors but for the local factors, like- water & soil contamination, effects on the bio-diversity, alteration of human and wild lives, land inundations, deforestations, floods, air pollution etc., the data (cost price) area not available in the sources.

For the global emissions and its associated effects on every single country is exactly the same. So, the price of 1 unit of carbon emission can be set for all hydroelectric production agents. And as it has the lifetime impact on global climate change, so the LCA method is the perfect one to apply for this price/tax settings (IEA; 2002). But as the local damage and its associated cost for different production units are completely different (page 55 for details), so a special CV as well as consumer behavioral studies (Choice modeling/qualitative study) can be applicable to find out these external impact costs for a particular production unit.

At section 3 (literature Review section) I´ve found some obvious global and local damages occurred by a hydropower plant development and run, like- 1) alteration/blocking of water flow will be happened; 2) Land on upstream will be inundated (loss of forest & agricultural land); 3) Deforestation will happen on the downstream area (lack of sufficient water flow); 4) Thousands of habitat alteration can happen due to building water dam; 5) Blocking water species forever; 6) Water gets in toxic due to the prohibition of water current which is the cause of thousands of water species death; 7) More carbon will create and emit to the air due to storing a large amount of water as well as deforestation; 8) Fishing and cultivation will be permanently blocked due to building water dam on Running River, 9) Human and wild lives replacement can also be happened if the project area is build near villages, 10) Massive Flood can sometimes caused because to dam collapse and overtopping, 11) Accidents are happened during the construction works, 12) Sometimes a huge air, water and sound pollution happen during the construction works. (Green ID, 2013; IEA, 2002; 2010; 2012; 2016; 2017; Maria Steinmetz & Nathalie Sundqvist, 2014; EEA, 2005; Ute Collier, 2004; Jonathon & Kleinman, 2010;Frischknecht & Muller-Lemans, 1996 And IRENA, 2012) which are unavoidable and has a huge risk of massive environmental damage.

So, before implementation any hydropower plant a planning body must study these global emission impacts on global climate change through LCA analysis to find the tax as well as the local impact studies through CV analysis, consumer behavioral studies, Revealed/stated preference to find out the external cost of local environmental damages and include all of these costs into the main Cost-Benefit Analysis of the project.

7. Concluding Remarks:

Based on the discussion and calculations of local and global environmental impacts with some fatal rick factors on human and wild life by hydropower generation on the section 5 & 6 it can be concluded that before any final implementation of hydropower generation projects, the probable environmental damage costs should be calculated, measured and given priority into the main CBA analysis of the whole time span of the project.

Some emissions as well as risk factors never be avoidable (section 3 & 6 last part) to build and run hydroelectricity dam which has serious human and wild live risk with all other water species (IEA, 2002 & IRENA, 2012) like all the gases emits by hydropower plant that increase GHG, some gases which decreases the oxygen both in the air and water (section 5 here), change of whole water quality due to building dams on river flow, destroying hundreds of water species by storage sediments on the bottom layer of the upper-stream area, replacement of habitats including human (Green ID, 2013), change of agricultural land on the down-stream regions, inundated lands on the upper-stream regions, fishing restriction & cultivations, restrictions of recreations and natural views, restrictions of water lives from down-stream to the up-stream regions etc. sholud be well defined, calculate their costs as the main environmental and ecosystem damages from hydropower production and make sure to include as the costs factors of CBA.

Some impacts of them are global where there is exactly the same effect on every single country's climate change due to increase one unit extra hydropower production, specifically one unit additional emission of carbon to the air (section 5.2.6). So, the associated costs of those emissions will exactly be the same (section 6, cost calculations). For an example, if Nagarjuna Sagar dam (India) emits one unit extra carbon gas on the air which increase one additional unit of GHG on the ozone layer, it has exactly the equal level of climate effect for every country of the world because the world climate region is the whole world itself and it has no boundary. So, no country can avoid this effect by any means. Similarly, all other gases, which emits to the air from the hydropower has exactly the same effect to the global environment and climate change. So, the price or costs of these global effects will be exactly the same for all countries, particularly all hydropower production plant (section 6). I've collected data for these GHG gases from the US Environmental Protection Agency for the fiscal year 1999/2000 and calculated the cost per metric ton of GHG emissions. But for the carbon emissions, I've collected data and followed the suggested cost/price for emitting per metric ton of carbon to the air, set by Intergovernmental Panel on Climate Change (IPCC). Costs (only for the substances which the data are available) are calculated based on the Giga Watt-hour to get a bigger amount because for Kilo Watt-hour, costs were too small to discuss. For Global impact emission groups, I did not find the data of cost for eutrophication process (a system of emission which reduces the amount of oxygen in the air & water). Table 17 & 18 at section 6 is prepared for these cost calculations based on the availability of data.

As part of local environmental impact, (as I've already discussed at the section number 6 that local impacts and their associated costs are completely different from one place to another and from one size of plant to other, even though they are situated inside a same country) I've calculated the life cycle land using rent suggested for the land category 1 & 2 (section 5.2.1 which has divided by ETH) which are usually used for the hydropower plants (except some special cases) by the Environment Agency of UK where I've converted land area from m^2a/kWh into hectare/GWh. For the green house effect emission amount and its associated cost/tax price for 1 GWh electricity, I´ve taken the tax/price suggested by IPCC, for the Ozone Layer Depletion & acidification I´ve taken the price/tax set by EPA, for the Eutrophication the data was not found, for the Photochemical Formation effect I´ve taken the data for cost suggested by EPA; in Maine for POCP equivalent emission tax for the current fiscal year 1999/2000.

For the local emission group, the data of water contamination, soil contamination, change of water quality and its associated impacts on local environment, deforestation, land inundation, flood destruction on human and wild life, overtopping, lose of wild life due to the lose of forestland, dissertation on the downstream region and its associated loss, etc were not found. Impacts on local water species, wild species, restrictions of fishing, cultivation of fishing, sightseeing (visual impacts), cultural heritages change, impacts on human life and health can be calculated by following the qualitative analysis, Contingent Valuation methods as well as the consumer behavioral methods like choice modeling and so on. For the particular hydropower plant a different set of these methods can be applied to collect the data of external costs arise from that particular hydropower plant and these data of external costs can be completely different from one plant to others because the nature and severity of local impacts of a particular hydropower project can be completely different from others.

Some costs associated hydropower production like, flooding and its short & long term effect, loss of habitat replacement, loss of upstream land & forest area (inundated land) are considered as the most fatal environmental impacts of a big hydropower plants but these costs are usually neglected and avoided by the implementation body of CBA analysis (Green ID, 2013). Accidents, overtopping, dam failure and its flooding impacts area are usually large but most of the cases, for the political reason and others, ruling government does not want to survey the actual loss for the society & environment as well as they do not want to forecast those costs publicly. Hennan Catastrophe; 1975; China; can be a good example here.

As a huge potential renewable sector of electricity production, safe hydroelectricity generation and its proper distribution can save a huge amount of other energy potentials and their combustion which is even dangerous (like nuclear energy production), expensive and environmentally more destructive source of energy production. According to the IEA survey 19% of total world energy production is supplied from the hydropower generation which can be double if all the potential capacity hydropower can be utilized and attain under production (IEA, 2016) which can also help to reduce pressure on the use of fossil fuel, like- coal, gas, oil etc. that has even more negative impacts on environment and human, animal lives.

So, the production of hydroelectricity should be reached on its optimum level but following the safe and secured way considering all probable, obvious and fatal environmental damages that are unavoidable and their all associated costs should be well defined, calculated following the proper methods and finally have to be reflected into the main CBA analysis of the project. Places like- highly cultural heritages, densely populated areas as well as with high risk of flooding and inundating chances of flat land areas should be avoided on the process of site selection for hydroelectricity power plant.

8. Sources of Data:

The data was the most important and sensitive issues for this study. I had to spend a huge amount of time to find out proper data and their calculation on current prices. The following sources have been randomly used to match and collect data sets that are used here-

➔World Bank Data. Link: http://data.worldbank.org

➔ Data of OECD. Link: https://data.oecd.org

➔ Eurostat data bank. Link: http://ec.europa.eu/eurostat/data/database

➔ International Energy Agency Statistics & their different publications. Link: http://www.iea.org/statistics

➔International Renewable Energy Agency. Link: http://www.irena.org/home/index.aspx?PriMenuID=12&mnu=Pri

➔ Statistics Norway. Link: https://www.ssb.no/en

➔ Environmental Agency (UK) and its different publications. Link: https://www.gov.uk/government/organisations/environment-agency

➔ US EPA (US Environmental Protection Agency). Link: https://www.epa.gov.

9. List of References:

Arne J. Carlsen, Jon Strand & Fred Wenstop, “Implicit Environmental Costs in Hydroelectric Development: An Analysis of the Norwegian Master Plan for Water Resources” (1993). Journal of Environmental Economics and management; Norwegian School of management, Box 580, 1301 Sandvika, Norway.

Australian Institute of Energy; Fact Sheet-6, “History and Development and How Hydro Electric Power Stations Operate”. National. Australian Institute of Energy. ABN 95 001. Sydney, Australia.

Brännström-Norberg, B.-M.; Rosen-Lidholm, S., and Tärnström, C. Analys av miljökonsekvenser för ett kraftvärmeverk eldat med Salix - Jämförelse med miljökonsekvenserna för kol och skogsbränsle [Analysis of environmental consequences for a co-generation power station burning Salix. Comparison with environmental consequences for coal and forest fuel]. Rapport Från Vattenfall Utveckling AB, Projekt Bioenergi. 1994 Jun 6; (1994/3):93 pp. + appendices.

Brannstrom & Nordberg: Environmental life cycle assessment (LCA) of Swedish semi-hard cheese Original Research Article International Dairy Journal, Volume 12, Issue 11, 1995, Pages 939-953.

Brännström-Norberg, B.-M. and Setterwall, C. Livscykelanalys för naturgaskombi. Stockholm, Sweden: Vattenfall Energisystem AB; 1996 Jun 564 pp. + appendices.

Brian Norton, ‘Renewable electricity - what is the true cost?’ Power Engineering Journal, February, 1999.

EEA (European Environment Agency), “External costs of electricity production” (20059 EN35. Kongens Nytorv 6, DK-1050 København K, Denmark.

Energy Information Administration (EIA). Analysis of the Relationship Between the Heat and Carbon Content of U.S. Coals. Washington, DC, USA: U.S. Department of Energy (DOE), Energy Information Administration (EIA), Office of Coal, Nuclear, Electric and Alternate Fuels; 1992 Sep.

Environment Agency, “Cost estimation for land use and run-off summary of evidence”. Flood & Coastal Erosion Risk Management Research and Development Program (2015), Environment Agency, Horizon House, Deanery Road, Bristol, UK.

Energy Efficiency and Conservation Authority. Energy-Wise Renewables. Guidelines for Renewable Energy Developments: Wind Energy [Web Page]. 1995 Jun 25.

EPA (US Environmental Protection Agency), “Gas Emission Cost List by EPA based on the South Coast Air Quality Management District (SAQMD)”. EPA main research paper-2001; South California; USA.

Frischknecht, R. and Müller-Lemans, H. Ökoinventare für Energiesysteme. Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz. Zürich, Switzerland: Bundesamt für Energiewirtschaft. Sozio-ökonomische Energieforschung, Gruppe Energie-Stoffe-Umwelt/Energy-Materials- Environment Group (ESU); 1996; Überarbeitung: Schlussbericht des BEW/NEFF-Forschungsprojektes "Umweltbelastung der End- und Nutzenergiebereitstellung. VIII: 63 pp.

Frischknecht, R.; Hofstetter, P.; Knoepfel, I.; Dones, R., and Zollinger, E. Ökoinventare für Energiesysteme. Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in Ökobilanzen für die Schweiz. Zürich, Switzerland: Bundesamt für Energiewirtschaft. Sozio- ökonomische Energieforschung; 1994 Mar; Schlussbericht des BEW/NEFF- Forschungsprojektes "Umweltbelastung der End- und Nutzenergiebereitstellung. I: 12 pp, II: 12 pp; III: 29 pp.; IV: 343 pp.; V: 154 pp; VI: 234 pp.; VII: 302 pp; VIII: 71 pp; IX: 80 pp; X: 21 pp; XI: 58 pp.; XII: 188 pp; XIII: 28 pp; XIV: 5 pp.; Anhang A: 134 pp.; B: 75 pp.; C: 18 pp.; D: 4 pp.; E: 13 pp.; F: 33 pp.; G: 28 pp.; H: 6 pp.

Green ID (Green Innovation and Development Center), “Analysis of Environmental and social Cost and Risks of Hydropower dams, with a Case Study of Song Tranh-2 Hydropower Plant”. Green Innovation and Development Centre (GreenID-2013) Suite 707, 7th floor, Sunrise Building, 90 Tran Thai Tong Street, Cau Giay, Ha Noi, Vietnam.

International Energy Agency (IEA). Natural Gas Information 1996. Paris, France: International Energy Agency (IEA/OECD); 1997 Jul; 458 pp. ISBN: 92-64- 15592-9.

IEA (International Energy Agency), “Environmental and Health Impacts of Electricity generation; A Comparison of the Environmental Impacts of Hydropower with those of Other Generation Technologies”, June 2002. International Energy Agency 9, rue de la Federation, 75739, Paris Cedex 15, France.

IEA (International Energy Agency; Statistics), “Renewable Energy Essentials: Hydropower” 2010. International Energy Agency 9, rue de la Federation, 75739, Paris Cedex 15, France.

IEA (International Energy Agency) & NEA (Nuclear Energy Agency), “Projected cost of Generating Electricity- 2010 Edition”. OECD/IEA & NEA. International Energy Agency, 9 rue de la Federation, 75739, Paris Cedex 15, France.

IEA (International Energy Agency), “Energy Policies of IEA countries- Norway 2011 review”. OECD/IEA, 2016. International Energy Agency 9, rue de la Federation, 75739, Paris Cedex 15, France.

IEA (International Energy Agency), “Technology Roadmap- Hydropower”. OECD/IEA, 2016. International Energy Agency 9, rue de la Federation, 75739, Paris Cedex 15, France.

IEA (International Energy Agency; Statistics), “Renewables Information”; OECD/IEA, 2016. International Energy Agency 9, rue de la Federation, 75739, Paris Cedex 15, France.

IEA (International Energy Agency), “Key Renewables Trends; Excerpt from: Renewable Information”. OECD/IEA, 2016. International Energy Agency 9, rue de la Federation, 75739, Paris Cedex 15, France.

IEA (International Energy Agency), “KEY ELECTRICITY TRENDS 2016 – BASED ON MONTHLY DATA”. OECD/IEA, 2016. International Energy Agency 9, rue de la Federation, 75739, Paris Cedex 15, France.

IPCC (Intergovernmental panel on Climate Change); “IPCC special report, emission scenarios, summary for policy makers” WMO & UNEP- 2002; Intergovernmental Panel on Climate Change, A Special Report of IPCC Working Group III; Published for the Intergovernmental Panel on Climate Change.

IRENA (International Renewable Energy Agency), “Renewable Energy Technologies” Cost Analysis Series (2012); Volume 1: power sector; Hydropower. IRENA Innovation and Technology Centre, Robert-Schuman-Platz 3, 53175 Bonn, Germany.

International Organization for Standardization (ISO). Environmental management - Life cycle assessment - Goal and scope definition and inventory analysis. Geneve, Switzerland: International Organization for Standardization (ISO); 1998 Oct 1; ISO 14041:1998(E). 22 pp.

Johanna Berlin, “Environmental life cycle assessment (LCA) of Swedish semi-hard cheese”. Environmental Systems Analysis (2002), Chalmers University of Technology, SE-412 96, Goteborg, Sweden.

Jonathan Kleinman & Patrick McCully, “Environmental Effects of Hydropower Plants Including Those Using Thermal, Tidal and Wave Power” 2010. Vermont Energy Investment Corporation, USA.

Jonathon J. Cole, Nina F. Caraco, George W. Kling, Timothy K. Kratz, “Carbon Dioxide Super Saturation in the surface of Western lake”. Science, New Series (1994), Volume 265, Issue 5178 (Sept. 9, 1994), 1568-1570.

Karin Flury, Rolf Frischknecht, “Life Cycle Inventories of Hydroelectric Power Generation”. ESU-Services, fair consulting in sustainability (2012); Commissioned by Oko-Institute e.V; CH - 8610 Uster.

Life Cycle Analysis of Photovoltaic Cell and Wind Power Plants. "Assessment of greenhouse gas emissions from the full energy chain of solar and wind power and other energy sources". An international Advisory Group Meeting on Assessment of Greenhouse Gas Emission from the Full Energy Chain of Solar and Wind Power; 1996 Oct 21-1996 Oct 24; IAEA Headquarters, Vienna, Austria. Vienna, Austria: International

Atomic Energy Agency (IAEA); 1997 Dec 31307 pp.

Luiz Pingueili Rosa and Roberto Schaeffer, “Global warming potentials; The case of emissions from dams”. Energy Planning Program (1995), Federal University of Rio de Janeiro, Centro de Tecnologia, Bloco C, Sala 211, C.P. 68565, Cidade Universit6ria, llha do Fundgm 21945-970 Rio de Janeiro, R J, Brazil.

Luc Gagnon & Joop F. van de Vate, “Greenhouse gas emissions from hydropower”. Energy Policy. Vol. 25, No. I, pp. 7-13. 1997, Copyright © 1997 Elsevier Science Ltd Printed in Great Britain.

McCully, P. Silenced Rivers. The Ecology and Politics of Large Dams.: Zed Books; 1996; 350 pp.

Malgorzata Goralczyk, “Life-cycle assessment in the renewable Energy sector”. Polish Academy of Sciences, Mineral and Energy Economy Research Institute (2002), ul. Wybickiego 7, 31-261 Krakow, Poland.

Maria Steinmetz, Nathalie Sundqvist, “Environmental Impacts of Small Hydropower Plants -A Case Study of Borås Energi och Miljö’s Hydropower Plants”. Department of Energy and Environment (2014), Division of Environmental System Analysis, Chalmers University of Technology, Gothenburg, Sweden.

Ottmar Edenhofer; IPCC Research paper, “The IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation”. WMO & UNEP (2011); the New School for Social Research, New York; USA.

Richard G. Walsh, Donn M. Johnson, and John R. McKean, “Issues in Nonmarket Valuation and Policy Application: A Retrospective Glance”. Western Journal of Agricultural Economics, 14(1): 178-188, Copyright 1989 Western Agricultural Economics Association.

Richard Clarkson and Kathryn Deyes, “Estimating the Social Cost of Carbon Emissions”. Climate Change and Energy Policy Branch Environment Protection Economics Department of Environment Food and Rural Affairs (2002), Ashdown House 123 Victoria Street, London, UK.

Richard G. Walsh, Donn M. Johnson, and John R. McKean, “Issues in Nonmarket Valuation and Policy Application: A Retrospective Glance”. Western Journal of Agricultural Economics, 14(1): 178-188 Copyright 1989 Western Agricultural Economics Association.

Rosenberg, D. M.; Bodaly, R. A., and Usher, P. J. Environmental and social impacts of large scale hydroelectric development: Who is listening? Global Environmental Change - Human and Policy Dimensions. 1995 May; 5(2):127-148.

Sandgren, J. and Sorteberg, S. Electric Power and Environmental Impacts. Norway: The

Norwegian Research Council; 1994; Report No. 93-3701. 68 pp.

San Martin, R. L. Environmental emissions from energy technology systems: The total fuel cycle, energy technologies for reducing emissions of greenhouse gases. Proceedings of an Expert's seminar; 1989 Apr 12-1989 Apr 14; Paris, France. Paris, France: International Energy Agency (OECD/IEA); 1989.

Sörensen, B. “Does wind energy utilization have regional or global climate impacts?” Proceedings of the 1996 European Union Wind Energy Conference; 1996 May 24; Gothenburg, Sweden. European Union; 1996.

Thöhne, E. and Kallenbach, U. Risikovergleiche für die Stromerzeugung. Energiewirtschaftliche Tagesfragen. 1988 (10):1.

Uchiyama, Y. Validity of FENCH-GHG study, methodologies and databases. "Comparison of energy sources in terms of their full-energy-chain emission factors of greenhouse gases", Proceedings of an IAEA Advisory Group meeting/Workshop; 1994 Oct 7; Beijing, China. Vienna, Austria: International Atomic Energy Agency (IAEA); 1994: 151-158. 179 pp.

UNECE-EMEP Task Force on Emission Inventories. Emission Inventory Guidebook. Co-operative Programme for Monitoring and Evaluation of the Long Range Transmission of Air Pollutants in Europe (EMEP) and The Atmospheric Emission Inventory for Europe (CORINAIR); 1996.

U.S. Department of Energy, “Energy Efficiency and Renewable Energy, Wind and Hydropower Technologies Program” (2012).

Ute Collier, “Hydropower and the Environment: Towards better decision-making”. Paper submitted to the United Nations Symposium on Hydropower and Sustainable Development, to be held in Beijing, October 27-29, 2004.

Varun, I.K. Bhat, Ravi Prakash, “LCA of renewable energy for electricity generation systems—A review”. NIT (2008), Hamirpur (HP) 177005, India & MNNIT, Allahabad, India.

Varun, Ravi Prakash & I. K. Bhat, “Life Cycle Energy and GHG Analysis of Hydroelectric Power Development in India’. International Journal of Green Energy (2010), 7:4, 361-375. Taylor & Francis Group, LLC.

Vladut, T. Environmental aspects of reservoir-induced seismicity. International Water Power & Dam Construction. 1993; 45(5):29-33.

VINCENT L. ST. LOUIS, CAROL A. KELLY, ÉRIC DUCHEMIN, JOHN W. M. RUDD, and DAVID M. ROSENBERG, “Reservoir Surfaces as Sources of Greenhouse Gases to the Atmosphere: A Global Estimate”. American Institute of Biological Sciences(2000); BioScience, 50(9):766-775.

Walter Wildi, “Environmental hazards of dams and reservoirs”. Institute F.-A. Forel (2010), University of Geneva, CP 416, CH-1290 Versoix, Switzerland.

World Energy Council, “2007 Survey of Energy Resources; Volume-2”. World Energy Council Regency House 1-4 Warwick Street London W1B 5LT United Kingdom.

World Energy Council. Survey of Energy Resources 1992. London, UK: World Energy Council; 1992.

10) Elaboration of all Abbreviations:

AP- Acidification Potential.
CFC- Chlorofluorocarbon.
CF_4- Tetrafluoromethane.
CH_4- Methane Gas (1 atom carbon + 4 atom hydrogen).
CO_2- Carbon Dioxide.
CBA- Cost-Benefit Analysis.
CV/CVA- Contingent Valuation Approach.
EP- Eutrophication Potential.
EP-UK- Environment Agency of United Kingdom.
ECA- European Club Association.
ECT- Electroconvulsive Therapy.
EIA- Energy Information Administration.
ETH- Eidgenøssische Technische Hochschule; Zurich, Switzerland.
FCKW- Fluorchlorkohlenwasserstoffe; in English: fluorochlorohydrocarbon.
GHG- Green House Gas.
GW- Giga Watt; GWh(Giga Watt-hour)
HCI- Hydrocarbon Indicator.
H_2S- Hydrogen Sulphide.
H_2O- Hydrogen and Oxygen.
IEA- International Energy Agency.
IPCC- Intergovernmental Panel on Climate Change.
IRENA- International Renewable Energy Agency.
IHA- International Hydropower Association.
ISO- International Organization of Standardization.
KWh- Kilo Watt-hour.
LCA- Life Cycle Assessment Approach.
LCIA- Life Cycle Impact Assessment.
LCI- Life Cycle Inventory Analysis.
LCOE- Levelised Cost of Electricity Generation.
M^2a- Square Meter Area.
N_2O- Nitrous Oxide.
NH_3- Compound of Nitrogen & Hydrogen. (1 atom nitrogen + 3 atom hydrogen).
NO_x- Nitrogen Oxide.
NF- Nitrogen Monofluoride.
NMVOC- Non-Methane Volatile Organic Compound.
ODP- Ozone layer Depletion Potentials.
O_2- Oxygen.
POCP- Photochemical Ozone creation Potentials.
QRA- Quantitative Risk Assessment.
REN- Resolute Energy Corporation.
RE- Renewable Energy.
SAQMD- South-Coast Air Quality Management District.
SO_x- Sulfur dioxide.
TWh- Tera Watt-hour.

UCPTE- European Network of Transmission System Operators for Electricity.
US-EPA- United Nations Environment Protection Agency.
USGS- United Nations Geographical Survey.
WEC- World Environment Commission.

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