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Quantification of Social Impacts of Large Hydropower Dams- a case study of Alborz Dam in Mazandaran Province, Northern Iran

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ABSTRACT: Despite the numerous advantages of large dams, there is still a deep suspicion about the real, long-term benefits and costs of their construction. Land use change on a vast scale, displacement of a large population of indigenous people, loss of biodiversity and production of greenhouse gas emissions, as well as environmental, socioeconomic and cultural consequences resulting therefrom, indicate clearly the need to reconsider the growing trend of dam construction in the world. The present study was conducted to calculate the real cost of generating electricity imposed on communities and environment in order to clarify the adverse socioeconomic impacts of large dams that are often ignored due to short-term, economic benefits. Accordingly, Alborz Dam, a large dam in northern Iran, was selected as a case study to run cost-benefit analysis by SIMPACTS Software. The obtained results revealed that the total external cost of electricity generation by the hydropower dam is about 0.16 US$/kWh. In other words, the annual cost of the electricity generation by Alborz Hydropower Plant is US$ 4.8 million/year. The highest share (163 US$/MWh) belongs to the loss of agricultural production while the lowest cost (0.10 US$/MWh) is associated with the loss of life. According to the estimated values, a total amount of 1074 tons of greenhouse gas emissions is expected to be released into the air by the hydropower dam operation. It should be stated that SIMPACTS Software only considers the adverse effects of hydropower dams and there is a need to improve the capability of the software by adding the positive impacts in to the overall computations, as well.

Key words: Large dam, Externalities, Environmental, Social, Resettlement, Land, Agriculture

INTRODUCTION

Construction of large dams which has always been regarded by governments as a development index is often accompanied by impacts on the environment and local communities (Brismar, 2004; Wang et al., 2012; Adams and Hughes, 1986; Sovacool and Bulan, 2011). Considering the necessity of using natural resource endowments, exploitation of surface water resources is essential and critical to achieve a sustainable development in a region. Furthermore, the protection of nature and environment cannot be ignored in order to avoid imbalance of ecosystem components and achieve sustainable development goals. There have been a lot of studies on the adverse consequences of dam construction. Han et al. (2008) measured economic value of multiple environmental impacts of large dam construction as a case study of Korea using a choice experiment approach. They concluded that monthly willingness-to-pay of the typical household for mitigating environmental impacts by large dam construction from the status quo to the highest attribute level is about US$ 2.12 and the total willingness-to-pay for the entire population of the study area is annually about US$ 174.9 million. Tetteh et al. (2004) examined the impact of the Barekese Dam in Ghana on the health status of three riparian communities downstream against a control. Their obtained results indicated that the control community consistently had a much better health status than two of the riparian communities, which were closer to the dam in all the three phases. Wyrick et al. (2009) used hydraulic modeling to address social impacts of small dam removals in southern New Jersey. They claimed that this method should at least allow more opportunities for constructive dialogue on dam

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removal alternatives between the stakeholders and governing agencies. Displacement of a large number of indigenous people from their homeland, extensive destruction of agricultural and forest lands, damages of historical and mineral resources, loss of archeological sites, loss of scenic and tourist sites all are a schema of what happens after dam construction (Wanga et al., 2013; Tilta et al., 2009; Arnell, 1994; Rico et al., 2008). Due to the issue importance lots of methods and tools have yet been offered by different researches of which SIMPACTS Software is known as a user friendly, useful one (Weijermars et al., 2012; Hainoun et al., 2010; Macías and Islas, 2010; Büke and Çiðdem Köne, 2011). The present study uses SIMPACTS Model to quantify the externalities of Alborz Hydropower Dam. The research findings would be an applicable tool towards actualizing the electricity generation costs and making the decision makers aware of environmental consequences of dam construction.

MATERIALS & METHODS

The study area includes (i) watershed, covering upper temperate forests and alpine rangelands; (ii) middle lands, which are comprised of irrigated valley bottoms and mostly degraded forests on hillsides; and (iii) lower lands that are composed of irrigated plains close to the Caspian Sea. With an average elevation of 298 m above sea level, the Alborz Dam is situated between the latitude of 36° 13' 49.2" N (36.2303°) and the longitude of 52° 48' 38.1" E (52.8106°). A short summary of the dam characteristics is given in Table 1. It is worth mentioning that the population density in the study area is 33 people/km^2. About 10000 people are at risk in the event of dam accident. Approximately, 40% of the study area is covered by forest, 59% by farmlands and 1% by other land uses.

Table 1. Characteristics of Alborz Dam used as input data in the cost-benefit analysis

Characteristic	Value	Unit
Dam Height (H_D)	78.0	m
Additional Head Correction (D_H)	-25.0	m
Plant Capacity (P)	10.0	MW
Average Plant Capacity Factor (CF)	20.0	%
Turbine Flow (Q_W) all Turbines	12.8	m^3/s
Additional Head Correction (D_H)	-25.0	m

In this research, the external cost of population displacement was calculated using the Eq.1. It was assumed that the resettlement cost per person is a function of *GDP* per capita.

$$Cost_{DIS} = POP_{DIS}\left[person\right] \times \left(1.33 \times GDP_{PerCapita}\left[\frac{US\$}{Person}\right]\right) \quad (1)$$

Due to internalization of resettlement cost, the external component of the displacement cost was intended to be calculated in US$ (*CostDIS,EXT*) based on the fraction of people displaced but not resettled or compensated (*FractionDIS,NOTRES*).

$$Cost_{DIS.EXT} = Cost_{DIS}\left[US\$\right] \times Fraction_{DIS.NOTRES} \quad (2)$$

Considering that it is a one-time payment, the calculated costs were then levelized over the economic lifetime (*ELife*) of the project based on the interest rate (*IR*) to estimate the externality per MWh generated by the hydropower station. The Eq. 3 was applied to compute the levelized external cost of displacement in US$ / MWh (*CostDIS,MWh,EXT*):

$$Cost_{Diss,MWh,EXT} = \frac{Cost_{DIS.EXT}\left[US\$\right] \times \left(\frac{IR \times (1+IR)^{ELife}}{(1+IR)^{ELife} - 1}\right)}{P\left[MWe\right] \times 8{,}760 \times \frac{CF\left[\%\right]}{100}} \quad (3)$$

For IR>0

As one of the most considerable impacts of dam construction, dam dewatering will result in an extensive loss of land. In this research, the economic cost of loss of land uses forest, farmland, and other (*IARS,i*) was estimated using:

$$Cost_{LandLoss.EXT} = (1 - FIC) \times \sum_{i=1}^{3}\left(IA_{RS.i}\left[Km^2\right] \times Cost_{LandUse.i}\left[\frac{US\$}{hectare}\right] \times 100\right) \quad (4)$$

The annual expected loss of life from failure of Alborz Dydro Dam was calculated using the statistical value of life. For this purpose, the same value as was used for the European Union in the ExternE project, that is 3.1 million ECU95 was taken. This value was then converted to 3.627 million €2000 or US$ 3,264,300 ($2000). Finally, it was adjusted based on the ratio of the most recent, available GDP at purchasing power parity, which is GDPPPP for 1998. Accordingly, using the adjusted value of a statistical life for Iran (*VSLCountryX*) (Eq.5), the Eq.6 was used to estimate the cost of the loss of life from accidents in US$ per MWh generated (*CostLossLife,MWh,EXT*).

In this research, the actual losses of agricultural and livestock production (*AGLoss, LSLoss*) and the associated unit costs were calculated to estimate the economic value of the losses. In order to estimate unit costs, the agricultural products (*AGMV*) and livestock (*LSMV*) affected by the inundation were also calculated. The economic loss in US$ per MWh generated (*CostLossAgLiv,MWh,EXT*) was estimated using:

The actual losses of resources (*RESLoss*) and the associated unit costs (*RESVal*) were two variables computed to estimate the economic value of the losses. The economic loss in US$ per MWh generated (*CostLossNatCulRes,MWh,EXT*) was calculated using:

The increased disease incidents were estimated based on inputs for additional incidents (*DISInc*) and costs per incident (*CostDISInc*). The economic cost in US$ per MWh generated (*CostDISInc,MWh,EXT*) was calculated using:

Based on the estimated annual emissions, the external costs related to the atmospheric releases of CO2, SO2, and NOX were calculated. For this, the estimated annual emissions for each of the three pollutants were taken and multiplied them with the unit

$$VSL_{CountryX} = \$3{,}264{,}300 \times \frac{GDP_{ppp.countryX}}{20{,}269} \quad (5)$$

$$Cost_{lossLife,MWh,EXT} = \frac{EXPLives_{Lost.Year} \times VSL_{CountryX}}{P[MWe] \times 8{,}760 \times \frac{CF[\%]}{100}} \quad (6)$$

$$Cost_{LossAgliveProd,MWe,EXT} = \frac{\sum_{i=1}^{n}\left(AGLoss_i[tons] \times AGMV_i\left[\frac{US\$}{ton}\right]\right) + \sum_{j=1}^{m}\left(LSLoss_j[units] \times LSMV_j\left[\frac{US\$}{unit}\right]\right)}{P[MWe] \times 8{,}760 \times \frac{CF[\%]}{100}} \quad (7)$$

$$Cost_{LossNatCulRes,MWh,EXT} = \frac{\sum_{i=1}^{n}\left(RESLoss_i[units] \times RESVal_i\left[\frac{US\$}{unit}\right]\right)}{P[MWe] \times 8{,}760 \times \frac{CF[\%]}{100}} \quad (8)$$

$$Cost_{DISInc,MWh,EXT} = \frac{\sum_{i=1}^{n}(DISInc_i \times Cost_{DISInc.i})}{P[MWe] \times 8{,}760 \times \frac{CF[\%]}{100}} \quad (9)$$

cost. As unit cost for carbon (*CARVal*), the carbon values used by the Global Environment Facility or the Prototype Carbon Fund of the World Bank were applied. For SO2, values from AIRPACTS were used. The same is true for NOX (*NOXVal*). The economic cost in US$ per MWh generated (*CostEmis,MWh,EXT*) was estimated using:

$$Cost_{Emis,MWh,EXT} = \frac{\left(GHG_{CETotalYear}\left[\frac{tons}{year}\right] \times CARVal\left[\frac{US\$}{ton}\right]\right) + \left(SO2\left[\frac{tons}{year}\right] \times SO2Val\left[\frac{US\$}{ton}\right]\right) + \left(NOX\left[\frac{tons}{year}\right] \times NOXVal\left[\frac{US\$}{ton}\right]\right)}{P[MWe] \times 8{,}760 \times \frac{CF[\%]}{100}} \quad (10)$$

Eq. 11 was applied to calculate the total external cost in US$ per MWh generated (*CostTOTAL,MWh,EXT*).

$$Cost_{Total,MWh,EXT} = \sum_{i-1}^{n} ExternalCosts_{MWh,EXT} \quad (11)$$

RESULTS & DISCUSSION

In order to estimate the cost imposed by the loss of agricultural production, it was necessary to prepare an inventory of main agricultural products and livestock (Table 2). As shown in Table 2, rice cultivation has a total market value of 4520 US$/ton. *Vica Faba*, *Hordeum sativum*, berry and *Trifolium Alexanderinium linn* are among other agricultural products in the study area with a total volume of 33057 tons/year. Bovine cattle (meat), chicken and others, eggs and milk are the main livestock products in the region with an economic benefit of about 260 US$/ton.

It is worth noting that during the operation of Alborz Hydropower Dam about 18.7 tons/km^2/year of CH_4 and 1450 tons/km^2/year of CO_2 are expected to be emitted into the atmosphere. In this research, the price of carbon was assumed to be 20 US$/ton. The overall GHGs emission (Dam life of about 50 years) is about 10000 tons.

Moreover the mentioned input data, there was a need for some cost characteristics to quantify the impacts of Alborz Dam which are presented in Table 3.

After determining all required variables, the model was run to obtain the real cost of electricity generation by the Alborz Hydropower Dam (Table 4). As the research findings revealed, 1MWh electricity generation by Alborz Dam costs US$ 165. Considering the total annual electricity generation (30660000kWh) by the power plant as well as US$-Rls exchange rate (US$ 1= Rls. 25000), it was concluded that socioeconomic cost of electricity generation by Alborz Hydropower Dam is US$ 4.8 million/year.

Loss of production has the highest proportion of total socioeconomic external cost of electricity generation (163 us$) by Alborz Hydropower Dam. The cost of emissions (70.1 us$) is the second factor that

Table 2. The price of main agricultural products and livestock loss due to construction of Alborz Hydropower Dam

Productions	Value	Unit	Market Price (US$/ton)
Rice (Tarom)	463.5	tons/year	2,000.0
Rice (Amol)	532.8	tons/year	1,520.0
Rice (Gerdeh)	1,022.0	tons/year	1,000.0
Vica Faba	12.0	tons/year	4,400.0
Hordeum sativum	45.0	tons/year	1,500.0
Berry	8,000.0	tons/year	680.0
Trifolium Alexanderinium linn	25,000.0	tons/year	900.0
Bovine cattle (meat)	0.0	units	259.0
Chicken and others	0.0	units	0.5
Eggs	0.0	units	0.4
Milk	0.0	units	0.2

Table 3.Cost characteristics

GNP of I. R. Iran	**6,900**	**US$$_{2000}$ Per Capita**
PPPGNP of Iran	13,072	US_{2000}$ per capita
Cost of forest	6,656,000	US_{2000}$ per hectare
Cost of farmland	4,993,200	US_{2000}$ per hectare
Cost of other land	637,880	US_{2000}$ per hectare
Fraction of land costs internalized	1.00	fraction
Economic lifetime of Alborz Dam	50	years
Interest Rate for Cost Levelization	15.0	%

Table 4. Summary of economic impacts of the Alborz hydropower Dam

DISPLACEMENT OF PEOPLE	**Value**	**Unit**
Total damage cost	22.67	million US$2000
External cost (displaced but not resettled/compensated)	0.00	million US$2000
Annual external cost of displacement	0.00	million US$2000 per year
External cost of displacement per MWh	0.00E+00	US$2000 per MWh
LOSS OF LAND	2,469.17	million US$2000
Forest	1,131.52	million US$2000
Farmland	1,333.18	million US$2000
Other	4.47	million US$2000
External cost of loss of land	0.00	million US$2000
Annual external cost of loss of land	0.00	million US$2000 per year
External cost of loss of land per MWh	0.00E+00	US$2000 per MWh
LOSS OF LIFE (ACCIDENTS)		
Annual damage cost (external)	0.00	million US$2000 per year
External cost of loss of life per MWh	1.02E-01	US$2000 per MWh
LOSS OF AGRICULTURAL AND LIVESTOCK PRODUCTION		
Annual damage cost (external)	4.99	million US$2000 per year
External cost of loss of agricultural/livestock production per MWh	1.63E+02	US$2000 per MWh
COST OF EMISSIONS		
Annual damage cost (external)	0.02	million US$2000
External cost of loss of life per MWh	7.01E-01	US$2000 per MWh
TOTAL EXTERNAL COST PER MWH	1.64E+02	US$2000 per MWh

has a significant role in raising the cost of electricity generation. The other external costs including displacement, loss of land and loss of life have a slight impact in the overall external costs.

CONCLUSION

Besides the obvious, short-term benefits of large dams, there are lots of "hidden" or external costs of dam projects including the actual cost of building the dams, paying for the massive replacement, loss of life and products as well as adverse socio-cultural impacts. Nowadays, by quantifying the hidden impacts and calculating the actual costs incurred to produce one kilowatt hour of electricity, it is attempted to shift attentions from apparent, short-term economic profits of large dams to their actual impacts and costs including ecosystem collapse, social upheaval due to massive relocations, the unnecessary risk of dam-related hazards, project cost over runs, and poor returns on investment, etc. Despite the large number of conducted studies, there is still a need for conducting a comprehensive study to consider and quantify all aspects of social, economic, cultural and environmental impacts of large dams. The present study was performed to estimate the external costs of generating electricity by Alborz Hydropower Dam. The obtained results indicated that the external cost of 1 MWh electricity generation is US$ 165. Loss of agricultural production has the largest share in the overall costs. In other words, socioeconomic cost of electricity generation by Alborz Dam is US$ 4.8 million/ year. Considering that the obtained values is far more than the actual social cost of fossil fuel power plants, and despite very high potential and computational capabilities of SIMPACTS Software, it seems that there is a need to modify and improve its capabilities. It is recommended to reformulate and incorporate the positive impacts of large dams including economic issues (increased cultivated area, aquaculture, etc.) and safety impacts such as flood control, into the SIMPACTs Software, as well. It should be noted that other benefits such as continues potable water supply to the local people should also be considered. The SIMPACT Software is a powerful tool for the assessment of negative impacts of hydro power dams and more research should be carried out to increase its ability for better assessment of impacts. It is our pleasure to announce that a research work has been initiated to increase the capability of the software.

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