DEVELOPMENT OF NEW MODEL FOR COMPUTATION OF EXTERNAL COSTS OF HYDROPOWER DAMS

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Abstract: Construction of hydropower dams is inevitable in areas with low precipitation. These types of constructions can impose external costs to local people. In order to estimate the external costs, it is necessary to identify and calculate not only the impacts of pollutants and destruction of different environmental units but the advantages of dam construction for the net benefit, as well. In order to compute the true external costs of hydropower dams, the earlier software known as SIMPACTs was revised. The new software is called HECAM that stands for Hydropower's Environmental Costs Analysis Model. In the present investigation Alborz dam that is located in northern part of Iran was selected as the case study. The external cost resulted from the calculation as per in the SIMPACTs Model is US$/ MWh164 US $/ KWh or 0.16 or 49 million dollars in a year. had It ought to be pointed out that original model had some bugs,which were removed. Eliminating the bugs from SIMPACTs, furnished US$ 1/KWh instead of US$ 0.16/KWh. It should be noted that this figure does not include advantages and disadvantages of dam construction of dam. Besides, HECAM model encompasses the costs of electricity generation, irrigation and drainage, aquatics and potable water. Moreover, incomes due to the sale of electricity, the exclusion of pollutants, the development of cultivated area, the sales of aquaculture products and potable water, and flood prevention are also included in this new model.

Keywords: *Social, Economic, External, Costs, Hydropower, HECAM*

Introduction

The construction of dam and the other related projects has always been associated with positive and negative consequences [1]. These impacts, in their turn, affect the physical, biological and socio-economic environments [2].The diverse consequences of a dam construction plan forcefully imposed on a community which are due to lack of a just and proper management namely are: poverty, risk of losing land, home and plants, employment, pastures and natural resources, lack of food supply, prevailing of diseases, increase of death, missing educational opportunities, child labor to compensate family budget deficit, Loss of cultural and social identity, abusing resources and creating ecological pollutions, reducing the safety and security of region, etc. [3].For the first time the social-environmental assessment of dams took place in the developing countries in the early 1970's in order to requests from the international financial organizations, The World Bank, the domestic development banks of Salogin in western Java, Mahaveliganga in Sri Lanka, Sobradinho in NW Brazil and Salto Grande ,as a joint development between Argentina & Uruguay [4].

There are several experiences out of social remarks in the world [5].One of the important social dam building experiences is the constant management of reservoirs in Japan. The Japanese government had to negotiate with the community inhabitants for the construction of a dam across the Tsurumi river to convince them for this construction in that region from 1970 to 1999 for 29 years. The Japanese had to organize over 600 meetings to discuss the matter in the communities. Important issues and social considerations in dam projects in Japan is noticeable, to such an extent, that the water companies of this country don't assign social studies of these projects an "outsider" , instead, the water companies' managers and staff committed themselves to handle this studies [6].

Many rivers and dams of Iran are situated in the countries border provinces and these regions are mainly inhabited by the Much of the Iranian ethnics [7]. In the contemporary history, in certain parts of these regions we have had costly tribal challenges and if the social planning of dam construction are not

appropriate, there will be diverse consequences and costs which will lessen the profit[8].
Most studies of social impacts assessments about the dams are dealing with the direct evident impacts on the social groups and the recommendations for the progress and execution of future control planning, set forth to reduce them (like the planning aimed at replacing the community's population from the underwater regions, medical aides, damage compensation strategy, etc. [9].

There is not any uniform record from the research of social impacts assessment. But, it seems that the results of social discussions not being quantified in the analysis of benefit relative to the cost of dam-projects, the final results are questionable and challenging [10]. Therefore, having considered the importance of this subject, and though most procedures and tools have been utilized by different researchers so far, the SIMPACTS has been recognized as one of the most suitable and the users' most favorite software due to being quantitative [11]. On the other hand this model due to its versatility can provide likely adding new parts and corrections [12]. The present paper is dealing with the description of the different parts added to the model including: electricity, aquacultures, irrigation and drainage, potable water, flood , and how to calculate the cost-benefit arising from each part.

Materials and Methods

The area of Alborz dam is geographically situated in 36.08 up to 36.45 degrees latitude northerly, and 52.36 up to 52.57 degrees longitude easterly [13]. This region is situated in Mazandaran Province according to the country's geographic division map, and extended to the Caspian Sea in the north, to the Alborz mountains in the south, to the Siyah-rud river in the east and the Babol river on the right side (Image 1). The area under study, has main connecting roads to the surrounding cities and the inter-cities and local villages within the region, and it is situated at 180km from Tehran on the north-east, and it is connected to Amol city via Haraz road and to Qaem-Shahr city via Firoozkooh road. The area of Alborz project , under study, is geographically situated in 4 countries: Babolsar, Babol, Qaem-Shahr and Savad-Kooh . All the regions including villages and cities are situated between the left bank of the Siyah-rud river at the east of the area and the right bank of the Babol river at the west of the area. The region, under study, includes six cities and about 351 Villages.

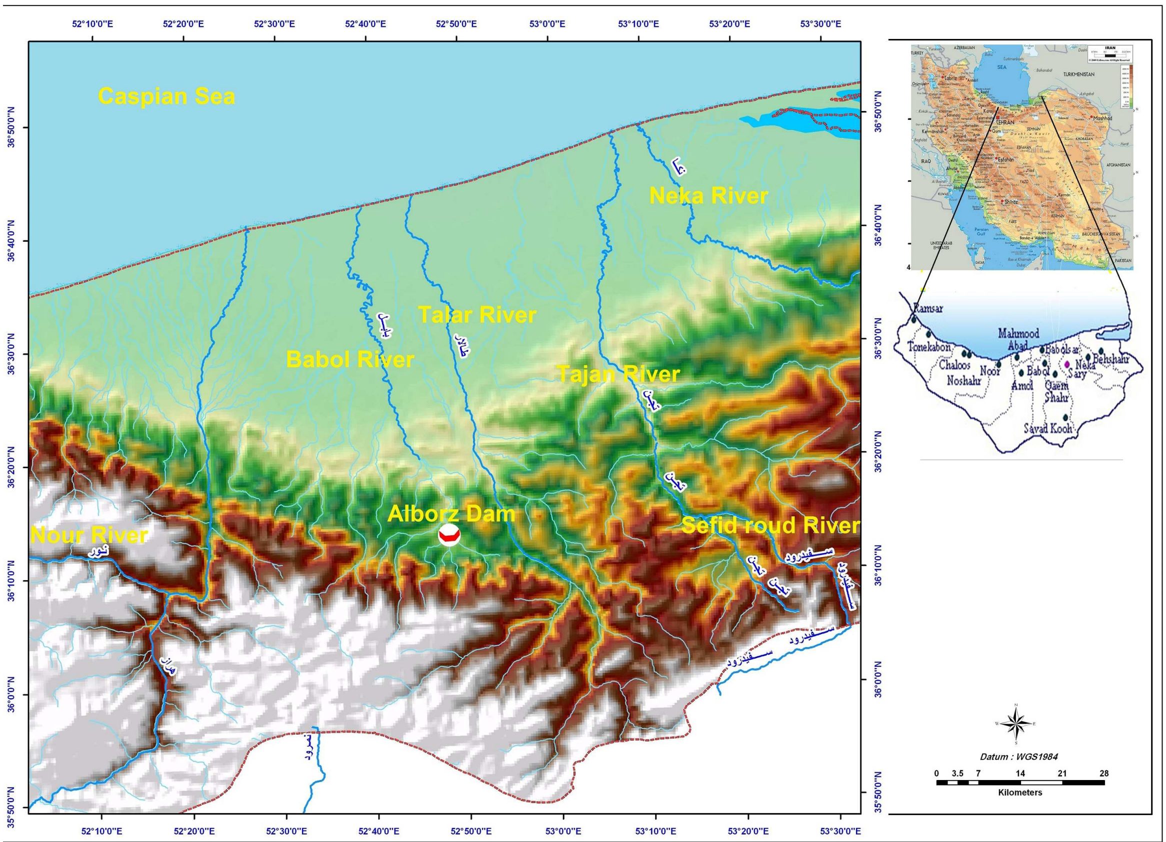

Image 1: the location of Alborz dam in Mazandaran Province

In line with the estimation of Alborz dam's actual social and economic costs, as well as, the calculation of net benefit, the following "parts" are added to the previous model:

Electricity part

Generally, the economic parameters of hydro-power plants are defined in terms of the costs and benefit of the construction of hydropower plants [14].The costs relevant to the costs of preliminary investments, the interest rate of construction period, and the present value of reconstruction and maintenance of hydropower plants are meant in the operational period in these definitions. Also, the benefit of erection of the power plants is deemed from the sale of generated electricity, and the reduction of social and environmental costs arising from the controlling of pollutants of the energy generated by the replaced thermal power plants. In this study, the procedure of Constant Monetary Amounts, is used. The costs include two constant and variable resultants [15]. The constant cost includes investment and fixed maintenance cost (mainly personnel's costs); and variable cost includes fuel and variable maintenance costs (spare parts & repair) [16] .The constant resultant which is at one kilowatt of the net valid capacity, and the variable cost which is at the operation of one kilowatt of the net capacity over the year are calculated with the presumed generation factor (net energy), and, in general, it is taken as a criterion for the cost calculation, as following equation:

TEH (MW/h) = PGH x PFH x AFH x 8760 Eq.1

PGH (power plants rated capacity) = 10 MW

PFH (annual generation capacity) = 35 %

AVFH (accessibility factor of power plants in a year) = 94%

TEH = (energy generated by power plants)

It's worth mentioning that the average accessibility factor in a year is a function of the emergency shot down rate and annual maintenance which is calculated equal to 94% for hydropower plants[17]. Having regarded that at the calculation of costs, the inclusion of inflation rate is not needed , the interest rate is used, instead. The annuity calculated with a constant factor (the present value factor) is equivalent to the present value of fixed and variable costs. The total income, arising from the erection of the power plants including a: sale of electricity, and b: lack of greenhouse gas emission, is deemed as follows.

Where, the total income is calculated equivalent to 6,708,957.00 US dollars. The income arising from the sale of electricity generated by the power-plants is taken as an advantage in the generated incomes due to the dam construction. Thus, the calculation capability of this benefit is included in the new model. In this study the sale price of electricity is deemed at cent/kWh 5. Of course, this price is being increased in our country and will make benefit go up, as a result of the dam construction. As the energy generation rate of this power plants is equal to MWh 28820 the sale condition of electricity is deemed at c /kWh 5.

Therefore, an income is resulted due to the sale of electricity which is calculated and is equivalent to 1,441,020 U S dollars. One of the most important benefits of hydropower plants construction is the lack of emission of greenhouse gases, because fossil fuels are not used [18]. The controlling of pollutants emission is actually the advantage of hydropower plants as it is considered a clean energy and has very little pollution in comparison to the similar power plants . On this basis, the benefit arising from the lack of pollution emission from the energy generated by thermal power plants is deemed equal to hydropower plants.
The figures represent the energy balance sheet of the year 2012. In the Table(1),the average index of greenhouse gas pollution of Iran during the year 2011 is included.

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Table(1): index of emission of gas pollution and the greenhouse impacts related to the country's power plants sector in the year 2011:

kilowatt/h.

C	NO_2	CH4	CO_2	SPM	CO	SO_3	SO_2	NO_x	**Types of powerplants**
									Ministry of Energy
222.88	0.004	0.021	817.226	0.162	1.458	0.031	6.79	2.544	Thermal
238.976	0.003	0.021	876.245	0.157	0.123	0.024	1	3.159	Gas
134.331	0.002	0.013	492.548	0.096	0.073	0.013	0.337	2.994	Combined cycle
203.799	0.006	0.032	747.264	0.281	0.001	0.068	4.431	1.467	Diesel
213.923	0.003	0.019	784.386	0.147	0.064	0.023	1.153	2.644	Private sector
210.808	0.001	0.012	772.964	0.075	0.318	0.001	0.07	2.829	Macro Industry
195.321	0.003	0.018	716.178	0.135	0.653	0.023	3.119	2.792	Total average mean

And having regarded the world's market of carbon sale which is equal to US$ 13-22/ton,is also available in the model data input, the sale price of carbon is selected at US$/ton 20. Finally the CO_2 rate which is generated by the similar thermal power plants in a year, it is deemed as an income due to dams construction. The income arising from controlling of ecological pollutants . The income due to controlling of ecological pollutants is equal to 5,267,937 dollars which is calculated according to the formula mentioned below. Where, this figure is considered as a benefit from the pollutants exclusion.

$$Rev._{Pol.} = C_P \times T_{emis.} \quad \text{Eq.2}$$

Where;

$Rev._{Pol.}$= revenue from decreased pollutants, C_P= Carbon price, $T_{emis.}$= The total amount of CO_2 equivalent emissions in dollars

Table (2): Data required for the model of electricity part

Input data		
Powerplants rated capacity	**10**	MW
Annual generation factor	**35**	%
Accessibility factor	**94**	%
Annual energy generation	**28820.4**	MWh
Annual interest rate of investment costs	**10**	%
Annual Discount rate	**10**	%
Powerplants beneficial life	**50**	year
Dam beneficial life	**100**	year
Cost of powerplants investment	**600**	$/KW

Cost of dam investment	**400**	$/KW
Cost of constant operation	**1.958**	$/KW-Year
Cost of variable operation	**0.00026**	$/KWh
Cost of powerplants reconstruction	**25**	% of inv.
Reconstruction period	**25**	year
Powerplants construction period	**4**	year
Dam construction period	**5**	year
Study period	**50**	year
Factor of powerplants payment cash flow	**1.165644056**	-
Factor of dam payment cash flow	**1.213832103**	-
Sale price of generated electricity	**5**	$C/KWh
Emission of Co2 pollutant at thermal powerplants	**912.152**	gr/KWh
Emission of SOX pollutant at thermal powerplants	**3.142**	gr/KWh
Emission of NOX pollutant at thermal powerplants	**2.795**	gr/KWh

Irrigation and drainage and agricultural development part

The purpose of performance of Alborz irrigation and drainage system project is to improve and develop the agriculture within the downstream region of Alborz dam and Ganj Afrooz diversion dike. This subject is not seen in the main model , but it is highly important to mention to the advantage of agricultural development in the downstream of dam due to dam construction; and the calculation of benefit resulted from its external cost due to dam construction. Therefore, a part in the name of *irrigation and drainage* is included. Certain sections are allocated to include the cost of water transfer in US dollar, the increase rate of under cultivation area, the production rate and the price of any kind of products. Finally, the annuity cost of water transfer is calculated and the annual total income of every product is also calculated and included, and then the grand total of the income arising from this section is determined. In the model it is presumed that the cost of water transfer including diversion tunnels and pumping is performed once over the study period. Thus, the present value of annuity cost is calculated and it is calculated in terms of the annual cost of irrigation and drainage of agricultural development. Therefore, this equation is used.

TCI & D = WTC* A (50) ($) Eq. 2

TCI & D: The present value of annuity for irrigation & drainage cost

WTC : Water transfer cost ($)

A(50) = annuity factor in study period

The income due to erection of installations associated with water transfer and drainage for the development of the area of under cultivation of ten products is included in the model. Therefore, equation below is used.

TBI & D = ∑ (Ai*Pi*Pri) Eq.3

Where:

Ai : area, under cultivation, rate of product in i (km2)

Pi : Production rate of product in I (tonnage/km2)

Pri: Price of product in i ($/ tonnage)

Based on the hypotheses and studies, the present values of cost and annual income in the model, the amounts equivalent to 100,859 dollars and 53.080.800 dollars will be obtained, respectively.

Table (3): The data required for irrigation & drainage part

input data		
Cost of water transfer	1000000	$
Increase rate of under cultivation area of product 1	20	Km 2
Production rate of product 1	30	tons/Km 2
Price of product 1	2000	$/tons
Increase rate of under cultivation area of product2	30	Km 2
Production rate of product2	30	tons/Km 2
Price of product 2	1520	$/tons
Increase rate of under cultivation area of product3	30	Km 2
Production rate of product 3	50	tons/Km 2
Price of product 3	1000	$/tons
Increase rate of under cultivation area of product 4	1	Km 2
Production rate of product 4	12	tons/Km 2
Price of product 4	4400	$/tons
Increase rate of under cultivation area of product 5	5	Km 2
Production rate of product 5	12	tons/Km 2
Price of product 5	1500	$/tons
Increase rate of under cultivation area of product 6	10	Km 2
Production rate of product 6	900	tons/Km 2
Price of product 6	680	$/tons
Increase rate of under cultivation area of product7	50	Km 2
Production rate of product 7	950	tons/Km 2
Price of product 7	900	$/tons
Increase rate of under cultivation area of product 8		Km 2
Production rate of product 8		tons/Km 2
Price of product 8		$/tons
Increase rate of under cultivation area of product 9		Km 2
Production rate of product 9		tons/Km 2
Price of product 9		$/tons
Increase rate of under cultivation area of product 10		Km 2
Production rate of product 10		tons/Km 2
Price of product 10		$/tons

Cost calculations		
Annuity cost of water transfer	100859.174	$
Total annual cost	100859.17	$
Income calculations		
Annual cost of product 1	1200000	$
Annual cost of product 1	1368000	$

Annual cost of product 1	1500000	$
Annual cost of product 1	52800	$
Annual cost of product 1	90000	$
Annual cost of product 1	6120000	$
Annual cost of product 1	42750000	$
Annual cost of product 1	0	$
Annual cost of product 1	0	$
Annual cost of product 1	0	$
Annual grand total of income	53080800	$

Fishery part

Besides, their original uses in preventing rivers from overflowing, and their water storage purpose, different dams also provide an appropriate condition for fish farming, which can create a suitable income source for the communities of catchment area [19].Indeed , this income which has not been seen in the model of International Nuclear Energy Organization can be considered another advantage among the others.

Also the cost of construction of fish farming pools, annual maintenance, and the cost of materials required for these pools should be included in the models and also the benefit arising from the production rate of any kind of fish, and its unit price is calculated in the model, too; and ultimately the total income due to the fishery is calculated in this part.

Table(4) : Data required for fishery part

Note: the figures in blue are input

Input data		
Cost of construction of fish farming pools	**10000**	**$**
Cost of annual maintenance	**800**	**$**
Cost of annual materials and equipment required	**5000**	**$**
Cost calculations		
Annuity cost of construction of fish forming pools	1008.59174	$
Annual total cost	6808.59174	$

Therefore,

TCF = TIF *A(50) + FVOM + DVOM ($) (Eq.4) is used; Where

TCF : annual cost ($)

TIF : Cost of construction of pool and installations required ($)

FVOM: Cost of annual maintenance ($)

DVOM: The cost of annual materials needs

A (50): annuity factor in study period

The income of this part dealing with the developed model is calculated for farming of ten types of fish.

Flood part

Regarding that the reservoir capacity of the dam is about 150m.m3 and its storage capacity is 122 m.m3 , the designed discharge of spillway is m3/s 1010 which is dealt with a max flood at m3/s 1465.Moreover, for the safety of Alborz dam against flood, the max. flood is assessed through fulfilling the studies about the flood trend and intake hydrograph; and consequently a proper Free Board part is at the altitude higher than the determined maximum safety of dam. The altitude is designed at 305.9m above the sea level at the dam spillway. It can be noted that the dam construction is a cause of reducing of the max flood at the rate of m3/s 455. This makes the downstream of dam remain without damage, and having performed the calculations, it is finally determined that the total damages can be equivalent to 12430000 US $.This figure is deemed for a damage as a result of flood in a course of 30 year period. However , it is included as a benefit of the dam construction at the present annual value in the 50 year of the study period. Thus,

TFDC = FDC*[1+ 1/(1+i) 30 * A (30)/A(20)] ($) Eq.5 is applied.
TFDC : present annual value of flood damage ($)
FDC : damage caused by flood in one period.
(30 years is deemed a period) .

As the flood period is deemed equal to 30 years , and as this dam in the study period is 50 years, therefore flood can occur in the downstream for 1.052 times in the lifetime. Therefore, the cost is calculated according to the flood probability frequencies, that can be repeated in the dam's useful life. This is the cost which is clearly overlooked in the benefit calculation in the original model due to the flood prevention. Consequently, the annual income for the dam prevention is 1.3 m $ dollars equivalent to 45.9 $dollars at megawatt due to dam construction.

Table (5): some input data in flood part

Note: the figures in blue are input

Input data		
Damage due to flood in one period	12480000	$
Flood period	30	year
Income calculations		
Annual income for preventing flood	1323869	$
Annual energy generation	28820.4	MWh
Annual total income	45.93513685	$/MWh

Potable water

- In this part the cost of water transfer, the cost of annual maintenance on the equipment of water transfer are calculated in the present value of cost annuity for the transfer of water. Then the income arising from the increase of salable water supply versus the rate of water sale are calculated and the income arising from potable water is calculated annually. Thus, Eq.6 is used.

- TCSF = TISF * A(50) + FOMSF + VOMSF $
- TCSF : annual cost of water transfer ($)
- TISF : cost of construction and water transfer installations ($)
- FOMSF : annual cost of maintenance on the transfer installations ($)
- VOMSF : annual cost of material and equipment required ($)
- A (50) : annuity factor in the study period

Having regarded the hypotheses included in the model of annual cost of potable water transfer to the other regions, which is calculated equal to 3013 dollars, the annual income arising from the water transfer is included in the model as the following term: The total annual income of potable water = increase of salable water supply m3* rate of water sale $/ m^3.

Table (6): Input data of potable water port

Note: the figures in blue are input

Input data		
Cost of water transfer	15000	$
Annual cost of maintenance	700	$
Annual cost of materials and equipment	800	$
Calculation of cost		
Annuity of cost of water transfer	1512.88761	$
Total annual cost	3012.88761	$

Calculation of income		
Increase of capacity of salable water supply	5000	m^3
Rate of water sale	0.5	$/$m^3$
Grand total of annual income	2500	$

Results & Discussion

As mentioned earlier, underestimating real cost of dam construction as well as lack of attention to the resulting benefits are of major criticisms of the original SIMPACTS Software. results costs and revenues of Alborz Dam in the SIMPACT and HEKAM model are here discussed in details.

Table (7) : costs of dam construction divided into the parts affected

The final costs of dam construction divided into the parts affected

area	description	dollar	Dollars per MWh of powerplant
original software	**reservoir/environmental damage**	**30837951**	**1005.80**
Developed software	**Electricity generation**	**1234313**	**42.83**
	irrigation & drainage	**100859**	**3.29**
	aquatics	**6809**	**0.22**
	potable water	**3013**	**0.10**
	total cost	**1344994**	**43.87**
grand total cost		32182945	1049.67

Table (8) : the incomes arising from the different parts in the completed software

description	dollar	Dollars per MWh of powerplant
Sale of electricity	1441020	47.00
Income arising from pollutants exclusion	5267937	171.82
Development of the area under cultivation	53080800	1731.27
Sale of aquatics	36000	1.17
Sale of potable water	2500	0.08
Flood prevention	1323869	43.18
Total income	61152127	1994.52

Table (9) : the economic indices in the completed software

The economic indices in the completed software	
description	$
Total costs	32182945
Total income	61152127
Net benefit	28969181
Ratio of benefits to costs	1.90

Conclusion

In the model pertinent to the International Nuclear Energy Organization, the software is without removal of the problems , in general, it has been replaced as a license in order to not allow to be used by the public. The complementary results the reservoir and environmental damages;of the Alborz dam is US$/MWh /164 that indeed is the cost at 0.16 dollar for generation of electricity at a kW/h, having removed the problems the latter figure is reached US$/MWh /1000. However, this figure is converted into $1 in MW/h having removed the model's bugs. It should be noted that this figure is without inclusion of disadvantages and advantages in the new model. But, as it has been mentioned earlier, SIMPACT software has had only the dam disadvantages at the calculations of the external costs. bearing in mind that the cost of electricity generation, irrigation and drainage, aquatics and potable water are added to this mode and Also, on the other hand, the incomes arising from selling electricity, excluding pollutants, developing the area- under cultivation, selling aquatics, selling potable water and preventing flood are included,The new model named (HEKAM) has generated. So, the total costs including these costs added, the new model touches 1049 US dollars per

MW/h. And, the complex income due to the cases mentioned and added above, it amounts to 1994 us dollars. Therefore, the rate of benefit of construction of this dam relative to the costs is equivalent to 1.5 Or alternatively it is indeed, the benefit less cost, which is equal to 28 m. dollars net profit or annual net benefit arising from the project. Where, it has been overlooked in the SIMPACT model as a whole. The results of the developed model are included in the tables above, herein after. As it is noticed, the damages of reservoir and environment have the highest share. The most benefits arising from the construction of dam are dealt with the increase of products area, under cultivation in the region having considered the model's hypotheses. It is worth mentioning, that the main objective of construction of the dam is the development of agriculture within the downstream, too. Though the generation of electricity has been the project auxiliary objective, its product creates a noticeable benefit for the project.

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