ECOLOGICAL AND ECONOMIC FEASIBILITY ANALYSIS OF IRRIGATION ENGINEERING PROJECTS

CHEN, D.[1,3] – LI, X. C.[1] – LUO, Z. H.[2,3*] – CHEN, J.[1]

[1]*Key Laboratory of Efficient Irrigation-Drainage and Agricultural Soil-Water Environment in Southern China (Ministry of Education), College of Agricultural Engineering, Hohai University, Nanjing 210098, Jiangsu Province, P. R. China*

[2]*College of Resources and Environmental Sciences, Nanjing Agricultural University Nanjing 210095, Jiangsu Province, P. R. China*

[3]*Department of Agricultural and Biological Engineering, The University of Florida Gainesville 32611, USA*

**Corresponding author*
e-mail: lzhui@njau.edu.cn; phone: +86-25-8439-5815

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Abstract. Irrigation improvement has been identified as an important adaptation strategy for the food and water security under climate change. Ecological and economic feasibility analysis of irrigation improvement projects is of vital importance to ensure the high investment efficiency and the sustainability of irrigation development. This study integrated emergy, economic and sensitivity analysis methods into a combined analysis. A case study on a small-scale irrigation project in plain areas of Jiangsu Province in China illustrated the methodology. The results indicated that different calculation results were obtained by using emergy and economic analysis methods, respectively. The conventional monetary-based analysis method could underestimate or overestimate the assessment indicators. Emergy as an eco-centric method could neglect the economic utility, human preference and demand. Economic analysis and emergy accounting as the complementary valuation methods should be jointly used to provide better insights into the environmental and economic effects of irrigation improvement projects.
Keywords: *water scarcity, eco-efficiency, emergy, benefit-cost ratio, sustainability*

Introduction

Debate about global water scarcity and food security has intensified in recent times (Steduto et al., 2017). Irrigation stabilizes crop production, improves crop quality, reduces rural poverty, and allows for diversification in farm production (Zhu et al., 2013). Yet continued increase in demand for water by non-agricultural uses have put irrigation water demand under greater scrutiny and threatened food security (Hanjra and Qureshi, 2010). Investments in irrigation infrastructure and management can minimize the impact of water scarcity and partially meet water demand for food production (Falkenmark and Molden, 2008). Irrigation improvement has been identified as an important adaptation strategy for the food and water security under climate change (Chen et al., 2014b, c). As the most populous country in the world, China faces the same challenges for food and water security (Peng, 2011; Zhu et al., 2013). The amount of water used for agriculture accounts for more than 62% of the total water use in China; the average efficiency of irrigation water use is 0.50, and the amount of available water per m^2 for the arable land is only 2 m^3 (Wang, 2012). Hence, the Chinese government issued its first national outline for agricultural water-saving development (2012–2020) in December 2012. The irrigated area will increase from 6.17E + 11 m^2 in

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2012 to 6.67E + 11 m^2 in 2020, and the efficiency of irrigation water use will rise from 0.50 in 2012 to 0.55 in 2020 (Chen et al., 2013). The investment in agricultural water-saving and irrigation improvement projects are expected to increase greatly in the near future. Scientific analysis of these projects is of vital importance in order to ensure high investment efficiency and the sustainability of irrigation systems.

A variety of methods have been developed to assess irrigation improvement projects, such as discount cash flow analysis, cost and benefit analysis, cost recovery analysis, and real option analysis, optimization methods, the analytic hierarchy process, linear programming, indicator systems, and synthetic evaluation approaches (Chen et al., 2011, 2014b; Abou El-Hassan et al., 2015). Yet these methods focus on the economic values or the monetization of non-economic values of material and resource uses. Natural, social and economic conditions are primary factors in the feasibility analysis of irrigation improvement projects. It is therefore essential to consider both the economic efficiency and the environmental sustainability of project implementation.

Emergy, based on the thermodynamic theory, measures both the free environmental and purchased inputs in the common unit of solar emergy (Chen et al., 2016). It is defined as the available energy of one kind that is used up in transformations directly and indirectly to make a product or service (Odum, 1996). It could put all products of nature, technology, and the economy on a common basis of the prior work required and embodied water (Buenfil, 2001). It has been proven to be a suitable parameter or index to assess the sustainability of water-related projects (Brown and McClanahan, 1996; Kang and Park, 2002; Martin, 2002; Chen et al., 2009, 2011, 2012, 2013, 2014b, 2016; Lv and Wu, 2009; Brown et al., 2010; Pulselli et al., 2011; Arbault et al., 2013; Díaz-Delgado et al., 2014). However, emergy as an eco-centric method could neglect the economic utility, human preference and demand. Conventional economic analysis is also needed as a complementary method for the emergy evaluation of projects. Therefore, this study uses both emergy and economic analysis methods to provide better insights into the feasibility of irrigation improvement projects.

The main objectives of this study are to (1) develop policy decision-making tools for feasibility analysis of irrigation improvement projects, (2) present a comparative analysis of evaluation results using emergy and economic analysis methods, and (3) discuss the related problems and recommendations in policy decisions and project management. The remainder of this paper is organized into the following sections. Section 2 presents a brief overview of the study area and the methods, including the emergy analysis method, the economic analysis method and the sensitivity analysis method. Results are presented and discussed in Section 3. Section 4 concludes by summarizing the main results and pointing to some suggestions based on the emergy and economic evaluations.

Materials and methods

Study area

The study area is located in Taixing City of the Jiangsu Province, China (31°55’N, 119°38’E). It is in the subtropical monsoon climate zone. The annual average temperature is 14.9 °C. Sunshine occurs on an average of nearly 2125 h a year. The frost-free period is about 220 days. The average annual precipitation is 1027 mm, but it rains mainly in the period from June to September. It is located in the plain areas with a seasonal water shortage characteristic. Thus, irrigation is essential for the agricultural

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production especially in dry years. Irrigation is accomplished by pumping water from the local river, mainly extracting water from the lower Yangtze River in dry seasons. The irrigation system in this case consisted of a pumping station and earth canals. The pumping station was originally constructed in the 1980s and ran at 56% efficiency in recent years. Due to the seepage in sandy soil, the water conveyance efficiency in earth canal system (the ratio between the water delivered to a farm or field and that diverted from the irrigation water source) was only 5%. Hence an irrigation improvement project was done to upgrade the irrigation system with a new pumping station and concrete-lined canals. Increasing both water efficiency and agricultural production were the main objectives of this project. In this study, this project is subjected to both emergy and economic analyses to evaluate its feasibility. The main data and materials originate from the planning and design report of this project and field survey data. Field survey involves local data collection, unstructured interviews on farmers, field measurements and sample analyses. Policies and practices information about planning, construction and management of irrigation projects are mainly from local department of water resources. Statistical data in agricultural production are mainly from local department of agriculture. The interviews offered some questions in relation to the topics, including operation of the old irrigation system, situation of water supply and demand, inputs and outputs in irrigated farming, and viewpoints on the irrigation improvement project. Data about operation time, electricity consumption and volume of water supply of the pumping station were obtained from the managers and supervisors in the village. Field measurements were mainly conducted on the area and size of the puming station and canals. Sample analyses of earthworks and construction materials were performed by the local quality monitoring station of construction projects.

Emergy analysis method

Emergy analysis is a top-down systems approach. Its general methodology can be found in detail in the original work (Odum, 1996), and in a series of emergy folios (Odum, 2000; Odum et al., 2000; Brown and Bardi, 2001; Brandt-Williams, 2002). Emergy analysis can identify and compare the contribution of natural resources and ecosystem services to a production process in the common unit of solar emergy. The unit of emergy is the solar emjoule or emergy joule (abbreviated sej) (Odum, 1996). Using the unit of emergy (sej), any resource, material and energy can be put on a common basis by expressing each of them in the emjoules of solar energy that is required to produce them. The costs and benefits of irrigation projects can be calculated and compared based on the emergy theory. The primary costs of this project can be divided into: the costs of construction, e.g. materials, machinery costs and installation services; and the operation and maintenance costs. The benefits include: the benefits of saving water and energy due to increasing water use efficiency; the benefit of arable land increase if concrete-lined canals reduce the canal width; and the benefit of agricultural yield increase due to the improved water-supply and farming conditions. By multiplying these items in Joules (or directly from its mass) by specific transformities, the solar emergy of each cost and benefit can be calculated. Values of transformities are mainly derived from previous studies of emergy evaluations. The global emergy baseline of reference used here is 9.44 E + 24 sej/year.

To evaluate the feasibility and eco-efficiency of projects, a composite index named the emergy cost-benefit ratio (*EmCBR*) is proposed based on the conventional cost-benefit analysis, using *Equation 1* (Chen et al., 2011).

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$$EmCBR = \frac{B + RV}{C} \quad \text{(Eq.1)}$$

where *C* is the emergy cost of the project; *B* is its emergy benefit; and *RV* is its residual value of the fixed assets. *RV,* approximated 10% of the construction cost, is the value this project should have at the end of its useful life. This irrigation project was assumed to have a 30-year life span under the effective maintenance and management. Thus, each item was divided by 30 to present data on a yearly basis. A value *EmCBR* = 1.0 is the lowest value for which the project is feasible. Based on the life cycle theory, projects with *EmCBR* greater than 1.0 are sustainable (Chen et al., 2011, 2014a).

Economic analysis method

The cost-benefit analysis is used in this study to measure the positive or negative consequences of irrigation projects. The costs and benefits of this project are accounted in monetary units. Three indicators are selected to help the economic feasibility analysis:

Net present value (NPV)

NPV is the sum of discounted net benefits: the difference amount between cash inflows and cash outflows, in *Equation 2*. If the *NPV* of a project is positive, it may be accepted. However, if its *NPV* is negative, the project should be rejected.

$$NPV = \sum_{t=1}^{n} (CI - CO)_t (1 + i_0)^{-t} \quad \text{(Eq.2)}$$

where *CI* is the cash inflows, *CO* is the cash outflows, *t* is the time of the cash flow, $(CI\text{-}CO)_t$ is the net cash flow at time *t*, and i_0 is the basic discount rate. 7% or 12% are recommended as the basic discount rate for the water conservancy projects in China.

Internal rate of return (IRR)

IRR is the discount rate that makes the net present value of all cash flows from a project equal to zero, in *Equation 3*. The higher a project's *IRR*, the more desirable it is to undertake the project.

$$\sum_{t=1}^{n} (CI - CO)_t (1 + IRR)^{-t} = 0 \quad \text{(Eq.3)}$$

Benefit-cost ratio (BCR)

BCR is the ratio of the benefits of a project relative to its costs, in *Equation 4*. All benefits and costs should be expressed in discounted present values. Projects with a *BCR* greater than 1 have positive net benefits. The higher the *BCR,* the more profitable will be the investment on projects.

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$$BCR = \frac{\sum_{t=1}^{n} B_t (1+i_0)^{-t}}{\sum_{t=1}^{n} C_t (1+i_0)^{-t}} \quad \text{(Eq.4)}$$

where B_t is the benefit at time t, C_t is the costs at time t.

Sensitivity analysis method

The above emergy and economic methods might lead to uncertainty, due to their extensive calculations and data. Sensitivity analysis could be used to test the robustness of the results by these two methods in the presence of uncertainty (Chen et al., 2014c). Through increasing or decreasing the costs or benefits in a certain proportion, a sensitivity analysis was performed in this study to assess the effects of variations on the results.

Results and discussion

The emergy flows of the irrigation project were calculated and presented in *Table 1*. The emergy input structure was then calculated and contrasted. The major cost was the Construction (I) in terms of emergy, 93.4% of the total cost. The Operation and maintenance (II) only made up 6.6% of the total emergy cost. The major specific costs associated with the irrigation project in terms of emergy were soil (37.94%), brick (19.88%) and stone (16.95%). These major inputs are raw materials, which are generally underestimated in conventional economic analysis based on monetary units. For example, the soil loss for the earthwork of pumping station and irrigation canals involved two kinds: the net loss of topsoil and other soil lost from land. The current unit cost of earthwork is lower (1.8 $\$/m^3$ for manual work or 0.9 $\$/m^3$ for mechanical work) than its true value (Chen et al., 2011). The most important benefits were irrigation water saving and rice yield increase in terms of emergy: 55.12% and 39.33% of the total benefit, respectively. These data also confirmed that the main objectives of this project were to increase the water efficiency and agricultural production. However, the calculated *EmCBR* of the irrigation project is 0.54, showing a low efficiency in terms of emergy evaluation.

As shown in *Table 2*, the values of *NPV* were greater than 0 and those of *BCR* were greater than 1, whenever the basic discount rate (i_0) was 7% or 12%. The values of *IRR* were also higher than i_0. These data indicated that the benefits of this project outweighed the costs, further demonstrating that this project was economically feasible.

By increasing or decreasing the benefits or costs in the certain ranges, changes in *EmCBR*, *NPV*, *IRR* and *BCR* were documented in *Tables 3* and *4*. The data showed that the results of emergy and economic analyses, to some extent, were not sensitive to the benefits or costs. It also indicated the robustness of the results using these two methods.

Considering the key indicators, the economic benefit cost ratio of this project was 2.05 (i_0 = 7%) and 1.39 (i_0 = 12%) in *Table 2*, greater than both 0.54 using emergy analysis in *Table 1* and 1.0. The ratios resulted in the opposite conclusion on the project feasibility analysis using emergy and conventional economic analysis methods respectively. The possible reasons include the differences in the accounting units, the estimate of environmental costs, the selection of accounting items and the calculation

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process. Conventional cost-benefit analysis could be used to demonstrate economic feasibility and compare investment opportunities in terms of the time-varying value of money (Chen et al., 2011). Yet some natural resources and environmental impacts could be well appraised in monetary units. The emergy analysis method can measure different forms of energy and resources, including free environmental and purchased inputs, using the unified basis of solar emergy (Chen et al., 2014b). It is also not affected by inflation. A previous study on the emergy evaluation perspectives of an improvement project proposal in a large irrigation district showed the similar assessment results with the values of *EmCBR* (0.97) and *BCR* (1.28), but it has not presented the process of economic analysis and conducted the sensitivity analysis of results (Chen et al., 2011). The emergy theory and method was also used to evaluate the process of water abstraction, distribution and use for irrigated agriculture, which helped the different understanding of the relationship between irrigation projects and agricultural development (Chen et al., 2013). An evaluation of irrigation water in an irrigation system showed the different transformities and emergy values of water in different processes, which provided various water values on the emergy concept (Chen et al., 2014b). An evaluation of three irrigation agricultural systems depicted the emergy contribution of irrigation water rather than the economic contribution (Chen et al., 2014c). These studies confirmed that the emergy theory and method had the merit of objective assessment of natural and environmental resources supporting human activities in terms of the biophysical account of emergy, different from the conventional monetary-based analysis. This method also provided fresh insights into the sustainability analysis of irrigation development. Yet emergy has also suffered a lot of resistance and criticism, such as theoretical arguments, problems of transformity calculations, accounting procedures, co-products or splits treatment, uncertainty, and sensitivity (Hau and Bakshi, 2004; Sciubba and Ulgiati, 2005; Ingwersen, 2010; Rugani and Benetto, 2012). Emergy evaluation is an often-used holistic approach with a uniform unit of measure for quantification or valuation of ecosystem goods and services. However, economic analysis is currently the dominant value measurement system. The application of emergy evaluation in real production and management systems is still limited without the results of economic analysis (Lu et al., 2009). Economic analysis and emergy accounting are complementary valuation methods (Lu et al., 2009; Zhang et al., 2011; Chen et al., 2014c). Integrating the two methodologies into a combined analysis can provide better insight into the environmental and economic effects of irrigated projects. Therefore, the values of *EmCBR*, *NPV*, *IRR* and *BCR* should be served as the feasibility analysis indicators of the projects. A project, only with *EmCBR* and *BCR* greater than 1, *NPV* greater than 0, and *IRR* higher than the basic discount rate (i_0), is considered to be feasible. Moreover, it is of vital importance to select accounting items of the costs and benefits considering the potential environmental and ecological impacts of a project, no matter which method is used in the feasibility analysis of irrigation improvement projects. Lacks of major accounting items can lead to unreliable results of the feasibility analysis, which will negatively affect scientific decision-making in irrigation development. For instance, concrete-lined irrigation canals can reduce seepage during water conveyance, but concrete works might weaken the ecosystem services of unlined canals. Yet it remains difficult to incorporate these ecological effects into the feasibility analysis of projects, due to the valuation complexity needed further studies.

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Table 1. *Emergy analysis table of the irrigation project (all values are on a yearly basis)*

No.	Item	Units	Raw data	Solar transformity (sei/unit)	Solar emergy (sej/year)	Em-value (Em$)
Emergy costs					3.70E+17	1.09E+05
	I. Construction				3.46E+17	1.02E+05
1	Soil	g	1.40E+08	1.00E+09	1.40E+17	4.15E+04
2	Cement	g	1.14E+07	3.04E+09	3.46E+16	1.02E+04
3	Sand	g	3.03E+07	1.00E+09	3.03E+16	8.96E+03
4	Stone	g	3.73E+07	1.68E+09	6.27E+16	1.86E+04
5	Steel	g	6.67E+04	6.94E+09	4.63E+14	1.37E+02
6	Brick	g	2.00E+07	3.68E+09	7.36E+16	2.18E+04
7	Labor	$	4.77E+02	3.38E+12	1.61E+15	4.77E+02
8	Machinery	$	3.46E+02	3.38E+12	1.17E+15	3.46E+02
9	Temporary works	$	3.31E+01	3.38E+12	1.12E+14	3.31E+01
10	Construction management	$	2.03E+02	3.38E+12	6.85E+14	2.03E+02
	II. Operation and maintenance				2.44E+16	7.23E+03
11	Electricity	J	5.97E+10	1.59E+05	9.49E+15	2.81E+03
12	Labor	$	3.06E+03	3.38E+12	1.03E+16	3.06E+03
13	Maintenance	$	1.36E+03	3.38E+12	4.61E+15	1.36E+03
Emergy benefits					1.65E+17	4.89E+04
14	Irrigation water saving	m^3	1.04E+05	8.80E+11	9.11E+16	2.69E+04
15	Energy saving	J	2.83E+10	1.60E+05	4.53E+15	1.34E+03
16	Arable land increase	J	5.59E+10	8.30E+04	4.64E+15	1.37E+03
17	Rice yield increase	J	7.83E+11	8.30E+04	6.50E+16	1.92E+04
Residual value of the fixed assets						
18	Residual value of the fixed assets				3.46E+16	1.02E+04
EmCBR					0.54	

Data sources and calculations are given in the *Appendix*. The raw data are from the planning and design report of this project and field survey. The method of energy transformation refers to (Odum, 1996). Solar transformity is the unit emergy value (sej/g, sej/J, sej/$), which is the emergy required to generate one unit of output. Transformities are from (Odum, 1996; Chen et al., 2014b). Accounting items with raw data are multiplied by transformities to obtain emergy values (sej/year) and divided by emergy/money ratios to obtain emdollars (Em$). *EmCBR* is the emergy cost-benefit ratio, referring to *Equation 1*

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Table 2. *Economic analysis table of the irrigation project*

Ratios	Values	
i_0 (%)	7	12
NPV (10^4Yuan)	50.10	17.19
IRR (%)	18	18
BCR	2.05	1.39

Data and calculations of costs and benefits are in monetary units rather than the unit of emergy, referring to the similar processes in the *Appendix*. i_0 is the basic discount rate (7% or 12% in China). Net present value (*NPV*) is the sum of discounted net benefits, referring to *Equation 2*. Internal rate of return (*IRR*) is the discount rate that makes the net present value of all cash flows from a project equal to zero, referring to *Equation 3*. Benefit-cost ratio (*BCR*) is the ratio of the benefits of a project relative to its costs, referring to *Equation 4*

Table 3. *Sensitivity analysis results on the values of EmCBR*

	+50%	**+20%**	**+10%**	**-10%**	**-20%**	**-50%**
Changes in emergy costs	0.27	0.34	0.37	0.45	0.51	0.82
Changes in emergy benefits	0.61	0.49	0.45	0.37	0.33	0.20

EmCBR is the emergy cost-benefit ratio, referring to *Equation 1*. Through increasing or decreasing the emergy costs or benefits in a certain proportion, the values of *EmCBR* are obtained to assess the effects of variations on the results

Table 4. *Sensitivity analysis results using the economic analysis method (i_0 = 7%)*

		NPV (10^4 Yuan)	***IRR*** (%)	***BCR***
Cost changes	+50%	27.24	11	1.48
	+20%	41.57	14	1.85
	+10%	45.32	16	1.86
	0	50.10	18	2.05
	-10%	54.87	20	2.28
	-20%	60.67	22	2.77
	-50%	75.01	37	4.43
Benefit changes	+50%	100.57	27	3.32
	+20%	70.90	21	2.66
	+10%	59.88	20	2.25
	0	50.10	18	2.05
	-10%	40.31	16	1.84
	-20%	31.34	14	1.77
	-50%	1.68	7	1.11

Net present value (*NPV*), internal rate of return (*IRR*) and benefit-cost ratio (*BCR*) refer to *Equations 2, 3* and *4*, resepectively. The values of *NPV*, *IRR* and *BCR* are obtained through increasing or decreasing the costs or benefits in a certain proportion, to conduct sensitivity analysis.

An integrated feasibility analysis contributes to the objective and rational understanding of the strengths and weaknesses of irrigation engineering projects. However, to date China remains a traditional idea of focusing on irrigation engineering

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technology and constructions and ignoring project management. Scientific decision making of project proposal might not be paid much attention at specific periods. For instance, since 2008 Global Financial Crisis, massive water conservancy projects have been rapidly planed and constructed. To assure the successful delivery of these projects, the life cycle of projects including the phases of planning, design, procurement, construction and operation should be considered into the sustainability assessment. Outcomes of policy decisions in ecological and economic terms could be also identified and valued into the development of a decision making tool. In addition, a sustainable mechanism in the political system is needed for achieve the objectives of projects, incorporating ecological and economic analysis in policy decision-making. More emergy evaluations and economic analyses should be conducted on irrigation improvement project proposals and the corresponding agricultural systems from the perspectives of environmental, social, political and economical aspects. These actions can provide adequate guidelines for the sustainability of irrigation and agricultural development.

Conclusions

It is of vital importance to evaluate the feasibility of irrigation improvement projects to ensure the high efficiency in the investments and the sustainability of irrigation systems. The comparative analysis of the results of evaluation using different methods will help to make the scientific decision. Emergy analysis, as an effective tool different from conventional economic analysis, highlights the role of the natural and environmental resources supporting human activities from the view of sustainable development. In this study the emergy analysis method was used to evaluate the feasibility of a small-scale irrigation project in plain areas of Jiangsu Province in China. An economic analysis was also conducted on this project for comparisons. The results indicated that different calculation results and conclusions were obtained by using the two methods respectively. The conventional monetary-based analysis method could underestimate or overestimate the assessment indicators. Yet emergy as an eco-centric method could neglect the economic utility, human preference and demand. Economic analysis and emergy accounting as the complementary valuation methods should be jointly used to provide better insights into the environmental and economic effects of irrigation improvement projects. Selection of accounting items of the costs and benefits should also receive great attention for the feasibility analysis of projects, considering more environmental and ecological impacts. The policy decision-making incorporating ecological and economic analyses can help achieve the objectives of irrigation improvement projects.

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APPENDIX

Footnotes to Table 1

1 Soil
Soil losses (earthworks) for construction of the irrigation pumping station = 60 m^3
Soil losses (earthworks) for construction of irrigation canals = 1500 m^3
Soil density in the case study = 2.7×10^6 g/m^3
Total weight = (60 m^3 + 1500 m^3) × (2.7×10^6 g/m^3) / (30 years) = 1.40×10^8 g/year
2 Cement
Cements for construction of the irrigation pumping station = 25 t
Cements for construction of irrigation canals = 316.8 t
Total weight = (25 t + 316.8 t) × (1.0×10^6 g/t) / (30 years) = 1.14×10^7 g/year
3 Sand
Sands for construction of the irrigation pumping station = 80 t
Sands for construction of irrigation canals = 829 t

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Total weight = (80 t + 829 t) × (1.0 × 10^6 g/t) / (30 years) = 3.03 × 10^7 g/year
4 Stone
Stones for construction of the irrigation pumping station = 90 t
Stones for construction of irrigation canals = 1030 t
Total weight = (90 t + 1030 t) × (1.0 × 10^6 g/t) / (30 years) = 3.73 × 10^7 g/year
5 Steel
Steels for construction of the irrigation pumping station = 2 t
Total weight = (2 t) × (1.0 × 10^6 g/t) / (30 years) = 6.67 × 10^4 g/year
6 Brick
Amount of bricks for construction of the irrigation pumping station = 4000
Amount of bricks for construction of irrigation canals = 160000
Standard size of a brick = 240 mm × 1150 mm × 530 mm
Total weight = (4000 + 160000) × (240 mm × 1150 mm × 530 mm) × (1.0E + 09) × (2.5 × 10^6 g/m^3) / (30 years) = 2.0 × 10^7 g/year
7 Labor
Labor costs for construction of the irrigation pumping station = 1716.6 $
Labor costs for construction of irrigation canals = 12580.0 $
Yearly costs = (1716.6 $+ 12580.0 $) / (30 years) = 477 $/year
8 Machinery
Costs for three sets of pumps and other machineries used in 30 years = 10367.3 $
Yearly costs = (10367.3 $) / (30 years) = 346 $/year
9 Temporary works
Temporary works for construction of the irrigation pumping station = 992 $
Yearly costs = (992 $) / (30 years) = 33.1 $/year
10 Construction management
Costs for construction management and production preparation = 6090 $
Yearly costs = (6090 $) / (30 years) = 203 $/year
11 Electricity
Volume of pumped water per year = 5.97 × 10^5 m^3
Electricity for pumping water = (5.97 ×10^5 m^3) / (792 m^3/h) × (22 kW) × [3.6×10^6 J/(kW·h)] = 5.97 ×10^{10} J/year
12 Labor
Labor costs for operation = 3060 $/year
13 Maintenance
Maintenance costs for the irrigation pumping station = 253 $/year
Maintenance costs for irrigation canals = 1110 $/year
Yearly costs = (253 $/year + 1110 $/year) = 1363 $/year
14 Irrigation water saving
Decrease of annual irrigation water quotas per area (667 m^2) for this project = 115 m^3
Volume of irrigation water saving = (115 m^3) / (667 m^2) × (900 × 667 m^2) = 1.04 × 10^5 m^3/year
15 Energy saving
Decrease of annual electricity consumption for this project = 7857 kW·h
Energy saving = 7857 kW·h × [3.6 × 10^6 J/(kW·h)] =2.83 × 10^{10} J/year
16 Arable land increase
Increased area = 6003 m^2
Yield per unit = 643 g/m^2 (assumed to be that of rice)
Total energy = (6003 m^2) × (643 g/m^2) × (1.45 × 10^4 J/g) = 5.59 × 10^{10} J/year

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17 Rice yield increase
Increased yield per unit = 90 g/m^2
Total energy = (90 g/m^2) × (900 × 667 m^2) × (1.45 × 10^4 J/g) = 7.83 × 10^{11} J/year
18 Residual value of the fixed assets
Total emergy (assumed to be 10% of the emergy costs of construction) = 3.46 × 10^7 sej/year × 10% = 3.46 × 10^6 sej/year

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