Emergy evaluation of the tidal power plant in Saemanguem, Korea

by

Laura Hija J. Kim

A thesis submitted in partial fulfillment of the requirements

for the degree of

Doctor of Philosophy

in Department of Ecological Engineering, The Graduate School,

Pukyong National University

August 2011

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Emergy evaluation of the tidal power plant in Saemanguem, Korea

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Abstract

The region of Saemangeum for this study is influenced by two major rivers, Dongin and Mankyung. Currently, a 33㎞ long seawall connecting Gunsan and Buan has been constructed for the purpose of reclamation of 283㎢ land area and fresh water reservoir area of 118㎢ for the major national internal development project, planned for its completion by 2030.

The Saemangeum provides an optimal location for tidal power generation with 3.93m tide range and existing seawall, which accounts for a large part of the cost advantage.

In this study, the concept of emergy is used in order to assess the human economic activity and the input from the natural environment on an equal value basis if tidal power plant would be economically feasible for saemangeum as well as its ecologic-economic value.

The study shows that the emergy value of the annual electricity produced by the tidal power plant is 7.22E+20 seJ/yr, which is equivalent to 211 billion Em ₩/yr in terms of emergy-based currency equivalent (ecologic-economic) value.

The EYR (environmental yield ratio) from the tidal power generation in Saemangeum is 5.14, which suggested that the contribution to the economy provided by this alternative energy source is large enough to be able to compete

with other fossil sources.

An ELR (environmental loading ratio) equal to 0.24 indicates a relatively minimal loading on the local environment. The ESI (environmental sustainability index) equal to 21.25 indicates that the sustainability of the system is very high.

Due to the consistent flow of seawater through the tidal power generation plant, tidal flat is expected to rehabilitate its system and restore other marine products as well. As a result of analyzing the recovering productivity of shellfishes, seaweeds and fish production. The total emergy value for those three items were 4.74E+19 seJ/yr and their ecologic-economic value was calculated for the amount of 13.8 billions Em₩/yr.

Furthermore, a reduction of 563,340 tons of carbon emission by the tidal power generation is expected, which would benefit of CDM revenue of 10.2 billion Em₩/yr. Thus, emergy cost and benefit analysis shows high feasibility of the tidal power generation with 3.66 (B/C ratio), confirmed as a net benefit of 171 billions Em₩/yr.

In conclusion, Saemangeum tidal power plant would enable Korea to benefit from natural renewable resources as well as to achieve a considerable reduction of CO_2 emissions. In addition, the circulation of seawater through seawall, the rehabilitation of the tidal flats were damaged from the seawall construction would occur for an ecologic-economic optimism and become a tremendous asset for the present and next generations to come. Furthermore, it would certainly contribute to both developments of the national policy and ecological engineering methods.

새만금 지역의 조력발전에 대한 에머지 평가

로 라 김

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요　약

본 연구 대상인 새만금 지역은 대표적인 간척사업으로 군산과 부안을 연결하는 33㎞의 방조제를 건설하여 간척토지 283㎢와 담수호 118㎢를 조성할 계획이다. 현재 방조제가 완공된 상태이며, 2030년까지 내부개발이 완성될 계획이다.

새만금 지역은 평균조차가 3.93m로 조수간만의 차가 크고 현재 방조제가 이미 완공된 상태이므로 조력발전을 위한 조건이 충분히 갖추어져 있다.

그러므로 본 연구에서는 인간 경제활동과 자연활동을 동일한 척도로 평가하는 에머지 개념을 이용하여 새만금 지역에 조력발전을 시행할 경우에 대한 생태경제적 가치 및 사업의 타당성을 분석하였다.

에머지 분석 결과 조력발전을 통해 생산되는 전기의 에머지는 7.22E+20 seJ/yr로 이의 생태경제적 가치는 2,110억 Em₩/yr 이었다.

시스템의 특성을 나타내는 에머지 지수 분석 결과 Emergy 생산성지수(Emergy Yield Ratio, EYR)는 5.14로 1차 에너지원이며 대체에너지로서의 가능성을 확인할 수 있다. 환경부하비(Environmental Loading Ratio, ELR)는 0.24로 시스템 내에서 지속적으로 공급가능한 조력자원의 의존이 큰 환경에 대한 영향이 매우 적은 시스템이었다. Emergy 지속성지수(Emergy Sustainability Index, ESI)는 21.25로 지속성이 매우 큰 시스템으로 평가되었다.

조력발전을 시행할 경우 꾸준한 해수유통으로 인하여 갯벌회복이 예상되며 그에 따라 복원될 패류, 해조류, 어류의 생산량을 추정하여 분석할 결과 4.74E+19 seJ/yr, 138억 Em₩/yr의 생태경제적 생산성 복원이 기대된다.

또한 새만금 조력발전을 통한 탄소저감량은 563,340 ton CO_2/yr로 연간 약 102억 Em₩의 CDM 수익을 창출 할 수 있으며, 사업의 타당성을 나타내는 에머지 비용·편익 분석 결과 비용편익비(B/C ratio)는 3.66이고, 연간 1,710억 Em₩의 순편익이 나는 사업으로 평가되었다.

결론적으로 새만금 조력발전 사업은 지속가능한 자연에너지를 활용한 전력 확보와 동시에 CO_2 저감효과, 훼손된 갯벌 복원과 같은 편익을 얻을 수 있으며 신재생 에너지 개발이라는 국가의 녹색성장전략에도 기여하고 갯벌 복원을 통한 생태공학의 발전에도 기여할 수 있을 것이다.

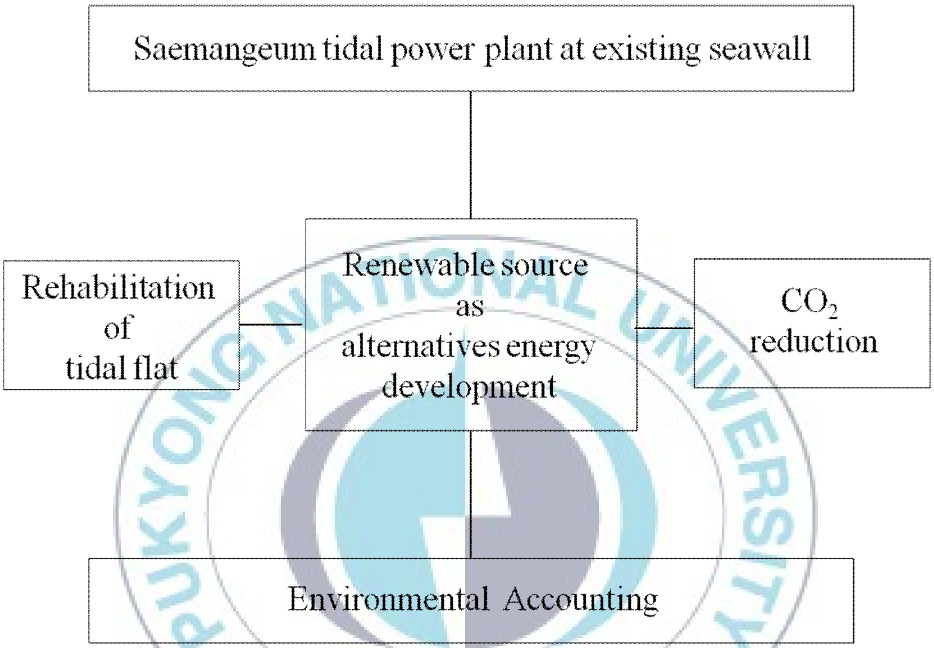


Fig. Study layout

Ⅰ. Introduction

The increase in the consumption of fossil fuels after the industrial revolution caused a rise in the concentration of greenhouse gases in the atmosphere, raising the average temperature of the earth. The world average temperature has risen by 0.74℃ over the last 100 years, and the average sea level rose by 1.8㎜ each year since 1961. The area of glacier at the North Pole has decreased by 2.7% every 10 years since 1978 and the speed is greater than 7.4% (IPCC, 2007).

In Korea, the average temperature in the six largest cities rose by 1.5℃ during the last 100 years. The sea level around Jeju rose by 22㎝ over the last 40 years. Average annual rainfall between 1995 and 2005 has increased by 10%. Damage due to unexpected downpours including typhoons rose by 3.2 fold in the same period (Climate Change Defence Committee, 2009).

Such changes have a great impact on many aspects including extinction of species, disturbance in the ecosystem, changes in the quality of farming land, a decrease in agricultural production, an increase in disease carrying organisms, and an increase in natural disasters.

Many of the advanced countries have set up mid to long-term goals to reduce greenhouse gas emissions in response to climate change. Amid such policies, industries related to prevention or mitigation of climate changes, including new and renewable energy sources, are growing fast. Therefore the emission trading scheme is getting larger and larger providing an impetus for a carbon market toward spontaneous growth.

Korea has 97% of energy resources met by energy imports; these concerns must be urgently addressed both the climate change and natural resource crisis. Since most of its energy sources depend on imports, Korea must respond quickly to both climate change and natural resource crisis. According to local statistics on alternative energy sources in Korea, most of the sources are from waste and hydro power. There are few clean alternative energy sources available for use currently. Marine energy sources including tides, tidal current and wind among others have a high transformation efficiency and relatively high energy concentration which suggests that they can provide low cost energy. The mid-west coastal area of Korean peninsula is one of 5 best worldwide recognized locations for great potential tidal power development as an alternative energy resource to fossil fuels which can be developed on a large scale.

Historically, Korea went through a series of reclamation in the last decades for the purpose of expansion of the land, securing of industrial and farmland, and water reservoir. As a result, 20.4% of the total tidal flat disappeared during the 1987 to 2005 period (MLTM, 2009), causing tremendous side effects on environment, society and economy. Such as drastic changes require careful perception and analysis.

The Saemangeum project is one of the flagship reclamation projects in the country. In the year of 2010, completed 33㎞ long seawall connecting Gunsan and Buan followed by reclaimed land of 283㎢ and a basin of 118㎢ for national development plan which has to be developed by 2030. Originally, the project was intended to increase agricultural land and foster better rural community focusing entirely on agriculture and fishery. After a series of several reasons for discussion, the national final goal was to create a city for international businesses, tourism and leisure in 2009 (MLTM, 2009). At the same time, the

Saemangeum project has faced many challenges including transparency of the economic feasibility on worsening water quality and aggravating ecosystem. The worsening water quality is the greatest challenge of all. In order to address the effect on the issue, a total of 2,900 billion ₩/yr will be invested by the government (MKE, 2011).

The total area of 208㎢ lost due to the reclamation is posing tremendous threats such as loss of habitats and a decrease in the biodiversity (KEI, 2007).

As the part of defence, the Saemangeum provides an optimal location for tidal power generation with tidal range of 3.93m and constructed seawall which accounts for a large part of the costs for the tidal power generation. Tidal power generation at the Saemangeum region can best serve the goal of decreasing the emissions of green house gases or acid rain associated with fossil fuel generated electricity. The tidal energy is a renewable source, it reduces environmental pollution, develops a new growth trend and creates jobs for local community. Furthermore, the movement of seawater will facilitate the rehabilitation of tidal flat.

Existing economic methodologies for the feasibility of the alternative energy sources, however, have excluded the natural environmental contribution to human and their economic values.

For the purpose of this study, needed to quantify the value of natural resources and human economic value. Therefore, evaluated emergy as a common unit to assess natural resource and economic value, and feasibility of the Saemangeum tidal power project.

Ⅱ. Theoretical background

1. Tidal power in Saemangeum region

1.1 Tidal power as renewable energy source

Natural resources available for use, such as coal, oil and natural gas, are decreasing while use of them causes climate change and environmental pollution. It is, therefore, urgently necessary to develop and commercialize clean energy which is not harmful to an environment.

Natural and bio-energy sources are called renewable energies. One of them is tidal force, which is abundant along the west coast of the Korean peninsula. The west coast is long and winding, embracing a lot of bays and featuring large tidal differences, making it an ideal place for electricity generation (MKE, 2008).

1.1.1 Definition of tidal power

Most coasts in the world experience two high tides and two low tides each day. Tidal power converts the difference between high and low tides into electricity. A seawall is built to capture the energy from masses of water moving in and out of a bay or river due to tidal forces (Kim et al., 2006; Oh et al., 2007). The greater the tidal difference is, the larger the basin is, and the shorter the seawall is, the more advantageous to have a tidal power plant (Lee et al., 2009; MKE, 2006)(Fig. 1).

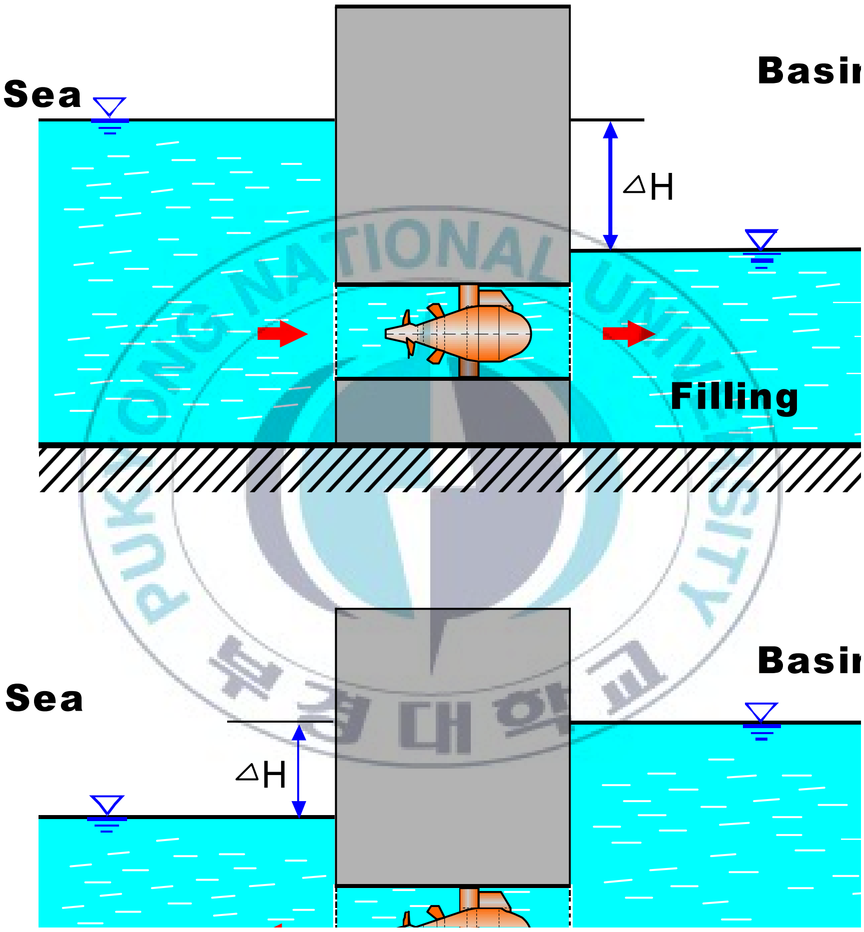


Fig. 1. Tidal power generator(www.VATECH-hydro.com).

1.1.2 Methods of tidal power

Tidal power can be classified into three generating methods; floating body method which uses buoyancy then applied to the body; compressed air method which compresses air into a vacuum chamber using the upward and downward movement of the sea level; and basin method uses a seawall which is built to create a basin for generation. But more generally, it is either a single basin or a double basin depending on the number of basin used and either single flow or double flow depending on the number of tidal flows used for generation (MKE, 2006)(Fig. 2).

a. Single basin, single flow method

This method, which uses one way of flow, can be classified into ebb and flood methods. Ebb generation uses a single basin and ebb tide. One basin is created, which is filled through the sluices until high tide. Then the sluice gates are closed. The turbine gates are kept closed until the sea level falls to create sufficient head across the seawall, and then sluice gates are opened so that the turbines generate until the head is again low. On the other hand, flood generation uses a single basin and flood tide. The basin is filled through the turbines which generate at flood tide. This is generally much less efficient than ebb generation.

b. Single seawall, double flow method

This method uses a single basin and both ebb and flood methods, providing a longer generating time than the single basin, single flow method. It is advantageous over the single flow method when it is used in a location where the tidal difference is very large. The power plant in La Rance, France, is a good example.

c. Two connected basin method

With two basins, one is filled at high tide and the other is emptied at low tide. Turbines are placed between the basins. This method can generate electricity on a continual basis, but suffers lower efficiency than the single basin methods.

d. Two separate basin method

This method involves two separately run basin, they're connected via a generating system. One basin uses the single flow during flood while the other fills the basin with seawater during ebb.

Table 1. Advantage and disadvantage of generating method type (MKE, 2006)

Types	Advantage	Disadvantage
Single basin single flow method	· simple generating type · low facility cost · practical	· flood; less efficiency
Single seawall double flow method	· increase of construction cost	· longer generation time than single basin
Two connected basin method	· continuos generating possibility	· less efficiency than single basin
Two separate basin method	· extend generating duration	—

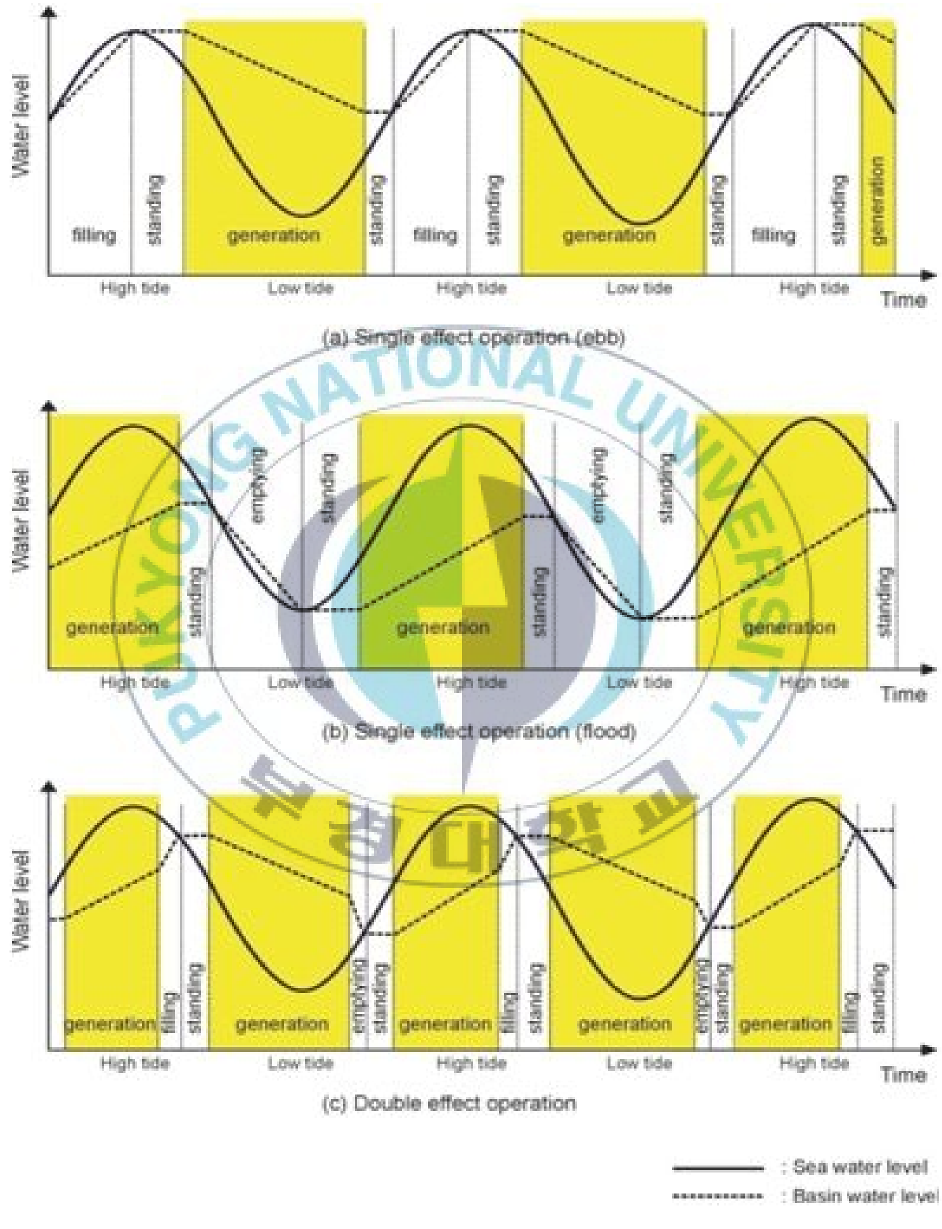


Fig. 2. Methods of tidal power generation(www.VATECH-hydro.com,04.2011).

1.2 Advantage and disadvantage of tidal power

Once installed, a tidal plant requires relatively low operating costs, with its annual maintenance cost being only 3.36% of the total investment. In addition, it can be used on a sustainable basis and, since the amount of seawater moving in and out is generally stable, is predictable over a long period of time in terms of output. Tidal power is renewable and also free from the influence of the weather and clean enough to cause no greenhouse gas emissions, waste and pollution. The seawall can also serve as a tourist destination (MKE, 2006).

On the disadvantages, changing tidal flows by damming the bay or estuary could, however, result in negative impact on aquatic and shoreline ecosystems. Tidal power also requires a great deal of initial investment, especially in building a seawall, and is less efficient than thermal power or nuclear power. In addition, it may change coastal ecosystem affecting food chain of birds. All these factors contribute to the low level of tidal power utilization around the world (Oh, 2007).

1.3 Present and future tidal power schemes

1.3.1 International tidal power plant

Since there are only a few locations fit for tidal power generation around the world, tidal power plants currently operating are also few. Table 2 shows the list of tidal power stations currently operating internationally.

Table 2. International tidal power plant in operation(Jeong et al., 2007)

Item	Rance, France	Annapolis, Canada	Kislaya, Russia	Jiangxia, China
Maximum perigean spring tide(m)	13.5	8.7	3.9	8.39
Average range between low and high tides(m)	8.57	7.0	1.0～3.9	5.08
Length of seawall(㎞)	0.75	-	0.15	-
Basin area(㎢)	22.5	11.5	1.1	1.37
Peak rating(㎿)	240	20	0.4	3.2
Year of opening	1966	1984	1968	1980
Annual output (GWh)	544	50	1.2	6.0
Overall use rate (%)	29	29	34	21
Generating method	Double flow	Single flow	Double flow	Double flow

a. La Rance power plant

Taking up only a fraction of the national grid of France in terms of output, the La Rance power station is managed as marginal energy source. It is, however, a good example of how tidal power can be used as a renewable energy source. Planned in 1954 and opened in 1966 after five years of construction, the La Rance power plant (Fig. 3) is the first of its kind and is the only tidal power plant operating commercially in the world. With an annual output of 544GWh, it features an operation rate of 97% annually. The average range between low and high tide levels is 8.5 m and the maximum perigean spring tide is 13.5m. The basin area is 22 ㎢. A total of 24 bulb type turbines are employed, allowing doubling flow generation. The La Rance tidal power plant is the world's first tidal power station and also the world's biggest tidal power station in terms of installed capacity. The facility is located on the estuary of the La Rance River, in Brittany, France. It is currently operated by Electricity de France, from a peak rating of 240㎿, generated by its 24 turbines, it supplies 0.012% of the power demand of France. The seawall is 750m long, from Brebis point in the west to Briantais point in the east. The plant portion of the dam is 332.5m long. The tidal basin measures 22.5㎢. This plant is also served as a popular tourist destination, making a huge contribution to the local economy. A total of 16,000 to 18,000 small scale cruise ships as well as around 0.3 to 0.4 million tourists visit the site in a year (Jeong et al., 2007; Kim et al., 2006; Oh, 2007).

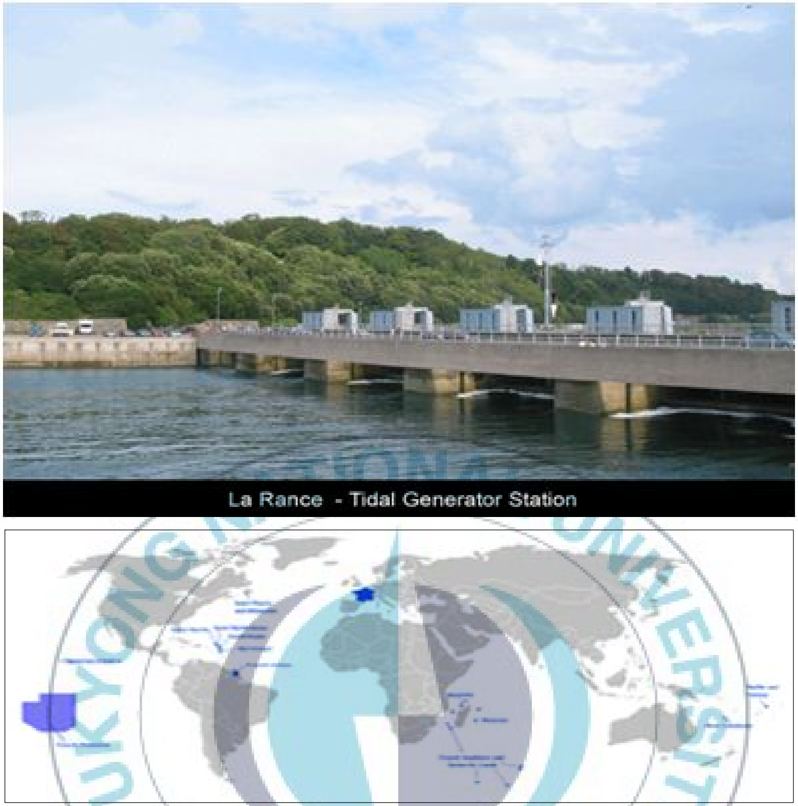


Fig. 3. La Rance power plant.

b. Annapolis power plant

The first proposal to build a tidal power station in the Fundy bay in Annapolis was made in 1919. It was originally planned as a research facility. In 1980, a construction plan was put forward, and construction commenced in 1981 and finished in 1984. The average range between low and high tide levels is 7m and the maximum perigean spring tide is 8.7m. The existing seawall and sluices were revised for generation. Annual output is 50GWh, enabled by one Straflo type turbine. The operation is done remotely from Milton Control Center, 100㎞ off the site. This station has fallen short of initial expectations due to a change in the tidal characteristics of the sea surrounding it (Kim et al., 2006; Jeong et al., 2007).

c. Kislaya Guba power plant

The Kislaya Guba power plant is an experimental facility intended to uncover various challenges associated with power plants in extreme locations. Originally planned in 1962 and opened in 1968, the plant has only one turbine for experimental purposes. The average range between low and high tide levels is 1.0 to 3.9m, featuring relatively low tidal difference. The basin area is 1.1㎢, the saewall being 0.15㎞ long. The annual output is 1.2GWh and uses the double flow method as the Rance power plant does (Kim et al., 2006; Jeong et al., 2007).

d. Jiangxia power plant

With the first geological research conducted in 1956, this power plant started operation in 1980 after eight years of construction and has produced electricity ever since. The perigean spring tide is 8.39m and the average range between low and high tide levels is 5.08m. The basin area is 1.37㎢. With an annual output of 6GWh, the station uses an existing seawall (Kim et al., 2006; Jeong et al., 2007).

1.3.2 Tidal power plants in Korea

The west coast of the Korean Peninsula has many potentially good locations for tidal power plants. Fig. 4 and Table 3 show summarized potential tidal power plants that are currently under planning in Korea.

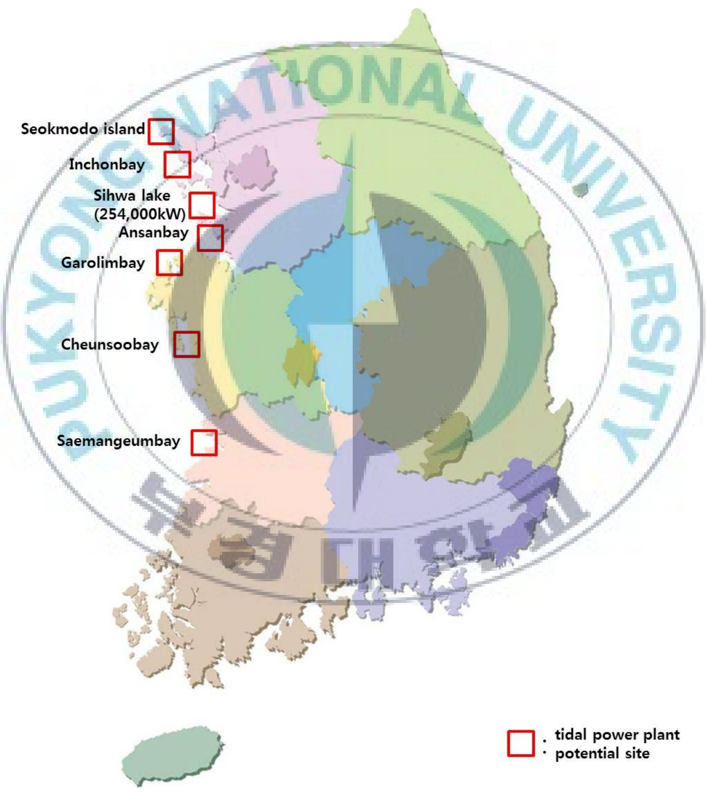


Fig. 4. Korea's potential site of tidal power plant .

a. Sihwa tidal power plant

This power plant is being constructed on Gari Island located half way through a 12㎞ long seawall connecting the Sihwa Industrial Park and Daebu Island. This is the first tidal power plant ever in Korea and the largest of its kind in the world. A huge seawall was built at Lake Sihwa between 1987 and 1994 to create a freshwater resource behind it. There since has been a build-up of pollution from nearby factories, and freshwater inside basin of the seawall was released in 1996. The resource changed from freshwater to seawater in 2000. In 2002, a plan was drawn up to build a tidal power plant at the lake in an effort to develop a clean and dependable energy source as well as improving the water quality of Lake Sihwa. Work on the power plant commenced in 2004 and is due for completion in the first half of 2011.

Using a flood method, the plant will produce 552GWh of electricity/year which is 1.56 times as large as that of Soyang Dam and enough to serve electricity to the local populations of 0.5 million (Jeong et al., 2007; Kim et al., 2006).

b. Garolim tidal power plant

With great tidal differences and a large basin area as well as a narrow estuary, Garolim Bay is one of the most optimal locations for tidal power generation. A “Feasibility Study on Tidal Power Plant in Garolim Bay” was conducted in 1981, from which the place was proven feasible. But the drop in oil prices and rising construction costs around 1986 made the project less economic and, as a result put it on hold in 2004 to 2005, the project was put under scrutiny again in the name of “Study to Calculate the Benchmark Price for Tidal Power Generation”, which established that the project is economically feasible. The basic design was prepared in March, 2007, and the construction work will commence in 2011 and finish in 2015. With assumed construction budget of 1,002.2 billion₩ will be provided as well.

The power plant will be located along a 2㎞ long seawall to be built between Iwon-myeon, Taean-gun and Oji-ri, Daesan-eup, Seosan City, Chungcheong South Province and use the single flow ebb method to produce an annual output of 918GWh (Jeong et al., 2007; Oh et al., 2007).

c. Incheon Bay tidal power plant

The project of Incheon bay tidal power plant involved a series of events including an agreement on the research and development and use of marine energy in 2005, three studies up to 2008 and an MOU in January 2010 for the construction of a tidal power plant in Incheon bay. Stretched over Jung-gu, Ganghwa-gun and Ongjin-gun, Incheon Metropolitan City, the plant will produce an annual output of 2,414GWh.

Table 3. Domestic potential tidal power development locations(Jeong et al., 2007)

Location	Tidal difference (m)	Basin area (㎢)	Peak rating (㎿)	Annual output (GWh)	Status
Seokmo Island	7.70	85	25.4 ㎿×32	1,518	Under feasibility study
Incheon bay	7.20	128	20 ㎿×36	1,396	Work to commence soon
Sihwa	7.80	39	25.4 ㎿×10	552	About to complete
Asan bay	8.33	19	20 ㎿×8	320	-
Garolim bay	6.94	96	25.2 ㎿×20	918	Work to commence soon
Chunsu bay	5.16	380	20 ㎿×30	966	
Seamangeum	3.93	185	20 ㎿×20	687	Feasibility study by MKE(2006)

1.4 Feasibility of tidal power in Saemangeum

According to international energy framework and Ocean Energy System in the extensive natural resources of ocean energy, the evaluated yearly generation quantity reached up to 93,000TWh, and exceeded five times over the world's yearly generation amount, nor emit CO_2 and it could be able to stabilize the reliable clean and renewable energy source. Furthermore, it could be developed in a large scale as it is highly concentrated type of energy and advantageous in the cost of space for energy production. But, available locations are limited as well as conquering technical support and be required an economical demand (KMI, 2010).

The types of available ocean energy are the tidal power, tidal current, wave power, seawater temperature variation power, seawater salinity variation power and ocean wind power.

The Saemangeum region at an existing seawall would be able to utilize self-supporting energy development from the tidal power generation. In addition, the tidal flats are expected for recovery from circulating seawater in and out of basin through the seawall. Furthermore, the tidal flat conservation/restoration movements around the world are obviously active, thus this study can provide a case study for rehabilitation of tidal flat.

1.4.1 Sihwa tidal power

As a significant reference study for Saemangeum, Sihwa tidal power plant ran for trial test and expected to begin generating in July 2011. From the sluices being built in Sihwa, the improvement of the water quality in Lake Sihwa continued to improve from 1997 to 2000, then no more improvement took place is shown in Fig. 6.

The study of the correlation between the movement of seawater and the COD in the lake revealed that they have a positive relation as shown in Fig. 7. This suggests that worsening in the water quality was due to decrease in seawater movement in and out of the lake after 2000.

The results concluded that maintaining the lake with fresh water would be impossible and decided turn it into a sea water lake in December 2000.

In the year of 2004, it has confirmed to construct a tidal power plant in the lake for the purposes of developing renewable energy source and water quality improvement.

Resulting from the operation of the tidal power plant at the Sihwa lake, a total of 315 thousand metric tons of CO_2 is expected to be reduced. Therefore, the saving of 862 thousand barrels of oil used for generation which would equivalent to 80 billion₩ in benefit. A computer simulation revealed that within 15 days after the initial operation, the average COD will improve to 2ppm from 3.7ppm. Experts expected that the exchange of freshwater from the lake and the seawater will help to improve the water quality in the lake. And in addition, the tidal flat of 27㎢ will be newly formed along the current coastline if the tidal power plant continues to operate (MLTM, 2007).

Therefore, Sihwa tidal power would be a crucial reference for Saemangeum tidal power at an existing seawall.

Fig. 5. Map of Sihwa lake.

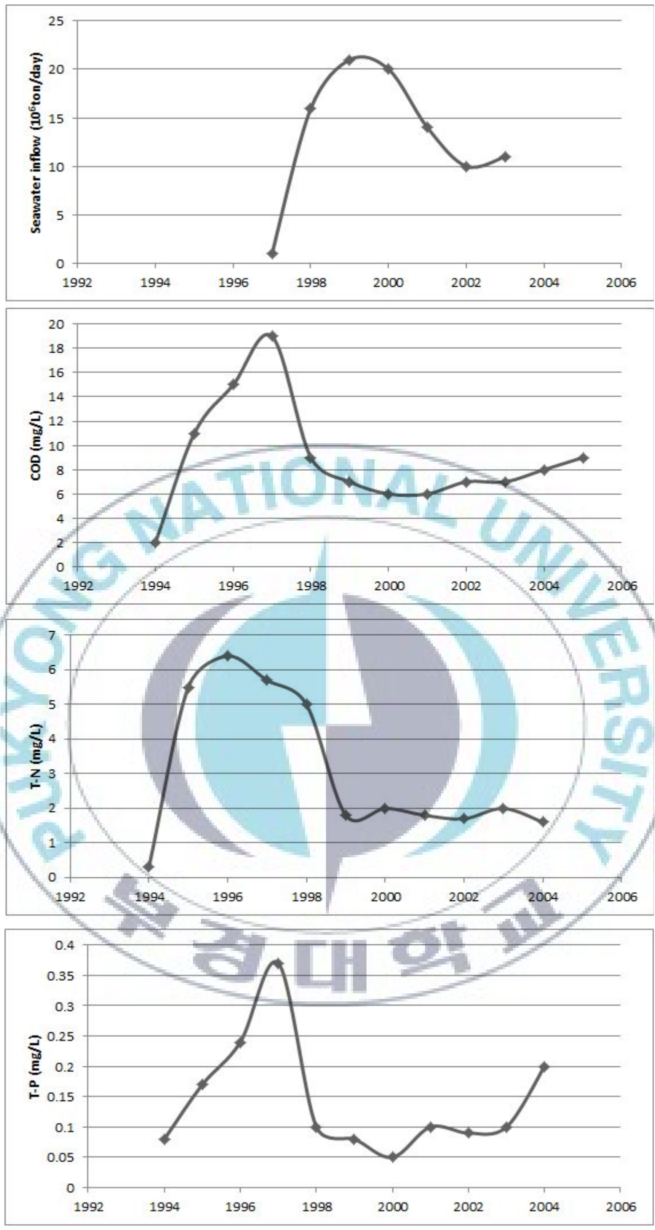


Fig. 6. Annual variations in pollution levels from seawater exchange (monitored by Korean Ministry of Environment and Korean Water Resources Corporation).

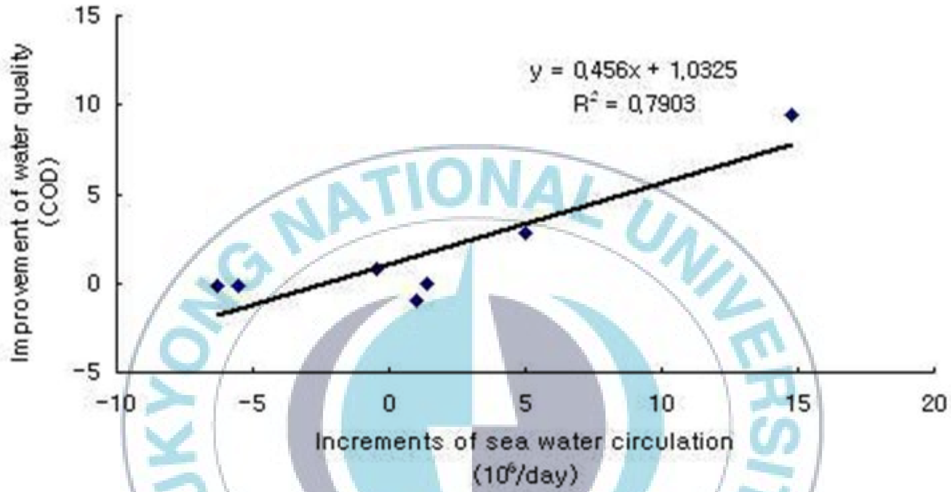


Fig. 7. Variations in the effectiveness of the water quality improvement by variation of the amount of seawater exchange (Kim, 2006).

1.4.2 Tidal flat restoration of Wadden sea

As shown in Fig. 8, the Wadden Sea stretches from the Netherlands, past Germany to Denmark along a total length of some 500㎞. It is one of the most widely known tidal flats including the one at Banc d'Arguin, Mauritania, West Africa, the one in Georgia, U.S. and the west coast of the Korean Peninsula (MLTM, 2009).

A considerable parts of the Wadden sea tidal flat were lost through the construction of dikes and other coastal defense works. In the past 50 year, 160㎢ of salt marshes was embanked and have remained 346㎢ of salt marshes to date. The relatively high level of contamination of the Wadden Sea is caused by a number of rivers, of which the catchment areas are highly industrialized and polluted materials have flown into the Wadden Sea (CWSS, 2008).

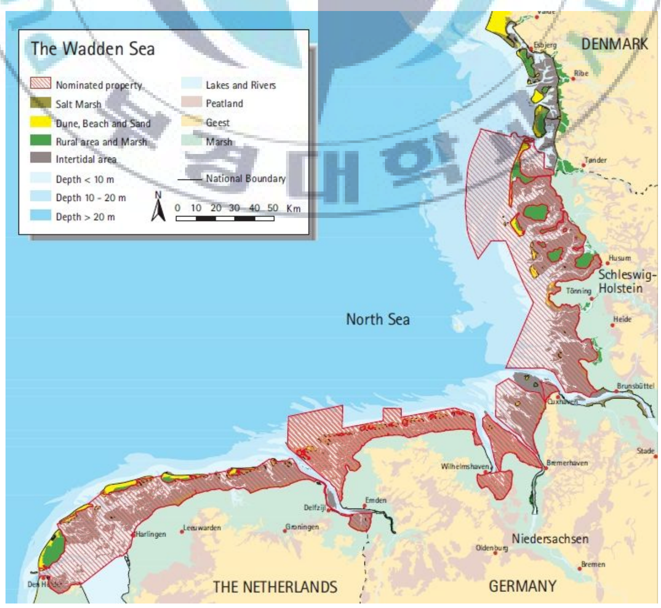


Fig. 8. Map of Wadden Sea (CWSS, 2008).

Thus, the reclamation of the saline environments could have contributed to the destruction of the rich and vulnerable ecosystem. 50～90% of the species living in tidal flats and salt marshes may have locally disappeared after reclamation and drying up causing a fast ecological succession to an entirely different ecosystems (Heydemann, 1981). In addition, disturbance of animals resulted in lower breeding success and lower survival rates. Some types of recreation, hunting and commercial fisheries are regarded as having the most impact.

Ultimately in the last third of the twentieth century, a turning point was reached. The idea that a coastal landscape is something to be valued and of itself has gained ground. Species and habitat protection and restoration efforts of the management have been initiated on a large scale.

Salt marshes of Wadden Sea are subject to nature conservation schemes by national and EU legislation, and are also covered by the Wadden Sea Plan. The salt marsh area increased in most parts of the Wadden Sea during the past decades. The recent comprehensive inventory of all salt marshes based on regular complete vegetation mapping resulted in a total area of 310.70km^2 in the nominated property (QSR 2004) and the salt marsh vegetation developments are monitored by the tri-laterally harmonized vegetation key.

The quality of various habitats have improved in recent decades, leading for instance to an increase in numbers of coastal birds such as the common red shank breeding on salt marshes (CWSS, 2008).

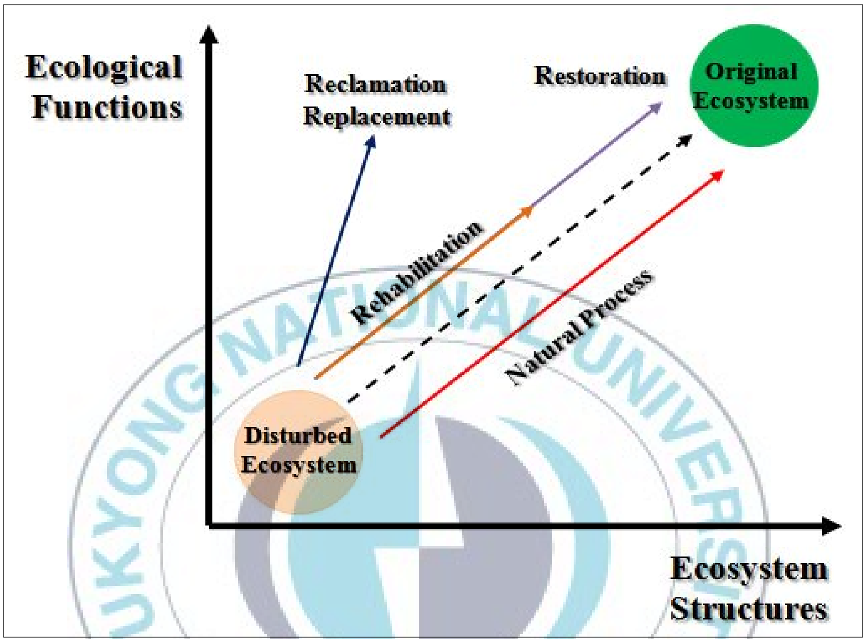


Fig. 9. The stage and type of natural environment (Redrawn from Krystyna M. et al., 1997).

2. Literature review

2.1 Economic evaluation of tidal power

Korea's literature on the economic feasibility of tidal power generation has been divided into two parts; firstly with traditional economic approach and secondly cost-benefit analysis using the concept of emergy. Areas that need to be studied including those with large tidal ranges are; Saemangeum, Lake Sihwa, Garolim Bay, Incheon Bay and Ganghwa. Their planned capacities are 1,440,000 ㎾ (Incheon Bay) > 810,000㎾ (Ganghwa) > 687,000㎾ (Saemangeum) > 520,000㎾ (Garolim) > 254,000㎾ (Lake Sihwa) compared with La Lance of France (240,000㎾), Jiangxia of China (3,200㎾) and Kislaya Guba of Russia (400㎾) which of these figures represent the potential tidal power of Korea is apparently very high (Lee et al., 2010).

There have been feasibility studies in Korea since 1980s (KORDI, 1981; KORDI, 1986; KORDI 1993). The Saemangeum region in particular, conceptual design and economic feasibility study were conducted using cost-benefit analysis where widely used as a financial analysis tool.

The costs include construction related products including tidal power generation facility, civil work and maintenance related materials while the benefits include fuel cost savings from less use of fossil fuels, supply cost savings from a reduced power usage and savings of environmental treatment costs.

Apparently, the analysis results revealed that the B/C (benefit and cost) ratio is 0.94 when discount rate is at 7%, and it is 1.24 when discount is at 5% which is suggesting that there is advantageous economic feasibility in the project while discount rate is low.

In cost-benefit for Garolim Bay, the B/C ratio is 2.8 when environmental cost is not included while it is 0.81 when environmental cost is included.

However, this study points out that the CVM (Contingent Valuation Method) does not include intangible welfare factors of the national economy and suggests that the CVM should be implemented by substantiating an assumed market conditions after the completion of the power plant. Study by Yoo (2010) on the economic feasibility and the environmental impact of a tidal power plant in the Garolim Bay, uses the CVM to calculate the economic and environmental value which reveals 100.71 billion₩.

Lee and Noh (2010) also conducted an economic feasibility study on tidal power plant in the Incheon Bay, which is the largest among the projects converting tidal power into electricity in terms of capacity. They used the CVM as well as I/O (Input-Output) analysis to calculate the socio-economic impact of the value in the course of and after the commercialization of the tidal plant, including R&D (Research and Development), construction, electricity and service on the total output and related industries as well. The result of the economic feasibility study reveals that the annual economic value will be 479.9 billion₩, suggesting that the economic value from the tidal plant will be greater than the total cost invested in the project (3921.5 billion₩) if the duration of the plant construction is 9 years or longer. The result of I/O analysis shows that the total production inducement effect over the development period for the tidal plant in the Incheon Bay is 2.1 times greater than the investment (8090.6 billion₩), creating 60 thousand jobs and generating a tax revenue of 184.9 billion (6% of the added value generated during the project).

In additional study by Korea West Generation and KMI (2005) to determine the economic feasibility, B/C ratios are 0.82 and 2.23 respectively when environmental costs are included; suggesting that the tidal power generation at the Garolim Bay is not economically feasible when environmental costs are taken into account. This can be interpreted as the assumption of that existing environmental value which will be lost from a result of the construction. Therefore, the tidal power plant resulted in low level of B/C ratio.

The contingent valuation, however, has a possibility which different method of surveying will deliver a different result. Likewise the I/O analysis fails to meet the requirement that the project does not replace other economic value if economic impact is interpreted as direct benefits.

The previous economic feasibility studies on tidal power generation in Korea have different conclusions depending on the direct and indirect costs as well as direct and indirect benefits selected.

Furthermore, all of them are based on monetary value, and many alternatives are used in them to take into account all factors that can be hardly assessed financially. Most alternatives, however, are based on the willingness-to-pay, which require a wholly new approach to economic valuation.

2.2 Emergy evaluation of renewable energy

One of the most plausible alterative for the assessment of natural environment or the economic feasibility of large scale projects is cost and benefit analysis using the concept of emergy. The concept of emergy to assess the value of renewable energy sources was firstly applied by H.T. Odum, whose compared the emergy cost and benefit of tidal, hydro, thermal, nuclear and solar power from the study of other reserchers or scientist (Odum, 1996). His study reveals that the emergy production ratio as represented by the ratio between emergy benefits and costs is the highest for tidal power, followed by hydro, thermal, nuclear and solar power as shown in Fig. 10.

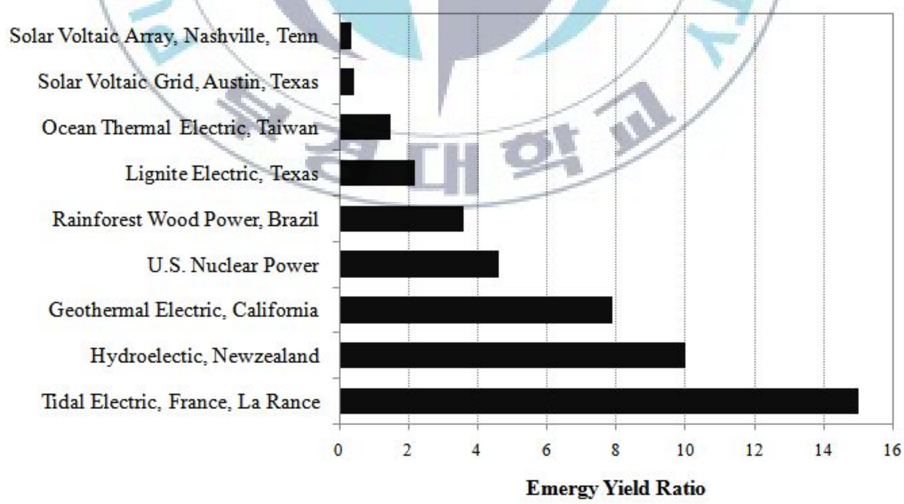


Fig. 10. Emergy yield ratio for electric power sources(revised from Odum, 1996).

A study on the feasibility of tidal power generation at Lake Sihwa using the concept of emergy (Joo, 2006) calculated emergy benefit and cost based on the existence of a seawall. This study analyzed based on emergy cost benefit of with/without seawall construction. The result reveals that economic revenues per year was 80.8 billion₩ while emergy analysis reflected 105 billion₩ including construction of seawall and excluding of construction of seawall reflected 127 billion₩.

Kim's study (2010) on wind power, one of promising renewable energy sources, in the province of Gangwon. Also, deals with an emergy cost-benefit analysis. It takes into account the electricity production and the securing of CO_2 emissions as direct benefits. Emergy B/C is 2.15, suggesting that wind farm has full economic feasibility.

Jang (2008) evaluated an emergy of rapeseed oil and its conversion to bio-diesel and reveals that the transformity of diesel is lower than that of bio-diesel, suggesting that the efficiency of bio-diesel is not high. Rapeseed oil is a meaningful petroleum saving factor, but it is not an alternative energy source.

The study (Im, 2010) on refuse derived fuel (RDF) technology that converts waste into an energy source, applied emergy to determine its economic feasibility. It concluded that RDF is a great possibility of resources, could be saved in large degree from recycling waste. The emergy B/C ratio of RDF project is assessed at 1.83.

The concept of emergy has been applied to various area of benefit/cost, ecosystem value, environmental accommodation, development alternative and cost assessment in connection with potential environmental damages. Therefore, it can be included among the evaluation methods based on economic feasibility. And emegy evaluation could be a useful tool that can help to present a wide range of choices to decision makers (Kang et al., 2006).

3. Emergy Analysis

3.1 Definition of emergy

Conventional economic approaches evaluate human economic value based on currency and expenditure or contribution judged subjectively by human beings. Howard T. Odum, a U.S. system ecologist argues that human oriented valuation based on willingness-to-pay has limitation in evaluating what natural environment contributes to human beings, failing to capture the real wealth of nature and resources. Odum presents emergy, a new scientific measure that uses solar energy as common currency to evaluate natural environment and human being's economic value at the same time. (Odum, 1996)

Emergy means an energy memory, as defined the available energy of one form that is used up in transformations directly and indirectly to make a product or service. The unit of emergy is emjoule or emergy joule. For the purpose of emergy, 'one form of useable energy' is calculated based on equivalents of solar energy. This is called solar emergy and the unit is solar emjoule (Odum, 1983; 1996).

3.2 Transformity

Under the concept of emergy, each form of energy has different energy quality to do work (Odum, 1996). All living systems on earth sustain each other by participating in a network of energy flow where lower quality energy is converted into both higher quality energy flows and degraded heat energy (Fig. 11). Therefore, the energy quality of one form of energy is expressed in embodied energy, a sum of all energies that were used in the work to make any product, bring it to market, and dispose of it.

In the emergy approach, the difference in energy quality is expressed by the concept of transformity. The transformity is defined as the emergy of one kind required directly and indirectly to make one unit of available energy of product flow (Odum, 1996). It can be considered as a measure of efficiency on the global scale of the biosphere. It may be useful to evaluate and compare the transformities of systems which produce the same product, in order to understand their performance and suggest choices.

The unit is solar emjoule/joule (seJ/J). It increases along the hierarchical structure and is used as a measure of energy quality of a flow or storage. For instance, solar energy flowing into the system as in Fig. 12 decreases as it goes from the energy transformation process involving trees via coal to electricity, namely from 40,000 J to 2 J, 1 J and ¼ J. The emergy inflow of this system is 40,000 seJ because solar energy contributes directly and indirectly to the energy transformation process. Transformities are 20,000 seJ/J for trees, 40,000 seJ/J for coal, and 160,000 seJ/J for electricity by dividing the value of solar emergy to the amount of available energy at each stage.

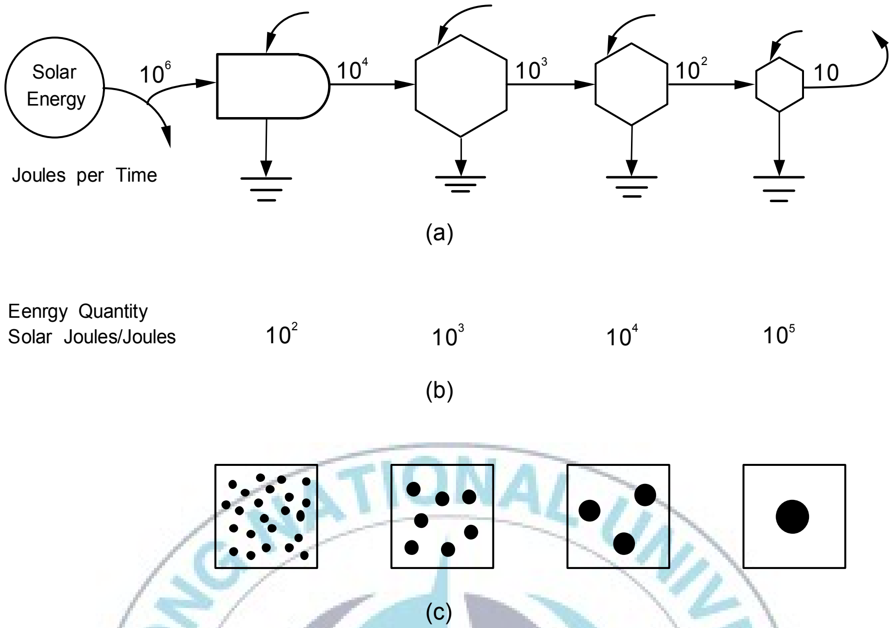


Fig. 11. Hierarchical chain of energy transformations: (a) decrease of energy in successive transformations; by-product pathways are omitted; (b) energy-transformation ratios in solar equivalents; (c) spatial hierarchy characteristics (Odum, 1983).

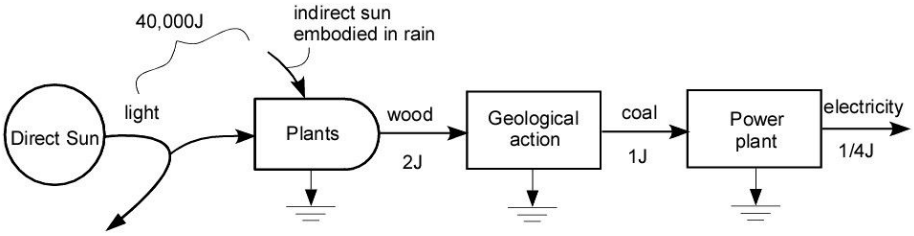


Fig. 12. Emergy quality chain used to calculate solar transformity (Odum, 1996).

Ⅲ. Materials and Method

1. Study area

As shown in Fig. 13, the Saemangeum area, which accommodates the world's longest seawall (33㎞) between Gunsan and Buan is located at the estuary of the Mangyeong River and Dongjin River. The Mangyeong River is 77.4㎞ long, running slow with a lot of bends. Its basin area is 1,527㎢. The Dongjin River (46.1㎞) is shorter than the Mangkyung River and its basin area is 1,129㎢ (Lee, 2004).

The purpose of Saemangeum reclamation project is to create 'globally recognized Samangeum, which will serve as a center stage for economic development, tourism prosperity and well-protected ecosystems. The outer facilities are now complete after construction between 1991 and 2010. A total of 2,800 billion₩ was spent on the project up to year 2009 and another 20,800 billion₩ will be invested for the improvement of water quality. By 1991 the internal development plan focused on the expansion of Korea's territorial land, securing of a freshwater source, agricultural land and improving the welfare of rural areas. By 2007, the ratio of agricultural and non-agricultural lands changed from 70 to 30 and 30 to 70 in 2008. After such a series of changes, the objective for the development of the Saemangeum area was approved to develop a prime commercial and residential zones. This is shown in Fig. 14 (MLTM, 2010; www.isaemangeum.co.kr, 12. 2010).

The average tidal range around seawall in the region is 3.93m, it is suitable installing tidal power plant facility at the existing seawall. The system boundary is 185㎢, the same area as the interior system boundary of the basin.

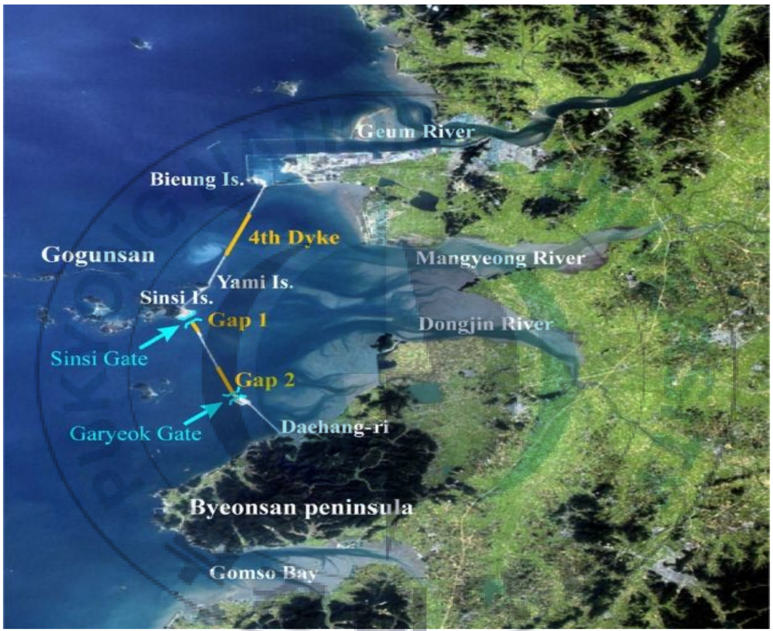


Fig. 13. Map of Saemangeum area (Lee, 2006).

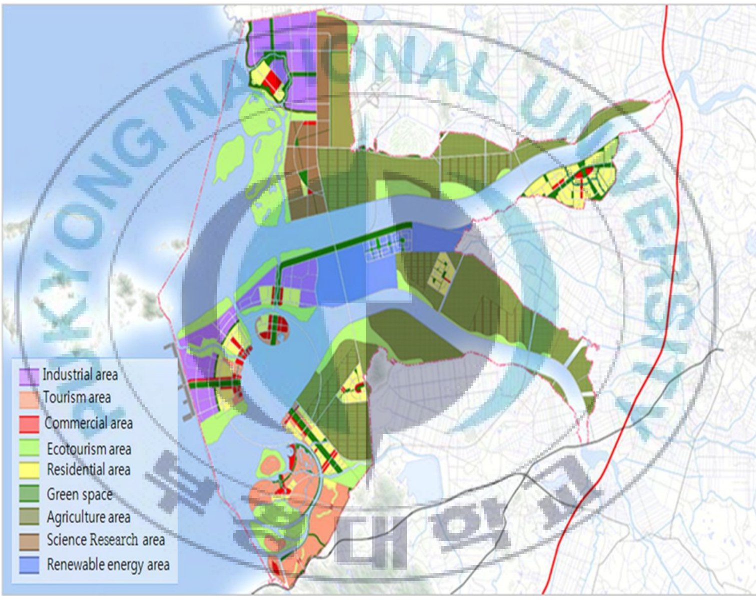


Fig. 14. Seamangeum land use planning (www.isaemangeum.co.kr, 03. 2011).

2. Proposed tidal power plant for the Saemangeum area

In reviewing Saemangeum tidal power feasibility by MKE (2006), identified and proposed for small and large generation of the 4 different alternatives applying ebb and flood tidal power generation at the existing seawall in the basin area near the intertidal zone.

The development plans for characteristics of the area and the economic efficiency are shown is Table 4.

Concerning the power capacities and the economics, the generation type of ebb with large capacity is shown the most superior one. But the generation type of flood with small capacity was chosen to develop intertidal zone applying to the government's development plan.

Therefore, this study analyzed the emergy of benefit and the cost based on flood generation type with small capacity from Table 5.

Table 4. Characteristics and economic efficiency of each generation types (MKE, 2006)

Generation type	Average of high tide difference (m)	Surface area (㎢)	Capacity of facility	Generation of electricity (㎿h)	Cost /Generation (₩/㎾h)	Ranking
flood, small capacity	5.32	185	40	687	960	4
ebb, small capacity	5.32	185	40	711	902	3
flood, large capacity	5.32	405	52	938	862	2
ebb, large capacity	5.32	405	52	964	802	1

Saemangeun tidal power plant structural layout plan is shown Fig. 15.

For the flood generation in a small capacity has been planned to install twenty turbines of 20㎿ and ten sluice gates, which are modified models of those at Sinsi.

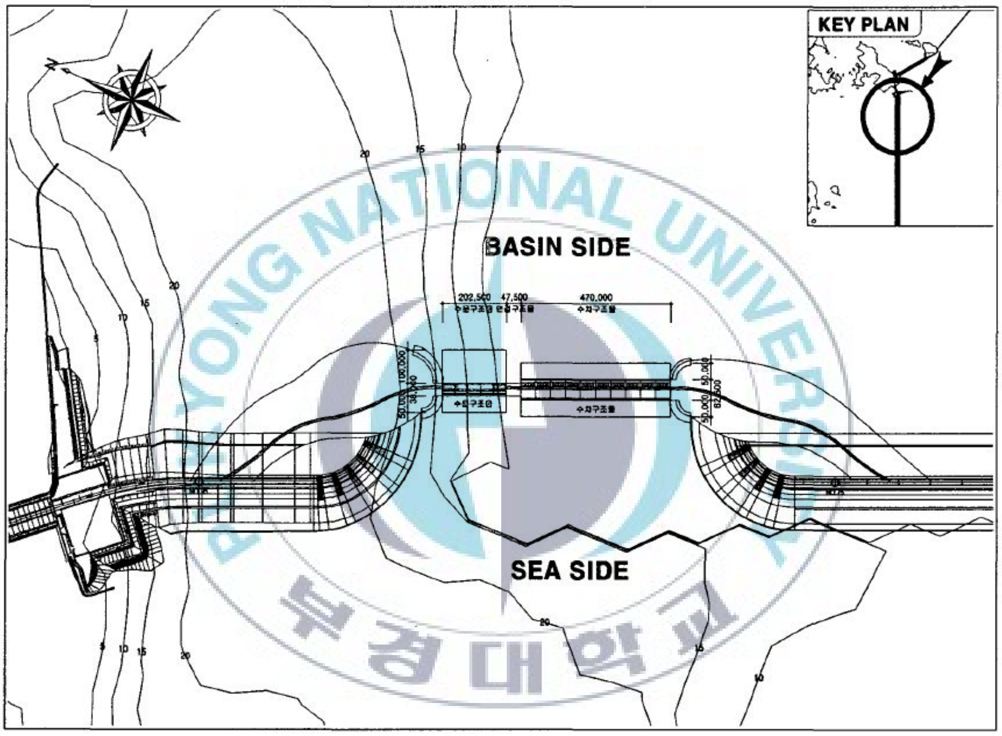


Fig. 15. Saemangeun tidal power plant structural layout plan (MKE, 2006).

Table 5 shows construction cost of small capacity. The prices for turbines and generators are the conversion of quotes from China using the relevant exchange rate. Cost for the mechanical work involving switchboards, gantry crane, and sluice gates are based on quotes from local contractors. The management cost is

3% of compensation, civil work and electric/mechanical works had been combined. The costs of a supervising survey and research at 3% of the civil work cost and 1.5% of the electric and mechanical work. Interest has been assumed at 5%.

Table 5. Construction cost of flood, small capacity (MKE, 2006)

Unit: million₩

Items	Amount	Note
(1) Civil work		
Temporary work	15,993	Twenty turbines
Power plant structures	149,191	Ten sluice gates
Sluice gates	61,132	
Demolition of an existing barrage	45,662	
Temporary water blockage	49,861	
Central pier	14,043	
Road paving	326	
Retaining walls	26,703	
Sub total	362,911	
(2) Electricity/mechanics		
Turbine-generator	190,550	
Sluice Gates	13,435	
Stop-log(power plant)	14,422	
Stop-log(sluice gate)	7,739	
Lock mechanics	9,588	
Gantry Crane etc.	8,392	
Switch gear & trans.	31,604	
Sub total	296,730	
Total (1+2)	659,641	
(3) Administration	51,127	(1+2)×3%
(4) Research, design and supervision	22,596	(1)×5%+(2)×1.5%
Total	733,364	(1)+(2)+(3)+(4)
(5)Interest	81,411	5% per annum at compound
Total cost	814,775	(1)+(2)+(3)+(4)+(5)

* Data for table 10

3. Emergy evaluation procedure

3.1 Energy system diagram

An energy system diagram needs to be prepared using the energy systems language proposed by Odum (1996) to identify the characteristics of the system and understand its structure and functions (Odum, 1996).

The diagram will be prepared in five stages including

1. Set the boundary of the system to take the evaluation goals into account.

2. Identify external factors including natural elements, goods and services, and labor that come into the system from outside.

3. Identify internal elements of the system.

4. Identify flows that connect the external and internal elements of the system.

5. Align the identified external and internal elements from left to right and connect them all as in the real system.

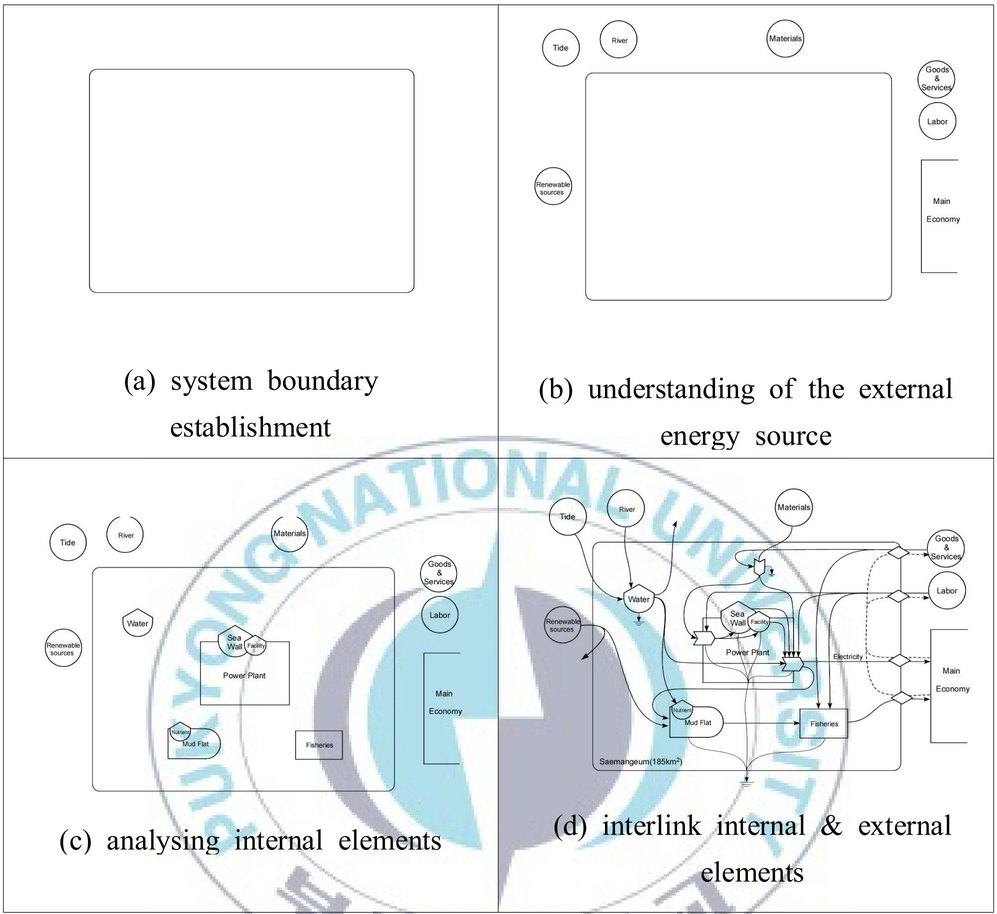


Fig. 16. Energy system diagram.

3.2 Emergy evaluation table

At the second stage, the diagram of the system is used to generate an emergy evaluation table as shown.

Column #1 is for the number of the footnote for each item and column # 2 is for the list of external energy sources and internal elements.

Column # 3 is for the raw data in J, g, dollars or other units.

Column # 4 is for the solar transformity of major energy sources from manual calculation or existing literature. If the raw data is in dollar unit, an emergy-money ratio (EMR) is used for the conversion to emergy.

Column # 5 is for the emergy value of the item, calculated by multiplying the third and fourth columns.

Column # 6 is for emvalue calculated by dividing the solar emergy value by the emergy-money ratio.

The total amount of emergy flowing into the system is the sum of all solar emergy inflows to each item. The analyst should pay special attention to the double counting risk, at this point. For example, wind and rain in nature are both generated by the solar energy flow, and if these three flows are summed up there will be a double counting. To avoid double counting, only the largest value is included in the calculation (Odum, 1996).

Table 6. Table for emergy evaluation

No.	Item	Raw data (J/yr, g/yr, $/yr)	Solar Transformity (seJ/unit)	Solar Emergy (seJ/yr)	Emvalue ($/yr)
(one line here for each source, process, or storage of interest)					

3.3 Emergy indices

Emergy indices as shown in Fig. 17 will be calculated in order to compare the systems under evaluation and identify their characteristics based on the evaluation table mentioned earlier.

For the purpose of calculating the indicators, non-renewable environmental contributions (N), renewable environmental inputs (R), and inputs from the economy as purchased goods and services (F and S) are aggregated and calculated.

Emergy indices used in this study will be explained in the sections that follow.

3.3.1 Emergy-money ratio

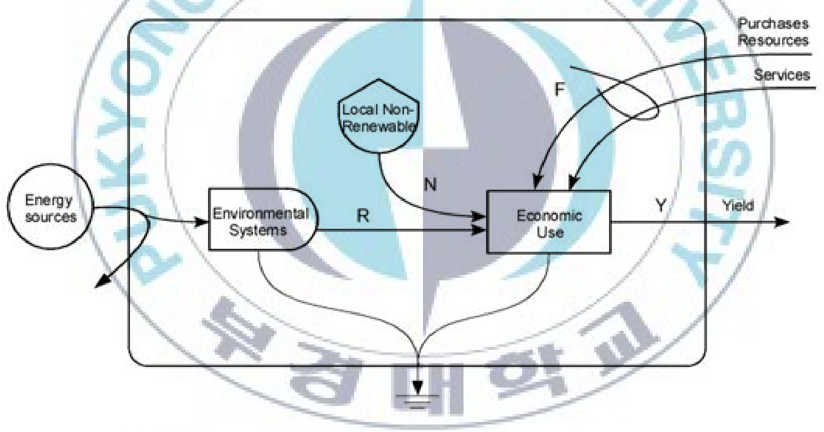
Emergy-money ratio (EMR) can be obtained by dividing the total emergy use of a country by its gross domestic product. EMR represents the emergy buying power of money for the economy under evaluation, meaning that a drop in the ratio leads to a decrease in the actual wealth, which the same amount of money can buy. In this study, EMR of Korea for 2006 used.

3.3.2 Emvalue

Emvalue allows comparison with existing economic evaluation by converting emergy units into currency units. This is achieved by dividing the emergy value of each item by the EMR (Odum, 1996).

3.3.3 Renewability

Renewability indicators are calculated by dividing the total amount of natural renewable resources flowing into the system (R) by the total emergy flowing into the system under evaluation (R+N+F) and represent the share of direct natural environment to the total emergy. The % Renew is an important factor that more precise the sustainability of the system and affects significantly the emergy yield ratio (EYR), emergy investment ratio (EIR), environmental loading ratio (ELR) and emergy sustainability index (ESI) (Brown and Ulgiati, 1997).



Yield(Y) = R+N+F
% Renew. = R/(R+N+F)
Emergy Yield Ratio(EYR) = Y/F
Emergy Investment Ratio(EIR) = F/(R+N)
Environmental Loading Ratio(ELR) = (F+N)/R
Emergy Sustainability Index(ESI) = EYR/ELR

Fig. 17. Emergy based indices, accounting for renewable emergy inputs (R), nonrenewable inputs (N) and purchased inputs from outside the system (F).

3.3.4 Emergy yield ratio, EYR

The emergy yield ratio (EYR) is calculated as the ratio of the emergy of the final products, U= R+N+F+S, (i.e. the total emergy driving the process) divided by the emergy purchased from outside (F). EYR is used to evaluate how a product of the investigated process contributes to the surrounding economy (Odum, 1996).

3.3.5 Emergy investment ratio, EIR

Emergy investment ratio (EIR) is calculated by dividing emergy invested from outside (F) by the sum of renewable and nonrenewable resources (R+N). This indicator indicates the extent to which the system depends on external resources and how much must be invested to exploit a local resource (Brown and Ulgiati, 1997).

3.3.6 Environmental loading ratio, ELR

The Environmental loading ratio (ELR) is an indicator that represents the pressure of human economic activities (summarized by the N and F flows together) on the evaluated system (summarized by the local renewable emergy flow R). The ELR is calculated as the ratio of the non-renewable and imported emergy flows to the local renewable emergy. The higher the ELR, the greater the impact on the local environment. Brown and Ulgiati (1997) argue that if an ELR is lower than 3, the impact of human's economic value on environment is mild and if it is greater than 10, the impact is significant. Values between 3 and 10 provide intermediate loadings (Brown and Ulgiati, 1997).

3.3.7 Emergy sustainability index, ESI

In order for a system to be sustainable, the amount of emergy purchased from outside must be minimal while internal emergy should make a greater contribution to the economic value of the system. In addition, renewable emergy sources must be larger than non-renewable ones. The emergy sustainability index (ESI) is calculated as the ratio of the emergy yield ratio (EYR) to the environmental loading ratio (ELR). If this is greater than 10, the system is relatively highly sustainable while if it is lower than 1, the system is hardly sustainable (Brown and Ulgiati, 1997).

4. Calculation of carbon reduction

There are measurement method and calculation method for evaluating the amount of carbon emission. Most of carbon emission programs and guidelines follow calculation method.

Table 7. Comparison of two different carbon inventory method

	Method	Strong	Weak
Measurement	concentration * flow amount	high accuracy	high cost
Calculation	activity data * emission factor	convenient method	low accuracy

Items such as amount of fuel consumed, emission factor and formulas for calculating emission are essentials for calculating the amount of emission.

Formula is as follow;

$$Emissions = Fuel\,consumption \times Emission\,Factor$$

Emissions = Amount of emission (㎏ GHG)

Fuel Consumption = Amount of Fuel Used (TJ)

Emission Factor = Given default emission factors for each type of fuel used

5. Emergy cost-benefit analysis

This study uses the concept of emergy to quantify the cost and benefit of tidal power generation in Saemangeum. Cost-benefit analysis uses currency flows, so the emergy values of cost and benefit are divided by the emergy money ratio (EMR) to be represented in Emvalue (Em₩).

Since the project uses an existing seawall, the costs incorporated only those for materials, maintenance of facilities for the tidal power plant, and G&S for fisheries. The benefit included electricity generation, increase in marine productivity and the carbon reduction from Table 8.

Table 8. Cost and benefit item category

Cost	Benefit
1. Facility installation	1. Electricity production
2. Facility management	2. Shellfishes
3. Fishery G&S	3. Seaweed
	4. Fishes
	5. Carbon reduction

Ⅳ. Results and Discussion

1. Emergy evaluation of the tidal power plant in the Saemangeum region

1.1. Energy system diagram

Fig. 18 shows a diagram of the tidal power generation in the Saemanguem region. The diagram represents the internal elements and processes affected and supported by external inputs.

The tide required for tidal power from renewable natural resources into the system, and necessary purchased inputs from outside such as materials, goods and services for operation and management are included.

The interaction of the tide and the power generator using the existing seawall produces electricity.

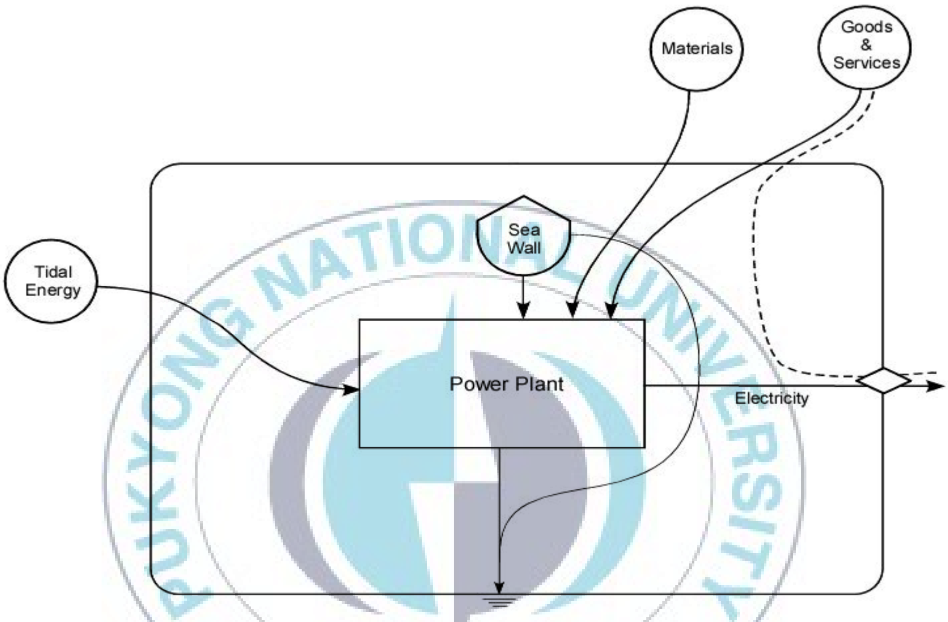


Fig. 18. Energy systems diagram of tidal power plant using the existing seawall for Saemangeum.

1.2. Emergy analysis

The data from Table 9 are used for the emergy analysis of Table 10.

The materials purchased from outside for the tidal power plant construction were mostly stone (4.01E+10g), sand (1.11E+12g), concrete (1.08E+12g) and iron and steel (8.69E+10g).

The life span of the tidal power generator was assumed to 55 years to calculate annual input (MKE, 2006).

Cost for management was 1.25E+10 ₩/yr and production of electricity was estimated to be 6.87E+08 ㎾h/yr.

Table 9. Raw data table for the tidal power plant

Renewable source				
1	Tide			
		Tidal area	=	1.85E+08 ㎡
		Avg. Tide range	=	3.93 m
Purchased input				
2	Power plant construction			
	a. Materials			
		Stone	=	4.01E+10 g
		Lifetime	=	55 yr
		Sand	=	1.11E+12 g
		Lifetime	=	55 yr
		Concrete	=	1.08E+12 g
		Lifetime	=	55 yr
		Iron & steel	=	8.69E+10 g
		Lifetime	=	55 yr
	b. Services		=	7.33E+11 ₩
		Lifetime	=	55 yr
3	Maintenance G&S		=	1.25E+10 ₩/yr
Production				
4	Electricity		=	6.87E+08 ㎾h/yr

Table 10 shows the result of emergy analysis for electricity generation at the Saemangeum power plant. The analysis is divided into renewable energy sources, purchased input and internal production. Detailed calculation procedures for raw data in the table are given in appendix A.

The tidal emergy from natural environment is 7.49E+20 seJ/yr. Conversion to currency equivalents based on Korea's emergy money ratio (EMR = 3.42E+09 seJ/₩), the ecologic-economic value of tidal energy is equivalent to 219 billion Em₩/yr.

The emergy of material inputs used for construction of the tidal power generator was; stone for 1.22E+18 seJ/yr, sand for 4.53E+19 seJ/yr, concrete for 3.55E+19 seJ/yr and, iron and steel for 1.07E+19 seJ/yr . These elements were divided by EMR and resulted into 0.36 billion Em₩/yr, 13.2 billion Em₩/yr, 10.4 billion Em₩/yr and 3.13 billion Em₩/yr, respectively.

The emergy of services required for construction of the tidal power plant was 4.56E+19 seJ/yr, which is equivalent to 13.3 billion Em₩/yr. Services (32.96%) and sand (32.72%) account for more than half of the total emergy (65.68%), followed by concrete, with no significant input of iron and steel.

In addition, the emergy for maintaining tidal power generator was 4.26E+19 seJ/yr, equivalent to 12.5 billion Em₩/yr, respectively.

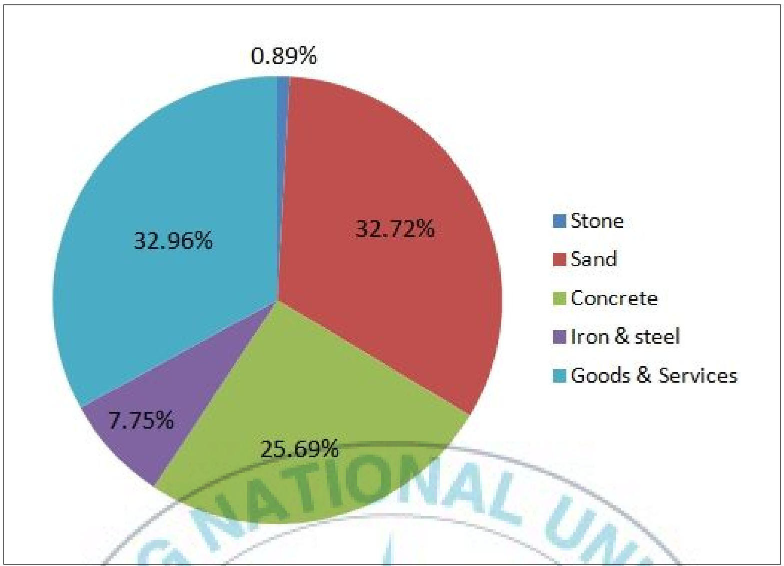


Fig. 19. Percentage of purchased inputs for Saemangeum tidal power at existing seawall.

Using the existing seawall by flood, small capacity type generator, electricity produced 6.87E+08㎾h and its unit of energy conversion calculated for 2.47E+15 J/yr. And by multiplying transformity of the average electricity value of emergy of 7.22E+20 seJ/yr was obtained as a results. Therefore, electricity emvalue of 211 billion Em₩/yr was reflected as an average ecologic-economic value.

The transformity of electricity generated by the tidal power plant in Saemangeum, without accounting for the seawall construction, is 3.76E+05 seJ/J. The total emergy supporting this electricity output is 9.30E+20 seJ/yr, equivalent to an emvalue of 272 billion Em₩/yr that reflects the emergy cost in value of this resource.

Table 10. Emergy table of tidal power plant using the existing seawall in Saemangeum, Korea

No.	Item	Raw Data	Transformity (seJ/unit)	Solar Emergy (seJ/yr)	Emvalue (Em₩/yr)
Renewable source					
1	Tide	1.01E+16 J/yr	7.39E+04 a)	7.49E+20	2.19E+11
Purchased input					
2	Power plant construction				
	a. Materials				
	Stone	7.29E+08 g/yr	1.68E+09 b)	1.22E+18	3.58E+08
	Sand	2.02E+10 g/yr	2.24E+09 b)	4.53E+19	1.32E+10
	Concrete	1.96E+10 g/yr	1.81E+09 c)	3.55E+19	1.04E+10
	Iron & steel	1.58E+09 g/yr	6.79E+09 e)	1.07E+19	3.14E+08
	b. G & S	1.33E+10 ₩/yr	3.42E+09 d)	4.56E+19	1.33E+10
		sub total		1.38E+20	4.05E+10
3	Maintenance				
	G & S	1.25E+10 ₩/yr	3.42E+09 d)	4.26E+19	1.25E+10
Production					
4	Electricity	2.47E+15 J/yr	2.92E+05 e)	7.22E+20	2.11E+11
5	Electricity	2.47E+15 J/yr	3.76E+05 f)	9.30E+20	2.72E+11

*Transformity based on total global emergy flow of 15.83E+24 seJ/yr

a) Cambell et al. (2005), b) Campbell and Brandt-Williams (2005), c) Simoncini (2006), d) Im (2010), e) Odum (1996), f) this study

* Detailed calculation procedures for raw data in the table are given in Appendix A

The emergy signature from the emergy evaluation Table 10 is shown in Fig. 19. The largest contribution was mostly provided by the tide, the largest the system boundary. Consequently, tidal power in Saemangeum was entirely affected by the tide from natural environment rather than by purchased nonrenewable inputs from outside.

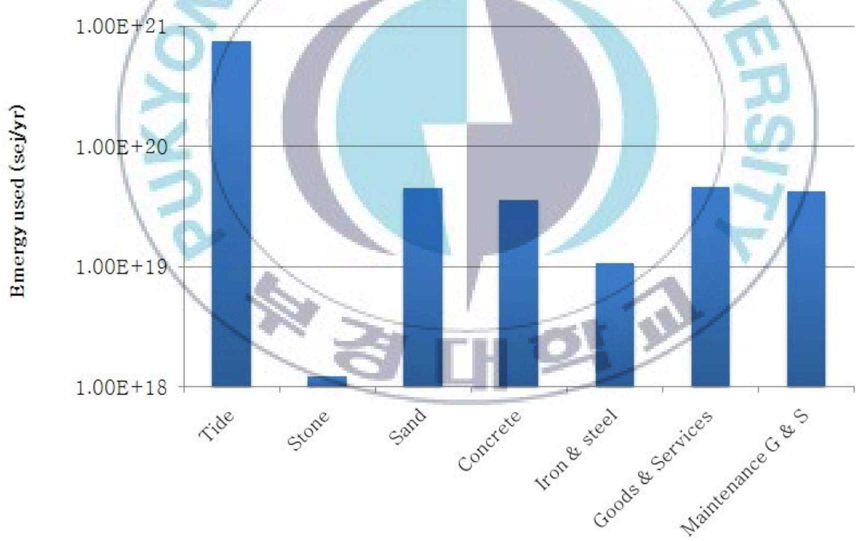


Fig. 20. Emergy signature of each energy source of tidal power in Saemangeum.

1.3. Generation efficiency with/without seawall construction

In this study, the transformity of the tidal plant including the construction of a new seawall and the transformity of the same type of power plant relying on an existing seawall in Saemangeum region are compared. Results are also compared with electricity production from literature.

Fig. 20 shows the diagram of tidal power plant including seawall construction. The diagram of Fig. 20 is similar as the earlier one except for the construction of the seawall. Additional purchased inputs such as material and goods and services for seawall construction were included.

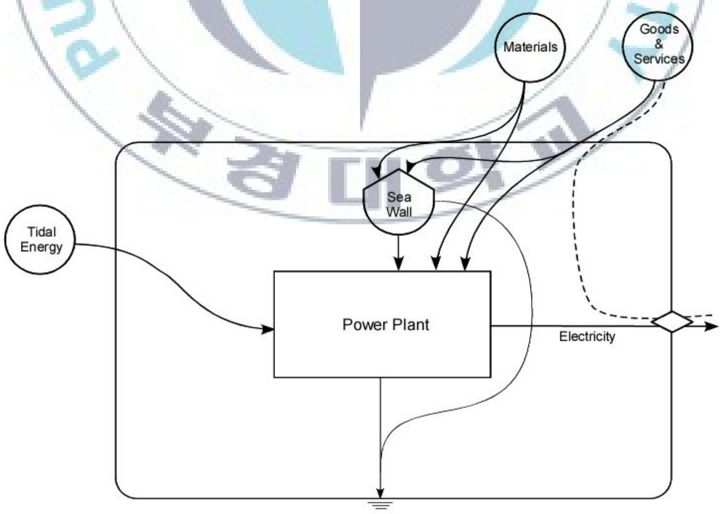


Fig. 21. Energy systems diagram of tidal power plant with seawall construction for Saemangeum.

The data excluding seawall construction are the same as in Table 10 while the raw data for seawall construction are shown in Table 11.

Materials for seawall construction can be calculated typically as stone 2.58E+13g, sand 3.03E+13g, and concrete 1.51E+12g. The life span of seawall was assumed to be the same as for the generator (55 years), thus translating into annual amounts of 4.69E+11 g/yr (stone), 5.50E+11 g/yr (sand), 2.75E+10 g/yr (concrete). And, seawall maintenance cost was calculated as 6.02E+09 ₩/yr.

Table 11. Raw data for seawall construction

Construction	Phase			
2	Seawall construction			
	a. Materials			
		Stone	=	2.58E+13 g
		Lifetime	=	55 yr
			=	4.69E+11 g/yr
		Sand	=	3.03E+13 g
		Lifetime	=	55 yr
			=	5.50E+11 g/yr
		Concrete	=	1.51E+12 g
		Lifetime	=	55 yr
			=	2.75E+10 g/yr
	b. Goods & Services		=	2.41E+12 ₩
		Lifetime	=	55 yr
				4.38E+10 ₩/yr
3	Maintenance			
	G&S for seawall		=	6.02E+09 ₩/yr

The complete emergy evaluation of the Saemangeum tidal power including seawall construction is shown in Table 12. Detailed calculation procedures for raw data in the table are given in appendix B.

Emergy inputs for seawall construction (stone, sand and concrete) were respectively 7.88E+20 seJ/yr, 1.23E+21 seJ/yr, 4.95E+19 seJ/yr, equivalent to an emvalue of 231 billion Em₩/yr for the stone, 360 billion Em₩/yr for the sand, and 14.6 billion Em₩/yr for the concrete. The emergy for seawall maintenance was 1.50E+20 seJ/yr, which is equivalent to 43.8 billion Em₩/yr.

The additional emergy input for seawall construction translate to a transformity of 1.28E+06 seJ/J, assuming the same output as in Table 10, which is higher than the previously calculated value, thus indicating a higher unit production cost.

Table 12. Emergy table of tidal power plant with seawall construction

No.	Item	Raw Data	Transformity (seJ/unit)	Solar Emergy (seJ/yr)	Emvalue (Em₩/yr)
Renewable source					
1	Tide	1.01E+16 J/yr	7.39E+04 a)	7.49E+20	2.19E+11
Purchased input					
2	Seawall construction				
	a. Material				
	Stone	4.69E+11 g/yr	1.68E+09 b)	7.88E+20	2.31E+11
	Sand	5.50E+11 g/yr	2.24E+09 b)	1.23E+21	3.60E+11
	Concrete	2.75E+10 g/yr	1.81E+09 c)	4.98E+19	1.46E+10
	b. G & S	4.38E+10 ₩/yr	3.42E+09 e)	1.50E+20	4.38E+10
		sub total		2.24E+21	6.55E+11
3	Maintenance G&S for seawall	6.02E+09 ₩/yr	3.42E+09 e)	2.06E+19	6.02E+09
4	Power plant construction				
	a. Materials				
	Stone	7.29E+08 g/yr	1.68E+09 b)	1.22E+18	3.58E+08
	Sand	2.02E+10 g/yr	2.24E+09 b)	4.53E+19	1.32E+10
	Concrete	1.96E+10 g/yr	1.81E+09 c)	3.55E+19	1.04E+10
	Iron & steel	1.58E+09 g/yr	6.79E+09 d)	1.07E+19	3.14E+08
	b. G & S	1.33E+10 ₩/yr	3.42E+09 e)	4.56E+19	1.33E+10
		sub total		1.38E+20	4.05E+10
5	Maintenance G&S for power plant	1.25E+10 ₩/yr	3.42E+09 e)	4.26E+19	1.25E+10
Production					
6	Electricity	2.47E+15 J/yr	1.28E+06 f)	3.17E+21	9.27E+11

Transformity based on total global emergy flow of 15.83E+24 seJ/yr

a) Cambell et al. (2005), b) Campbell and Brandt-Williams (2005), c) Simoncini (2006), d) Brown and Buranakarn (2003), e) Im (2010), f) this study

* Detailed calculation procedures for raw data in the table are given in Appendix B

Based on emergy evaluation from Table 12, the emergy signature is shown in Fig. 21.

Among the materials required for seawall construction, stone and sand are those contributing the highest emergy input followed by the emergy of tide. Apparently, the evaluation of the tidal power plant with seawall construction in Saemangeum highlights a substantial resource cost, determined by the seawall construction, that could be indicated an inefficient way to enforce tidal power in Saemangeum. Of course, it would be considerably cost effective to install tidal power generator where there is an pre-existing seawall as in Saemangeum region or a suitable natural basin as elsewhere in the world.

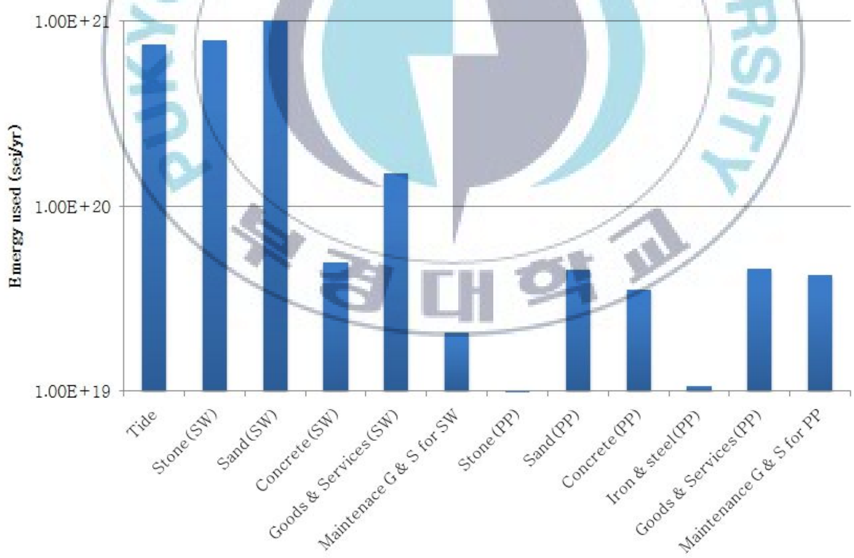


Fig. 22. Emergy signature of each energy sources including seawall construction.

Table 13 shows transformity of various power facilities.

The transformity in this table was compared data from Odum(1996) base on entire earth emergy of 15.83E+24 seJ/yr.

Some of the these plants are very well matured technologies, others are still developing (photovoltaic, for example), some are benefited by low transformity (such as coal and lignite). Others have higher combustion efficiency and therefore provide more input (such as methane, translating into a lower transformity). All the cases are different and reflect the local situation, including the cases in Korea. For example hydro power plant in Korea and Brazil are not the same; each location has its local emergy resources and opportunities. There are so many different ways of generating electricity in the world. But all the fossil plants will sooner or later be dismissed for lack of fossil fuels or for environmental reasons, while the ones running on renewable sources will still be usable, although a bit more expensive in emergy terms.

Transformities of tidal power with and without seawall construction were also included, being respectively 3.38E+05 seJ/J and 3.56E+05 seJ/J (Joo, 2007). Therefore, including construction of seawall decreases the efficiency compared with tidal power generation at existing seawall, although not much effected by the seawall construction in the case of Sihwa plant.

Referring to power plant, including seawall, the transformity (Garolim tidal power project, 2008) is 2.01E+05 seJ/J. Garolim transformity is lower than Saemangeum (3.76E+05 seJ/J). The higher efficiency in Garolim is due to the greater tidal range (4.72m) as well as the relatively shorter length of the seawall.

Based on earlier calculation, the construction of seawall in Saemangeum increases the transformity of electricity up to 12.8E+05 seJ/J.

However, if the tidal power plant would be installed at existing seawall in Saemangeum, which was constructed for other purposes, its construction emergy is need not be included into the assessment, thus allowing to accept a transformity equal to 3.76E+05 seJ/J. This means that tidal power generators would rather be located where a natural basin is already available or a seawall was already constructed for other reasons (multi-functional use) than where it has to construct a new seawall.

Table 13 indicates that the local conditions affect the result and the final efficiency in many ways (more product, less construction costs, higher tide power, multi-functional use, etc). In each case, the emergy assessment allows to quantify the advantage based on one unit of measure only. (the solar emergy joule.)

Table 13. Solar transformity of electric power facilities

Power facilities	Solar empower (seJ/yr)	Electric Power (J/yr)	Solar transformity ($\times 10^5$seJ/J)
Wood power plant, Thailand	4.07E+14	3.60E+09	1.13 [a)]
Hydroelectric power, Sweden	3.28E+22	2.43E+17	1.35 [a)]
Tidal power plant, Garolim, Korea(with seawall construction)	6.76E+20	3.36E+15	2.01 [c)]
Lignite power plant, Thailand	9.19E+14	3.60E+09	2.55 [a)]
Coal power plant	268,800	1	2.69 [a)]
Hydroelectric, Tucurui, Brazil	2.77E+22	1.00E+17	2.77 [a)]
Coal power plant, Thailand	1.02E+15	3.60E+09	2.85 [a)]
Oil power plant, Thailand	1.20E+15	3.60E+09	3.33 [a)]
Tidal power plant, Sihwa, Korea (using the existing seawall)	6.73E+20	1.99E+15	3.38 [b)]
Wood power plant, Jari, Brazil	4.00E+20	1.17E+15	3.42 [a)]
Lignite power plant, Texas	9.07E+21	2.65E+16	3.42 [a)]
Tidal power plant, Sihwa, Korea (with seawall construction)	7.08E+20	1.99E+15	3.56 [b)]
Tidal power plant, Saemangeum, Korea(using the existing seawall)	9.30E+20	2.47E+15	3.76 [d)]
Solar voltaic grid, Austinm Tex.	1.26E+18	1.80E+12	7.00 [a)]
Tidal power plant, Saemangeum, Korea(with seawall construction)	3.17E+21	2.47E+15	12.8 [d)]

a) revised from Odum (1996), b) Joo (2006), c) Garolim tidal power project (2008), d) this study

1.4. Emergy indices

Table 14 shows the emergy indices calculated from the emergy evaluation Table 10.

The total emergy (U) is 9.30E+20 seJ/yr which is the sum of renewable emergy (R), 7.49E+20 seJ/yr, and emergy from outside, 1.81E+20 seJ/yr.

The ratio of renewable emergy to the total emergy is 80.53%, mainly due to the renewable contribution from the tide.

The emergy yield ratio is 5.14, which means that about 5 times more benefits can be obtained compared to the emergy cost. The environmental loading ratio is 0.24, which means that the impact on environment is quite low. The emergy sustainability index is 21.25, much higher than 10, which indicates that this system is highly sustainable.

Brown and Ulgiati (2002) divided energy sources according to the EYR. They argue that if EYR > 5, the source is a primary energy source; if EYR is between 2 and 5, the source is a secondary energy source. If EYR < 2, the product of the process is rather a consumer good, not an energy contribution. The EYR for electricity produced is 5.14, which suggested that electricity in Saemangeum from the tidal power still can be considered primary energy.

Table 14. Emergy indices of tidal power plant at existing seawall in Saemangeum

Name of index	Value
Renewable emergy (R, seJ/yr)	7.49E+20
Puchased emergy (F, seJ/yr)	1.81E+20
Total emergy flows (U, seJ/yr)	9.30E+20
Renew %	80.53
EY = Y/F	5.14
ELR = (N+F)/R	0.24
ESI = EYR/ELR	21.25

Table 15 shows the comparison of emergy indices in various power production facilities. Saemangeum and Sihwa tidal power using existing seawall and constructed seawall are compared in this Table.

ESI on the table 15 are in order of increasing value for the power facilities. They are showing either very low or intermediate or else very high ESI.

Generating tidal power with constructing seawall in Saemangeum, ESI is 0.41 indicating system's sustainability appears to be poor. Coal power of ESI in Italia was 0.53, reflected that impact on environment is high and also sustainability of the system is non-persistent.

Intermediate ESI for Geothermal was 11.05, Hydro was 16.90, Tidal energy Saemangeum at existing seawall was 21.25 and Tidal energy Garolim was 65.25.

And, with higher ESI for tidal energy for Sihwa with seawall construction was 188.61 and Tidal energy Sihwa at existing seawall was 2005.59.

Coal power plant and Saemangeum with constructing seawall are very low ESI due to low EYR and relatively high ELR. Intermediate ESI for Hydro, Geothermal and Saemangeum without seawall are due to the low ELR. And the rest of other power facilities with high ESI are due to low ELR coupled to a very high EYR. The reasons of these different behaviors are several factors in some instants. The seawall maybe short, or the huge polluting emissions from coal, or else, the low ELR for Hydro and Geothermal are renewable sources versus non-renewables of several other power facilities.

The Fig. 22, emergy indices of EYR, ELR and ESI are expressed on the graph for each power facilities and reflected that sustainability of Sihwa tidal power is highest of all facilities and would be highly competitive as well.

Table 15. Comparison of emergy indices for power production facilities

Power production facilities	EYR	ELR	ESI
Tidal energy, Saemangeum with seawall construction (400㎿)	1.31	3.21	0.41
Coal, Italy (1280㎿) [a]	5.48	10.37	0.53
Geothermal, Italy (20㎿) [a]	4.81	0.44	11.05
Hydro, Italy 85㎿) [a]	7.65	0.45	16.90
Tidal energy, Saemangeum at existing seawall (400㎿)	5.14	0.24	21.25
Tidal energy, Garolim with seawall construction (520㎿) [b]	8.59	0.13	65.25
Tidal energy, Sihwa with seawall construction (254㎿) [c]	14.24	0.08	188.61
Tidal energy, Sihwa at existing seawall (254㎿) [c]	45.29	0.02	2005.59

a) Brown and Ulgiati (2002), b) Garolim tidal power project (2008), c) Joo (2006)

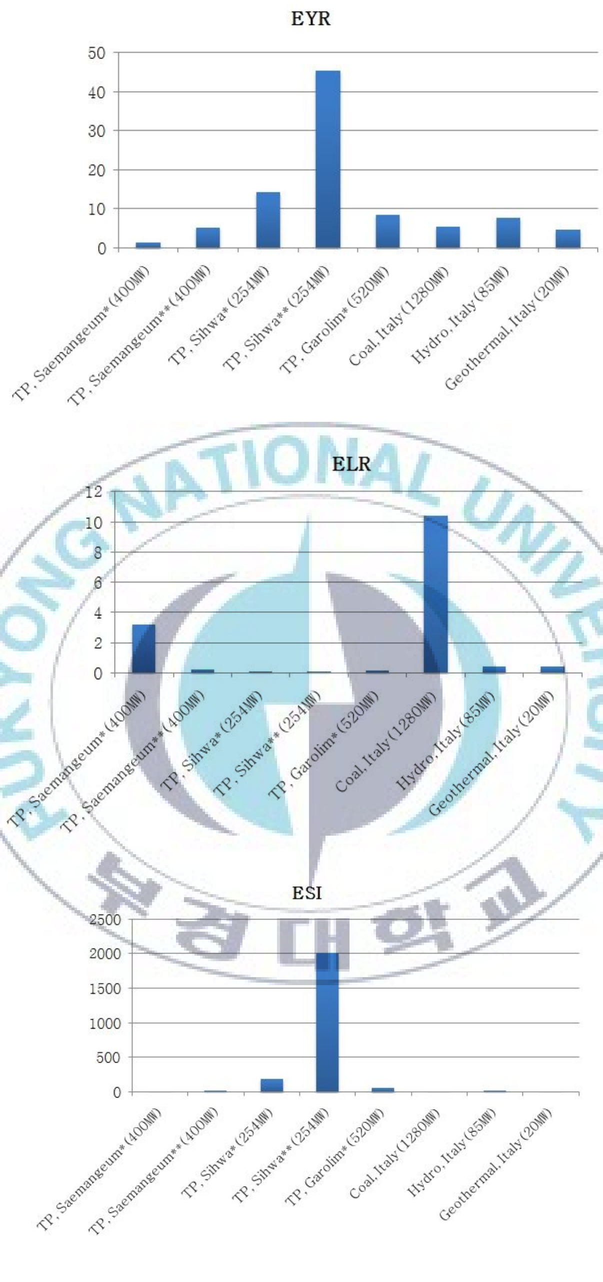


Fig. 23. Comparison of emergy indices for power production facilities; * with seawall construction, ** at existing seawall.

2. Emergy evaluation of tidal flats rehabilitation in Saemangeum region

2.1. Energy system diagram

Fig. 23 explains the rehabilitation of tidal flat after the operation of generating tidal power. From the generation of tidal power, seawater would be able to flow consistently. Thus it is highly expected that this will rehabilitate tidal flats which were destroyed from the construction of seawall.

The inflows of natural environmental resources from outside the system (such as sun, wind, rain, tide, and river) and, input of goods and services for fishery are included in the assessment. The damaged tidal flats were expected to rehabilitate through circulating seawater from tidal power. Fishing activities may take place and become beneficial to the local economy.

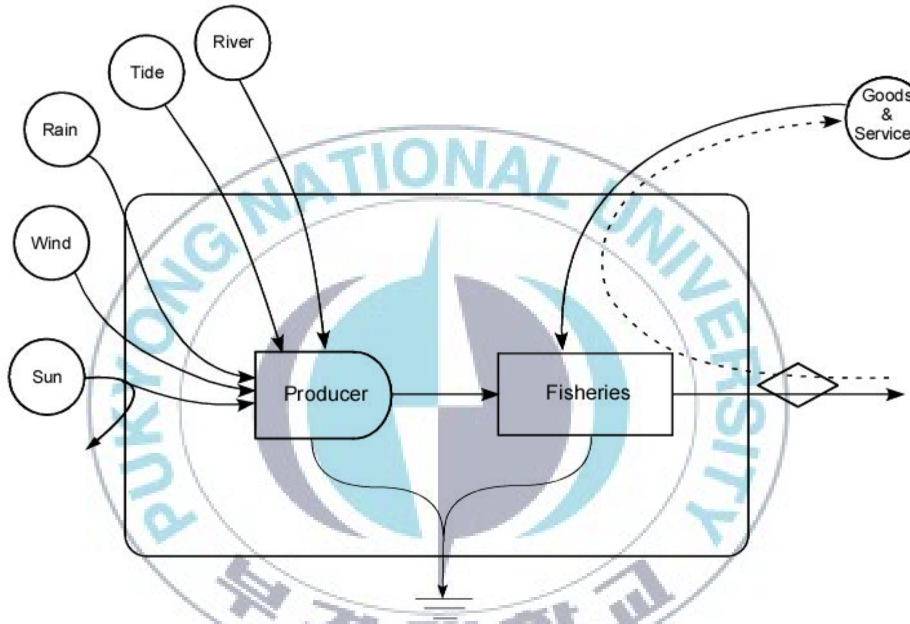


Fig. 24. Energy system diagram of rehabilitation of tidal flat.

2.2. Emergy analysis

Following tidal power generation, recovery of the tidal flat through circulating seawater was expected for the increase of marine products and an improvement of the fishing industry in the region of Saemangeum.

The emergy of rehabilitated tidal flats was evaluated by estimating the production of shellfish, seaweed and fish using data from Table 16.

Areal boundary of the system is determined for 185㎢ from the small power generation. Solar radiation of 4.66E+09 J/㎡/yr was obtained from the meteorological annual report (KMA, 2006).

For the local wind speed and average precipitation data in Saemangeum region, the same statistical report was used, yielding respectively 2.50㎧, 1.17m/yr.

In the case of the inflow of river, used data from the water information system, 2010 for Mankyung river exported data from Mok stream and, for Dongjin river exported data from Taein and Kobu stream.

Required data on the purchased goods and services for fishery activity were obtained from the expenses per fisherman’s family and number of houses of fishermen. Products of fisheries were estimated from the ratio of rehabilitated area/original area, as shellfish for 2.09E+07 ㎏/yr, seaweed for 4.86E+06 ㎏/yr, and fishes for 3.18E+05 ㎏/yr.

Tidal flat recovery and its marine productivities may not be the same as exactly as before the reclamation project and the seawall construction. The basin area was 401㎢ originally before the seawall was built, but for this study, the rehabilitated area was 185㎢ based on considering the government's development plan.

There are not many available places exploiting the tidal power in other nations for a reference studies. Even so, it’s rare to find a research about the restoration of marine productivity through tidal power. Therefore, the recovery of the marine productivity can only be assumed from the basin area of 185㎢, which is an area fraction of 0.46 from the original area of 401㎢.

Emergy evaluation of the rehabilitation for tidal flat is shown in Table 17. Detailed calculation procedures for raw data in the table are given in appendix C.

The inflowing solar emergy from outside system boundary was 7.75E+17 seJ/yr, the wind emergy was 1.30E+18 seJ/yr, rain chemical 3.27E+19 seJ/yr, tide 7.49E+20 seJ/yr, and river emergy was 6.84E+20 seJ/yr. To avoid double counting in total emergy from natural environment, only the tide and river emergy were added, yielding a total emergy of 1.43E+21 seJ/yr, which is equivalent to 419 billion Em₩/yr of ecologic-economic value.

Emergy purchased from outside for fishery is 3.86E+19 seJ/yr, at an assumed cost of 11.3 billion Em₩/yr.

The emergy of supporting shellfishes calculated for 4.54E+19 seJ/yr, which is equivalent to 13.3 billion Em₩/yr; for seaweeds was 4.55E+16 seJ/yr, which is equivalent to 0.013 billion Em₩/yr; and for fish was 1.86E+18 seJ/yr, which is equivalent to 0.544 billion Em₩/yr. Therefore Total production emergy through rehabilitation of tidal flat was 4.74E+19 seJ/yr, which is equivalent to 13.8 billion Em₩/yr. were calculated.

Table 16. Raw data table of tidal flats rehabilitation in Saemangeum

Renewable source					
1	Sunlight				
		System area	=	1.85E+08	㎡
		Insolation	=	4.66E+09	J/㎡/yr
2	Wind, kinetic energy				
		Avg. wind speed	=	2.50E+00	㎧
3	Rain				
		Rain	=	1.17E+00	m/yr
4	Tide				
		Tidal area	=	1.85E+08	㎡
		Avg. Tide range	=	3.93E+00	m
5	River				
		Volume flow	=	1.08.E+09	㎥/yr
		Volume flow	=	6.29.E+08	㎥/yr
Purchased input					
10	Goods & Services for fisheries				
		yield(Aquaculture)	=	2.58E+07	kg/yr
		Expenditure/fishery household	=	8.15.E+06	₩/yr
		Number of fishery household	=	6.94E+04	
		Gross Domestic Fishery Product	=	1.31.E+09	㎏/yr
		yield(Fishery)	=	3.18E+05	㎏/yr
		Expenditure/fishery household		1.10.E+07	₩/yr
		Number of fishery household	=	6.94E+04	
		Gross Domestic Fishery Product		1.23.E+09	㎏/yr
Production					
11	Shellfishes		=	2.09E+07	kg/yr
12	Seaweeds		=	4.86E+06	kg/yr
13	Fishes		=	3.18E+05	kg/yr

Table 17. Emergy table for rehabilitation of tidal flat

No.	Item	Raw Data	Transformity (seJ/unit)	Solar Emergy (seJ/yr)	Emvalue (Em₩/yr)
Renewable source					
1	Sunlight	7.75E+17 J/yr	1.00E+00 a)	7.75E+17	2.27E+08
2	Wind	5.17E+14 J/yr	2.51E+03 a)	1.30E+18	3.79E+08
3	Rain, chemical	1.07E+15 J/yr	3.05E+04 a)	3.27E+19	9.57E+09
4	Tide	1.01E+16 J/yr	7.39E+04 a)	7.49E+20	2.19E+11
5	River, chemical	8.42E+15 J/yr	8.13E+04 a)	6.84E+20	2.00E+11
		sub total		1.43E+21	4.19E+11
Purchased input					
6	G & S for fisheries	1.13E+10 ₩/yr	3.42E+09 d)	3.86E+19	1.13E+10
Production					
7	Shellfish	3.34E+13 J/yr	1.36E+06 f)	4.54E+19	1.33E+10
8	Seaweeds	2.46E+12 J/yr	1.85E+04 f)	4.55E+16	1.33E+07
9	Fish	6.92E+12 J/yr	2.69E+06 f)	1.86E+18	5.44E+08
		sub total		4.74E+19	1.38E+10

Transformity based on total global emergy flow of 15.83E+24 seJ/yr

* Detailed calculation procedures for raw data in the table are given in Appendix C

Based on the Emergy analysis Table 17, an emergy signature can be drawn as in Fig. 24. As indicated by the emergy signature for rehabilitation of the tidal flat, the system is highly influenced by the renewable sources of tide and river.

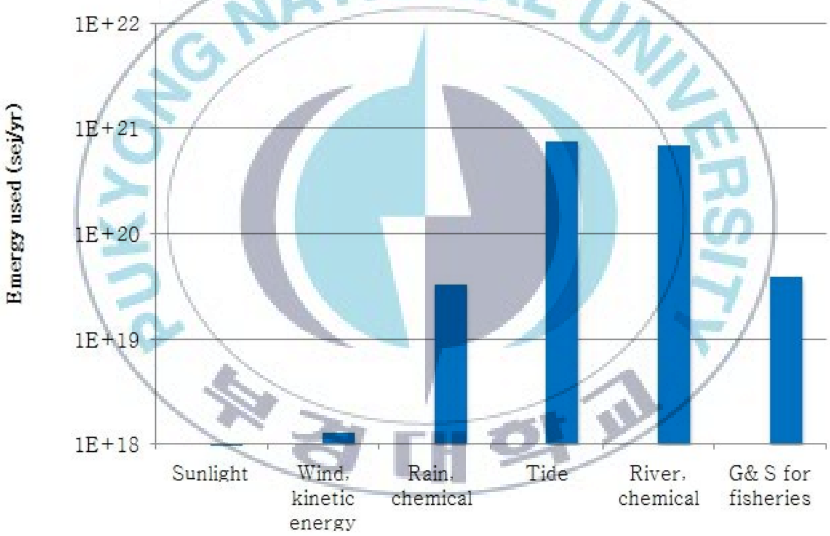


Fig. 25. Emergy signature of each energy source for rehabilitated tidal flat in Saemangeum.

3. Carbon reduction through tidal power plant

Table 18 shows the amount of domestic power generation and the CO_2 emission factors calculated by KPX (Korea Power Exchange) in 2008. Between 2003 and 2007 average amount of power generation was 178,060 GWh and the average emission factor was 0.82 ton/㎿h.

By constructing tidal power plant in Saemangeum, electricity produced for 687 GWh/year. Calculation was based of the KPX emission factors, it revealed a reduction of 563,340 metric tons in CO_2 emissions every year from the time generating tidal power in Saemangeum. While converting a price range as per current carbon trading market price was at 18,270₩/ton as of Feb. 2010, and then multiplied CO_2 reduction quantity to obtain the benefit of 10.2 billion through CDM from the tidal power in Saemangeum (Table 19).

Table 18. Emission factors for domestic power plant(Korea Power Exchange, 2008)

	Generation(㎿h)	Emission Factors(tCO_2e/㎿h)
2003	152,482,247	0.8283
2004	170,100,668	0.8139
2005	176,319,607	0.8158
2006	182,948,720	0.8202
2007	208,453,116	0.8000
average	178,060,872	0.8200

Table 19. Summary of carbon reduction through tidal power plant

Power	Emission Factor	Emission	Price	Exchange Rate	Price	CERs Price
GWh/yr	ton CO_2 /GWh	ton CO_2 /yr	£/ton (2010.12)	₩/£	₩/ton	₩/yr
687	820	563,340	11.81	1,547	18,270.07	10,292,261,234

4. Emergy cost-benefit analysis of Saemangeum tidal power plant

Table 20 shows the result of an emergy cost-benefit analysis of Saemangeum tidal power plant using existing seawall and expected rehabilitation of the tidal flat. Marine productivity is also expected to improve from circulating seawater. In addition, while generating electricity from the tidal power, is also expected a reduction of carbon emissions.

Emergy of electricity at 7.22E+20 seJ/yr, shellfishes at 4.54E+19 seJ/yr, seaweeds at 4.55E+16 seJ/yr, fishes at 1.86E+18 seJ/yr, carbon reduction (data given Table 19) and 3.52E+19 seJ/yr were calculated. Their em-values respectively equivalent to 211 billion Em₩/yr, 13.3 billion Em₩/yr, 0.013 billion Em₩/yr, 0.54 billion Em₩/yr, and 10.3 billion Em₩/yr were calculated. Total emergy 8.04E+20 seJ/yr was equivalent to 235 billion Em₩/yr accounted in benefit.

The costs for the construction of seawall; include stone 1.22E+18 seJ/yr, sand 4.53E+19 seJ/yr, concrete 3.55E+19 seJ/yr, iron and steel 1.07E+19 seJ/yr and, goods and services for 4.59E+19 seJ/yr, were also computed. Maintenance emergy 4.26E+19 seJ/yr and goods and services for fishery 3.86E+19 seJ/yr were calculated as well. Therefore, a total emergy of 2.20E+20 seJ/yr, which equivalent to 64.2 billion Em₩/yr was calculated.

For a review of the feasibility of the project, calculated the total net profit and cost/benefit ratio. Emvalue of benefit versus cost differences was 171 billion Em₩/yr indicating that a net profit of 171 billion Em₩/yr could be obtained from using existing seawall for tidal power generation in Saemangeum. Also a cost/benefit ratio of 3.66 represented over 3 times higher benefit compared to the cost for tidal power.

Table 20. Emergy cost-benefit evaluation of tidal power plant using the existing seawall in Saemangeum

No.	Item	Raw Data	Solar transformity (seJ/unit)	Solar Emergy (seJ/yr)	Emvalue (Em₩/yr)
Emergy benefits					
1	Electricity	2.47E+15 J/yr	2.92E+05	7.22E+20	2.11E+11
2	Shellfishes	3.34E+13 J/yr	1.36E+06	4.54E+19	1.33E+10
3	Seaweeds	2.46E+12 J/yr	1.85E+04	4.55E+16	1.33E+07
4	Fishes	6.92E+12 J/yr	2.69E+06	1.86E+18	5.44E+08
5	Carbon reduction	1.03E+10 ₩yr	3.42E+09	3.52E+19	1.03E+10
	Sub total			8.04E+20	2.35E+11
Emergy costs					
6	Power plant construction				
	a. Materials				
	Stone	7.29E+08 g/yr	1.68E+09	1.22E+18	3.58E+08
	Sand	2.02E+10 g/yr	2.24E+09	4.53E+19	1.32E+10
	Concrete	1.96E+10 g/yr	1.81E+09	3.55E+19	1.04E+10
	Iron & steel	1.58E+08 g/yr	6.79E+09	1.07E+19	3.14E+08
	b. G & S	1.33E+10 ₩/yr	3.42E+09	4.56E+19	1.33E+10
7	G&S for Maintenance	1.25E+10 ₩/yr	3.42E+09	4.26E+19	1.25E+10
8	G&S for fisheries	1.13E+10 ₩/yr	3.42E+09	3.86E+19	1.13E+10
	Sub total			2.20E+20	6.42E+10
	Net benefit				**1.71E+11**
	B/C ratio				**3.66**

Comparison with previous literature on the Saemangeum project has been evaluated as shown in Table 21. According to MKE(2006), the cost of constructing a tidal power plant consists of direct costs for electrical construction and civil construction, and indirect costs including maintenance. Electrical construction cost of 436,634 million₩ and civil construction cost of 296,730 million₩ representing the total construction cost for tidal power plant reflected for 733,364 million₩ during 5 years. And operation and maintenance cost was estimated at 1.7% of the total construction cost, which was estimated from comparison with the La Rance plant. The calculation of the cost for electricity and mechanical work for plant are based on an assumption that half of the total construction cost will be reinvested over the 40th year, and reference data was from the feasibility study of the Garolim tidal plant in 1993.

Direct benefits (MKE, 2006) from the tidal power generation in Saemangeum region include reduction of supply cost for equipments, fuel saving benefits and reduction of environmental disposal costs, while indirect benefits are tourism and fisheries in the basin. In this paper, data associated with tourism benefits based on the survey from the Garolim project were used. Reduction of supply cost for equipments is 878 million₩. Fuel saving benefits is 49,802 million₩, and there will be no facility cost to treat waste from the power plant because it does not emit any polluted matter. Reduction of environmental disposal costs 18,293 million₩.

The tidal power allows free movement of seawater leading to cleaner waters in the bay area for more abundant nutrient salt and more fishery production. The tidal power plant can provide a good location for tourism and a learning resource for an education purposes because it is a rare location across the globe. In this study, the effects as a tourism destination benefits were 17,282 million₩, based on the reference data of Garolim.

The data from Table 21 were applied to cost/benefit evaluation and its emergy was evaluated according to Table 22. Tide as renewable source, imported materials, goods & services from outside, and production of electricity were accounted for in the calculation. Detailed calculation procedures for raw data in the table are given in appendix D.

Tide from renewable resources entering into system, the tide 7.49E+20 seJ/J divided by EMR, expressed 219 billion Em₩/yr of the value.

Considering civil work, facility and gate structure contained concrete and their emergy are each 3.51E+19 seJ/yr, and 8.99E+18 seJ/yr, and steel and sand for temporary water blockage were each about 4.25E+18 seJ/yr and 4.40E+19 seJ/yr. The central pier's stone and sand emergy were each 1.22E+18 seJ/yr and 1.24E+18 seJ/yr, goods and services emergy of civil work were 2.26E+19 seJ/yr, totalling 1.17E+20 seJ/yr equivalent to a total emvalue of 34.3 billion Em₩/yr.

Emergy of iron & steel for power generator from the construction of electricity equipment was 3.39E+18 seJ/yr, for turbine was 2.04E+18 seJ/yr, stop-log was 5.84E+17 seJ/yr, crane was 8.56E+17 seJ/yr, and goods and services were 1.71E+19 seJ/yr were accounted. Therefore, the total emergy of 2.40E+19 seJ/yr was calculated, translating into an economic value of 7.02 billion Em₩/yr.

Management and labor cost were each 3.18E+18 seJ/yr, 1.41E+18 seJ/yr. Emergy of electricity was 7.22E+20 seJ/yr equivalent to 211 billion Em₩/yr of economic value.

Based on Table 22, emergy costs and benefits were evaluated in Table 23.

The cost/benefit from Table 23 was evaluated using limited data for the benefit, items are reduction of supply cost for equipments (3.00E+18 seJ/yr), fuel saving benefits (1.70E+20 seJ/yr), reduction of environmental management costs (6.26E+19 seJ/yr), tourism (5.91E+19 seJ/yr) applied with currency units, and the results showed a total benefit of 2.95E+20 seJ/yr. Thus, from the tidal power in Saemangeum a total benefit of 86.3 billion Em₩/yr can be obtained.

Also the costs for the project by MKE (2006) was calculated including materials from their database. Civil work, electricity/mechanics, management cost, labor, Goods and services for maintenance were included. The total emergy cost was 1.87E+20 seJ/yr which equivalents to 54.8 billion Em₩/yr, therefore, the net benefit from the cost/benefit difference was 31.5 billion Em₩/yr and B/C ratio was 1.57, so the benefit was somewhat higher.

Comparing the cost/benefit between 1.17 of Table 21 and 1.57 of Table 23 showed minimal differences but in second case it was slightly higher since it was based on real value.

Emergy cost-benefit from this study and economic analysis studied by MKE and emergy costs-benefit based on their study showed different results.

These results originate from the differences of evaluation methods determined to reflect the existing economic value and to reflect real value of emergy analysis.

Consequently, economic evaluation based on units of currency for feasibility of the project was lower, but emergy evaluation based on real value of the project in Saemangeum reflected three times higher in benefit versus cost for the project.

Table 21. Cost and benefit item and B/C ratio(MKE, 2006)

Unit: million₩

Cost	1. Construction	
	· Electrical construction	436,634
	· civil construction	296,730
	2. Plant maintenance	733,364*1.7%
Benefit	1. Direct Benefit	
	· reduction of supply cost for equipments	878
	· fuel saving benefits	49,802
	· reduction of environmental disposal costs	18,293
	2. Indirect benefits	
	· tourism	17,282
	· marine productivity	
B/C	Direct	Direct + Indirect
	0.94	1.17

Table 22. Emergy evaluation of tidal power plant by MKE table 21

No.	Item	Raw Data	Solar transformity (seJ/unit)	Solar emergy (seJ/yr)	Emvalue (Em₩/yr)
Renewable sources					
1	Tide	1.01E+16 J/yr	7.39E+04	7.49E+20	2.19E+11
Purchased input					
2	Civil work				
	Facility structure (concrete)	1.94E+10 g/yr	1.81E+09	3.51E+19	1.02E+10
	Gate structure (concrete)	4.97E+09 g/yr	1.81E+09	8.99E+18	2.63E+09
	Temporary water blockage				
	steel	6.27E+08 g/yr	6.79E+09	4.25E+18	1.24E+09
	sand	1.97E+10 g/yr	2.24E+09	4.40E+19	1.29E+10
	Central pier				
	stone	7.29E+08 g/yr	1.68E+09	1.22E+18	3.58E+08
	sand	5.55E+08 g/yr	2.24E+09	1.24E+18	3.63E+08
	G & S	6.60E+09 ₩/yr	3.42E+09	2.26E+19	6.60E+09
		sub total		1.17E+20	3.43E+10
3	Electricity/mechanics				
	Generator (Iron & Steel)	5.00E+08 g/yr	6.79E+09	3.39E+18	9.92E+08
	Turbine (Iron & Steel)	3.00E+08 g/yr	6.79E+09	2.04E+18	5.96E+08
	Stop-Log(concrete)	3.23E+08 g/yr	1.81E+09	5.84E+17	1.71E+08
	Crane	1.26E+08 g/yr	6.79E+09	8.56E+17	2.50E+08
	G & S	5.01E+09 ₩/yr	3.42E+09	1.71E+19	5.01E+09
		sub total		2.40E+19	7.02E+09
4	Management cost	9.30E+08 ₩/yr	3.42E+09	3.18E+18	9.30E+08
5	Labor	4.11E+08 ₩/yr	3.42E+09	1.41E+18	4.11E+08
Production					
6	Electricity	2.47E+15 J/yr	2.92E+05	7.22E+20	2.11E+11

* Detailed calculation procedures for raw data in the table are given in Appendix D

Table 23. Economic evaluation through emergy analysis for cost-benefit of the tidal power plant

No.	Item	Raw Data	Solar transformity (seJ/unit)	Solar Emergy (seJ/yr)	Emvalue (Em₩/yr)
Emergy benefits					
1	Reduction of supply cost for equipments	8.78E+08₩/yr	3.42E+09	3.00E+18	8.78E+08
2	Fuel saving benefits	4.98E+10₩/yr	3.42E+09	1.70E+20	4.98E+10
3	Reduction of environmental management costs	1.83E+10₩/yr	3.42E+09	6.26E+19	1.83E+10
4	Tourism	1.73E+10₩/yr	3.42E+09	5.91E+19	1.73E+10
	sub total			2.95E+20	8.63E+10
Emergy costs					
5	Civil work				
	a. Facility structure(concrete)	1.94E+10g/yr	1.81E+09	3.51E+19	1.02E+10
	b. Gate structure (concrete)	4.97E+09g/yr	1.81E+09	8.99E+18	2.63E+09
	c. Temporary water blockage				
	steel	6.27E+08g/yr	6.79E+09	4.25E+18	1.24E+09
	sand	1.97E+10g/yr	2.24E+09	4.40E+19	1.29E+10
	d. Central pier				
	stone	7.29E+08g/yr	1.68E+09	1.22E+18	3.58E+08
	sand	5.55E+08g/yr	2.24E+09	1.24E+18	3.63E+08
	e. G & S	6.60E+09₩/yr	3.42E+09	2.26E+19	6.60E+09
6	Electricity/mechanics				
	a. Generator (Iron & Steel)	5.00E+08g/yr	6.79E+09	3.39E+18	9.92E+08
	b. Turbine (Iron & Steel)	3.00E+08g/yr	6.79E+09	2.04E+18	5.96E+08
	c. Stop-Log(concrete)	3.23E+08g/yr	1.81E+09	5.84E+17	1.71E+08
	d. Crane	1.26E+08g/yr	6.79E+09	8.56E+17	2.50E+08
	e. G & S	5.01E+09₩/yr	3.42E+09	1.71E+19	5.01E+09
7	Management cost	9.30E+08₩/yr	3.42E+09	3.18E+18	9.30E+08
8	Labor	4.11E+08₩/yr	3.42E+09	1.41E+18	4.11E+08
9	Maintenance for G&S	1.21E+10₩/yr	3.42E+09	4.14E+19	1.21E+10
	sub total			1.87E+20	5.48E+10
	Net benefit				3.15E+10
	B/C ratio				1.57

V. Conclusion

Development of tidal power in Saemangeum region was analyzed for the ecologic-economic value points and the feasibility of the project.

And the findings are as follows;

1. The emergy of electricity produced from tidal power generation was 7.22E+20 seJ/yr and the corresponding ecologic-economic value was 210 billion Em₩/yr.

2. Transformity of tidal power plant with seawall construction in Saemangeum was 12.8+05 seJ/J which is higher than other power facilities. The results indicated that harnessing tidal energy including seawall construction in Saemangeum region for tidal power would be inefficient.

3. However, analyzed emergy indices using the existing seawall, transformity of electricity of 3.76E+05 seJ/J is lower than including seawall construction. The efficiency is similar to fossil fuel fired power plants compared with other facilities.

EYR indicated the characteristics of the system was 5.14, meaning that it's a primary energy source as an alternative energy. ELR was 0.24, indicating very low impact on environment. ESI for the system was 21.25, therefore, the sustainability is very high for the system.

4. From the tidal power generation in Saemangeum, steady water circulation is expected. Consequently, tidal marine product could be increasingly restored. Furthermore, analyzing the results of an estimated total production of shellfish, algae and fish of marine products, its total emergy are 4.74E+19 seJ/yr in which equivalent to 13.8 million Em₩/yr of ecologic-economic value was accounted for.

5. Carbon reduction from the tidal power generation of 687GWh/yr of electricity in Saemangeum was estimated approximately 563,340 metric tons of CO_2/year in which equivalent to 10.2 billion₩/yr of CDM revenues.

6. The ratio of benefit to cost was 3.66, the benefit earned close to four times greater than the cost. So the net benefit for the production was 171 billion Em ₩/yr.

Finally, this study reveals that using an existing seawall for tidal power generation in Saemangeum could secure sustainable natural energy sources as an alternative energy and reduce CO_2 as well as providing rehabilitation of the damaged tidal flats through circulating seawater in the basin.

In conclusion, development of new cleaner renewable energy and alternative ways of producing electricity from tidal energy would be one of the reliable solution for the present energy crisis and is truly meaningful for the rehabilitation of the disturbed tidal flat.

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Appendix

Appendix A. Footnotes to table 10

Renewable source					Reference
1 Tide					
	tidal area	=	1.85E+08	㎡	MKE, 2006
	avg. tide range	=	3.93	m	MKE, 2006
	density	=	1.03E+03	kg/㎥	
	energy	=	(area)(0.5)(tides/yr)(height)^2(density)(gravity)		
		=	(1.85E8㎡)*(0.5)*(706/yr)*$(3.93m)^2$*(1025kg/㎥)*(9.8㎨)		
		=	1.01E+16	J/yr	
Purchased input					
2 Power plant construction					
a. Materials					
	stone	=	4.01E+10	g	MKE, 2006
	lifetime	=	55	yr	MKE, 2006
		=	7.29E+08	g/yr	
	sand	=	1.11E+12	g	MKE, 2006
	lifetime	=	55	yr	MKE, 2006
		=	2.02E+10	g/yr	
	concrete	=	1.08E+12	g	MKE, 2006
	lifetime	=	55	yr	MKE, 2006
		=	1.96E+10	g/yr	
	iron & steel	=	8.69E+10	g	MKE, 2006
	lifetime	=	55	yr	MKE, 2006
		=	1.58E+09	g/yr	
b. Good & Services		=	7.33E+11	₩	MKE, 2006
	lifetime	=	55	yr	MKE, 2006
		=	1.33E+10	₩/yr	
3 Maintenance G&S		=	(Construction Costs)(1.7%)		MKE, 2006
		=	1.25E+10	₩/yr	Calculated 1.7% of the total annual construction cost
Production					
4 Electricity		=	6.87E+08	㎾h/yr	MKE, 2006
		=	3.60E+06	J/㎾h	
		=	2.47E+15	J/yr	

Appendix B. Footnotes to table 12

Construction phase						Reference
2	Seawall construction					
	a. Materials					
		stone	=	2.58E+13	g	MIFFAF, 2002
		lifetime	=	55	yr	
			=	4.69E+11	g/yr	
		sand	=	3.03E+13	g	
		lifetime	=	55	yr	
			=	5.50E+11	g/yr	
		concrete	=	1.51E+12	g	
		lifetime	=	55	yr	
			=	2.75E+10	g/yr	
	b. Goods & Services		=	2.41E+12	₩	www.isaemangeum.co.kr
		lifetime	=	55	yr	
				4.38E+10	₩/yr	
3	Maintenance G&S SW		=	(construction costs)(1.7%)		MKE(2006)
			=	6.02E+09	₩/yr	

Appendix C. Footnotes to table 17

Renewable source					Reference
1	Sunlight				
	system area	=	1.85E+08	㎡	MKE, 2006
	insolation	=	4.66E+09	J/㎡/yr	Korean Weather Yearbook, 2006
	albedo	=	0.10		
	energy	=	(System area)(Insolation)(1-albedo)		
		=	(1.85E+08㎡)(4.66E+9J/㎡/yr)(1-0.1)		
		=	7.75E+17	J/yr	
2	Wind, kinetic energy				
	system area	=	1.85E+08	㎡	MKE, 2006
	density of air	=	1.23E+00	kg/㎥	
	avg. wind speed	=	2.50E+00	㎧	Korean Weather Yearbook, 2006
	geostrophic wind speed	=	4.17E+00	㎧	
	drag coeff.	=	1.00E-03		
	energy	=	(System area)(Airdensity)(Drag coeff.)(Geo.Wind speed)^3(3.14E+07s/yr)		
		=	5.17E+14	J/yr	
3	Rain, chemical				
	system area	=	1.85E+08	㎡	MKE, 2006
	rain	=	1.17E+00	m/yr	Korean Weather Yearbook, 2006
	Gibbs free energy	=	4.94E+03	m/yr	
	energy	=	(System area)(Rain)(1000kg/㎥)(Gibbs free energy)		
		=	1.07E+15	J/yr	
4	Tide				
	tidal area	=	1.85E+08	㎡	MKE, 2006
	avg. tide range	=	3.93E+00	m	MKE, 2006
	density	=	1.03E+03	kg/㎥	
	energy	=	(area)(0.5)(tides/yr)(height)^2(density)(gravity)		
		=	(1.85E8㎡)*(0.5)*(706/yr)*(3.93m)^2*(1025kg/㎥)*(9.8㎨)		
		=	1.01E+16	J/yr	
5	River, chemical				
	volume flow	=	1.08.E+09	㎥/yr	water information system,2010
	Gibbs free emergy	=	4.92E+00	J/g	water information system,2010
	energy	=	(Volume flow)(Density)(Gibbs free emergy)		
		=	5.33E+15	J/yr	
	volume flow	=	6.29.E+08	㎥/yr	water information system,2010
	Gibbs free emergy	=	4.91E+00	J/g	water information system,2010
	energy	=	(Volume flow)(Density)(Gibbs free emergy)		
		=	3.09E+15	J/yr	
Purchased input					
10	Goods & Services for fisheries				

yield(Aquaculture)	=	2.58E+07	kg/yr	MIFAFF, 1994
expenditure/fishery household	=	8.15.E+06	₩/yr	Agriculture and fisheries economy research, 2009
number of fishery household	=	6.94E+04		Korea Statistical Yearbook, 2009
annual cost	=	(Expenditure/fishery household)(Number of fishery household)		
	=	5.65E+11	₩/yr	
gross domestic fishery product	=	1.31.E+09	kg/yr	Korea Statistical Yearbook, 2009
unit cost	=	(Annual cost)/(Gross Domestic Fishery Product)		
	=	4.31E+02	₩/kg	
cost	=	(yield)(Unit Cost)		
		1.11E+10	₩/yr	
yield(Fishery)	=	3.18E+05	kg/yr	MIFAFF, 1994
expenditure/fishery household		1.10.E+07	₩/yr	Agriculture and fisheries economy research,2009
number of fishery household	=	6.94E+04		Korea Statistical Yearbook, 2009
annual cost		(Expenditure/fishery household)(Number of fishery household)		
		7.62E+11	₩/yr	
gross domestic fishery product		1.23.E+09	kg/yr	Korea Statistical Yearbook, 2009
unit cost		(Annual cost)/(Gross Domestic Fishery Product)		
		6.21E+02	₩/kg	
cost		(yield)(Unit Cost)		
		1.97E+08	₩/yr	
total cost	=	1.13E+10	₩/yr	

Production

11 Shellfishes				
yield	=	2.09E+07	kg/yr	MIFAFF, 1994
energy	=	(yield)(1E+03g/kg)(3.474E+03J/g)		
	=	3.34E+13	J/yr	
12 Seaweeds				
yield	=	4.86E+06	kg/yr	
energy	=	(yield)(1E+03g/kg)(1.102E+03J/g)		
	=	2.46E+12	J/yr	
13 Fishes				
yield	=	3.18E+05	kg/yr	
energy	=	(yield)(1E+03g/kg)(4.73+E3J/g)		
	=	6.92E+11	J/yr	

Appendix D. Footnotes to table 22

Renewable source				
1	Tide		1.85E+08	㎡
			3.93	m
			1.03E+03	kg/㎥
			(area)(0.5)(tides/yr)(height)^2(density)(gravity)	
			(1.85E8㎡)*(0.5)*(706/yr)*(3.93m)2*(1025kg/㎥)*(9.8㎨)	
			1.01E+16	J/yr
			7.39E+04	seJ/J
Purchased input				
2	Civil work			
	Facility structure(concrete)		53,260	ton/ea
			1.07E+06	ton
			1.07E+12	g
		lifetime	55	yr
			1.94E+10	g/yr
	Gate structure(concrete)		27,320	ton/ea
			2.73E+05	ton
			2.73E+11	g
		lifetime	55	yr
			4.97E+09	g/yr
	Temporary water blockage			
		steel	3.45E+04	ton
			3.45E+10	g
		lifetime	55	yr
			6.27E+08	g/yr
		sand	1.08E+06	㎥
			1.08E+12	g
		lifetime	55	yr
			1.97E+10	g/yr
	Central pier			
		stone	4.01E+04	㎥
			4.01E+10	g

	lifetime	55	yr
		7.29E+08	g/yr
	sand	3.05E+04	㎥
		3.05E+10	g
	lifetime	55	yr
		5.55E+08	g/yr
	G & S	6.60E+09	₩/yr
	temporary structure cost	1.60E+10	₩
	facility structure	1.49E+11	₩
	gate	6.11E+10	₩
	removal of seawall	4.57E+10	₩
	temporary blockage	4.99E+10	₩
	cental pier	1.40E+10	₩
	street paving	3.26E+08	₩
	wall	2.67E+10	₩
	sub total	3.63E+11	₩
	lifetime	55	yr
3	Electricity/mechanics		
	Generator(Iron&Steel)	1,374	ton/ea
		27,480	ton
		2.75E+10	g
	lifetime	55	yr
		5.00E+08	g/yr
	Turbine(Iron & Steel)	826	ton/ea
		16520	ton
		1.65E+10	g
	lifetime	55	yr
		3.00E+08	g/yr
	Stop-Log(concrete)	3.23E+08	g/yr
	power plant	4.93E+02	ton/ea
		9.86E+03	ton
		9.86E+09	g
	lifetime	55	yr
		1.79E+08	g/yr
	Sluice gate	4.93E+02	ton/ea

		7.89E+03	ton
		7.89E+09	g
	lifetime	55	yr
		1.43E+08	g/yr
Crane		1.26E+08	g/yr
	Turbine		
	250ton	1.75E+02	ton/ea
		3.50E+03	ton
		3.50E+09	g
	lifetime	55	yr
		6.36E+07	g/yr
	50ton	4.80E+01	ton/ea
		9.60E+02	ton
		9.60E+08	g
	lifetime	55	yr
		1.75E+07	g/yr
	30ton	3.00E+01	ton/ea
		6.00E+02	ton
		6.00E+08	g
	lifetime	55	yr
		1.09E+07	g/yr
	Gate		
	100ton	1.09E+02	ton/ea
		1.09E+03	ton
		1.09E+09	g
	lifetime	55	yr
		1.98E+07	g/yr
	50ton	4.80E+01	ton/ea
		4.80E+02	ton
		4.80E+08	g
	lifetime	55	yr
		8.73E+06	g/yr
	30ton	3.00E+01	ton/ea
		3.00E+02	ton
		3.00E+08	g

		lifetime	55	yr
			5.45E+06	g/yr
	G & S		5.01E+09	₩/yr
		turbine-generator	1.91E+11	₩
		sluice gates	1.34E+10	₩
		stop-log(power plant)	1.44E+10	₩
		stop-log(sluice gate)	7.74E+09	₩
		lock equipment	9.59E+09	₩
		gantry crane ect.	8.39E+09	₩
		switch gear & trans.	3.16E+10	₩
		sub total	2.76E+11	
		lifetime	55	yr
4	Management cost		5.11E+10	₩
		lifetime	55	yr
			9.30E+08	₩/yr
5	Labor		2.26E+10	₩
		lifetime	55	yr
			4.11E+08	₩/yr
Production				
6	Electricity		6.87E+08	㎾h/yr
			3.60E+06	J/㎾h
			2.47E+15	J/yr

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Laura Hija J, Kim

July, 2011

감사의 글

"인생은 여행과 같다." 라고 들었습니다..

저는 이제 막 어느 한 곳 의 7년 6개월 동안 여행을 마쳤습니다. 그 어느 곳 보다 아름다웠고 즐거웠던 기억들을 감사하는 마음으로 되돌아보고자 합니다.

나이를 의식하지 않은 채로 적지 않은 나이에 저에게 새로운 도전이자 목표이었습니다.

환원이라는 삶의 분기점을 두고 자기가 하고자 하는 것을 할 수 있다는 것이 무척 행복하다고 늘 항상 생각하면서 부경대학교 생태공학과 생태공학전공을 할 수 있는 계기가 되었습니다.

아름다운 친구 Sue와 직원들의 도움으로 입학식 날 넓은 운동장에 가득 찬 입학생들 사이에 용감하게 참석했던 기억이 납니다. 학교, 강의실, 연구실, 얼굴 등 모든 것이 낯설었습니다.

입학 전부터 지금까지 장선덕 전 총장님의 사려 깊은 조언 항상 감사합니다.

항상 "로라의 학부형" 이라고 하신 박현기 과장님, 정말 친절하시고 다정하십니다. 대단히 감사합니다. 학부형님으로 늘 지켜 주시기를...

그리고 이석모 교수님 연구실로 들어갔습니다.

이석모 지도교수님의 소개로 신입생 동료학생들을 만났고 학생들과 거리낌 없이 지내기 위해 저를 로라 라고 불러달라고 했습니다.

젊은 학우들과 강의 시간표를 짜고 오리엔테이션을 하면서 잘 할 수 있다고 생각하며 긴장과 부푼 마음으로 제 자신에게 다짐을 하면서 학교생활을 시작했습니다.

처음 연구실로 향했을 때, 자그마한 공간에 앉아 이석모 지도 교수님과 함께 연구에 대한 열정을 불태우던 여러 학생들의 모습을 본 순간 나도 함께 할 수 있다는 희망과 기쁨이 마음속에 가득 했습니다.

이석모 교수님은 아주 친절하셨고 겸손히 저를 반기셨으나 후에 말씀하시기를 제가 아마도 한 2-3주쯤 견디고 학교에 나오지 않을 거라고 생각하셨답니다. 그러나 저는 지도교수님 덕분에 7년6개월이나 학교생활을 계속 할 수 있었습니다. 대단히 감사합니다.

해양실습, 외국 연구학습활동, 체육대회, 그 외 학교활동 등으로 서로가 서로를 더 잘 알 수 있는 계기가 되었고 습지실습, 새만금 간척지 현장, 유류 유출 사고현장, 소각장, 하수처리장 등을 견학하면서 생태계의 중요성을 인식함과 동시에 지도교수님께서 항상 강조 하시는 말씀 "지구는 우리가 지킨다." 라는 생태공학의 중요성을 더욱 느꼈습니다.

학부시절 계속되는 강의로 친구들과 10분 동안 김밥 또는 간단한 식사를 함께 하였으며, 때로는 각자의 고민, 진로 등에 대해 이야기 하며 보낸 시간들도 저에겐 아주 행복한 시간들 이었습니다.

또한 남학생들이 군대에 갈 때는 저도 모르게 눈물을 흘리기도 했고, 제대하고 다시 만났을 때는 너무도 반가웠습니다.

이렇게 우리들은 추억을 나누면서 캠퍼스 생활을 함께 하였습니다.

그러나 아픔도 함께 있었습니다. 학교에 입학 후 익숙하지 않았던 의자로 인해 디스크가 생겼으며, 10가지 과목 중 수년 만에 다시 접하는 화학, 물리화학, 공업수학 등은 너무 어려워 과외수업을 받아야만 했습니다. 학업과 사업을 병행하다 보니 하루 3시간 정도의 수면으로 눈이 자주 충혈 되었으나 덕분에 장학금이라는 특별한 선물을 받게 되었습니다.

그 장학금은 제 활력소가 되어준 고마운 친구들에게 다시 선물이 되어 돌아갔습니다.

설레던 2004년 봄에 입학식을 한 후 어느덧 7년 6개월이란 시간이 지났습니다.

저는 이 학교에서의 생활이 너무 즐거웠고 행복했습니다. 그리고 가르치시는 교수님 앞에서는 부족한 학생이지만 박사 학위를 받는 행운을 받았습니다.

저의 학위를 위해 도와주신 모든 분들께 머리 숙여 깊은 감사드립니다.

특히 나의 지도교수이신 이석모 교수님, 진심으로 감사드립니다. 평범하지만 또 그렇지도 않은 로라 학생을 지도하시느라 어느덧 흰머리가 많아지셨습니다. 특히 저녁 늦게 강의하실 때는 더욱더 열정적으로 가르치시는 모습이 너무나 존경스러웠습니다. 앞으로 더욱 좋은 제자가 되도록 최선을 다하겠습니다.

아직 외국에 계신 정용현 교수님, 다음 달에는 한국에 돌아오시겠지요. 항상 저에게 끊임없이 조언해주시고 격려해주셔서 대단히 감사합니다.

강대석 교수님, 항상 열심히 가르쳐 주시며, 저의 부족한 부분을 지적해 주시고 조언해 주셔서 감사합니다. 부족 한 대로 졸업은 하지만 항상 열심히 최선을 다하는 로라 되겠습니다.

성기준 교수님!! 습지조사 갔을 때 기억하시지요? 열심히 지시하시는 대로 근주와 함께 조사에 임한 것이 기억에 남아요. 재미있고 좋은 추억이 되었습니다. 감사합니다.

조용하시며 그러나 아주 친절하신 김동명 교수님, 새만금 지역 해양생물 변화에 대해 논문에 추가 하고 싶다고 교수님 찾아가서 부담 드린 것 죄송합니다. 다음에는 꼭 도와주세요? 그리고 그동안 많은 것을 가르쳐 주셔서 대단히 감사합니다.

항상 웃으며 대해주시는 최창근 교수님, 많은 기간은 아니었으나 너무 가깝게 느껴집니다. 자료가 필요하다면 어느새 구해주시고 언제나 도와주시려는 교수님 마음 대단히 감사합니다.

김진만 박사님, 강의 아주 멋지게 하십니다. 목소리도 좋으시고요. 여러모로 감사합니다.

영윤 선배, 그동안 자주 질문도 많이 했고 또한 도움도 여러모로 많이 주신데 대하여 대단히 감사합니다.

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진아, 근주, 민지, 혜진, 미소 언제나 나에게 가까이서 활력소가 되어주고 도와준 친구들 사랑해요!

끝으로 돌아가신 아버지와 미국에 사시는 사랑하는 엄마, 가족, 지인들 그리고 직원들께 진심으로 감사하며, 그 외에도 제가 공부를 할 수 있도록 도움을 주신 분들과 함께 했던 추억을 항상 간직하며 지내겠습니다. 감사합니다.