Small scale capture fisheries sustainability analysis using energy (embodied energy) approach

Robin1*, R Kurnia2, K Soewardi2, I Setyobudiandi2, A H Dharmawan3

1Student of Coastal and Marine Resources Management Study Program, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, Bogor, Indonesia
2Department of Aquatic Resources Management, Faculty of Fisheries and Marine Sciences, Bogor Agricultural University, Bogor, Indonesia
3Department of Communication Science and Community Development (SKPM) FEMA, Bogor Agricultural University, Bogor, Indonesia

*E-mail: robinbahari@gmail.com

Abstract. Fishery in Jakarta bay has been the backbone of coastal livelihood for many years. The purpose of this research was to analyze the sustainability of capture fishery system in Jakarta bay based on embodied energy (energy) approach. An energy evaluation method or so-called energy synthesis, the whole system is considered through a diagram in which the resource emerge flow and information are encouraged for system analysis, or in this study using the Ugiani and Brown (1998); Odum (1996) approach. The results of this study showed that the energy sustainability index (ESI) = 0.001159 sej/yr which explains that the system is not sustainable while the contribution of the catching fishery sector to the economy can be seen on the value of emergy yield ratio (EYR) = 1.00 which indicates the still low contribution of capture fishery sector to the economy of DKI Jakarta. From this research, it can be concluded that intrinsically capture fishery at the bay of Jakarta not sustainable and not give a maximal contribution to the economy of DKI Jakarta.

Keywords: emergy, fisheries, Jakarta, livelihood

1. Introduction

The embodied energy approach has been widely known to calculate how much the level of sustainability of activity is carried out in a particular system, where the basis is the flow of energy based on the principle of thermodynamics. Ecosystem goods and services (EGS) are merit received from the natural environment that is very important for the welfare of mankind. The Millennium Ecosystem Assessment clarify that about 60 percent of the ecosystems around the world have been classified or used in unsustainable ways. An adequate assessment of EGS can lead stakeholders to maintain the natural environment so that they can continue providing services that are useful for the sustainability of natural resources. Ecological engineering had widely known as an imitative work schemed to deal with an environment that deteriorates low energy and resource utilization. To assess energy and resource use and environmental support contained in ecological maintenance engineering, emergy as a coding energy-based solar energy is carried out and a relative emergy-based index [1]. The accurate calculations of inflows, outflows, and storage of energy, materials and information are needed to understand and manage environmental systems at all levels of hierarchical organizations. The calculation tool, which is in the form of an emergy income report, an emission balance, and the emergy index described in this document can be used to analyze and understand the system set for each selected...
Fisheries in the Jakarta bay have been the backbone of coastal communities for many years. Although currently, Jakarta is transforming into a megapolitan city with high development and urbanization activities, fisheries activities are still the main livelihood of the bay of Jakarta coastal communities and the Kepulauan Seribu. According to data taken from the Food Security, Marine and Agricultural services DKI Jakarta Province, the number of fishermen who inhabit the coast of Jakarta and the Thousand Islands reaches 33,000 fishermen, most of whom are fishermen from outside Jakarta who have settled or are nomadic on a boat. The fishermen who exploit fishery resources to meet the need for animal protein in the area of DKI Jakarta and surrounding cities. According to DKI Jakarta Provincial Government, the contribution of the fisheries sector to GRDP is still very low at around 0.01%, but this sector is the backbone of around 4 million residents throughout Jabodetabek, although explicitly the trend of fisheries production for several important economic species continues to decline such as snapper, rabbit-fish, mullet and some other economically important fish. One of the decreases in fisheries production is due to the high level of water pollution originating from 13 rivers that flow into the Bay of Jakarta, not to mention the population density that inhabits the Jakarta coast causing Jakarta Bay to become a major waste disposal site for the community [2]. The existence of these activities has a negative impact on the high potential for eutrophication of waters caused by domestic waste entering the waters. Aquatic eutrophication triggers blooming of toxic algae, which causes mass death in fish due to hypoxia. Inorganic wastes sourced from industrial areas such as in Marunda and Muara angle coupled with waste heat from the PLTU allegedly posed a threat to the existence of the crab which was one of the main livelihoods of fishermen in the Jakarta Bay. This study aimed to determine the level of sustainability of small-scale fisheries and the contribution of the capture fisheries sector in the bay of Jakarta based on energy analysis.

Most cities around the world experience serious problems caused by a lack of resources and habitat degradation, consist of water deficiency, land deficiency, ecological breakage, air desecration, and traffic congestion. The core of this problem is the demand related to housing consumption and economic expansion, which is greater than the supply of resources and the carrying capacity of the municipal environment. Generally, about 54% of the world's population lives around municipal areas in 2014 [3]. The world's urban population has been grown quickly from 1950. It was escalated from 746 million to 3.9 billion in 64 years. By 2045, the number of people inhabit in cities is projected to escalate 1.5 times to 6 billion, based on United States forecasting [3]. Calculating higher than 80% of global GDP, the city also plays an important role in global economic development. As developing countries become more desirious to develop their economies, this problem become more nasty in developing countries such as Indonesia, especially Jakarta as a metropolitan city with a percentage of GDP of 68.9% of Indonesia's total GDP [4]. Because of the relative density of cities and under pressure caused by economic development, population expansion and consumption, sectional resources cannot fulfill the requirement of urban development; thus, many physical resources are imported into the city for untilitation and exploitation. Meantime, considerable waste is produced due to the exploitation of resources, exceeding the carrying capacity of municipal ecology; Therefore, the urban environment has been diminished. To discuss the effect of economic development and population, exploitation of resources and the environment in the urban ecology-economic system will assist to producing effective policies for sustainable municipal development [5]. A large city has a system that is open, large, and complex ecological-economic systems, with interactions between economic, social, population, resources, and environmental factors, etc. It is difficult for common econometric approaches to organize a exhaustive analysis and consistent on the interaction between social, economic, and environmental factors of a city from a system perspective. Therefore the energy oncoming was introduced by Odum in 1996, researchers have utilized new theories and methodologies to explore social-ecological systems. Emergy is the total energy available from one type that is needed to form resources, products, or services [6-7]. Emergy methods contribute directly and indirectly to nature in producing resources and supporting production activities and human labor that improves economic performance. Thus, it serves an interconnection between ecology and economics in the study of municipal ecological-economic systems [8-10], [5]. In the fisheries sector, such as fisheries, cultivation, post-harvest processes and
product distribution, are highly dependent on external energy use, especially fossil fuels. World fish production for human consumption increased from around 20 million tons in 1950 to more than 136 million tons in 2012 [11].

The yield of fishing may be almost reach the peak, and all the advantage from resources can only be accomplished through management, a more effectual process that is better and less waste. Energy has been utilized in the fishery industries whether directly or indirectly, for example, heating or light, or more commonly for conversion works in the form of the motives and driving forces, leverage, or in compression and cooling cycles. Energy is also applied in producing various capital goods and input of raw materials, and in efforts to treat or dispose of various unwanted or unused wastes. Energy use can be explained and measured in several ways, and some standardization of concepts and steps is necessary to ensure adequate data comparability and implications over complicated and diverse sectors as fisheries. The description of it is as follows:

a. The usage of direct fuel - especially petroleum products (diesel, liquefied natural gas [LNG], petroleum), but in some cases, materials such as wood or coal are defined as specific uses for certain products in each activity or with other words are referred to as output, both in terms of quantity or value of combustion. this is the simplest and most common focus of measurement, by linking the direct impact of fuel prices to operating costs.

b. Energy use as a whole, uses a wider measurement system where total fuel, electricity, and energy sources are included as units of energy relative to certain activities or outputs. This provides a more complete picture of a broader topic and the meaning of using fuel is not the only element of energy. Especially for cultivation and processing, where various energy sources are involved.

c. Industrial energy use - measures the energy needed to produce all capital and operations. Inputs in processes, such as steel, wood, synthetic fibers, plastics in ships, equipment, cultivation facilities, and cultivation equipment, and including inputs such as fish feed, chemicals and processed water. This amount is then related to output. These values are sometimes referred to in the reviews to show wider implications than they should.

d. Emergy as embodied energy - take a more holistic approach, including industry, energy, including photosynthetic energy inputs into biological processes that support processes in ecosystems such as food chain supply in fisheries systems and cultivation processes, and ecosystem support to take the process of absorption of waste and consumption of resources.

e. The use of renewable and non-renewable energy, such as energy sources, solar power, wind, tides, air power, or in accordance with biomass plants, or other energy obtained from fossil fuels. This can be used to provide support for the sustainability of the potential of the fisheries sector or other sectors.

2. Methods

Emergy evaluation methods or so-called energy synthesis, the whole system was considered through diagrams where the energy flow of resources and information that drive for system analysis. The steps commonly used to carry out an energy synthesis, analysis begin with defining system boundaries using energy system diagrams to describe system features, inputs, and outputs. The next step was to create a table that summarizes the energy values of the system stock and flow. Stock and flow converted from equivalent units of energy or mass using the energy transformation coefficient. The sustainability of this system was then be evaluated using several emery indicators [12].

Here were some emery synthesis, analysis methods:

a. System boundaries defined as areas used for overall production and for individual sub-systems (management fields). The dimensions of this limitation were in time.

b. All major energy sources and material resources that flow and were stored in the system is identified and tabulated using the language of the energy system and the quantity was recorded and converted into energy units (Joules), mass units (grams), or monetary units.
c. Various resources flowing is measured directly or estimated not only from records of production and financial but also available data. To obtain the emergy value of the resource, flow, the amount was tabulated and multiplied by the corresponding transformation from various available literature.

Figure 1. Emergy-based index for an area, which takes into account local emergy (R) renewable inputs, local non-renewable emergy inputs (N), and emergy inputs purchased from outside the system (F) Based on the diagram by [13].

Fisheries as a system which includes planning, resource exploitation, post-harvest handling of sales to efforts to protect ecosystems as an effort to manage the impact of these activities. Fisheries activities have so far experienced a significant decline mainly in capture fisheries which directly affect the lives of fishermen as users of these resources [14].

2.1. Calculate emergy
After the evaluation table results of all emergy inputs are obtained, then the energy value of the product unit can be calculated. The output of the calculation is transformed into units of energy, exergy, or mass; henceforth the energy input is summarized and is assessed using an energy unit for the calculation of energy as the output unit. Thus, the existence of an emergy evaluation produced the emergy value of a new unit [15]. Some differences were made to differentiate resource energy flows as described by [16] in figure 1. Among them were:

a. Renewable streams (R) were limited flow (cannot increase their flow rate through the system), free or locally available.
b. Non-renewable flow (N) was: limited stock (can be withdrawn route, but the available amount was limited in a closed system time scale), not always available free of charge sometimes there were costs that exploit this energy flow, available locally.
c. The feedback flow (F) was: limited stock (as above), never limited, never imported locally always imported.

Energy flow data after tabulation and adjustment are then transformed. some ratios and energy-based indices are measured. The aggregate results of the indicators obtained will be very helpful in the interpretation of the analysis. The main indicators used in this analysis are defined as follows [17-18]:

a. Comparison of emergy results (EYR) is the ratio of energy output (Y) divided by the input energy (F). A comparison of how many processes will contribute to the economy.
   \[ \text{EYR} = \frac{Y}{F} \]

b. Environmental load ratio (ELR) is a non-renewable emission ratio (N) and import emission (F) for renewable (R) emergy. This is an indicator of the amount of pressure from the production process in the local environment.
   \[ \text{ELR} = \frac{F}{R} \]
c. EIR (Emergy Investments Ratio), EIR is the ratio of resources purchased from renewable and non-renewable local inputs. This will tend to be economical if the ratio is less or equal to one that applies in the region [18]. The fewer ratios, the less economic costs, so that processes with lower ratios tend to compete, prosper in the market [19].

\[
EIR = \frac{F}{R + N} \tag{3}
\]

d. The Emergy Sustainability Index (ESI) is an outcome and sustainability measure that assumes that the objective function for sustainability is to get the highest yield ratio of the lowest environmental load.

\[
ESI = \frac{EYR}{ELR} \tag{4}
\]

e. Renewability ratio (% R) is the relationship between inputs from renewable resources to the total energy. % R is used for environmental sustainability assessment, % R shows the percentage of renewable energy used by the system. A high percentage system has high sustainability capabilities of systems that use most non-renewable energies.

3. Result and Discussion

In calculating the emergy value, we observed and collected data around the fishing village in North Jakarta as a database. For the addition, we also observed thousand islands (Tidung and Pramuka Islands). We determined 12 items for the emergy calculation approach (see the table of results).

3.1. Renewable resources

Renewable resources are needed as the main capital in an important system in the ecosystem. Some renewable resources will hardly run out like solar energy, wind energy, and geothermal pressure. While other resources that are considered to be renewable but have a period of time for their renewal, such as wood, oxygen, leather and fish.

Most precious metals are considered renewable too; even though they are not naturally replaced, they can be recycled because they are not destroyed during extraction and use. In this study, we measured the emergy value of renewable resources in the Jakarta bay such as sunlight, sea tides, and wind. Sunlight is calculated by means of area x insolation x albedo x transformation from the calculation generated emergy value of 1.4 x 10^8 while for wind is calculated by taking into account the area of the sea, drag coefficient and wind speed that is 2.37 x 10^{14}. Sea tide as the main source of mass transport movement and aquatic biota has an emergy value of 1.02 x 10^{16}. From these results it can be seen that the tides have a much greater emergy value, this shows the magnitude of the tidal effect on the Jakarta bay ecosystem. While the sun's energy functions as the main energy source that grows food sources for all organisms that live in the sea waters.

a. Paid input

The fisheries system as a unit has a causal relationship that coheres with each other, including the cost of carrying out fishing activities. High fishing activities have been suspected as a result of a decline in a number of fishery commodities. The condition of a resource contained in a natural ecosystem such as the sea, will experience variation from year to year due to the influence of biotic and abiotic factors contained in the ecosystem, so that if an ecosystem has experienced the symptoms of over-population and exploitation, it will be difficult for the ecosystem to recover [23]. Measurement of the sustainability of fisheries resources can be approached with many methods such as Catch per Unit effort and in this study will be illustrated by the value of energy transformation that is produced in each fishing effort.

Paid inputs in small-scale capture fisheries in the Jakarta Bay consist of operational costs including fuel and capital costs (machinery, fishing gear, ice, ships). From the results of emergy calculations produced for fuel worth 5.64 x 10^{17}, labor 2.25 x 10^{15}, operating costs 8.2 x 10^{18}, vessels 6.5 x 10^7, fishing gear 1.01 x 10^3, engine 1.26 x 10^2.
b. Emergy yield ratio

Based on emergy algebra, the emergy output of a system equals the sum of all independent emergy inputs (IE non-product) to the system. Emergy analysts are often called the sum of the types of resources that can be renewed with the types of resources that cannot be renewed (Non-Renewable) and the inputs spent (F) (Yield = R + N + F) of a system. Although what is actually the theory represents the total "memory" of the total exergy (available energy) needed to produce a system. So, consistent with the command of emergy theory, the so-called "Yield" is actually a donor-side measure of the resources needed to make something, rather than a user-side measure of what can be obtained from energy [24]. Furthermore, the value of EYR is also defined to calculate how much influence a resource has on the economy in an area. From the results of Emergy Yield Ratio calculation of capture fisheries in the Jakarta Bay produced a value of 1.001158 or in other words, capture fisheries activities have not provided a significant influence on the economy in the Jakarta area. This can be seen from the low contribution of the fisheries sector to the DKI Jakarta GRDP which only reached 0.001% [25]. The Emergy Yield ratio is an index defined as the ability of a particular system to support the use of local resources including a description of system support for the larger economic sector [26]. In an activity application, the EYR reflects 'efficiency' in processing local resources: the smaller the emergy input (M + S), the higher the EYR value, which means the more efficient the activity [27].

Furthermore, from the calculated value, it can be seen that emergy values >1 and <2 have no effect on the economy because the results obtained are more supported by local resources. However, this interpretation is not entirely correct because for the evaluation of technological systems (i.e. process chains) generally do not have a specific location in the global economy [28]. Therefore, the perspective on EYR explores developments in its application. Switching from local resources to import resources or in other words foreground vs background by adopting a life cycle perspective when calculating EYR for industrial processes [27]. For instance, in the case of diesel oil input into the modeled process, crude oil emergy is considered as foreground input, while background investment includes additional emergy.
inputs throughout the production chain used to extract crude oil and convert it into diesel oil. The EYR value may be compared with several economic investment theories. For example, it is related to the value of the incremental capital output ratio (ICOR) and Incremental Labor Output Ratio (ILOR) which, according to the [29] analysis the value of both items can show the investment pattern of a resource by looking at the efficiency of a project. However, calculations related to EYR will be greatly influenced by the accuracy of determining the transformity value of each calculation item to avoid bias from the approach.

| Table 1. Emergy calculation results of capture fisheries in Jakarta Bay. |
|----------------------------------------------------------|
| Item                  | Unit          | Data (Unit/Year) | Transformity (Sej/Unit) | Emergy       | Reference |
|-----------------------|---------------|------------------|-------------------------|--------------|-----------|
| **Renewable energy**  |               |                  |                         |              |
| Solar                 | J             | 1.46 x 10^8      | 1                       | 1.46 x 10^9  | [18], [20]|
| Wind                  |               | 1.41 x 10^9      | 2450                    | 3.45 x 10^12 | [21]      |
| Tide                  |               | 2.31 x 10^14     | 44                      | 1.02 x 10^16 |           |
| **Total R**           |               |                  |                         | 1.02 x 10^16|           |
| **Paid Input**        |               |                  |                         |              |
| Labor                 |               | 1.35 x 10^12     | 1670                    | 2.25 x 10^15 | [20]      |
| Fuel                  |               | 1.06 x 10^13     | 53000                   | 5.64 x 10^15 | [22], [21]|
| Operational Cost      | Rp/Yr         | 4.64 x 10^10     | 1.77 x 10^8             | 8.21 x 10^18| [21]      |
| **Capital Cost**      |               |                  |                         |              |
| Fishing vessel        | Rp            |                  | 1.77 x 10^8             | 656.0419     |           |
| Fishing gears         | Rp            |                  | 1.77 x 10^8             | 1009.295     |           |
| Machine               | Rp            |                  | 1.77 x 10^8             | 126.1619     |           |
| **Total F**           |               |                  |                         | 8.78 x 10^18|           |
| **Output**            |               |                  |                         |              |
| Fish production       | g/yr          |                  | 1.77 x 10^8             | 6.79 x 10^13|           |
| Fishing value         | Rp            |                  | 1.77 x 10^8             | 2.73 x 10^19|           |
| **Total J**           |               |                  |                         | 2.73 x 10^19|           |
| Y = I + F             |               |                  |                         | 8.79 x 10^18|           |
| R                     |               |                  |                         | 1.02 x 10^16|           |
| F                     |               |                  |                         | 8.78 x 10^18|           |
| Emergy Yield Ratio (EYR) |             |                  |                         | 1.001158   | Does not affect the economy |
| Environmental Load ratio (ELR) |       |                  |                         | 863.4472   |           |
| Emergy Sustainability Index (EYR/ELR) |       |                  |                         | 0.001159   | unsustainable |

c. Environmental Load Ratio (ELR)

ELR is illustrated as the amount of the energy value of a non-renewable or invested resource divided by the value of renewable energy (ELR = (N + M + S) / R). The escalation of ELR value indicates that the high exploitation of non-renewable (N) and/or high technology (M + S) resource use of the process. Moreover, it is frequently declared as high levels of environmental pressure in the local environment [26]. The value of capture fisheries ELR is 863.4472 a year. The greater the value of ELR shows the greater pressure of human activities on resources. Even if the idea of environmental pressure can be used for emergy calculation, where it concentrate on resource utilitation, generally does not include pollution-related impacts. The considerable environmental burden (Figure 3b) has suppressed the existence of several important economic fish species that were captured by fishermen in the Bay of Jakarta. This is reflected in Figure 3a that the number of reef fish catches has continued to decline due
to the high catching effort and the decreasing environmental conditions due to pollution and land
conversion [30].

![Graph showing trend of catching several economically important fish](image1)

**Figure 3.** The trend of catching several economically important fish (a) and comparison of
the value of ecological footprint and biocapacity in Jakarta Bay (b), = *Lutjanus bitaeniatus*, = *Mugil chepalus*, = ecological footprints (km²/Yr), = BC.

In figure 3b, it can be seen that the ecological footprint in the Jakarta Bay has experienced a very large
increase that has exceeded environmental biocapacity to support the sustainability of fisheries resources
in the Jakarta Bay [30]. This phenomenon can theoretically be correlated with the increasing burden of
the Jakarta Bay ELR which, if left unchecked will cause the bay fisheries system to become obstructed
and possibly even permanently damaged.

d. **Emergy sustainability index**
The Emergy Sustainability Index (ESI) is the comparison between Emergy Yield Ratio (EYR) and the
Environmental Loading Ratio (ELR), generally used to measure the continuity of a good and services
or process. Therefore, a higher ESI shows better sustainability than those that are suitable for goods,
processes, or services. Calculation of the sustainability index of capture fisheries energy in Jakarta Bay
is 0.001159. A process is not proceed in the long run when ESI <1; a process can have an ongoing
endowment to the economy for the medium period when 1 <ESI <5; a process can be said to be
sustainable in the long period when ESI>5; a process does not develop when ESI>10 [31].

4. **Conclusion**

The conclusion that can be drawn from this research is that from the ELR and ESI values it can be seen
that capture fisheries activities have put pressure on fisheries resources besides the very small ESI
values indicate that in the long run fisheries activities are not sustainable and do not contribute
significantly to the regional economy.
Acknowledgments

We would like to express our deepest gratitude to the Southeast Centre for Tropical Biology (SEAMEO B IOTROP) for financing this research and also to all fisheries authorities of DKI Jakarta province, in this case, the food, marine, and agricultural security services for their assistance in providing secondary data and access to fishermen in the Bay of Jakarta.

References

[1] Chen B, Chen Z M, Zhou Y, Zhou J B and Chen G Q 2009 Emergy as embodied energy based assessment for local sustainability of a constructed wetland in Beijing Comm. Nonlinear Sci. Numer. Simul. 14 (2) 622–635
[2] Baum G, Januar H I, Ferse S C A and Kunzmann A 2015 Local and regional impacts of pollution on coral reefs along the Thousand Islands north of the megacity Jakarta, Indonesia PLoS. 10 (9) e0138271. doi:10.1371/journal.pone.0138271
[3] United Nations 2015 World Urbanization Prospects: The 2014 Revision, Department of Economic and Social Affairs – Population Division. <http://esa.un.org/unpd/wup/Highlights/WUP2014-Highlights.pdf>
[4] Badan Pusat Statistik 2004 Statistik Indonesia 2004 (Statistical Years Book of Indonesia) (Jakarta: Badan Pusat Statistik Indonesia)
[5] Fang W, Haizhong A, Huajiao L, Xiangyun G, Xiaoqi S and Weiqiong Z 2017 Accessing on the sustainability of urban ecological-economic systems by means of a coupled energy and system dynamics model: A case study of Beijing. J Ener Pol. 100 326–337
[6] Odum H T 1996 Environmental accounting, emergy and decision making (New York: J. Wiley) 370. ISBN-471-11442-1
[7] Brown M T, and Ulgiati S 2004 Energi quality, emergy, and transformity: HT. Odum’s contributions to quantifying and understanding systems Ecological Modelling Elsevier 201-213
[8] Hardin G 1986 Cultural carrying capacity: a biological approach to human problems Bioscienc. 36 (9) 599–606
[9] Daily G C and Ehrlich P R 1992 Population, sustainability, and earth’s carrying capacity: a framework for estimating population sizes and lifestyles that could be sustained without undermining future generations. Bioscience 42 61–771
[10] Mayer P and Ausubel J 1999 Carrying Capacity: a Model with logistically varying limits. Tech forcas soc chan. 61(3) 209-214
[11] FAO 2015 Fuel And Energy Use In The Fisheries Sector: Approaches, inventories and strategic implications (Roma: FAO Fisheries and Aquaculture Circular No. C1080) ISBN 978-92-5-108934-7
[12] Voora V and Thrift Using emergy to value ecosystem goods and services International institute for sustainable development. Winnipeg, Manitoba Canada. 2010
[13] Brown MT and Ulgiati S. Emergy-based indices and rations to evaluate sustainability: monitoring economies and technology toward environmentally sound innovation, J Ecol Eng. 9: pp 51–69. 1997
[14] Djau M S 2013 Analisis keberlanjutan sistem perikanan di kawasan konservasi laut daerah (KKLD) olele dan perairan sekitarnya Kabupaten Bone Bolango Provinsi Gorontalo (Thesis) (Bogor: Sekolah Pascasarjana Institut Pertanian Bogor)
[15] Brown M T and Ulgiati S 2004 Energi quality, emergy, and transformity: H.T. Odum’s contributions to quantifying and understanding systems Ecological Modelling Elsevier 201-213
[16] Odum H T and Odum E C 2000 Modelling for All Scales: An Introduction System Simulation (California: University of Florida Academic Press)
[17] Ulgiati S and Brown M T 1998 Monitoring patterns of sustainability in natural and man-made ecosystems. Ecol. Model. 108 23–36
[18] Odum H T 1996 Environmental accounting, energy and decision making (New York: J. Wiley) 370 ISBN-471-11442-1

[19] Li L, Lu H, Campbell D E and Ren H 2010 Emergy algebra: improving matrix methods for calculating transformities. Ecol Model. 221 411–422

[20] Brown M T and Eliana B 2001 Emergy of ecosystem Handbook emery evaluation Center for Environmental Policy Environmental Engineering Sciences University of Florida Gainesville

[21] Patria A 2012 Model resiliensi sistem sosial ekologi perikanan skala kecil: studi kasus pada wilayah pesisir Kabupaten Cilacap Jawa Tengah (disertasi) (Bogor: Postgraduated School of the Bogor Agricultural University)

[22] Haden A C 2002 Emergy analysis of food production at S&S homestead farm Lopez Island (US) S&S Center for Sustainable Agriculture

[23] Tim Proyek Carrying Capacity Badan Riset Kelautan dan Perikanan Daya dukung kelautan dan perikanan (Selat Sunda, Teluk Tomini, Teluk Saleh, Teluk Ekas) (Jakarta: Marine and Fisheries Research Agency-Ministry of Maritime Affairs and Fisheries of the Republic of Indonesia) ISBN 979-97572-8-9-2. 2017

[24] Raugei M, Bargigli S and Ulgiati S 2005 Emergy “yield” ratio – problems and misapplications In: Brown M T, Bardi E, Campbell D E, Comar V, Huang S, Rydberg T, Tilley D and Ulgiati S. Emergy Synthesis 3: Theory and Applications of the Emergy Methodology Proceedings of the 3rd Biennial Emergy Conference (Gainesville: Center for Environmental Policy University of Florida) 159–164

[25] Badan Pusat Statistik Provinsi DKI Jakarta 2012 Jakarta dalam angka 2012 (Jakarta: Central Bureau of Statistics of DKI Jakarta Province)

[26] Brown M T and Ulgiati S 1997 Emergy-based indices and rations to evaluate sustainability: monitoring economies and technology toward environmentally sound innovation, Ecol. Eng 9 51–69

[27] Arbault D, Benedetto R, Ligia T B and Enrico B A 2014 Semantic study of the energy sustainability index in the hybrid lifecycle-emergy framework Ecol Indic. 43 252–261

[28] Brown M T, Raugei M and Ulgiati S 2012 On boundaries and investments in emergy synthesis and LCA: a case study on thermal vs. photovoltaic electricity J. Ecol. Indic. 15 227–235

[29] Rudiyanto A, Luky A, Alan F K, Fajar S, Yudi W and Suryo W 2014 Strategic report arahan pembangunan nasional bidang kemasrativek 2015-2025 (Jakarta: Kementrian PPN/Bappenas RI)

[30] Robin, Rahmat K, Kadarwan S, Isdradjad S and Arya H D 2018 Jakarta bay regional fisheries ecological footprint (an Carrying capacity analysis base on primary production requirement) Paper manuscript (publication on process)

[31] Ren J, Shiyyu T, Le Y, Michael E G, Chengfang P and Lichun D 2015 Optimization of emergy sustainability index for biodiesel supply network design. J En Conv Manag. 92 312–321