Master's of Engineering

METHODOLOGICAL ASPECTS OF EMERGY ASSESSMENT FOR SUSTAINABILITY OF NEPAL AND IMPACT OF GORKHA-EARTHQUAKE

The Graduate School of the University of Ulsan

Department of Civil and Environmental Engineering

Keshab Shrestha

METHODOLOGICAL ASPECTS OF EMERGY ASSESSMENT FOR SUSTAINABILITY OF NEPAL AND IMPACT OF GORKHA-EARTHQUAKE

Advisor: Professor Hung-Suck Park

A Thesis

Submitted to

the Graduate School of the University of Ulsan

In Partial Fulfillment of the Requirements

for the Degree of

Master's of Engineering

By

Keshab Shrestha

Department of Civil and Environmental Engineering

University of Ulsan, South Korea

February 2018

METHODOLOGICAL ASPECTS OF EMERGY ASSESSMENT FOR SUSTAINABILITY OF NEPAL AND IMPACT OF GORKHA-EARTHQUAKE

This certifies that the thesis
of Keshab Shrestha is approved

Prof. Byeong-Kyu Lee, Committee Chair

Prof. Seok Young Oh, Committee Member

Prof. Hung Suck Park, Committee Member

Department of Civil and Environmental Engineering
University of Ulsan, South Korea
February 2018

ABSTRACT

A system is considered as sustainable, if the processes do not harm the environment and provides suitable products to human society without undermining its future generations. Sustainability assessment is a comprehensive appraisal method that evaluates the extent of sustainability of systems and supports the development of sustainable strategies if system is not sustainable. The emergy method is one of the sustainability assessment tools that quantify the value of environment and economic resources that flow into the system and measures the impact of the system in the human sphere.

Emergy is defined as the total direct and indirect energy of one source type (solar energy) required producing product or providing a service. This is evaluated through a common unit of solar emjoule (sej). This common unit approach provides fair sustainability assessment in the evaluation of environmental resources, human services and economic resources to human well-being. Emergy indices calculated in the emergy assessment of a system such as emergy money ratio (EMR), environmental loading ratio (ELR), emergy yield ratio (EYR), emergy investment ratio (EIR) and environmental sustainability ratio (ESI) help to understand the overall sustainability of the system and provide clear 'action- guiding power' to decision makers. Since the development of emergy in the last three decades, this method has already been applied in various sustainability assessment systems such as industrial system, agricultural system, wastewater treatment system, eco-industrial parks, cities, provinces, nations, infrastructures, etc. This research has been divided into drawing out three novel outputs as follows:

1. Sustainability assessment of Nepal's development: In this research, the emergy of Nepal from 1998 until 2015 was calculated first. A simulation of emergy parameters was then done for the next twenty-five years (until 2040) using Systems Thinking, Experimental Learning Laboratory with Animation (STELLA) modeling program. Finally, based on the simulated result, the sustainable policies for Nepal was recommended in terms of non-renewable resources extraction, trade, soil erosion control and renewable resources use.

2. Impacts study of natural disaster: The Gorkha-earthquake that hit Nepal in April 2015 was employed for the case study. The impact of the Gorkha-earthquake on society, economy and

environment of Nepal was analyzed with the new perspective of emergy. The total emergy use of the country showed a decreased by 10 %. This caused the declined of per capita emergy use by 12 %, reducing the well-being of people in Nepal. All economic activities of the country were affected, which lowered the national production. The distinct impact was observed in the exports. The export was dropped by 50 % after the earthquake. Similarly, the import was also dropped by 2 %. Though, economic activities and non-renewable resource use were reduced, the positive impact was observed in the environmental load. The ELR was dropped from 6.79 before the earthquake to 5.98 after the earthquake. This suggests that the economic growth before the earthquake was more sustainable than after the earthquake because the contribution of renewable resources in the economic growth before was higher therefore, the environmental stress was lower.

3. Methodological aspects of emergy accounting in co-production system: The problem of transformity calculation in the co-production system network in previous methods was identified and the new method, modified physical quantity method (MPQM) was introduced to solve the problem. A case of *Eucalyptus* pulp production was applied to make a validation of the new method. MPQM followed all the rules stated in the emergy algebra. Finally, the transformity value calculated through the new MPQM was applied in the production efficiency analysis of *Eucalyptus* pulp production system. The result showed the pulp production industry was not efficient in resource use during its production because the joint transformity of pulp production is lesser than weighted average transformities.

.

ACKNOWLEDGMENT

I would first like to express my sincere gratitude to my research advisor, Professor Hung-Suck Park for his advice, guidance and valuable suggestions in conducting this research work. From the very beginning Professor Park inspired me to take an initiation in emergy accounting, which was completely new and unknown topic for me. But due to his continuous encouragement and instructions, I have the result now with me.

I am also very grateful to Professor Daeseok Kang from Pukyong National University. He was always comfortable to my queries and replied all my emails without hesitation. His suggestions for reference literature greatly supported me in in-depth understanding of emergy accounting. I also appreciate Dr. Angelo Earvin Choi, Izhar Hussain Shah and Taka Nkam Gideon for their valuable inputs in this dissertation. I am thankful to the University of Ulsan for providing me a scholarship, to my laboratory members for their help to adjust me in different environment and to all staffs and faculties of the Department of Civil and Environmental Engineering.

Finally, I am indebted to my beautiful wife, Yang Doma Sherpa for her love and cheering me on in whatever I attempt.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER I

INTRODUCTION

Natural resources such as fertile soil, clean water, clean air and habitable climate in the earth are providing life supporting biosphere to all living creatures. However, the exponential human population growth and indiscriminate resources use, competition for the economic development, urban sprawl, etc. have created immense pressure to natural resources in the last few decades. Therefore, the environmental problems such as climate change, global warming, acid rain, sea level rise, etc. are accelerating and in return it is affecting the biosphere. Mostly, the developing countries that are weak segment of the international community are more vulnerable to those environmental phenomenon because of lack of development strategies and resources to cope against the changing environment (UNESCO, 2016). But it cannot be ignored that developed countries are also the victim of those problems because we all are travelling in the same boat.

In 1987, World Commission on Environment and Development (WCED) (also called Brundtland declaration) first coined the concept of sustainable development to resolve the problems. “Our common future”, the report issued by the commission defined the sustainable development as the development that meets the need of present generation without compromising the ability of future generation to meet their needs (WCED, 1987). The report suggested that the conventional way of measuring the prosperity of a country only through the growth in gross domestic product (GDP) is not correct. For the sustainable development it is necessary to pursue balance between economical, social developments taking into consideration to ecological factors. In other words, for the sustainable development, the three factors namely environment, society and economy (also called the three pillars of sustainability) should be considered together and there should be reasonable level of balance among these sectors (Figure 1.1) (González-Mejía and Ma, 2017). The development that is environmentally bearable, socially equitable and economically viable is sustainable (Waas *et al.*, 2014).

However, there is a big barrier regarding the implementation and achievement of sustainability, mostly in the developing countries like Nepal. Developing countries are poor countries with low level of socio-economic development, weak institutional capacities and scarcity of domestic financial resources. Population in developing countries is highly dependent in the natural resource and they are surviving with low quality of life. Poverty is considered as the basic cause of environmental degradation and hindrance for sustainable development. In developing countries, it is still believed that the prosperity and happiness is achieved only through growth in the GDP of a country. Therefore, they ignore the ecological service in their development policies. The GDP entails the depletion of natural resources as current income and do not take into account the depreciation of the country's assets that is involved environmental degradation. But it should be understood that, unless the environment is treated as an integral part of the economy the long-term development cannot be achieved.

In 2016, United Nation Environment Program (UNEP) set seventeen sustainable development goals (SDGs) to alleviate poverty, conserve natural resources and protect the planet. The intention of the SDGs is also to integrate whole world in common arena such that, all the developed and developing countries focus their development trend to sustainable future. With this, the developing countries are being more responsible and deliberately focusing their policies for economic, finance, trade, energy, agriculture, industry, etc. towards economically, socially, and environmentally viable and healthy. But the problems regarding the achievement of sustainable development goals in developing countries are the lack of efficient strategies in their development policies. Though, developing countries like Nepal are very enthusiastic to implement sustainable development plan, they lack proper expert to use assessment tools to measure the sustainability of a country that helps to develop policies.

Sustainability assessment is the comprehensive and holistic assessment procedure that analyzes the sustainable development trend of a country and guides in making sustainable development action-guiding policy (Waas *et al.*, 2014). The sustainability assessment should be inclusive and should appraise the three pillars of sustainability (social, economy and environment). This should facilitate in management and planning for human system with responsible long-term perspectives (González-Mejía and Ma, 2017). In sustainability assessment, sustainable indices should be determined such that they can lead to better decision and more effective actions by simplifying, clarifying and making aggregated information available to policy makers. Sustainability indices incorporate physical and social knowledge into decision making and help to measure progress towards sustainable development goals. They can provide an early warning to prevent economic, social and environmental setbacks. In the last decades, many sustainability assessment tools and indices have been proposed by research scholars such as human development index, environmental performance index, ecological footprint, carbon footprint, etc. But there has always been debate regarding the holistic agreement and application of the sustainability assessment tools because they fail to integrate the social, environmental and economic dimensions into a common ground. The measurement of three pillars of sustainability into common ground is difficult task because these three aspects are measured in different scales. None of the previous sustainability assessment methods were successful to measure them in common unit. In this regard, a new method was in need such that, those different aspects could be measured in aggregate.

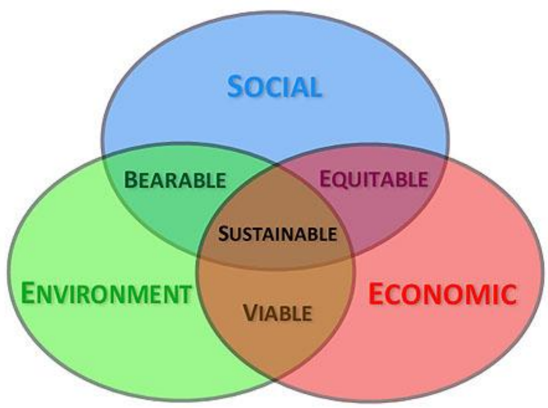


Figure 1.1: The three pillars of sustainable development

In the 1980s, Howard T. Odum developed new method called emergy (spelled with 'm') method for the sustainability assessment of a system. This new method integrates social, economic and environmental factors into common unit of measure, solar emjoule (sej). Emergy is defined as the total direct and indirect energy of one source type (e.g. solar) required to produce a product or provide a service.(Odum, 1996). Emergy theory assumes that all the activities on the earth are driven by solar energy. For example the fossil fuel formation represents millions of years of embodied energy from the sun and geological activities, wind, rain, rivers are initiated by more recent solar energy, plant growth depends in minerals, rain and solar insolation, further more money is related to emergy by considering the circulation of money through the environmental-economic interface (Odum, 1996). Therefore, every product or service in the earth is comprised of energy and that can be measured in equivalent to solar energy. In this research, emergy method is applied in the sustainability study of Nepal. This new approach of sustainability study through emergy will provide a foundation for the sustainability assessment and to develop new action guiding policies for developing countries like Nepal.

Furthermore, in emergy based sustainability assessment of a country, emergy indices (EI) are also calculated that help to quantify and measures the environmental loads due to economic activities, social and economic improvement of people in different time scale. The EI are calculated with the inclusion of economic welfare, environmental quality and social coherence of a country (Giannetti *et al.*, 2010; Liu *et al.*, 2017). This simplifies the complexity of socio-economic and environmental information and supports the decision makers monitoring the performance and benchmarking the comparison (King, 2006). The most notable EI are environmental loading ratio (ELR), emergy yield ratio (EYR), emergy investment ratio (EIR) and emergy sustainability index (ESI). ELR measures the environmental load due to economic activity and is useful index for pollution control, EYR measures the net benefit of locally available resources in an economy of a country, EIR measures the trade interdependent of a country. ESI is the ratio of EYR and ELR and this measures the sustainability of a country in aggregate (Brown and Ulgiati, 1997; Brown and Ulgiati, 2004; Odum, 1996). The detailed of EI are explained in literature section (Chapter II).

1.1 OBJECTIVES

The main objective of this research work is to apply emergy method in the sustainability assessment of Nepal through integrating three different aspects namely; social, environmental and economic aspects into a common unit of emergy. This research report comprises three different researches with different objectives. The specific objectives of individual research are presented below:

1. Apply emergy method in sustainability assessment of Nepal and draw out recommendation on sustainability policies for Nepal
2. Evaluate the impacts of a natural disaster on the environment and the socio-economy of a country applying emergy assessment tool
3. Propose a new method of transformity calculation for emergy calculation in co-production system networks

1.2 THESIS ORGANIZATION AND SCOPE

This is the Master's thesis and contains six chapters. Chapter I is the introduction which includes the background, objectives and scope of the study. Chapter II is the literature reviews. The literature reviews include the detailed literatures on emergy, its calculation procedures, and its applications. Chapter III, chapter IV and chapter V are the chapter that includes researches with different research title. The results and discussion including conclusion of individual research are included in respective section. The titles of three researches are:

1. Emergy assessment and prospects towards sustainable development of Nepal
2. The impact analysis of natural disaster by emergy method: The case of Gorkha-earthquake in Nepal
3. Methodological aspect of emergy accounting in co-production branching systems

Chapter VI summarizes the research findings and lists the main conclusions derived from this work. The recommendations for future research works are also included in this section.

In this study, for the emergy calculation in individual research, data collection and analysis are limited according to research objectives. For the sustainability assessment of Nepal, the emergy of Nepal was calculated based on the socio- economic and environmental data from 1998 until 2015. Furthermore, the simulation of emergy indices was done applying the Systems Thinking, Experimental Learning Laboratory with Animation (STELLA) modeling program for next 25 years until 2040. For the natural disaster impact assessment through emergy method, the Gorkha-earthquake that hit Nepal in 2015 was used. The emergy of Nepal in 2014 (before the earthquake) and 2015 (after the earthquake) was determined and compared for impact analysis in the socio-economy and the environment of the country. For the emergy accounting in co-production network system, new modified physical quantity method (MPQM) was proposed for transformity calculation. A case study of *Eucalyptus* pulp production was presented to show the validation of new method. Here the emergy of 610 tons of pulp production was calculated and analyzed.

REFERENCES

Brown, M.T., Ulgiati, S. (1997). Emergy-based indices and ratios to evaluate sustainability: Monitoring economies and technology toward environmentally sound innovation. *Ecol. Eng.*, **9** (1), 51-69.

Brown, M.T., Ulgiati, S., (2004). Emergy analysis and environmental accounting. *Encyclopedia of Energy*, **2** 329-354.

Giannetti, B.F., Almeida, C.M.V.B., Bonilla, S.H. (2010). Comparing emergy accounting with well-known sustainability metrics: The case of southern cone common market, mercosur. *Energy Policy*, **38**,(7), 3518-3526.

González-Mejía, A.M., Ma, X. (2017). The emergy perspective of sustainable trends in puerto rico from 1960 to 2013. *Ecol. Econ.*, **133**, 11-22.

King, D.M.D. (2006). Emergy accounting of the resource basis of nations, human well-being and international debt. University of Florida.

Liu, G., Brown, M., Casazza, M. (2017). Enhancing the sustainability narrative through a deeper understanding of sustainable development indicators. *Sustainability*, **9** (6), 1078.

Odum, H.T. (1996). Environmental accounting: Emergy and environmental decision making, john wiley & sons, inc.

UNESCO (2016). Sustainable development in the least developed countries , towards 2030. UNESCO, Paris.

Waas, T., Hugé, J., Block, T., Wright, T.*et al.* (2014). Sustainability assessment and indicators: Tools in a decision-making strategy for sustainable development. *Sustainability*, **6** (9), 5512.

WCED (1987). Our common future. The world commission on environment and development.

CHAPTER II

LITERATURE REVIEW

In this section, the comprehensive review on emergy and its application in sustainability study are presented. First, the detailed emergy theory is explained. Second, the emergy calculation procedure and emergy indices that evaluate the sustainability in a system are explained. Finally, the application of emergy method in sustainability study in different sectors is discussed.

2.1 EMERGY THEORY AND EMERGY ACCOUNTING (EA) OF A SYSTEM

By definition emergy is the available energy of one kind that has been used up directly or indirectly to make a product or service. In emergy, energy is transformed to make a product or services therefore emergy accounts for the conservation and loss of energy that result from the law of thermodynamics. According to the second law of thermodynamics, any energy transformation consumes many calories of available energy, to one kind, to generate fewer calories of available energy of another kind. The more work that is done to produce something, the more energy must be transformed to perform that work and the higher the emergy value stored in the product. Emergy therefore measures the environmental work in both the past and the present, that is necessary to produce a given resources or provide a given service.

This theory is based on the principle that every element in the universe constitutes energy and that can be measured. In emergy, solar energy is considered as the primary energy source that produces resources and service in the earth. For example, sunlight, fuel, electricity and human service can be put on a common basis by expressing them all in solar energy that is required for each. Therefore, emergy is measured in terms of solar emjoule also sometime called solar equivalent joules (sej). In the beginning, the term 'embodied energy' was used to refer energy quality but later David Scienceman proposed the term 'emergy'. Emergy is a measure of the available energy that has already been used up. In other word, it is a record of previously used-up energy that is a property of the smaller amount of available energy in the transformed product. Therefore, emergy is also called "energy memory" (Odum, 1996). This theory has been coherently adopted to the study of ecologically and economically couples system that exhibit characteristic designs and reinforce energy use (Rydberg and Haden, 2006).

The study of energy and material flow in combined ecological and economic systems was neglected due to its interdisciplinary nature. After the development of emergy method, the energy and matter flow in ecological and economic systems are evaluated in new perspective. In emergy method, the valuation of input and output energy is done converting them into equivalent of one form of energy (solar energy) with reference to the theory of energy hierarchy in systems ecology. The term, energy hierarchy indicates that in all systems, a greater amount of energy must be dissipated in order to produce a product containing less energy of a higher quality. In the earth system, solar energy is the largest but dispersed energy input that dissipates to product other products and services (Odum 1996). In traditional economic assessment method, the ecological service to produce a product is considered as a free service and was excluded in total calculation. This makes the method inappropriate in sustainability assessment that should incorporate economic and natural value in together. Emergy method accounts the value of the work of nature on a common basis of nonmonetary measure that fall outside the moneyed economy (González-Mejía and Ma, 2017). Therefore, emergy analysis solve the problem inherent in monetary valuation in traditional economic methods (Rydberg and Haden, 2006).

2.2 SELF-ORGANIZATION, MAXIMUM EMPOWER PRINCIPLE AND SUSTAINABILITY OF A SYSTEM

Self-organization and the maximum empower principle are fundamental concepts in emergy that help to understand the sustainability of a system. Sustainability is the prolongation or maintenance of a state desired by human. In other word sustainability means to keep an entity in existence and in this sense it is related to the survival of a system. Self-organization is the process by which the various parts of a system be connected so as to work together. The self-organization help to estimate which system would survive in competition with other system. During the competition, the self-organized systems that contribute to the better use of available resources succeed because they receive beneficial returns for their actions. The good example of natural competition and the survival is explained through the relation of bees and flower. Bees pollinate the flowers which produce nectar, so both the bees and flowers survive. Regarding a system with emergy and matter flows, the system which uses the energy more efficiently and develop well organized structure survive and succeed in competition or in other such systems are sustainable. The self-organized systems are able to survive and self-repair even the substantial damage is occurred, and they easily recover from moderate perturbations. Self-organization provides a framework for understanding how system utilizes incoming emergy sources to develop new organizational states over time (Rydberg and Haden, 2006).

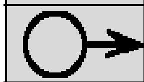
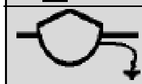
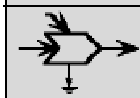
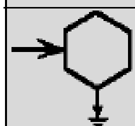
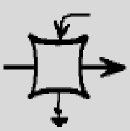
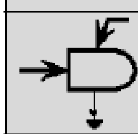
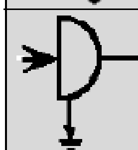
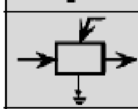
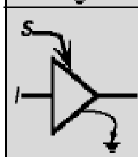
During self-organization, systems are guided by the maximum power principle, stated as 'system designs organize so as to bring in energy as fast as possible and use it most efficiently' (Odum 1998). In emergy the same principle is called as maximum empower principle (MEP). Empower is defined as emergy flow per unit time (Odum 1996). This principle states that, system that are self-organized to develop most useful work with flowing emergy sources by reinforcing productive processes and overcoming limitations through system organization will prevail in competition with others. A system that process more useful emergy will prevail in competition with alternate systems because more available emergy provides contingency needs and better adaptation to surrounding conditions. Odum offered MEP as the fourth law of thermodynamics (Odum 1996). During the sustainability assessment of a country using emergy method, it states that self-dependence country that utilizes the resources more efficiently present within its geographical boundary and relies more on renewable emergy than non-renewable emergy storage are self-sustained and prevail in competition with other countries and are sustainable (Rhydberg and Haden, 2006).

2.3 UNDERSTANDING SYSTEM, EMERGY CALCULATION OF A SYSTEM AND THE SUSTAINABILITY INDICES

Emergy method is based on the system theory and energy transformation into the system (Odum, 1996). Thus, first understanding of the system is essential in emergy accounting. The system consists of defined boundary, interacting components interlinked with each other that exchange energy, matter and information. The system may be simple or complex depending on space and the number of interacting components (Graedel and Allenby, 2003). For example, considering the emergy accounting of a country as a single system, its essential to conceptulise on the system boundarues. Primary resource inflow, internal resource transformation, trade should be carefully determined. Basically, a country that rely more on renewable emergy than non-renewable emergy storage are self-sustained,prevail in competition with other countries and are more sustainable. For the long-term sustainability this requires an internal organization that use renewable resources in an effective way. Utilizing non-renewable resources to their greatest potential is an example of the maximum empower principle (Rydberg and Haden, 2006).

In emergy accounting, the system and its components are illustrated through different language and symbols (Odum, 1996). The symbol has characteristic meaning and it is diagrammed for the flows, storages, intersections and feedback of energy, materials, information, money, etc. The symbols used in system diagram are summarized in the table 2.1

Table 2.1: Emergy system symbols

	*Energy circuit:* A pathway whose flow is proportional to the quantity in the storage or source upstream.
	*Source:* An outside source of energy delivering forces according to a program controlled from outside; a forcing function.
	*Tank:* A compartment of energy storage within the system storing a quantity as the balance of inflows and outflows; a state variable.
	*Heat sink:* The dispersion of potential energy into heat that accompanies all real transformation processes and storages; loss of potential energy from further use by the system.
	*Interaction:* An interactive intersection of two pathways required to produce a particular outflow, such as a product or service.
	*Consumer:* A unit that transforms energy quality, stores it and feeds it back autocatalytically to improve inflow.
	*Switching action:* A symbol that indicates one or more switching actions—which means that the process can be turned on or off. The controlled flows enter and leave from the sides, and the pathways (thresholds and other information) that control the switches are drawn on top. Examples of switching actions include earthquakes and flooding events.
	*Producer:* These include units that collect and transform various inputs into a particular product. Examples of producers include plants and manufacturing processes.
	*Self-limiting energy receiver:* A unit that has a self-limiting output when input drives are high because there is a limiting constant quality of material reacting on a circular pathway within.
	*Box:* A miscellaneous symbol to use for whatever unit or function is labelled.
	*Constant-gain amplifier:* A unit that delivers an output in proportion to the input, *I*, but is changed by a constant factor as long as the energy source, *S*, is sufficient.
	*Transaction:* A unit that indicates a sale of goods or services (solid line) in exchange for payment of money (dashed line). Price is shown as an external source.

2.4 THE GLOBAL EMPOWER

In emergy accounting of a system, the emergy flow in a unit time should be calculated. The flow of emergy per unit time is called empower and called global empower is the total emergy flow in the earth (Odum, 1996). The total global empower is important because this serve as the baseline for unit emergy values (UEVs) or transformity calculation (Park, 2015). The total global empower is calculated based on the three main energy source in the earth namely, solar insolation, deep earth heat and tidal energy. The global empower is approximately 15.83E+24 sej/yr (Brown *et al.*, 2016)(Odum,2000). From the total global empower, 3.93E+24 sej/yr comes from the solar insolation, 8.06E+24 sej/yr comes from deep earth crust and 3.83E+24 sej comes from the tidal energy (Table 2.2). This total global empower is also called the emergy baseline (Odum, 1996).

Table 2.2: The global empower (Brown *et al.*, 2016)(Odum, 2000)

	Source	Units	Quantity	Solar transformity (sej/j)	Empowr
1	Solar insolation	j/yr	3.93E+24	1	3.93E+24
2	Deep earth heat	j/yr	6.72E+20	1.20E+04	8.06E+24
3	Tidal energy	j/yr	0.52E+20	7.37E+04	3.83E+24
	Total global empower				15.83E+24

2.5 EMERGY CALCULATION METHOD AND UNIT EMERGY VALUES

Mathematically, the emergy is the product of energy and unit emergy values (UEVs) (Odum, 1996).

$$\text{i.e. Em} = \text{En x Tr}$$

Where, Em is the emergy of the product, En is the energy of the product and Tr is the UEV, also called transformity.

2.5.1 Unit emergy values (UEVs)

UEVs are the ratio of emergy per unit energy or mass (Odum, 1996). UEVs are the conversion factor that converts energy, matters and information that flow in and out of a system into emergy. (Brown *et al.*, 2012). UEVs are of two types:

2.5.2 Transformity

If UEV is expressed in the unit of energy (J) then it is called transformity. In emergy accounting, the solar energy is considered as a basic source of energy in resources production in the earth, thus in emergy accounting, solar transformity implies the transformity factor. The solar transformity is defined as the solar emergy required producing a joule of service or product. Its unit is solar emergy joule per joule (sej/j) (Odum, 1996). For example if 4000 sej are required to generate a joule of wood, than the solar transformity of that wood is 4000 sej/j. The solar transformity of the sunlight is 1.0 sej/j (Brown and Ulgiati, 2004; Odum, 1996).

2.5.3 Specific emergy

If UEV is expressed in the unit of mass or money ($) then it is called specific emergy. The specific emergy of mass is expressed in sej/g and money is expressed in sej/$. Basically, in emergy accounting, solid products are evaluated through emergy per unit mass. Elements and compounds that are not abundant in nature has high emergy/mass ratio because much energy is required to concentrate those substances spatially and chemically for example metallic and non-metallic minerals (Brown and Ulgiati, 2004). Money flow in emergy accounting is evaluated in term of emergy per unit money. U.S. dollar is frequently used for the international exchange around the world. Therefore, sej/$ is used as the specific emergy for money circulation.

2.5.4 Emergy calculation procedure

Emergy accounting of any system should follow the defined procedure suggested by H.T. Odum (Brown and Ulgiati, 2004). The emergy accounting procedure can be summarized into four steps:

Step 1: Construction of detailed emergy system diagram

System diagram is constructed with the defined system boundary. System diagram show the input and output of energy, matters, information, etc. in a system. The purpose of the system diagrams is to conduct a critical inventory of processes, storages and flows that are important to the system under consideration and are necessary to evaluate (Brown and Ulgiati, 2004). The components and flows in the diagram are arranged according to the energy transformation. The more available and dissipated energy sources are placed in the left side of the diagram, more transformed and high quality energy are placed in the right. The detailed emergy diagram is constructed with complete information and emergy symbols as shown in Table 2.1.

Step 2: Emergy evaluation table

Emergy evaluation table provide a template for the calculation of the emergy value for emergy storage and flow. In the emergy table, energy or mass or money data are converted to emergy through transformity factor. The emergy table should be constructed in six-column format as presented below:

Table 2.3: Emergy calculation table format

1	2	3	4	5	6
Note	Items	Data	Units	Emergy/unit (sej/unit)	solar emergy sej/yr
1	First items	xx.x	sej/yr	xxx.x	xxx.x
2	second items	xx.x	g/yr	xxx.x	xxx.x
:					
n.	nth items	xx.x	sej/yr	xxx.x	xxx.x
O.	Output	xx.xx	sej or g/yr	xxx.x	∑ Em

Column 1 is the line items which is also the number of footnote found below the table where raw data sources are cited and calculations are shown

Column 2 is the name of the input and output items which is also shown in the aggregated diagram

Column 3 is the raw data which may be in different units, joules, grams, dollars or other units. The units for each raw data items are shown in column 4

Column 5 is the UEVs expressed in solar emergy joules per unit. The unit may be in grams, joules or dollars (sej/hr, sej/g, sej/$)

Column 6 is the solar emergy and calculated multiplying column 3 and column 5.

Later, all the emergy value in emergy evaluation table is aggregated in emergy summary table.

Step 3: Aggregated system diagram

After all the flows indicated in detailed system diagram are quantified and tabulated, they are accumulated and presented in aggregated system diagram. This diagram should include all resources and components shown in detailed system diagram with fewer pathway and symbols. All flows are presented in unit of sej.

Step 4: Emergy indices table

Finally, emergy indices are calculated to evaluate sustainability of a system in emergy indices table. Some of the important emergy indices are discussed in next section with respective calculation formula.

2.6 EMERGY BASED SUSTAINABILITY INDICES

One of the effective trend of analyzing the sustainability of system is, calculation of sustainability indices. Sustainabiulity incices help to understand and make easy comparision of sustainability level of different systems. In Emergy analysis of a system, important indices are calculated called emergy indices. Emergy indices are calculated integrating socio-economic and environmental factors (Brown and Ulgiati, 2004). The emergy indices further helps in drawing inference, gain perspective, aid in making comparison with other systems and provide information for public policy decision making (Odum, 1996). The emergy indices for sustainability study are presented in Table 2.4. The terms used in emergy indices can be generalized from figure below.

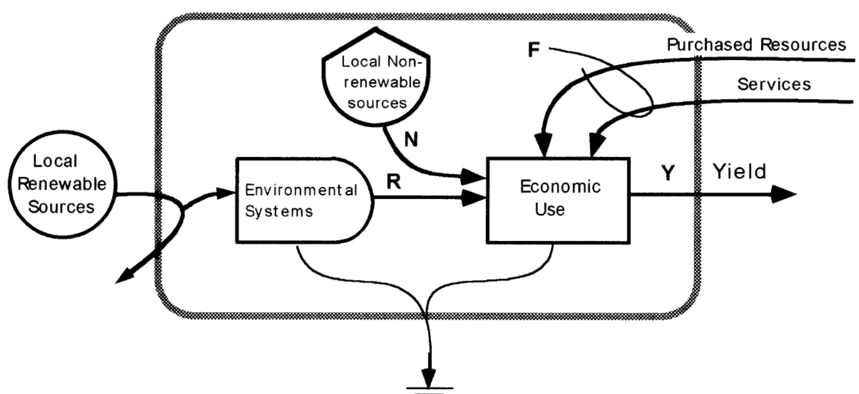


Figure 2.1: Basic terms used in emergy indices (Ulgiati and Brown, 1998)

Table 2.4: Emergy indices

Indices and symbol	Description	Equation
Percent Renewable (%R)	%R is the percent of the total emergy driving a process that derived from renewable resources. In long run only the system with higher %R value are sustainable	$\frac{R}{R+N+F}$ X 100
Emergy yield ratio (EYR)	It is an indicator of the yield compared to the inputs other than local and gives a measure of ability of the process to exploit local resources. The lowest possible value of EYR is 1, which indicates that a process delivers the same amount of emergy that was provided to drive it and that it is unable to usefully exploit any local resource (Brown and Ulgiati, 2004). Low EYR in production system indicates low economic benefits and a weak market competition where as the higher value indicates strong competition that the developed product has and a high economic benefits.(Londoño *et al.*, 2014).	$\frac{R+N+F}{F}$
Emergy Investment Ratio (EIR)	EIR shows the relation between the emergy of the economic input with those provided by the environment, renewable or not. This index measures the intensity of the economic development and the loading of the environment	$\frac{F}{N+R}$
Environment Loading Ratio (ELR)	The ELR is an indicator of the stress of the local environment due to the production activities. The lower the portion of renewable resources use the higher the pressure on the environment. ELR value between 3 to 10 are indicative of moderate environmental impacts, while ELR ranging from 10 and above indicates much higher environmental impacts due to flow of concentrated non-renewable emergy in a relatively small local environment.	$\frac{N+F}{R}$
Emergy Sustainability Index (ESI)	ESI aggregates the measure of yield and environmental loading. The objective function is to obtain highest yield at the lowest environmental loading. ESI lower than 1 is the indicative of highly developed consumer oriented system and the value between 1 to10 is developing economics and greater than 10 indicate that economics have not yet significantly started any industrial activities. (Brown and Ulgiati, 2004; Giannetti *et al.*, 2010)	$\frac{EYR}{ELR}$

2.7 APPLICATION OF EMERGY METHOD IN SUSTAINABILITY STUDIES

Emergy has been applied in the sustainability assessment in diverse sectors. H.T. Odum first used the emergy method in the sustainability assessment of the United States. He proposed the emergy indices to understand the economic sustainability of the United States (Odum, 1996) and also compared the EMR (national emergy used per year divided by the GDP) of the United States with other countries (Park, 2015). Since, than many researchers applied this tool in sustainability study of many countries.

Tilley, (2006) later applied the emergy to measure the national metabolism of the United States of last two centuries from 1790 to 2000. The results showed that the total emergy use of the United States has increased by 1600 percentage during those 210 years. The total emergy use suppressed during the bad economic time for example, the Great Depression (1930), the Gulf war recessions (1990-91), the oil embargo (1974). ELR of the United States was higher since the early years due to high use of non-renewable fossil fuels (e.g. coal). He applied "emergy use per capita" for analyzing the well-being of people, which has increased gradually.

Yang *et. al.*, (2010) did the emergy evaluation of the Chinese economy from 1978 till 2005. They found that total emergy use and emergy use per capita of China has increased largely during the study period. The contribution of non-renewable resources in the economy was significantly high. The higher consumption of non-renewable resources increased the ELR of China from 1.71 in 1978 to 7.41 in 2005.

Gasparatos and Gadda, (2009) studied the economic growth of Japan applying emergy synthesis over the period of 1979 to 2003. The results revealed, due to the limited natural resources, Japan was highly dependent in importation. There was a significant increase in the total emergy use of Japan during those twenty four years. The total emergy consumption was increased by 66.9%, emergy-to-money ratio was decreased by 60.1%. The EIR increased to double in 2003 compared to 1979. The ELR was also increased by 93.7 % in shortly.

Lomas *et. al.*, (2008) studied Spain economy through emergy synthesis of last twenty years starting from 1984. The result showed the total emergy use of Spain has grown each year with an average of 3.77%. The EYR has decreased due to the growing trend of the imports such as energy and goods from neighbor countries. The ELR has increased during initial years of study but it has decreased during the recession period (1989-2000). With increasing ELR, the ESI has decreased due to the reduction in the flow of renewable emergy.

Ferreyra and Brown (2007) studied the Argentine economy of 20th century through emergy perspectives and found that, during those hundred years, total emergy use of Argentina has increased significantly. But the contribution of renewable energy in the total emergy use has decreased from 67% to 55%. International debt is the big issue in Argentina. In term of emergy (emergy exchange ratio), Argentina was supposed to pay all the debt by 1985 but due to unfair emergy trade the debt is still not paid.

Giannetti *et. al.*,(2013) Studied the sustainable development and resources use of Brazil from 1979 to 2007. They compared the emergy of Brazil with BRICS (Russia, India, China, and South Africa) member countries. The results explained that, the GDP of Brazil has increased by seven times during those time period and this has also increased the total emergy use of Brazil. The per capita emergy use of Brazil was greater than China and India but less than Russia and South Africa. They suggest that, BRICS are mostly concentrated in the export of raw resources instead they should focus in the export of finished products for best performance and economic benefits.

Haitao and Brown, (2017) performed emergy based environmental accounting of Mongolia based on data from 1995 to 2012. The total emergy use of Mongolia has increased by 75% during those eighteen years. Because of the high EMR value of Mongolia compared to world average EMR, Mongolia is facing trade disadvantage. In 2012, the export emergy of Mongolia was higher than the import emergy but late years, the import emergy exceed the export emergy, suggesting that Mongolia economy is down turning in the world economy.

Zhu *et. al.,* (2012) conducted the time series environmental accounting of Inner Mongolia Autonomous Region (IMAR) of China from 1987 to 2007. They compared the emergy indices of Inner Mongolia with the average value of China and with other regions of China. The EIR of IMAR is gradually increasing in different years. The EIR of IMAR is greater than other regions of China but lower to the national average. Similarly, the emergy use per person of IMAR is larger than other regions. But the ELR of IMAR is small indicating IMAR is more sustainable in term of resource utilization.

Lei and Wang, (2008)analyzed the emergy of Macao of last twenty years starting from 1983 and they also make a simulation of emergy for next twenty years. Being a popular tourist destination, Macao has experienced drastic economic and natural changes in short time period. The importation (fresh water, electricity, minerals, raw materials, etc.) has increased sharply in last year. Total emergy used has increased by more hundred percentages. The ELR of Macao is very high and the ESI is very low, indicating the consumer oriented economic system. The simulation result explains that the total emergy use of the Macao will increase sharply with increasing ELR in the future. They also suggest recommendations and sustainable policies to improve the environment of Macao for the future.

Campbell *et. al.*, (2007) compared the emergy of Israel and Palestine, conflict zone of the Middle East. Israel has higher total emergy use and EMR than Palestine, suggesting that Israel is more developed than Palestine. Israel is more dependent in non-renewable fuel and minerals for their economic development hence the ELR of Israel is also higher than Palestine.

Hossaini and Hewage, (2013) conducted emergy accounting of different province of Canada and compared emergy indices. Ontario has the highest emergy consumption in Canada followed by Alberta. They also have higher EYR value indicating highly industrialized province in Canada. Being highly industrialized they also have higher ELR value. The ELR of Manitoba and British Colombia is lowest among all provinces. This show the industrial activities have not significantly started in those regions. They recommend preserving the natural resources of Manitoba and British Colombia for future generation. The province like Newfoundland and Labrador are environmentally sustainable and mostly relies in renewable energy resources.

The above mentioned researches are the time series emergy analysis of different countries. Emergy evaluation of countries based on data of fixed fiscal year has done by many researchers, South Korea (Kang, 2015; Kang and Park, 2002; Nam *et al.*, 2010; Odum, 1994), China (Jiang *et al.*, 2008), Albania (Harizaj, 2010), Italy (Ulgiati *et al.*, 1994).

Emergy methodology has also been applied in sustainability assessment of other systems including industrial system (Angelakoglou and Gaidajis, 2015; Fan *et al.*, 2017; Geng *et al.*, 2014; Geng *et al.*, 2010; Ren *et al.*, 2013; Zhang *et al.*, 2011; Zhe *et al.*, 2016), agricultural production system (Chen *et al.*, 2006; de Barros *et al.*, 2009; Rydberg and Haden, 2006), wastewater and landfill (Merlin and Lissolo, 2010; Shao *et al.*, 2017; Vassallo *et al.*, 2009), infrastructures (Meillaud *et al.*, 2005; Pulselli *et al.*, 2009; Yang, 2016)Pollution (Zhang *et al.*, 2012), tourism (Lei and Wang, 2008a), etc.

REFERENCES

Angelakoglou, K., Gaidajis, G. (2015). A review of methods contributing to the assessment of the environmental sustainability of industrial systems. *J.Cleaner Prod.,* **108,** 725-747.

Brown, M.T., Campbell, D.E., De Vilbiss, C., Ulgiati, S. (2016). The geobiosphere emergy baseline: A synthesis. *Ecol. Modell.,* **339,** 92-95.

Brown, M.T., Raugei, M., Ulgiati, S. (2012). On boundaries and 'investments' in emergy synthesis and lca: A case study on thermal vs. Photovoltaic electricity. *Ecol. Indic.,* **15** (1), 227-235.

Brown, M.T., Ulgiati, S. (2004). Emergy analysis and environmental accounting. *Encyclopedia of Energy, ,* **2,** 329-354.

Campbell, E., Campbell, D., Cobb, S., (2007). Emergy analysis of israel and palestine. EMERGY SYNTHESIS 4: Theory and Applications of the Emergy Methodology, Proceedings from the Fourth Biennial Emergy Conference, Gainesville, Florida.

Chen, G.Q., Jiang, M.M., Chen, B., Yang, Z.F.*et al.* (2006). Emergy analysis of chinese agriculture. *Agric. Ecosyst. Environ.,* **115** (1), 161-173.

de Barros, I., Blazy, J.M., Rodrigues, G.S., Tournebize, R.*et al.* (2009). Emergy evaluation and economic performance of banana cropping systems in guadeloupe (french west indies). *Agric. Ecosyst. Environ.,* **129** (4), 437-449.

Fan, Y., Qiao, Q., Fang, L., Yao, Y. (2017). Emergy analysis on industrial symbiosis of an industrial park – a case study of hefei economic and technological development area. *J.Cleaner Prod.,* **141,** 791-798.

Ferreyra, C., Brown, M.T. (2007). Emergy perspectives on the argentine economy during the 20th century: A tale of natural resources, exports and external debt. *International journal of environment and sustainable development,* **6** (1), 17-35.

Gasparatos, A., Gadda, T. (2009). Environmental support, energy security and economic growth in Japan. *Energy Policy,* **37** (10), 4038-4048.

Geng, Y., Liu, Z., Xue, B., Dong, H.*et al.* (2014). Emergy-based assessment on industrial symbiosis: A case of shenyang economic and technological development zone. *Environ. Sci. Pollut. Res.,* **21** (23), 13572-13587.

Geng, Y., Zhang, P., Ulgiati, S., Sarkis, J. (2010). Emergy analysis of an industrial park: The case of Dalian, China. *Sci. Total Environ.,* **408** (22), 5273-5283.

Giannetti, B.F., Almeida, C.M.V.B., Bonilla, S.H. (2010). Comparing emergy accounting with well-known sustainability metrics: The case of southern cone common market, Mercosur. *Energy Policy,* **38** (7), 3518-3526.

Giannetti, B.F., Demétrio, J.F.C., Bonilla, S.H., Agostinho, F.*et al.* (2013). Emergy diagnosis and reflections towards Brazilian sustainable development. *Energy Policy,* **63,** 1002-1012.

González-Mejía, A.M., Ma, X. (2017). The emergy perspective of sustainable trends in Puerto Rico from 1960 to 2013. *Ecol. Econ.,* **133**, 11-22.

Graedel, T.E., Allenby, B.R. (2003). Industrial ecology. Prentice Hall.

Haitao, L., Brown M. (2017). Emergy-based environmental accounting toward a sustainable Mongolia. *Journal of Geophysical Sciences*, **27** (10), 1227-1248.

Harizaj, P., (2010). Emergy synthesis of Albania for 2007. *Albanian Journal of Agricultural Sciences*.

Hossaini, N., Hewage, K. (2013). Emergy accounting for regional studies: Case study of Canada and its provinces. *J. Environ. Manage.,* **118,** 177.

Jiang, M.M., Zhou, J.B., Chen, B., Chen, G.Q. (2008). Emergy-based ecological account for the Chinese economy in 2004. *Commun. Nonlinear Sci. Numer. Simul.,* **13** (10), 2337-2356.

Kang, D. (2015). Emergy evaluation of the Korean economy and environment: Implications for the valuation of marine ecosystem services. *Journal of the Korean Society for Marine Environment & Energy,* **18** (2), 102-115.

Kang, D., Park, S.S. (2002). Emergy evaluation perspectives of a multipurpose dam proposal in Korea. *J. Environ. Manage.* **66,** 293-306.

Lei, K., Wang, Z. (2008a). Emergy synthesis of tourism-based urban ecosystem. *J. Environ. Manage.,* **88** (4), 831-844.

Lei, K.P., Wang, Z.S. (2008b). Emergy synthesis and simulation for Macao. *Energy,* **33** (4), 613-625.

Lomas, P.L., Álvarez, S., Rodríguez, M., Montes, C. (2008). Environmental accounting as a management tool in the mediterranean context: The Spanish economy during the last 20 years. *J. Environ. Manage.,* **88** (2), 326-347.

Londoño, N.A.C., Suárez, D.G., Iván, H. (2014). Emergy evaluation: A tool for the assessment of sustainability in project development. *International Journal of engineering Research and Applications,* **1** (4), 172-178.

Meillaud, F., Gay, J.-B., Brown, M. (2005). Evaluation of a building using the emergy method. *Sol. energy,* **79** (2), 204-212.

Merlin, G., Lissolo, T. (2010). Energy and emergy analysis to evaluate sustainability of small wastewater treatment plants: Application to a constructed wetland and a sequencing batch reactor. *J. Water Resour. Prot.,* **02** (12), 997-1009.

Nam, J., Chang, W., Kang, D. (2010). Carrying capacity of an uninhabited island off the southwestern coast of Korea. *Ecol. Modell.,* **221** (17), 2102-2107.

Odum, H.T. (1994). Emergy analysis overview of Korea. *Journal of Environmental Science International,* **3** (2), 165-175.

Odum, H.T. (1996). Environmental accounting: Emergy and environmental decision making, john wiley & sons, inc.

Park, H. (2015). E4-emergy evaluation of south korea's sustainability progression since signing the Kyoto protocol. University of Delaware.

Pulselli, R.M., Simoncini, E., Marchettini, N. (2009). Energy and emergy based cost–benefit evaluation of building envelopes relative to geographical location and climate. *Build. Environ.,* **44** (5), 920-928.

Rydberg, T., Haden, A. (2006). Emergy evaluations of Denmark and Danish agriculture: Assessing the influence of changing resource availability on the organization of agriculture and society. *Agric. Ecosyst. Environ.,* **117** (2-3), 145-158.

Shao, S., Mu, H.L., Yang, F.L., Zhang, Y.*et al.* (2017). Application of emergy analysis to the sustainability evaluation of municipal wastewater treatment plants. *Sustainability,* **9** (1), 16.

Tilley, D.R. (2006). National metabolism and communications technology development in the United States, 1790-2000. *Environ. Hist. Camb.,* **12** (2), 165-190.

Ulgiati, S., Brown, M.T. (1998). Monitoring patterns of sustainability in natural and man-made ecosystems. *Ecol. Modell.,* **108** (1), 23-36.

Ulgiati, S., Odum, H.T., Bastianoni, S. (1994). Emergy use, environmental loading and sustainability an emergy analysis of Italy. *Ecol. Modell.,* **73** (3), 215-268.

Vassallo, P., Paoli, C., Fabiano, M. (2009). Emergy required for the complete treatment of municipal wastewater. *Ecol. Eng.,* **35** (5), 687-694.

Yang, J. (2016). Emergy accounting for the three gorges dam project: Three scenarios for the estimation of non-renewable sediment cost. *J.Cleaner Prod.*, **112,** 3000-3006.

Yang, Z., Jiang, M., Chen, B., Zhou, J.*et al.* (2010). Solar emergy evaluation for chinese economy. *Energy Policy*, **38** (2), 875-886.

Zhang, B., Chen, G.Q., Yang, Q., Chen, Z.M.*et al.* (2011). How to guide a sustainable industrial economy: Emergy account for resources input of Chinese industry. *Procedia Environ. Sci.*, **5,** 51-59.

Zhe, L., Yong, G., Park, H-S., Huijuan, D.*et al.* (2016). An emergy-based hybrid method for assessing industrial symbiosis of an industrial park. *J.Cleaner Prod.*, **114,** 132-140.

Zhu, L.P., Li, H.T., Bouldin, J., John, R.*et al.* (2012). Emergy-based environmental accounting: Evaluation of inner Mongolia autonomous region. *Acta Ecologica Sinica*, **32** (2), 74-88.

CHAPTER III

EMERGY ASSESSMENT AND PROSPECTS TOWARDS SUSTAINABLE DEVELOPMENT OF NEPAL

ABSTRACT

Emergy accounting is a sustainability appraisal method that provides a holistic understanding of sustainable development integrating social, environmental and economy dimensions (also called three pillars of sustainability) through common unit, solar emjoule (sej). This study addresses emergy assessment of Nepal using social, environmental and economic data of Nepal from 1998 to 2015. In addition, prospect of emergy for next 25 years until 2040 was simulated by using System Thinking Experimental Learning Laboratory with Animation (STELLA) modeling software. The resource use trend in Nepal, including renewable and non-renewable resources has changed significantly during the 17 years (1998-2015). The emergy indices indicated that the sustainability of Nepal had declined exponentially during this period. Until 2000, the load to the environment due to the economic activities was very low and the emergy yield was high. Therefore, the country was sustainable. However, after 2007, the increased industrialization heavily relied on imported fossil fuels, goods and services, ensued country to be unsustainable and more dependent to other countries. In total emergy use of Nepal, the share of renewable resources (%renewable) decreased but the share of non-renewable resources increased rapidly. This increased the environmental load that makes the country environmentally unsustainable. Furthermore, the simulation showed that the environmental load will increase by four times to the current status in the next 25 years. In order to solve the environmental problems and improve the social and economic status, the strategies and polices in terms of non-renewable resources extraction, trade, soil erosion control, renewable resources use are suggested for a sustainable future of Nepal.

3.1 INTRODUCTION

Sustainable development is the popular idea that has captured attention in the development agenda of all countries around the world (Campbell and Garmestani, 2012; Waas *et al.*, 2014). The concept of sustainable development was initiated in 1987 by World Commission on Environment and Development (WECD) (also called the Brundtland commission). “Our common future”, the report developed by the commission defined the sustainable development as the development that meets the needs of present generation without compromising the ability of future generation to meet their needs (WCED, 1987). The core of sustainable development model includes, the development model that integrates the social, environmental and economic dimensions of a country also called “three pillars of sustainability” (Giannetti *et al.*, 2010). Therefore, sustainable development should capture the essence of development acknowledging social equity, environmental protection and economic growth and that ensure the good future of coming generations (González-Mejía and Ma, 2017). Sustainability assessment on the other hand is comprehensive assessments that analyze the sustainability trend of a country and guides the country towards sustainable path if its development trend is unsustainable. The sustainability assessment is called integrated assessment that offer new perspectives towards planning and decision-making on sustainable development (Hacking and Guthrie, 2008).

Emergy is an emerging sustainability assessment tool that helps to analyze the sustainability of a country holistically through integrating social, environmental and economic dimensions of a country. In emergy method, integration of disparate social, environmental and economical dimensions are done by converting them into common unit of solar emergy joules (abbreviated as “sej”). This unique approach has made this method widely applicable in the sustainability assessment in different field such as the sustainability assessment of wastewater treatment plant system (Björklund *et al.*, 2001), agricultural production system (Rodríguez-Ortega *et al.*, 2017), industrial production system (Zhang *et al.*, 2011a), circular economy (Wang *et al.*, 2017).

The emergy method has already been applied in sustainability assessment of many countries. Mostly the developed countries that have adequate and easy access to social, environmental and economic data have rigorously used this tool for sustainability assessment and proposed policies for a sustainable future. The countries that have applied emergy method in sustainability study includes the United States (Odum, 1996), China (Jiang *et al.*, 2008), Japan (Gasparatos and Gadda, 2009), Spain (Lomas *et al.*, 2008), Argentina (Ferreyra and Brown, 2007), Brazil (Giannetti *et al.*, 2013), Taiwan (Huang *et al.*, 2006), etc. However, this assessment tool is confined to small group of research scholars and barely applied in the assessment of developing countries and least developed countries (LDCs). Developing countries and LDCs are poor and a weak segment of the international community and are more vulnerable to the current emerging global challenges, such as climate change, global warming, rapid urbanization, poverty, environmental degradation, financial crises are therefore sustainable that policies are urgent in those countries (UNESCO, 2016). Emergy method for sustainability assessment will be a new approach for the development of long-term action-guiding policy in those countries (Waas *et al.*, 2014). In this research, emergy method is applied in the sustainability assessment of Nepal. Nepal is one of the LDCs listed by the United Nations. Nepal has experienced rapid economic development and massive social changes in the last few years. The objective of this research paper is distinguished in two folds. First, to analyze the sustainability of Nepal based on the emergy method. Second, to propose the sustainability development policies for Nepal based on emergy results and emergy indices. Until now, comprehensive sustainability assessment of Nepal through emergy method has not been done. Although, in 2000, National Environmental Accounting Database (NEAD) for the first time automated emergy synthesis for 169 countries including Nepal through global energy, material and money flow. However, there is higher probability of error in the emergy value and results because the emergy values are calculated based on the general global average data. Therefore, the emergy calculated through the authentic data produced by authentic governmental institutions will produce the accurate results. However, the effort of NEAD to aggregate the global emergy is highly appreciated. In this research, first, the emergy of Nepal from 1998 until 2015 will be calculated through standard emergy methodology and forecasting of emergy parameters and indices will be simulated by STELLA modeling program for next 25 years, until 2040. Based on the results, the sustainable policies for Nepal will be recommended.

3.1.1 Environmental and economic characteristics of Nepal

Nepal (28° 00ˈ N, 84° 00ˈ E) is the LDCs with low level socio-economic development, weak human and institutional capacities, low and unequally distributed income and the scarcity of domestic financial resources (UNESCO, 2016). It is located in South Asia between India and

China (Figure 3.1). The total land area of Nepal is 147,181 sq. km. The population o was twenty eight million in 2015 (CBS, 2015). Nepal has distinct geographical features in small land area. The elevation ranges from lowest level of 70 m to the highest point of the earth at 8848 m (Mount Everest) above sea level. Due to distinctive elevation range, Nepal has developed unique ecological belts. The ecological belt range from 70 to 300 m is called ‘Terai region’. The Terai region has a tropical to sub-tropical climate and is rich in biodiversity. The Terai region is also called grain basket of Nepal because of its fertile land and high agricultural productivity. The range from 300 to 2500 m is called ‘Hill region’. This is the middle range of Nepal with temperate to sub-alpine climate. Similarly, the zone above 2500 m is called ‘the Mountain’ (the Himalaya) zone. This zone have sub-alpine to alpine climate (DHM, 2015).

The economy of Nepal is highly dependent on an agriculture that contributes one third of gross domestic product (GDP) (CIA, 2017). Beginning in 1996, the country faced a decade long civil war. The civil war greatly disturbed the economy of the country (Einsiedel and Salih, 2017; Sharma, 2006). After the end of the civil war in 2006, the social and economic tension was resolved and this improved the economic and social well-being in the country. The poverty level was decreased from 42% in 1995 to 23.8% in 2015. Recently, substantial progress in hunger reduction was made by Nepal with the top position in hunger reduction in South Asia (IFPRI, 2017). Unfortunately, Nepal was hit by the devastating Gorkha-earthquake in April 2015. The magnitude of earthquake was 7.8 on the Richter scale, and a strong aftershock of magnitude 7.3 was felt after a month in May 2015 (Mugnier *et al.*, 2017). Nearly 9,000 people died and more than 22,000 people were badly injured due to the earthquake. The total direct economic loss was estimated to be seven billion US$ (NPC, 2015). The overall economic growth of the country was at its lowest in the last five years in 2015 (NPC, 2015a; The World Bank, 2016). With all the challenges, Nepal has set the goals for graduating from the status of LDCs by 2022 (NPC, 2015b). These new goals have raised both the opportunities and challenges for the sustainable future of Nepal. The simultaneous, socio-economic growth with considering environmental issues may be a great challenge but there are no choices to secure sustainable future of coming generation. This research will support in the development of sustainability policies through new perspectives of emergy method.

Figure 3.1: Map of Nepal

3.1.2 Emergy theory and sustainability

Emergy method of sustainability assessment was developed by Howard T. Odum in the 1980s. The emergy is defined as the available energy of one kind previously used up directly and indirectly to make a service or product, usually quantified in solar energy equivalents (Odum, 1996). Its unit of measurement is solar emjoule. Emergy method is grounded in the fields of system ecology and ecological economics. Unlike traditional economic and ecology, ecological economics explores the interactions between environment and the economy by taking broad long term view (Ferreyra and Brown, 2007; Rydberg and Haden, 2006). In emergy method, ecological system, human social and economic systems are considered as the energetic systems that reinforce energy use and the dynamics of these systems are measured on an equal basis of solar emjoule (Rydberg and Haden, 2006). To explain the sustainability of a system, H.T. Odum posited the maximum empower principle that states, systems that self-organize to develop the most useful work with inflowing emergy sources by reinforcing productive processes and overcoming limitations through system organization will prevail in competitions and are sustainable (Odum, 1996).

Emergy is the product of energy and transformity. Transformity is the conversion factor defined as the emergy required producing a joule of service or product. In sustainability assessment of a system, this factor converts disparate environmental, economic and social products and services into emergy unit and provides a holistic measurement and comparison (Campbell and Garmestani, 2012). Transformity also describes the energy quality factor required to produce product or services. The more energy transformations there are contributing to a product, the higher is that product's transformity. In term of energy hierarchy, the rank of such products are high (Odum, 1996). Transformity on the other hand also measures the quality and renewability of resources and analyze the long term impacts of resource use in the system (Brown and Ulgiati, 1997). The natural resources that have lower transformity have short turn-over time or replacement time, and can be renewed in a short time interval whereas resources with high transformity take longer time to renew. Basically, the renewable resources (e.g. wood, water, geothermal heat, etc.) have low transformity value and such resources can be regenerated in short time interval (human life-time scale) whereas non-renewable resources (e.g. metallic and non-metallic minerals, fossil fuels, etc.) have high transformity value and their regeneration time is long. Thus, a system that relies more on renewable resources rather than non-renewable resources are sustainable in the long run (Campbell and Garmestani, 2012).

Sustainability assessment of a country applying emergy method is done considering the entire country as a system and geographical boundary of a country as a system's boundary. The resources production and energy flow such as local indigenous resources and non-renewable resources that supports system including import and export of energy, materials and information in and out of the system are quantified in emergy unit and analyzed. The sustainability of any country depends on its available resources, its rate of use and interaction with other countries. The country that relies more on renewable emergy than non-renewable emergy storage are self-sustained and prevail in competition with other countries and are sustainable (Brown and Ulgiati, 1999; Campbell, 1998). In addition, the emergy indices quantify the sustainability, environmental load, resource use intensity and economic performance of a country. The important emergy indices are emergy yield ratio (EYR), environmental load ratio (ELR) and emergy sustainability index (ESI). EYR is the emergy of yield divided by the emergy of all the feedbacks from the economy and services. ELR measures the potential environmental damage caused by the resource extraction and its use. It is calculated dividing sum total of non-renewable resource use and imported resources use by the renewable resource use emergy. ESI is the ratio of EYR to ELR that measures the sustainability of a country. Country that achieve highest yield with least load possible on the environment are sustainable (Odum, 1996).

3.2 METHODOLOGY

3.2.1 Data collection and analysis

Emergy accounting of a country requires a lot of socio-economic and environmental data. The required data were collected from publicly issued year books published by different government institution of Nepal such as, Central Bureau of Statistics (CBS), Department of Customs (DoC), Ministry of Agriculture Development (MoAD), Ministry of Finance (MoF), Nepal Tourism Board (NTB), Department of Mines and Geology (DMG), etc. Similarly, the global resource production such as the global production of petroleum oils, coal, metallic and non-metallic minerals, etc. were collected from the United States Geological Survey (USGS, 2017).

Time series emergy of Nepal from 1998 to 2015 was calculated. This time interval was selected based on political history of Nepal. From the mid 1990s until the mid 2000s Nepal was on the severity of civil war. During this period, the economic activities and the economic growth of Nepal were greatly affected (Einsiedel and Salih, 2017). Therefore, this time series emergy study will help to understand the sustainability trend of Nepal before and after the war.

Data availability is a big issue in developing countries like Nepal. The specific years for emergy calculation in this research are selected based on data availability. Therefore, the year of emergy calculation is inconsistent with different time laps. For the emergy calculation procedure, the methodological procedure explained in CHAPTER II was followed.

3.2.2 Simulation of emergy parameters for next 25 years using SPSS and STELLA software

Second, the simulation of emergy parameters (total emergy use, emergy use per capita, import emergy, export emergy, electricity use per capita and fuel use per capita) was done based on the real data of the last seventeen years. STELLA software was used for the simulation. STELLA is modeling software that helps to make system models and allow to observe the behavioral changes of the variables in a complex system where mental models are inadequate (Costanza and Gottlieb, 1998; Costanza and Voinov, 2001). Before the visual model was developed through STELLA software, the regression analysis of the emergy parameters was used to develop a regression equation. The regression equation was inserted into STELLA software to make simulation and prediction of emergy parameters.

The regression analysis was done using Statistical Package for the Social Sciences (SPSS) software. For the regression analysis following equation was applied,

$$Y = f(X) \text{ (i)}$$

Here X is an independent variable and Y is a dependent variable. Regression analysis of individual emergy parameters was done using population/year as the independent variable and the emergy parameters as the dependent variable. Choosing the right regression equation for simulation was done through careful study of probable curve regression models. The curve regression models such as linear logarithmic model, inverse model, quadratic model, growth model, exponential model were analyzed first by putting the emergy parameter values. Finally, the best regression equation among all regression models was selected based on high goodness of fit (i.e. R square value) and the best visual trend observed. The error in simulated value and real value was then estimated applying the following equation:

$$\mu_i = Y_i - \overline{Y}_i \text{ (ii)}$$

Here, Y_i is the actual emergy value and $\overline{Y_i}$ is the simulated value calculated through regression equation. The mean simulated error was estimated by following equation,

$$\bar{\mu} = \frac{\sum \mu_i f_i}{\sum f_i} \text{ (iii)}$$

Here, $\bar{\mu}$ is the mean simulated error, f_i is the frequency of the error μ_i. The $\bar{\mu}$ was added to $\overline{Y_i}$ to calibrate the final result following the method done by (Lei and Wang, 2008). After the simulated value was corrected, the final regression equation was applied in STELLA software to make a visual model and calculate emergy for next 25 years.

3.3 RESULTS AND DISCUSSION

3.3.1 Detailed emergy system and emergy flow of Nepal

A detailed emergy diagram of Nepal is presented in Figure 3.2. The rectangular box in the diagram represents the geographical boundary of Nepal. External energy sources that plays vital role in national metabolism are shown as circles and are arranged in order of increasing transformity from left to right around the system's boundary. The inflow and outflow of energy and matters in the system are shown by arrows. The emergy value of resources flow are tabulated in an emergy evaluation table (Table 3.1) with resource classification named as renewable resources, indigenous renewable resources, non-renewable resources, imports and exports. The random resource data were converted into solar emjoule (sej) through multiplying with its respective transformity value. An Emergy calculation for the year 2015 is provided in appendix.

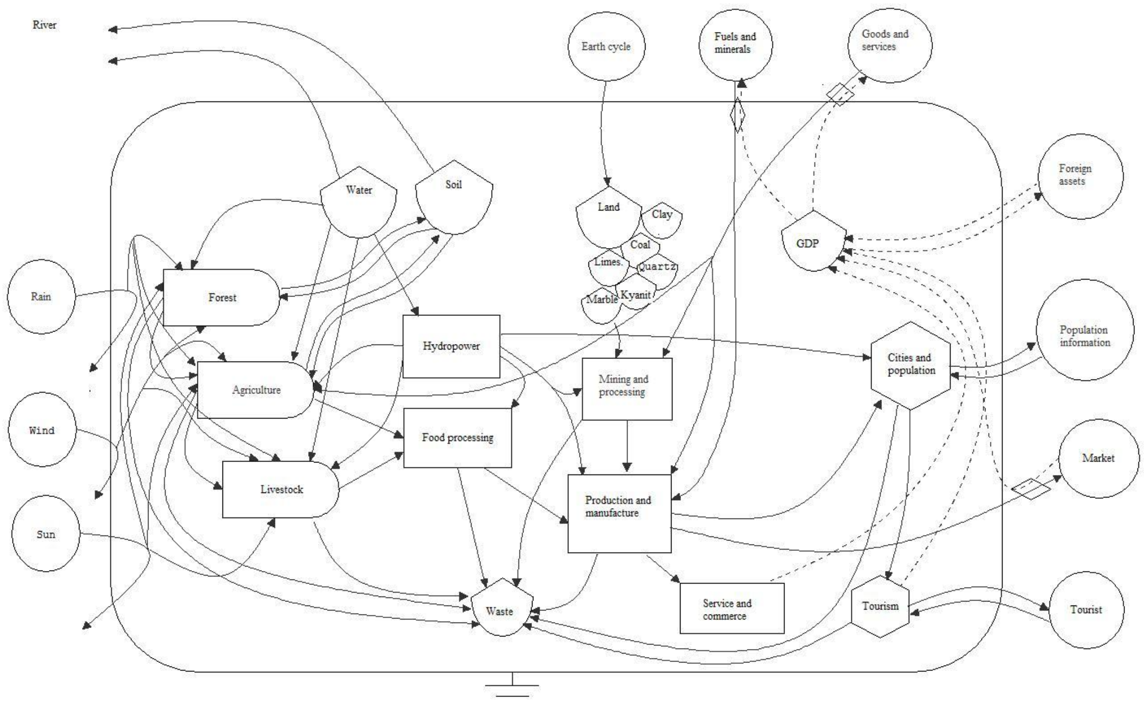


Figure 3.2: Detailed emergy diagram of Nepal

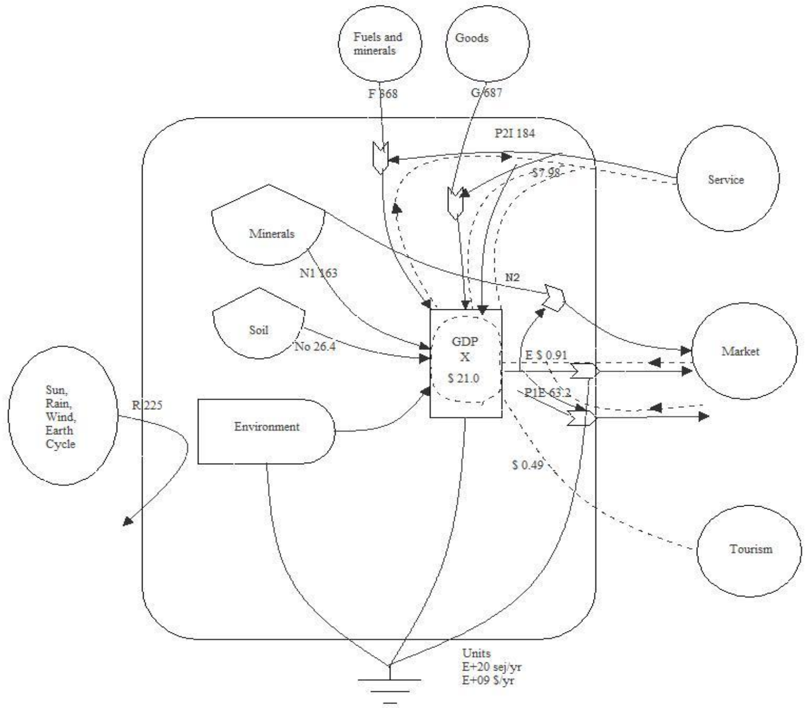


Figure 3.3: Aggregated emergy diagram

Table 3.1: Emergy evaluation of resource basis of Nepal (1998-2015) (notes for 2015, see Appendix A)

No.	Item	Years							
		1998	2000	2003	2007	2009	2012	2014	2015
	Renewable Resources (sej)								
1	Sun	1.79E+18	1.79E+18	1.79E+18	1.79E+18	1.79E+18	1.79E+18	1.79E+18	1.79E+18
2	Wind	5.04E+21	5.04E+21	5.04E+21	5.04E+21	5.04E+21	5.04E+21	5.04E+21	5.04E+21
3	Rainfall chemical	4.49E+20	4.49E+20	4.49E+20	4.49E+20	4.49E+20	4.49E+20	4.49E+20	4.49E+20
4	Rainfall geo-potential	3.33E+21	3.33E+21	3.33E+21	3.33E+21	3.33E+21	1.27E+22	3.33E+21	3.33E+21
5	Earth cycle	1.75E+22	1.75E+22	1.75E+22	1.75E+22	1.75E+22	1.75E+22	1.75E+22	1.75E+22
	Indigenous Renewable Resources (sej)								
6	Agriculture production	1.56E+22	3.24E+22	3.62E+22	4.31E+22	4.62E+22	5.50E+22	4.61E+22	5.54E+22
7	Livestock production	2.07E+22	1.83E+22	2.00E+22	7.22E+22	2.42E+22	2.84E+22	2.92E+22	2.95E+22
8	Fishery production	5.62E+20	3.06E+20	7.98E+20	1.03E+21	5.19E+20	1.22E+21	1.42E+21	1.52E+21
9	Fuel wood production	5.71E+18	4.21E+18	8.90E+18	2.93E+18	3.23E+18	8.72E+18	2.23E+19	6.16E+19
10	Industrial round wood production	1.91E+21	2.41E+21	3.90E+21	1.27E+21	2.19E+19	1.02E+20	1.04E+19	4.68E+18
11	Hydroelectricity production	7.78E+20	9.98E+20	2.10E+21	2.70E+21	1.84E+21	4.17E+21	3.35E+21	3.62E+21
12	Total electricity used	1.02E+21	1.27E+21	2.33E+21	3.13E+21	3.22E+21	5.07E+21	4.81E+21	5.15E+21
	Nonrenewable Sources from within system								
13	Top soil loss	1.66E+21	1.66E+21	7.36E+20	1.16E+21	2.62E+20	1.73E+20	2.64E+21	2.64E+21
14	Coal production	1.95E+19	3.31E+19	2.14E+19	3.19E+19	2.14E+19	1.83E+19	1.59E+19	2.32E+18
15	Non-metallic Minerals	4.14E+21	4.16E+21	2.96E+21	9.89E+19	4.93E+21	1.15E+22	3.21E+22	1.63E+22
	Imports (sej)								
16	Fuels	4.32E+21	5.72E+21	5.52E+21	4.89E+21	5.80E+21	7.36E+21	8.68E+21	9.55E+21
17	Metal imports	2.10E+20	9.16E+19	2.37E+20	4.57E+21	1.19E+22	2.20E+22	2.35E+22	2.17E+22
18	Non-metal products	9.41E+19	1.72E+20	1.06E+20	1.25E+21	2.63E+21	4.43E+21	5.28E+21	5.58E+21
19	Food and agricultural production	3.07E+20	2.10E+20	3.47E+20	3.86E+21	3.82E+21	7.61E+21	4.13E+21	8.52E+21
20	Livestock, meat, fish	2.47E+19	1.39E+19	2.80E+19	3.80E+22	4.46E+22	5.65E+22	6.22E+22	5.44E+22
21	Plastic and synthetic rubber	9.47E+19	4.76E+19	1.07E+20	1.35E+21	2.53E+20	3.62E+20	7.97E+20	4.87E+20
22	Chemicals	1.39E+20	1.68E+20	1.57E+20	9.90E+20	2.37E+21	1.53E+21	2.10E+21	2.19E+21
23	Finished products	3.82E+20	5.57E+20	4.32E+20	1.40E+22	3.89E+20	8.27E+20	2.56E+21	9.55E+20
24	Machinery and transportation equip.	3.03E+20	3.13E+20	3.43E+20	3.60E+21	1.18E+21	1.36E+21	3.11E+21	2.32E+21
25	Service in import	1.36E+21	1.86E+21	2.10E+21	3.61E+21	5.41E+21	7.66E+21	1.66E+22	1.02E+22
	Exports (sej)								
26	Metals	4.95E+20	6.51E+18	3.75E+20	7.72E+20	9.05E+20	7.70E+20	8.83E+20	1.46E+21
27	Non-metal products	8.96E+19	2.12E+19	6.80E+19	4.43E+17	1.49E+20	1.59E+21	1.06E+21	1.69E+18
28	Food and agriculture products	1.01E+21	2.22E+20	7.64E+20	6.76E+20	5.14E+20	1.38E+15	5.98E+20	6.36E+20
29	Livestock, meat , fish	9.02E+19	3.11E+20	6.84E+19	6.17E+21	9.60E+21	1.45E+22	1.45E+22	4.78E+20
30	Plastic and synthetic rubber	1.38E+20	1.81E+18	1.05E+20	2.23E+20	2.10E+20	2.53E+17	2.87E+20	2.23E+20
31	Chemicals	3.18E+20	4.23E+20	2.42E+20	6.89E+19	6.75E+19	8.80E+19	1.14E+20	1.16E+20
32	Finished products	2.68E+21	3.84E+21	2.04E+21	3.55E+21	2.89E+21	3.13E+18	3.79E+21	2.90E+21
33	Machinery and transportation equip.	2.04E+19	2.30E+19	1.55E+19	7.59E+19	1.88E+20	1.36E+18	5.07E+19	4.73E+19
34	Service in export	3.03E+21	4.84E+21	3.66E+21	8.05E+21	6.61E+21	6.79E+21	8.50E+21	6.32E+21
35	Tourism	1.13E+21	1.14E+21	7.56E+20	1.38E+21	3.12E+21	2.97E+21	4.45E+21	3.98E+21

Table 3.2**:** Summary of emergy flow in Nepal economy (1998-2015)

			Years							
Code	Item	Units	1998	2000	2003	2007	2009	2012	2014	2015
R	Renewable sources used	sej/yr	2.25E+22	2.25E+22	2.25E+22	2.25E+22	2.25E+22	2.25E+22	2.25E+22	2.25E+22
N	Total nonrenewable extraction	sej/yr	5.83E+21	5.86E+21	3.72E+21	1.29E+21	5.21E+21	1.17E+22	3.47E+22	1.89E+22
N0	Dispersed rural source	sej/yr	1.66E+21	1.66E+21	7.36E+20	1.16E+21	2.62E+20	1.73E+20	2.64E+21	2.64E+21
N1	Concentrated use	sej/yr	4.16E+21	4.19E+21	2.98E+21	1.31E+20	4.95E+21	1.15E+22	3.21E+22	1.63E+22
N2	Exported without use	sej/yr	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Fi	Imported fuels and minerals	sej/yr	4.63E+21	5.99E+21	5.86E+21	1.07E+22	2.03E+22	3.38E+22	3.74E+22	3.68E+22
Gi	Imported goods	sej/yr	1.25E+21	1.31E+21	1.41E+21	6.19E+22	5.26E+22	6.82E+22	7.19E+22	6.89E+22
I	Money paid for imports	$/yr	1.31E+09	1.56E+09	1.80E+09	3.14E+09	4.68E+09	6.28E+09	7.20E+09	7.98E+09
P2I	Imported services	sej/yr	1.36E+21	1.86E+21	2.10E+21	3.61E+21	5.41E+21	7.66E+21	8.84E+21	1.02E+22
Fe	Exported fuels and minerals	sej/yr	5.84E+20	2.77E+19	4.43E+20	7.73E+20	4.72E+21	2.36E+21	2.04E+21	1.46E+21
Ge	Exported goods	sej/yr	4.26E+21	4.82E+21	3.23E+21	1.08E+22	1.35E+22	1.46E+22	1.91E+22	4.40E+21
E	Money paid for exports	$/yr	4.09E+08	7.09E+08	6.50E+08	8.36E+08	7.70E+08	8.93E+08	9.01E+08	8.65E+08
P1E	Exported services	sej/yr	3.03E+21	4.84E+21	3.66E+21	8.05E+21	6.61E+21	6.79E+21	8.01E+21	6.32E+21
X	Gross domestic product	$/yr	4.80E+09	5.49E+09	6.33E+09	1.04E+10	1.24E+10	1.89E+10	1.98E+10	2.15E+10
P2	World emergy-money ratio	sej/$	1.03E+12	1.19E+12	1.17E+12	1.15E+12	1.16E+12	1.22E+12	1.23E+12	1.28E+12
P1	Nepal emergy-money ratio	sej/$	0.00E+00	6.83E+12	5.63E+12	9.62E+12	8.59E+12	7.60E+12	8.88E+12	7.31E+12
Area	Land area	m^2	1.47E+11	1.47E+11	1.47E+11	1.47E+11	1.47E+11	1.47E+11	1.47E+11	1.47E+11
POP	Population	people	2.21E+07	2.32E+07	2.45E+07	2.56E+07	2.65E+07	2.70E+07	2.75E+07	2.80E+07

Table 3.3: Summary indices for evaluation (1998-2015)

Name of Index	Expression	1998	2000	2003	2007	2009	2012	2014	2015
Renewable emergy flow (sej/yr)	R	2.25E+22	2.25E+22	2.25E+22	2.25E+22	2.25E+22	2.25E+22	2.25E+22	2.25E+22
Non-renewable emergy flow (sej/yr)	N	5.83E+21	5.86E+21	3.72E+21	1.29E+21	5.21E+21	1.17E+22	3.47E+22	1.89E+22
Total imported emergy (sej/yr)	$Fi+Gi+P_2I$	7.24E+21	9.15E+21	9.38E+21	7.62E+22	7.83E+22	1.10E+23	1.18E+23	1.16E+23
Total emergy used (U) (sej/yr)	$R+N_0+N1+Fi+Gi+P_2I$	3.56E+22	3.76E+22	3.56E+22	1.00E+23	1.06E+23	1.44E+23	1.75E+23	1.57E+23
Total exported emergy (sej/yr)	Fe+Ge+P1E+Tourism	9.00E+21	1.08E+22	8.09E+21	2.10E+22	2.79E+22	2.67E+22	3.34E+22	1.62E+22
Fraction of emergy use from indigenous sources (sej/yr)	$(N_0+N_1+R)/U$	7.97E-01	7.56E-01	7.37E-01	2.38E-01	2.62E-01	2.38E-01	3.26E-01	2.64E-01
Imports minus exports (sej/yr)	$(Fi+Gi+P_2I)-(Fe+Ge+P_1E+Tourism)$	-6.36E+20	-5.35E+20	2.05E+21	5.66E+22	5.35E+22	8.59E+22	8.90E+22	1.04E+23
Ratio of imports to exports	$(Fi+Gi+P_2I)/(Fe+Ge+P_1E+Tourism)$	1.21E+00	9.45E-01	1.28E+00	3.89E+00	3.16E+00	4.61E+00	3.54E+00	7.17E+00
Fraction used, locally renewable	R/U	6.33E-01	6.00E-01	6.33E-01	6.15E-02	2.12E-01	1.57E-01	1.28E-01	1.43E-01
Fraction of emergy use purchased	$(Fi+Gi+P_2I)/U$	2.03E-01	2.44E-01	2.63E-01	7.62E-01	7.38E-01	7.62E-01	6.74E-01	7.36E-01
Fraction of use that is free	(R+N0)/U	6.80E-01	6.45E-01	6.53E-01	2.37E-01	2.15E-01	1.58E-01	1.43E-01	1.60E-01
Ratio of concentrated to rural	$(Fi+Gi+P_2I+N_1)/(R+N_0)$	4.71E-01	5.51E-01	5.31E-01	3.22E+00	3.65E+00	5.33E+00	5.97E+00	5.25E+00
Emergy use per unit area (empower density) (sej/m^2)	U/A	2.42E+11	2.55E+11	2.42E+11	6.80E+11	7.21E+11	9.77E+11	1.19E+12	1.07E+12
Emergy use per capita (sej/person)	U/population	1.61E+15	1.62E+15	1.45E+15	3.90E+15	4.00E+15	5.33E+15	6.38E+15	5.61E+15
Nonrenewable emergy use per capita (sej/person)	N/population	2.63E+14	2.53E+14	1.51E+14	5.03E+13	1.96E+14	4.33E+14	1.26E+15	6.76E+14
Renewable carrying capacity at present living standard	(R/U)*(population)	14039383	13916174.5	15513803	5776437.2	5.64E+06	4.23E+06	3.53E+06	4.01E+06
Emergy-money ratio (sej/$)	P_1=U/GDP	7.4173E+12	6.8348E+12	5.6289E+12	9.62E+12	8.59E+12	7.60E+12	8.88E+12	7.31E+12
Electricity used per capita (sej/person)	Total electricity used/population	4.60E+13	5.48E+13	9.49E+13	1.22E+14	1.21E+14	1.88E+14	1.75E+14	1.84E+14
Fuel used per capita (sej/person)	Total fuel used/population	1.95E+14	2.47E+14	2.25E+14	1.91E+14	2.18E+14	2.73E+14	3.16E+14	3.41E+14
Emergy investment ratio (EIR)	$(Fi+Gi+P_2I)/(R+N_0+N_1)$	0.26	0.32	0.36	3.20	2.82	3.20	2.06	2.79
Environmental loading ratio (ELR)	$(N0+N_1+Fi+Gi+P_2I)/R$	0.58	0.67	0.58	3.44	3.71	5.38	6.79	5.98
Emergy yield ratio (EYR)	$U/(Fi+Gi+P_2I)$	4.92	4.10	3.80	1.31	1.35	1.31	1.48	1.36
Emergy sustainability index (ESI)	EYR/ELR	8.49	6.16	6.54	0.38	0.365	0.244	0.219	0.23

The dispersed emergy values of resources are then aggregated in emergy summary table (Table 3.2). Based on the emergy data in emergy summary table and the detailed emergy system diagram, the aggregated emergy diagram was constructed. The aggregated emergy diagram of the year 2015 is presented in Figure 3.3.

In the last seventeen years from 1998 to 2015, the total emergy use (U), sum of the indigenous sources produced inside the country plus imported emergy has increased by 342.13% from 3.56E+22 sej in 1998 to 15.7E+22 sej in 2015. The increment trend of the total emergy use was slow and steady until 2003. However, after 2007 it rose sharply (Figure 3.4). The slow and steady growth until 2003 was due to the political unrest and civil war in Nepal which ended in 2006. After the war, the economic activities (indigenous resource production, imports, exports, etc.) inside the county increased and also increased the total emergy use of the country. However, in 2015, the total emergy use decreased. This was due to the Gorkha-earthquake that hit Nepal in April 2015. Because of the earthquake, economic activities were affected, and this reduced the total resource production and consumption.

In total emergy use of Nepal, significant contributions come from indigenous sources. In 1998, the indigenous sources account for more than 78% in total emergy use. However, the contribution of indigenous resources in total emergy use decreased gradually in the following years and this was only 26% in 2015. In recent years, large amount of emergy inside the country comes from importation. Therefore, the contribution of the imported resources in the total emergy use of Nepal is increasing. In 2015, out of total emergy used, 74% came from importation.

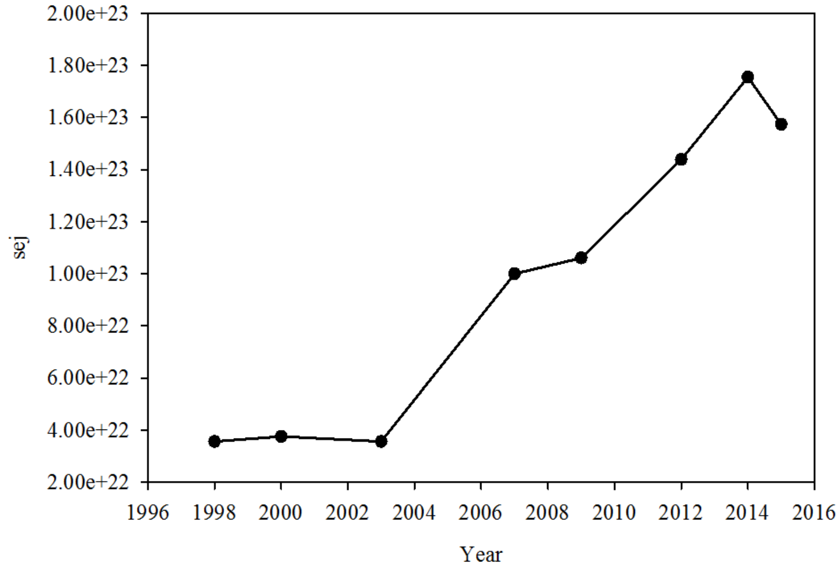


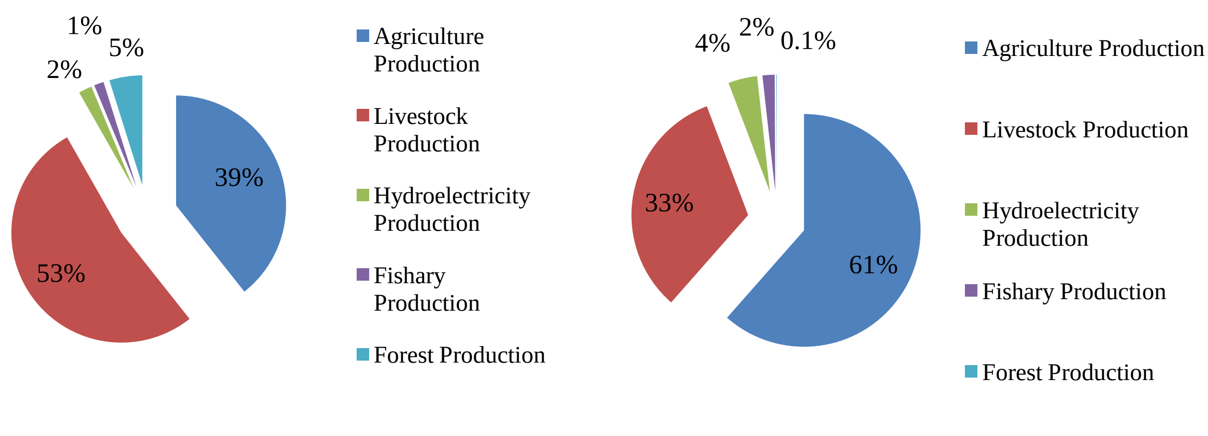
Figure 3.4: The trend of the GDP and the total emergy use (U) of Nepal from 1998-2015.

3.3.1.1 Renewable resources flow and production

Renewable emergy inflow includes the perpetual resource flow that can be utilized continuously free of cost such as solar radiation, rain water, wind and geological heat of the earth. In total emergy accounting, to avoid double counting, only two largest contributors are summed up (Brown and Ulgiati, 2004; Odum, 1996). In this research, the wind and the earth cycles were summed to determine the renewable emergy base and the average inflow value of all resources were applied in emergy calculation. As per our results, the total emergy of perpetual resources calculated for Nepal is 2.25E+22 sej.

Renewable resources production (also called indigenous resource production) in Nepal includes agricultural production, livestock production, fishery production, forestry and hydroelectricity production. The agricultural production was the largest indigenous resource production in Nepal followed by livestock production and hydroelectricity production respectively. In 1998, the emergy of total agricultural production was 1.56E+22 sej and this was increased by 72% and reached 5.54E+22 sej in 2015. Similarly, the emergy of livestock production and electricity production were 2.07E+22 sej and 7.78E+20 sej in 1998 and the productions increased to 2.95E+22 sej and 36.2E+20 sej respectively, until 2015.

The share of agricultural production in the total indigenous resources production was 53% in 1998 and this increased to 61% in 2015. But the share of the livestock production in the total production decreased to 33% in 2015 this was 39% in 1998. From 1998 to 2015, the import of livestock and meat products in Nepal from other countries increased by nearly two thousand folds (Table 3.1). Similarly, with the increase of the mega hydro-electricity projects in the last few years, the share of electricity in indigenous resource production has increased from 2 % to 4%. The share of the forest production has decreased from 5% in 1998 to below 1% in 2015 (Figure 3.5) which is mainly due to transition from use of biomass fuel to high energy fuels such as natural gas and electricity.



a. b.

Figure 3.5: Fraction of indigenous resources production in Nepal in different years, a. 1998 b. 2015

3.3.1.2 Non-renewable resource production

Non-renewable resources are the natural resources that are consumed faster than its regeneration rate. In Nepal, non-renewable resources production mainly includes the extraction of non-metallic minerals such as clay, kyanite, limestone, tourmaline, talk, marble and quartz. Some low-grade fossil fuels such as sub-bituminous coal are also extracted. In 2015, 1.19E+03 Mt of sub-bituminous coal was produced (MoF, 2015).

The yearly production of non-metallic minerals in Nepal show unusual trend over the study period (Figure 3.6). Until 2007, the resource production decreased from 4.16E+21 sej in 1998 to 1.31E+20 sej. However, after 2007, the production raised sharply with highest production in 2014, with emergy 34.7E+21 sej. This was six-fold higher productions than in 1998. In 2015, the production was decreased sharply. This was because of the Gorkha-earthquake that hit Nepal in April, 2015. After the earthquake mining activities were stopped by the government of Nepal and this reduced the total production of minerals.

The emergy of soil loss is yearly increasing in Nepal. In 1998, the emergy of soil loss was 1.66E+21 sej and this was increased by 1.56 fold in 2015 with emergy value of 2.64E+21 sej. Basically, lack of proper land management, cultivation in slope terrain causes massive washout of the top soil by water and wind in Nepal (Shrestha, 1997).

The use of fossil fuels such as petrol, diesel, natural gas, etc. and metallic minerals has increased very highly in Nepal (Figure 3.7). Nepal itself does not produce those resources inside the county. Therefore, resource demands are fulfilled through importation. India is the largest exporter of fuel and metallic minerals to Nepal (NOC, 2015). The use of fossil fuel rose from 4.32E+21 sej in 1998 to 9.55E+21 sej in 2015. Similarly, emergy of metallic minerals use increased from 2.36E+20 sej in 1998 to 2.17E+22 sej in 2015.

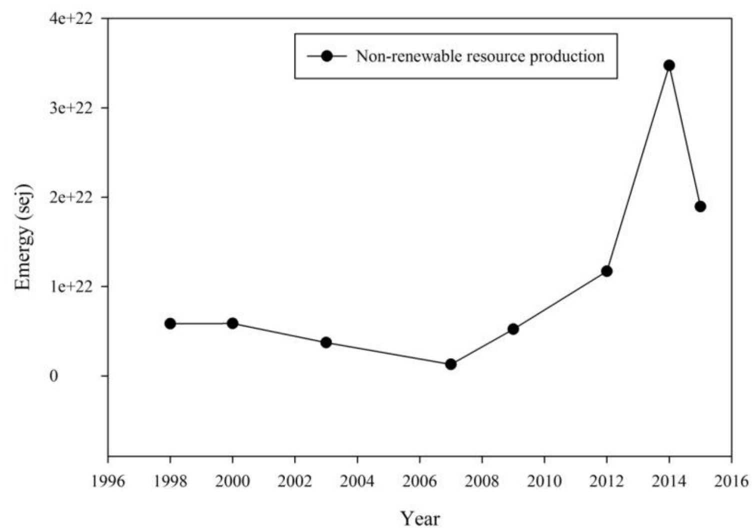


Figure 3.6: Trend of non-renewable resource production in Nepal (1998-2015)

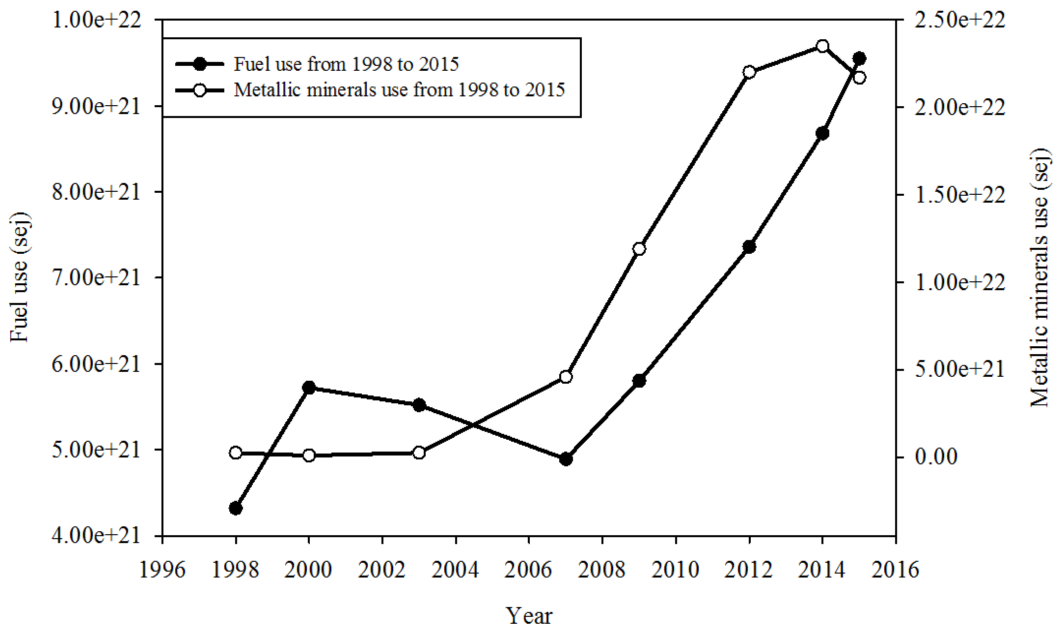


Figure 3.7 :Fuel use and metallic minerals use of Nepal from 1998 to 2015

3.3.1.3 Imports and exports

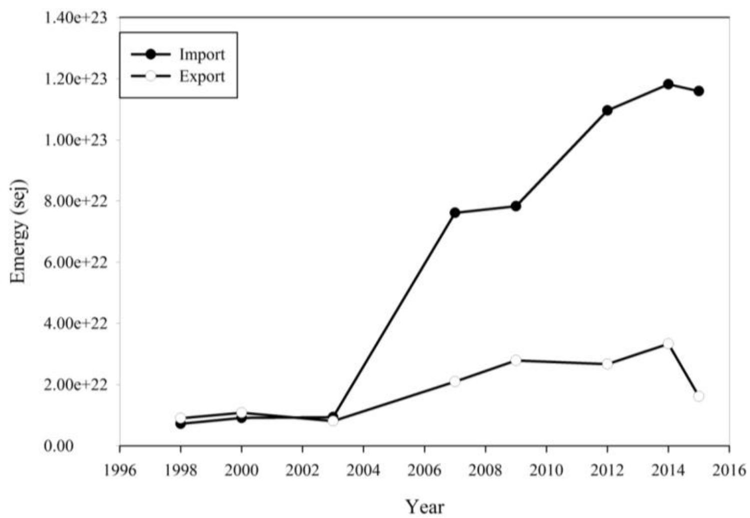
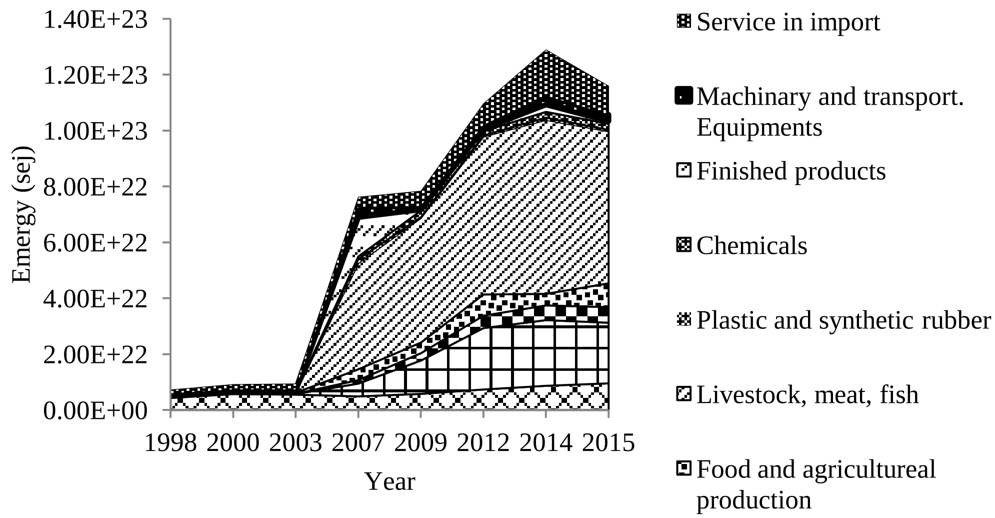
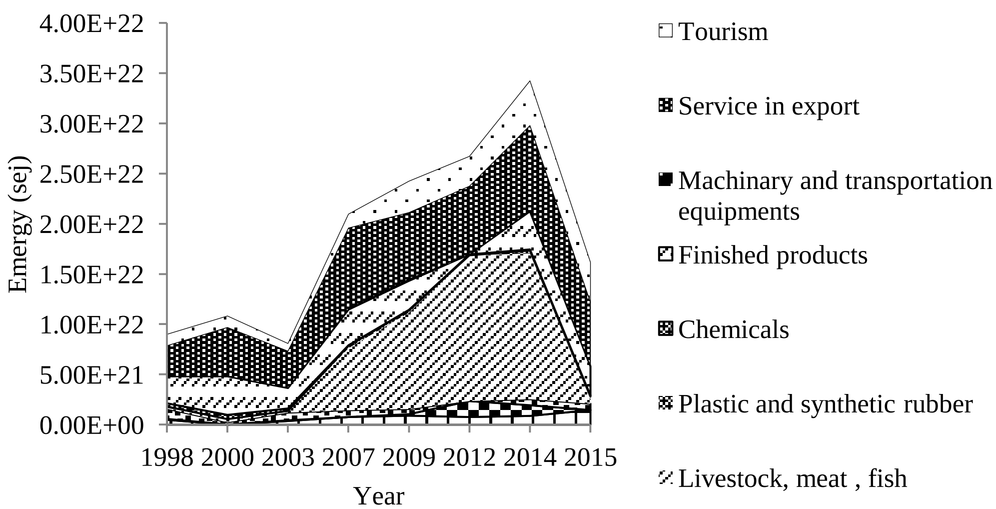


Figure 3.8: Import and export trend in Nepal

In Nepal, both the imports and exports have improved in the last seventeen years (Figure 3.8). From 1998 to 2015, the imports increased by 1425% from 7.60E+21 sej to 116.21E+21 sej, while the exports increased by 77.76% from 9.10E+21 sej to 16.20E+21 sej. Until 2003, the growth trend of the imports and exports was similar indicating balance of real wealth in the foreign trade. However, after 2003, the trade pattern of Nepal shifted with accelerated increase of the imports and decrease of the exports. In 2015, the imports and exports both were lowered due to the Gorkha-earthquake.



a.



b.

Figure 3.9: Resource import and export types and trend in Nepal. a. Import b. Export

The imports in Nepal mostly include agriculture products, livestock meat and fish products, metallic and non-metallic minerals, transportation and mechanical equipments and finished products (Figure 3.9a). Among all the imported resources, the livestock meat and fish products account for the largest share. The share of livestock meat and fish products rose from 2.78E+19 sej in 1998 to 5.44E+22 sej in 2015. The metal takes the second place after the livestock products, with a emergy value of 2.36E+20 sej in 1998 and 217.01E+20 sej in 2015. The service showed the quick and highest growth, and was followed by the machinery and transportation equipments and finished products respectively. The emergy of those imports in 2015 was: 1.36E+21 sej, 3.03E+20 sej, 3.82E+20 sej in 1998 and 1.02E+22 sej, 2.32E+21 sej, 9.55E+20 sej, respectively.

The trend of the exports from Nepal is shown in Figure 3. 9b. The livestock, meat and fish products shared the largest share in exportation and this is followed by the service and finished products. In the study period, the highest export from Nepal was achieved in 2014. In 2014, 1.45E+22 sej livestock and fishery products were exported and this was 42% of total exports. Similarly, the emergy of service and finished products were 8.01E+21 sej and 3.57E+21 sej, respectively. After the earthquake in 2015, the export of livestock and fishery products, service and finished products reduced by 96.70%, 21.09% and 18.76%, respectively.

Tourism is an important source of economic income in Nepal. In emergy accounting, tourism is accounted in export category because tourists coming from other countries use the international dollar to buy goods and enjoy the services (Jiang *et al.*, 2008). The income from tourism industry has increased in Nepal with 1.13E+21 sej in 1998 and 3.96E+21 sej in 2015. Tourism alone accounted for 25% of the total exports in 2015.

3.3.2 Analysis of emergy indices

3.3.2.1 Emergy use per capita

Emergy use per capita is considered as effective social indicator for analyzing the living standard and well-being than fuel and electricity use per capita, because this indicator integrates non-renewable and renewable resources use that is not included in other social indicator (Brown and Ulgiati, 2004; Odum *et al.*, 1997; Yang *et al.*, 2010). The emergy use per capita of Nepal in 1998 was 1.61E+15 sej and increased to 5.61E+15 sej in 2015 (Figure 3.10). With the increase of population the emergy use per capita has also increased. The highest emergy used per capita was achieved in 2014 with emergy value 6.38E+15 sej but in 2015 the value dropped due to the great Gorkha earthquake.

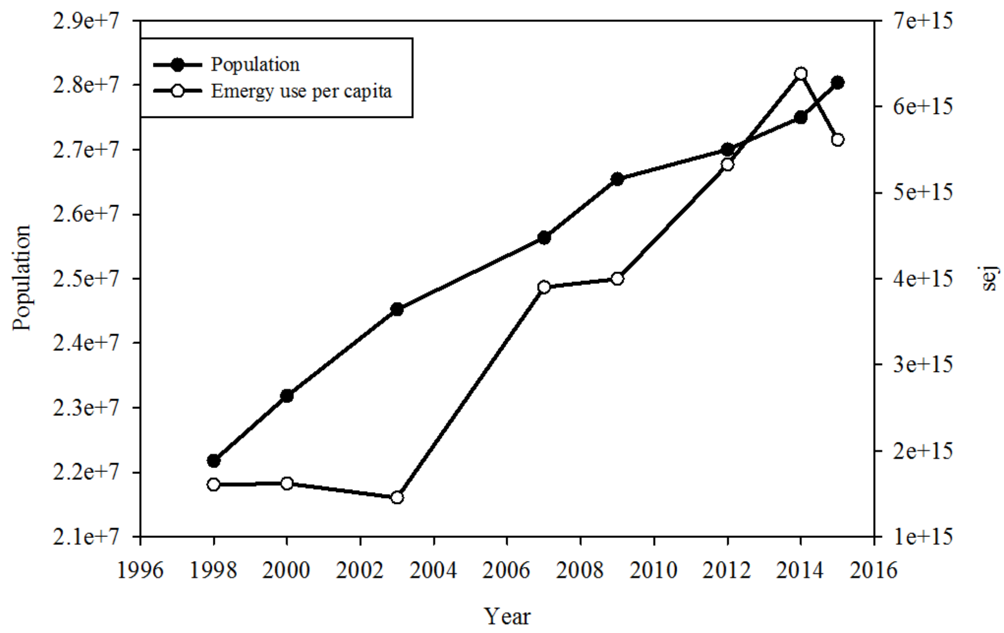


Figure 3.10: Emergy use per capita of Nepal from 1998 to 2015

3.3.2.2 Emergy money ratio (EMR)

EMR is the ratio of total emergy use to gross domestic product (GDP) of a country. Country that use higher quantity of free environmental resources without money exchange have higher EMR value (Odum, 1996). Mostly developing countries use large quantity of free environmental resources thus they have higher EMR value than the developed countries. The EMR of Nepal decreased from 1998 to 2015. The lowest EMR was in 2003. 5.63E+12 sej/$ (Figure 3.11). Time series emergy analysis of different countries shows the decreasing trend of EMR value (Ferraro and Benzi, 2015; Liu *et al.*, 2011; Yang *et al.*, 2010; Zhang *et al.*, 2011b). This also explains the purchasing power of money (dollar) is decreasing. Before, more resources could be bought per dollar spent than today.

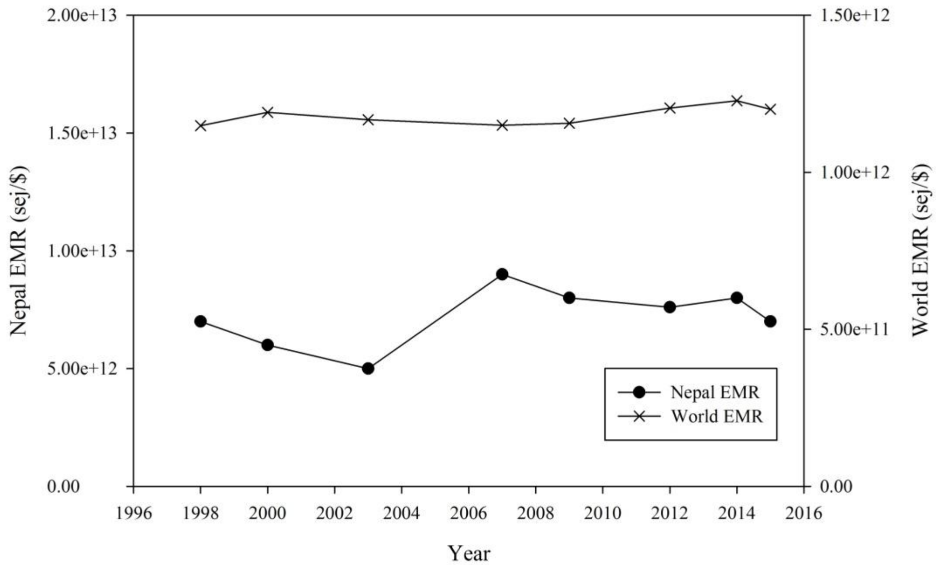


Figure 3.11: Trend of emdollar ratio of the world and Nepal

3.3.2.3 Foreign trade and emergy exchange ratio (EER)

The trade status of a country is explained by EER. EER is the ratio of emergy received by a country during import to emergy given in export (Haitao and Brown M, 2017; Zhu *et al.*, 2012). The EER greater than 1.0 indicates positive trade with higher exports than the imports. For sustainable trade, the EER should always be greater than 1.0. The EER of Nepal was greater than 1.0 until 2003, which explains the exports was larger than import. However after 2003, the EER is below 1.0, indicating negative trade or more resources being imported than exported. The EER value has decreased gradually to 0.14 in 2015. In 1998, 1.77E+21 sej more resources were exported than the total import but in 2015, 99.80E+21 sej more resources were imported compared to being exported (Figure 3.12). This shows the trade imbalance and deficit in Nepal.

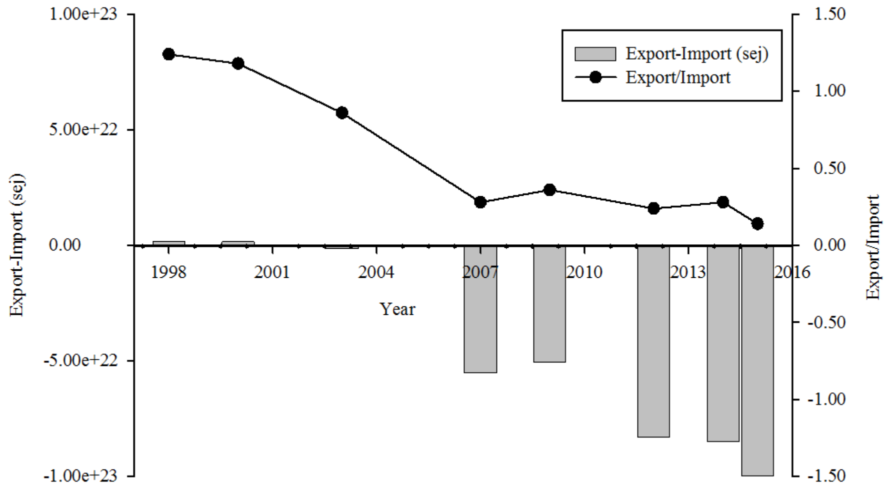


Figure 3.12: Trade and emergy exchange ratio of Nepal.

3.3.2.4 Emergy investment ratio (EIR)

EIR is the aggregate index of purchased emergy and indigenous input emergy (both renewable and non-renewable). It is the quotient of the purchased emergy from outside the system to the indigenous emergy input (Table 2.4). This is an important indicator that evaluates the dependence of country on external investment for resources. The higher value of EIR suggests the higher economic activities. The countries strongly dependent on the global economy for resources acquisition have large EIR value (Brown and Ulgiati, 2004; Ulgiati *et al.*, 1995). The developed countries like Japan, Sweden, Switzerland, Netherlands and Italy are very much dependent on other countries for the resources because of few resources available in their country so they have high EIR values. The EIR of Nepal has increased gradually from 0.26 in 1998 to nearly 3.0 in 2015 (Figure 3.13). The increasing EIR suggests that, the economy of Nepal is more dependent on other countries for resources demand and the internal production has decreased gradually in last few years.

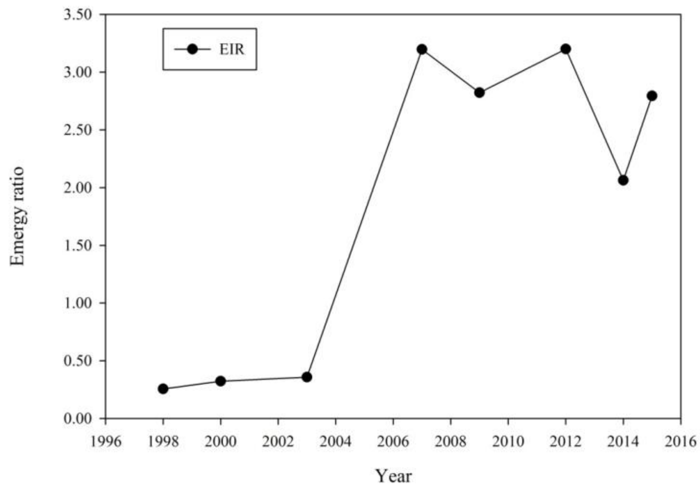


Figure 3.13: Trend of EIR in Nepal

3.3.2.5 Emergy yield ratio (EYR) and emergy loading ratio (ELR)

EYR of a country is calculated by dividing total emergy supporting an economy from all sources, locally available and imported by the imported emergy (Odum, 1996). This index measures how successfully a country has exploited and used its the resources present within its boundary and also made them available to the economy. The lowest possible value of EYR is 1.0 and this indicates the resources extraction and its use are not providing a significant emergy to the economy and that the economy is dominated by imported emergy (Brown and Ulgiati, 2004; Londoño *et al.*, 2014). Before 2007, the EYR of Nepal was significantly higher than 1.0, with largest EYR in 1998, 4.73. This explains, before 2007, most of the resources were produced and transformed inside the country with potential additional contribution to the economy and the dependence for resources with other countries was lower. However, after 2007, the EYR has decreased gradually with lowest EYR 1.3. This indicates, after 2007, the indigenous resources production in Nepal decreased whereas the imports of resources increased.

ELR on the other hand measures the pressure exerted on environment to absorb impacts due to the economic activities and resource use intensification (UNEP, 2012). The ELR also measures the indirect environmental pressure on local ecosystem due to the importation of energy and materials that are not indigenous (Ulgiati and Brown, 1998). It is calculated by dividing non-renewable and imported emrgy use of a country by its total renewable emergy use (Brown and Ulgiati, 2004). The higher the fraction renewable emergy use by a counry the lower the ELR. Generally, the ELR value between 3 and 10 describe the moderate environmental impact, while a value greater than 10 indicates a higher environmental impact (Brown and Ulgiati, 2004). The ELR of Nepal was significantly low before 2003. However, afer 2007, the ELR increased from 3.44 to 5.96 in 2015. Mostly, the imports of fossil fuels and metallic minerals have increased in Nepal in the last few years and this also increased the ELR.

The relationship of EYR and ELR helps to understand the sustainability of a country. Country that has the trend of higher EYR and lower ELR is sustainable (Zhu *et al.*, 2012). Until 2003, the economy of Nepal was sustainable because the EYR was higher and ELR was low (Fig. 12). However after 2003, the growth trend of EYR and ELR is reverse with lower EYR and higher ELR. Therefore the economic growth of Nepal is not sustainable.

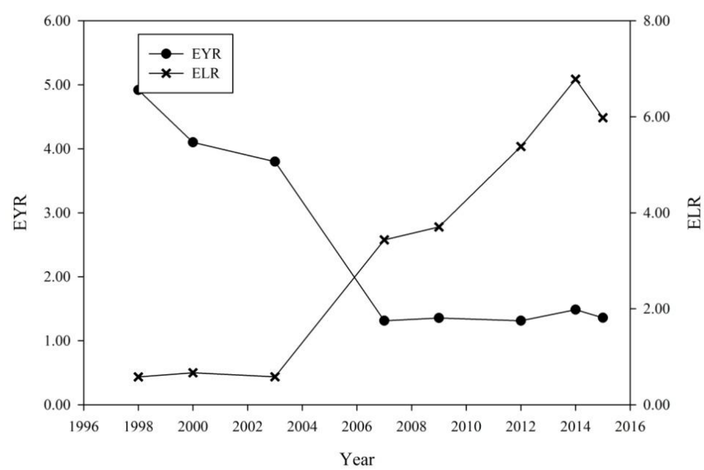


Figure 3.14: Trend of EYR and ELR of Nepal from 1998-2015

3.3.2.6 Emergy sustainability index (ESI)

ESI is an important sustainability index that evaluates the sustainability of an economy. It is the ratio of EYR and ELR and states that the objective of sustainability is achieved by minimizing environmental load with high potential yield (Odum, 1996). A country with ESI greater than 1.0 is comparatively sustainable and ESI below 1.0 indicates consumer-oriented economy and relies more with neighbor countries for resource fulfillment (Brown and Ulgiati, 2004; UNEP, 2012). The ESI of Nepal was higher than 1.0 before 2003. In 1998, the ESI of Nepal was 7.95 indicating the economy of Nepal was highly sustainable. However, after 2007, this has decreased below 1.0 with lowest ESI, 0.21 in 2014. Before 2003, the contribution of renewable fraction (% renewable) in total emergy use was high (Table 3) and the import of non-renewable resources was low. Thus, the environment load was lower. After 2007, the contribution of renewable fraction decreased and the import and use of non-renewable resources increased simultaneously. This increased the ELR and decreased the ESI of Nepal. Mostly after 2007, the economy of Nepal was inclined towards the consumer economy with less resources production inside the country and more dependent to other countries for resources.

3.3.3 Comparison of emergy indices calculated by NEAD and this research for the year 2000

Table 3.4 shows the comparision of socio-economic and environmental indices (EIR, EYR, ELR and ESI) calculated by NEAD and this research for the year 2000. The emergy indices calculated by NEAD generally shows different results compared to the emergy indices calculated through authentic data of the respective country (Harizaj, 2010). In 2007, Harizaj (2010) calculaed the emergy of Albania and compared it with the emergy indices calculated by NEAD. The data in this research for emergy calculation were collected from authentic government institutions. The emergy indices thus calculated showed different results to the NEAD. All the emergy values of the NEAD were significantly larger than the real value (Harizaj, 2010). Similarly, the emergy of renewable resources, non-renewable resources, imports, exports, etc. calculated by NEAD for Nepal in 2000 shows different results to this research. For the comparison, important emergy indices calculated by NEAD and this research are presented in table 3.4. The emergy indices are calculated based on the flows of renewable resources (e.g. sun, wind, rain, etc.), non-renewable resources (e.g. metallic and non-metallic minerals, fossil fuels), import and export of raw minerals, agricultural products, fibers, equipments and machinery, labor and services, exchange of money, etc. inside a system. Therefore, for complete emergy assessment, the real data developed by an authentic institute inside the country is essential. The general global data are mostly available in monetary value (such as imports, exports, purchased services, etc) which utilized in the NEAD. But the emergy evaluation of a country only through monetary value may exaggerate the results. Therefore, emergy calculation in other physical units such as mass and energy can well define the emergy indices which is done in this study. The transformity value used in the emergy calculation also sometime affects the results. However, the results of the NEAD could still be utilized as the reference value such as a basis for the direction of the research and its results could be appropriately evaluated.

Table 3.4: Emergy indices calculated by NEAD and this research for 2000

Emergy indices	NEAD	This research
EIR	0.32	0.67
EYR	4.13	4.10
ELR	0.83	0.67
ESI	5.0	6.0

3.3.4 Simulation result analysis

Based on emergy parameters calculated in the last seventeen years, simulation of those parameters was done for next 25 years. Table 3.4 shows the detail of curve regression models and simulation done. Table 3.4a shows the correlation between dependent and independent variables. For convenient to explain further calculation procedure, here only one emergy parameter i.e. electricity use per capita is illustrated. The electricity use per capita showed the close relationship with the population (r=0.97). Using population as independent variable, nine different regression curve models are developed as shown in Table 3.4b. Based on the criteria, the model should be logical with high goodness of fit (R^2 value) we choose logarithmic model for further analysis and simulation. The simulated results of electricity use per capita and the error analysis are shown in Table 3.4c. To prove that the simulated value resembles the real value two tailed t-test was performed between the real value and the simulated value. The result shows the real per capita electricity use value was not significantly different from simulated value (P= 0.736; two tailed t-test). This proves that, the logarithmic model provides realistic simulation.

Similar procedure was applied to all the emergy parameters. The Table 3.4d shows the results for all other emergy parameters. In the table 3.4d, the first column presents the correlation coefficient value of individual emergy parameter with year or population. The fourth column is the curve regression model chosen for simulation. The column six is the calibrated value calculated following the equation (iii). Table 3.5 is the final regression equation of different emergy parameters. Those equations were applied in STELLA software for simulation.

Table 3.5: (a) Pearson's correlation coefficient (b) Regression models with R^2 value, this table is for electricity use per capita, population as independent variable (C) the error analysis for real and simulated value from 1998 to 2015 (d) correlation coefficient, regression parameters, regression models and calibration values of different emergy parameters.

(a)

Pearson's correlation coefficient		
Emergy category	year	Population
Import emergy	0.97	0.94
Export emergy	0.76	0.75
non-renewable resources	0.6	0.60
electricity per capita	0.92	0.97
Fuel use per capita	0.74	0.76
Emergy per money ratio	0.157	0.150
Total emergy (U)	0.97	0.93

(b)

	Model Summary					Parameter		
Regression Models	R Square	F	df_1	d.f.	Significance level	b_0	b_1	b_2
Linear	0.941	94.959	1	6	0	-5.40E+14	2.60E+07	
Logarithmic	0.934	85.179	1	6	0	-1.09E+16	6.47E+14	
Inverse	0.926	75.078	1	6	0	7.55E+14	-1.61E+22	
Quadratic	0.949	46.226	2	5	0.001	4.36E+14	-5.22E+07	1.556
Compound	0.962	149.861	1	6	0	1.67E+11	1	
Power	0.965	167.735	1	6	0	8.00E-34	6.365	
Sigmodial	0.967	178.571	1	6	0	38.58	-1.59E+08	
Growth	0.962	149.861	1	6	0	25.844	2.54E-07	
Exponential	0.962	149.861	1	6	0	1.67E+11	2.54E-07	

(c)

		Electricity per capita		Errors terms		
Year	Population	real value (sej/j)	Simulated value (sej/j)	Errors	Errors/real value	Errors/simulated value
1998	2.22E+07	4.60E+13	3.43E+13	1.17E+13	0.25	0.34
2000	2.32E+07	5.48E+13	6.05E+13	-5.70E+12	-0.10	-0.09
2003	2.45E+07	9.49E+13	9.52E+13	-2.88E+11	0.00	0.00
2007	2.56E+07	1.22E+14	1.24E+14	-1.88E+12	-0.02	-0.02
2009	2.65E+07	1.21E+14	1.48E+14	-2.61E+13	-0.21	-0.18
2012	2.75E+07	1.85E+14	1.72E+14	1.30E+13	0.07	0.08
2014	2.70E+07	1.78E+14	1.59E+14	1.90E+13	0.11	0.12
2015	2.80E+07	1.84E+14	1.86E+14	-2.50E+12	-0.01	-0.01
				9.05E+11	0.01	0.03

(d)

Emergy category	Correlation coefficient	Independent variables	Curve model	Regression coefficient	Calibrated value	t-test
Electricity use per capita	0.92	Population	Linear	0.94	9.05E+11	pass (0.9)
Import emergy	0.97	Year	Linear	0.94	-1.62E+19	pass (0.9)
Export emergy	0.76	Year	Growth	0.63	2.27E+21	pass (0.9)
Non-renewable emergy	0.66	Year	Quadratic	0.71	6.03E+20	pass (0.9)
Total emergy (U)	0.96	Year	Growth	0.92	3.95E+19	pass (0.9)
Fuel use per capita	0.76	Population	Quadratic	0.61	4.73E+12	pass (0.8)
EMR	0.21	Year	Growth	0.23	4.87E+11	pass (0.8)

Table 3. 6: Regression equation used to simulate further temporal changes in Nepal emergy from 2015 to 2040

Regression equations used to simulated future emergy trends	
Emergy category	Simulation equations
Imported emergy	7.52E+21×(year-1990)+(-6.42E+22)
Exported emergy	Exp(49.9+0.069×year-1990)
Non-renewable resources	3.83E+22+(-5.47E+21×year-1990)+(1.99E+20×year×year)
Electricity use per capita	5.40E+14+2.59E+7×population
Fuel use per capita	4.17E+15+(-3.33E+8×population)+(6.98×population×population)
Emergy per money ratio	Exp(29.50+0.8/year)
Total Emergy use (U)	Exp(50.931×0.106×year)

Figure 3.15 is the analytical diagram developed using the STELLA. Here each emergy parameters are interrelated with each other. The top rectangle represents the population dynamics of Nepal. The arrow shows the inflow and outflow in population structure, that affects the population size. The birth increases the population whereas the death decreases the population. The crude birth rate of Nepal is 22 per thousand and the crude death rate is 7 per thousand (GoN, 2016). The regression equation of each emergy parameters presented in Table 3.5 was applied to develop the model and calculate the emergy value for next 25 years. The Figure 3.16 is the graphical presentation of emergy parameters growth trend from 2015 to 2040. Table 3.6 lists the predicted emergy parameters for 2040 and comparison with 2015 (predicted emergy values of all years are presented in Annex).

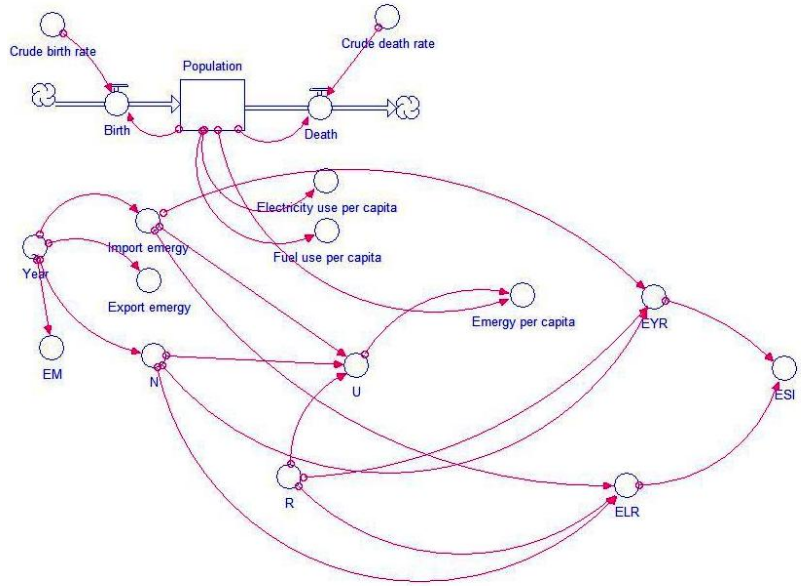


Figure 3.15: Simulation variables and their relationship

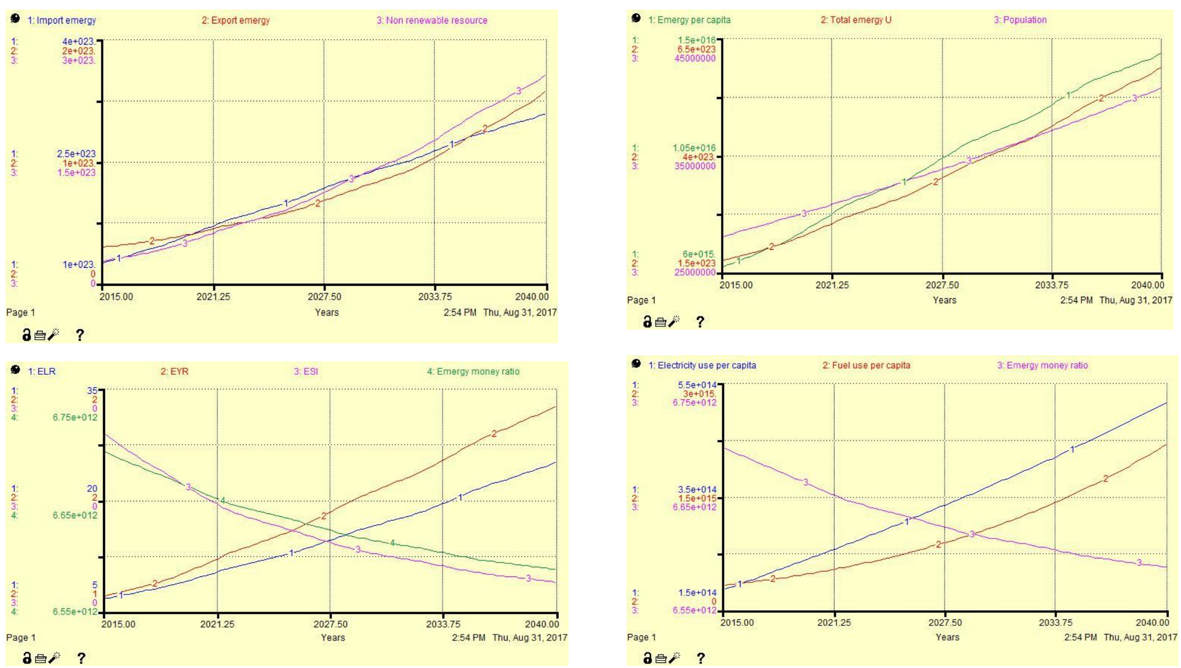


Figure 3.16: Prediction of emergy parameters trends for Nepal from 2015 to 2040 using STELLA model (a) import, export and non-renewable resource extraction (b) Emergy per capita, total emergy and population (c) Electricity per capita, Fuel per capita and EMR (d) ELR, EYR and ESI

As per calculations, in 2040 the population of Nepal will be approximately 4.07E+7. The total emergy use (U) will be increased by five fold, 5.87E+23 sej. This will also increase per capita emergy use. The per capita emergy use will reach 1.44E+16 sej in 2040. The extraction of non-renewable resources will increase 14 fold than 2015, 2.56E+23 sej. The trade data shows the export will increase by 9.71 times and import will increase by 2.66 times and reach 1.57E+23 sej and 3.09E+23 sej respectively. However, the trade loss will be prevalent. The trade loss in 2040 will be around 1.52E+23 sej. The trade loss in 2015 was 9.98E+22 sej. Therefore, trade loss will rise by 1.52 times in 2040. Each emergy parameters shows the increased trend but the EMR showed the opposite trend. The EMR will decrease to 6.59E+12 sej/$ in 2040. In 2015 this was 7.31E+12 sej/$. The lowering EMR indicates the inflation will rise up. The inflation will rise up by 10% in next 25 years.

The EYR will increase to 1.90 due to increasing economic activities. But this will also increase load to environment. The exploitation of natural resources will also increase the strain to environmental. The ELR value will reach nearly 25 in 2040. Similarly, the ESI, the ratio of EYR and ELR will decrease to the lowest, 0.10. This suggests that the resource production and consumption in Nepal in the coming year will be very unsustainable, thus increase the probability of environmental disasters.

Table 3.7: Comparisons of temporal change of emergy parameters in 2015 and 2040

Items	2015	2040	Ratio of emergy (2040 to 2015)
Population	2.80E+07	4.07E+07	1.45
Electricity use per capita (sej/person)	1.84E+14	5.14E+14	2.80
Fuel use per capita (sej/person)	3.41E+14	2.18E+15	6.40
Emergy use per capita (sej/person)	5.61E+15	1.44E+16	2.57
Export emergy (sej/yr)	1.62E+22	1.57E+23	9.71
Import emergy (sej/yr)	1.16E+23	3.09E+23	2.66
Emergy money ratio (sej/$)	7.31E+12	6.59E+12	0.90
Non-Renewable res. emergy (sej/yr)	1.89E+22	2.56E+23	13.52
Total emergy (U) (sej/yr)	1.57E+23	5.87E+23	3.73
ELR	5.98	25.10	4.19
EYR	1.36	1.90	1.40
ESI	0.23	0.1	0.33

3.4 CONCLUSIONS AND POLICY SUGGESTION

The sustainability assessment of Nepal was done through the emergy method. All heterogeneous environment and economic data were unified in solar emergy joule (sej) and analyzed. The results show, that the economy and well being of people in Nepal have improved greatly in the last seventeen years. The total emergy use of Nepal increased from 3.56E+22 sej in 1998 to 1.57E+23 sej in 2015. Similarly, the emergy use per capita has also increased from 1.61E+15 sej in 1998 to 5.61E+15 sej in 2015. The result of the last eight years of studied period from 2007 to 2015 shows the extensive results. All the emergy parameters showed the increased trends. This was the period after the civil war in Nepal. After the end of civil war in Nepal in 2006, the economic activities were boosted up. The internal and external investments were raised to establish new industries. This also increased the imports of non-renewable resources from other countries. Before the civil war imports and exports were in balanced. However, after 2007, imports exceeded the exports. The negative balance in trade increased the trade debt of Nepal. The trade debt was 1.04E+23 sej in 2015. The simulation revealed that the trade debt will be increased by two folds in the coming decades until 2040.

Similarly, the series of emergy indices such as EYR, ELR, and ESI explained that Nepal was highly engaged towards the use of non-renewable resources in the last few years. Thus, this also increased the pressure on the environment. The forecast showed that in next 25 years, the environmental load will be increased by four folds with high probability of environmental disasters in the future. To overcome an environmental problem, long term economic growth and improve social well-being of people in Nepal the following sustainable policies are recommended in term of non-renewable resource extraction, trade, soil erosion control and renewable resources use:

3.4.1 Non-renewable resources extraction and refinement policy

From 1975 to 1980, systematic and detailed minerals exploration done by Mineral Exploration Development Board of Nepal and United Nation Development Program (UNEP) discovered the presence of many useful mineral deposits in Nepal such as iron, manganese, chromite, nickel, copper, zinc, etc. (Kansakar et al., 1986). However, the systematic and scientific extractions of these minerals are not done yet. Therefore, such minerals should be extracted and utilized. This will decrease the import of non-renewable resources. Furthermore, this will also create new job opportunities in mining sites inside the country. In the long run, due to the reduction of imports of non-renewable resources, this will help to lower the trade deficit which is rising sharply in the last few years.

Similarly, instead of exporting raw minerals from the country, the export of final products (processed final mineral products) should be encouraged because raw minerals has large emergy and its exchange for foreign currency convey large emergy with less amount of money and this work against long-term sustainability and economic well-being of a country, (Ferreyra and Brown, 2007; Giannetti et al., 2013; Odum, 1996; UNEP, 2012).

3.4.2 Sustainable trade policy

As per our findings, Nepal has a negative trade balance. In 2015, Nepal's trade ratio (import emergy to export emergy) was 7:1, i.e. the import emergy was seven times higher than the export emergy. Therefore, Nepal should develop new trade policy to reduce trade emergy loss. The careful analysis of national EMR and global EMR can support in trade policy development and reduce trade loss (Ferreyra and Brown, 2007). EMR is the ratio of total emergy use (U) to the GDP of a country. A country with high EMR is in competitive disadvantage when trading is done with a country with low EMR (Ferreyra and Brown, 2007). If the resources are imported from the country with low EMR, few quantities of resources could be imported per money spent. On the other hand, if the resources are imported from the country with higher EMR, more resources could be imported with the same amount of money spent (UNEP, 2012). For instance, Nepal mostly imports resources from India and China. The EMR of India is 11.3E+12 sej/$ (Giannetti et al., 2013) and EMR of is 5.87E+12 sej/$ (Yang et al., 2010). The EMR of India is 1.92 times higher than that of China. Hence, Nepal should import resources from India instead of China. This is because more resources could be imported from India with same amount of money spent with China.

3.4.3 Soil erosion control policy

The intensity of soil erosion in Nepal has largely increased in last few years. The emergy of soil erosion was 1.66E+21 sej in 1998 and increased to 2.64E+21 sej in 2015. The soil loss was worth 3.61E+08 US$ in 2015. The emergy of soil loss accounted, nearly 14 % to the total indigenous non-renewable resource extraction in 2015 with no contribution to national economy. Therefore, the soil erosion accounts for no benefit in national economy but show an increment in total emergy use without positive inputs. On the other hand, soil loss reduces the soil fertility and huge quantity of chemical fertilizer is needed to be imported each year. In 2010, 4.09E+05 metric tons of chemical fertilizers was imported to Nepal (Takeshima et al., 2016) which also increased the trade debt. Thus, the soil erosion has the large hidden cost to the country. The control of soil erosion (conservation of top soil) will improve the agriculture production and reduce the import of chemical fertilizers. This finally increases the EYR of the country, reduce the ELR and improve ESI.

3.4.4 Promote the use of renewable resources

Renewable energy resources (solar, wind, wave, geothermal, hydro-electricity, etc.) are also called clean energy that induce insignificant environmental impacts. The use of clean energy will help to solve the problems of environmental impacts that are produced due to the extensive use of non-renewable fossil fuels (coal, petroleum products, etc.). In seventeen years, % renewable, the ratio of renewable resources use to the total emergy use of Nepal has decreased very quickly. In 1998, %renewable of Nepal was 63% and this decreased to 14% in 2015. A country with high %renewable is sustainable in the long run (Brown and Ulgiati, 1997; Jiang et al., 2008). Therefore, Nepal should promote the use of renewable energy to reduce the environmental load.

Nepal is rich in water resources with big river networks. These rivers have a very high potential for hydro-electricity production. Nearly 50,000 MW is estimated to be technically and economically feasible to produce the electricity through these perennial rivers. Unfortunately, only 900 MW electricity is produce in Nepal currently (Alam et al., 2017). Therefore, Nepal should accelerate the production of hydro-electricity. Similarly, there are other potential options of renewable energy sources such as solar energy, wind energy, etc. The incentive policy in renewable energy can further support the use of renewable energy both at a local and regional level within Nepal.

If the use of renewable energy is increased by 40%, the import of petroleum fuel is decreased by 10% and the use of non-renewable minerals is decreased by 30%, the ELR can be reduce to 14 until 2040 (Appendix D). Thus, the public and government should consider the benefits of renewable energy use.

REFERENCES

Björklund, J., Geber, U., Rydberg, T. (2001). Emergy analysis of municipal wastewater treatment and generation of electricity by digestion of sewage sludge. *Resources Conservation & Recycling,* **31** (4), 293-316.

Brown, M.T., Ulgiati, S. (1997). Emergy-based indices and ratios to evaluate sustainability: Monitoring economies and technology toward environmentally sound innovation. *Ecol. Eng.,* **9** (1), 51-69.

Brown, M.T., Ulgiati, S. (1999). Emergy evaluation of the biosphere and natural capital. *Ambio*, 486-493.

Brown, M.T., Ulgiati, S. (2004). Emergy analysis and environmental accounting. *Encyclopedia of Energy*,, **2,** 329-354.

Campbell, D. (1998). Emergy analysis of human carrying capacity and regional sustainability: An example using the State of Maine. An International Journal Devoted to Progress in the Use of Monitoring Data in Assessing Environmental Risks to Man and the Environment, **51** (1), 531-569.

Campbell, D.E., Garmestani, A.S. (2012). An energy systems view of sustainability: Emergy evaluation of the San Luis Basin, Colorado. *J. Environ. Manage.*, **95**,(1), 72-97.

CBS (2015). Nepal in figures, 2015, Central Bureau of Statistics, National Planning Comission secretrait, Government of Nepal.

CIA (2017). Nepal economy 2017, the world factbook 2017, accessed september, 2017 at: https://www.Cia.Gov/library/publications/the-world-factbook/

Costanza, R., Gottlieb, S. (1998). Modelling ecological and economic systems with STELLA: Part ii. *Ecol. Modell.*, **112** (2), 81-84.

Costanza, R., Voinov, A. (2001). Modeling ecological and economic systems with STELLA: Part iii. Elsevier.

DHM (2015). Study of climate and climatic variation over nepal, Government of Nepal, Ministry of Science Technology and Environment, Department of Hydrology and Meteorology.

Einsiedel, S.V., Salih, C. (2017). Conflict prevention in Nepal: Background paper for the United Nations- World Bank flagship study on the prevention of violent conflict. United Nations Univerisy Centre for Policy Research. Conflict prevention series: No. 1.

Ferraro, D.O., Benzi, P. (2015). A long-term sustainability assessment of an Argentinian agricultural system based on emergy synthesis. *Ecol. Modell.*, **306,** 121-129.

Ferreyra, C., Brown, M.T. (2007). Emergy perspectives on the Argentine economy during the 20th century: A tale of natural resources, exports and external debt. *International journal of environment and sustainable development*, **6** (1), 17-35.

Gasparatos, A., Gadda, T. (2009). Environmental support, energy security and economic growth in Japan. *Energy Policy*, **37** (10), 4038-4048.

Giannetti, B.F., Almeida, C.M.V.B., Bonilla, S.H. (2010). Comparing emergy accounting with well-known sustainability metrics: The case of southern cone common market, mercosur. *Energy Policy*, **38** (7), 3518-3526.

Giannetti, B.F., Demétrio, J.F.C., Bonilla, S.H., Agostinho, F.*et al.* (2013). Emergy diagnosis and reflections towards Brazilian sustainable development. *Energy Policy*, **63,** 1002-1012.

GoN (2016). Nepal population report 2016, Government of Nepal, Ministry of Population and Environment.

González-Mejía, A.M., Ma, X. (2017). The emergy perspective of sustainable trends in Puerto Rico from 1960 to 2013. *Ecol. Econ.*, **133**, 11-22.

Hacking, T., Guthrie, P. (2008). A framework for clarifying the meaning of triple bottom-line, integrated, and sustainability assessment. *Environ. Impact Assess. Rev.*, **28** (2), 73-89.

Haitao, L., Brown M. (2017). Emergy-based environmental accounting toward a sustainable Mongolia. *Journal of Geophysical Sciences,* **27** (10), 1227-1248.

Harizaj, P. (2010): Emergy synthesis of Albania for 2007. Emergy synthesis 6: Theory and application of the emergy methodology. Proceeding from the sixth bienneal emergy conference.

Huang, S-L., Lee, C-L., Chen, C-W. (2006). Socioeconomic metabolism in Taiwan: Emergy synthesis versus material flow analysis. *Resources, Conservation and Recycling,* **48** (2), 166-196.

IBPUSA (2007). Nepal mineral & mining sector investment and business guide. International Business Publications USA.

IFPRI (2017). Global hunger index, the inequalities of hunger, international food policy research institute, .

Jiang, M.M., Zhou, J.B., Chen, B., Chen, G.Q. (2008). Emergy-based ecological account for the Chinese economy in 2004. *Commun. Nonlinear Sci. Numer. Simul.,* **13** (10), 2337-2356.

Lei, K.P., Wang, Z.S. (2008). Emergy synthesis and simulation for Macao. *Energy*, **33** (4), 613-625.

Liu, G., Yang, Z., Chen, B., Ulgiati, S. (2011). Monitoring trends of urban development and environmental impact of Beijing, 1999–2006. *Sci. Total Environ.,* **409** (18), 3295-3308.

Lomas, P.L., Álvarez, S., Rodríguez, M., Montes, C. (2008). Environmental accounting as a management tool in the mediterranean context: The Spanish economy during the last 20 years. *J. Environ. Manage.,* **88** (2), 326-347.

Londoño, N.A.C., Suárez, D.G., Iván, H. (2014). Emergy evaluation: A tool for the assessment of sustainability in project development. *International Journal of engineering Research and Applications,* **1** (4), 172-178.

MoF (2015). Economic servey, Government of Nepal, Ministry of Finance.

Mugnier, J-L., Jouanne, F., Bhattarai, R., Cortes-Aranda, J.*et al.* (2017). Segmentation of the Himalayan megathrust around the Gorkha earthquake (25 april 2015) in Nepal. *J. Asian Earth Sci.,* **141,** 236-252.

NOC (2015). Nepal oil corporation, Government of Nepal, http://www.Nepaloil.Com.Np/

NPC (2015a). Post disaster needs assessment, vol. B: Sector reports. Kathmandu, Nepal: Government of Nepal, National Planning Commission.

NPC (2015b). Sustainable development goals, 2016-2030. Government of Nepal, National Planning Comission, Nepal.

Odum, H.T. (1996). Environmental accounting: Emergy and environmental decision making, john wiley & sons, inc.

Odum, H.T., Odum, E.C., Brown, M.T. (1997). Environment and society in florida. Taylor & Francis.

Rodríguez-Ortega, T., Bernués, A., Olaizola, A.M., Brown, M.T. (2017). Does intensification result in higher efficiency and sustainability? An emergy analysis of mediterranean sheep-crop farming systems. *J. Cleaner Prod.,* **144,** 171-179.

Rydberg, T., Haden, A.C. (2006). Emergy evaluations of Denmark and Danish agriculture: Assessing the influence of changing resource availability on the organization of agriculture and society. *Agric. Ecosyst. Environ.,* **117** (2), 145-158.

Sharma, K. (2006). The political economy of civil war in Nepal. *World Devel.,* **34** (7), 1237-1253.

Shrestha, D.P. (1997). Assessment of soil erosion in the Nepalese Himalaya, a case study in Likhu khola valley, middle mountain region. *Land Husbandry,* **2** (1), 59-80.

The World Bank (2016). Nepal development update: Development amidst distrubances. The world Bank, 1818 h street nw, Washington, DC, USA.

Ulgiati, S., Brown, M.T., (1998). Monitoring patterns of sustainability in natural and man-made ecosystems. *Ecol. Modell.,* **108**,(1), 23-36.

Ulgiati, S., Brown, M.T., Bastianoni, S., Marchettini, N. (1995). Emergy-based indices and ratios to evaluate the sustainable use of resources. *Ecol. Eng.,* **5** (4), 519-531.

UNEP (2012). Environmental accounting of national economic systems: An analysis of west african dryland countries within a global context, United Nations Environment Programme, Nairobi.

UNESCO (2016). Sustainable development in the least developed countries , towards 2030. UNESCO, Paris.

USGS (2017). United States Geological Survey. https://www.usgs.gov/. Accessed September, 2017

Waas, T., Hugé, J., Block, T., Wright, T.*et al.* (2014). Sustainability assessment and indicators: Tools in a decision-making strategy for sustainable development. *Sustainability,* **6** (9), 5512.

Wang, X., Li, Z., Long, P., Yan, L.*et al.* (2017). Sustainability evaluation of recycling in agricultural systems by emergy accounting. *Resources, Conservation and Recycling,* **117**, 114-124.

WCED (1987). Our common future. The world commission on environment and development.

Yang, Z., Jiang, M., Chen, B., Zhou, J.*et al.* (2010). Solar emergy evaluation for Chinese economy. *Energy Policy,* **38** (2), 875-886.

Zhang, B., Chen, G.Q., Yang, Q., Chen, Z.M.*et al.* (2011a). How to guide a sustainable industrial economy: Emergy account for resources input of Chinese industry. *Procedia Environ. Sci.,* **5,** 51-59.

Zhang, Y., Yang, Z., Liu, G., Yu, X. (2011b). Emergy analysis of the urban metabolism of Beijing. *Ecol. Modell.,* **222** (14), 2377-2384.

Zhu, L.P., Li, H.T., Bouldin, J., John, R.*et al.* (2012). Emergy-based environmental accounting: Evaluation of inner Mongolia autonomous region. *Acta Ecologica Sinica,* **32** (2), 74-88.

CHAPTER IV

THE IMPACT ANALYSIS OF NATURAL DISASTER BY EMERGY METHOD: THE CASE OF GORKHA-EARTHQUAKE IN NEPAL

ABSTRACT

The impact of natural disasters is cyclic that greatly affects the economy, society, and environment of a country. In traditional disaster impact assessment method, the impact assessment was done based on the direct economic loss and ignored social and environmental impacts in total assessment. However, for comprehensive disaster assessment, environmental and economic factors should be integrated together, and the impact observed in society should be analyzed. Applying emergy method, all the impacts observed are evaluated in common unit of solar emergy joule (sej). This research paper presents a new approach of natural disaster impact assessment based on emergy method and provides series of emergy indices. A case study of the Gorkha-earthquake that hit Nepal was applied and discussed to show the emergy method's practical potential. The result showed that the total resource use of Nepal was decreased by 10% and per capita resource use was declined by 12% after the earthquake. The economic activities inside the country were significantly affected leading to lowered total export from the country. The extraction of non-renewable resources mainly the non-metallic minerals were dropped by 49%. But the lowering of non-renewable resource extraction and its use used showed the positive impact in environment. The environmental load was dropped from 6.79 before the earthquake to 5.98 after the earthquake. The impact in society, economy and environment were discussed individually with potential application of emergy method in other type of natural disasters.

4.1 INTRODUCTION

Natural disasters are caused by natural phenomenon which cannot be controlled or interfered by human beings (Mata-Lima *et al.*, 2013). Modern forecasting technology somehow has eased in forecast of natural disasters, but accurate prediction of natural disaster is not achieved thus each year billion dollars of properties are destroyed by natural disaster in different parts of the world. The intensity of damage or impacts of natural disasters depends on many factors such as natural disaster type (such as flood, landslide, storm, earthquake, etc.), geographical conditions of disaster hit region, time of disaster occurred and the status of disaster hit communities (Benson and Clay, 2004; Kliesen, 1994). Natural disaster of even small magnitude which is classified as small or moderate kind can significantly affect economy, society and environment in developing countries due to lack of preventive action plans, low level of social capital, low resilience, etc. (Mata-Lima *et al.*, 2013). The good example of different level of impacts due to same disaster with different magnitudes in different regions of the developing and developed world can be distinguished through the Haiti earthquake, 2010 and Japan earthquake, 2011. The magnitude of earthquake that hit Haiti in 2010 was 7 in Richter scale whereas the magnitude of Japan earthquake in 2010 was 9 Richter scale. The economic damage of the Haiti earthquake was fourteen billion US$ this was equivalent to 160 percent of Haiti's GDP whereas the economic damage of Japan earthquake was 200 billion US$ but this was only three percent of Japan's GDP. This only shows the economic aspects of natural disaster but the social and environmental impacts are rarely encountered in natural disasters report.

Mostly, natural disasters impact analysis are done on direct economic loss such as the financial cost of physical damage to capital, raw materials, crops, livestock and infrastructures. The traditional method does not include the social and environmental impacts of natural disaster in total assessment. This is because of the multitude of elements and functions constituting the natural environment and social impact is even less definable and hard to express in quantitative terms (Kreimer, 2001; Mata-Lima *et al.*, 2013). But the impacts of natural disasters are cyclic. The natural disaster affects the economy, society and environment of hit region simultaneously (Srinivas and Nakagawa, 2008). For example, the direct loss of physical assets due to natural disaster degrades the social-well being of people and this increases the interdependence of people to the natural resources. The overexploitation of natural resources finally degrade environment. In the developing countries, the post effects of natural disasters are even more severe because of the lack of proper resettlement program of the government. The environmental assessment of natural disasters such as Hurricanes Ivan and Jeanne revealed that, the vegetation destruction and surface and ground water contamination was exaggerated in Haiti, Grenada and the Dominican Republic in September-October 2004 after the disaster (Srinivas and Nakagawa, 2008). Therefore for the comprehensive natural disaster impact analysis the social and environmental factors should also be integrated with the economic impact assessment such that the impacts could be analyzed in holistic. The result thus obtained is also helpful for resource allocation during recovery and reconstruction after disaster.

Applying emergy method, the impacts caused by the natural disasters in society, environment and economy of the hit region can be evaluated in aggregate and quantitatively. Emergy method is an ecological-economic accounting method that integrates economic resources with monetary value and environmental service required producing that resource and evaluates its relation with human society by taking broad, long-term view in common unit of solar emjoule (sej) (abbreviated, sej) (Brown and Ulgiati, 2004). The integration of ecological and economic system in common unit also facilitates in public policy development regarding resource-use and conservation (Doherty *et al.*, 1993). The emergy method has been widely applied in sustainability assessment and sustainability policy development of many geographical regions (Ulgiati *et al.*, 1994; UNEP, 2012; Zhang *et al.*, 2010). Through the emergy method, the impacts of disaster high region can be studied in similar approach done in the study of geographical regions. Considering disaster hit region a system and region's administrative boundary as a system boundary, complete emergy evaluation of disaster hit region can be done. Sometime the detailed socio-economic and environmental data of particular disaster hit region many not be available. In emergy method, this can be solved by expanding the boundary to national administrative boundary or through emergy-based simulation models (Geng *et al.*, 2010).

Application of emergy method in ecological-economic assessment of geographical system was first done by Howard T. Odum. He applied emergy method to evaluate resource use intensity, trade balance, sustainable resource production of the United States (Odum, 1996). After, many researchers applied emergy method with new concept of sustainability assessment of countries such as China(Yang *et al.*, 2010), Japan (Gasparatos and Gadda, 2009), Spain (Lomas *et al.*, 2008), Argentina (Ferreyra and Brown, 2007), Brazil (Giannetti *et al.*, 2013), etc. However, the application of emergy method is confined in small area and small research group. H.T. Odum in his publication "Environmental Accounting, Emergy and Environmental Decision Making" stated that this method could be implemented in the assessment of universities, culture, television, evolutionary products, information, etc. But, this methodology has not been widely acknowledged within research scholars. In this research, the emergy method for the first time is applied in the impact assessment of natural disaster. Natural disaster's impact in the society, environment and economy of a country is evaluated in an aggregate, quantifying them in common unit of sej. A case of the Gorkha-earthquake that hit Nepal in 2015 is presented in order to analyze disaster impacts and emergy method application.

4.2 METHODOLOGY

4.2.1 Area of study

Nepal (28° 00ˈ N, 84° 00ˈ E) is a landlocked country located in South Asia between two economic giant countries, India and China (Figure 4.1). The total area of Nepal is 147,181 sq. km. Nepal lies in the lap of the Himalaya range. The Himalaya range is the youngest mountain range in the world and the most seismically active intra-continental region (Gupta, 2000). The seismic activity in the Himalaya is the result of continental collision between Indian and Eurasian continental plates (Dhakal, 2015; Mugnier *et al.*, 2017). Nepal has long history of earthquake. Some large and devastating earthquakes recorded in different time period includes, the earthquake of magnitude 7.6 in 19th century in 1833. The earthquake of magnitude 8.4 in 20th century in 1934 and the Gorkha-earthquake is the largest earthquake recorded in 21st century until now with magnitude 7.8 (Mugnier *et al.*, 2017). The epicenter of the earthquake was in Gorkha, 80 km northwest of Kathmandu, the capital (N: 28° 08' 49.2"; E 84° 42' 28.8"). Another strong aftershock of magnitude 7.3 was felt after a month on 12 May, 2015 (Moss *et al.*, 2015; Sharma *et al.*, 2016). Nearly 9,000 people were killed and more than 22,000 people were badly injured due to the earthquake.

The Gorkha-earthquake greatly affected the country. Thirty-one districts of total seventy-five districts were affected by the disaster. The hit districts are classified as severely hit, crisis hit, hit with heavy loss, hit and slightly hit districts based on casualties and damaged occurred by the earthquake, (Figure 1) (NPC, 2015). The total direct economic loss was estimated to be seven billion US$ (NPC, 2015).The overall economic growth of the country was at its lowest in the last five years in 2015 (NPC, 2015; The World Bank, 2016).

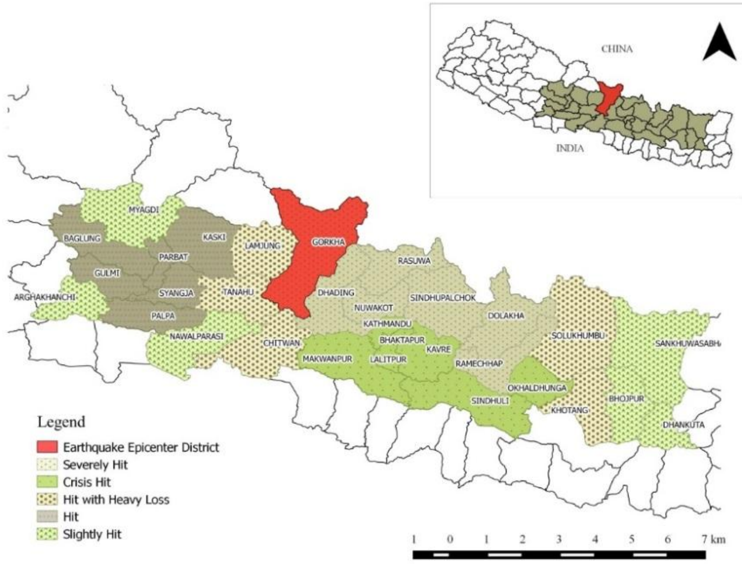


Figure 4.1 **:** Classification of districts according to the earthquake casualties and damage

4.2.2 Data collection and emergy calculation

Data required for the emergy accounting were collected from publicly issued year books published by the government of Nepal. The social demographic data and economic data of Nepal were collected from year book published by Central Bureau of Statistics Nepal (CBSN). The agricultural production data were collected from resource book published by Ministry of Agriculture (MoA), data on trade in different years were collected from resource book of Department of Customs (DoC). Data on finance were collected from resource book published by Ministry of Finance (MoF), etc. The global resources production data required for world emergy money ratio calculation were collected from United States Geological Survey (USGS, 2017).

The widely applied practice to determine the impacts of natural disasters in socio-economy and environment of a country is, estimating the post-disaster impacts and make comparison with the pre-disaster scenario (ECLAC, 1991). Therefore, in this research, the emergy of Nepal of post-disaster was calculated and made comparison with the emergy of pre-disaster. Since, the Gorkha-earthquake hit Nepal in 2015, emergy of 2015 is compared with the emergy of 2014. In this research, the terms, before the disaster and after the disaster are frequently used. It should be understood that the term ‘before the disaster’ means the conditions in 2014 and the term ‘after the disaster’ means the conditions in 2015.

In emergy accounting, many emergy indices are calculated. Those emergy indices are calculated with the inclusion of social, economical and environmental values. Therefore, those indices will help to understand the socio-economic and environmental conditions and make comparison with before and after the disaster. The important emergy indices are emergy per money ratio (EMR), emergy yield ratio (EYR), emergy density (ED), emergy investment ratio (EIR), environment loading ratio (ELR) and environmental sustainability index (ESI). The EMR is a socio-economic indicator that explains the status of well-being after the disaster and compares the social living standard and the purchasing capacity of people. ED, EIR, EYR explain the economic changes that occurred inside the country after the disaster. ELR explain how the resources consumption exert the pressure to environment i.e. it measures the environmental load due to the economic activities (Brown and Ulgiati, 2004; Odum, 1996).

4.3 RESULTS AND DISCUSSION

4.3.1 Comprehensive emergy accounting before and after the earthquake

Comprehensive emergy accounting before and after earthquake Comprehensive emergy system diagram with resources flow of Nepal for 2015 is shown in Figure 4.2. The input and output resources that plays vital role in Nepal economy includes free environmental resources (sunlight, wind, rain and earth heat), extracted non-renewable resources (metallic and non-metallic minerals), imported resources from other countries, purchased services and exchange of cash and information. Table 4.2 is the emergy evaluation table here heterogeneous input and output data are converted into emergy multiplying with respective transformity factor. Table 4.3 is emergy summary table. The values in this table are summarized from the emergy evaluation table.

Table 4.4 lists the emergy indices of Nepal before and after the earthquake. Figure 4.3 is the aggregated emergy diagram of Nepal for year 2015. The emergy values presented in this diagram are cited from emergy summary table (Table 4.3).

The economic growth of Nepal was decreased after the earthquake. At the constant price of 2013, the GDP growth of Nepal was 16% before the earthquake but after the earthquake it was dropped to 8% (Table 4.1). Similarly, the total emergy used (U) of Nepal before the earthquake was 1.75E+23 sej but this was decreased by 10.28% after the earthquake and reached 1.57E+23 sej.

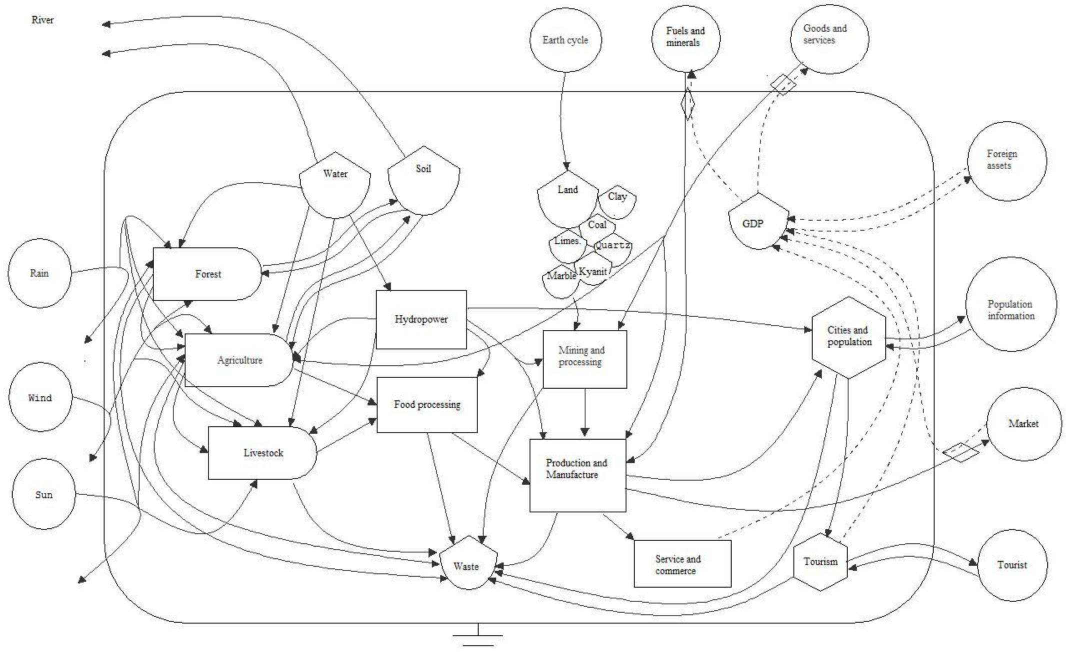


Figure 4.2 **:** Comprehensive emergy system diagram of Nepal,

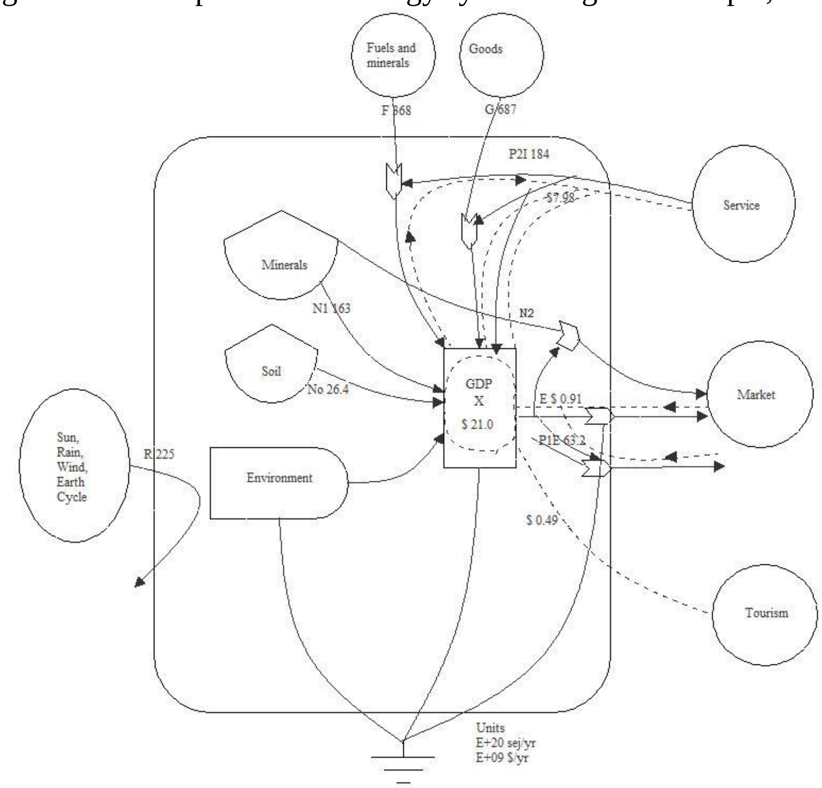


Figure 4.3 : Aggregated emergy diagram of Nepal, 2015

Table 4.1**:** GDP, import and export of Nepal before and after the earthquake, (at constant, 2003 prices US$)

Year	GDP (at constant, 2013 Prices US$)	Import (at constant, 2013 Prices US$)	Export (at constant, 2013 Prices US$)
2013	1.93E+10	7.00E+09	8.83E+08
2014	2.24E+10	8.17E+09	1.02E+09
2015	2.42E+10	8.97E+09	9.72E+08

Table 4.2**:** Emergy evaluation table (before and after the earthquake) (Notes for 2015 see Appendix A)

No.	Item	Flow		Unit Value (UEV[a])	Emergy	UEV source*	Emergy (sej/yr) before the earthquake	Emergy (sej/yr) after the earthquake
Renewable resources (sej)								
1	Sun	1.79E+18	J/yr	1	sej/J	1	1.79E+18	1.79E+18
2	Wind	2.06E+18	J/yr	2.45E+03	sej/J	1	5.04E+21	5.04E+21
3	Rainfall chemical	1.28E+16	J/yr	3.50E+04	sej/J	1	4.49E+20	4.49E+20
4	Rainfall geo-potential	1.89E+17	J/yr	1.76E+04	sej/J	1	3.33E+21	3.33E+21
5	Earth cycle	3.02E+17	J/yr	5.80E+04	sej/J	2	1.75E+22	1.75E+22
Indigenous Renewable resources (sej)								
6	Agriculture production	3.76E+17	J/yr	Varies	sej/J	Multiple	4.61E+22	5.54E+22
7	Livestock production	9.01E+15	J/yr	Varies	sej/J	Multiple	2.92E+22	2.95E+22
8	Fishery production	1.81E+14	J/yr	8.40E+06	sej/J	3	1.42E+21	1.52E+21
9	Fuel wood production	2.73E+15	J/yr	2.26E+04	sej/J	Multiple	2.23E+19	6.16E+19
10	Industrial round wood production	5.09E+13	J/yr	9.20E+04	sej/J	Multiple	1.04E+19	4.68E+18
12	Hydroelectricity production	1.31E+16	J/yr	2.77E+05	sej/J	4	3.35E+21	3.62E+21
13	Total electricity used	1.80E+16	J/yr	2.86E+05	sej/J	4	4.81E+21	5.15E+21
Nonrenewable sources from within system (sej)								
14	Top soil loss	2.15E+17	J/yr	1.23E+04	sej/J	5	2.64E+21	2.64E+21
15	Coal production	2.29E+13	J/yr	1.01E+05	sej/J	6	1.59E+19	2.32E+18
16	Nonmetallic minerals	1.63E+22	J/yr	Varies	sej/J	7	3.21E+22	1.63E+22
Imports (sej)								
17	Fuels	5.68E+16	J/yr	Varies	sej/J	6	8.68E+21	9.55E+21
18	Metal products	2.02E+12	g/yr	Varies	sej/g	7	2.35E+22	2.17E+22
19	Non-metal products	5.45E+12	g/yr	Varies	sej/g	7	5.28E+21	5.58E+21
20	Food and agricultural products	4.30E+16	J/yr	Varies	J/yr	7	4.13E+21	8.52E+21
21	Livestock, meat, fish	8.35E+15	J/yr	Varies	J/yr	7	6.22E+22	5.44E+22
22	Plastic and synthetic rubber	3.80E+08	$/yr	1.28E+12	sej/$	8	4.25E+20	4.87E+20

23	Chemicals	1.82E+12	g/yr	Varies	sej/g	7	2.10E+21	2.19E+21
24	Finished products	7.45E+08	$/yr	1.28E+12	sej/$	8	1.37E+21	9.55E+20
25	Machinery and transportation equipment	1.81E+09	$/yr	1.28E+12	sej/$	8	1.66E+21	2.32E+21
26	Service in import	7.98E+09	$/yr	1.28E+12	sej/$	8	8.84E+21	1.02E+22
Exports (sej)								
27	Metals	1.36E+11	g/yr	Varies	sej/g	7	8.83E+20	1.46E+21
28	Non-metal products	1.20E+09	g/yr	Varies	sej/g	7	1.06E+21	1.69E+18
29	Food and agricultural products	9.87E+15	J/yr	Varies	sej/J	7	5.98E+20	6.36E+20
30	Livestock, meat , fish	1.20E+09	J/yr	Varies	sej/J	7	1.45E+22	4.78E+20
31	Plastic and synthetic rubber	3.05E+07	$/yr	7.31E+12	sej/$	9	2.70E+20	2.23E+20
32	Fuels	1.97E+07	g/yr	Varies	sej/g	6	9.77E+19	8.60E+16
33	Chemicals	4.06E+11	g/yr	Varies	sej/g	7	1.14E+20	1.16E+20
34	Finished products	3.97E+08	$/yr	7.31E+12	sej/$	9	3.57E+21	2.90E+21
35	Machinery and transportation equipment	6.47E+06	$/yr	7.31E+12	sej/$	9	4.78E+19	4.73E+19
36	Service in export	8.65E+08	$/yr	7.31E+12	sej/$	9	8.01E+21	6.32E+21
37	Tourism	5.44E+08	$/yr	7.31E+12	sej/$	9	4.19E+21	3.98E+21

* UEV source: 1) Odum et al. (2000a) 2) Odum et al. (2000) 3) Brown et al. (1993), Kang (2011) 4) Odum (1996), Kang (2011) 5) Brown and Ulgiati (2011a), 6) Brown et al. (2011b), 7) Cohen et al. (2007), 8) Kang (2011) 9) this study

Table 4.3: Emergy summary table

Code	Item	Units	After the earthquake	Before the earthquake
R	Renewable sources used	sej/yr	2.25E+22	2.25E+22
N	Total nonrenewable extraction	sej/yr	1.89E+22	3.47E+22
N_0	Dispersed rural resource	sej/yr	2.64E+21	2.64E+21
N_1	Concentrated resources	sej/yr	1.63E+22	3.21E+22
N_2	Exported without use	sej/yr	0.00E+00	0.00E+00
Fi	Imported fuels and minerals	sej/yr	3.68E+22	3.74E+22
Gi	Imported goods	sej/yr	6.89E+22	7.19E+22
I	Money paid for imports	$/yr	7.98E+09	7.20E+09
P2I	Imported services	sej/yr	1.02E+22	8.84E+21
Fe	Exported fuels and minerals	sej/yr	1.46E+21	2.04E+21
Ge	Exported goods	sej/yr	4.40E+21	1.91E+22
E	Money paid for exports	$/yr	8.65E+08	9.01E+08
P_1E	Exported services	sej/yr	6.32E+21	8.01E+21
X	Gross domestic product	$/yr	2.15E+10	1.98E+10
P_2	World emergy-money ratio	sej/$	1.28E+12	1.23E+12
P1	Nepal emergy-money ratio	sej/$	7.31E+12	8.88E+12
A	Land area	m^2	1.47E+11	1.47E+11
POP	Population	people	2.80E+07	27500000

Table 4.4: Emergy indices table

Name of Index	Expression	Before the earthquake (2014)	After the earthquake (2015)
Renewable emergy flow (sej/yr)	R	2.25E+22	2.25E+22
Non-renewable emergy flow (sej/yr)	N	3.47E+22	1.89E+22
Total imported emergy (sej/yr)	$Fi+Gi+P_2I$	1.18E+23	1.57E+23
Total emergy used (U) (sej/yr)	$R+N_0+N_1+Fi+Gi+P_2I$	1.75E+23	1.57E+23
Total exported emergy (sej/yr)	Fe+Ge+P1E+Tourism	3.34E+22	1.62E+22
Fraction of emergy use from indigenous sources	$(N_0+N_1+R)/U$	3.26E-01	2.64E-01
Imports minus exports (sej/yr)	(Fi+Gi+P2I)-(Fe+Ge+P1E+Tourism)	8.90E+22	1.04E+23
Ratio of imports to exports	$(Fi+Gi+P_2I)/(Fe+Ge+P_1E+$ Tourism)	3.54E+00	7.17E+00
Fraction used, locally renewable	R/U	1.28E-01	1.43E-01
Fraction of emergy use purchased	$(Fi+Gi+P_2I)/U$	6.74E-01	7.36E-01
Fraction of use that is free	$(R+N_0)/U$	1.43E-01	1.60E-01
Empower density (sej/m^2)	U/A	1.19E+12	1.07E+12
Emergy use per capita (sej/person)	U/POP	6.38E+15	5.61E+15
Renewable emergy use per capita (sej/person)	R/POP	8.20E+14	8.04E+14
Nonrenewable emergy use per capita (sej/person)	N/POP	1.26E+15	6.76E+14
Renewable carrying capacity at present living standard	(R/U)*(POP)	3.53E+06	4.01E+06
Emergy-money ratio (sej/$)	U/GDP	8.88E+12	7.31E+12
Hydro-electricity used per capita (sej/person)	Total electricity used/POP	1.75E+14	1.84E+14
Fuel used per capita (sej/person)	Total fuel used/OPO	3.16E+14	3.41E+14
Emergy investment ratio (EIR)	$(Fi+Gi+P_2I)/(R+N_0+N_1)$	2.06	2.79
Environmental loading ratio (ELR)	$(N_0+N_1+Fi+Gi+P_2I)/R$	6.79	5.98
Emergy yield ratio (EYR)	$U/(Fi+Gi+P_2I)$	1.48	1.36

4.3.1.1 Renewable resources flow and production before and after the earthquake

Renewable resources are categorized into two types, perpetual resource flow and indigenous renewable resource production. The perpetual resource includes free natural resources such as solar radiation, rain, wind and the deep geological heat of the earth. These resources play important role in energy and matter flow in a system. Accounting of the perpetual resource in total emergy use should be done carefully to avoid double counting (Odum, 1996). In emergy accounting the perpetual resource that has the largest contribution are accounted. In this research, two largest contributors, the wind and the earth cycle are included. The emergy of perpetual resource flow of Nepal is 2.25E+22 sej.

The indigenous renewable resources production includes agricultural production, livestock production, fishery production, forestry production and electricity production. These are the important components of national gross production. In Nepal, agriculture is the largest indigenous resource production followed by livestock production, hydro-electricity production, fishery production and forest resource productions respectively (Figure 4.4). In 2014, i.e. before the earthquake in total 4.61E+22 sej agricultural product was produced. This was about 58% of the total indigenous resources produced. In 2015, the agriculture production was increased by 18% as compared to previous year. The emergy of agriculture product in 2015 was 5.44E+22 sej and this was 61% of the total indigenous resource production. The increment in agricultural production despite the earthquake is explained in few points. First, most of the earthquake hit districts are in the Hilly region and Mountain region of Nepal (Nepal is classified as Terai region, Hill and Mountain based on the ecological zone) (Figure 4.1). These regions of Nepal are not good agrarian region because of harsh topography and low fertile land. Basically, the agricultural activities in Nepal are concentrated in low land region. This low land is called “Terai” and recognized as the “grain basket” of Nepal because of its fertile and productive land. The Terai districts were not badly affected by the earthquake, in fact, no casualties and infrastructure damages were reported in this region (ICIMOD, 2016; NPC, 2015). Therefore, people in this region safely engaged in the agricultural activities despite having the tremor in other parts of the country. Second, the agriculture cultivation in Nepal, rely on the monsoon. The monsoon is the rainy phase of seasonally changing pattern that sprouts ample rainfall in South Asia that originates from the Bay of Bengal. The monsoon in Nepal starts from the month of

June until September. Since the earthquake hit Nepal in April, therefore the agricultural cultivation was not disturbed by the disaster.

Livestock production is second largest indigenous resource production after the agriculture production in Nepal. The livestock production shows insignificant improvement after the earthquake. The emergy of livestock production before the earthquake was 2.92E+22 sej and this was only improved by 1.02% after the earthquake with emergy 2.95E+22 sej. However, the overall contribution of the livestock production in total indigenous resource production was decreased after the earthquake. Before the disaster, the contribution of livestock production in total indigenous resource production was 36% but after the earthquake this was decreased to 33%.

The fishery and hydro-electricity production were also feebly increased after the earthquake. The emergy of fishery production was 1.42E+21 sej in 2014 and this was increased by 7.0% in 2015 with emergy of 1.52E+21 sej. After the earthquake, the large hydro-electricity power plants were not badly damaged as expected and this did not halt the electricity production. Few micro-hydropower (capacity of 5 to 20 kw) were damaged in the remote area of Nepal but this did not completely affect the national electricity grid (Baidar *et al.*, 2016; NPC, 2015). Therefore, the hydro-electricity production was increased from 3.35E+21 sej before the earthquake to 3.62E+21 sej after the earthquake. The contribution of fishery production and hydro-electricity production in the total indigenous resources production remained constant in both years with the contribution of 2% and 4% respectively.

The production and use of forest resources (including both fuel wood and industrial round wood) grew remarkably after the earthquake. In 2014, 3.27E+19 sej forest product were produced but after the earthquake production doubled to 6.63E+19 sej (Table 4.2). The large increment in the forest resource production was because of the active reconstruction program initiated by the Government of Nepal after the earthquake. During the reconstruction program, large quantity of tree wood was used to rebuild the houses. Nearly 500,000 houses were completely destroyed and 250,000 houses were partially destroyed by the earthquake (NPC, 2015).

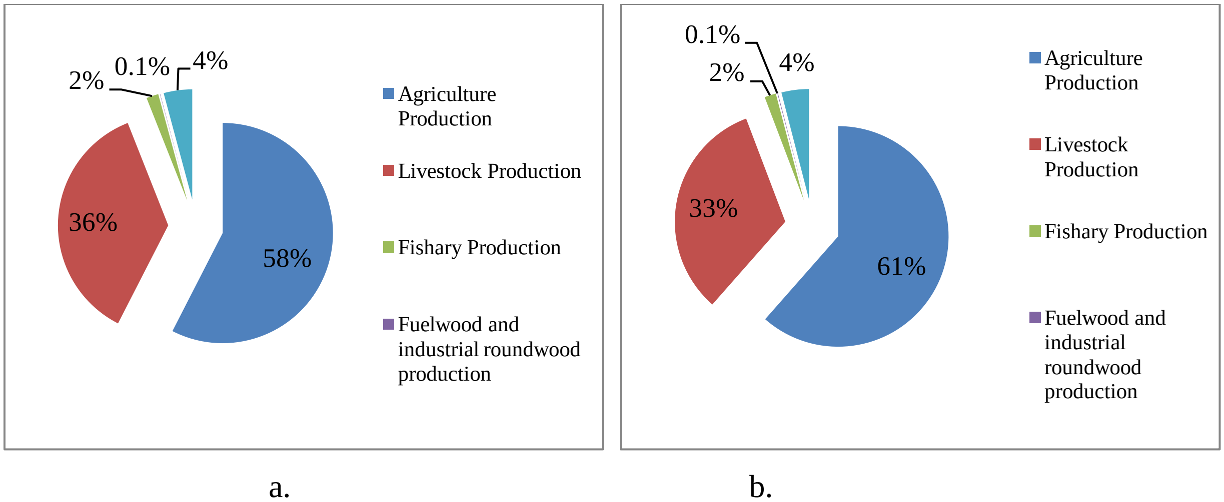


Figure 4.4 : Indigenous resource production in Nepal a. Before the earthquake b. after the earthquake

4.3.1.2 Non-renewable resources production before and after the earthquake

Non-renewable resources are the natural resources that are produced in the long run through geological processes and cannot be reproduced in short time interval. Non-renewable resources plays important role in the national economy. The non-renewable resources production in Nepal mainly includes the production of coal and other non-metallic minerals (clay, kyanite, limestone, tourmaline, talc, marbles, quartz, etc.). Other high quality metallic-minerals and fossil fuels are not extracted in Nepal (IBPUSA, 2007). For the demand of high quality mineral and fuels, this is fulfilled by the importation, and India is the largest supplier to Nepal.

The extraction of non-renewable resources in Nepal was sharply decreased after the disaster. The emergy of total non-renewable resources produced before the earthquake was 3.47E+22 sej but the production was decreased by 45.53% after the earthquake with total emergy of 1.89E+22 sej (Table 4.3). After the earthquake, the mining activities were halt by the Government of Nepal because of the security purpose and this also reduced the total resource production.

4.3.1.3 Analysis of imports and exports

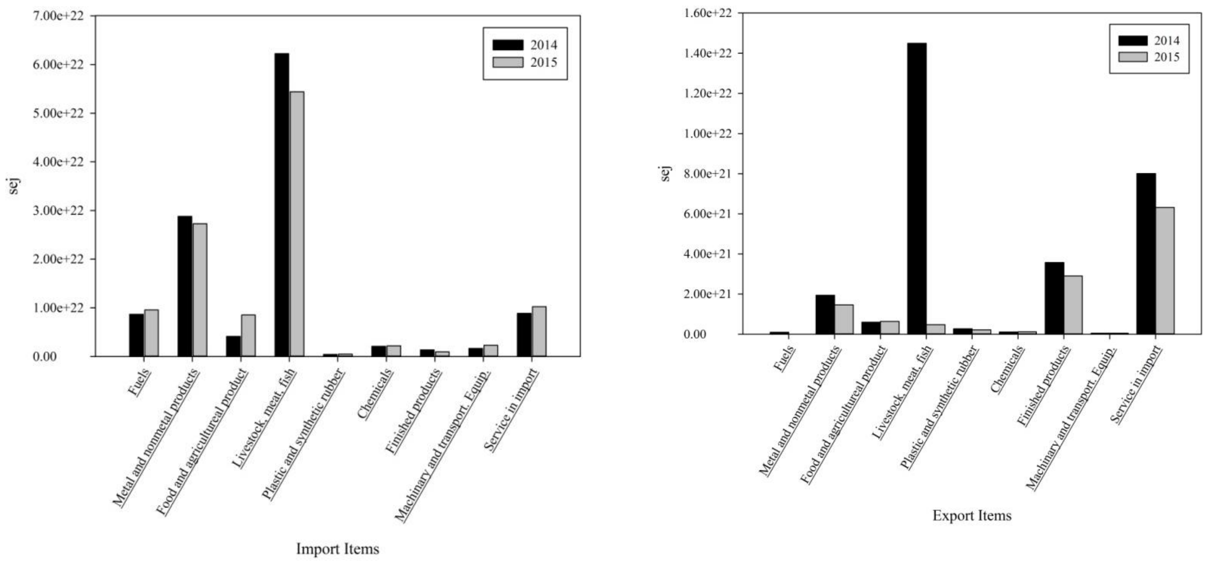


Figure 4.5 : Import and export in 2014 and 2015

Figure 4.5 shows the imports and exports scenario of Nepal before and after the earthquake. Livestock products (meat, fish, crustaceans, dairy products, etc.), food products, metal and non-metal minerals and fuels are imported in largest quantity by Nepal. Before the earthquake, the emergy of import was 1.18E+23 sej. This was about 67% of the total emergy use in that year. The import was decreased after the earthquake with import emergy, 1.16E+23 sej. However, the contribution of import emergy was increased to 74% in total emergy use after the earthquake. This indicates, the resource production inside the country was decreased therefore the country was more dependent with neighbor country for resources demand.

Before the earthquake, 6.22E+22 sej livestock, meat and fish products were imported. This alone accounted 46% in the total imports. The import was decrease to 5.44E+22 sej after the earthquake. Metal and non-metal minerals and products are the second largest imported resources. The import of this resource was also decreased from 6.22E+22 sej to 5.44E+22 sej after the earthquake. However, the import of food and agriculture products increased by two folds from 4.31E+21 sej before the earthquake to 8.52E+21 sej after the earthquake. Similarly, import of fuels (fossil fuels), machinery equipment, and service was also increased gently (Figure 4.5).

The export was most badly affected by the earthquake (Figure 4.5). Before the earthquake, emergy of the total exports was 3.34E+22 sej but after the earthquake, the exports decreased by 51% with total export emergy of 1.75E+23 sej. The exportation of livestock and fish products was decreased profoundly after the earthquake. Before the earthquake, 1.45E+22 sej livestock and fish products were exported but this was decreased by 96% with emergy of 4.78E+20 sej after the earthquake. Similarly, the emergy of metal and non-metal product exported was about 1.94E+21 sej before the earthquake and this decreased to 1.46E+21 sej after the earthquake. This is about 25% less exportation. The exports of other resources such as finished products, chemical, plastic and synthetic products were also decreased. In contrast, the export of agriculture and food products was feebly increased by 7% despite the earthquake.

Tourism is the largest industry in Nepal and important source of foreign exchange (MCTCA, 2015). People worldwide travel Nepal to experience nature adventure and refreshment. Tourist utilizes goods and resources of travelled country and support in revenue collection thus, tourism is included in the export section during emergy accounting (Jiang *et al.*, 2008). The tourism industry was also affected by the earthquake. The emergy of tourism before the earthquake was 4.19E21 sej but after the earthquake this decreased to 3.98E+21 sej. After the earthquake most countries prevented their citizens to travel Nepal and also the tourism activities such as trekking, hiking, mountain climbing, etc. were temporarily closed by government of Nepal due to frequent earthquake aftershocks and frazil geological condition. This consequently reduced the tourist arrival number and revenue collection.

4.3.2 Analysis and discussion of emergy indices before and after the earthquake

4.3.2.1 Emergy used per person

Emergy used per person measures the living standard of the people in country. This is a social indicator and considered as a comprehensive index for the evaluation of quality of life. Emergy use per capita gives the detailed information of well-being of people than other social indicators because this is calculated including the utilization of free environmental resources for which no money is paid by person (Giannetti *et al.*, 2013). The emergy use per capita of Nepal before the earthquake was 6.38E+15 sej but after the earthquake this was decreased to 5.61E+15 sej. Before the earthquake, resource consumption per capita was high but this was decreased by factor of 1.12 after the earthquake. This indicates that the quality of life of people in Nepal was degraded after the earthquake. The emergy used per person of Nepal in general is lower than the world average. The average global emergy per capita is 2.86E+16 sej (Giannetti *et al.*, 2013; NEAD, 2000). This explains the people in Nepal have limited excess to the resources than the global average people.

4.3.2.2 Emergy per money ratio (EMR)

Emergy per money ratio is a socio-economic indicator that relates total natural resources used by a county to its total economic productivity. It is calculated by dividing the total emergy use of the country by GDP (Odum, 1996). This index measures the resource purchasing power of money. In another term, this index evaluates the inflation scenario of a country in different years. The higher EMR value indicates higher purchasing power of money i.e. more resources could be bought in less money (Jiang *et al.*, 2008; Odum *et al.*, 1997).

The EMR of Nepal before the earthquake was 8.88E+12 sej/$. This explains, per dollar could purchase the resources equivalent to 8.88E + 12 sej. After the earthquake, the EMR of Nepal was decreased to 7.31E+12 sej/$. Therefore, after the earthquake per dollar could purchase resources equivalent to 7.31E+12 sej. This explains the purchasing power of money was decreased after the earthquake. This also explains the inflation was raised up after the disaster. After the earthquake the purchasing power of dollar decreased by nearly 18%. The decrease in national production and total emergy use of the country after the earthquake caused more money to circulate to the limited resources and this declined the buying power of money and caused inflation.

4.3.2.3 Foreign trade and emergy exchange ratio (EER)

The international trade of Nepal is not equivalent i.e. the imports is higher than the exports. The ratio of import to export describes the trade scenario of a country (Odum, 1996). The ratio value one means the equivalent trade (imports equals exports) with no net loss in trading. The value greater than one explain the unfair trade (imports is higher than exports). The import to export ratio of Nepal before the earthquake was 3.54. After the earthquake this increased to 7.17, indicating increased tread losses. The trade loss was 8.90E+22 sej before the earthquake and this was increased by 1.17 folds after the earthquake. Therefore, the trade loss increased to 1.04E+23 sej after the earthquake.

The inequity in trade is explained by EER). The EER is the ratio of EMR value of trading partners that share the resources through trading. For e.g. Nepal trade with many countries around the world so, the EER of Nepal is the ratio of EMR value of trading partners to the EMR of Nepal. Here for convenient to understand the trade loss, the EMR of the global economy is considered. Therefore, the EER of Nepal is the ratio of EMR of the global economy to the EMR of Nepal (EMR_{globe}/ EMR_{Nepal}). In 2015, the EER of Nepal was 0.18 and in 2014 this was 0.14 (Table 4.3). Per dollar resource traded to the world caused Nepal, the relative loss of 18% in 2015 and the loss was 14% in 2014. In 2015, Nepal traded 7.31 E+12 sej resource per dollar to other world. But in return Nepal was buying 1.28E+12 sej resources from other world. The value differ by an order of magnitude 5.7 ($EMR_{Nepal} = 5.7 \times EMR_{global}$). Nepal was exporting 5.7 times more resources per dollar to other world than it received. In 2014, this difference was even more ($EMR_{Nepal} = 7.2 \times EMR_{global}$). Nepal was exporting 7.2 times more resources than it was receiving.

4.3.2.4 Emergy investment ratio (EIR)

EIR is the ratio of the purchased resources to the total emergy of free environmental resources (Table 2.4). This emergy index quantifies the degree to which national economy is dependent on external investment for its resources. The small EIR suggest lower dependence to external investment and most resources were produced inside a country. Such economic growth is beneficial because products could be bought at lower price and economy will be more prosperous (Jiang *et al.*, 2008). The EIR of Nepal before and after the earthquake were 2.06 and 2.79, respectively. Before the earthquake national resource production was high, the import was lower but after the earthquake internal production was decreased and the import was higher. Therefore, EIR before the earthquake was smaller than after the earthquake. The EIR suggest that the economy of Nepal before the earthquake was more prosperous than after the earthquake.

4.3.2.5 Emergy yield ratio (EYR)

EYR is the ratio of total emergy input into of a country to the imported resources (Table 2.4). This is also called as the emergy performance index (Londoño *et al.*, 2014). This index measure how successfully a country has exploited and used the natural resources present within its boundary and make available to the economy. The EYR of Nepal before the earthquake was 1.48 and after the earthquake it was decreased to 1.36. Before the earthquake, the resource exploitation and its use were significantly higher, imports was lower therefore the EYR was high. However, after the earthquake the production of resources mostly non-renewable resources was decreased sharply and this also decreased the economic performance of the country.

4.3.2.6 Environmental loading ratio (ELR)

ELR is an important emergy index. This reflects the pressure put upon local ecosystem to absorb impacts due to the economic activities and process waste flow associated with resource use intensification (UNEP, 2012). The formula for the ELR calculation is discussed in CHAPTER II, Table 2.4. The local resource input from non-renewable resources increases the load on environment. The ELR value between 3 and 10 describes the moderate environmental impact, while a value greater than 10 indicates a high environmental impact (Brown and Ulgiati, 2004). Before the earthquake, the ELR of Nepal was 6.79 but after the earthquake this decreased to 5.98. Large quantity of non-renewable resources extraction before the earthquake put large environmental pressure but after the earthquake the extraction of non-renewable resources was decreased by 49% thus the ELR also decreased. In general, the non-renewable resources extraction is creating moderate environmental impact in Nepal because the ELR of Nepal before and after the earthquake is between 3 and 10.

4.4 CONCLUSIONS

The impact of the Gorkha-earthquake in national economy, social well-being and environment of Nepal was analyzed applying the emergy method. Converting parameters with heterogeneous units into sej by the transformity factor showed the effective analysis of disaster impacts. This help to visualize which sector was mostly affected by the disaster. This can further support in the development of reconstruction strategies after disaster.

The impact analysis of the Gorkha-earthquake explained that, the economic growth of Nepal was greatly affected by the earthquake. The total emergy use, which explains the resources resource use of a country, was decreased by 10%. The internal resource production was also affected by the disaster. The non-renewable resources extraction was decrease by nearly 49% after the earthquake.

The results of social emergy revealed that the well-being of people in Nepal was degraded after the earthquake. The per capita resources use was dropped by 12% from 6.38E+15 sej to 5.61E+15 sej. The inflation was risen up by 18% after the earthquake i.e. more money was needed to be paid for the same resource than before. The economic emergy showed that the purchasing power of the money (US$) was lowered after the disaster. Before the earthquake per dollar spent could purchase resources equivalent to 8.88E+12 sej but after the earthquake this was decreased to 7.31E+12 sej. Similarly, the trade of Nepal was also affected by the earthquake. The export was lowered by more than 50% and trade emergy loss was increased from 8.90E+22 sej before the earthquake to 1.04E+23 sej after the earthquake. The tourism, which is the important industry in Nepal, was depressed by the disaster. The tourism gross revenue collection was lowered by 11% after the earthquake.

However, the environmental emergy index explained that, because of the lowering of the extraction of non-renewable resources and resource used after the disaster, the environmental burden was lowered. The ELR was decreased from 6.79 before the earthquake to 5.98 after the earthquake. This research applied emergy method in the impact assessment caused by the earthquake but there are numerous opportunities for extend this work in impact assessment in other natural disasters such as drought, flooding, hurricane, etc.

REFERENCES

Angelakoglou, K., Gaidajis, G. (2015). A review of methods contributing to the assessment of the environmental sustainability of industrial systems. *J. Cleaner Prod.,* **108,** 725-747.

Baidar, B., Koirala, R., Neopane, H., Shrestha, M.*et al.* (2016). Strategic rehabilitation of the earthquake affected microhydropower plants in Nepal, IOP Conference Series: Earth and Environmental Science. IOP Publishing, 102003.

Benson, C., Clay, E.J. (2004). Understanding the economic and financial impacts of natural disasters. World Bank.

Brown, M.T., Ulgiati, S. (2004). Emergy analysis and environmental accounting. *Encyclopedia of Energy,* **2,** 329-354.

Dhakal, S. (2015). Evolution of geomorphologic hazards in Hindu Kush Himalaya, in: Nibanupudi, H.K., Shaw, R. (eds.), Mountain hazards and disaster risk reduction. Springer Japan, Tokyo, 53-72.

Doherty, S.J., Brown, M.T., Murphy, R.C., Odum, H.T.*et al.* (1993). Emergy synthesis perspectives, sustainable development and public policy options for Papua New Guinea. Centr for Wetlands and Water Resources, Univeristy of Florida, Gainesville, Florida, U.S.A.

ECLAC, (1991). Manual for estimating the socio-economic effects of natural disasters. United Nations, Economic Commission for Latin America and the Caribbean

Ferreyra, C., Brown, M.T. (2007). Emergy perspectives on the Argentine economy during the 20th century: A tale of natural resources, exports and external debt. *International journal of environment and sustainable development,* **6** (1), 17-35.

Gasparatos, A., Gadda, T., (2009). Environmental support, energy security and economic growth in Japan. *Energy Policy,* **37** (10), 4038-4048.

Geng, Y., Zhang, P., Ulgiati, S., Sarkis, J. (2010). Emergy analysis of an industrial park: The case of Dalian, China. *Sci. Total Environ.,* **408** (22), 5273-5283.

Giannetti, B.F., Demétrio, J.F.C., Bonilla, S.H., Agostinho, F.*et al.* (2013). Emergy diagnosis and reflections towards Brazilian sustainable development. *Energy Policy,* **63,** 1002-1012.

Gupta, H.K. (2000). Major and great earthquakes in the Himalayan region: An overview, in: Balassanian, S., Cisternas, A., Melkumyan, M. (eds.), Earthquake hazard and seismic risk reduction. Springer Netherlands, Dordrecht, 79-85.

IBPUSA (2007). Nepal mineral & mining sector investment and business guide. International Business Publications USA.

ICIMOD (2016). The impact of nepal's 2015 Gorkha earthquake- induced geohazards. International center for integrated mountain development, Nepal.

Jiang, M.M., Zhou, J.B., Chen, B., Chen, G.Q., (2008). Emergy-based ecological account for the chinese economy in 2004. *Commun. Nonlinear Sci. Numer. Simul.*, **13** (10), 2337-2356.

Kliesen, K.L. (1994). The economics of naural disasters. https://www.Stlouisfed.Org/publications/regional-economist/april-1994/the-economics-of-natural-disasters.

Kreimer, A. (2001). Social and economic impacts of natural disasters. *In.l Geol. Rev*, **43** (5), 401-405.

Lei, K., Wang, Z. (2008). Emergy synthesis of tourism-based urban ecosystem. *J. Environ. Manage.*, **88** (4), 831-844.

Lomas, P.L., Álvarez, S., Rodríguez, M., Montes, C. (2008). Environmental accounting as a management tool in the mediterranean context: The spanish economy during the last 20 years. *J. Environ. Manage.*, **88** (2), 326-347.

Londoño, N.A.C., Suárez, D.G., Iván, H. (2014). Emergy evaluation: A tool for the assessment of sustainability in project development. *International Journal of engineering Research and Applications*, **1** (4), 172-178.

Mata-Lima, H., Alvin-Borba, A., Pinheiro, A., Mata-Lima, A.*et al.* (2013). Impacts of natural disasters on environmental and socio-economic systems: What makes the difference? *Ambiente & Sociedade*, **16**.

MCTCA (2015). Nepal tourism statistics, 2015, Government of Nepal, Ministry of Culture Tourism and Civil Aviation, Kathmandu, Nepal.

Moss, R.E.S., Thompson, E.M., Scott Kieffer, D., Tiwari, B.*et al.* (2015). Geotechnical effects of the 2015 magnitude 7.8 gorkha, nepal, earthquake and aftershocks. *Seismol. Res. Lett.*, **86** (6), 1514-1523.

Mugnier, J-L., Jouanne, F., Bhattarai, R., Cortes-Aranda, J.*et al.* (2017). Segmentation of the Himalayan megathrust around the Gorkha earthquake (25 april 2015) in Nepal. *J. Asian Earth Sci.*, **141,** 236-252.

NEAD, (2000). National environmental accounting database (http://www.Cep.Ees.Ufl.Edu/nead/data.Php) (Accessed April, 2017).

NPC (2015). Post disaster needs assessment, vol. B: Sector reports. Kathmandu, nepal: Government of Nepal, National Planning Commission.

Odum, H.T. (1996). Environmental accounting: Emergy and environmental decision making, john wiley & sons, inc.

Odum, H.T., Odum, E.C., Brown, M.T. (1997). Environment and society in florida. Taylor & Francis.

Rydberg, T., Haden, A. (2006). Emergy evaluations of Denmark and Danish agriculture: Assessing the influence of changing resource availability on the organization of agriculture and society. *Agric. Ecosyst. Environ.*, **117**,(2-3), 145-158.

Sharma, K., Deng, L., Noguez, C.C., (2016). Field investigation on the performance of building structures during the April 25, 2015, Gorkha earthquake in Nepal. *Eng. Struct.*, **121,** 61-74.

Srinivas, H., Nakagawa, Y., (2008). Environmental implications for disaster preparedness: Lessons learnt from the Indian Ocean Tsunami. *J. Environ. Manage.,* **89** (1), 4-13.

The World Bank, (2016). Nepal development update: Development amidst distrubances. The world Bank, 1818 h street nw, Washington, DC, USA.

Ulgiati, S., Odum, H.T., Bastianoni, S., (1994). Emergy use, environmental loading and sustainability an emergy analysis of Italy. *Ecol. Modell.,* **73** (3), 215-268.

UNEP (2012). Environmental accounting of national economic systems: An analysis of West African dryland countries within a global context, United Nations Environment Programme, Nairobi.

USGS, (2017). United states geological survey. https://www.usgs.gov/. Accessed September, 2017

Vassallo, P., Paoli, C., Fabiano, M. (2009). Emergy required for the complete treatment of municipal wastewater. *Ecol. Eng.*, **35** (5), 687-694.

Yang, Z., Jiang, M., Chen, B., Zhou, J.*et al.* (2010). Solar emergy evaluation for chinese economy. *Energy Policy*, **38** (2), 875-886.

Zhang, X.H., Deng, S., Jiang, W., Zhang, Y.*et al.* (2010). Emergy evaluation of the sustainability of two industrial systems based on wastes exchanges. *Resources Conservation and Recycling*, **55** (2), 182-195.

CHAPTER V

METHODOLOGICAL ASPECT OF EMERGY ACCOUNTING IN CO-PRODUCTION SYSTEMS

ABSTRACT

Emergy accounting analyzes the resource use efficiency of a production system. A production system consists of several kinds of branches and intersections and each branch has different emergy accounting procedures. Co-production is one of the branches in production systems. Emergy accounting in a system with co-production branch should be done carefully because each branch has different transformity value. Previous methods applied in emergy accounting in co-production system were not appropriate because they failed to follow emergy algebra (also called emergy rules) that guides to calculate transformity and emergy of outputs in different branches. To solve the existing problems of transformity and emergy calculation in co-production system, the modified physical quantity method (MPQM) is theoretically proposed considering emergy algebra. The applicability of MPQM was compared with conventional method tested by a case study of *Eucalyptus* pulp production. The MPQM solved all the problems of transformity calculation and emergy accounting in co-production system prevalent in previous methods. The MPQM followed all the rules stated in emergy algebra during the emergy accounting of a system with co-production.

5.1 INTRODUCTION

Sustainability is the most concerned issue in all sectors and the industrial sector cannot be an exception. In industrial sectors, the sustainable resource use is even more crucial because during the production stage a lot of resources are utilized to obtain the finite product. The industry efficiency in the resource use can prosper and get benefits in the long run. In other word, resource efficient industries are sustainable. Efficiency is the maximum utilization of resources that minimizes the waste of materials, energy, time and money during production. The industrial production systems are revolving in the same principles of efficient resource utilization in the last decades and this was most distinctly highlighted after the industrial revolution. Many theories and assessments have been postulated in efficiency analysis that confirms the efficient resource use in industrial production. However, not all theories have successfully accomplished their objectives. In the meantime, H.T. Odum developed the emergy method during the 1980s to analyze the sustainability and resource use efficiency of a system. This method evaluates the resource used efficiency of a system based on the scientific principle of energetic, system theory and system ecology (Brown and Ulgiati, 2004; M. T Brown and Herendeen, 1996; Odum *et al.*, 1997). The emergy method is much appreciated by scientific scholars and has been applied in the sustainability study of many industrial production systems (Geng *et al.*, 2014; Geng *et al.*, 2010; Ren *et al.*, 2010; Wang *et al.*, 2006; Zhang *et al.*, 2011; Zhang *et al.*, 2017; Zhe *et al.*, 2016).

In the aspect of emergy algebra, this states that the production systems networks develop to form two different pathways in production process, the split pathway and the co-production pathway. In emergy accounting, the difference between split and co-product should be understood in prior. In split branching, a pathway divides into two branches of the same kind and each path has the same transformity. The example of split pathway is, a steam supply in a pipe divided into two branches going to two different locations (Odum 1996). In co-production branching, the flow in each branch is a different kind and has a different transformity. Co-products are joint products with more than one output and are up-grades of inputs. All products in co-product have an economic value. Co-production branching occurs with energy transformation (Odum, 1996). For example, milk and beef production from livestock, paper and electricity production in pulp production industry, etc. Emergy accounting in co-production should be done very carefully because the transformity of individual product are different.

All the researches previously done in the sustainability assessment of industrial production applying emergy method are based on the macro aspect of industrial production process that evaluates the sustainability giving holistic approach (Cao and Feng, 2007). Most researches are devoted to sustainability assessment through existing emergy indices or through development of new emergy indices. However, their focus is far from the methodological aspect of emergy accounting of the unit product and its emergy evaluation. Basically, the emergy accounting in production process with co-products should be done carefully to prevent the mistake of double counting (M. T Brown and Herendeen, 1996). These issues are rarely encountered in previous research work. Moreover, there are only limited research work such as in Bastianoni and Marchettini (2000), Cao and Feng (2007), Kamp and Ostergard (2013), and

Viera and Domingos (2005) that have raised those issues but still incurs faults in the transformity calculation or are complicated to replicate in other production system. This study addresses the problem of transformity calculation in co-production systems. A new method of transformity calculation called modified physical quantity method (MPQM) is proposed. This is easy to understand and applicable in every co-production systems. The proposed MPQM is tested by a case study of *Eucalyptus* pulp production.

5.2 Methodological aspects of emergy accounting of co-production

In systems networks there are several kinds of branches and intersections. Emergy accounting of systems network depends on the type of branches and intersections. Much of the confusion in emergy accounting comes when the kinds of branches and connections are not identified for the appropriate evaluation procedure. Emergy accounting in systems networks should follow the rules stated in emergy algebra (Odum 1996). The rules of emergy algebra are as follow:

Rule 1: All source emergy to a process is assigned to the processes' output

Rule 2: When pathway splits the emergy is assigned to each leg based on the percentage of total energy flow on the pathway each with same transformity

Rule 3: Co-products from the process have a total emergy assigned to each pathway. Each branch has a different transformity

Rule 4: Emergy cannot be counted twice within a system: a) emergy in feedbacks cannot be double counted b) co-products, when reunited cannot be added to equal a sum greater than the source emergy from which they were derived.

The emergy of a product is calculated by multiplying the energy with transformity. Transformity is the conversion factor that converts emergy and matter flow in a system into emergy. Transformity is defined as emergy per unit of available energy and its unit in sej/j. If the transformity is expressed in mass (sej/g) or money (sej/$), it is called specific emergy. Transformity is a core concept in emergy assessment that measures the work efficiency involved in conversion of solar energy into product and also gives the position of an energy flow within hierarchical structure(Brown *et al.*, 2004). High transformity value suggests more energy is required to produce a product and ranked in higher position in the emergy hierarchy. In nature, resources with higher transformity reveal that, those resources require large quantity of dissipated energy to produce. Such resources are less renewable and need longer time to be produced (Brown and Ulgiati, 1997; Li *et al.*, 2010).

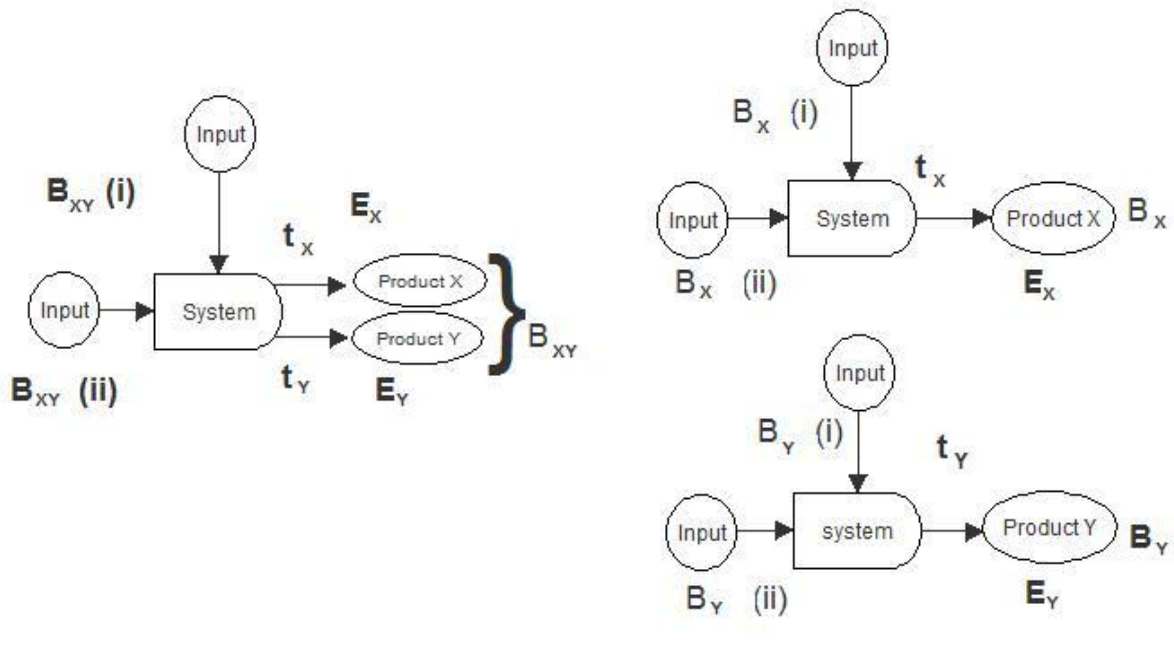
In emergy calculation of product and service, the information on energy content of resource is widely available but the transformity values are often unknown. Therefore, the accurate information on transformities is a limiting factor in emergy accounting. Emergy accounting in co-production systems is more complicated because the transformity of individual product is unknown (Bastianoni and Marchettini, 2000; M. T Brown and Herendeen, 1996). The transformity in co-products are calculated based on the input and output of energy and matters in the system. There are few methods already cited to calculate the transformity in co-production systems. However, the transformity value estimated through those methods tends to obtain wrong emergy calculation in complete systems because they mislead to the rules of emergy algebra.

5.2.1 Current transformity calculation and emergy accounting in co-production systems networks

In emergy accounting of systems with co-product, all input emergy must be assigned to individual output because each output account for all input energy to make particular output and the transformity of individual output are different (Herendeen, 2004; Odum, 1996). Applying single product's transformity calculation procedure as stated in conventional method in co-production system will lead to wrong emergy calculation because in co-production more emergy is required to support all products than in single product systems (Kamp and Østergård, 2013). In single production systems, transformity is calculated dividing total output emergy by input energy (Odum 1996) (Figure 5.1a).

$$\boxed{t_x = \frac{B_{xy}}{E_x} \quad t_y = \frac{B_{xy}}{E_y}}$$

Here, B_{xy} is emergy of the product from the system, E_x and E_y are energy required to make a product x and y.



a. b.

Figure 5.1 :(a) Simplified coproduction with two inputs and two outputs. (b) Separate production of two products . Here x and y are two outputs from the system (a), B_{xy} is total input emergy , E_x and E_y are the energies of coproducts x and y, t_x is the transformity of product x and t_y is the transformity of product y

The emergy of the products calculated using this transformity value in co-production systems will lead to wrong emergy calculation. The total output emergy will be greater than the input emergy. This is against the emergy algebra which state, sum total in output emergy cannot be greater than input emergy. The similar issue of wrong transformity calculation in conventional method was raised by Vieira and Domingos (2005). To overcome the problems of transformity calculation in conventional method, they proposed emergy/exergy values weighting approach method (Vieira and Domingos, 2005).The emergy/exergy values weighting method is given as:

$$\boxed{B_x = \frac{E_x}{E_x + E_y} B_{xy}\,, B_y = \frac{E_y}{E_x + E_y} B_{xy}}$$

Here B_x and B_y are the emergy of individual product, B_{xy} is the total input emergy to the system ($B_{xy} = B_{xy\,(i)} + B_{xy(ii)}$). E_x and E_y are the energies of co-products x and y respectively (Figure. 3 b).

Using energy as a weighting factor, they develop the new concept of redefined transformity($\hat{t}_{xy}$). Redefined transformity is defined as the total emergy of the system divided by its total energy.

$$\boxed{\hat{t}_{xy} = \tilde{t}_x = \tilde{t}_y = \frac{B_{xy}}{E_x + E_y} \quad B_x = E_x\tilde{t}_x\,,\ B_y = E_y\tilde{t}_y}$$

Here, $\tilde{t}_x$ and $\tilde{t}_y$ are the transformity of individual co-products. In this method, the transformity values of individual products are same. This is against emergy algebra which states, the transformity value of individual product are different in co-product.

5.2.2 Modified physical quantity method (MPQM)

In this research, to solve the problems of transformity calculation in co-production systems, a new MPQM is introduced. This method is the modification of physical quantity method. The physical quantity method is widely applied in allocation of joint cost in monetary accounting. The physical quantity method allocate joint cost based on the physical measures like volume, weight, surface area or any other common measures of the physical characteristics (Drury, 2013; Jain, 2000; Jiambalvo, 2009). Similarly, in MPQM, joint transformity is allocated to individual products in co-production systems.

Joint transformity is the sum of the emergy of inputs divided by the sum of available energy of outputs (Bastianoni and Marchettini, 2000). The concept of joint transformity was developed by Bastianoni and Marchettini (2000) to analyze resource use efficiency in co-production systems. They stated that, in the production systems, if the joint transformity is less than weighted average of the transformities, the co-production represents the most efficient energy use (Bastianoni and Marchettini, 2000). The joint transformity and the weighted average of the transformities in co-production systems are calculated as:

$$\boxed{\text{i.e. } T_{xy} = \frac{B_{xy}}{E_x + E_y}}$$

Where, T_{xy} is joint transformity, B_{xy} is the total input emergy to the system ($B_{xy} = B_{xy\,(i)} + B_{xy(ii)}$). E_x and E_y are the energies of co-products x and y respectively (Figure 5.1b). Similarly,

$$\tau_{xy} = \frac{E_x}{E_x + E_y} t_x + \frac{E_y}{E_x + E_y} t_y = \frac{B_x + B_y}{E_x + E_y}$$

Where, τ_{xy} is average weighted transformity E_x and E_y are the energies of co-products x and y, t_x and t_y are the transformity of individual co-products (Figure 5.1b).

In MPQM, first the joint transformity of entire co-production systems is calculated. After the joint transformity is determined, the MPQM is applied to allocate joint transformity to individual product. Finally the emergy of each product is calculated multiplying individual transformity with energy (Odum, 1996).

The following MPQM is applied to allocate the joint transformity to individual product

$$\boxed{\text{Individual coproduct transformity} = \frac{\text{Energy of individual coprodcut}}{\text{total energy of output from system}} \times \text{Joint Transformity}}$$

$$\boxed{(t_x) = \frac{E_x}{\sum E_x + E_y} \times T_{xy}} \quad \boxed{(t_y) = \frac{E_y}{\sum E_x + E_y} \times T_{xy}}$$

Here, (t_x) and (t_y) are transformity of individual product X and Y, E_x and E_y are energy of product X and Y, T_{xy} is the joint transformity in joint products.

After allocating transformity of individual product, the emergy is calculated multiplying transformity value with energy.

$$\boxed{\text{Emergy of individual coproduct} = \text{Individual coproduct transformity} \times \text{Energy of coproduct}}$$

$$\boxed{EM_x = t_x \times E_x} \boxed{EM_y = t_y \times E_y}$$

Here EM_x and EM_y are emergy of product X and Y.

5.3 A case study: The *Eucalyptus* pulp production

A case study of *Eucalyptus* pulp production system is presented in this section. Data are cited from Vieira and Domingos (2005). The pulp production system has co-production of a pulp and electricity. In this production system, pulp is the main product and electricity is side product. The economic value and energy content of a main product is higher than side product. so the main product with high energy should have higher transformity and the side product with low energy should have lower transformity (Lei *et al.*, 2014). Renewable resource input into the production system includes sunlight and water. Purchased resource input includes fossil fuels and chemicals (Vieira and Domingos, 2005).

Table 5.1: Emergy contributions to pulp production considering the production of 1000 ton of printing and writing paper

S.N	Input with Units	Inflow (units/FU)	Emergy/Unit (sej/Unit)	Emergy (sej/FU)
	Input Resources for Eucalyptus Production			
1	Sunlight (j)	1.04E+14	1.00E+00	1.04E+14
2	Rain (water) (g)	6.40E+11	1.28E+05	8.19E+16
3	Nutrient Loss (g)	2.30E+04	1.68E+09	3.86E+13
4	Fuel (j)	6.44E+10	6.60E+04	4.25E+15
5	Coal (j)	4.98E+06	5.71E+04	2.84E+11
6	Natural gas (j)	8.20E+07	5.71E+04	4.68E+12
7	Nitrogen (fertilizer) (g)	1.98E+06	2.41E+10	4.77E+16
8	Phosphate (fertilizer) (g)	5.80E+04	2.20E+10	1.28E+15
9	Potash (fertilizer) (g)	0.00E+00	1.74E+09	0.00E+00
	Transport			
10	Fuel (j)	1.98E+12	6.60E+04	1.31E+17
	Pulp Production			
11	Water (g)	2.75E+10	1.28E+05	3.52E+15
12	Fuel (j)	9.39E+11	6.60E+04	6.20E+16
13	Chemicals (g)	9.92E+07	6.68E+08	6.63E+16
14	Total			3.98E+17
	Co-production			
15	Pulp (j)	7.66E+12		
16	Co- generated electricity (j)	3.96E+11		
	Total (J)	8.06E+12		

Abbreviations: seJ: Solar emjoules; yr: year; FU: functional unit, 1000 tons of printing and writing paper, corresponding to 610 tons of pulp.

Table 5.2: Transformity and emergy value calculated through different methods

Prod.	En. in co-products (j)	Trans. using Conv. method sej/unit	Trans. using Energy/Exergy weighting approach sej/unit	Trans. using MPQM sej/unit	Em. value using Conv. method sej/unit	Em. value using Energy/Exergy weighting approach sej/unit	Em. value using MPQM sej/unit
Pulp	7.66E+12	5.19E+04	4.94E+04	4.69E+04	3.98E+17	3.78E+17	3.60E+17
Elect.	3.96E+11	1.00E+06	4.94E+04	2.43E+03	3.96E+17	1.95E+16	9.60E+14
Total	8.06E+12				7.94E+17	3.98E+17	3.60E+17

Abbreviations: Elect.: Electricity; Prod.: Productions; En: Energy; Em: Emergy; Trans.: Transformity; Conv.: Conventional

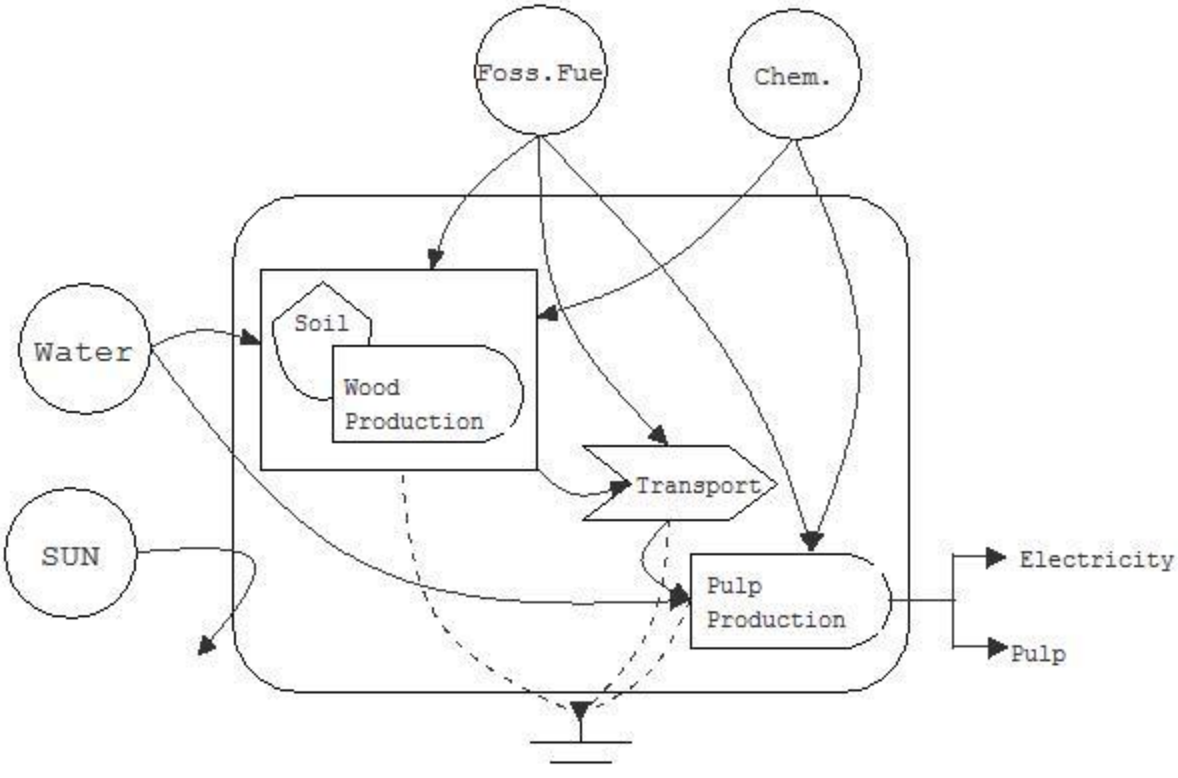


Figure 5.2: Emergy diagram of *Eucalyptus* pulp production

Detailed emergy diagram of *Eucalyptus* pulp production is shown in Figure 5.1. Table 5.1 presents the data of resources input and product output in production process. Table 5.2 shows transformity value and emergy value calculated applying different methods.

Applying the conventional method, the transformity value calculated for pulp and electricity are 5.19E+04 sej/j and 1.00E+06 sej/j, respectively. The calculated transformity value was multiplied with energy of pulp (7.66E+12 J) and electricity (3.96E+11 J) to find the individual emergy. The emergy of the pulp and electricity are 3.98E+17 sej and 3.96E+17 sej, respectively. The sum total of output emergy was 7.94E+17 sej (Table 5.2). The total output emergy is higher than total input emergy, 3.98E+17 sej (Table 1). This is against the emergy algebra rule 4, which states, the sum total of output emergy cannot be greater than input emergy. This makes the conventional transformity calculation method inappropriate in emergy accounting in co-production system.

The transformity value calculated applying energy/exergy values weighting method was 4.94E+04 sej/j (Table 5.2). The emergy of the co-products, pulp and electricity are 3.78E+17 sej and 1.95E+16 sej, respectively. The sum of total output emergy was 3.98E+17 sej. The total output emergy is equal to the input emergy (Table 5.1). However, in this method the single transformity was applied in the emergy calculation of co-products. This is against the emergy algebra rule 3, which states the transformity of individual product are different in co-products. Only in the split product systems each product has similar transformity. Therefore, this method lead to an inaccurate emergy calculation in co-production systems.

Transformity of pulp and electricity calculated through MPQM are 4.69E+04 sej/j and 2.43E+03 sej/j, respectively (Table 5.2). The emergy of pulp and electricity calculated by multiplying with its respective energy and transformity resulted to 3.60E+17 sej and 9.60E+14 sej, respectively. Applying the MPQM, the transformity and emergy value of the main product (pulp) is higher than the side product (electricity). Similarly, the sum of the total output emergy, 3.60E+17 sej/j (Table 5.2) is lower than the total input emergy, 3.98E+17 sej/j (Table 5.1), which is in accordance to the emegy rules. Therefore, the MPQM follows all the rules stated in emergy algebra. This states to prove that the MPQM is valid method in emergy accounting in co-production systems.

5.4 Efficiency analysis and its implications

Production efficiency of pulp production industry is analyzed based on the relations between the joint transformity (T_{xy}) and weighted average of the transformities(τ_{xy}) stated by Bastianoni and Marchettini (2000). If the joint transformity of co-product is less than the weighted average of the transformities $(\text{i.e.}\, T_{xy} < \tau_{xy})$, then the production process is considered efficient in term of resource and energy use. As such, co-production process will induce less stress to the environment and the total yield of the production system will be higher (Bastianoni and Marchettini, 2000). The individual transformity value estimated through MPQM was applied for the calculation of the joint transformity and the weighted average of the transformities.

$$\text{Joint Transformity } (T_{xy}) = \frac{B_{xy}}{E_x + E_y} = \frac{3.68E+17}{7.66E+12+3.96E+11} = 4.94E + 04 \text{ sej/j}$$

$$\text{Average weighte transformity } (\mathrm{T}_{xy}) = \frac{E_x}{E_x + E_y} t_x + \frac{E_y}{E_x + E_y} t_y = \frac{B_x + B_y}{E_x + E_y}$$

$$= \frac{3.60E + 17 + 9.60E + 14}{7.66E + 12 + 3.96E + 11} = 4.47E + 04 \text{ sej/j}$$

The joint transformity and the weighted average of the transformities of the pulp production industry are 4.94E+04 sej/j and 4.47E+04 sej/j, respectively. The result shows, the joint transformity is greater than the weighted average of the transformities (i.e. $T_{xy} > \mathrm{T}_{xy}$). Hence, pulp production industry is not efficient in energy and resource consumption and this production is not sustainable in the long run. In other words, the total yield of the pulp industry is lower whereas the load to the environment created by the production system in terms of resource use is high. Therefore, this industry will produce numerous environmental problems in the coming future. Strategies towards reducing the environmental load should be implemented to enable long term sustainability.

5.5 CONCLUSIONS

The methodology of emergy accounting in co-production was studied by applying different methods, the conventional method, emergy/exergy values weighting method and MPQM through the case study of *Eucalyptus* pulp production. Previous methods such as the conventional method and the emergy/exergy values weighting method tend to give wrong transformity and emergy calculation of outputs in co-production system. Applying the conventional method, the total output emergy was higher than the total input emergy, which was against emergy algebra rule 4. Similarly, in emergy/exergy values weighting method the same transformity value was applied in emergy calculation of individual product in co-production. This was against the emergy algebra rule 3. The issue of transformity and emergy accounting in the previous method was solved by the MPQM. The transformity value calculated applying MPQM was different to the individual output and the total output emergy was lower than the total input emergy.

5.6 Future research question and directions

The MPQM is a newly proposed method for the transformity calculation in co-production systems. In this research, the proposed method was applied in the *Eucalyptus* pulp production with pulp as main product and electricity as side product. The emergy accounting with the application of MPQM shows the right direction because it follows all the rules as stated in the emergy algebra. However, an in-depth analysis of the contributions of the individual products in terms of energy and emergy contradicts the results. For example, the total energy of outputs (pulp and electricity) in joule unit is 8.06E+12 J. The energy content of the individual product, the pulp and electricity are 7.66E+12 J and 3.96E+11 J, which is 95% and 5%, respectively, for the total output energy. Similarly, the total output emergy of the products (pulp and electricity) is 3.60E+17 sej. The emergy of the individual co-products, pulp and electricity in total output emergy are 99.7% and 0.3%, respectively, and this shows the disparate result with the individual energy share. Although the MPQM follows all the rules as stated in the emergy algebra during emergy accounting in co-production systems, a further comprehensive analysis in terms of quantitative accounting of energy and emergy is required. Further application of the MPQM in other forms of co-production systems is also recommended in future works.

REFERENCES

Bastianoni, S., Marchettini, N. (2000). The problem of co-production in environmental accounting by emergy analysis. *Ecol. Modell.,* **129** (2), 187-193.

Brown, M., Ulgiati, S. (2004). Energy quality, emergy, and transformity: Ht odum's contribution to quantifying and understanding systems. *Biologi Italiani,* **34** (5), 58-67.

Brown, M.T., Odum, H.T., Jorgensen, S.E. (2004). Energy hierarchy and transformity in the universe. *Ecol. Modell.,* **178** (1), 17-28.

Brown, M.T., Ulgiati, S. (1997). Emergy-based indices and ratios to evaluate sustainability: Monitoring economies and technology toward environmentally sound innovation. *Ecol. Eng.,* **9** (1), 51-69.

Cao, K., Feng, X. (2007). The emergy analysis of multi-product systems. *Process Safety and Environmental Protection,* **85** (5), 494-500.

Drury, C.M., (2013). Management and cost accounting. Springer.

Geng, Y., Liu, Z., Xue, B., Dong, H.*et al.* (2014). Emergy-based assessment on industrial symbiosis: A case of Shenyang Economic and Technological Development Zone. *Environ. Sci. Pollut. Res.,* **21** (23), 13572-13587.

Geng, Y., Zhang, P., Ulgiati, S., Sarkis, J. (2010). Emergy analysis of an industrial park: The case of Dalian, China. *Sci. Total Environ.,* **408** (22), 5273-5283.

Herendeen, R.A., (2004). Energy analysis and emergy analysis—a comparison. *Ecol. Modell.,* **178** (1-2), 227-237.

Jain, P.K. (2000). Cost accounting. Tata McGraw-Hill Publishing Company Limited.

Jiambalvo, J. (2009). Managerial accounting. John Wiley & Sons.

Kamp, A., Østergård, H. (2013). How to manage co-product inputs in emergy accounting exemplified by willow production for bioenergy. *Ecol. Modell.,* **253,** 70-78.

Lei, K.P., Zhou, S., Wang, Z. (2014). Ecological emergy accounting for a limited system., 1. ed. Berlin, Heidelberg : Springer Berlin Heidelberg, Berlin, Heidelberg.

Li, L., Lu, H., Campbell, D.E., Ren, H. (2010). Emergy algebra: Improving matrix methods for calculating transformities. *Ecol. Modell.,* **221** (3), 411-422.

M. T Brown, Herendeen, R.A., (1996). Embodied energy analysis and emergy analysis. *Ecol. Econ.,* **19,** 219-235.

Odum, H.T., (1996). Environmental accounting: Emergy and environmental decision making, john wiley & sons, inc.

Odum, H.T., Odum, E.C., Brown, M.T., (1997). Environment and society in florida. Taylor & Francis.

Ren, J-M., Zhang, L., Wang, R-S. (2010). Measuring the sustainability of policy scenarios: Emergy-based strategic environmental assessment of the chinese paper industry. *Ecol. Complexity*, **7** (2), 156-161.

Vieira, R., Domingos, T. (2005). Discussion on emergy allocation in joint production and wastes. EMERGY SYNTHESIS 3: Theory and application of the Emergy Methodology, Preceeding from the Third Biennial Emergy Conference Gainesville, Florida

Wang, L., Ni, W., Li, Z. (2006). Emergy evaluation of combined heat and power plant eco-industrial park (chp plant eip). *Resources, Conservation and Recycling,* **48** (1), 56-70.

Zhang, B., Chen, G.Q., Yang, Q., Chen, Z.M.*et al.* (2011). How to guide a sustainable industrial economy: Emergy account for resources input of chinese industry. *Procedia Environ. Sci.,* **5,** 51-59.

Zhang, L.X., Hao, Y., Chang, Y., Pang, M.Y.*et al.* (2017). Emergy based resource intensities of industry sectors in china. *J. Cleaner Prod.,* **142,** 829-836.

Zhe, L., Yong, G., Hung-Suck, P., Huijuan, D.*et al.*, (2016). An emergy-based hybrid method for assessing industrial symbiosis of an industrial park. *J. Cleaner Prod.,* **114,** 132-140.

CHAPTER VI

SUMMARY AND FUTURE RESEARCH

6.1 SUMMARY

6.1.1 Emergy assessment and prospects towards sustainable development of Nepal

The objective of this research was to apply emergy method in sustainability assessment of Nepal and recommend sustainable development policies. For the sustainability assessment, social, economic and environmental data of Nepal from 1998 to 2015 was analyzed through emergy method. Based on the real emergy parameters calculated, simulation of emergy parameters was done applying STELLA modeling program and sustainable policies for Nepal was recommended. The following conclusions were made based on the results:

1. The total emergy use of Nepal was increased by 342.13% in those seventeen years. Similarly, emergy use per capita was also increased by 248.44%.
2. Extraction of non-metallic minerals (marble, quartz, limestone, talc, etc.) has increased by 224.19%.
3. From 1998 until 2003, the export and import of Nepal was equal. However, after 2003, imports exceeded exports and trade loss was increased.
4. Larger import of non-renewable resources such as fossil fuels and metallic minerals has increased EIR of Nepal.
5. In seventeen years, the EYR of Nepal has decreased gradually from 4.92 in 1998 to 1.36 in 2015. This accounts for the decrease in the self resource production of Nepal and its dependence on other countries for resource fulfillment.
6. The ELR was increased from 0.58 in 1998 to 5.98 in 2015. The simulation result showed that the ELR will increase more than 25 in next twenty five years with large probability of environmental disaster in future
7. The ESI was lowered from 8.49 to 0.23 and this will further be lowered to 0.1 in future. This suggests the economic growth of Nepal was not sustainable and might be worst in coming days.
8. The sustainable development policies in term of non-renewable resource extraction, trade, erosion control and renewable resource use were recommended.

6.1.2 Natural disaster impact analysis by emergy method: The case of Gorkha-earthquake in Nepal

The objective of this research was to apply emergy method in the impact analysis of natural disasters to society, environment and the economy of Nepal. The case of the Gorkha-earthquake that hit Nepal in April 2015 was presented for the methodological application of emergy method in the impact analysis of natural disasters. The following conclusions were made in this research:

1. The social well-being of people in Nepal and the economy and environment of the country was significantly affected by the Gorkha-earthquake. The total emergy use, emergy use per capita, trade was decreased after the earthquake.
2. The total emergy use of the country was decreased by 10.28%. Similarly, per capita resource use was dropped by 12% and inflation was raised up by 18% after the earthquake.
3. The trade of the country was also greatly affected and as a result the export was lowered by more than 50%
4. However, due to lowering of economic activities inside the country the ELR was decreased from 6.79 before the earthquake to 5.98 after the earthquake.

6.1.3 Methodological aspect of emergy accounting in co-production branching systems

The methodology of transformity calculation in co-production system in previous researches was wrong because they failed to follow the emergy algebra. Through this research MPQM, a new method of transformity calculation was introduced. A case study of *Eucalyptus* pulp production was presented to valid the method. The MPQM solved the issues of transformity calculation in conventional method and emergy/exergy values weighting method and also follow all rules stated in emergy algebra.

6.2 RECOMMENDATIONS FOR FUTURE RESEARCH

The following recommendations for further research are suggested:

1. The emergy method in sustainability assessment could be replicated in sustainability assessment of other countries and sustainability assessment of different production systems such as, agricultural production system, wastewater treatment system, urban planning, etc.
2. Emergy method could be applied in impacts studies of many other natural disasters such as: floods, droughts, etc.
3. The modified physical quantity method for transformity calculation in co-production system network is newly proposed method. In this research, co-production system with only two outputs (electricity and pulp) was presented to prove the validity of MPQM. However, this new method should be applied in co-production system with more than two outputs such that the validity and applicability of method could be enhanced

Appendix A

Footnote to Table 3.1 and Table 4.2

Renewable Resources				
1	Sunlight			
	Land area	1.47E+11	m^2	CBS 2015
	Albedo	2.80E-01		Brown and Bardi (2001)
	Insolation	1.69E+07	$J/m^2/yr$	SWERA (2006)
	Energy	area × insolation × (1- albedo)		
		1.79E+18	J/yr	
2	Wind			
	Area	1.47E+11	m^2	
	Average wind speed	3.12E+00	m/s	SWERA (2006)
	Geostrophic wind speed	(average wind speed)×(10/6)		
		5.20E+00	m/s	
	Air coefficient	3.17E+00	kg/m^3	
	Drag coefficient	1.00E-03		
	Energy	(air coefficient) × (Drag coefficient) × (geostrophic wind)^3 × (3.14E+07 s/yr) x (Area)		
		2.06E+18	J/yr	
3	Rainfall, Geo potential			

	Area	1.47E+11	m^2	DHM (2015)
	Rainfall	1.80E+00	m/yr	
	Average elevation	5.90E+01	m	
	water density	1.00E+06	g/m3	
	Gibbs free energy	4.94E+00	J/gm	
	Gravity	9.80E-03	N/g	
	Run- off*	2.50E-01		
	Energy	(area) × (Rain) × (density of water) × (Mean elevation) × (Gibbs free energy) × (gravity) × (Run- off)		
		1.89E+17		
	* Elevation measured relative to the low point on the nation's border where rivers leave the country (Odum 1996)			
4	Rainfall, Chemical			
	Area	1.47E+11	m^2	
	Rainfall	1.80E+00	m/yr	DHM (2015)
	water density	1.00E+06	g/m^3	
	Gibbs free energy (G)	4.94E+00	J/gm	
	Gravity	9.80E-03	N/g	
	Energy	(area) × (Rain) × (density of water) ×(Gibbs free energy) × (gravity)		
		1.28E+16	J/yr	
5	Earth Cycle			
	Land area	1.47E+11	m^2	
	Heat flow per area	6.50E+01	mW/m^2	

	Energy	(area) × (heat flow per area) × (0.001 W/mW) × (31536000 sec/yr)		
		3.02E+17	J/yr	
Internal Transformation				
6	Agricultural Production	2.01E+07	mt/yr	Statistical information on Nepalese agriculture (2014/15)
	Energy	3.76E+17	J/yr	Sum of 80 agricultural products
	Emergy	5.54E+22	sej/yr	sum of emergy for 80 agricultural products
7	Livestock production	2.06E+06	mt/yr	Statistical information on Nepalese agriculture (2014/15)
	Energy	9.01E+15	J/yr	Sum of 11 livestock products
	Emergy	2.95E+22	sej/yr	Sum of emergy for 11 livestock products
8	Fishery production	6.95E+04	mt/yr	Statistical information on Nepalese agriculture (2014/15)
	Energy	(production)×1E+06 g/MT)×2600 j/g)		
		1.81E+14	J/yr	
9	Fuel wood Production	4.37E+05	m^3/yr	DoF (2015)
	Energy	(production)×(6.0E+5g/m^3×10400 j/g)		
		2.73E+15	J/yr	
10	Industrial round Wood	8.74E+03	m^3/yr	DoF (2015)
	Energy	(production)×(5.6E+05g/m3)×(10400 J/g)		
		5.09E+13	J/yr	
11	Hydroelectricity			CBS (2015)
	Production	3.63E+03	GWh/yr	

	Energy	(production)×(3.6E+12) J/GWh)		
		1.31E+16	J/yr	
12	Total electricity used	5.00E+03		CBS (2015)
	Energy	(consumption)×(3.6E+12 J/GWh)	GWh/yr	
		1.80E+16	J/yr	
Non renewable Resources from within system				
13	Top soil loss			
Forest Land		5.75E+06	ha	DoF (2015)
	Erosion rate	1.40E+01	mt/ha/yr	Shrestha (1977)
	Soil Loss	(area) x (erosion rate) x (1.0E+6 g/mt)		
		8.06E+13	g/yr	
	Energy	(Total soil loss) × (0.07 gOM/g sed) × (3.6 kcal/g) × (4186 j/kal)		
		8.50E+16	J	
	Agriculture land	4.39E+06 ha		
	Erosion rate	2.80E+01	mt/ha/yr	Shrestha (1977)
	Soil Loss	(area) × (erosion rate) × (1.0E+6 g/mt)		
		1.23E+14	g/yr	
	Energy	(Total soil loss) × (0.07 gOM/g sed) × (3.6 kcal/g) × (4186 J/kal)		
		1.30E+17	J	
	Total energy	2.15E+17 J/yr		

14	Coal Production	1.19E+03	mt	Economic Survey (2014)
	Energy	(Production)*(1.93E+10 J/MT)		
		2.29E+13	J/yr	
15	Non metallic Production	1.72E+06 mt		Economic Survey (2014)
	Emergy	1.63E+22	sej/yr	
	Imported Sources			
16	Fuels			
Petrol		1.76E+06	bbl/yr	NOC (2015)
	Energy	8.66E+15	J	
	Emergy	1.69E+21	sej/yr	
	Diesel	5.59E+06	bbl/yr	NOC (2015)
	Energy	3.14E+16	J	
	UEV	1.89E+05	sej/J	
	Emergy	5.94E+21	sej/yr	
	Aviation Fuel	8.64E+05	bbl/yr	NOC (2015)
	Energy	4.72E+15	J	
	UEV	1.92E+05	sej/J	
	Emergy	9.06E+20	sej/yr	
	Furnace oil	5.47E+03	bbl/yr	
	Energy	3.15E+13	J	

UEV	1.89E+05	sej/J	
Emergy	5.96E+18	sej/yr	
LPG	2.33E+05	mt/yr	NOC (2015)
Energy	1.14E+16	J/yr	
UEV	8.05E+04	sej/J	
Emergy	9.21E+20	sej/yr	
Anthracite	0.00E+00	mt/yr	NOC (2015)
Energy	0.00E+00	J	
UEV	1.37E+05	sej/J	
Emergy	0.00E+00	sej/yr	
Bitumen	0.00E+00	mt/yr	NOC (2015)
Energy	0.00E+00	J	
UEV	1.37E+05	sej/J	
Emergy	0.00E+00	sej/yr	
Coal	0.00E+00	mt/yr	NOC (2015)
Energy	0.00E+00	J	
UEV	1.16E+05	sej/J	
Emergy	0.00E+00	sej/yr	DoC (2015)
Kerosene	1.15E+05	bbl/yr	
Energy	4.84E+14	J	
UEV	1.92E+05	sej/J	
Emergy	9.30E+19	sej/yr	NOC (2015)

	Total energy in Fuel	5.68E+16	J/yr	sum of 9 fuels
	Total Emergy in Fuel	9.55E+21	sej/yr	sum of emergy of 9 fuels
17	Metals Import	2.02E+12	g/yr	DoC (2015)
18	Non metallic minerals Import	5.45E+12	g/yr	DoC (2015)
19	Food and agriculture products import	2.27E+12		DoC (2015)
	Energy	4.30E+16	J/yr	
20	Livestock, meat, fish import	2.99E+11		DoC (2015)
	Energy	8.35E+15	J/yr	
21	Plastic and synthetic rubber	3.74E+10	Rs/yr	DoC (2015)
		3.80E+08	$/yr	
22	Chemical Import	1.82E+12	g/yr	DoC (2015)
23	Finished products	7.33E+10	Rs/yr	DoC (2015)
		7.45E+08	$/yr	
24	Machinery, transportation equipments	1.78E+11	Rs/yr	DoC (2015)
		1.81E+09	$/yr	
25	Service in Import	7.98E+09	$/yr	DoC (2015)

	Exports			
26	Metals	1.36E+11	g/yr	DoC (2015)
27	Non metallic minerals	1.20E+09	g/yr	DoC (2015)
28	Food and agriculture products	3.54E+11	g/yr	DoC (2015)
	Energy	9.87E+15	J/yr	
29	Livestock, meat , fish	2.93E+10	g/yr	DoC (2015)
	Energy	1.20E+09	J/yr	
30	Plastic and synthetic rubber	3.00E+09	Rs/yr	DoC (2015)
		3.05E+07	$/yr	
31	Chemicals	4.06E+11	g/yr	DoC (2015)
32	Finished Products	3.91E+10	Rs/yr	DoC (2015)
		3.97E+08	$/yr	
33	Machinery and transportation equipments	6.37E+08	Rs/yr	DoC (2015)
		6.47E+06	$/yr	
34	Service in export	8.65E+08	$/yr	DoC (2015)
35	Tourism	5.44E+08	$/yr	MCTCA 2015

Appendix B

(Footnote to Table 5.1)

Resources for Eucalyptus Production				
1	Sunlight			
	Insolation	6.49E+09	J/m^2	Institute of Ambient, 2003
	Area	2.30E+04	m^2	
	Albedo	0.3		
	Energy	area × insolation × (1- albedo)		
		1.04E+14	J	
2	Rain			
	Area	9.14E+05	m2	To produce 1000 Ton of *Eucalyptus*
	Rainfall (water)	0.7	m	Water required to produce 1000 Ton of eucalyptus
	water density	1.00E+06	g/m3	
	Energy	Area×rainfall×water density		
		6.40E+11	g	
3	Nutrient loss in during top soil Loss			Nutrient loss are K_2O_5 and CaO
	Energy	2.30E+04	g	Value from Vieira, 2000
4	Fuel			
	Crude oil mass	1.46E+03	kg	Salgueiro et. al. 1996 cited froı Vieira 2002
	Specific energy	4.40E+07	J/kg	http://wec.ankara.edu.tr/wec/enersour.html.
	Energy	Oil mass× specific energy		
		6.44E+10		

5	Coal			
	Coal used	0.17	kg	
	Specific energy	29300	kJ/kg	
		29300000	J/kg	
	Energy	4.98E+06		
6	Natural gas			
	Gas used	2.03	kg	
	Specific energy	40370	kJ/kg	
		4.04E+07	J/kg	
	Energy	8.20E+07		
7	Nitrogen			
	amount	1.98E+06	g	Field survey
8	Phosphate			
	amount	5.80E+04	g	Vieira 2002
9	Potash	0	g	Vieira 2002
1(	Fuel			
	Cured Oil	4.50E+04	Kg	
	Specific energy	4.40E+07	J/kg	http://wec.ankara.edu.tr/wec/enersour.html.
	Energy	1.98E+12		
	Pulp Production			
1:	Water	2.75E+10	g	Vieira 2002
1:	Fuel			
	Crude oil	21351.05	Kg	Vieira 2002
	Specific energy	4.40E+04	KJ/Kg	

		4.40E+07	J/Kg	
	Energy	9.39E+11	J	
1:	Chemicals	9.92E+07	g	Vieira 2002
	Outputs			
	Pulp produced	610	Tons	Vieira 2002
		610000	Kg	
	Specific energy			

Appendix C

Forecasting of Emergy Parameters

Years	Electricity use per capita (sej/per)	Fuel use per capita (sej/per)	Emergy money ratio (sej/$)	Emergy per capita (sej/per.)	Export emergy (sej)	Import emergy (sej)	Non renewable emergy (sej)	Population	Total emergy use (sej)	ELR	EYR	ESI
2015	1.85E+14	3.18E+14	6.69E+12	6.15E+15	2.88E+22	1.24E+23	2.59E+22	2.80E+07	1.72E+23	6.65	1.39	0.209
2016	1.96E+14	3.44E+14	6.69E+12	6.43E+15	3.06E+22	1.30E+23	2.99E+22	2.84E+07	1.83E+23	7.12	1.40	0.197
2017	2.07E+14	3.73E+14	6.68E+12	6.70E+15	3.24E+22	1.37E+23	3.42E+22	2.89E+07	1.93E+23	7.59	1.41	0.186
2018	2.19E+14	4.04E+14	6.67E+12	6.98E+15	3.44E+22	1.43E+23	3.88E+22	2.93E+07	2.04E+23	8.08	1.42	0.177
2019	2.30E+14	4.39E+14	6.67E+12	7.32E+15	3.69E+22	1.51E+23	4.45E+22	2.97E+07	2.18E+23	8.67	1.44	0.167
2020	2.42E+14	4.77E+14	6.66E+12	7.73E+15	3.99E+22	1.59E+23	5.15E+22	3.02E+07	2.33E+23	9.37	1.46	0.156
2021	2.53E+14	5.19E+14	6.65E+12	8.14E+15	4.32E+22	1.68E+23	5.90E+22	3.06E+07	2.49E+23	10.08	1.48	0.147
2022	2.65E+14	5.64E+14	6.65E+12	8.55E+15	4.67E+22	1.76E+23	6.70E+22	3.11E+07	2.66E+23	10.82	1.50	0.139
2023	2.77E+14	6.13E+14	6.64E+12	8.83E+15	4.95E+22	1.83E+23	7.34E+22	3.16E+07	2.79E+23	11.39	1.52	0.134
2024	2.90E+14	6.66E+14	6.64E+12	9.11E+15	5.26E+22	1.89E+23	8.01E+22	3.20E+07	2.92E+23	11.97	1.54	0.129
2025	3.02E+14	7.23E+14	6.63E+12	9.39E+15	5.58E+22	1.96E+23	8.70E+22	3.25E+07	3.05E+23	12.57	1.55	0.124
2026	3.15E+14	7.84E+14	6.63E+12	9.73E+15	5.97E+22	2.03E+23	9.55E+22	3.30E+07	3.21E+23	13.28	1.58	0.119
2027	3.28E+14	8.49E+14	6.62E+12	1.01E+16	6.47E+22	2.12E+23	1.06E+23	3.35E+07	3.40E+23	14.12	1.60	0.114
2028	3.41E+14	9.19E+14	6.62E+12	1.06E+16	7.00E+22	2.20E+23	1.16E+23	3.40E+07	3.59E+23	14.97	1.63	0.109
2029	3.54E+14	9.94E+14	6.62E+12	1.10E+16	7.57E+22	2.29E+23	1.28E+23	3.45E+07	3.79E+23	15.85	1.65	0.104
2030	3.68E+14	1.07E+15	6.61E+12	1.13E+16	8.03E+22	2.36E+23	1.36E+23	3.51E+07	3.94E+23	16.53	1.67	0.101
2031	3.81E+14	1.16E+15	6.61E+12	1.15E+16	8.52E+22	2.42E+23	1.45E+23	3.56E+07	4.10E+23	17.22	1.69	0.098
2032	3.95E+14	1.25E+15	6.61E+12	1.18E+16	9.04E+22	2.48E+23	1.55E+23	3.61E+07	4.26E+23	17.92	1.71	0.096
2033	4.10E+14	1.34E+15	6.60E+12	1.21E+16	9.68E+22	2.56E+23	1.66E+23	3.67E+07	4.45E+23	18.76	1.73	0.093
2034	4.24E+14	1.44E+15	6.60E+12	1.25E+16	1.05E+23	2.65E+23	1.79E+23	3.72E+07	4.66E+23	19.73	1.76	0.089
2035	4.38E+14	1.55E+15	6.60E+12	1.29E+16	1.13E+23	2.73E+23	1.93E+23	3.78E+07	4.89E+23	20.73	1.79	0.086
2036	4.53E+14	1.66E+15	6.60E+12	1.34E+16	1.23E+23	2.82E+23	2.08E+23	3.83E+07	5.12E+23	21.75	1.81	0.084

2037	4.68E+14	1.78E+15	6.59E+12	1.36E+16	1.30E+23	2.88E+23	2.19E+23	3.89E+07	5.30E+23	22.54	1.83	0.082
2038	4.83E+14	1.91E+15	6.59E+12	1.39E+16	1.38E+23	2.95E+23	2.30E+23	3.95E+07	5.47E+23	23.33	1.85	0.080
2039	4.99E+14	2.04E+15	6.59E+12	1.41E+16	1.47E+23	3.01E+23	2.42E+23	4.01E+07	5.66E+23	24.14	1.87	0.078
2040	5.14E+14	2.18E+15	6.59E+12	1.44E+16	1.57E+23	3.09E+23	2.56E+23	4.07E+07	5.87E+23	25.10	1.90	0.076

Appendix D

Reduction in ELR with an increase of renewable energy by 40% until 2040

Years	Electricity use per capita (sej/capita)	Emergy money ratio (sej/$)	Emergy per capita (sej/capita)	Export emergy (sej/yr)	Fuel use per capita (sej/capita)	Import emergy (sej/yr)	Non renewable emergy (sej/yr)	Total emergy use (U) (sej/yr)	EYR	ELR	ESI
2015	1.85E+14	6.69E+12	5.75E+15	2.88E+22	3.18E+14	1.11E+23	1.81E+22	1.61E+23	1.45	4.11	0.35
2016	1.96E+14	6.69E+12	5.97E+15	3.06E+22	3.44E+14	1.17E+23	2.09E+22	1.70E+23	1.45	4.39	0.33
2017	2.07E+14	6.68E+12	6.19E+15	3.24E+22	3.73E+14	1.23E+23	2.39E+22	1.78E+23	1.45	4.67	0.31
2018	2.19E+14	6.67E+12	6.40E+15	3.44E+22	4.04E+14	1.29E+23	2.71E+22	1.87E+23	1.46	4.95	0.29
2019	2.30E+14	6.67E+12	6.67E+15	3.69E+22	4.39E+14	1.36E+23	3.11E+22	1.98E+23	1.46	5.29	0.28
2020	2.42E+14	6.66E+12	6.99E+15	3.99E+22	4.77E+14	1.43E+23	3.60E+22	2.11E+23	1.47	5.69	0.26
2021	2.53E+14	6.65E+12	7.31E+15	4.32E+22	5.19E+14	1.51E+23	4.13E+22	2.24E+23	1.48	6.11	0.24
2022	2.65E+14	6.65E+12	7.63E+15	4.67E+22	5.64E+14	1.59E+23	4.69E+22	2.37E+23	1.49	6.53	0.23
2023	2.77E+14	6.64E+12	7.84E+15	4.95E+22	6.13E+14	1.65E+23	5.14E+22	2.47E+23	1.50	6.86	0.22
2024	2.90E+14	6.64E+12	8.05E+15	5.26E+22	6.66E+14	1.70E+23	5.61E+22	2.58E+23	1.51	7.19	0.21
2025	3.02E+14	6.63E+12	8.26E+15	5.58E+22	7.23E+14	1.76E+23	6.09E+22	2.69E+23	1.52	7.53	0.20
2026	3.15E+14	6.63E+12	8.52E+15	5.97E+22	7.84E+14	1.83E+23	6.69E+22	2.81E+23	1.54	7.93	0.19
2027	3.28E+14	6.62E+12	8.84E+15	6.47E+22	8.49E+14	1.91E+23	7.40E+22	2.96E+23	1.55	8.40	0.18
2028	3.41E+14	6.62E+12	9.16E+15	7.00E+22	9.19E+14	1.98E+23	8.15E+22	3.11E+23	1.57	8.89	0.18
2029	3.54E+14	6.62E+12	9.47E+15	7.57E+22	9.94E+14	2.06E+23	8.94E+22	3.27E+23	1.59	9.38	0.17
2030	3.68E+14	6.61E+12	9.67E+15	8.03E+22	1.07E+15	2.12E+23	9.55E+22	3.39E+23	1.60	9.76	0.16
2031	3.81E+14	6.61E+12	9.87E+15	8.52E+22	1.16E+15	2.18E+23	1.02E+23	3.51E+23	1.61	10.15	0.16
2032	3.95E+14	6.61E+12	1.01E+16	9.04E+22	1.25E+15	2.24E+23	1.08E+23	3.63E+23	1.63	10.54	0.15
2033	4.10E+14	6.60E+12	1.03E+16	9.68E+22	1.34E+15	2.30E+23	1.16E+23	3.78E+23	1.64	11.00	0.15
2034	4.24E+14	6.60E+12	1.06E+16	1.05E+23	1.44E+15	2.38E+23	1.26E+23	3.95E+23	1.66	11.55	0.14
2035	4.38E+14	6.60E+12	1.09E+16	1.13E+23	1.55E+15	2.46E+23	1.35E+23	4.13E+23	1.68	12.10	0.14
2036	4.53E+14	6.60E+12	1.12E+16	1.23E+23	1.66E+15	2.54E+23	1.45E+23	4.30E+23	1.70	12.67	0.13
2037	4.68E+14	6.59E+12	1.14E+16	1.30E+23	1.78E+15	2.59E+23	1.53E+23	4.44E+23	1.71	13.10	0.13
2038	4.83E+14	6.59E+12	1.16E+16	1.38E+23	1.91E+15	2.65E+23	1.61E+23	4.58E+23	1.73	13.54	0.13
2039	4.99E+14	6.59E+12	1.18E+16	1.47E+23	2.04E+15	2.71E+23	1.69E+23	4.72E+23	1.74	13.98	0.12

2040	5.14E+14	6.59E+12	1.20E+16	1.57E+23	2.18E+15	2.78E+23	1.79E+23	4.89E+23	1.76	14.51	0.12

CONFERENCE PARTICIPATION AND AWARD

1. Keshab Shrestha, Hung-Suck Park. Methodological Aspect of Emergy Accounting in Co-Production Branching Systems. Tokyo, Japan. (Oral presentation)
2. Keshab Shrestha, Angelo Earvin Sy Choi, Hung-Suck Park. Emergy for the Sustainability Assessment of Nepal Economy. Ulsan, South Korea

CERTIFICATE OF BEST PRESENTATION AWARD

ICENRM 2017 : 19th International Conference on Environment and Natural Resources Management hereby certifies that

Keshab Shrestha

has presented an outstanding work entitled

Methodological Aspect of Emergy Accounting in Co-Production Branching Systems

Keshab Shrestha, Hung-Suck Park

INTERNATIONAL SCIENTIFIC RESEARCH AND EXPERIMENTAL DEVELOPMENT

TOKYO, JAPAN

MAY 28-29, 2017