Doctor of Philosophy

Resource Flows in Countries and Industrial Parks towards Low-carbon Economic Growth

The Graduate School of the University of Ulsan

Department of Civil and Environmental Engineering

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Resource Flows in Countries and Industrial Parks towards Low-carbon Economic Growth

Advisor: Professor Hung-Suck Park

A Dissertation

Submitted to
the Graduate School of the University of Ulsan
In Partial Fulfillment of the Requirements
for the Degree of

Doctor of Philosophy in Environmental Engineering

by

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August 2020

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August 2020

Acknowledgement

I will forever be indebted to my supervisor, Professor Hung-Suck Park, for his untiring advice, constructive criticisms, corrections, comments, suggestions, and words of encouragement that greatly improved the quality of this research. I appreciate him a lot more for allowing me to participate in various international projects with the World Bank, International Finance Corporation (IFC), and the Korean Government that helped to strengthen my hands-on capacity. My sincere appreciation also goes to the lecturers of the Graduate School of Environmental Engineering especially to Professor Seok-Young Oh and Professor Byeong-Kyu Lee for courses they taught me. I strongly acknowledge the Korean Government for enormously supporting me with a four-year full scholarship to study at Pai Chai University and the University of Ulsan. The contributions of Dr. Liang Dong of the Department of Public Policy, City University of Hong Kong, were enormous in shaping the outcome of this thesis. I appreciate my lab mates for their support as well, especially Da Ye Lee, Yujin Park and Izhar Hussain Shah.

I am incredibly grateful to my Dad, Tapufor Akamantso Fai Gideon Taka and my loving mum, Taka Justine Lum, for their relentless financial, spiritual, and moral assistance during my academic career. I am very much thankful to my siblings, especially Taka Peter, Taka Derick, Taka Hanson, Taka Elijah, and Penn Promise for always cheering me up during my most difficult moments in Korea. I am indebted to my friends, Mudoh Mercy, Muluh Mengie, Umenjoh Fon, Macgiland Sikod, Dr Che Awah Clovis, Professor Achiri, Awa George, Tangi Nneh, Nuigo Mbiengkong, Awondo Nelson, Nsoh Divine and everyone for their love and support throughout my PhD studies at Ulsan University in South Korea.

Finally, I shall forever remain grateful to the Lord Almighty, for his boundless grace and strength that saw me through.

Abstract

In most recent times, the world has been battling with a lot of environmental externalities and this has led to the desired industrial development. In the midst of vast resources on our planet, 10% of the World's population still lives in abject poverty. Diagnosis of resource flows in some countries and industrial parks towards low-carbon economic growth is very pertinent in global resource sustainability and the core of our research. The main tools of this research are material flow analysis, decomposition analysis, eco-industrial park transitioning, eco-efficiency analysis, policy analysis, and their combinations for the sustainable management of the earth's resources. This research is divided into two tiers, the national level resource flow and the industrial park transitioning level. At the national level, this research was conducted on the carbon emissions and resource efficiency of Ethiopia and resource dynamism of Central Africa. At the industrial park transitioning level, we developed an eco-industrial park monitoring tool and applied to Ulsan eco-industrial park, Korea and addressed the Hawassa Eco-industrial Park transition, in Ethiopia.

In national level study, firstly, the major determinants of energy-based CO_2 emissions in Ethiopia were examined between 1990 and 2017 using Kaya identity combined with Logarithmic Mean Divisia Index (LMDI) decomposition approach. Main findings revealed that energy-based CO_2 emissions were strongly driven by the economic effect (52%), population effect (43%), and fossil fuel mix-effect (40%), while the role of emission intensity effect (14%) was less pronounced during the study period. At the same time, energy intensity improvements reduced the CO_2 emissions by 49% indicating significant progress towards reduced energy per unit of gross domestic product (GDP) during 1990-2017.

Secondly, the economy-wide material flow analysis (EW-MFA) using four main categories and 13 sub-categories was conducted to characterize driving forces of domestic material

consumption for Ethiopia within the African Perspective. Results indicated that Ethiopia predominantly depends on biomass, while Nigeria and South Africa depend on fossil fuels. There were fluctuations of material flows from 1980s to early 2000s, which in line with the domestic instability in Ethiopia, caused by international/domestic economic crisis. Ethiopia presented the Environmental Kuznets Curve (EKC)-like curve on its resource consumption and economic development, thereby indicated a need to strengthen the resource efficiency counter measures.

Thirdly, the material flow from 1978 till 2017 for Cameroon, the Democratic Republic of Congo (DRC), and Gabon were analyzed, by applying an up-to date standardized methodologies of economy-wide materials flow accounting (EW-MFA). Decomposition analysis was used to examine the drivers of material use and the EKC hypothesis was tested to analyze undergoing dematerializing trends in this region. As per the results, Domestic Material Consumption (DMC) was highest in Cameroon (3.54%), followed by Gabon (3.33%) and lastly the DRC (1.84%). Material intensity (per capita DMC) for 2017 was highest in Gabon (5.87t), followed by Cameroon (4.09t), and lastly by the DRC (2.30t). Resource productivity in Gabon (1,567USD/t) was found to be very far ahead of Cameroon (362USD/t) and the DRC (178USD/t), indicating that the economy of Gabon is at high-end, and high-value oriented, with relatively low material intensity.

In industrial park level, firstly, eco-industrial park transition monitoring method is proposed. The static approach in monitoring eco-industrial park progress accounts for all inputs and output of all companies in the industrial park at the reference year, and the monitoring year. But to collect all the quality data is almost impossible and time consuming with a negligible improvement at an early stage to attract stakeholder attention. The proposed dynamic approach in monitoring eco-industrial park was simply applied to the companies that were participating in the industrial symbiosis activities. This approach would have an advantage of reducing the administrative workload of data gathering, and this would translate into less time-consuming in tracking the workload. Theoretically, assuming that they are 5 companies in an industrial park and there is one network every year, company to company network is one, the Static approach should increase network efficiency annually, as 1/10, 2/10, 3/10…9/10, while the dynamic approach would result to 1/1, 2/3, 3/4…9/10. This method was then applied to the Ulsan Eco-industrial Park. Results indicated that the dynamic monitoring approach is more suitable to continuously monitor Eco-industrial Park performances. This dynamic monitoring approach can be easily applied to evaluate the economic, environmental, and social performance of EIP's, and this will mobilize stakeholders such as policy makers, park managers and tenant companies, to support and participate in EIP activities even more.

Additionally, Industrial Parks are effective tools towards the sustainable development of an economy. Green industrialization pathway by employing EIP development policy will go a long way to achieving economic buoyancy, sustainable industrial development, and an environmental appraisal in Ethiopia. This chapter is based on practicality of research into business development (R&BD), Korean EIP transition approach being applied to Hawassa Industrial Park in Ethiopia. This chapter presents industry situation and discusses the potential Industrial Symbiosis opportunities in HIP in Ethiopia by analyzing its demand for energy, utilization of its waste streams and locating potential symbiotic networks. Energy efficiency can be enhanced at company level by cleaner production technology such as compressed air, inverter, and LED lightening system. In addition, opportunities for water quality enhancement were identified in Hawassa Wastewater Treatment Facility (WWTF). Finally, sustainable sludge treatment was proposed by environmental infrastructure centered on IS business. This research proposes sustainable EIP transition potentials and draws insightful policy recommendations for HIP and Ethiopia.

The dissertation potentially contributes to resource management/environmental engineering in general, and to industrial ecology application in particular, in a number of ways. Firstly, the dissertation developed and applied the Kaya identity tool for carbon emission analysis towards a low-carbon economic growth. Secondly, the resource efficiency of several countries was analyzed based on their material flows and sustainability policy implications were made. Thirdly, we proposed a new dynamic eco-industrial park monitoring tool and applied it to Ulsan Eco-industrial Park, Korea and addressed issues in the Hawassa Eco-industrial Park transition, in Ethiopia. Finally, this dissertation provided critical insights on materialization and carbonization in the developing world, thus extending the application of industrial ecology to regions not studied before.

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CHAPTER ONE

Introduction

1.1 Overview

In order to promote sustained, inclusive, and sustainable low-carbon economic growth, industrial ecology tools are very instrumental. Industrial ecology deals with identifying all possible energy and material exchanges that allow mitigation of the resources used (e.g., materials and the environmental impacts of human activities for sustainable developments) [1]. This deals entirely with resource flows within systems and industrial processes and so to evaluate resource flows within, would improve on its efficiency and hence reduce environmental externalities. This resource efficiency can be enhanced using a number of approaches such as material recycling, energy recovery, cleaner production, product innovation, and industrial symbiosis; while it can be quantitatively assessed using a variety of tools such as material flow accounting tool, eco-efficiency assessment tool, life cycle assessment tool, emergy analysis tool, and eco-industrial park monitoring tool. Therefore, optimizing resource flows at the industrial and national levels requires an in-depth understanding of the materials involved and their flows in and out of the system boundaries. This would enable the design and execution of policy scenarios thereby emphasizing resources and economic sustainability as its guiding principles. Applying industrial ecology tools is expected to provide efficient resource transformation pathway towards sustainable economic and eco-industrial development in the African sub-region. Also, sustainable development can be achieved through contributions from resource flows within countries and at industrial park levels. Resource flows are resources which are neither renewable nor non-renewable and must be used where it occurs and replenishes itself. Humans are obliged to find a balance between the two to ensure the sustainability of resources in the future. The quantity and characteristics of resources can be distinguished by whether they are renewable, or non-renewable resources. Non-renewable resources can only be used once after extraction whereas renewable resources can be replenished so long as their environment remains unaltered. The dissertation aims at, contributing to the field of industrial ecology by extending its application to some African member countries.

1.2. Background: Resource flows in countries and industrial parks

Globally resource flows are very fundamental for the growth of countries and industries and extremely low resource consumption will not be ideal to support rapid low-carbon as well as high resource consumptions will definitely lead to huge environmental impacts [3]. Worldwide resources have indicated exponential growth and in 2015 material extraction went up to an all-time high of about 12tons per capita [4] out of which most ended up being consumed in the developed countries [5]. This means that low-income developing economies are consuming far less quantity of resources which could affect their survival and quality of life [6]. At the same time, developing countries consume resources inefficiently due to technological limitations and industrial structure. As a result, they are likely to consume more resources to produce an equivalent amount of economic output when compared with developed countries [7]. Industrial parks are great contributors towards national economic growth, and at the same time, they also act as a large source of environmental emissions due to extensive resource consumption [8]. Moreover, the intensity of material and energy consumption is dictated by the industry structure and its technological characteristics. The essence of the material flow analysis (MFA) is understood, through the measure of the material input and output. Material flow analysis (MFA) is the methodology for quantifying the stocks, flows, inputs, and losses of a resource. It is sometimes used for mixed materials (e.g., construction minerals) but more commonly is directed to a specific resource such as a particular metal or plastic. For specific resource applications, the methodology is sometimes termed substance flow analysis (SFA) [2].

It helps to understand he pathway and flux of each material flow in the whole system. This will reveal the composition and changes of the materials, reflect both the wealth and the pressure caused by economic activities will, illustrate the dynamic link between economic development and the natural environment. It will also help to find the potential of material use and environmental improvement, and then for us to effectively regulate and control the flow directions and quantities, in order to amend resource efficiency and cleaner production patterns and reduce carbon emission rates. In a word, it is an important way that leads to a resource-saving and environment-friendly society, and to achieve the goals of circular economy and sustainable development [9].

As the continent with the least developed industries, Africa has chosen industry as a significant engine of growth in the economy, by nurturing a large amount of industrial parks [10]. With the encouragement of international development partners, some African countries are addressing these environmental issues at the industrial park level to have efficient industrial output by developing eco-industrial parks (EIP). There has been some related literature on Africa's industrial ecology, symbiosis, and its success and limiting factors to EIP development. Therein, the researchers discussed greening of industrial parks [11,12] by assessing the parameters for industrialization in South Africa and Ethiopia; identified enabling policy to accelerate the transition to EIPs in Kenya with focus on the role of government policy in facilitating the development of EIPs [13] ; and the success and limiting factors for EIP development in Egypt based on analysis from a global perspective [14]. Even comparing with their counterparts in developing countries, industrial parks in Africa are still in their infancy. According to the build and recruit model proposed by [15], the target of Africa's EIP initiatives is to establish a planned EIP model by recruiting foreign enterprises on the basis of the weak transitional industrial base.

The dissertation further aims at contributing to the field of industrial ecology and national and industrial park level resource by extending its application to countries and industrial parks in transition. Moreover, to characterize nexus between resource flows and low-carbon economic growth, the dissertation further compares developing and under-developed countries in Africa for sustainable development.

1.3. Research objectives and questions

With respect to resource flows in countries and industrial parks transition towards, low-carbon economic growth, this dissertation employs a variety of environmental assessment tools: Material Flow Analysis tool, Decomposition Analysis tool, and the Eco-industrial Park Transitioning Mechanisms. The overall objective can be achieved by addressing the following research questions:

i) At the national level, what are the determining factors for energy-based CO_2 emissions in Ethiopia?

ii) How can African states respond to rising materialization and carbonization levels? What are their coping mechanisms for low-carbon economic growth in the future?

iii) At industrial level, how can we monitor and track progress efficiently in an eco-industrial park using the static and dynamic approach?

iv) What does it take for an industrial park to transit into an eco-industrial park?

v) What are the sustainable policies to adapt for sustainable development growth for resource flows at country level and at industry level?

1.4. Assessment tools and scope

The quantitative assessment tools used in this dissertation are solely based on the concepts of environmental engineering and industrial ecology. The methods used in this dissertation will include the following: material flow accounting (MFA), IPAT hypothesis, Kaya identity, Log-mean Divisia Index (LMDI) decomposition, Environmental Kuznets Curve (EKC) analysis, macro-policy analysis, and eco-efficiency assessment. These approaches will be used in a variety of combinations to address our research questions. The results based on the above-described assessment methods will then be used to synthesize key policy recommendations for a transition towards a low-carbon economy and resource sustainability. The scope of this dissertation is branched in to two tiers the national level resource flows and the industrial park transitioning level. The scope of the "national level resource flows" research will be limited to Africa, covering countries such as (Ethiopia in East Africa, Nigeria in West Africa, Cameroon, Gabon, Democratic Republic of Congo (DRC), all in Central Africa and South Africa of about 40 years. Whereas the scope of the "industrial park transitions" research will be confined to developing a new indicator (Dynamic approach indicator) to track and monitor progress in an eco-industrial park, with a practical case of Ulsan eco-industrial park, South Korea. And finally, the transitioning from an industrial park to an eco-industrial park with the first industrial case in Africa (Ethiopia).

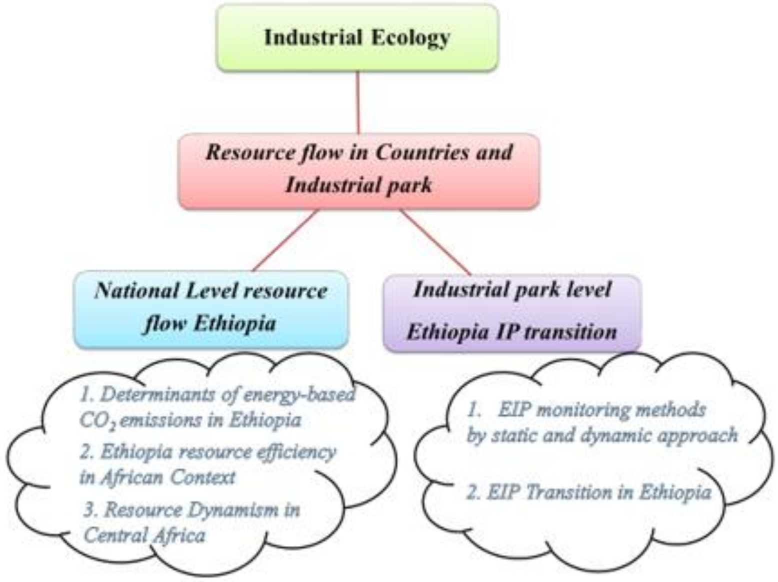

Figure 1.1: Structural organization of dissertation

1.5. Dissertation organization

This dissertation has been written in an updated manuscript format where in chapters composed of completely separate research ideas. Following this chapter (Chapter 1) which is the introduction, the next three chapters are dedicated to national level resource flows in countries. The research on "resource flows in countries" in chapters 2, 3 and 4, will cover contents such as economy-wide material flow analysis (EW-MFA), decomposition analysis, material use efficiencies, national-level policy implications, driving forces behind several environmental impacts, dematerialization trends, carbonization patterns, country comparisons, and future sustainability transition scenarios. In this quarter of the dissertation fastest growing economy in Africa (Ethiopia), Africa's largest economies (Nigeria and South Africa), chapters 2 and 3. Top 3 economies in central Africa (Cameroon, Gabon, Democratic Republic of Congo), chapter 4, have been assessed based on their material flows and resource efficiencies.

The research on "industrial park transitions" covers chapters 5 and 6. Chapter 5 dwells on the comparison of the static approach and dynamic approaches for monitoring EIP over a time series. The proposed method in this study is to adopt a dynamic approach in monitoring the industrial symbiosis and transition activities. This method simply is applied to the companies that are participating in industrial symbiosis activities. This would have an advantage by reducing the administrative workload of data gathering, and this would also translate into less time-consuming in tracking the workload. And chapter 6 explores a shift from Industrial Parks to Eco-industrial Parks in order to achieve economic buoyancy in Ethiopia. Then also the Eco-industrial Park roadmap, energy efficiency network, zero liquid discharge issues and sludge management mechanisms, are considered with lessons learned from the EIP of Korea.

Finally, Chapter 7 presents conclusions and policy implications of countries for sustainable development on the bases of: Low-carbon Economic Growth and the Sustainable Development Goals (SDGs) of 2030.

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CHAPTER TWO

Determinants of Energy-based CO_2 Emissions in Ethiopia

Abstract

Ethiopia, among the fastest growing economies worldwide, is witnessing rapid urbanization and industrialization that is fueled by greater energy consumption and high levels of CO_2 emissions. Currently, Ethiopia is the third largest CO_2 emitter in East Africa, yet no comprehensive study has characterized the major drivers of economy-wide CO_2 emissions. This paper examines the energy-related CO_2 emissions in Ethiopia, and their driving forces between 1990 and 2017 using Kaya identity combined with Logarithmic Mean Divisia Index (LMDI) decomposition approach. Main findings reveal that energy-based CO_2 emissions have been strongly driven by the economic effect (52%), population effect (43%), and fossil fuel mix effect (40%) while the role of emission intensity effect (14%) was less pronounced during the study period. At the same time, energy intensity improvements have slowed down the growth of CO_2 emissions by 49% indicating significant progress towards reduced energy per unit of gross domestic product (GDP) during 1990-2017. Nonetheless, for Ethiopia to achieve its 2030 targets of low-carbon economy, further improvements through reduced emission intensity (in the industrial sector) and fossil fuel share (in the national energy mix) are recommended. Energy intensity could be further improved by technological innovation and promotion of energy-frugal industries.

2.1 Introduction

A hike in global warming, the accumulation of carbon dioxide (CO_2) emissions and greenhouse gas (GHG) emissions have attracted global attention. Most recently, an increasing number of countries have embarked on the road to promoting industrialization and economic restructuring and this has consequently led to higher levels of energy related CO_2 emissions. In addition, rapid population growth and urbanization have been huge contributors to the changes in CO_2 levels around the globe [1]. Emissions of $CO_2$are also a strong environmental consequence of economic development around the world [2]. Africa, with the lowest Human Development Index (HDI) in the world, has an obvious need to strive for economic posterity at all costs in the years ahead [3]. Around the globe, there is undeniable ample evidence of increasing CO_2 emissions, with Africa ranked the most susceptible to global warming. With the rising share of fossil fuels as an energy resource, two major challenges have emerged especially for the developing economies, namely: increasing CO_2 emissions and lowering efficiency of energy consumption [4]. This region has set sustainable development targets of reducing CO_2 emissions by 80% from 1990 to 2050, with 1.44 global hectares (gha) per capita of development in ecological footprints and an increase in their HDI. Economic growth, high population and other factors have led to experience an increase in CO_2 emissions in Sub-Saharan Africa (SSA) countries [5]. The strong connection between energy use and economic growth has led to ever-increasing CO_2 emissions, and thus has directly affected the environment and local ecosystems [6,7]. In addition, a rapid depletion of non-renewable energy resources has also taken place worldwide [8] with huge implications for Africa's future economic development.

From a prospective viewpoint, Africa's future energy use is expected to be influenced by a fast-growing population and expanding economic activities, thus making the region more relevant from the global supply chain perspective [9]. Ethiopia is among the African countries that have achieved slow technological advancement, in the face of structural economic challenges, and have depended largely on rain-fed agriculture that is greatly damaged by droughts and witnessed overexploitation of natural resources [10,11].Ethiopia is also among the five nations (Nigeria, South Africa, Angola, Kenya and Ethiopia) that make up 70% of the gross domestic product (GDP) of SSA and 40% of its population [3]. As far as energy consumption is concerned, the total primary energy supply (TPES) in Ethiopia is primarily from biofuels and waste (Figure 1)**.** Although electricity generation is mainly hydroelectric (the country has a large hydropower infrastructure), yet the TPES comes from biofuels and waste followed by fossil fuels [12].

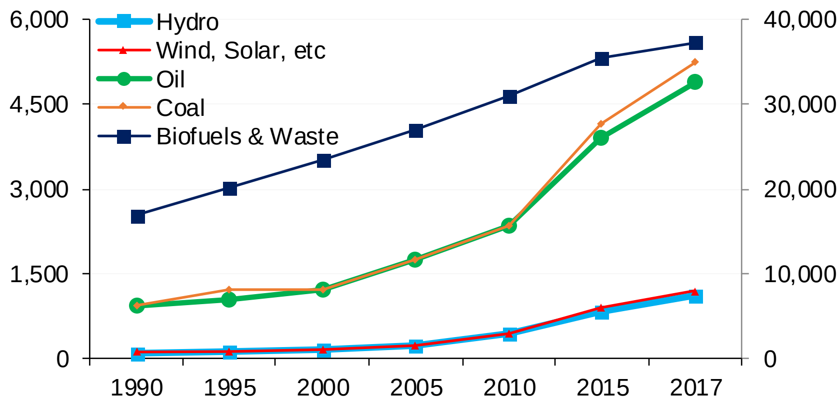

Figure 2.1: Total primary energy supply in Ethiopia measured as ktoe (1990–2017).

Meanwhile, many studies have confirmed Kaya identity (extended IPAT approach, where "I" stands for environmental impact, "P" for population, "A" for affluence and "T" for technology) as a tool to assess a variety of determinants (population, economic growth, energy intensity, fossil fuel mix and emission intensity) with a flexibility of adding more factors to investigate drivers of environmental impacts. Previously, different variables have been introduced into this Kaya framework such as the labor input effect [13], industrial structure effect [14], and fuel mix component effect [15]. The application of Kaya identity has been quite global with several studies for China, Europe and United States [16], G20 countries [17], Cameroon [18], and other parts of Africa [19–22]. Among different variations of Kaya identity, some groups of researchers have used the Autoregressive Distributed Lag (ARDL) and the Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT) models in decomposition related studies. The

STIRPAT model has been previously used for multi-country comparisons [23], and for different countries such as Ghana [24], Tunisia [25], the United States [26], China [27–29], and for several developing economies and economic sectors [30–32].

According to [33], within the global CO_2 emissions in 2018 as represented by 65.7 $MtCO_2$ in East Africa, Ethiopia accounts for only 15 $MtCO_2$. Although Ethiopia is ranked 94th in the world, it is extremely far from being one of the world's largest emitters of CO_2. It is currently the third largest emitter of CO_2 in East Africa, alongside Sudan (21 $MtCO_2$), Kenya (19 $MtCO_2$), Tanzania (13 $MtCO_2$), Uganda (5.8 $MtCO_2$), Republic of South Sudan (1.9 $MtCO_2$), Rwanda (1.1 $MtCO_2$), Somalia and Eritrea (0.7 $MtCO_2$) each, and Burundi (0.5 $MtCO_2$). Following the Paris Agreement, Ethiopia is set to reduce its GHG emissions by 64% below the business-as-usual levels by 2030. To succeed with this high emission reduction target in a low-carbon growth economy, knowledge of changes in the country's CO_2 emissions and their determinants must be assessed quantitatively in order to devise informed policy decisions.

To quantitatively determine the drivers of environmental impact, such as energy-based CO_2 emissions, the Logarithm Mean Divisia Index (LMDI) is a well-regarded decomposition analysis approach [34]. The main strength of this method is that it can be applied to more than two factors and it would give a perfect decomposition; it creates a link between the multiplicative and additive decomposition, thereby giving estimates of an effect on the sub group level [35–38]. In recent years, this approach has been applied at various levels, both national and sub regional [27, 39] such as in China [40–41], Latin America [42], the United States [30], Iran [43], India [44], Pakistan [45], Philippines [46], the European Union [47], Greece [48], Spain [49], Ireland [50], South Korea [51], United Kingdom [52], Brazil [53], and Turkey [54].

Until the present day, there has not been any single study on the decomposition of CO_2 emissions in Ethiopia, which considers all five determinants selected in this study (population, economy, energy intensity, fossil fuel mix, and emission intensity). As per the literature review, this is the first study to assess five factors using the Kaya identity and LMDI for CO_2 emissions in Ethiopia. The various determinants of carbon emissions studied can well provide more indicators that would expand the existing mitigative strategies in order to curb GHG emissions, and therefore help to attain the mitigation targets set by the country. Secondly, the data used in this study is the most recent available (including data for until 2017). In addition, the study of the determinants of CO_2 emissions in Ethiopia could help strengthen carbon mitigation practices in Ethiopia as well as at the African regional level. With this circumstance, this study aims to achieve following research objectives:

(i) Examine the determinants for Ethiopia's CO_2 emissions from 1990–2017.

(ii) Assess the effect of each determinant with its effect coefficient factor.

(iii) Elaborate on policy implications for Ethiopia towards achieving low-carbon and sustainable economic development.

The study analyses the effect of five determinants on Ethiopia's CO_2 emissions from 1990–2017: population, economic growth, energy intensity, fossil fuel mix and emission intensity, together with their effect coefficient for the very first time. An extended Kaya identity and LMDI decomposition are used to explain the various determinants of Ethiopia's CO_2 emissions. Africa being most susceptible to global warming issues and Ethiopia among the top CO_2 emitters in East Africa makes this study very pertinent in curbing emissions in developing African countries. Additionally, Ethiopia is emerging as a manufacturing hub of Africa with increasing consumption of total primary energy, which requires huge attention as concerns CO_2 emission issues. The rest of the article is organized as follows: in the next Section 2, we present the materials and methods used in the study, followed by Section 3 which presents the results, while Section 4 presents the policy implications and recommendations. Finally, Section 5 presents the conclusion of the study.

2.2 Materials and methods

The overall methodological framework applied in this study is illustrated in Figure 2.2. Firstly, the use of Kaya identity with LMDI approach was integrated to decompose changes in CO2 emissions in Ethiopia from 1990–2017. As shown, extended Kaya identity and LMDI approach served as the basis of analysis in which activity effect was analyzed for five different drivers of CO2 change. The extended Kaya identity and LMDI approach was used to analyze the population effect, economic growth effect, energy intensity effect, fossil fuel mix effect and emission intensity effect. The Kaya identity is a renewed version of the IPAT identity postulated previously [55–56].

Next, a policy analysis was performed to better understand the energy policy developments in Ethiopia based on official reports and policy documents, in relation to changing carbon emissions in the country. This analysis carried out to overview the situation from a regional perspective.

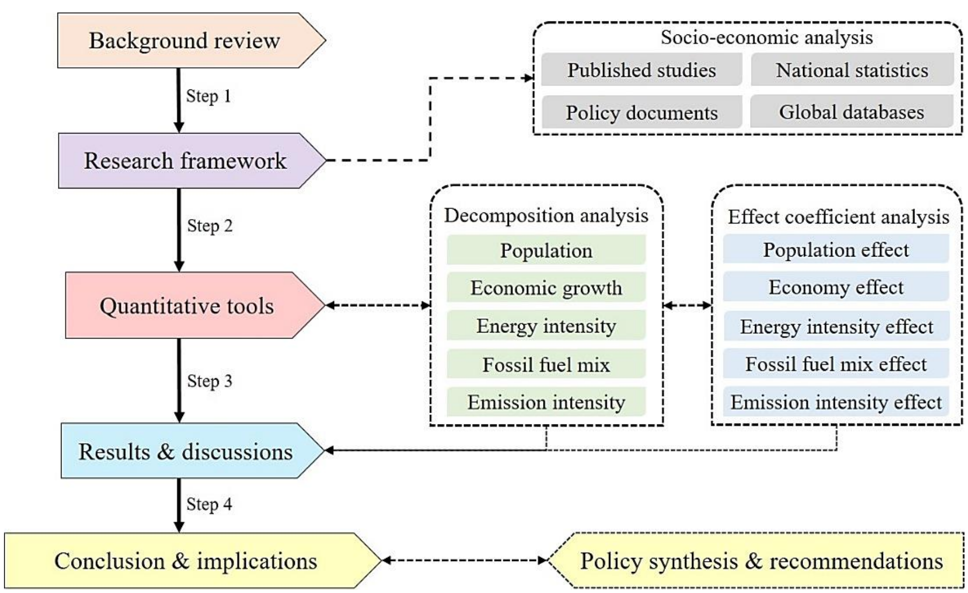

Figure 2.2: Methodological approach followed in this study.

2.2.1. Socio-economic status of Ethiopia

Ethiopia is located Northeast of Africa, at the horn of the continent, surrounded by Sudan to the East, Kenya to the North, Eritrea to the South, Djibouti to the West and Somalia to the Northeast [57]. In 2018, Ethiopia ranked second in SSA in terms of population (107.5 million) and fifth in economic status in Africa (2018) (GDP of 80.3 billion USD) [58]. During the last two decades, the country has undergone huge structural and economic changes, and experienced high economic growth, averaging 10.9% a year from 2005–2015, according to official data, and compared to its regional average of 5.4% [59,60]. As of 2018, the share of industries in national GDP was 28.1% which was considerably lower than that of services (40.0%) and agriculture (33.3%). But later, the Ethiopian economy recorded a 9% growth in 2018–2019, with a 12.6% growth by the industrial sector. With a shift from agriculture to manufacturing in recent years, Ethiopia is fast becoming the manufacturing hub of Africa with enormous progress made, especially following policies which include the Growth and Transformation Plan (GTP) [61]. Socio-economic statistics for Ethiopia from 1990–2017 are presented in Table 2.1.

Table 2.1: Socio-economic statistics for Ethiopia from 1990–2017 (The World Bank, 2018).

Year	1990	1995	2000	2005	2010	2015	2017 [b]
Population (Million)	47.9	57.0	66.2	76.3	87.6	100.8	106.4
GDP, Billion USD [a]	9.9	10.5	13.1	17.9	29.9	48.7	58.3
GDP per capita, USD	208.1	183.5	197.4	233.9	341.6	482.6	548.1
GDP Growth Rate (%)	2.7	6.1	6.1	11.8	12.6	10.4	9.5

[a] based on constant US dollar prices of 2010.
[b] Data are in intervals of 5 years with a last segment of two years to reflect the extent of the study period.

From a policy perspective, in response to global rising carbon emission levels, Ethiopia is a signatory to the United Nations Framework Convention on Climate change (UNFCCC), as ratified in 1994, followed by the Kyoto Protocol ratified in 2005, and the Paris Agreement ratified in 2017.

These protocols set certain nationwide emission reduction targets. Ethiopia has made several policy efforts to fulfill carbon emission mitigation, such as the 1994 Environmental Policy, the Climate-Resilient Green Economy (CRGE) Strategy, GTP policy (2010–2015 and 2015–2020), etc. The GTPs as its development framework, Ethiopia has registered GDP growth rates averaging slightly above 10% [62]. Poverty levels have been reduced substantially and Ethiopia is on track to meet most of the Millennium Development Goals (MDGs). Ethiopia is now embarking on GTP II, with the goal of moving towards a low-carbon growth economy, with middle-income status by 2025 [63]. The government of Ethiopia intends to curb its GHG emissions by 2030 to 145 $MtCO_2e$, in line with the 255 $MtCO_2e$ reductions projected by business-as-usual emissions with the integration of CRGE and GTP II, with the GTP II aiming at achieving a carbon neutral economy. Currently at 1.8 tCO_2e, Ethiopia's per capita GHG emissions are not high compared to global average but achieving its targets of reducing to 1.1 tCO_2e by 2030 is a priority concern [64].

2.2.2 Kaya identity approach

Kaya identity has been applied to many fields of energy, energy economics, environmental science, climate change, resource metabolism, etc.; examples include [50,65–67]. Here, assumptions of population growth, economic factors, and energy technology, as well as the carbon cycle itself play an important role in predicting the growth of CO_2 emissions. The conventional approach related to developing a series of emission scenarios depends on those factors and the use of those scenarios to manipulate mathematical models on how the atmospheric and climate systems will react with these inputs. At the therapeutic level given in the short section, we cannot begin to approach the complicated models. However, we can perform some simple calculations to at least give some meaning to some important factors. One way to establish some simple models of environmental problems is to start with the notion that the impacts are driven by the population, affluence, and technology, also called the IPAT equation.

$$\text{Environmental Impacts} = (\text{Population}) \times (\text{Affluence}) \times (\text{Technology}) \qquad (1)$$

The following application of IPAT for carbon emissions from energy sources is often referred to as the Kaya identity, which is a more concrete form of IPAT in this case. Kaya identity, a modified/extended form of the IPAT equation, is often used to study carbon emissions related with energy resources [68]. In this study, we have used the Kaya identity framework to calculate the environmental impact of energy consumption for Ethiopia during 1990–2017, as given by Equations (2)– (4). The factors in Equation (2) represent ratios which are part of the Kaya identity and these factors showcase the relationship between anthropogenic CO_2emissions and its determinants.

$$\text{C} = \text{Population} \times \frac{\text{GDP}}{\text{Population}} \times \frac{\text{TPES}}{\text{GDP}} \times \frac{\text{FFC}}{\text{TPES}} \times \frac{\text{CO}_2}{\text{FFC}} \qquad (2)$$

Here the environmental impacts "C" are represented by carbon emissions, other factors include population "P", affluence "A" expressed as GDP per person, technology "T" expressed as energy consumption per unit of GDP, and finally fossil fuel consumption "FFC" which is a fraction of TPES as fossil fuels. In this study, we have extended both the IPAT equation and Kaya identity as given by Equations (3) and (4). When incorporating the fossil fuel consumption (FFC) per unit of TPES (fossil fuel mix effect) we get Equation (3) or its simplified version in Equation (4)

$$\text{I}_t = \text{P}_t \times \frac{\text{GDP}_t}{\text{P}_t} \times \frac{\text{TPES}_t}{\text{GDP}_t} \times \frac{\text{FFC}_t}{\text{TPES}_t} \times \frac{\text{co}_{2\,t}}{\text{FFC}_t} \qquad (3)$$

and simplified as

$$\text{I}_t = \text{P}_t \times \text{A}_t \times \text{E}_t \times \text{F}_t \times \text{C}_t \qquad (4)$$

where I = CO_2 emissions (Mt), P = national population, A = affluence considered in terms of GDP per capita measured in constant US dollar prices of 2010, and T = technology. In Equation (4), P_t and A_t are the population and affluence at time t, E_t represents energy intensity in terms of TPES per unit of GDP measured in Mt per million USD, F_t represents fossil fuel mix effect, in terms of fossil fuel consumption (FFC) per unit of TPES, and C_t represents emission intensity in terms of CO_2 emissions per unit of FFC. All five impact categories in Equation (4) will be used to analyze their relative impacts on CO_2 emissions during 1990–2017 in Ethiopia.

2.3. Decomposition and effect coefficient analysis

The LMDI decomposition analysis proposed in [34] is popular in evaluating the determinants of carbon emissions in various case scenarios. Based on the Kaya identity, the following equations illustrate the universal form of LMDI decomposition analysis. At the start year (t = 0) and end year (t = 27), using Equation (5), changes in the total environmental impact "ΔI_t" is calculated.

$$I_i(t) = P_i(t) \times A_i(t) \times E_i(t) \times F_i(t) \times C_i(t) \quad (5)$$

Where ΔPt represents the population effect, ΔAt represents economy (or income) effect, ΔEt represents the energy intensity effect, ΔFt represents the fossil fuel mix (or substitution) effect, and ΔCt represents the emission intensity effect. Each of the activity effect parameters will be calculated using Equations (6)– (10), respectively:

$$\Delta P_t = \sum \frac{P_{t_1} - P_{t_0}}{\ln P_{t_1} - \ln P_{t_0}} \times \ln \frac{P_{t_1}}{P_{t_0}} \quad (6)$$

$$\Delta A_t = \sum \frac{A_{t_1} - A_{t_0}}{\ln A_{t_1} - \ln A_{t_0}} \times \ln \frac{A_{t_1}}{A_{t_0}} \quad (7)$$

$$\Delta E_t = \sum \frac{E_{t_1} - E_{t_0}}{\ln E_{t_1} - \ln E_{t_0}} \times \ln \frac{E_{t_1}}{E_{t_0}} \tag{8}$$

$$\Delta F_t = \sum \frac{F_{t_1} - F_{t_0}}{\ln F_{t_1} - \ln F_{t_0}} \times \ln \frac{F_{t_1}}{F_{t_0}} \tag{9}$$

$$\Delta C_t = \sum \frac{C_{t_1} - C_{t_0}}{\ln C_{t_1} - \ln C_{t_0}} \times \ln \frac{C_{t_1}}{C_{t_0}} \tag{10}$$

Following the decomposition approach, we also used effect coefficient analysis to further study the changing impact of drivers of CO_2 emissions over time. The effect coefficient of each driving force (effect) was calculated using Equation (11):

$$e_P = \frac{\Delta P}{I_{Abs}} ;\ e_A = \frac{\Delta A}{I_{Abs}} ;\ e_E = \frac{\Delta E}{I_{Abs}} ;\ e_F = \frac{\Delta F}{I_{Abs}} ;\ e_C = \frac{\Delta C}{I_{Abs}} \tag{11}$$

Where, $I_{Abs} = |\triangle P| + |\triangle A| + |\triangle E| + |\triangle F| + |\triangle C|$

2.4 Data collection

The CO_2 emissions data for Ethiopia were compiled using national emission records for the years between 1990 and 2017 and were complemented by energy use data from the International Energy Agency (IEA) database [12], where required. Country population and GDP were acquired from national economic reports and global databases, such as the World Bank database. For the policy analysis, there were publicly available policy documents, such as the CRGE, GTP (2010–2015 and 2015–2020) as describe in Section 2.1. Some of the official reports by the Government of Ethiopia and IEA were also analyzed.

2.5 Results

This section presents the outcomes of this work based on the Kaya identity and LMDI decomposition. Activity effect and its coefficient analysis are also discussed in this section.

2.5.1 Kaya identity analysis

Results for the five parameters considered in the Kaya identity analysis such as the changes in population, economy, energy intensity, fossil fuel mix, and emission intensity, during the study period, are illustrated in Figure 2.3. As observed over the study period, most parameters have increased steadily over the study period (1990–2017) while only energy intensity was seen to be declining over the same period. As per the statistics for the period 1990–2017, the population grew by 122.1% (from 47.9 million in 1990 to 106.4 million in 2017), while the per capita GDP rose by 163.4% (from 208.1 USD in 1990 to 548.1 USD in 2017). This is indicative of large significant economic prosperity achieved by Ethiopia during the study period. The population is a strong factor for CO_2 emissions, as there is a linear relationship; as it grows, human consumption patterns also swell, creating the need for fuel increases and increasing anthropogenic contributions to global emissions [69]. With the implementation of the second phase GTP policy (2015–2020), several industrial parks are being developed throughout the national territory, which plays an important role in boosting economic growth in Ethiopia [70]. Economic growth, asset consumption and financial affluence do affect the CO_2 emissions and could cause high consumption of non-renewable energy resources [71]. Endowed with a higher economic growth rate, Ethiopia was able to rapidly develop urban and industrial infrastructures, transforming some of the industrial parks to eco-industrial parks, and thereby uplifting living standards of the growing population [20]. Considering the technological advancement and foreign direct investments in the industrial, agricultural, and service sectors, a rising fuel mix share of 49.4% was observed (0.045 in 1990 to 0.89 in 2017). This indicated a high rate of consumption of fossil fuels in the country. The rising intensity of fuel mix was observed accompanied by rising economic growth and industrialization, indicating a rapid carbonization of the local economy. Similarly, emission intensity has also been on the rise in Ethiopia evidently by rising energy consumption. From 1990 to 2017, emission intensity increased from 2.46 to 3.22 (Mt CO_2 per ktoe of fossil fuels) indicating higher emissions being released. The country is, however, considered energy insecure because of rising emission intensity that is mainly due to changing industrial structures and rising CO_2 emissions from non-fossil fuel resources, such as biomass, wood, etc., as well as inefficient use of fossil fuel resources and the lack of high-efficiency energy conversion technologies, such as power plants, industrial boilers, steam generators, etc. [21]. Moreover, the early 1990s saw a drop in emission intensity mainly attributable to the industrial restructuring efforts in Ethiopia, whereas the years 2015–2017 have shown rising emission intensity as the industrial and GDP growth rates also increased sharply in those years.

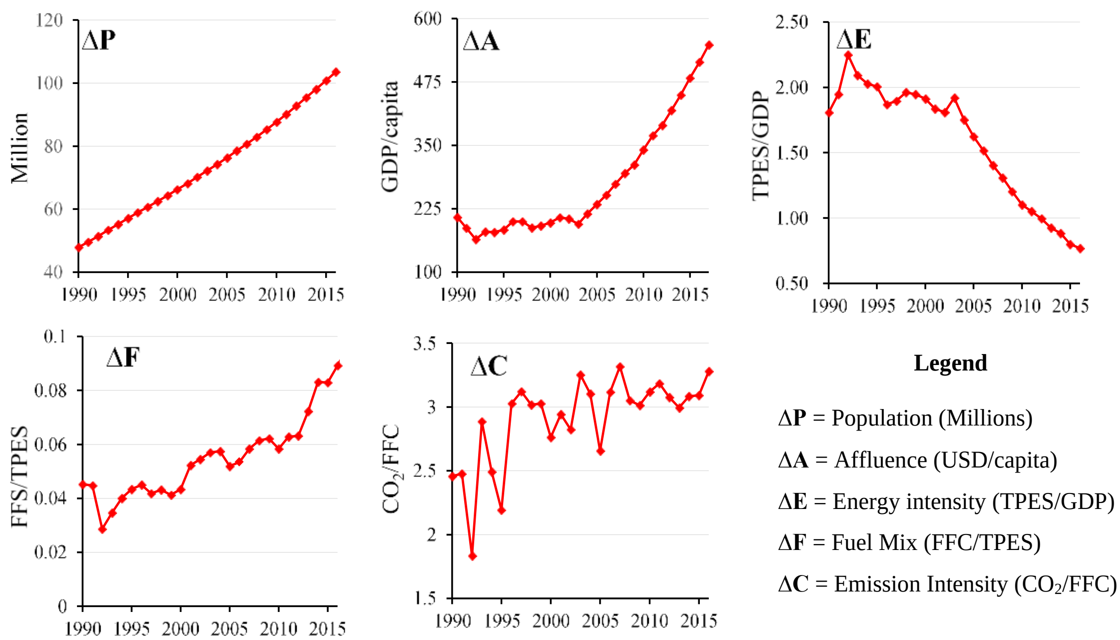

Figure 2.3: Temporal changes in selected parameters used in this study.

The energy intensity of Ethiopia surprisingly is the only factor that decreased over the study period, that is from 1.81 (toe per 1000 USD) in 1990 to 0.72 (toe per 1000 USD) in 2017, indicative of a significant drop. As Ethiopia heavily relies on biomass and waste for energy, improved cook-stoves, universal electrification, and efficient lighting as measures put in place by Ethiopia, have gone a long way to improve emission intensity in recent years [22].

2.5.2 Decomposition analysis

The five determinants of CO_2 emissions for Ethiopia are analyzed from 1990 to 2017. With an interval of five years and for 2016–2017, the determinants of carbon emissions and their relative contributions are presented in Table 2.2 (effect during the entire study period is also given in the last column). As shown, during the first half of the 1990s, CO_2 emissions were largely driven by emission intensity because the rising population growth was pushing for increasing use of fossil fuels. This was closely followed by higher population growth which also greatly affected the agricultural patterns and hence the carbon emissions in the country. It is well known that an increase in the population would put pressure on rising energy consumption patterns and hence cause higher impact on carbon emissions. The role of energy intensity in Ethiopia was less pronounced, yet it is important enough to be considered in national level policies. During the very same period, fossil fuel mix effect and affluence played a significant role in slowing down CO_2 emissions in Ethiopia. This can be attributed to the popular use of biomass, promotion of low-carbon energy sources, and improved methods of cooking (with environmentally friendly stoves) during that period. However, this was the only period when fossil fuel mix effect and economy effect were relatively low, and this helped to slow down the rate of carbon emissions significantly.

Table 2.2. Decomposition results for Ethiopia based on Kaya framework, %.

Effect (%)	5-Year Intervals					Full Period
	1990–1996	1996–2001	2001–2005	2006–2011	2011–2017	1990–2017
Population	50.98	50.85	63.24	41.13	26.79	42.65
Economy Effect	−9.86	13.35	86.90	113.26	63.83	51.75
Energy Intensity	8.38	−6.14	−86.01	−108.58	−61.17	−49.13
Fossil Fuel Mix	−0.97	51.70	10.15	47.82	68.68	40.26
Emission Intensity	51.47	−9.77	25.72	6.37	1.87	14.48

During the latter part of 1990's, change in CO_2 was mainly driven by the fossil fuel mix effect and population growth. Meanwhile, energy intensity and emission intensity played the smallest role in changing the carbon emissions. As the years went by, the economy effect, population factor and emission intensity caused a rise in CO_2 emissions from this point onwards. During 2001–2005, CO_2 emissions more than doubled from previous periods and thus indicated a rise in carbonization from national economic development, and the impacts that played a positive role were economy effect, population increase, and emission intensity. The period from 2006 to 2011 also saw a substantial increase in carbon emissions driven by economy effect, fossil fuel mix effect, and population effect. Thus, this period was highly responsible for increased CO_2 emissions in Ethiopia and apparently no effective effort was made towards carbon emission mitigation. This is usually the case with developing countries that always consider improvement in energy efficiency with the aim of reducing energy consumption patterns to output [19]. However, between 2011 and 2017, emission intensity was improved, and the population factor was greatly improved, both resulting in slowing down the rising CO_2 emissions. On the whole, during the entire study period, the major driver of CO_2 emissions was found to be affluence (promoting higher consumption patterns), followed by population influx (higher resource demand per capita); also followed closely was fossil fuel mix effect (rising fossil fuel shares), emission intensity (higher CO_2 emissions per unit of FFC). The only negative driver of CO_2 emissions during 1990–2017 was found to be energy intensity (more economic output per unit of TPES). Thus, in order to promote a low-carbon growth, energy intensity could be focused in the future to further slowdown the growth in carbon emissions [72].

a. Population effect and its coefficient

As shown in Table 2.2, population played a significant role in increasing carbon emissions during the study period (1990–2017). This is a clear indication that population growth is directly proportionate to CO_2 emissions and in future, population growth and urban demographic patterns will directly increase carbon emissions. Rising population is also an indication of increase in household size, high levels of urbanization, emerging infrastructure, increased transport facilities, increase in levels of energy consumption, change in lifestyle patterns and an ever-increasing exploitation of natural resources. Results for population effect and its coefficient for CO_2 emissions in Ethiopia from 1990–2017 are shown in Figure 2.4.

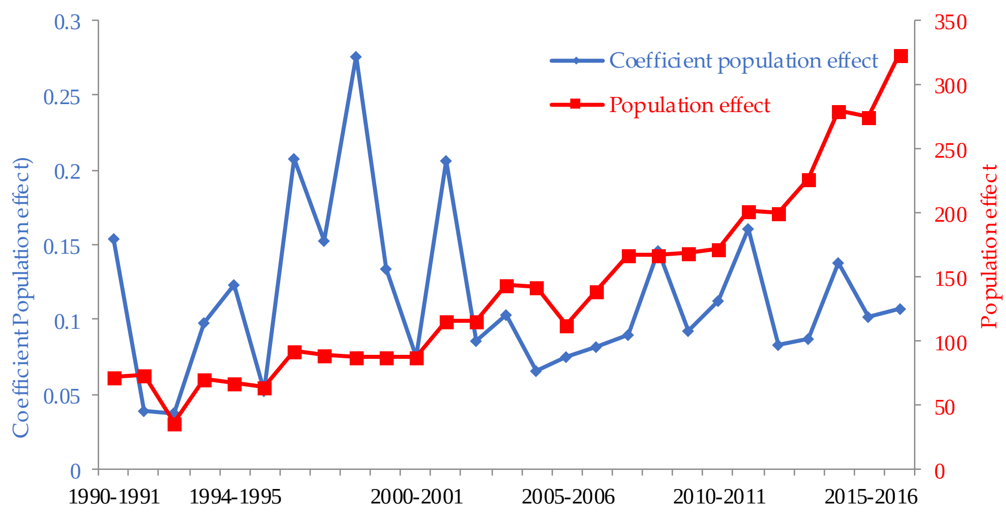

Figure 2.4: Population Effect and its Coefficient Effect for CO_2 Emissions.

As shown in Figure 2.4, population effect (colored red) has been fluctuating upward. Within the study period from 1995 to early 2000, the population was relatively stagnant, but with a rather high coefficient effect, the share of population effect is somehow at a standstill and other determinants in the study are relatively becoming stronger drivers of CO_2 emissions. For the entire study period, the coefficient population effect was reduced from 0.15 in 1990 to 0.10 in 2016, which is a 33% drop implying an overall drop with the impact share. Studies have proven that population growth contributes enormously to CO_2 emissions in both developed and developing countries [69] and with a steady rise in both populations and with CO_2 emissions in Ethiopia, much attention is needed to reduce the CO_2 emissions per capita. In this regard, some efforts made by the government of Ethiopia to promote low-carbon economic development should be appreciated. However, more efforts are required to protect their population from adverse effects of climate change such as extreme droughts through responsive action against climate change.

b. Economic growth effect and its coefficient

Economic growth is synonymous to affluence, standards of living and the socio-economic performance of a country. As Ethiopia has made a good economic progress during the study period, it has heavily impacted its CO_2 emissions as well. So far, Ethiopia has witnessed relatively fast growth in per capita GDP levels, higher consumption of finished goods, material intensive living patterns, and increased overall energy consumption. As given in Table 2.2, rising affluence was the major driver of carbon emissions in the country during 1990–2017. This can be seen at its peak between 2006–2011. Results for the economy effect and its coefficient for CO_2 emissions in Ethiopia from 1990–2017 are shown in Figure 2.5.

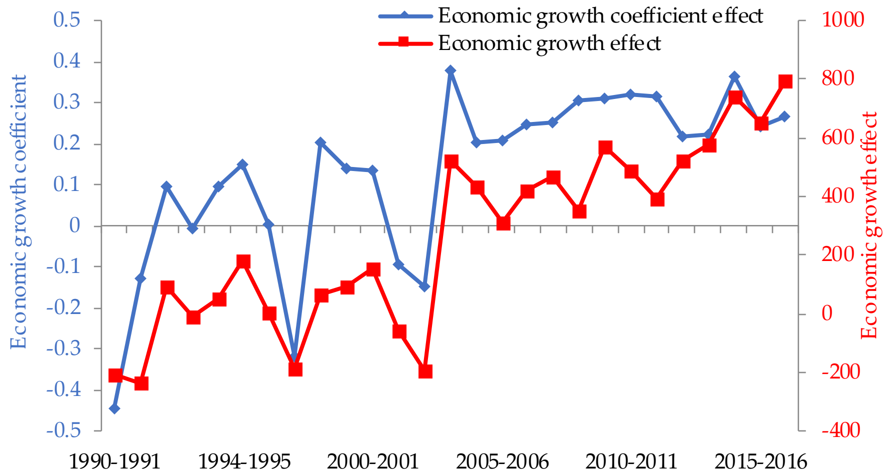

Figure 2.5: Economic growth effect and its coefficient for CO_2 emissions.

As seen in Figure 2.5, the economic growth effect was fluctuating in the early and late 1990s but assumed a sharp rise from the year 2000 onwards. Especially in the year 2003, the Ethiopian economy experienced an economic boom, and this had a bearing on economic growth, and by extension, on the standards of living. This did not come without a spinoff in CO_2 emission levels. However, the economic growth somehow experienced another fluctuation between 2004 till 2011 before having a dramatic increase until date. This also strongly accounted for the changes in CO_2 emissions. For the period 1990 to 2017, economic growth effect coefficient increased from −0.44 in 1990 to 0.26 in 2017, indicating a large rise in its overall impact share. This highlights the fact that desirable economic prosperity will invite unwanted environmental implications along the way. As a way forward, Ethiopia, and the countries alike, could achieve sustainable economic growth by promoting clean energy technologies, and by incorporating the concepts of material circularity in their urban, regional, and industrial development as part of their sustainable development strategy.

c. Energy intensity effect and its coefficient

In this study, energy intensity represented TPES per unit of GDP. It expresses the energy requirement of an economy with increasing values indicating higher energy demand from the economic processes. Moreover, as energy intensity rises, carbon emission intensity also rises indicating a direct relationship and a recoil effect of economic growth and higher energy demand. As shown in Table 2.1, energy intensity was the only driver of carbon emissions with the most negative values (apart from 1990-1991) with a positive value in the country during the study period, although it positively contributed to CO_2 emissions in Ethiopia. The trend for energy intensity in Ethiopia was a downward slope, indicating a drop in its values as the years went by. Results for energy intensity effect and its coefficient for CO_2 emissions in Ethiopia during 1990-2017 are shown in Figure 2.6.

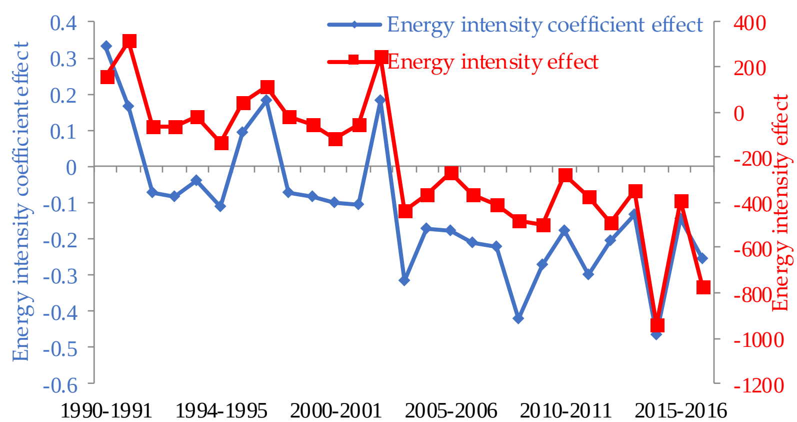

Figure 2.6: Energy Intensity Effect and its Coefficient for CO_2 Emissions.

As shown in Figure 2.6, energy intensity effect has dwindled over the last few decades. Especially during 2004–2005 and 2014–2015 when energy intensity effect decreased significantly, indicating its slowing effect on CO_2 emissions during these periods. Moreover, the energy intensity effect coefficient has been coincidental with the energy intensity effect, indicating its fluctuating relative impact on net carbon emissions has remained somehow similar. This means the share of energy intensity in 1990 has not changed much in 2017 as well. For the entire study period, the energy intensity effect coefficient decreased from 0.32 in 1990 to −0.26 in 2017, a substantial change in its overall impact share. With heavy reliance on biomass and waste for energy, and the lack of up-to-date energy technologies, Ethiopia needs to further improve its energy intensity to curb rising carbon emissions. To this end, hydropower is could be an important source of clean renewable energy in Ethiopia. Acknowledgement is made of the improved cook-stove initiative, efficient lighting systems and the universal electrification, which are promising efforts in Ethiopia to improve energy intensity [22]. Other measures to further improve energy intensity in Ethiopia could be to change the light bulbs to those with lower voltage (use of LED bulbs in lightening), consumption and minimization of energy waste, capacity building and public awareness towards energy savings.

d. Fossil fuel mix effect and its coefficient

Fossil fuel mix effect refers to the proportion of fossil fuels in TPES, which is an important factor in determining the changing impact of fossil fuels and non-fossil resources on carbon emissions. For the study period, Ethiopia's share of fossil fuels has been unsteadily rising, as seen in Figure 2.7. Presented in Table 2.2, the impact of fossil fuel mix effect has been second (after population effect) in rising CO_2 emissions. Results for the fossil fuel mix effect and its coefficient for CO_2 emissions in Ethiopia for 1990–2017 are shown in Figure 2.7.

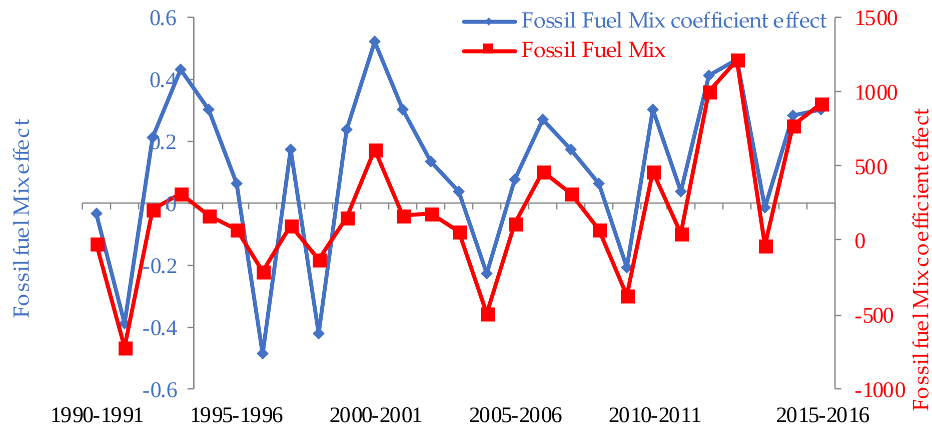

Figure 2.7: Fossil fuel mix effect and its coefficient for CO_2 emissions.

As shown above (Figure 2.7), the fossil fuel mix effect has mostly fluctuated during the study period with a peak shown for the year 2014. This indicates that the fossil fuel mix effect has been a uniform driver of carbon emissions in the country, and extraordinarily little structural change has occurred to minimize the fossil fuel mix effects. Although there have been periods when the fossil fuel mix effect helped in slowing down CO_2 emissions, its overall impact has been positive. Moreover, the fossil fuel mix effect coefficient has followed a similar trajectory to the energy intensity effect, indicating a strong coupling of the two factors. In the near future, alternate energy resources such as the wind energy, solar, bioenergy, and geothermal could be developed to support the existing hydroelectric resources. Short-term measures could include the use of fuel-efficient on-road vehicles, reduced travelling per person per car (e.g., carpooling and sharing) in order to minimize country's CO_2 emissions coming from fossil fuel combustion.

e. Emission intensity effect and its coefficient

Emission intensity effect refers to the emissions of CO_2 per unit fossil fuels that are consumed, and this can clearly predict the changing energy mix and technological advancement. With increasing demand for fossil fuels in Ethiopia, as the population grows with time, CO_2 emissions per unit fossil fuels consumed has increased, indicating higher emissions now as compared to the previous years. This can be partly attributed to the increased use of coal and petroleum fuels, as compared to natural gas. Moreover, ageing energy infrastructure and mobile sources (such as vehicles) also have a negative effect on Ethiopia's emission intensity. As shown in Table 2.2, the impact of emission intensity effect on CO_2 emissions has been negative during the late 1990s and positive during the rest of the period. Results for emission intensity effect and its coefficient for CO_2 emissions in Ethiopia during 1990–2017 are shown in Figure 2.8.

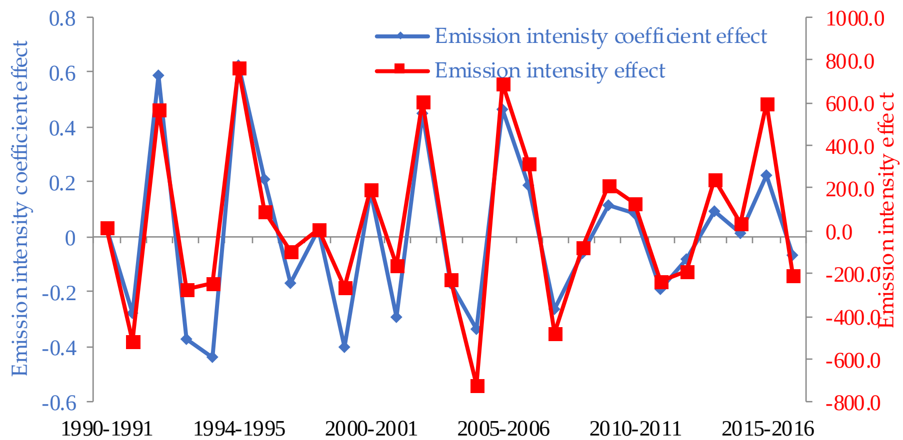

Figure 2.8: Emission intensity effect and its coefficient for CO_2 emissions.

As shown above (Figure 2.8), the emission intensity effect has been fluctuating during the study period 1990–2017. The emission intensity effect had the value of 14.48 during 1990–2017 (Table 2.2) which indicates less prominent impact on rising carbon emissions in comparison with other positive drivers. This means that current emission intensity levels are less harmful to the levels of CO_2 emissions when compared with economy effect, population effect, and fuel mix effect. Nonetheless, attention must be paid to minimizing emission intensity through innovative structural changes. With increasing carbon emissions from fossil fuels, the emission intensity effect coefficient has dropped slightly during 1990-2017 indicating a diminishing impact share for this determinant.

2.6 Policy Implications and Recommendations

In view of the present results and Ethiopia's target on limiting its net GHG emissions by 2030 to 145 Mt CO_2e, it is pertinent to draw up some policy insights based on this study and make key recommendations for the future. At the country level, rising CO_2 emissions and air pollution issues have made it necessary for Ethiopia to draw up strategies to combat these environmental adversities. In addition, as the Government of Ethiopia has put in place a number of strategies and programs aimed at enhancing the adaptive capacity against climate change, reducing the vulnerability of the country to CO_2 emissions still remains a great challenge. Policy initiatives such as CRGE and GTP are now greatly focusing agriculture, forestry, renewable energy, and advanced technologies to develop a green economy. In addition, issues related to the environment, forests and climate change are being actively discussed at the national level. During the last two decades, emissions have been shifting their major sources; formerly the emissions were mainly from the agricultural sector (including livestock, soils, forestry etc.), but currently a huge portion of the emissions are coming from the industrial sector (including manufacturing and building construction). Some of the important policy implications based on the results of the study are outlined below.

- From the population standpoint, organization of trainings and capacity building programs could be implemented regarding green issues and the issues of carbon emissions. These can be complemented by increasing public awareness on energy savings and conservation to curb rising carbon emissions and poor air quality issues currently faced by the country.
- Economic growth must be sustainable in nature. This means that renewable energy resources should be promoted at the national level and low-carbon economic growth should be part of the national economic development agenda.

- The use of clean and renewable energy needs to be encouraged at all levels of society. For example, the use of efficient cook-stoves as against the use of wood for fuels could be a good initiative specially for the regional communities and sub-urban populations.
- Leapfrogging to modern and energy-efficient technologies in transport and industrial sectors could support the achievement of their 2030 carbon mitigation targets if adequate policy decisions are taken.
- From the energy intensity viewpoint, more efforts could be directed to enhance higher GDP generation per unit energy consumed. This could be done by eliminating energy intensive sectors and promoting high-end production of finished goods and services. This, however, could involve multinational and regional cooperation with industrialized economies so that the transfer of technology is materialized.
- From a fossil fuel mix effect perspective, energy efficient strategies in industries (such as industrial symbiosis and waste-to-energy), housing (such as LED lighting, smart lighting, green construction), transportation (such as clean fuels, emission control systems in vehicles), and agriculture (such as solar powered grids, rain water harvesting) could be encouraged from a policy perspective. In addition, alternative sources of energy (such as geothermal, wind, solar) could also greatly help curb GHG emissions at the national level.
- From an emission intensity perspective, improvements could be achieved in all sectors of economy. For instance, in the agricultural sector, best farm practices for improving crop yield and livestock production could create co-benefits such as higher food security and reduced carbon emissions.

2.7 Conclusions

With a fast-growing economy such as that of Ethiopia, there are bound to be some adverse effects to the environment. Ethiopia has so far achieved a plausible economic growth especially in the last two decades. The environmental cost of economic progress is also quite high. This study examined major drivers, based on Kaya identity, in rising CO_2 emissions from fossil fuel consumption in Ethiopia from 1990 till 2017. Important outcomes of this study are presented below.

- From an analysis of the results obtained, the population of Ethiopia grew by 122% from 1990–2017, its GDP grew by 385% while CO_2 emissions increased by 450% portraying a true picture of economic buoyancy at the cost of massive carbonization.
- Based on the decomposition analysis, major influencers of rising CO_2 emissions in Ethiopia included economy effect (49.1%) followed by population effect (42.7%) and fossil fuel mix effect (40.3%). However, emission intensity effect (14.5%) was four times less harmful than economy effect.
- The only negative driver of CO_2 emissions was energy intensity effect which played the greatest role in mitigating rising carbon emissions in the country during 1990-2017.
- Based on the effect coefficient analysis, the shares of energy intensity effect and emission intensity effect have been declining in recent years, while the impact shares of population effect, economy effect, and fossil fuel mix effect have been on the rise meaning they could further cause carbon emissions to increase unless mitigation strategies are adopted.

These results, and policy implications discussed in this article, could very well be used as an instrument to promote low-carbon and sustainable economic growth in Ethiopia and other emerging countries of the world.

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CHAPTER THREE

Ethiopia Resource Efficiency in the African context

Abstract

Sustainable resource management together with resource efficiency is critical for fast-growing economies. The authors have conducted an innovative in-depth MFA research on Ethiopia's economy from 1988 to 2017 in the African context and this has added value to the current global MFA studies. Firstly, for Ethiopia's MFA, designed indicators reflecting resource utilization intensity and efficiency were analyzed and compared with other typical African economic giants (Nigeria and South Africa). Dematerialization analysis based on modified Environmental Kuznets Curve (EKC) was further applied, to investigate the coupling statements and trends of resource consumption and economic growth in Ethiopia compared with its regional countries. Finally, driving forces for the changes of material flows were investigated with decomposition approach based on IPAT (Impacts = Population × Affluence × Technology) in periods divided according to key domestic development stages. Results highlighted a fluctuation of material flows, which in line with the unstable development (1980s to early 2000s) periods in Ethiopia. While in its stable development (after early 2000s), the EKC-like curve was revealed, indicating increasing resource consumption stage and requirement on strengthening resource efficiency counter measures. IPAT analysis highlighted the critical role of economic instability on the fluctuation of DMC in the periods of 1980–1986, 1986–1996 and 1996–2002. While in the period of 2002–2008, with economy recovery and stable development, DMC increased and significantly offset by resource efficiency enhancement (DMC/GDP). In African context, compared with South Africa, a more developed country, Ethiopia did not reach the real dematerialization stage yet. While with comparison to Africa's biggest economy, Nigeria, Ethiopia

was by far achieving the material and economic prosperity. Therefore, with setting stable economic as priority, to enhance resource efficiency measures like cleaner production and regional eco-industrial development, market measures on resource price and tax, as well as decision support tool development are critical to Ethiopia's future sustainable resource management. With above highlights, this paper provides critical insights to the ever-improvement of Ethiopia and other African countries' resource efficiency.

3.1 Introduction

Economic buoyancy, growing urban populations, rapid technological advancement and industrial revolution in recent times has brought about over-exploitation of global resources. These global natural resources both renewable and non-renewable when exploited unsustainably cause huge environmental damage [3,4]. Most countries in Africa are fueled by natural resources and their extraction rates often overweight their consumption rates. Looking to the recent past, Africa is a net exporter of resources in terms of its Physical Trade Balance (PTB) and Raw Material Trade (RMT)[5]. The future of Africa is seen with a rapid growing population and extensive rates of economic activities [6]. Ethiopia with a fast growing economy, The country is undergoing huge structural and economic changes, and experiencing high growth, with Gross domestic product (GDP) averaging 10.9 % a year from 2005-2006 and also 2014-2015, according to official data, and compared to its regional average of 5.4 % [7,8]. In 2018, Ethiopia also stands as the fastest growing economy in the world.

Based on available literature, many studies have been carried out on MFA for national and regional policies. These include the following [9,10] with strong resource efficiency policy implications, and these studies have extensive knowledge on global resource use and patterns [11].

In western countries, MFA is a component of environment Previous studies provide a basis for better decision making through MFA or material accounting [9,10].

Best decisions can be made in a comprehensive perspective of resource efficiency and productivity, sustainable development and environmental issues considered in one unit [4].Using Economic worldwide Material Flow Accounting (EW-MFA), resource consumption and policy formulation plays a paramount role in moving an economy through a transition towards sustainable development. This can't be done without the alignment of good economic indicators such as the GDP [9,12–14]. However, resource use trajectories and country-wide comparisons are rather scarce especially for the large developing economies, thus, providing an opportunity to analyze past material transactions and provide policy recommendations for future sustainable resource management in the context of global resource supply chain. The different stages of economic development in every country is somehow due to peculiar economic conditions of the said country, structural characteristics of industry, technological innovation and regional resource efficiency [15–17]. Substantially the sustainability of the ecosystem depends on the maintenance and improvement of the planets life supportive capacity through the best ways to utilize its natural resources [18]. The developing economies have an advantage over developed economies due to their larger ecological surplus [19].

Therefore, conducting the MFA research on Ethiopia in the African context is important especially as African now spear heads the world with fast growing economies, and Ethiopia fast becoming the manufacturing hub of Africa, with number one position in world fast growing economies, this study would definitely complement global MFA studies. For fastest growing economies, an investigation on their material flows trends and socioeconomic drivers will be critical to uncover how these countries under different development statements and conditions can address their own opportunities and challenges on sustainable resource management. Till date there are no comprehensive studies on resource efficiency of Ethiopia, thus this paper is an innovation, which would portray the systematic in-depth analysis on material flows and resource efficiency.

The research would seek to give answers strictly to the following:

(1) What are the trends of material flows and their imperative indicators in Ethiopia in the past three decades?

(2) What are the main driving forces to the changes in resource consumption and efficiency in Ethiopia under various periods?

(3) Comparing with other African countries, can any periodical regular pattern of material flows be identified?

4) What critical policy insights can be achieved?

To address these issues, long time series analysis on the material flows and indicators in Ethiopia, as well as improved dematerialization analysis is conducted. We also apply the IPAT approach (Impact = Population × Affluence × Technology) to investigate the driving forces to the periodic changes of material flows, in order to provide critical policy insights for Ethiopia and other African countries with similar conditions, through clustering the periodical regular patterns. To our best knowledge, it is one of the first study to systematically analyze the material flows, indicators, dematerialization condition and driving forces in Ethiopia. The results of this research will not only contribute to the domestic resource management, but also provide valuable implications to other African countries. The paper is organized as follows: the introductory section commences, then the general socio-economic conditions of Ethiopia, with methods, indicators and data proceeding and the analytical results and the discussions, as well as policy implications. The paper ends with a conclusion to the study.

3.2 Material and methods

3.2.1 General conditions of Ethiopia

Figure 3.1: Map of Ethiopia

Ethiopia is located Northeast of Africa, at the horn of the continent, surrounded by Sudan to the East, Kenya to the North, Eritrea to the South, Djibouti to the west and Somalia to the Northeast [20]. In 2018, Ethiopia was ranked second in SSA in terms of population (107.5millions) and fifth in economic status in Africa (2018) (GDP of 80.3 billion USD) with just one party state and a well-planned economy [21]. The country is undergoing huge structural and economic changes, and experiencing high growth, averaging 10.9 % a year from 2005-2006 and also 2014-2015, according to official data, and compared to its regional average of 5.4 % [7,8]. This growth rate is all driven by government's investment in infrastructure, as well as sustained progress in the agricultural and service sectors. More than 70% of Ethiopia's population is still employed in the agricultural sector, but services have surpassed agriculture as the principal source of GDP. The state is heavily engaged in the economy. Ongoing infrastructure projects include power production and distribution, roads, rails, airports, and industrial parks. Key sectors are state-owned, including telecommunications, banking and insurance, and power distribution. Under Ethiopia's constitution, the state owns all land and provides long-term leases to tenants. Ethiopia’s foreign exchange earnings are led by the services sector - primarily the state-run Ethiopian Airlines, followed by exports of several commodities. While coffee remains the largest foreign exchange earner, Ethiopia is diversifying exports, and commodities such as gold, sesame, khat, livestock and horticulture products are becoming increasingly important. Manufacturing represented less than 8% of total exports in 2016, but manufacturing exports should increase in future years due to a growing international presence. Generally, the share of the industry’s GDP was road to have increased from 27% in 2017-2018 to 28.1% in 2018-2019. The share of the service sector also increased slightly from 39.2% to 40.0% but the share for agriculture dropped from 34.9% to 33.3% within the same years. But later, the Ethiopian economy recorded a 9% growth in 2018-2019, with also a 12.6% growth in the industrial sector, there was also 11% in the service sector and 3.3% in the agricultural sector. With a shift from the agricultural sector, through service sector to manufacturing sector in recent years, Ethiopia has become the manufacturing hub of Africa following and these enormous contributions are as a result of the Growth and Transformation Plan (GTP). [17]. One of the world’s oldest civilizations, Ethiopia has shown solid progress in socioeconomic fronts. The government aspires to reach lower middle-income status over the next decade.

Table 3.1: General socio-economic data of the three selected countries, as of 2018

	Ethiopia	South Africa	Nigeria
Population, million	112.08	58.56	200.96
Population rank (world)	12th	25th	7th
GDP, billion USD [a]	105.00	420.00	690.00
GDP rank (world)	66th	36th	28th
GDP rank (Africa)	7th	2nd	1st
Avg. GDP growth rate, 2018	2.61%	1.33%	2.60%
Per capita GDP, USD	801	6,606	2.366
Per capita DMC, tons [b]	4.8	14.4	3.6
GDP growth projection 2019	7.9%	7.6%	7.1%
GDP growth projection 2023	6.7%	7.8%	6.7%

[a] GDP figures are based on constant 2010-dollar prices from The World Bank (2017)

[b] DMC = domestic material consumption for 2008

Ethiopia is a member of the Common Market for Eastern and Southern Africa (COMESA) and the Inter-Governmental Authority on Development (IGAD). The country has also ratified several regional integration protocols. Cross-border financial activities/investments are constrained, however, by the absence of enabling legislation, particularly related to the harmonization of fiscal regimes, banking and insurance, and the stock exchange. Ethiopia is among the 44 countries that signed the protocol establishing the African Continental Free Trade Area (AfCFTA) in March 2018. The AfCFTA pledges to eliminate tariffs on 90% of goods and to gradually eliminate the remaining 10%. In addition, negotiations to join the World Trade Organization (WTO) and the Economic Partnership Agreement (EPA) with the European Union are ongoing. Merchandise exports increased by 1.4% to USD 2.9 billion in 2016/17 compared to last year. Coffee is the leading export, accounting for 30.4% of total exports earnings, followed by oilseeds (12.1%), pulses (9.6%), chat (9.4%), flowers (7.5%), and gold (7.2%). The leading six export items accounted for over 76.2% of total export earnings whereas largely unprocessed commodities account for over 90% of total merchandize export receipts, indicating the need to reduce export concentration. Ethiopia's imports from and exports to African countries accounted for 3.5% and 22.3% of total imports and exports, respectively, in 2016. The largest share of this trade is with countries in Eastern Africa. Merchandise imports decreased by 5.5% to 15.8 billion in 2016/17 compared to the previous year, reducing the trade deficit to USD 12.8 billion in 2016/17, which is about USD 1 billion lower than the previous year. Consequently, the overall balance of payments position posted a surplus of USD 658.6 million in 2016/17 compared to a deficit of USD 830.9 million in 2015/16.

3.2.2 Analytical framework

Analytical framework here refers to: First, a standard economy-wide resource Material flow analysis (EW-MFA) framework, three basic MFA indicators are analyzed, which include domestic material consumption (DMC), domestic extract (DE) and physical trade balance (PTB). They make up for further integrated indicators analysis and decomposition analysis. In addition, the Intensity indicators and resource productivity indicators are further applied and tested. This was compared with that of South Africa and Nigeria which are the strongest economies in Africa. This analytical framework can be seen in Fig 3.2.

Secondly, Improved dematerialization analysis based on Environmental Kuznets Curve(EKC): EKC analysis is prevailing and effective approach to investigate the statement and trend of dematerialization. Enlightened from [22], this paper conducted a modified dematerialization and EKC analysis on material flow and economic indicators of Ethiopia, with coefficient of log-linear coupling measured between DMC/capita and GDP/capita.

Finally, IPAT analysis is applied to investigate the periodic driving forces to the material flows change, so that policies insights for different stages can be obtained.

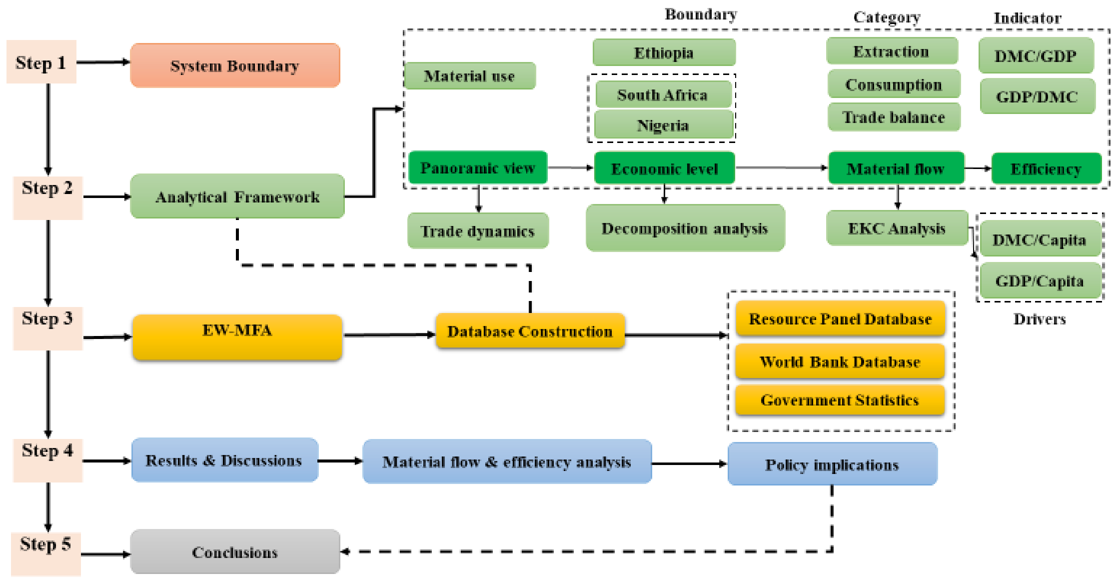

Figure 3: Analytical framework for this research

Ethiopia is the target country, while Nigeria and South Africa are selected because they are economic giants of Africa, to compare it as the fastest growing economy. The three countries represent, West East and Southern part of Africa. In conducting this study, most recent long-time series data, from 1978 to 2017, has been used as per the established guidelines [23]. As 2017 was the end year, the start year was selected to be 1978 considering past studies which have used datasets of 28 years [24], 29 years [17], 35 years [16], and 38 years [15]. The selected timeline of 40 years was considered to adequately cover both resource use patterns and policy developments in the region. A four-category demarcation of material flows was done into metal ores, fossil fuels, non-metallic minerals, and biomass which is in line with the standard guidelines [25]. Details of material categorization are given in Table 3.2.

Table 3.2: Material categorization used in this study

No.	Main category	Sub-category
1.	**Metal ores**	Ferrous ores
		Non-ferrous ores
2.	**Fossil fuels**	Coal
		Natural gas
		Oil shale and tar sands
		Petroleum
3.	**Non-metallic minerals**	For construction use
		For industrial/agricultural use
4.	**Biomass**	Crops
		Crop residues
		Grazed biomass/fodder crops
		Wild catch/harvest
		Wood

3.2.3 MFA approach and indicators

There is no previous economy-wide MFA studies Ethiopia. The analysis uses the most recent long-time series data, from 1988 to 2017, in compliance with established guidelines [23]. As complementation, we referred to the up-to-date and related studies [9,15,16,26] to design and define the mainly indicators. In summary, three basic indicators were applied, namely, domestic material consumption (DMC), domestic extract (DE), and physical trade balance (PTB). More indicators were analyzed based the combination of other socioeconomic indicator and these three indicators. Finally, the Environmental Kuznets Curve (EKC) is drawn based on the MFA indicators.

In detail, among different material flow indicators, DMC is an important factor representing territorial consumption of primary materials, while at the same time, taking imports and exports into consideration. The second material flow indicator refers to domestic extraction

(DE) within a territorial boundary and is a function of local material input used in national economic processes. It quantifies the amount of raw materials extracted in a given year from the natural environment and is an important indicator for domestic material availability [27].

Mathematically, DMC is calculated as: DMC = DE + imports – exports. The third material flow indicator refers to the intra-country material transactions i.e. physical trade balance (PTB), which can be used to determine the level of self-reliance of a country or a region for a specific material category. PTB indicates flow of materials from importing regions to the exporting regions. All material flows will be expressed in tons (t) or million tons (Mt), where required. Once we identify material flow and their scale, the next step is to analyze them in connection with local economic indicators. Material intensity was measured as material consumed per unit of GDP, while material productivity was calculated as economic value generated (in terms of GDP) per unit of material consumed (in terms of DMC).

3.2.4. Decomposition approach and analysis on driving forces

Finally, based on the MFA indicators, decomposition approach was applied to identify the driving forces to the resource utilization. The widely used equation in environmental analysis is the master equation that determines the environmental impacts driven by socio-economic and technological factors [28] and originally proposed by Ehrlich and Holdren (1971) as given by Eq. (1):

$$I = P \times A \times T \qquad (1)$$

Where I denote environmental impact, P accounts for population, A is the economic affluence indicator usually represented by GDP per capita, and T is the technological indicator measured in terms of environmental impact per unit of GDP, thus we can re-write the above equation as Eq. (2):

$$Environmental\ Impact = Population \times \frac{GDP}{capita} \times \frac{Environmental\ Impact}{unit\ of\ GDP} \quad (2)$$

As environmental impacts are influenced by all of the three components in the master equation, this necessitates a need to gain insights into the drivers of environmental impact [30], thus, leading to the decomposition of IPAT equation. Among the two widely used decomposition methods i.e. Laspeyres and Divisia index, LMDI is often recommended [30] and was employed in our analysis to decompose drivers of 'I' in the IPAT master equation. The additive factorial decomposition method has been selected due to its ability to report results in absolute quantity of DMC variations whereas multiplicative factorial decomposition in often used when relative contributions are required, however, both produce similar results [31]. As per our selected method, drivers of change in DMC can be calculated according to Eq. (3) to (6).

$$\Delta I = \Delta DMC = DMC_{t_1} - DMC_{t_0} = \Delta P + \Delta A + \Delta T \quad (3)$$

$$\Delta P = \sum \frac{DMC_{t_1} - DMC_{t_0}}{\ln DMC_{t_1} - \ln DMC_{t_0}} \times \ln \frac{P_{t_1}}{P_{t_0}} \quad (4)$$

$$\Delta A = \sum \frac{DMC_{t_1} - DMC_{t_0}}{\ln DMC_{t_1} - \ln DMC_{t_0}} \times \ln \frac{A_{t_1}}{A_{t_0}} \quad (5)$$

$$\Delta T = \sum \frac{DMC_{t_1} - DMC_{t_0}}{\ln DMC_{t_1} - \ln DMC_{t_0}} \times \ln \frac{T_{t_1}}{T_{t_0}} \quad (6)$$

Where ΔDMC is the environmental impact indicator representing changes in DMC from the starting year t_0 (1978) to end year t_1 (2017), ΔP represents the influence of population change, ΔA represents the contribution of economic affluence (in terms of GDP per capita), and ΔT represents the influence of technology (in terms of DMC per GDP), respectively, on changes in DMC.

3.2.5. Data source

The International Resource Panel database (www.resourcepanel.org), launched by the United Nations Environment Programme and collaborated by multiple organizations, was used to collect data on economy-wide material flows from 1988 to 2017 in 13 different categories as given in Table 2. According to International Resource Panel, the material flows and consequent resource productivity indicators can be used for monitoring changes in the patterns and rates of resource use with high accuracy and reliability, although, some of the datasets are projected based on 2012 values and require adequate caution when interpreting the results. The socio-economic statistics were gathered from the world bank database based on constant 2010 US dollar prices (or otherwise indicated) available at the World Bank's statistical archives (data.worldbank.org). Dollar prices based on exchange values were used in this study instead of purchasing power parities (PPPs) as they accurately represent a stable value of economic activity within a country [32]. This was done to avoid any overestimation of resource productivity and underestimation of resource intensity that may occur due to inflated nominal GDP reported by individual countries. 3.4. Results and discussion.

3.3 Results

3.3.1 Basic indicators

a. Domestic Material Consumption (DMC)

Three indicators presenting the resource utilization are analyzed, including DMC, DE, and PTB. DMC presents the resource consumption inside one nation. Presented in Fig. 3.3, the values of DMC had increased from about 250 Mt in 1980 to about 400 Mt in 2008. According to the decomposition of DMC, construction materials, crops and crop residues were identified as the top three consumed resources. This is mainly due to rapid urbanization in Ethiopia. Moreover, crops and crop residues revealed the specific resource feature of Ethiopia. Based on the DMC analysis, targeted resource management policies should be emphasized, including the recycling of construction wastes and crop residues, as well as wastes to energy promotion. In addition, it was also highlighted that, a large amount of crop residues increased in the poor rural areas, but clean energy was not fully promoted yet. Hence waste to energy technologies were suggested to be better implemented.

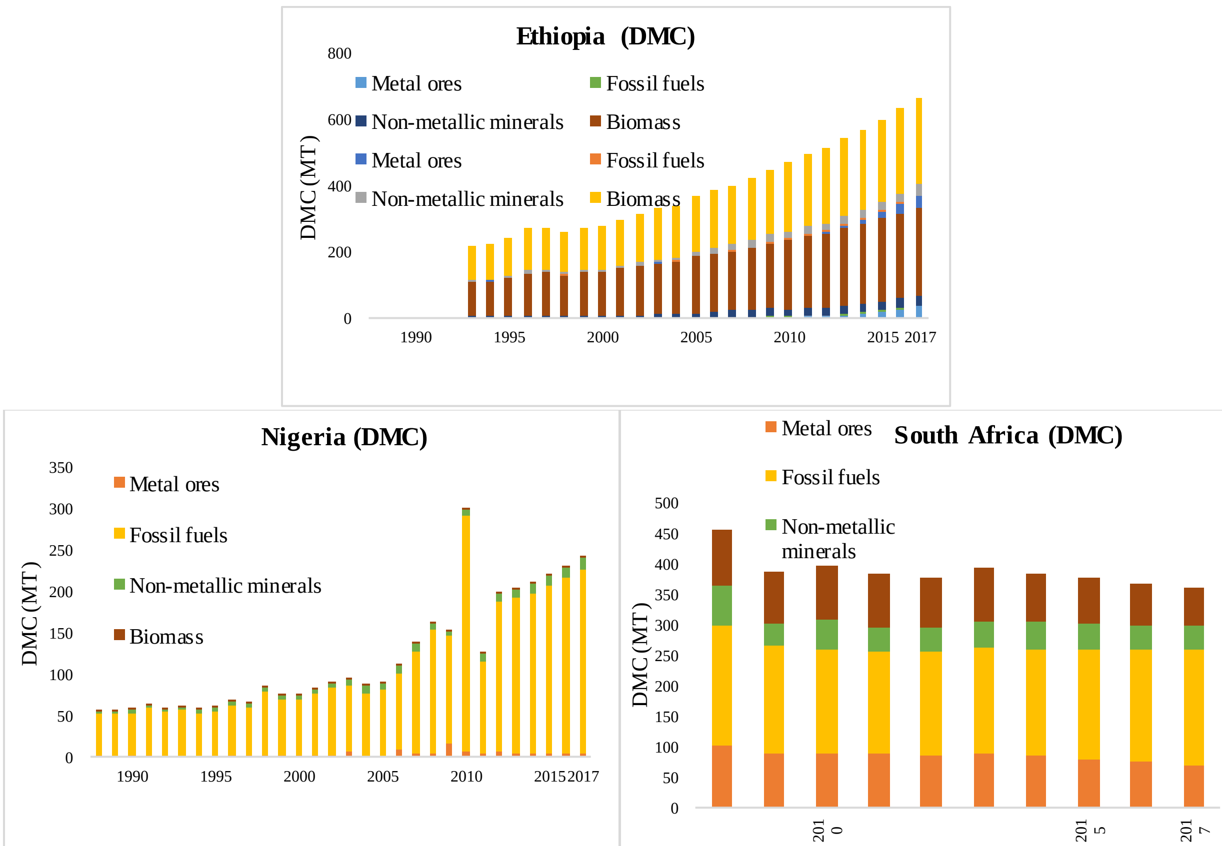

Figure 3.3: DMC of Ethiopia compared with Nigeria and South Africa

b. Domestic Extraction DE and PTB

Apart from DMC, the comparison of the trends of DE can provide other critical insights. Presented in Fig. 3.4, the overall DE changes for Ethiopia over time were close to its DMC. On the whole, DE also presented an increasing trend, although with some fluctuation in 1980s and late

1990s. Construction material, crop and crop residues were the top three domestic explored and produced materials. Another key finding was that, DE showed rather close to DMC, indicating that Ethiopia was highly self-independent for main materials.

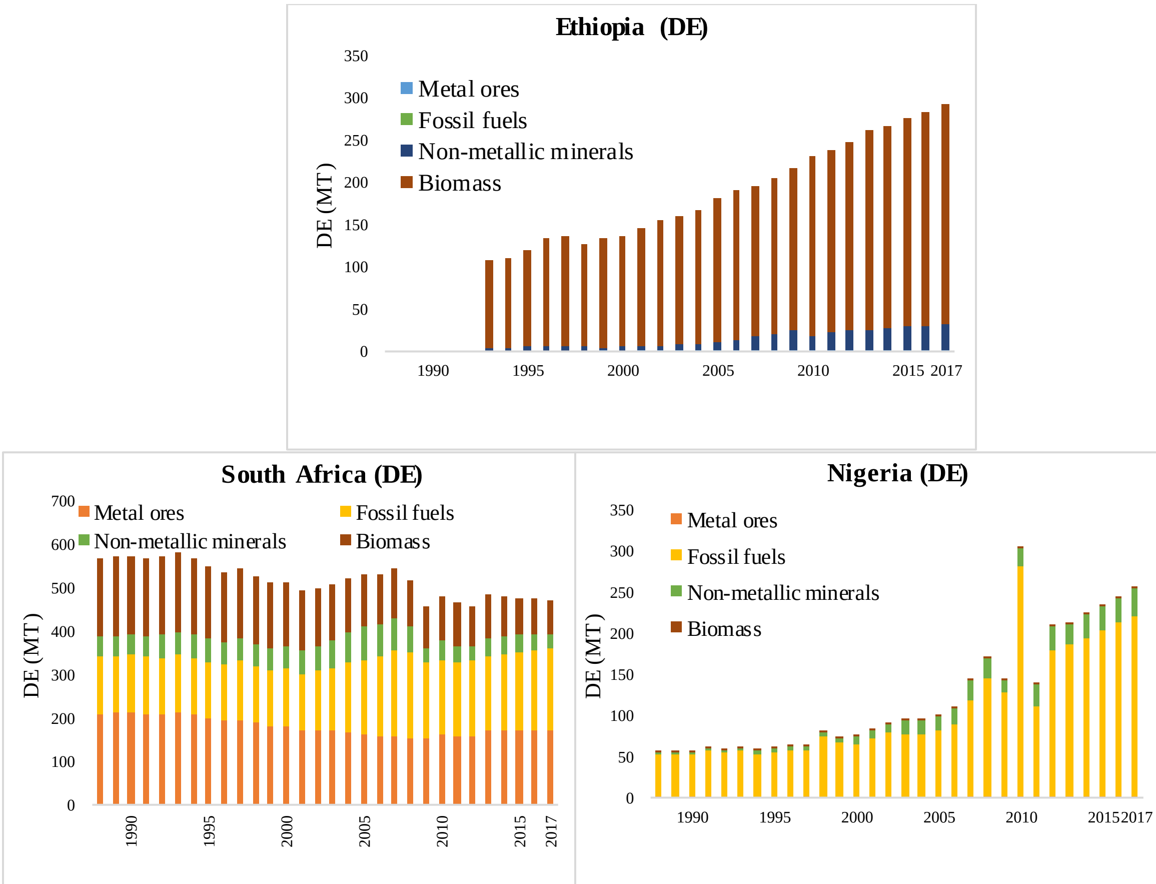

Figure 3.4: DE of Ethiopia compared with Nigeria and South Africa

c. Physical Trade Balance (PTB)

PTB further verified the relatively high resource independency of Ethiopia (Fig. 3.5). On the whole, the percentage of imported materials on the total DMC was less than 10%. However, due to increasing energy demand, Ethiopia depended on the imports of oil. Another important imported material was ferrous ores, indicating the rapid growth of industry. About the net exported materials, in recent years, crop residues were the major products.

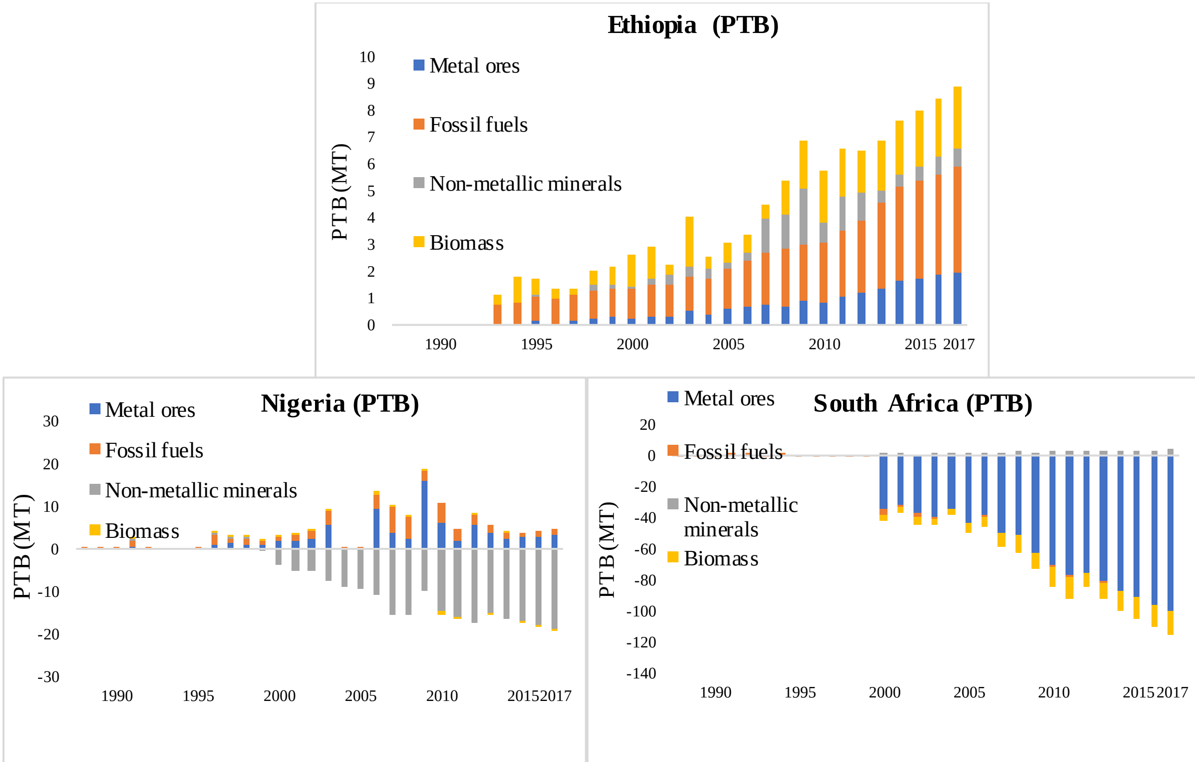

Figure 3.5: PTB of Ethiopia compared with Nigeria and South Africa

d. Resource Productivity

DMC/capita as intensity indicator was further investigated (Fig. 3.6). The general trend of per capita DMC slowly increased, while some fluctuation existed during 1980s–1985, and 1997 to 2001. Usually, with the economic growth and improvement of living standards, the DMC would keep increasing until reaching the peak. However, in the case of Ethiopia, the fluctuation of per capita DMC was in line with its unstable economic development plaguing Africa. In addition, its economy was also affected by the unstable domestic political situations. Furthermore, the data inaccuracy and consistence should also be noted. As a developing country, national data compiling was still not mature in Ethiopia.

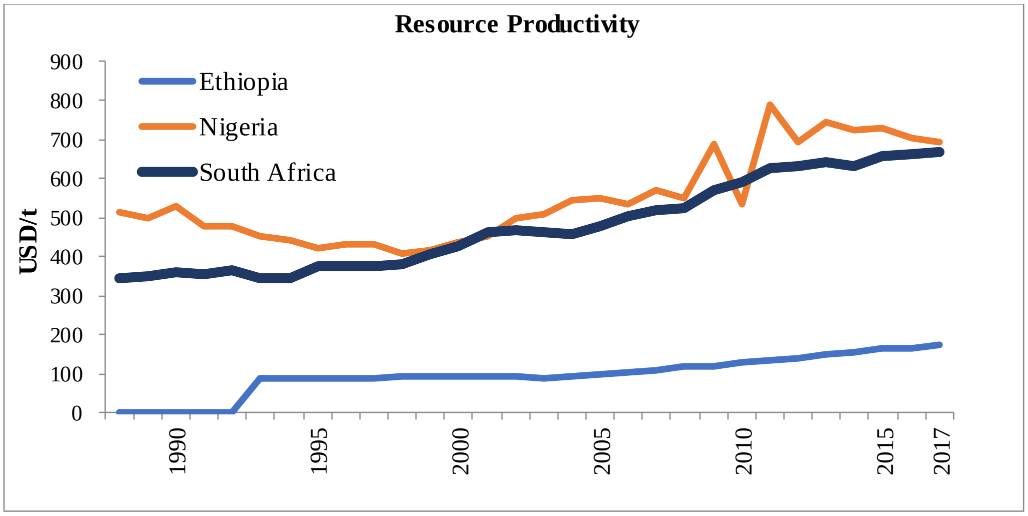

Figure 3.6: Resource Productivity trends for three countries

The comparison with other African countries members provided further insights. Typical huge African economies, including South Africa (developed country), Nigeria (developing country).

3.3.2 Dematerialization analysis with modified EKC approach

In order to further investigate the coupling of resource use (in term of DMC per capita) and economic development (in term of GDP per capita), this paper conducted a dematerialization analysis via modified EKC, inspired by (Steinberger et al., 2013). Results were illustrated in Fig. 3.7. X-axis represents GDP/capita (indicating the economic condition), and Y-axis represents DMC/capita (indicating the environmental impacts or load). It enabled to trace the status and trend of the resource consumption and efficiency, as well as to cluster the countries with similar conditions, so that diversified resource management policies could be proposed for different countries under various context. Among all the countries, South Africa started from the lowest DMC/capita, but then experienced rapid growth for both GDP per capita and resource exploration, illustrating the typical first half of the inverse "U" curve. On the contrary, Nigeria illustrated the second half of the inverse "U" curve, indicating its primary dematerialization process. As a typical country with successful transition, Ethiopia experienced both the first half trend of inverse "U" curve as South Africa, and the beginning trend of the second half of inverse "U" curve as Nigeria. The transition point occurred when the per capita GDP reached about 8000–10 000 USD.

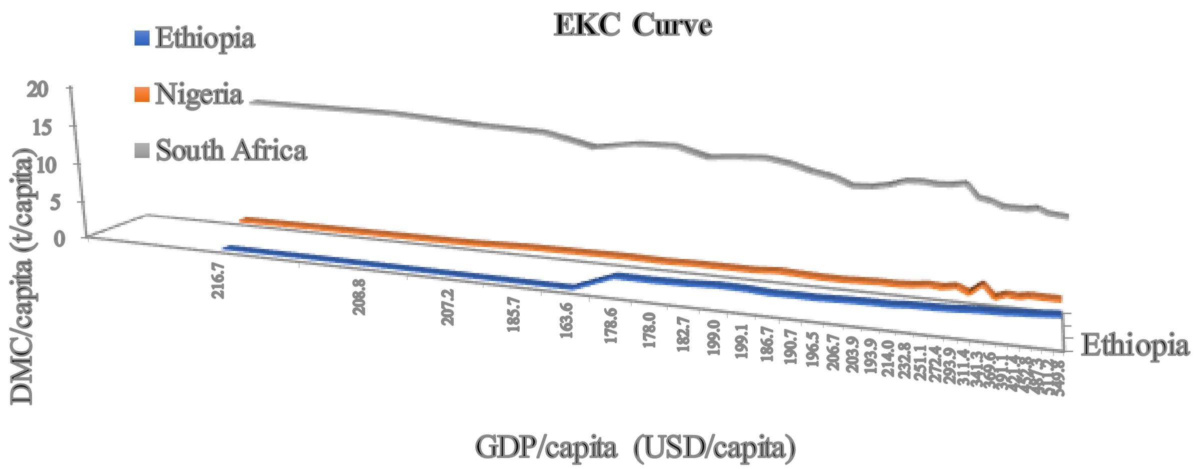

Figure 3.7: EKC for three countries

Compared with the above countries, Ethiopia presented slight decoupling of material consumption and economic growth, but such "fake" phenomenon largely attributed to the impacts of periods of recession and/or economic crisis that occurred in regional and global economies, domestic political instability, as well as natural calamities (e.g., typhoon) that are frequent in this country. Fig. 3.7 presented the periods of economic growth and recession in this country from 1988 to 2017. It highlighted that: Ethiopia experienced economic development stagnation in the 1980s, due to the economic crisis in the world in late 1970s and early 1980s, as well as the shrink of global capital market. The GDP/capita decreased in this period. As a result, resource consumption, which highly related to the national economic development (enhancement of living standard, infrastructures construction, as well as imports/exports), presented a stop or even decrease trend (e.g., DMC presented in Fig. 3.3). Entering 1990s, the economic condition had slightly improved in short period, but the Africa financial crisis in 1997 dropped it again.

Therefore, the general condition in 1990s was still not well. After 2000, Ethiopia economic began stable, although the growth was not fast (around 5% annually). And it was noted that the overall economic growth was still influenced by domestic and international crisis, such as political instability in 2001 and the global financial crisis in 2010.

The coupling coefficients of selected countries were summarized in Table 3.2, for the sake of clustering selected Asian countries with specific features. Overall, our results were close to (Steinberger et al., 2013). Ethiopia presented typical fast-growing economies with coupling coefficients of 0.7 and 1.0. As the most mature industrialized country, Nigeria primarily realized decoupling of resource consumption and economic development. While Ethiopia, its minus coupling coefficient attributed to its unstable development in the past decades according to the former analysis.

3.3.3 Driving forces of analysis with IPAT

Driving force analysis is based on “IPAT”, and it is used to bring out changes and to uncover driving forces of resource consumption in Ethiopia and the two economic giants in Africa. I which denotes “Impact” is equal to P which denotes “population” (P), multiplied by A which denotes “affluence” (GDP/capita), and by T which denotes “technology” (DMC/GDP).

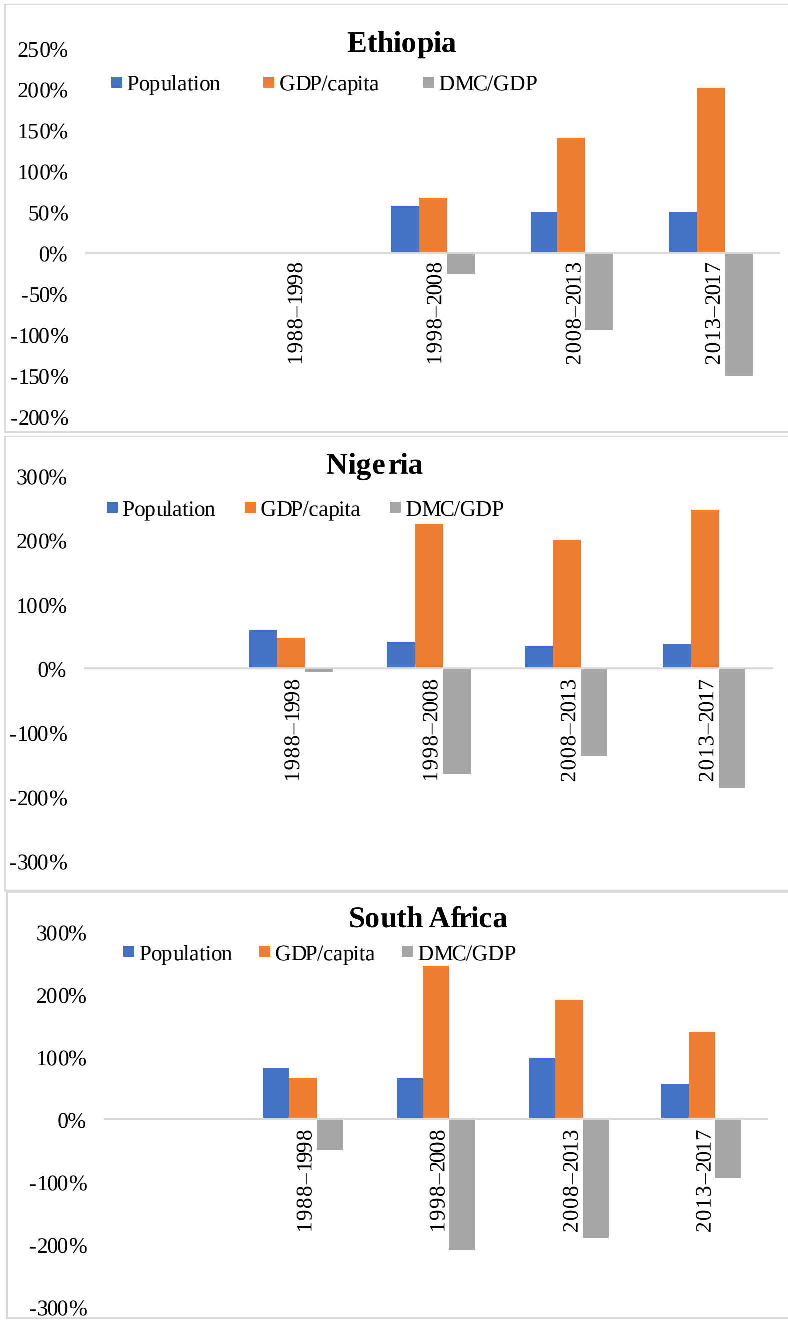

Figure 4: Drivers of material consumption in three countries

As Fig. 3.8 indicated, from 1988 to 2017, 4 periods could be identified, which include 1988 to mid-1999, economic stagnation, caused by the international economic crisis and the shrink of global capital market; from late 1998 to 2008: economic recovery and development; 2008–2013: seriously affected financial crisis; and 2013–2017 economic recovery and development, timely affected by domestic political instability. To better link our IPAT analysis to these periods, we apply the LMDI method to the periods reflecting the above situations: 1988–1998, 1998–2008, 2008–2013, and 2013–2017. Fig. 3.8 illustrated the analysis on the three drivers over the periods in Ethiopia, while Table 3.3 summarized the detailed contributing rate of each driver for different periods.

Table 3.3: Decomposing ΔDMC for four decades.

Driver (%)	1988–98	1998–2007	2007–2013	2013–17
	Ethiopia			
ΔDMC (Mt)	32	84	105	104
Population	109	49	43	37
Affluence	50	56	55	59
Technology	-	-16	-21	-26
	South Africa			
ΔDMC (Mt)	723	1045	1780	1957
Population	71	59	42	37
Affluence	66	100	114	165
Technology	-37	-59	-56	-102
	Nigeria			
ΔDMC (Mt)	135	137	189	192
Population	69	82	66	75
Affluence	68	42	72	66
Technology	-37	-24	-38	-41

In line with the general condition of developing countries, GDP/capita (reflects amenity and economic growth) and population were the main drivers to the increase of DMC, while technology improvement (DMC/GDP) partly offset the growth of DMC. In detail, from 1980 to 1986, Ethiopia's DMC reduced by 32 Mt and the economic recession played the most important role (contribution ratio was −148%), population increase was the second driver, accounted to

114%. From 1986 to 1996, economic condition had improved and A (GDP/capita) played as the main driver (the value was 63%) to the change of DMC, which had increased by 174 Mt in this period. The Asia financial crisis caused severe recession to Ethiopian economy from 1996 to 2002, and as a result, under the population increase, the DMC reduced by 7% in this seven years and A (GDP/capita) was the key driver (−59%). The economic development was revitalized again from 2002 to 2008, and the DMC increased by 8% in this period. The reason why the DMC didn't surged a lot was that, although the increase of GDP/capita (amenity) contributed a lot to the increase of DMC (116%), but meanwhile, technology improvement (T) presented obvious offset effect, with a factor value of −45%. The enhancement of technologies efficiency also derived from reinforced environmental regulation and application of a series of resource efficiency options, since the late 1990s and early 21st century. For example, the beginning of implementation of cleaner production as well as Environmental Management Systems (ISO 14001) in manufacturing enterprises played critical role during this period.2

From a national EKC-like behavior perspective, that indicating a slowing down of resource use and environmental impacts at higher incomes, Ethiopia began to follow a similar way with other fast developing countries like Nigeria. With entering into the stable pathway of economic growth, the idea to grow first and to deal with environmental issues latter became a critical concern. On the whole, technology improvement (in our case the factor value was about 45% from 2002 to 2008) in Ethiopia was not as effect as other fast developing countries like South Africa (achieved significant resource and energy conservation, and pollutants mitigation since 2000) and developed countries like South Korea. Therefore, there was still huge space for the continuous implementation of cleaner production (technology and enterprise level), eco-industrial parks (regional level), green supply chain (social level) and other environmental management measures.

3.4 Policies implications

After more than two decades' fluctuation of its economic growth, Ethiopia began to sail into a stable and fast developing pathway from the 21st century. With expected stable and fast economic growth in the future, dealing with environmental issues becomes critical issue for the sustainable development of this country. With this context, the experiences and lessons from Ethiopia's material flows and resource efficiency indicators can not only provide valuable policy insights to its resource management policies, but also enlighten to other African countries, so that they can find appropriate pathways on improving resource efficiency. With this circumstance, the key findings of this work are expected to help decision-makers in these countries to reconsider their long-term development strategies so that both economic development and environmental protection can be equally addressed.

Based on the above analytical results, several critical policies implications are proposed and discussed:

Enhance the living standard is of course the priority. On the whole, the DMC per capita of Ethiopia is much lower than developed and fast developing countries, indicating the lower level of economic development (e.g., living standard, urbanization level, and infrastructures development). Hence the first policy implication is to prepare rational policies so that stable development can be achieved. Consequently, politicians in Ethiopia should seriously discuss such issues with more stakeholders so that new policies can equally address the concerns from different classes, communities, sectors, and areas.

Keep improving technology efficiency to offset the expecting "rebound effect": economic data indicated that Ethiopia's economy has entered into the stable growing stage after 2015. It is expected that with the stable economic growth, rapid urbanization and industrialization process (which results in high requirements on bulky material like ores, construction materials), Ethiopia's material consumption and intensity will surge in the near future, which is observed in the case of South Africa. With this circumstance, technology improvement for better resource efficiency is usually offset (the so called "rebound effect"). In addition, our IPAT result also reveals that the technology effect on DMC change is not extraordinarily strong, which requires that the technology improvement and advanced technology transfer (particularly cleaner production technologies and energy efficiency technologies) needs to be strengthened.

Promote the implementation of Cleaner Production and regional eco-industrial development, via strengthening the applications of mixture of policy tools, from command and control approaches to self-regulation and market-based instruments. Such tools included but not limited to integrated waste management system (IWMS), low interest loans, eco-labels, ISO 14001 certifications, technical assistance on cleaner production and environmental management system.

Strengthen market measures to improve resource efficiency. Economic instruments should also be employed, such as pricing, taxes, and financial subsidies. MFA results highlighted natural resources like fossil fuels, woods and ores played important role in national economy, as well as the exports. Resource prices in developing countries are usually under debate that is much lower than those in developed countries, leading to that most consumers pay less attention on conserving them. As a result, a reform on the resource price and tax will help to utilize the market to balance the consumption on resources and expects to enhance resource efficiency. Moreover, increased tax rates on certain materials can help the government recover funds for supporting resource efficient technologies and equipment. Similarly, financial subsidies can help those poor areas or key sectors solve their budget limit issues so that they can also actively participate in resource efficiency actions. In addition, analysis on the PTB indicator indicated that Ethiopia's exported large volume of fossil fuels, woods, and ores. Such activities caused negative impacts on domestic environment. Hence price mechanism should also be reformed on such materials so that a balance on the economic gains and environmental loss can be achieved.

Finally, build decision support tools and improve the material flows accounts/database for better decision support to the national policy makers and stakeholders. One feature of Ethiopia material flows is its fluctuation. Of course, the instable economic development in the research period, is the main reason, but it also indicates a lack on the integrated MFA database construction, which is a commonsense concern in many developing countries. Hence it is suggested the stakeholders strengthen the construction on the MFA database and account, and design and publish proper national MFA indicators, for example the "resource productivity" applied in South Africa, to monitor its resource efficiency within economic development.

3.5 Research limitations and future concerns

This paper conducted an integrated study on the material flows and indicators in This paper conducted an integrated study on the material flows and indicators in Ethiopia from 1988 to 2017 and put them into the African context for comparison. The results are critical to complement the current research gap and enlighten the national policy makers, but still, some future concerns need to be addressed. Due to the limits of research boundary and main topics, the inter-regional trade within the African and the international trade between Ethiopia and the rest of world are not investing in-depth. By elaborating the trade issues, more environmental and economic insights can be addressed, such as the emission leak due to the trade commodities difference between developing and developed regions; the relationship of environmental efficiency and the position on global supply chain, and how to tackle such issue. Also, to cluster the countries including

Ethiopia in terms of their resource consumption features and economic conditions, will also offer helpful insights.

3.6 Conclusions

With targeting on putting Ethiopia's material flows, indicators, and resource efficiencies into African context, which enabled to enrich the global MFA studies, this paper conducted an in-depth analysis on MFA application on Ethiopia and compared with typical countries with huge economies in Africa. As a basis, Ethiopia material flows from 1988 to 2017 and MFA indicators reflecting resource utilization intensity and efficiency were designed, analyzed, and compared with other typical African economies. Furthermore, dematerialization analysis based on modified Environmental Kuznets Curve (EKC) was applied to investigate the coupling statements and trends of resource consumption and economic growth. Finally, driving forces for the changes of material flows were investigated with decomposition approach based on IPAT in periods reflecting the key domestic development stages. Results highlighted a fluctuation of material flows from 1980s to early 2000s, which in line with the domestic instability in Ethiopia, whether caused by international/domestic economic crisis or and domestic political instability. From 2002 to 2008 (a relative stable development stage), Ethiopia presented EKC-like curve on its resource consumption and economic development, which indicated a need to strengthen the resource efficiency countermeasures. IPAT analysis highlighted the critical role of economic fluctuation on the change of DMC in the periods of 1988–1998, 1998–2008, 2008–2013, and 2013–2017. While in the period of 2008–2013, with economy recovery and stable development, DMC increased and significantly offset by resource efficiency enhancement (DMC/GDP).

Enlightened by the analytical results, policies implications including keeping the stable economic development; enhancing technology efficiency; promoting cleaner production and environmental management system, as well as regional eco-industrial development (e.g., industrial symbiosis and eco-industrial parks); reforming market to optimize the resources' prices; as well as improving MFA database construction and developing accounting methods and national monitoring indicators, were proposed and discussed in-depth. The experiences and lessons from MFA analysis on Ethiopia can not only provide valuable policy insights to its resource management policies, but also enlighten African countries to find appropriate pathways on improving resource efficiency.

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CHAPTER FOUR

Resource Dynamism in Central Africa: MFA and Policy Recommendations

Abstract

This study is based on a long-time series data on the material flow from 1978 till 2017 analysis on Cameroon, Democratic Republic of Congo, and Gabon, applied with up-to date standardized methodologies of economy-wide materials flow accounting. These three countries are in a similar level of development, barely developing economies and are the most important Central African countries based on their economic dominance. This study is the first of its kind in Africa, based on comparing three economies with respect to their socio-economic metabolism and environmental performances, so that enlightenment on global resource management policies can be made. Till date, material flows analysis (MFA) and its database has become mature tools to diagnose the national resource utilization and efficiency, but still, few attentions and systematical analysis have been done for African countries. Material flows, resource productivity data, indicators as well as Environmental Kuznets Curve are presented and compared. Driving forces for the material flow change were further investigated with IPAT approach. Results obtained highlighted a rise in Domestic Material Consumption for the 4 decade time series as seen Cameroon increased from (25.90 - 100.43) Mt, 4-folds, while in the Democratic Republic of Congo the DMC (91.68 - 186.99) Mt, 2-foldsand that of Gabon (3.38 - 12.2) Mt, which is also a 4-folds increase. Cameroon and the Democratic Republic of Congo moved from net exporters in 1978 to net importers in 2017 meanwhile Gabon has been a net exporter for the past 40 years. This is due to the living standards enhancement, improved urban infrastructure as well as rapid industrial development. Resource productivity was significantly higher in Gabon (1567.6USD/t), moderate in Cameroon (362.1 USD/t) and quite low in the Democratic Republic of Congo (170.0

USD/t).Information and insights behind results, like the industrial structure, value chain position in the global supply-demand chain and how they had impacts on the resource efficiency and productivity were discussed in-depth. Resource efficiency and sustainable resource management is critical to transitional economies to move forward their pathway to sustainable development. The research results provide critical insights to future effective and efficient global resource management policy making.

4.1 Introduction

One critical debate on the global environmental issues are the disparities of domestic situations (e.g. resource condition, industrial structure and the position in the global supply chain) and economic development stages in different countries [33]. Resources play the role as the basis for human being's life on Earth. Meanwhile, material extraction has brought about serious environmental burden on the earth. Resource efficiency and productivity is key to realize the sustainable development goals (SDGs), particularly for transitional economies. Therefore, the pursuit of sustainable resource management is critical to the sustainable development of the Economic and Monetary Community of Central Africa (CEMAC) zone. An in-depth investigation on the material flows provide basis to a better decision making [4,10,16]. With various industrial and economic patterns, the difficulties of sustainable transition will be different. As a result, focuses on certain groups of countries, as well as in-depth analysis and comparison on the material flow features and patterns is beneficial to further resource management policy implications [34,35].The rapidly soaring global resource consumption [36,37] is bringing multitude of environmental and socio-economic problems [38,39]. It seems very crucial to mitigate environmental damage caused by current developmental policies and extensive natural resource consumption. A pathway to inhibit such a global material use trajectory is to understand resource metabolism across different regions and diverse ecosystems [40]. The role national policy in transboundary material flows, domestic material intensity and productivity is also an important area of concern to materialize sustainable use of natural resources. Among various approaches used for examining human use of natural resources, material flow analysis (MFA) has become an important methodological approach for environmental accounting and to better understand material metabolism from an ecological perspective [41,42] with economy-wide MFA incorporating an economic dimension to this approach [23]. Economy-wide MFA can be used to understand flows and consumption of natural resources within the boundaries of an economic system such as a country or a region [25,43] and analyze resource exploration, its trade, and the nexus between nature and economic growth [35,44]. With regards to economy-wide resource consumption, developing countries are at a comparative advantage to overcome the environmental 'bads' associated with the growth model of developed nations by following a frog-leap approach and innovative resource management policies [15].

Eight countries make up the Central Africa Region (CAR) (Table 4.1). Economic growth in the region was sluggish from 2016 to 2017. Estimated average growth for the region in 2017 is 0.9 %, barely up from 0.1 % in 2016 and noticeably below the estimated African average of 3.6 %. The positive economic outlook for 2018–2019 is driven by the same factors. São Tomé and Príncipe, Central African Republic (CAR), Cameroon, and Democratic Republic of Congo (DRC) are expected to record the highest growth rates in the region in 2017 and in the next two years. Among countries whose economies contracted, Equatorial Guinea experienced the largest estimated GDP decline, at –7.3 % in 2017, followed by Congo, at 4 %. These contractions in growth are due partly to a heavy dependence on oil, whose price and production both declined, as well as to security threats. Little change in these circumstances is expected in the near future, putting a strain on the region. On a sectoral basis, industry accounted for the largest share of the regional economy in 2016, contributing about 42 % of regional GDP, followed by services, which contributed 41 % while agriculture contributed 17 %. It was reported that the material extraction and consumption nearly had doubled from 1980 to 2009 [27].

The resource extraction and production is overwhelming in contrast to the consumption fed in Africa and this is shown in net resource exporter in terms of the physical trade balance (PTB) or raw material trade balance (RTB) [5].During the last four decades, Western and Central Africa shows the highest cumulative material consumption at 54Gt dominated by biomass consumption [45]. As a brief literature review, a number of MFA researches had been conducted in various spatial scales [46], such as national scale [47,48], regional and local level [46], urban systems [49,50] and industrial areas [51]. On the whole, Economy-wide MFA (EW-MFA) was mostly widely applied and already become mature approach for national accounting on the socio-economic metabolism [52–54][49,52,53]. To date, many countries had finished the MFA studies, including but not limited to EU members (e.g. Finland [48], MFA guidelines published by Eurostat [52–54], Asia-Pacific countries like Japan [4,55], China [26,56][26] and Australia [57], as well as regions and countries group [17,34], Asian-Pacific region [15],for some countries in East Asia, by [24] for the Philippines, by [58] for Uzbekistan and by [59] for Laos and by [45] for Africa.

Table 4.1: **Countries of Central Africa and their percentage of GDP contributions in 2018**

Country	Percentage GDP contribution (2018)
Cameroon	29.3
Democratic Republic of Congo (DRC)	24.4
Gabon	13.2
Equatorial Guinea	10.5
Congo	10.5
Chad	10.6
Central African Republic	1.2
São Tomé and Príncipe	0.3

However, there exist useful details on material use and resource efficiency of African sub-regions [45], while material flow trends and typical patterns analysis and comparisons among different economies had been rather few and completely absent in the case of Central African countries. This study is to analyze the resource metabolism in these three countries using MFA to characterize their material consumption and enhance resource management strategies. Although economy-wide MFA is a conventional approach [17,34,55,60], yet the novelty of this work settles on the facets that this work is the first of its kind in the Central African zone and the entire African continent when comparing three countries (Cameroon, Gabon and DRC), based on material consumption and policy evolution on a longer, more recent and complete time series data.

The results and experiences from other countries with MFA studies were able to provide critical policies insights on sustainable resource management. With the literature from these countries, this chapter aims to answer the following major questions:

(1) What is the material flow trends in three typical economies (Cameroon, DRC, and Gabon)?

(2) Which factors drive the increase in resource consumption in the three countries within various periods?

(3) Are there any periodical regular pattern of the material flow trends in the three countries?

(4) What critical policies insights can be summarized from this work?

To address these, long time series comparison analysis on the material flows and resource productivity, in Cameroon, DRC and Gabon was conducted. We further applied an IPAT (Impact = Population × Affluence × Technology) framework to investigate the key drivers to the main change of material flows over time. Critical policy insights for developing a number one economy like Cameroon in Central Africa are provided, through analyzing and summarizing the periodical regular patterns of developed economies.

The remainder of this research work is organized as follows: after this introduction section, section 2 describes the methods and data; section 3 overviews the socioeconomic and environmental conditions in three countries (Cameroon, DRC and Gabon) and analyses the regional features; section 4 presents the results and their discussions; finally, section 5 draws the conclusions and policies implications in the Central African Regional Context.

With a focus on examining current material consumption trends in Cameroon, Gabon and Democratic Republic of Congo, and identifying a transition towards emerging economies in the Central African Sub Region from a historical policy perspective, this study aims to provide policy level insights into economy-wide resource metabolism especially in the context of emerging economies. The idea is, based on the material flow accounts within the three countries, to analyze resource use efficiency and productivity based on important MFA indicators and regional environmental development. With the help of an extensive Central African Sub Regional policy analysis, this study also discusses structural policy changes over time to better understand economic development and environmental policy evolution in three countries.

4.2 Materials and Methods

4.2.1 General information of Cameroon, Gabon, and DRC

The geographical proximity of Cameroon, Gabon and DRC makes them important trade partners of primary resources and finished products and services, as shown in Fig. 4.1.

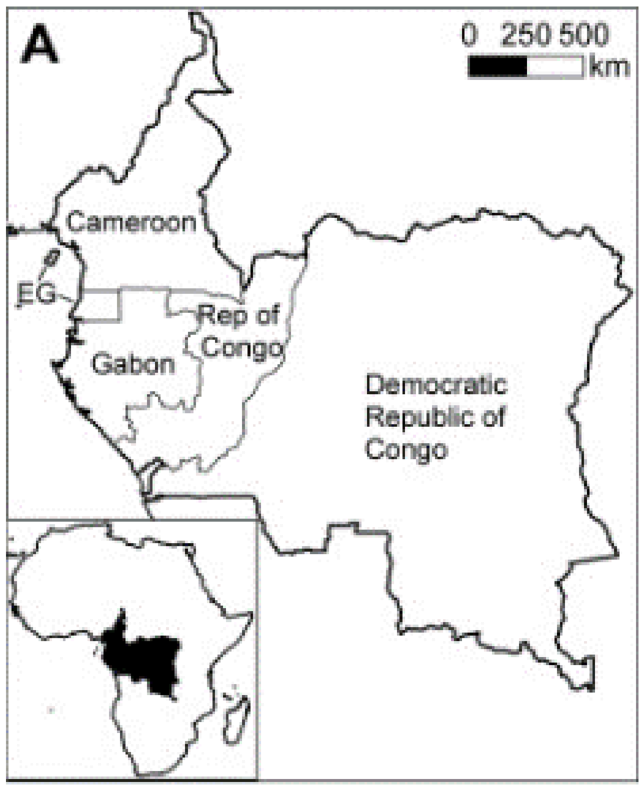

Figure 4.1: The map of Cameroon, Gabon, and DRC

Table 4.2 presents the current socio-economic status of Cameroon, Gabon, and DRC. Generally, the economic growth in the region was sluggish from 2016 to 2017. Estimated average growth for the region in 2017 is 0.9%, barely up from 0.1% in 2016 and noticeably below the estimated African average of 3.6%. Low commodity prices accounted for much of the sluggishness of growth [61]. Among them, DRC is most populated, followed by Cameroon and the lowest being Gabon. This also follows same with their per capita GDP, where in, DRC has as per capita GDP of 9204 UD dollars, followed by Cameroon with a per capita GDP of 1480 USD and the least is

Gabon with a per capita GDP of 408 USD. This can be attributed to resource consumption in these countries [62]. However, On the flip side, Cameroon ranks highest in the Central African sub region with a GDP of 36.36 billion USD, followed by the DRC with 33.28 billion USD and then Gabon with a GDP of 19.00 billion USD.

Table 4.2: General socio-economic data for subject countries, as of 2017

	Cameroon	Gabon	DR Congo
Population, million	24.56	2.06	81.39
GDP, billion USD*	36.36	19.00	33.28
GDP/capita, USD	1480.0	408.9	9204.0

*based on constant 2010-dollar prices

4.2.2 Methodological framework

The EW-MFA have been based on the widely accepted international datasets such as the International Resource Panel database. The analysis uses the most recent long-time series data covering four decades, from 1978 to 2017, and is in compliance with established guidelines [23]. The end year was selected based on most recently available data i.e. 2017, while the start year was selected considering past MFA studies which have used datasets ranging from 28-29 years [17,24] to 35-38 years [15,16]. The selected timeline, comprising 40 years, was considered adequate to cover both resource patterns and policy developments in the CEMAC region. Based on the available data, thirteen material types have been classified into four categories such as: metal ores, fossil fuels, non-metallic minerals, and biomass. Detailed material categorization is shown in Fig. 4.2. The core research analysis was based on the mass balance of material flows involving local and regional trade, and the work was complemented by the decomposition analysis of the factors of 'the master equation: IPAT' to analyze the drivers of material consumption in the selected CEMAC economies.

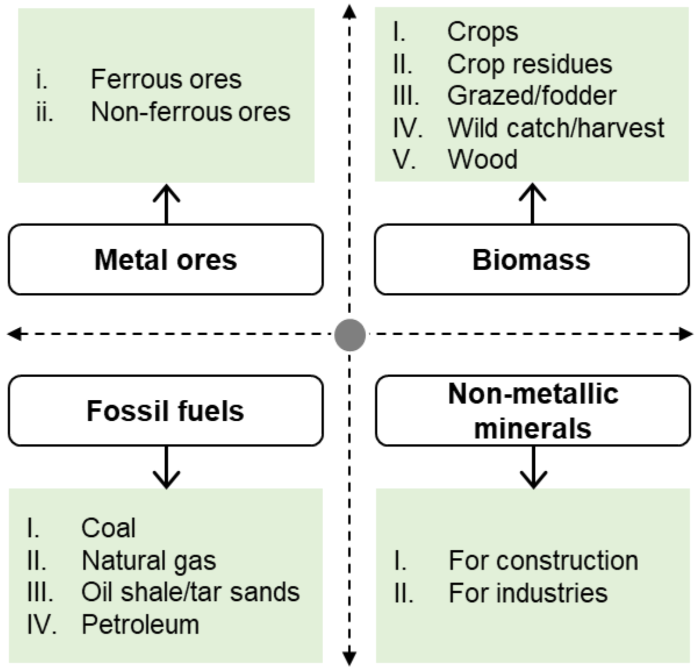

Figure 4.2: Material categorization used in this study.

4.2.3 Analytical methods

a. Material flow and efficiency analysis

The list of material flow and efficiency indicators applied in this study along with their brief description is presented in Table 4.3. The material flow indicators are usually expressed in physical terms while efficiency indicators can have socio-economic dimensions depending on the parameters used. All prices are reported in United States dollar (USD) based on 2010 constant prices (or otherwise stated), however, reporting physical and economic dimensions does require adequate care [16].

Table 4.3: **Details of material flow and efficiency indicators applied in this study**

Indicator	Abbreviation	Description
Domestic extraction	DE	Extracted resources from natural environment used as an input for an economy (except water and air).
Domestic material consumption	DMC	Annual quantity of raw materials extracted from the domestic territory, plus imports and minus exports, directly used in an economy.
Physical trade balance	PTB	Physical imports minus physical exports.
Material intensity	MI	It is the intensity with which material resources are consumed in an economy. In this study, MI was measured in two ways: (i) MI_p = DMC per capita (ii) MI_e = DMC per GDP
Material productivity	MP	It is the economic value generated (GDP) per unit of material consumed (DMC).

b. Decomposition analysis

The IPAT equation is widely recognized for analyzing effects of human activities on the environment [57]. IPAT specifies that environmental impacts are the multiplicative product of three socio-economic drivers (SED) comprising population, affluence and technology [63]. In this study, DMC was taken as the environmental impact driven by three SEDs under the IPAT assumption as given in Eq. 1:

$$\Delta DMC = DMC_{(t)} - DMC_{(0)} = \sum_{i}^{n} \Delta SED_i \qquad (1)$$

Where ΔDMC represents the growth in DMC from 'time=0' (the start year) to 'time=t' (the end year), and SED_i represents any of the three drivers of IPAT relation including population 'P' (number of persons), affluence 'A' (GDP per capita), and technology 'T' (material consumption per GDP). The log-mean Divisia index (LMDI) method was applied to measure the contributions of the three drivers [64]. Based on the LMDI method, the changes in SED from ‘time=0’to ‘time=t’ can be calculated as given in Eq. 2:

$$\Delta \mathrm{SED_i} = \sum \frac{\mathrm{SED_{(t)}} - \mathrm{SED_{(0)}}}{\ln\{\mathrm{SED_{(t)}}\} - \ln\{\mathrm{SED_{(0)}}\}} \times \ln \frac{\mathrm{SED_{(t)}}}{\mathrm{SED_{(0)}}} \quad (2)$$

c. Dematerialization analysis

Dematerializing analysis, using the EKC hypothesis, was applied to examine the relationship between environmental pressure and economic development. This analysis was based on long-time series data using second degree regression curves, as done previously [65]. The indicator representing environmental pressure was taken as DMC per capita (y-axis) while that representing economic development was taken as GDP per capita (x-axis). With the help a dematerialization analysis, decoupling of resource consumption from economic growth was analyzed in the three countries, respectively.

4.2.4 Data Sources

International trade material flows and monetary flows for Cameroon, Gabon, and DRC during 1970–2008 are well recorded in the updated under the CAR database released by the International Trade Statistics and Commonwealth Scientific and Industrial Research Organization (CSIRO). More details about the assembling techniques of this dataset are described in [26,66]. Each MFA indicator (e.g., DE, DMC, and PTB) is composed of four main categories of materials, namely, biomass, fossil fuels, metal ores and industrial minerals, and construction materials. To evaluate the affluence (GDP/capita) and material efficiency (equals to the inverse of material intensity, i.e., DMC/GDP) in Cameroon, Gabon, and DRC, we used the population and GDP data in U.S. dollars (on constant year 2010 exchange rate basis) published by the World Bank (2013). Exchange value based national GDP (constant 2010 prices) was applied. The purchasing power parities (PPPs) was argued to be less accurate to represent the value of economic activity compared with exchange value of GDP [26,66]

4.3 Results and discussions

4.3.1 Material flow and efficiency in Central Africa

a. Domestic Extraction (DE)

Fig. 4.3 shows the per capita DE for (a) Cameroon, (b) Gabon and (c) DRC, and the total DE results for all three countries from 1978-2017. The DE trends and shares of each material type varied significantly among the three countries meaning raw material extraction with the exclusion of water and air was done in different quantities and at different levels within the three countries. Moreover, the total DE per capita increased during 1978-2017 was highest in Cameroon (3.43%) followed by DRC (1.80%), while that of Gabon was lowest (0.85%). During the 40-year period, total DE in Cameroon has been a steady rise within the period from 1978 till 2017. That is from 26.10 million tons to 97.06 million tons, almost a 5-fold increase. Similarly, that of Gabon has been on a steady rise as well within the 40 years period, leaving 15.94 million tons in 1978 to 22.18 million tons in 2017. Whereas the total DE of the DRC has been fluctuating, as seen with in steady increase from 92.02 million tons in 1987 to 128.74 million tons in 1986, it stayed relatively linear till the year 2000, where it left from 124.19 million tons to 160.97 million tons in 2005, it experienced yet another decline in 2008 to a value of 146.57 million tons before finally rising to 184.72 million tons in the year 2017, which gives a 2-fold increase.

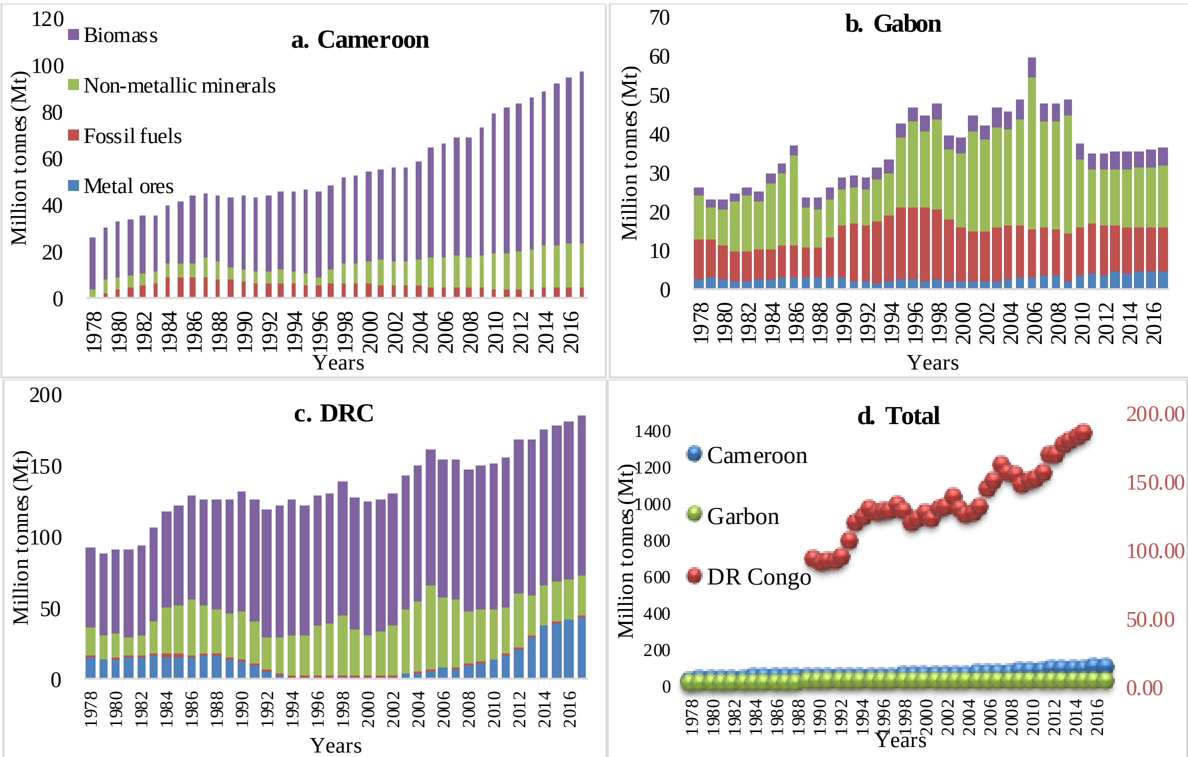

Figure 4.3: DE from 1978-2017 for three countries

Share of Biomass is available for all three countries with Cameroon having a high share of Biomass. With a drop in Cameroon's share of biomass from 85.60% in 1978 to 75.61% in 2017, and a rise in fossil fuels from 1.94% in 1978 to 4.14 % in 2017 indication of a transition towards fossil fuel-based economy. Cameroon also experienced a rise in construction-based materials with metal ore values of 0.01% in 1978 to 0.14% in 2017. Non-mineral ores also experienced an increase. Non-metallic minerals for construction had a share of 12.45% in total DE and in 2017, the value was 20.10% in 2017, which is almost two times the value for over 40 year and this indicates that there has been large-scale extraction of mineral resources for construction and infrastructure development. Thus, as of 2017, construction minerals were the largest resource that was domestically extracted and showed highest growth during 1978-2017 in Cameroon among the three countries. On the other side, share of biomass and fossil fuels resources in total DE reduced in all three countries, over the study period, mainly due to the overwhelming increase in the share of construction materials. Although, absolute quantities for most of the resource categories had increased over time, yet the extraction of construction minerals was significantly higher than the rest - making it the biggest shareholder in total DE.

Fossil fuels are important energy resources especially for industrialization, urbanization and for meeting other energy demands. For the study countries, fossil fuel extraction increased considerably in Cameroon with a threefold increase for the period of the study, meanwhile in DRC, fossils left from a value of 1.10 % to a 0.53% which is a 50% drop and in Gabon left from 67.79% to 99.29%. Fossil fuels mostly increase in the case of Cameroon, followed by Gabon and lowest with the DRC. The case of Gabon has the highest percentage values from 1978 till 2017, indicating that the Cameroon depends mostly on fossil fuels, not much on metal ores, non-metallic ores, and biomass. For Cameroon and Gabon, industrial development and availability of domestic energy resources helped in the expansion of fossil fuel extraction including coal, oil and natural gas, while in DRC with a 50% drop can be attributed to depleting fossil fuel reserves coupled with alternate energy policies and alternative energy sources[67].

b. Domestic Material Consumption (DMC)

The DMC trends for (a) Cameroon, (b)Gabon and (c) DRC, are all shown in Fig. 4.4. Overall, the DMC has been on a rise which is quite similar to DE with strong variations on the type of material. With the period of 1978-2017, the DMC of Cameroon increased from 25.90Mt to 100.43Mt which is a four-fold increase, while in the DRC the DMC increased from 91.68Mt to 186.99Mt, which is a 2 fold increase and that of Gabon also increased from 3.38Mt to 12.2Mt, which is also a four-fold increase. The DMC of all three countries experienced a rise. These developing economies are seen to have a rapid increase in industrialization, urban development and this regional economic rise is expected to drive the per capital DMC in the coming years. With regards to specific material categories, DMC patterns coincided with DE patterns for construction -based minerals showing almost a similar growth trend in all three countries. This can be seen with Cameroon recording no metal ores in the DMC trends from 1978 to 2017, meanwhile nonmetallic minerals left from 13.49% in 1978 to 22.43% in 2017. The Biomass also experience a decline from 84.44% in 2017 to 74.80% in 2017, while fossil fuels moved from 2.07% in 1978 to 2.78% in 2017. The reduced share of biomass was compensated partly by fossil fuels and mostly by non-metallic minerals that were used in construction, industrial and agricultural activities.

For the DRC, the DMC for metal ores arose from 16.03% in 1978 to 23.12% in 2017, while the non-metallic minerals left from 22.50% in 1978 to 14.81% in 2017. Biomass experienced a slight increase from 60.47% to 61.07% and non-metallic minerals experienced a huge decline from 22.50% in 1978 to 14.81% in 2017 for values of DMC. For Gabon, the metal ores left form 1.01% in 1978 to 39.48% in 2017 indicating a tremendous rise, while the non-metallic minerals left from 37.63% in 1978 to 12.81% in 2017, that is experiencing a huge decline. Except for Cameroon the DMC for non-metallic minerals seems to have dropped drastically. For the DRC, the DMC for fossil fuels dropped from a 1.01% contribution in 1978 to a 1.00% in 2017. While in Gabon the DMC of Fossil fuels dropped drastically from a 28.25% in 1987 to a 11.01% in 2017.

To further analyze the natural material independency of the three countries, the ratio of DE over DMC was computed to indicate resource consumption in relation to locally extracted or imported resources. In 1978, DE/DMC was 1.00 in Cameroon 1.00 in the DRC indicating somewhat balanced extraction and consumption status while Gabon had 4.70, indicating marginal resource inflow from other countries to meet the local resource demand. However, in 2017, the situation for Cameroon and DRC remained almost same with DE/DMC of 0.97 and 0.99 respectively, indicating higher domestic consumption and increasing reliance on foreign material inflow. That of Gabon drastically went down to 1.83. Factors that may alter resource demand and net resource imports include insufficient local material extraction, higher demand for locally unavailable resources, limited or declining material reserves, incentives on certain material imports, and an increased overall economic and industrial activity. However, for dematerialization to begin, developing countries need to develop locally applicable policies for reducing material consumption with efficient technologies so that resource sustainability is achieved with reduced per capita DMC at all economic levels.

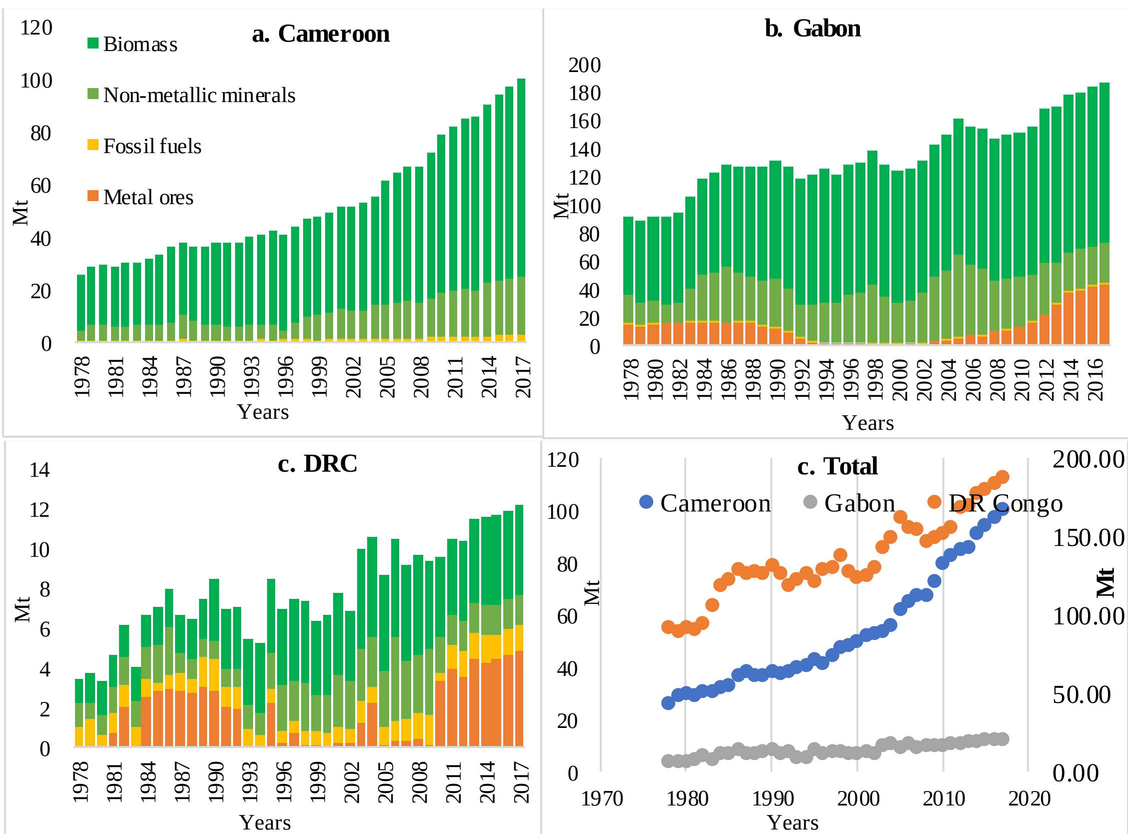

Figure 4.4: DMC in subject countries from 1978-2017

c. Physical Trade Balance (PTB)

Fig. 4.5 presents net PTB trends for (a) Cameroon, (b) Gabon, (c) DRC and their aggregate PTB patterns for the period 1978-2017. PTB trends provide an understanding of net resource flow to and from an economy, with a positive PTB indicating net resource imports and a negative PTB indicating net resource exports. Generally, the PTB is different for all three countries. As shown in figure 4.5, Cameroon and the DRC moved from net exporters in 1978 to net importers in 2017 meanwhile Gabon has been a net exporter for the past 40 years. Details indicated that the PTB for Cameroon (imports minus exports) was -0.20Mt in 1978, moved sharply to -8.47Mt in 1985 where the country was a net exporter and then suddenly the values sprung up from 0.44Mt in 2010 to 3.37Mt in 2017. Cameroon has been a net importer of resources since 2010. Component wise, Cameroon in 1978 was a net exporter of Metal ores with -88.71%, net exporter of fossil fuels with -12.84%, net exporter of non-metallic minerals with -108.45% and net importer of Biomass with 310.00%. while in 2017, Cameroon was net exporter of fossil fuels with -36.90%, and net importer of metal ores with 9.66%, net importer of non-metallic minerals with 86.22% and net importer of biomass with 41.02%. Gabon has been a net exporter of resources as from 1987 with -13.90Mt, through -19.73Mt in 1995 to a -10.05Mt in 2017. Majority of its exports come from fossil fuels. Relatively, Gabon has stayed a next exporter of its resources, with 24.13% of metal ores in 1978, 67.79% of fossil fuels in 1978, 99.21% of fossil fuels in 2017. There has been a sharp rise in the values of exports of fossil fuels within the last 40 years. Also, Gabon exported biomass with a 9.14% in 1978 and a 0.79% of exports in 2017. Gabon only imported -1.05% of non-metallic minerals in 1978.Lastly for the DRC, the country has left from being a major imported in 1978, when it was importing -0.35Mt of resources to 1994, when it imported -0.29Mt of resources to a 2.28Mt exported of resources in 2017. Explicitly, The DRC imported up to 101.91% of metal ores in 1978, 24.35% of fossil fuels in 1978, while in 2017, the country imported 28.83% in 2017 and lastly, they imported 61.16% of biomass in 2017. They also exported -1.55% of nonmetallic ores in 1987 and -24.70% of biomass in 1978 as well.

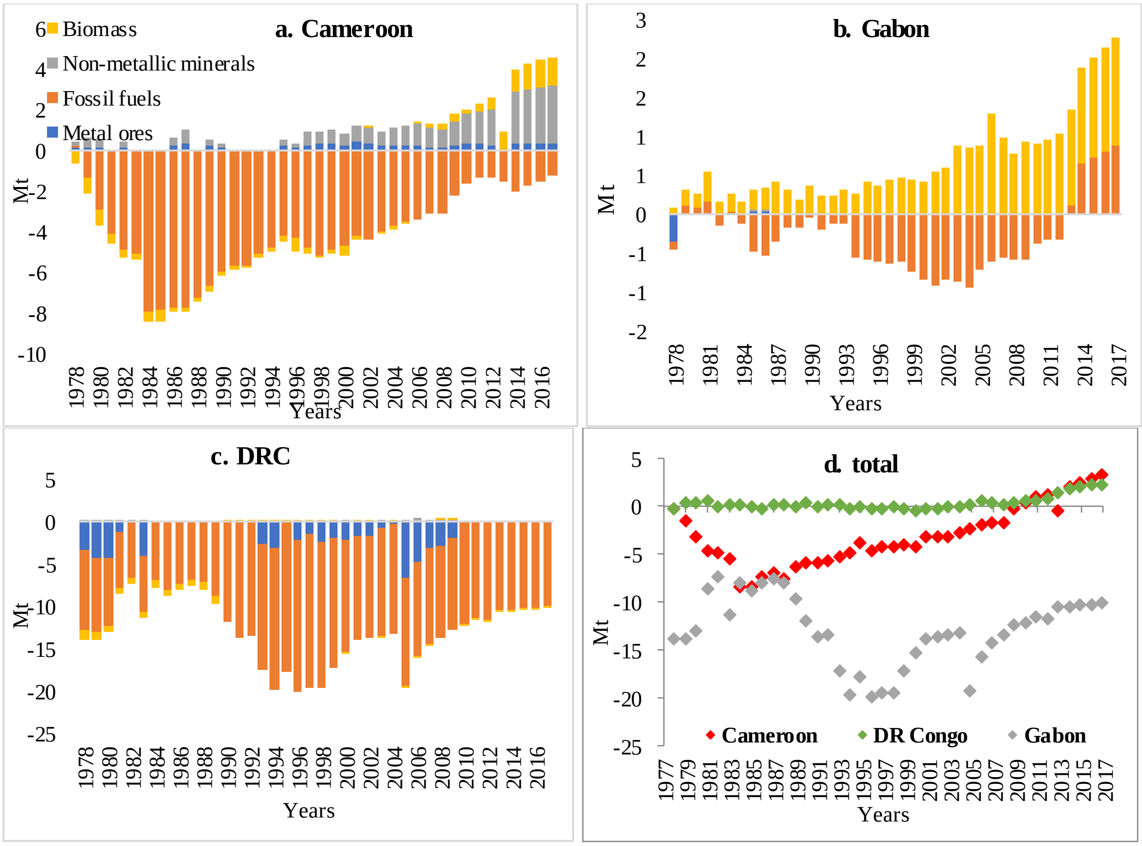

Figure 4.5: PTB in subject countries from 1978-2017

d. Material Intensity (MI)

Fig. 4.6 shows MI as a function of (a) population 'MI_p' (tons of resource consumption per person) and (b) economy 'MI_e' (total kilograms of resource used per USD added to the national GDP). As of 2017, MI_p in Cameroon, Gabon and the DRC were equal to 4.09t, 5.87t and 2.30t, respectively, as given in Fig. 4.6 (a). As shown, increase in MI_p from 1978 to 2017, has been increased for both Cameroon and Gabon (3.19t – 4.09t), (4.89t- 5.87t) while for the DRC, it has fallen (3.67t – 2.30t). This implies the economies of Cameroon and Gabon have been growing in terms of the material intensity indicator, while that of the DRC has experience a backdrop by measure of the material intensity indicator. This explains how the three economies are consuming resources per unit of economic output had a backdrop in the material intensity for the DRC is attributed to the fact that less resources are being consumed per unit contribution to the country's national GDP. Interestingly the population for Cameroon grew by 202.50 % during this period, while that of DRC grew by 226.16% during, that of Gabon increased by 198.35% within the period of 1978 – 2017. This is an inverse relationship between the population growth and material intensity indicator. As of 2017, material intensity Gabon (5.87kg/USD), closely followed by Cameroon (4.09kg/USD) and the DRC (2.30kg/USD). These values are high compared to values recorded in developed countries such as the United states of America (0.4 kg/USD, Japan (0.2 kg/USD) and South Korea (0.6 kg/USD). This is simply the improvement of material intensity by post industrial economies have been counter balanced by material intensive countries in the developing world, offsetting some of the material gains made at the global scale[68].

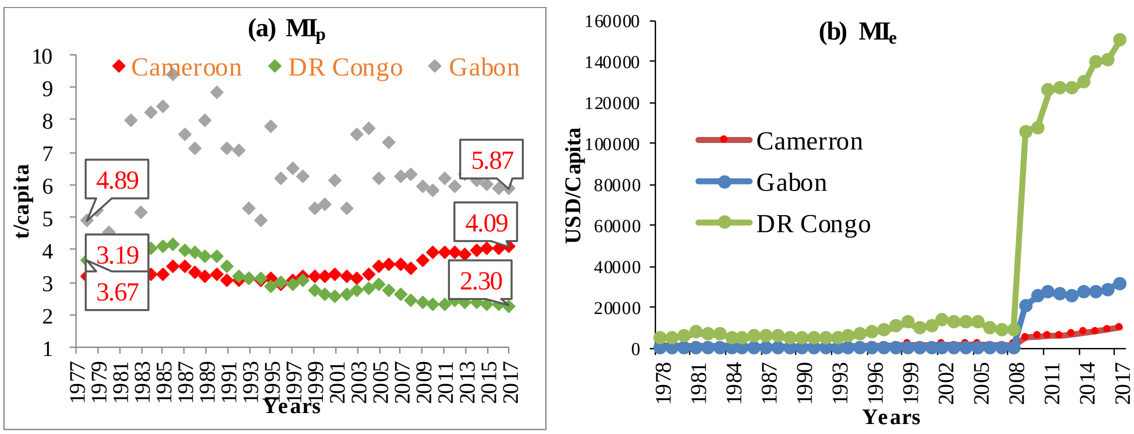

Figure 4.6:MI as a function of (a) Population and (b) Economy in three CEMAC Countries

Fig. 4.6 (b) shows the MI_e in terms of DMC per GDP. This indicator helps in analyzing changes in economy-wide material use in relation to the national GDP. The MI_e Cameroon's and Gabon has been considerably declining since 1978 indicating less and less resources being consumed to produce the same or even higher economic output. During 1978-2017, Cameroon's total DMC increased about 2 times while the GDP increased about 35 times highlighting the fact that higher GDP growth can help reduce MI_e although the role of sectors with less material-intensity and high-value is also important. On the other side, the decline in MI_e for the DRC has been moderate during this time, yet, their MI_e is still lowest among the three countries indicating higher GDP output from least possible resources with sizeable contribution from material-frugal and services sectors. In Cameroon, however, MI_e had gradually increased until 2010 when it was around 9.4kgs per USD after which MI_e began to decrease reaching 7.9kgs per USD in 2017. The reduced MI_e in all three countries also indicate technological improvements and industrial restructuring concurrently taking place with national economic development.

e. Material Productivity (MP)

Material productivity refers to the efficient consumption of resources within an economy and is measured as USD added to national GDP per ton of DMC. Fig. 4.7 presents MP among the three CEMAC countries during 1978-2017. As of 2017, MP is significantly higher in Gabon, moderate in Cameroon and quite low in the DRC. In Cameroon, Gabon and the DRC, MP has actually reduced since 1978- 2017, leaving from (223.5 USD/t – 362.1 USD/t) with the case of Cameroon, from (2538.9 USD/t – 1567.6USD/t) in the case of Gabon, and finally from 236.6USD/t – 170.0USD/t) in the case of the DRC, indicating the fact that domestic economic sectors have become material intensive and tend to produce low-value products and services unlike a country such as South Africa where high-tech and value-added economic sectors have greatly contributed to the increased MP. It can, thus, be emphasized that developed countries have highly efficient resource management policies and cleaner production technologies, while low-income developing countries tend to focus more on the economic output and less on the inefficient resource use, making their MP far behind industrialized economies. Moreover, the relocation of resource-intensive industries to developing countries without technology transfer also inhibit their MP improvements.

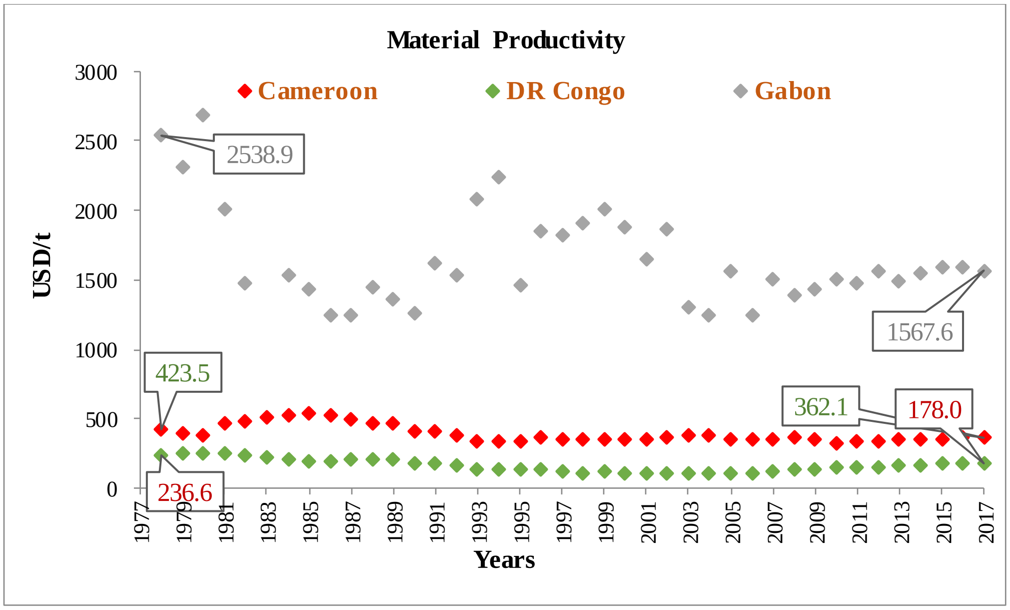

Figure 4.7: MP in three countries

4.3.2. Decomposition analysis

The IPAT equation was decomposed into three constituents to analyze individual contributing factors of resource consumption in Cameroon, Gabon, and DRC. Based on the decomposition results, drivers of material change in all three countries are shown in Table 4.4. The environmental impact (ΔDMC) was decomposed into population, affluence (GDP/capita) and technology (DMC/GDP) and the overall results are presented.

Table 4.4: **Decomposing ΔDMC for four decades**

Driver (%)	1978–87	1988–97	1998–2007	2008–17
	Cameroon			
ΔDMC (Mt)	10.56	11.09	19.27	18.96
Population (%)	90	104	78	54
Affluence (%)	-128	171	52	531
Technology (%)	138	-175	-29	-485
	Gabon			
ΔDMC (Mt)	3.04	0.99	2.21	1.85
Population (%)	41	183	104	95
Affluence (%)	-76	521	203	2129
Technology (%)	136	-603	-207	-2124
	Democratic Republic of Congo			
ΔDMC (Mt)	35.09	11.08	8.92	23.18
Population (%)	81	386	474	114
Affluence (%)	-152	818	803	2554
Technology (%)	171	-1104	-1177	-2568

For Cameroon, rising DMC was partly driven by population and mainly by economic affluence, notwithstanding technological advancement played a major role in slowing the growth for DMC. Among the drivers of DMC increase, the role of population was relatively less but yet vary significantly as compared to affluence, highlighting large resource consumption due to expanding urban and social lifestyles. For the case of Gabon, the variations in DMC was mostly driven by affluence and partly by population, whereas technology has greatly helped in offsetting higher resource demand from rising affluence. As shown, population has nearly two times less impact on ΔDMC as compared to affluence. Although, contribution from technology has been -2124%, yet it was able to offset the growth in resource use driven by affluence. The case of the DRC, the rising DMC was driven largely by population, followed by affluence, however technological enhancement played a relatively small role to curb ΔDMC (Mt). This indicated significant impacts of rapid population growth in the DRC which has led to higher human consumption of resources without much contribution to the National economy. Thus, to minimize impacts of population on ΔDMC from a policy perspective, efforts should be directed towards reducing population growth rates and discourage extravagant resource use in modern-day and social lifestyles.

The decomposition results for individual 10-year periods are presented in Table 4.4. Interestingly, ΔDMC for Cameroon was significantly higher during 1998-2007 as compared to 2008-2017, which is in accordance with large urban and infrastructure development in the country. For the case of Gabon, ΔDMC was highest in 1978-1987 three countries. In all three countries, there is a rise in exports coupled with rapid urbanization mainly fueled by economic affluence which in turn has pushed rising resource consumption. As of now, all three countries show a large potential for technological innovation that can be strengthened through improved environmental management via eco-industrial development and promotion of sustainable agriculture – the two major economic sectors in this region.

4.3.3. Dematerialization analysis

Based on the EKC hypothesis, environmental pressure increases with economic growth until reaching a point after which it decreases, thus, making an inverted U-shaped curve. Fig. 4.8 shows (a) standard EKC and (b) EKC for three CEMAC countries. Cameroon and the DRC are approaching industrialization, with Cameroon being more industrialized. In Cameroon, increasing urbanization is caused by rising per capita GDP and rapid consumption of construction minerals and energy resources to meet the local demands. Countries that have achieved dematerialization do not follow a straight economic path, rather their economic capacity varied at the time of crossing the inversion point as indicated in the standard EKC Curve. All the results are based on 2010-dollar prices, and the EKC inversion point does not appear to be correlated with any particular range of GDP per capita. Although, all three CEMAC countries are still far behind to reach the EKC inversion point, they however need not to follow the same development path of matured economies such as the United States of America, rather, they should focus on applying locally developed innovative technologies and efficient resource management strategies to decouple rising resource consumption from economic growth [69]. United States of America is outsourcing parts of its primary production due to large resource demand [16], dematerialization in any country may result in increased material intensity on another country, the case of unchanged sustainability from a system's perspective.

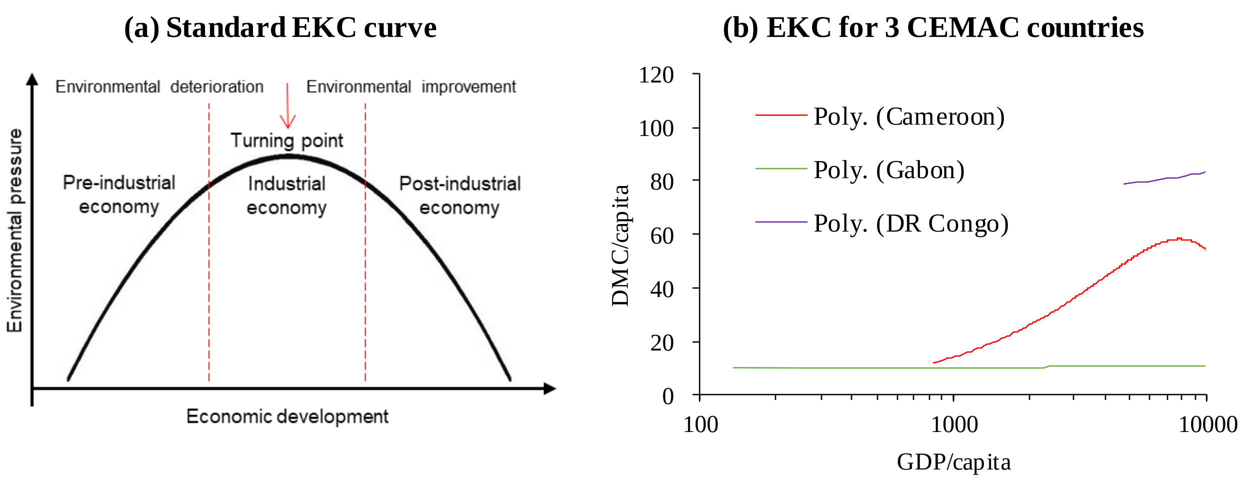

Figure 4.8: (a) Standard EKC (b) EKC for 3 CEMAC Countries

4.4 Conclusions and Policy implications

4.4.1 Conclusions

This study has made meaningful contributions to the economy-wide resource metabolism in Cameroon, Gabon and the DRC which are the top three economies in Central Africa from 1978-2017. MFA indicators and various efficiency indicators were analyzed in the context of regional and global resource supply chain. The domestic drivers of material consumption, potential dematerialization of economic growth, policy impacts on resource efficiency were also analyzed. Decomposition analysis was used to examine drivers of material use and EKC hypothesis was tested to analyze undergoing dematerializing trends in the region. As per the results, DMC was greatest in Cameroon (3.54%), followed by Gabon (3.33%) and lastly the Democratic Republic of Congo (1.84%). Rise in Cameroon and Gabon is due to and an observed increase in construction minerals dominating materials consumed. Material intensity (per capita DMC) for 2017 was highest in Gabon in (5.87t), followed by Cameroon (4.09t) and lastly by the DRC (2.30 t). Resource productivity in Gabon (1,567USD/t) which was found to be very far ahead that of Cameroon (362USD/t) and the DRC (178USD/t), indicating that the economy of Gabon is high-end, high-value oriented with relatively low material intensity. As per the decomposition analysis, population factor was a major driver, economic affluence was a minor driver in all three countries, but however, technological advancement was on a rise in 2017 for all three countries. Moreover, based on technological improvements and resource efficiency measures, Cameroon and the DRC are approaching the turning point on the EKC curve. With the help of a thorough Central African Regional policy analysis, critical insights into domestic resource management and environmental evolution in the three countries at similar economic development levels were also discussed. It is evident that CEMAC countries are still to transit from a biomass-based economy to a mineral-based economy. The increased consumption of biomass in this top three CEMAC countries might have significant implications for the economic growth in order to fulfill the demand of the growing populations. With a relatively higher per capita GDP for Gabon and small population it is able to institutionalize resource efficiency as compared to Cameroon and the DRC. This presents an impressive economic growth model for the rest of the Central African Countries and other developing countries.

4.4.2 Policy Implications

The outcomes of this study provide key lessons especially for emerging economies towards sustainable natural resource consumption based on reduced material intensity and increased resource productivity.

Technological improvement for better resource efficiency will be the best option that allows Central African States to develop in a sustainable manner. Technology can significantly but not fully offset the pressures from other two factors in domestic material consumption. Transforming into a greener lifestyle in CEMAC Zone is also essential. However, it will instead require an enormous amount of effort on some part of the countries policymakers to harness and guide technological improvement towards achieving sustainable development. The differences in Central African countries could be a basis to spur mutual communication and cooperation among Central African countries on the governance of resource production and use. It is African people that most care about the future of Africa and move Africa to a sustainable future. The experiences and lessons from material flow analysis of African sub-regions in this study can not only provide valuable insights into resource management policies but also enlighten international organizations advocating appropriate pathways to improve global resource efficiency.

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CHAPTER FIVE

Comparison of Eco-industrial Park monitoring methods by static and dynamic approach

Abstract

There exist a number of evaluation tools that are available to assist governments and industry stakeholders, to monitor the performance of eco-industrial park transitions. In order to track the performance enhancement of eco-industrial parks, there are various indicators that are generally used, such as resource reduction, energy saving, waste reduction, revenue generation, job creation and eco-efficiency enhancement by industrial symbiosis network expansion. But, the improvement of eco-industrial Park must be compared to the baseline year when the eco-industrial Park Program is not operated. However, to get these done, all the reference data of the industrial complexes, such as monitoring reports, which are particularly important for policy and decision-makers, must be well documented. This operation is exceedingly difficult and time-consuming. This study constitutes an amazingly simple and practical EIP performance monitoring method, by theoretically comparing the reference and industrial symbiosis transition. Traditional static approach always accounts for separate data of the total resource, in the form of energy and waste of all the companies at the reference year, and the monitoring year. This approach has a drawback of time consumption as huge data collection experiences a negligible improvement at an early stage. The proposed method in this study is to adopt a dynamic approach in monitoring the industrial symbiosis transition activities. This method simply applied to the companies that are participating in industrial symbiosis activities. This would have an advantage by reducing the administrative workload of data gathering, and this would translate into less time-consuming in tracking the workload. A theoretical monitoring example has been presented in the virtual industrial park, with 5 companies that have two resources per company and thus produces a product

and waste (1 networking per year for 5 years). If one of the company's waste could be compared to a resource in another company, the traditional static approach could increase network efficiency annually, like 1/10, 2/10, 3/10 … 5/10 for 5 years. Meanwhile, the dynamic approach would result in 1/2, 2/3, 3/4 … 5/10. Hence, the dynamic approach of this study would effectively track EIP activities in an easy and more practical way. This could consequently attract policymakers and businessmen to EIP transition activities.

Highlights

- Appraisal of evaluation tools available to assist governments and industrial stakeholders, to monitor the performance of EIP transitions.
- An amazingly simple and practical EIP performance monitoring method by theoretically comparing the reference and industrial symbiosis transition.
- The static approach could increase network efficiency annually, as 1/10, 2/10, 3/10 while the dynamic approach would result to 1/2, 2/3, 3/4.
- Dynamic approach has advantage of reducing the administrative workload of data gathering, that translates to less time-consuming in tracking the workload.

5.1 Introduction

Eco-industrial Park (EIP), new and in transition, can be defined as a dedicated area for industrial use at a suitable site in order to ensure sustainability through the integration of social, economic, environmental quality aspects in siting, planning, management, and operations. This type of industrial park can receive the denomination of EIP based on different reasons, related on the sharing of materials, energy, or infrastructure. It is also possible to develop green infrastructure or foster scavenger companies in the park. So Industrial Symbiosis become one possible aspect of EIPs.

Industrial symbiosis (IS) can be seen in the collection and sharing of resources, by-products, energy, waste, wastewater among others and among co-located industries [1,2]. From the case of a small industrial town in Denmark, the Kalundborg [3,4], industrial symbiosis was based and has since then been adopted by many private initiatives and public policies around the globe as a strategy to reduce the environmental impacts of agglomerated industrial production (for reviews of scholarly work and practices in industrial symbiosis, [5–7]). Industrial Symbiosis (IS) is a systematic approach to enhance a more sustainable and integrated industrial system [8], which identifies business opportunities that leverage underutilized resources (such as materials, energy, water, capacity, expertise, assets, etc.) [9]. IS indulges with various facilities engaging in a mutual beneficiary business with an exchange of either waste, energy, water, by-products, etc. This only goes a long way to valorize and optimize resources and energy in the system. Is has been the most recently optimized approach to enhance resource efficiency in a system, cut on carbon emissions, reduce the waste streams to the minimum [10]. This is why it, has been included at the core of strategies in order to promote the transition towards the Circular Economy (CE), through promoting flows of resources through many different channels. The keys to industrial symbiosis are collaboration and the synergistic possibilities that are offered by geographic proximity.

In the 1980s, life cycle assessment (LCA) was widely applied, which indicated that focus had been transformed from traditional pipe technology to pollution prevention, and the system/product design [11]. In 1989, a milestone achievement was the birth of "Industrial Metabolism" [12], [11,13], and then in 1994, the concept of "Industrial Ecology" was formed. This meant that a new discipline had been established and under a number of national projects had been established. Such famous practices included: "Eco-Industrial Park (EIP) program" in the US. Since 1995, lots of progress was made [14,15] an "eco-town project "in Japan, and since 1997 [16,17]. In 2000, as the other milestones, significant environmental and business benefits were gained by IS, through saving the virgin materials, thereby mitigating waste generation, and reducing costs. The achievement came by using wastes alongside by-products, as well as the cascading use of energy and water, and infrastructure share. A number of case studies were carried out to verify the benefits of IS. The most famous one was the Kalundborg, Denmark [18]. There are also EIP's and the industrial complex in Puerto Rico, USA [19], National industrial symbiosis project in United Kingdom [20,21], Australia [22], and "circular economy pilot", China [23], and [24]. Particular note should be on the promotion of IS that could significantly reduce the carbon emissions at industrial cluster and city levels [25], [18,26].

With this background, many different IS practices have been conducted in the form of EIP, regional symbiosis and circular economy, as well as Eco-Industrial Development (EID). A good number of countries are involved, e.g.UK (in 2000, came up with the national industrial symbiosis project-NISP, focusing on regional waste recycling; Then [20,27], Korea from 2005, it had conducted the national EIP project under the national strategy of "Green Growth", focusing on heavy industrial cluster), [28,29], and China in 2001, launched the national EIP project (Fig.5.1), and the circular economy consequently became national strategies) [30–32]. As an extended concept of IS, urban (and/or regional) symbiosis refers to a specific opportunity that arises from the geographic proximity of urban and industrial areas [17,33,34]. This could innovatively utilize the urban wastes in industries and thereby reduce the related environmental impacts. Especially, some urban refuge could be utilized by the nearby industry and in return, the industry could provide the urban area with such living necessities like heat. Under such a concept, urban and industry could be connected harmoniously, and the resource consumption and emission of pollutants could be reduced, accordingly. In the 1970s, environmental protection issues became popular, [35] and since 1972, the Kalundborg eco-industrial Park in Denmark was constructed and it gradually became well known [18]. Nowadays, this has become the most famous industrial symbiosis practice, alongside the Ulsan industrial symbiosis case in the world

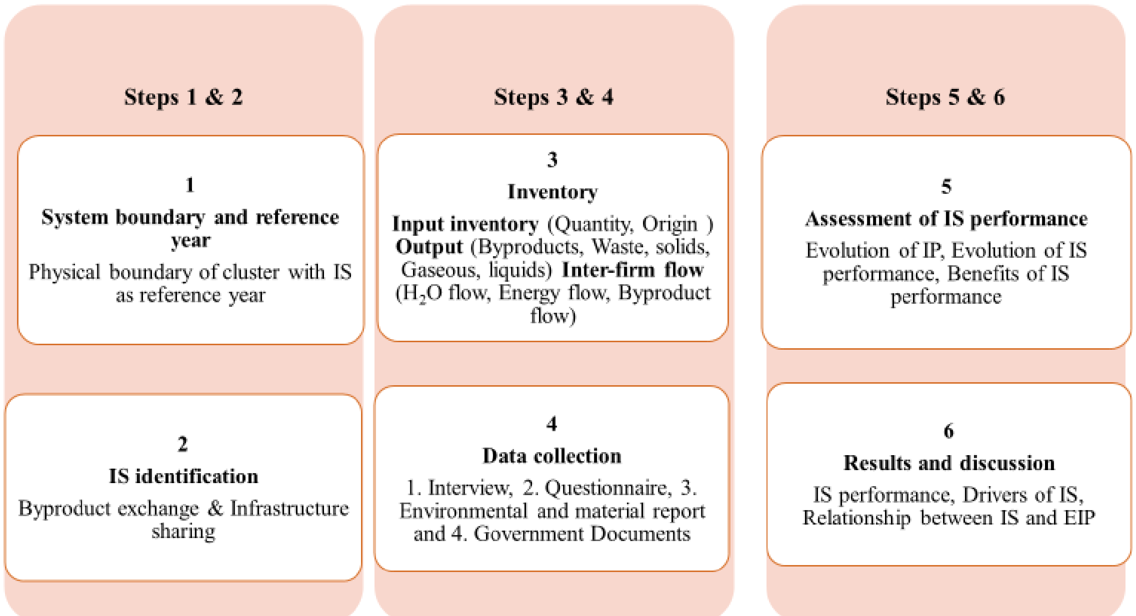

Figure 5.1: EIP performance monitoring procedure in China

5.1.1 Eco-Industrial Park framework

The International EIP Framework describes the performance requirements for EIPs in four key categories: park management performance, environmental performance, social performance, and economic performance. This framework provides the basis for defining and setting prerequisites and performance requirements for EIPs, based on 51 criteria (benchmarks). The criteria are inclusive in scope and are aimed at all types of industrial parks (e.g., Special Economic Zones, Industrial Estates, and Manufacturing Zones) in different contexts. The criteria relate to stakeholders in the private and public sectors (e.g., park management, tenant companies, local/regional/national government agencies), wherever these industrial parks are located. While adherence to all of these criteria is recommended, it is understood that some countries may still want to adjust the criteria to their local specificities. However, compliance with national and local regulations is a requirement for all industrial parks, regardless of their specific geographic location and characteristics. But the focus of the framework is to encourage industrial parks to go beyond compliance with local and national regulations, with respect to environmental and social issues.

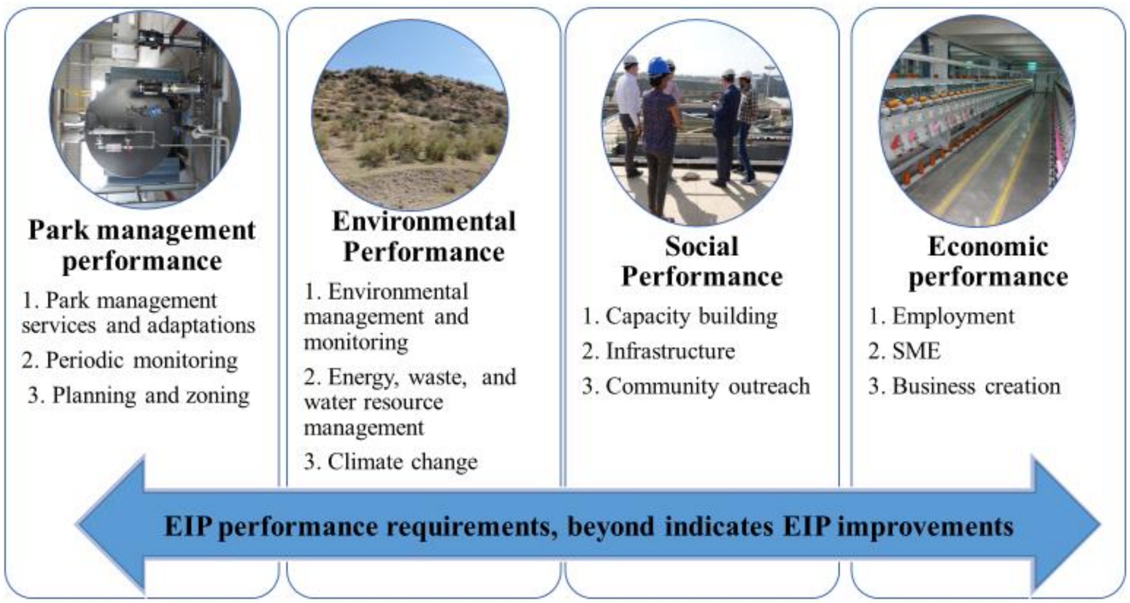

Figure 5.2: International EIP Framework components

5.1.2 Current indicators to track performance of EIPs

Current indicators encompass the Eco-Industrial indicator: assessment using one or more specific eco-efficiency measurements of impacts, Material Flow Analysis indicator: Assessment using material flow indicators and the Life Cycle Assessment indicator: Assessment of impacts using the concepts and methods from LCA theory. According to the IS approach, Eco-Industrial Parks are industrial clusters, i.e., a set of industrial companies located near each other, and which take advantage of their geographical proximity and consider environmental preservation as a key issue when developing cooperation among their businesses, thus resulting in economic and social benefits. The network of such firms is built on the sharing of resources that include materials, energy, water, infrastructures, and facilities. But this will also include the natural habitat and information, and the exchanges of materials and energy aimed at minimizing the use of resources and the waste thus generated. EIP projects can be developed from spontaneous cooperation initiatives carried out by companies motivated to improve efficiency and thereby cut costs (bottom-up-model) or promoted by governmental or other institutional initiatives (top-down model) [36].A variety of indicators are however available for assessing the economic, environmental, and social aspects of an Eco-industrial park (EIP).

Importantly to know that selecting a sustainable indicator is difficult, and so to deal with this selection issue, the following criteria are constructed to be functional, clear, and adaptable to the application context. In this case, the proposed criteria are understanding, pragmatism, relevance, and partial representation of sustainability [37], wherein 249 indicators were filtered by using the four criteria, and classified according to three dimensions of sustainability; social, environmental, and economic dimensions. These four criteria provide a formal way to filter a large set of possible indicators, improving the mechanism for their selection.

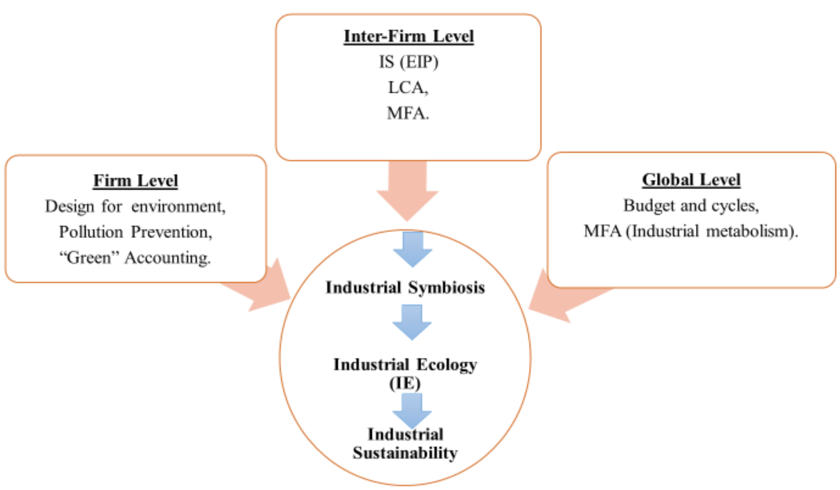

Figure 5.3: Operational Levels of Industrial Ecology

5.1.3 Economic, environmental, and social benefits of EIPs

Benefits of applying IS to an industrial park are related to economic, environmental and social aspects [38,39], and they are focused on:

(i) improving profits and resilience of the companies,

(ii) reducing environmental impacts, and

(iii) concerns about the life of the people in local communities.

Some of them are mentioned in the works of [40] and [41]. Economic benefits are to reduce the cost of waste disposal and decrease the purchase of raw materials. The environmental achievements are seen in a reduction of waste production and exploitation rate of new resource inputs [40].

The social issues of IS are not too pronounced as companies would make profits, lifestyles would improve as more goods would be acquired and more services performed. This would bring alongside employment and many more lives would be touched. [41].

Other social effects are related to the lifestyle and health of the population in the surroundings of the EIP. While the effects of economic and environmental benefits are easy to measure because they are often assessed in an industrial context, the social effects require a suitable evaluation tool as they are cumbersome to evaluate. Therefore, all the sustainability dimensions must be accurately assessed in order to quantify the total effect of applying IS to an industrial park. The benefits of the symbiosis for this industrial park and the surrounding community are found in the [42]. The significant reduction in energy consumption and coal, oil, and water use, the reduction in sulfur dioxide (SO_2) and carbon dioxide (CO_2) emissions and improved quality of effluent water and the transformation of traditional waste products, such as fly ash, sulfur, and biological sludge, can lead into raw materials for production.

On the other hand, drawbacks in tracking performances with the various sustainable indicators for industrial symbiosis are exceedingly difficult and time-consuming, due to numerous criteria and huge data sets that are involved. This paper proposes a more technical approach to monitoring progress in an Eco-industrial Park wherein the old approach, which is the static approach, is compared with the dynamic approach to measure the progress in an Eco-industrial park.

This paper covers an introductory chapter, addressing issues on industrial ecology, industrial symbiosis, Eco-industrial park framework, and various indicators to measure EIP performance and triple bottom line benefits of EIP. The second chapter covers methods of the study: Static IS monitoring approach, approach; dynamic IS monitoring approach and eco-efficiency monitoring and ta source. The third chapter cover application to Ulsan eco-industrial park IS monitoring to track the progress of IS evolution. The fourth covers the conclusion and policy implications of the study.

5.2 Methodological aspect of static and dynamic approach

There are two different theoretical monitoring methods related to resource flow within an EIP that are represented in Fig. 5.4a and Fig 5.4b. In the first static monitoring method, all the company in the parks are considered as base line for resource and energy efficiency improvement. the process begins with the entry of resources obtained from outside the EIP, which are then used for the individual production processes of each company. In the process, the companies produce different types of by-products that can be used by other companies. This is known as industrial symbiosis. It is possible to envision the flow of by-products circulating within the EIP, and as such, the flow exits one company and is then received by another. Some companies undertake networking and thereby exchange their by-products and energy, while others do not. All the companies are considered for the tracking of the performance of the EIP. It takes a long time and it is seemingly very cumbersome. This is the static monitoring approach due to the baseline of reference year.

In the dynamic method baseline is changed based on the step by step industrial symbiotic network expansion. Here the resource and energy consumption before and after industrial symbiosis of only the companies involved in industrial symbiosis activities are calculated to evaluate the performance of EIP. As not all the companies in industrial park are considered, and it is quite easy to track the performance of the EIP. This saves time, saves energy and money. Fig. 5.4a presents a theoretical scenario in which not all participating companies are involved in symbiotic relations with one another. Some are while others are not. Fig. 5.4b shows a hypothetical flow in which all companies are involved in symbiotic relations and in this way, it is easier to track the performance of the EIP.

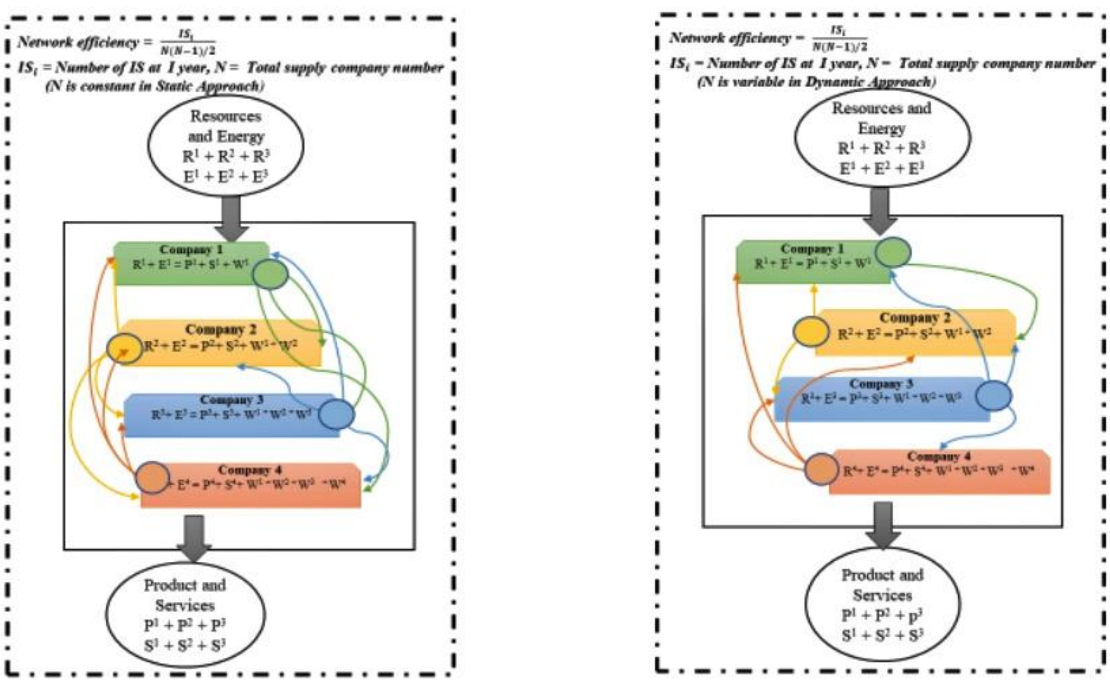

Figure 5.4: (a) Static approach (left) and (b) Dynamic approach (right)

5.2.1 Static monitoring approach

A theoretical example is found in 5 companies that have two resources (material and energy) per company and produce a product and waste (1 networking per year for 5 years). If the waste from one company would be accounted to a resource in another company, the traditional static approach accounts for the efficiency as 1/10, 2/10, 3/10 … 9/10.

1^{st} Year Efficiency $= \frac{IS}{N(N-1)/2} = \frac{1}{10}$

2^{nd} Year Efficiency $= \frac{IS}{\frac{N(N-1)}{2}} = \frac{2}{10}$

4^{th} Year Efficiency $= \frac{IS}{N(N-1)/2} = \frac{4}{10}$: where *IS* is industrial symbiosis, while *N* is network efficiency for static approach.

5.2.2 Dynamic monitoring approach

The dynamic approach accounts for an initial of two willing companies, and an annual addition of 1 company per year for 5 years. The efficiency would result in 1/1, 2/3, 3/4, … 9/10. EIP performance must be simple and easily monitored. Thus, network connection efficiency can be selected as a basic indicator as shown below. Network efficiency is an implemented network number divided by the total number of potential networks, as is indicated below:

1^{st} Year Efficiency $= \frac{IS}{N(N-1)/2} = \frac{1}{1}$

2^{nd} Year Efficiency $= \frac{IS}{N(N-1)/2} = \frac{2}{3}$

4^{th} Year Efficiency $= \frac{IS}{N(N-1)/2} = \frac{4}{10}$: where *IS* is industrial symbiosis, while *N* is network efficiency for a dynamic approach.

5.2.3 Network efficiency monitoring

The application of the network efficiency to monitor progress in an eco-industrial park can be seen in the number of symbioses divided by the total number of companies. In the case of the static approach, the total number of companies stays constant, while the symbiotic networks increase over the years, while in the case of dynamic approach the number symbiosis and a total number of companies both vary over the years.

$$\text{Network Efficiency} = \frac{\text{ISi}}{N(N-1)/2} \quad (1)$$

Where: IS_i is number of IS at *i* Year

N is the number of companies at *i* year

a. Application to Pollution Reduction Efficiency

The application of pollution reduction efficiency is pollution reduction by industrial symbiosis network divided by the total pollution reduction as shown below:

$$\text{Pollution Reduction} = \frac{\sum \text{IS}_i\ x\ \text{PR}_i}{\sum \text{N}eij} \quad (2)$$

Where: IS_i is network *i* at *i* year

PR_i is pollution reduction at *i* network

N_{eij} is total pollution of *i* companies at *j* year

b. Application to Water-Saving Efficiency

The application of water-saving efficiency is the water-saving by industrial symbiosis network divided by the total water consumption as shown below:

$$\text{Water savings (\%)} = \frac{\sum \text{IS}_i\ x\ \text{WS}_i}{\sum_i \text{N}_{wij}} \quad (3)$$

Where: IS_i is network *i* at *i* year

WS_i is water saving of i network

N_{wij} is total water consumption of *i* companies at *j* year

c. Application of Energy-saving efficiency

The application of energy-saving efficiency is the energy-saving by industrial symbiosis network divided by the total energy consumption as shown below:

$$\text{Energy saving} = \frac{\sum \text{IS}_i \; x \; \text{ES}_i}{\sum_i \text{N}_{enij}} \qquad 4$$

Where: IS_i is network *i* at *i* year

ES_i is the energy-saving at i network

N_{enij} is total energy consumption of *i* companies at *j* year

d. Application to Cost-Saving Efficiency

The application of cost-saving efficiency is the cost-saving by industrial symbiosis network divided by the total economic cost as shown below:

$$\text{Cost saving efficiency} = \frac{\sum \text{IS}_i \; x \; \text{CS}_i}{\sum_i \text{N}_{eij}} \qquad 5$$

Where: IS_i is network *i* at *i* year

CS_i is cost saving at *i* network

N_{eij} is a total cost-saving of *i* companies at *j* year

5.2.4 Data source

Sustainable indicators are essential to assess the effectiveness of an EIP, regarding the axes of sustainable development in domains of economic, environmental, and social dimensions, [38,39]. These indicators have to be identified with the main characteristics of an EIP: to compare with other contexts and to support decisions concerning its configuration. The comparison of an EIP can be done with: (i) its historical performance, (ii) a new configuration of the same park, (iii) or other parks. For a complete sustainability assessment, the indicators must quantify all impacts like internal, external, positives, and negatives, produced by the geographical location of firms and their connections through an industrial network. In this case, the dynamic approach for monitoring EIP progress is compared with the traditional static approach. First, it is done on theoretical bases with hypothetical figures from 1 through 5, comparing the old fashion way of tracking progress in an industrial park, wherein it is time consuming and huge data making it difficult. Secondly, the industrial symbiosis data from companies in Ulsan Eco-Industrial park are used to elaborate on the theory of the static and dynamic approach using the 5 steps approach. This is the same as that of the dynamic approach where the progress is tracked based on the company's networking, in a symbiotic manner. It is easier to track and monitor progress as it is time saving. The core originality of the new approach is only to consider the change of flows due to the industrial symbiosis of the company's networking. In this way, no need to collect all the input and output flows for the companies or processes in the EIP, as in the case of the old traditional static approach. And the newly proposed indicator, the dynamic approach can directly present the direct effect of industrial symbiosis. Such information can be presented by mathematical equations.

5.3 Application to Ulsan Eco-industrial Park monitoring

Industrial production has been crucial for the growth of local economies, especially since the historical Industrial Revolution. In this respect, the development of local industrial production systems (LIPS), which is composed of agglomerated industries in specific locations, has been central to regional development strategies [43]. In the meantime, sustainability has become a mainstream concern related to industrial development and problems have emerged related to resource scarcity and environmental pollution due to territorially concentrated industrial production activities from LIPS [23,44–47]. In this vein, the industrial ecology literature argues that the problem of the industrial production systems is the linear Industrial production routines, which are based on the extract-produce-throw away approach to resources [48]. Researchers in the same field have created modern ways of balancing symbiosis issues in production lines and closing the ecological loops [49].Industrial symbiosis aims to benefit from the advantages of industrial agglomerations in LIPS to adopt and develop industrial ecosystems [50,51].Conceptually, industrial parks around the world monitor their progress with various sustainability indicators. Monitoring performance of EIP can be done by the static and dynamic approach.

5.3.1 Stepwise symbiotic network expansion in Ulsan Eco-industrial Park

All the developed symbiosis networks in Ulsan Eco-industrial Park (UEIP) began with a proposal (through a top-down or bottom-up approach) to a business model and a feasibility investigation, which were subsequently commercialized through negotiations and contracts amongst the different stakeholders [52]. Because of the new qualities of these beneficial interaction systems, sharing of advantages is viewed as significant during symbiotic dealings. Business information on the companies involved and the energy exchanges are presented in some simple steps.

Step One shows three companies involved in symbiotic network exchanges. These companies include Sungam Municipal Waste Incinerator Facility (SMWIF) networking with Hyosung Yongyeon Factory 2 (HYF2) and Hyosung Yongyeon Factory 3 (HYF3). The SMWIF has two incinerators with a capacity of 115,000ton/y. Here 45ton/h of steam (pressure:16kg/cm^{2}g) was produced by utilizing the heat generated as a result of incineration of municipal solid waste (300ton/d). Out of 45ton/h of steam from the SMWIF, 35ton/h (pressure:16kg/cm^{2}g) in the ratios of 25ton/h (pressure:16kg/cm^{2}g) to HYF2 and 10ton/h (pressure:16kg/cm^{2}g) to HYF3. The remaining 20ton/h is used by the SMWIF to meet its own requirements.

In Step Two, 5 companies involved in the network included: KP chemical, Hanhwa Chemical, Korea PTG, Hansol EME (extension in 2014) which is a chemical company and SKC. Using the

ESCO fund and here the core business was the establishment of an enterprise-wide steam swap network, through the reconstruction of utility in the Yongyeon Industrial Complex. Initially, KP Chemical produced 20ton/h (pressure:5kg/cm^{2}g) of low pressured steam, together with Hansol EME (10ton/h-pressure:18kg/cm^{2}g) and supplied it to Korean PTG, which was giving 30ton/h (pressure:45kg/cm^{2}g) high pressure steam to SKC. Hanhwa Chemical is giving 25ton/h (pressure: 45kg/cm^{2}g) to SKC. Hansol EME (extension in 2014) was giving 10ton/h (pressure:18kg/cm^{2}g) to Korea PTG. Korea PTG profited monetarily by accepting low and medium weight steam at a low cost and selling high-pressure steam at a high cost. Therefore, this procedure of steam swap brought about both monetary and ecological advantages.

In Step Three, 3 companies were involved in the networking scenario and steam energy was swapped. The four participating companies included: SK Chemical, Hansol EME (2014, extension) and SK Energy. SK Chemical produced high-pressure steam 70ton/h (pressure:45kgf/cm^2) and Hansol EME produced medium pressure steam 30ton (pressure:45kgf/cm^2). SK Chemical and Hansol EME (2014, extension) and supplied 100ton/h (pressure:45kgf/cm^2) of high-pressure steam (pressure:45kgf/cm^2) to SKC. As a result, SK Energy (Petrochemical company) reduced the coal consumption needed to run the boiler for its steam requirement, thus minimizing the adverse effects of environmental pollution.

In Step Four, it included four energy network interactions, Sungam 2 incineration plants (2012, extension) (S2IP), HYF2, HYF3, and SKC. Here the core business was the high-pressure steam supply business in Ulsan where in S2IP that was extended in 2012 with an incineration capacity of 115,000ton/y. Involvements included S2IP giving 35ton/h (pressure:45kg/cm^{2}g) to HYF2, S2IP giving 15ton/h (pressure:45kg/cm^{2}g) to HYF2 and HYF2 giving 20ton/h (pressure:45kg/cm^{2}g) to SKC.

In the final step, which is Step five, there are four companies involved in the pressured steam exchange. These companies included: HYF2, Hyosung Yongyeon Factory (HYF1), KP Chemical and Eastman. HYF2, produces 25ton/h (pressure:16kg/cm^{2}g), and then after meetings its requirements, 15ton/h (pressure:45kg/cm^{2}g), to HYF1. Same HYF2 10ton/h (pressure:7kg/cm^{2}g) to KP Chemical and 25ton/h (pressure:5kg/cm^{2}g) to Eastman.

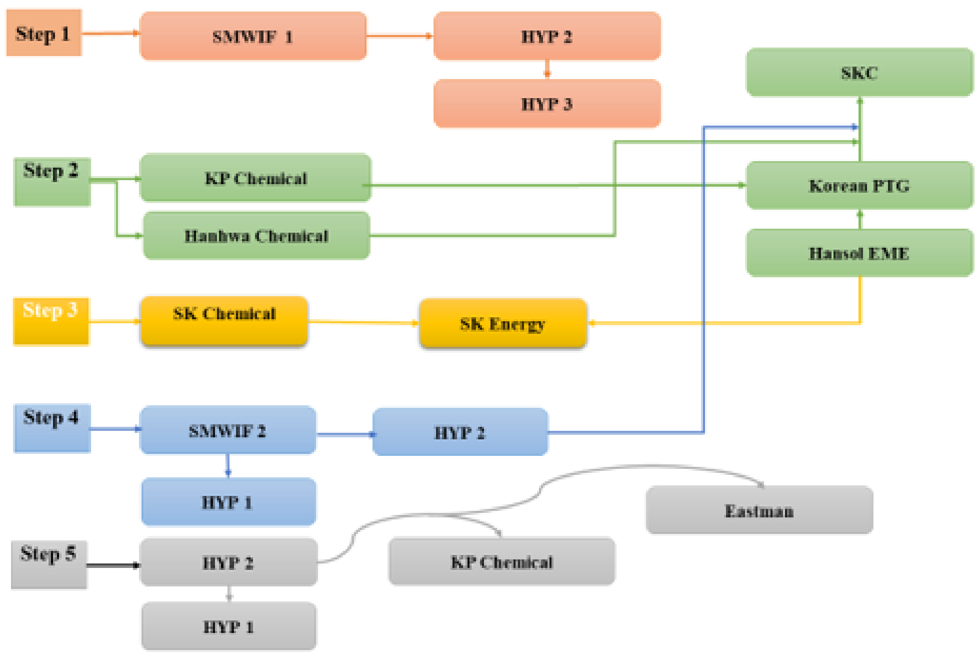

Figure 5.5: Industrial Symbiosis network evolution in UEIP

5.3.2 Monitoring network efficiency

In this study, a quite simple and practical EIP performance monitoring method theoretically compares the reference and industrial symbiosis transition data. The Dynamic approach simply accounts for the companies that are participating in industrial symbiosis activities. This generally would have an advantage of minimizing the administrative workload of data gathering, which translates to less time-consumption and easy tracking workload. A theoretical monitoring example is presented in a virtual industrial park with 5 companies which have two resources per company and produce a product and waste (1 networking per year for 5 years). If one company's waste would be accounted to a resource in another company, the traditional static approach increases network efficiency annually as 1/10, 2/10, 3/10, …9/10 for 5 years. Meanwhile, the dynamic approach would result in 1/2, 2/3, 3/4 … 9/10. Data from some selected five steps in the UEIP was used and the resource efficiency was calculated for both the static and dynamic approach cases (Table 5.1).

Table 5.1: Industrial symbiosis network of companies with Static and Dynamic efficiencies

	Company	Total Network	Actual network	Static efficiency	Dynamic efficiency
Step 1	3	3	2	2/91	2/3
Step 2	8	28	6	6/91	6/28
Step 3	10	45	8	8/91	8/45
Step 4	12	66	11	11/91	11/66
Step 5	14	91	14	14/91	14/91

Efficiency here is obtained by dividing actual networks (industrial symbiosis steps) with the number of companies. Nineteen companies are included in the 5-step approach. For the static approach scenario, the actual symbiotic network is divided by the total number of companies participating in the industrial park, (*see equation 1*) while in the dynamic approach scenario, the efficiency is obtained by dividing the actual symbiotic networks with a gradual accumulation of the companies at the various steps involved (*see equation 2*). The theoretical network is actually gotten by multiplying the supply by two, while the actual networks are the networks in the real situation as per the Ulsan Symbiotic network cases in the 5-step scenarios.

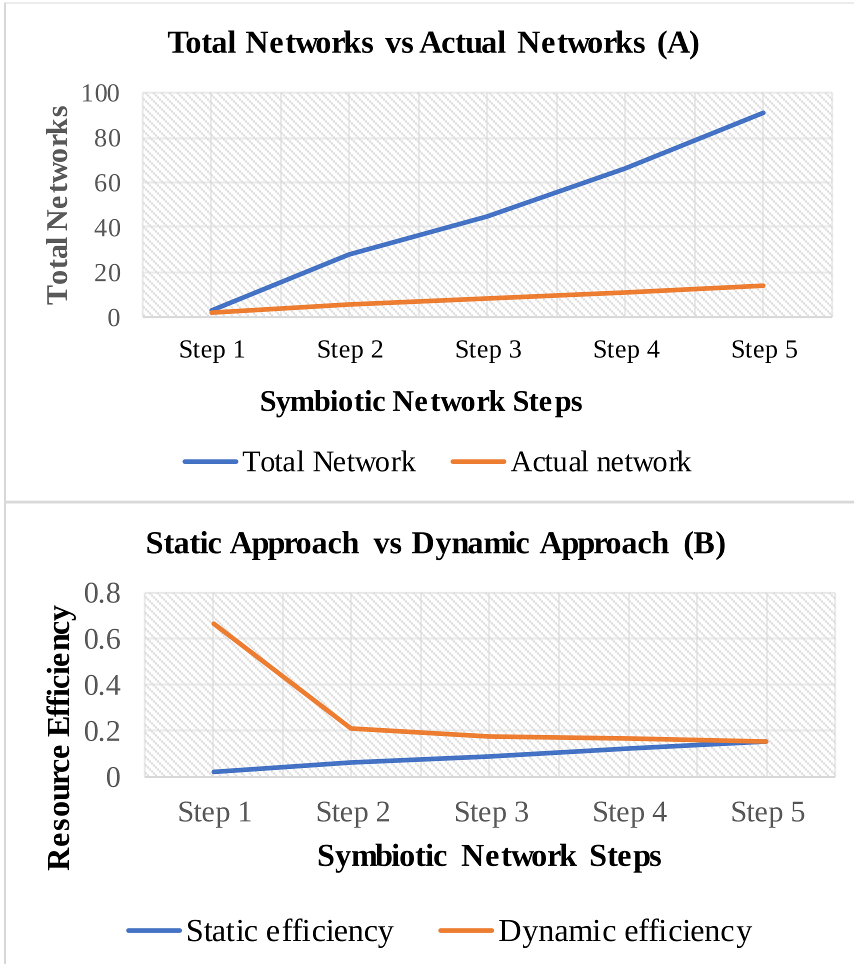

Figure 5.6: Total network Vs. Actual network (A) and Static Vs. Dynamic Approach (B)

5.3.3 Comparison and Discussion

Table 5.2: Data of energy saving efficiency of static and dynamic approach

Steps	Total energy consumption (ton/hr)	Actual Energy savings (ton/hr)	Actual network	Energy saving efficiency (Static Approach)	Energy saving efficiency (Dynamic Approach)
Step 1	200	35	2	0.020588	0.175
Step 2	300	55	6	0.052941	0.18
Step 3	500	100	8	0.111765	0.19
Step 4	300	75	11	0.155882	0.203846
Step 5	400	35	14	0.176471	0.176471
Total	1700	295	41	0.517647	0.925317

N/B: The total energy consumption (ton/hr), for the 5 steps are based on assumptions since it is difficult to get these data.

The actual energy-saving efficiency and actual network are presented in some 5 simple steps. These 5 steps are considered and based on available steam exchange data for the Ulsan symbiotic data. In Step One with the SMWIP1, there are just two networks and 35ton/h of energy being saved. The beneficiaries are both HYP2 and HYP3. The ratio of energy saved by the dynamic approach (0.17) to a static approach (0.02) is 9:1. For Step Two, 55ton/h of energy is saved. The major suppliers are the KP chemical and the Hanhwa Chemical, while the beneficiaries are Korea PTG and SKC. There are four symbiotic network steps identified. Energy-saving efficiency by dynamic approach (0.18) is three folds higher than the energy saved by the static approach (0.05). For Step Three, 100ton/h of energy is saved. Here, SK energy is benefitting this energy from both SK chemical and Hansol EME (extension in 2014). There are basically just two symbiotic network steps, and here the tracking of performance by Energy-saving efficiency (Dynamic Approach) (0.19) is higher than the Energy-saving efficiency (Static Approach) (0.11). In Step Four, 75ton/h of energy is being saved. Here, there are four companies involved in the symbiotic relationship with three actual networks. SMWIP2 is benefitting, both HYP2 and HYP1 and then HYP2 are benefitting to SKC. The Energy-saving efficiency (Dynamic Approach) (0.20) is slightly higher than the Energy-saving efficiency (Static Approach) (0.15). Finally, in the last step, there are four companies involved in three symbiotic relationships. HYP2 is the supplier (35ton/h), and then HYP 1, KP chemical and Eastman are the beneficiaries. Tracking the performance of the EIP using the Energy-saving efficiency (Static Approach) and Energy-saving efficiency (Dynamic Approach) (0.17) are the same. With the above analysis of tracking EIP performance, using the static and dynamic approaches, the dynamic approach tracks the performance more, saving time, saving-energy and reducing the administrative workload. The dynamic approach can be seen to track and monitor the progress of the symbiotic network exchanges, in the industrial park better and faster than the static approach (Figure 5.7).

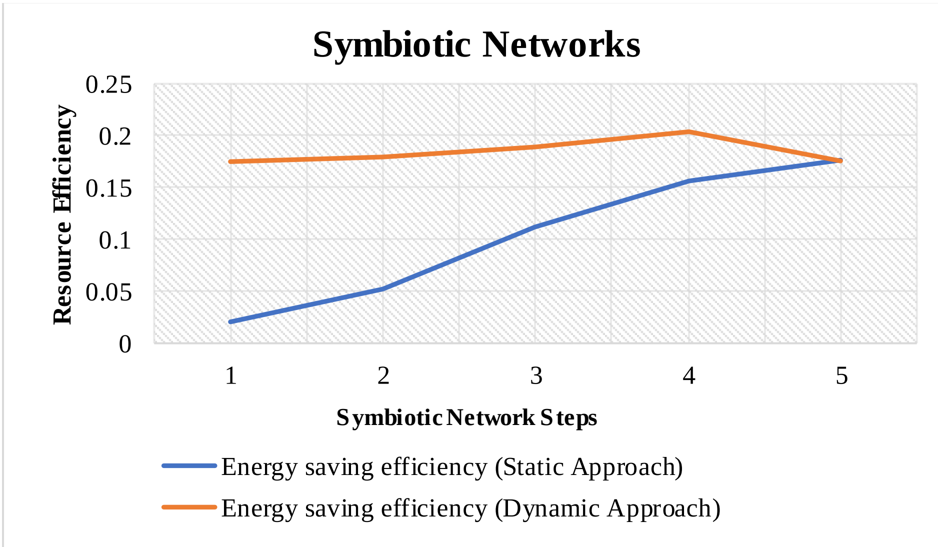

Figure 5.7: Static and dynamic resource efficiencies with symbiotic network steps

5.4 Conclusions and policy implications

A well-designed industrial symbiosis network is economically feasible, technological replicable, environmentally neutral, or positive, and socially adaptable. This generally works in the prevention of waste generation and possible alternatives can emerge, such as symbiotic networks adopted by two or more willing companies to improve on the eco-efficiency of an eco-industrial park. In this recent study, the performance of Eco-industrial Parks can be traced using several suitable sustainable indicators. These suitable sustainable indicators are seen in economic, environmental, and social dimensions. Other indicators have been particularly useful over the years, with a few shortcomings such as difficulty to obtain holistic outcomes that can best track industrial symbiosis performances. So, to deal with these selection issues, some criteria are constructed to make the indicators functional, clear, and adaptable to the application context. Though EIP development strategies are well applied in many countries, systematic monitoring of

EIP performance is still lacking due to difficulties in data collection because of complex administrative procedures. The former indicators have been time consuming in tracking performances of EIP. This research delves into an industrial symbiosis and transition monitoring by using network efficiency in static and dynamic approaches. The proposed dynamic monitoring of network efficiency can easily be expanded to triple bottom line evaluation, multiplying the performance of the networks in economic, environmental, and social advantages. The network approach is clearly seen in the energy-saving scenarios of the Ulsan Eco-industrial Park (UEIP) examples, where much energy is saved through symbiotic networks. The dynamic approach tracks the performances faster and much more visible as compared to the static approach. This is done with a simple five-step industrial symbiosis network approach; the dynamic approach measures the performance more visible than the static approach as seen in Step 1 of the symbiotic networks. The ratio of energy saved by the dynamic approach (0.17) to a static approach (0.02) is 1:9. Also for step 2, the energy-saving efficiency for dynamic approach was (0.18) which is five times higher than the energy saved by the static approach (0.05), with a ratio of 3:1. Thus, the dynamic approach of this research would effectively track EIP activities in an easy and more practical way than the static approach. This also saves time and reduces the administrative workload. The dynamic approach to monitor performance is strongly recommended as an indicator to be used to measure the performance of an Eco-Industrial Park.

This approach can be used elsewhere irrespective of geographic location, to trace more visibly the performance of industrial activities. This would be so beneficial to industries as it would attract policymakers, stakeholders, and businessmen in EIP transition activities.

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CHAPTER SIX

Eco-industrial park transition in Ethiopia with lessons learned from Korea

Abstract

Industrial Parks are effective tools towards the sustainable development of an economy. In developing countries, fostering industrial development is paramount, however these industrial activities are major contributors of greenhouse gas emissions and diverse environmental degradations. Greening these industries is a gate way to curbing emissions and reducing environmental externalities while maintaining low-carbon economic growth. Eco-industrial parks (EIP) could be a major platform to green economic growth through introducing the resource efficiency and clean production (RECP), industrial symbiosis (IS), and shared utility infrastructure and sustainable park management attracting new businesses. Following the Sustainable Development and Poverty (SDPRP) strategy (2002-2005), an ambitious Climate Resilient Green Economy (CRGE) strategy alongside a multi-sectoral Growth and Transformation Plans (GTPI & II), Ethiopia is becoming the major manufacturing hub in Africa with a lead in the textile sector. Green industrialization pathway in Ethiopia by employing EIP development policy will go a long way to achieving economic buoyancy, sustainable industrial development, and an environmental appraisal. In this study, the practicality of research into business development (R&BD), Korean EIP transition approach was applied to HIP in Ethiopia. This research presents industry situation and discusses the potential IS opportunities in HIP in Ethiopia by analyzing its demand for energy, utilization of its waste streams and locating potential symbiotic networks. Energy efficiency can be enhanced at company level by cleaner production technology such as compressed air, inverter, and LED lightening system. In addition, opportunities for water quality enhancement were identified in Hawassa Wastewater Treatment Facility (WWTF). Finally, sustainable sludge

treatment was proposed by environmental infrastructure centered on IS business. This research proposes sustainable EIP transition potentials and draws insightful policy recommendations for HIP and Ethiopia.

6.1 Introduction

In 2002, the government of Ethiopia formulated the Industrial Development Strategy (IDS), while assuming the leadership and coordinating role on the vision of the Agricultural Development Led Industrialization (ADLI). Four key principles were formulated: (i) strong linkage between industry and agriculture (ii) export oriented sector to lead industrial development (iii) labor intensive sectors to exploit comparative advantage and (iv) public-private partnership that recognizes the role of the private sector as engine of low-carbon economic growth [1].

Following the IDS, Ethiopia's economic development was governed by a succession of large-scale government plans that led to a series of other policy initiatives including Sustainable Development and Poverty (SDPRP) strategy (2002-2005), an ambitious Climate Resilient Green Economy (CRGE) strategy alongside a multi-sectoral Growth and Transformation Plans I and II (GTPI 2010-2015 and GTPII 2015-2020) [2]. Emphasis are laid on the importance of industrial transformation, export-oriented and labor-intensive industries. The GTPI and GTPII aim to consolidate and transform Ethiopia into a middle-income status country by 2020 by strengthening industrial production and development of light manufacturing industries. The GTPI envisioned the development of five industrial parks: Bole Lemi , Kilinto, Hawassa, Dire Dawa and Kombolcha [3]. Leading up to the GTPII there are now a total of 22 industrial parks under various phases of the establishment (Table 6.1, Table 6.2).

Table 6.1: Industrial Parks (IPs) Progress and Status; State owned IPs

S/N	Industry Park	Sector Focus	Size (ha)	Status
1	Addis Ababa - Bole Lemi 1	Textile, Apparel, Leather & Leather Goods	156	100.0%
	Addis Ababa - Bole Lemi 2	Textile, Apparel, Leather & Leather Goods	171	80.0%
	Addis Ababa - Kilinto	Pharmaceutical	279	80.0%
2	Hawassa Phase-I, Cycle -I	Apparel & Textile	300	100.0%
	Hawassa Phase-I, Cycle -II	Apparel & Textile		95.0%
3	Adama	Machinery, Equipment, Footwear, Apparel & Textile	2,000	95.0%
4	Dire Dawa	Machinery, Equipment, Chemical, Apparel & Textile	4,000	95.0%
5	Mekelle	Textile, Apparel, Leather & Leather Goods	1,000	100.0%
6	Kombolcha	Textile, Apparel, Leather & Leather Goods	700	100.0%
7	Jimma	-	1,000	50.0%
8	Bahir Dar	-	1,000	50.0%
9	Arerti	Building Materials & Furniture	100	-
10	Aysha	Mixed and Open		-
11	Debre Berhan	Agro-Processing	1,000	60.0%

Table 6.2: Industrial Parks (IPs) Progress and Status; Privately Owned IPs

No	Name of industry park	Sector	Location	Size (ha)
1	Eastern Industrial Zone	Mixed	Dukem	400
2	George Shoes Cluster Park	leather processing & products	Modjo	86
3	Huajian Group Cluster Park	Mixed	Lebu	138
4	CGCOC		Debre Berhan	122
5	CCCC Arerti	Construction materials & home appliances	Arerti	100
6	CCECC Dire Dawa	Mixed	Dire Dawa	1000
7	Kingdom Industry Park	Textile and garment	Adama	32
8	Vogue Industrial Park	Textile and garment	Mekelle	176.7
9	Hunan	Heavy Machineries and Equipment	Adama	120
10	Sunshine	Textile and garment	Adama	80

However, Ethiopia witnessing a rapid development of industrial parks (IP), with concentrated economic development, will definitely witness environmental externalities into within its scope area and consequently present both opportunities and challenges for sustainable industrial development [4].

Thus, Ethiopia seeks a transition from industrial parks (IP) to EIP. EIP is a networked evolution of IS, which results from the directed efforts to identify firms from different sectors with a plan to locate them together in order to stimulate resources sharing among tenant companies. Despite past efforts, many industrial zones around the world are not yet considered as EIP's because of the low number (or total lack) of symbiotic relationships among industries. Ethiopian industrial parks are not an exception. A promising strategy is to develop those existing industrial parks to be sustainable EIPs [5], based on symbiotic networks among existing companies within the parks, as implemented in Korean research and development into business'(R&DB) framework for IS. This is a promising strategy for infancy stage EIP's to emerge to world first class EIP's. This can be achieved through Industrial symbiosis (IS). One of the concrete examples of IS development is EIP's, which improves resource efficiency and cleaner production (RECP) and minimizes environmental impacts by adopting IS models for waste exchanges between industries.

The main objective of this research is to show case the potential of transition from IP to EIP in the Hawassa Industrial Park (HIP) in Ethiopia based on experience from the R&DB IS development framework.

Thus, the specific objectives of this study are to:

(i) Examine the general status of the HIP in Ethiopia,

(ii) Identify energy improvement opportunities at the company level and WWTF level,

(iii) Identify IS items and supporting IS commercialization for HIP.

The research work is organized as follows: following this section, section 2 presents literature review of EIP including the Korean EIP Initiative, section 3 dives into the materials and methods including Hawassa Industrial Park (HIP) as a case study, section 4 describe the results and discussions on the uniqueness of the HIP; and finally, section 5 gives conclusions and new EIP business case recommendations.

6.2 Literature review

6.2.1 Eco-industrial park in Africa

Eco-industrial parks emerged from the classic Kalundborg IS case in Denmark. Then their implementation drew overwhelming attention and as they were seen as a group of industrial businesses evolved spontaneously to reduce resource and energy demands of different organizations within a given zone, contributing enormously to conceptualizing of sustainable industrial development strategies of many countries and their sub regions. Thus, EIP's have received increasingly more attention over time [6]. Early industrialized countries including the United States [7], the Netherlands [8,9], the United Kingdom [10], South Korea [11] and Japan [12,13] carried out pilot activities and even formulated national-level EIP implementation plans, but also Thailand [14], Vietnam, China [4] and other developing countries also regard it as an essential means of sustainable industrial development.

Industrial Symbiosis (IS) is an integral part of EIP that connects different industries by the transaction of material, energy or physical exchange of services with the aim to obtain an economic and competitive advantage in an environmentally and socially sustainable manner [15]. IS is closely related to creating relations among companies to increase the sustainability and efficiency of material and energy flows through the entire production process [16]. Sustainability requires a consideration of the social or community dimension as well as ecological integrity and economic efficiency [7]. It is based on these three dimensions (socio-economic performance, park management performance and environmental performance) that makes EIP requirements crucial [7].

Africa recently has chosen industry as a significant engine of growth in the economy, by nurturing a large amount of industrial parks [17]. With the encouragement of international development partners, some African countries have started to address environmental issues at the industrial park level to have efficient industrial output by adopting EIP concept and policy. There have been a few related literature reviews on Africa's industrial ecology, industrial symbiosis, and its success and limiting factors to EIP development. Wherein, the researchers discussed greening of industrial parks [18] by assessing the parameters for industrialization in South Africa; identified enabling policy to accelerate the transition to EIPs in Kenya with focus on the role of government policy in facilitating the development of EIPs [19]; and the success and limiting factors for EIP development in Egypt based on analysis from a global perspective [20]. Though, when comparing with the other developing countries, Africa is still at the infancy stage EIP development. According to the build and recruit model proposed by [21], the target of Africa's EIP initiatives is to establish a planned EIP model by recruiting foreign enterprises on the basis of the weak transitional industrial base.

6.2.2 Korean National EIP Initiatives

The National EIP program in South Korea was based on transformation of successful research outcomes into business ideas with a potential to provide triple bottom line benefits. A masterplan was carefully developed based on the strengths, weaknesses, opportunities, and threats (SWOT) analysis conducted during pre-feasibility study of Korean EIP program in 2004 and was finalized by Korea Industrial Complex Corporation (KICOX) [11], and was divided into 3 phases:

- ❖ Phase 1 (2005 - 2010) aimed at establishing a foundation through experimentation with 5 Pilot industrial complexes shifting to EIPs [22].
- ❖ Phase 2 (2010 - 2014) was focused on expanding the network of physical exchanges by disseminating knowledge and experience to industrial complexes connected to the pilot sites in a hub-and-spoke network [22].

- ❖ Phase 3 (2015 - 2019) was aimed to complete the national EIP network and establish Korea's own EIP model based on the lessons learnt from the previous 2 phases [22].

6.2.2.1 Implementation Strategy: research into IS business development

The concept of industrial ecology expressed with 8 regional EIP centers affiliated to KICOX, composed of a team of academic experts or company managers who have, over time, demonstrated to possess deep understanding of the local society and culture and have proven track records of industrial innovation were selected by the local municipal city government. The salient feature with the EIP project in South Korea lies in the transformation of successful research outcomes into business with a potential to provide triple bottom line benefits. To begin with, the symbiosis projects are submitted to the regional EIP centers where the proposals are screened and sent to KICOX for further evaluation by its assessment committee (figure 6.1). Upon successful approval of the proposals, the project management agency approaches the regional EIP center to collect the research fund required to start the project. A maximum of 75% of the total research budget is supported by KICOX and the 25% by the project participants [23].

In some special cases, the local city government support deficits in the funding, in cases where a particular symbiosis project has a significant local/regional environmental effect and are unable to bear higher costs. Interim inspection is made by the regional EIP centers to monitor the progress of the research projects. The final report prepared, based on the research outcome, is submitted by the project management agency to the regional EIP center. Thereafter, the regional EIP centers forward the report to the KICOX authorized assessment board. Finally, the research result is commercialized through a comprehensive negotiation among all the stakeholders involved in the project [23].

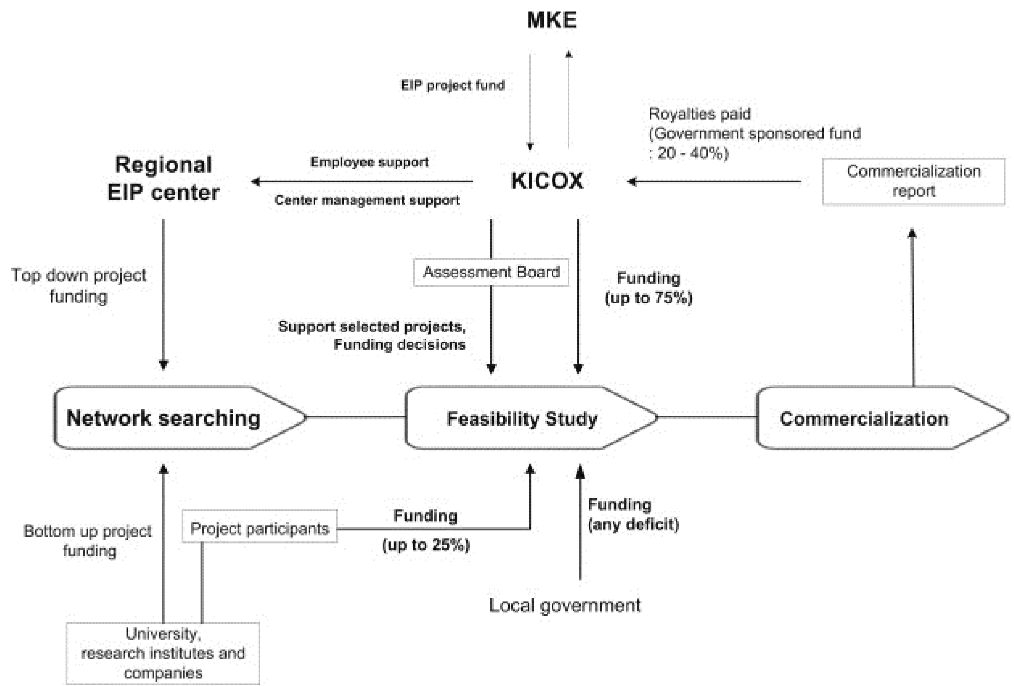

Figure 6.1: Funding mechanism to support the development of IS networks (source: KICOX)

The R&DB framework (Fig. 6.2) could be summarized in steps as follows:

In step 1 of the R&DB framework, the potential synergy networks are identified, either by a top-down or bottom-up approach.

In step 2, feasibility study entails an assessment of the potential uses of by-products, an assessment of the techno-economics and environmental feasibilities, and a conceptual design for the particular network type.

Step 3 is the most important element in the R&DB framework is the commercialization and implementation of the newly identified networks.

This framework follows certain rules and principles for some of the critical activities viz., recruiting potential partners, feasibility investigations, business model development and commercialization with due negotiations among the partners, to ensure the successful establishment of a network. The potential partners are selected based on their geographic proximity and willingness to participate/cooperate in the synergy development [23].

The most important step prior to the IS network implementation is the development of a suitable IS business model. The factors that must be considered to be important are as follows: (i) IS can be achieved with the currently available technology, (ii) benefits should overcome and exceed the investments, and (iii) IS activities must be allowed under the existing laws. The most delicate step prior to implementation is the negotiation among the key partners participating in the network. The basic concept of IS development is to create value-added IS related products and services by stakeholders based on common and differentiated responsibility and benefits sharing principles. So, sharing of benefits among the partners should be acceptable to be equivalent based on the contribution and value-added created in the synergy. Therefore, in this stage, the benefit is proportionately shared based on their contribution and investments in the infrastructure development for a particular synergy network. Additionally, minimizing various risks of failure led to the gradual, yet smooth establishment of the designed networks.

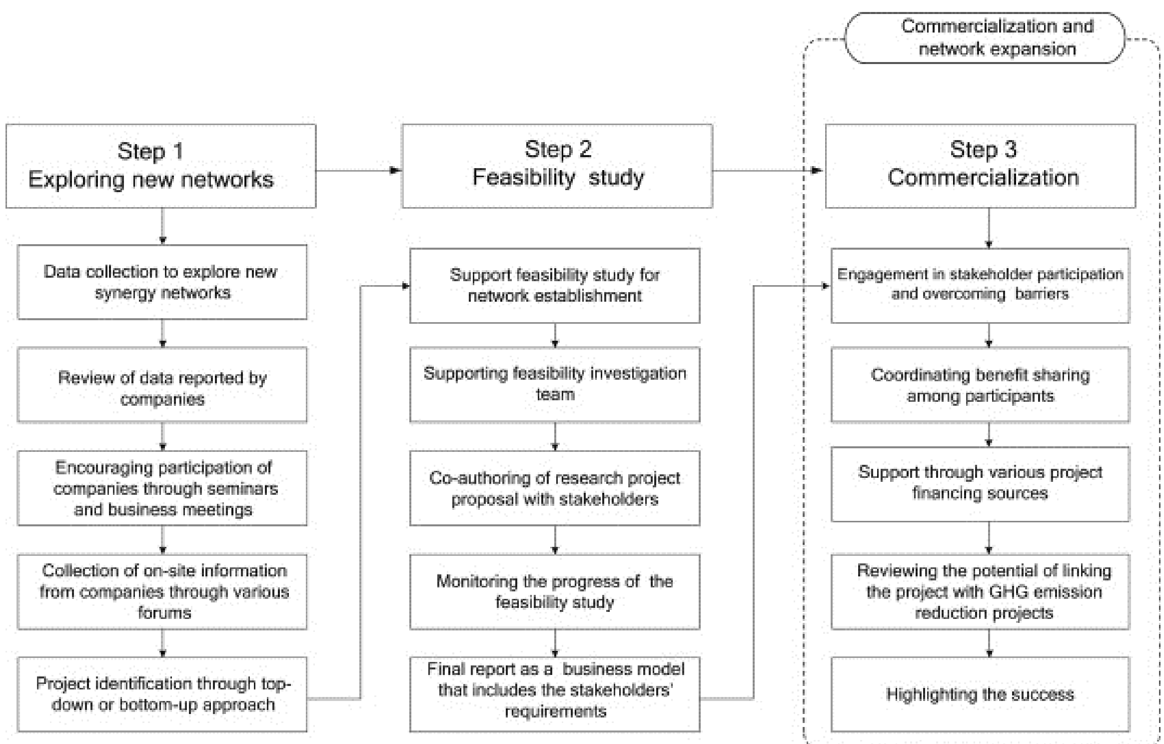

Figure 6.2: ‘R&DB’ framework tailored for the development of the ‘IS’ networks [23]

6.2.2.2 Achievements and limitations

1) Achievements

By 2015, 595 project proposals were submitted from which 388 projects were funded for further research and development and 197 actually materialized. The first phase saw the development of 175 projects, and 116 of them were authorized for implementation. Some 47 projects generated 189 million USD of economic benefits, which is the sum of 97 million dollars of cost reduction and 92 million dollars of revenue generation. From the 47 projects reduced waste by 477,633 metric tons, wastewater by 110,032 metric tons, energy by 176,781 toe, and greenhouse gases by 668,198 metric tons CO2-eq.

The second phase of the Korean EIP program saw the implementation of 221 symbiosis projects out of the 346 projects that were developed. The second-phase projects reduced the generation of 1,283 thousand tons of by-products (compared to 501 tons in the first phase), 379 thousand tons of oil equivalent (toe) of energy (vs. 74 toe in the first phase), 238 thousand tons of wastewater (vs. 164 tons in the first phase), and 1,584 thousand tons of CO_2 equivalent of GHG emissions (vs. 700 tons in the first phase).

The third phase saw the completion of 355 projects with 235 of them being commercialized. Creation of 992 new jobs by 2016, energy savings of close to 1730 thousand toe, GHG reductions of close to 8,540 thousand toe and waste reduction of 6,850 thousand toe.

2) Limitations

Though, general key barriers to EIP implementation can be seen in Table 6.3, Korean EIP have specific barriers as follows. The lack of comprehensive co-ordination between Ministry of Trade, Industry and Energy (MOTIE) and Ministry of Environment (MoE) seems to be a barrier to bring the present environment regulations and standards in line with the EIP approach, and so streamline the following legal framework is needed. Also, many regulations and standards viz., the Industrial Park Management Law (1975), the Industry Location Law (1977), and the Promotion of Industrial Clusters and Factory Establishment Law (2002) intersect in the management and operation of industrial parks [22]. There is no government incentives and/or subsidy to renovate aged industrial infrastructure development. Transparency of data and reluctance to release information from companies is also an issue. There is the lack of comprehensive baseline site assessment information (this is required to provide information and identify IS opportunities existing in the industrial complexes) and design and implementation of optimized networks in specific categories (e.g. steam)

Table 6.3: Key Barriers in the implementation of EIP Projects [22]

Economic barriers	**Technical barriers**	**Operational & knowledge barriers**	**Regulatory & policy barriers**
Loss of competitiveness	Hazardous waste management, (central) effluent treatment plants and other facilities may not work properly, leading to high environmental pollution	Lack of experience	Lack of regulation and its enforcement
High prices of fuels and natural gas may lead to switch to coal		Lack of awareness of government, community	Excessive dependence on policies (unreliable when policy changes)
		Lack of proper organization among companies	
Low demand for green technologies and lack of incentives that encourage clean technology development and adoption		Lack of management resources	Lack of support for industrial symbiosis and other environmental measures
	Multiple sources of water supply hamper control of water consumption	Lack of reference and guidelines of what exactly an Eco-Industrial Park is	
		Lack of proper indicators	High proportion of small and medium sized enterprises (SMEs), SMEs comply less to environmental standards, which leads to more pollution
		Problem to attract skilled workers (many industrial parks train workers nearby)	
More pressing priorities than environment and safety	Many parks are not fully operational		

6.3 Materials and methods

6.3.1 Hawassa Industrial Park (HIP)

HIP is located in the southern city of Hawassa, close to lake Awassa and is 275km from Addis Ababa, the capital of Ethiopia, see figure 6.3. The city of Hawassa is a key cotton corridor in Ethiopia. It has a high supply of labor of up to five million people within 50 km radius, making it an ideal investment destination for labor-intensive industries [24]. In addition to the direct rail connection between port of Djibouti, Addis Ababa and Modjo, the key node of the emerging Ethiopian Intermodal Logistics system and the Ethio-Djibouti Corridor, the main corridor that handles nearly all Ethiopia's trade among other factors making Hawassa city the important political and economic center in Ethiopia and the ideal location for construction of the HIP park [25].

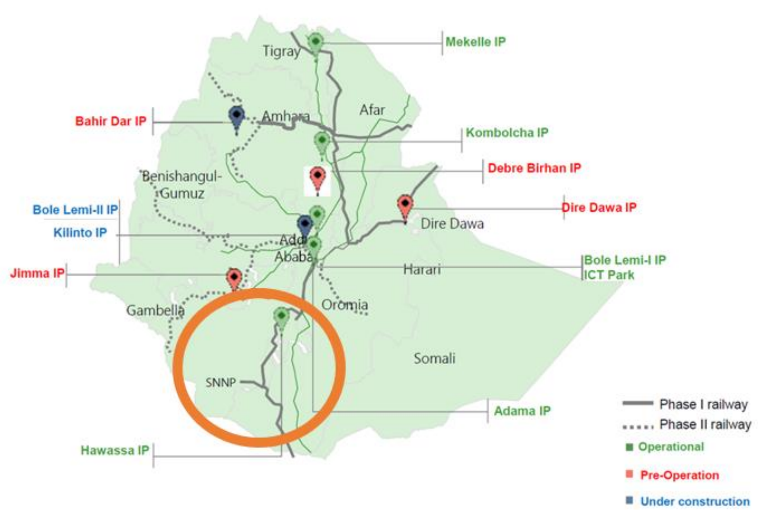

Figure 6.3: Map of industrial Parks in Ethiopia showing HIP [26]

HIP was planned and designed as a world-class EIP in 2015 and is one of the first Ethiopian and Africa's largest export orientated textile and garment industrial parks. Constructed by China Civil Engineering Group Co., Ltd. (CCECC) and completed in nine months [25], it covers a total area of 300 hectares(ha).

6.3.2 Research framework EIP transition; expanding IS networks

Research framework comprises of 5 simple steps. Step 1 is R&DB objective and scope setting to transform HIP to EIP by Korean EIP transition strategy applying RECP and IS networks expansion. Step 2 is the data collection on sludge, wastewater, electricity and equipment usage through environmental and material reports, Government documents, guided questionnaires and interviews, Step 3 is the feasibility study on RECP and IS potentials, while step 4 is the identification of the RECP and IS business case based on triple bottom lines. Finally step 5 are results, conclusions and insightful policy recommendations.

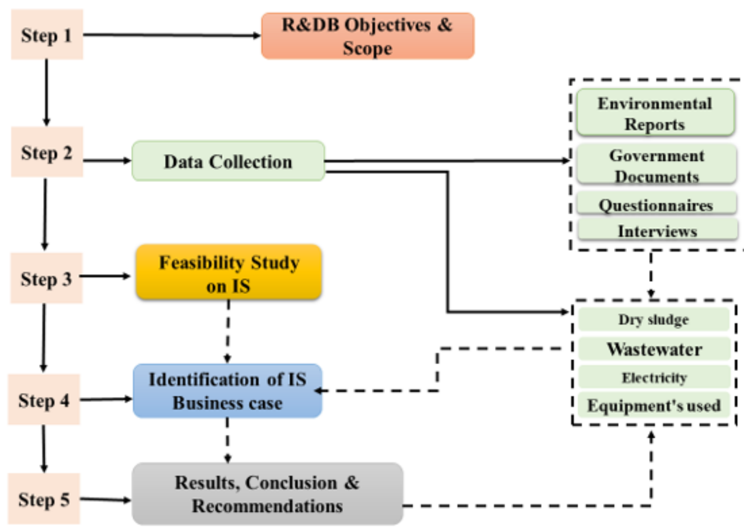

Figure 6. 4: Methodological Framework of HIP EIP transition

The methodology draws inspiration from a wide range of reference literature and reports produced by international organizations such as the World Bank, International Monetary Fund (IMF), and the African Development Bank (AfDB). Other referenced literature on Ethiopian documents include; "Environmental Impact Assessment report of HIP [27], Developing new business case for EIP development in Ethiopia [28], Looking Beyond the Horizon: A case study of Philips-Van Heusen Corp (PVH's) commitments in Ethiopia's HIP [25], A study on the industrial parks development: Issues, Practices and Lessons for Ethiopia [1], Ethiopia's CRGE [29], and a book on Industrial Policy and late industrialization in Ethiopia [30]" .

Additionally, there were multiple field visits to the HIP by the Ulsan Eco-industrial Development (EID) Center, during which discussions with stakeholders were conducted and data collected for purposes of HIP transition.

6.3.3 Korean experience in the Textile industry

There are three sectors where in Korea EIP IS experience focused with the textile industries, and these sectors include the waste sector, the energy sector, and the wastewater sector. Detailed IS business cases in Korea are summarized in Table 6.4. Based on the Korean EIP experiences in textile industry, conceptual Ethiopia textile centered EIP transition network can be envisioned as shown in Figure 6.6.

Table 1: Korean Experience in the Textile industry

Sector	Name of Business model for textile industry in Korea
Waste	Production of functional products of waste fibers generated in the textile industry
	Production of non-woven raw materials recycled from textile manufacturing
	Recycling of Waste from Manufacturing Digital Printing Fabrics
	Production of multi-purpose wiping products that recycled household textile waste materials
	Production of high-performance mats from textile waste and waste rubber scrap
	Production of flame-retardant chips for textile fillers using polyester scrap
Energy	Separation and reuse of waste toluene from the fiber coating process as energy
	Recovery of waste oil from the tenter process and recycling of refined fuel oil
	Recovery and recycling of waste resources (waste oil) of exhaust gas from fiber dyeing process heat processing device
	Waste oil and waste heat energy recycling from tenter facility using electrostatic precipitating technology from exhaust gas
	Establishment of energy supply network for neighboring residential area using surplus heat source
Wastewater	Reuse of industrial water using effluent from wastewater treatment plant

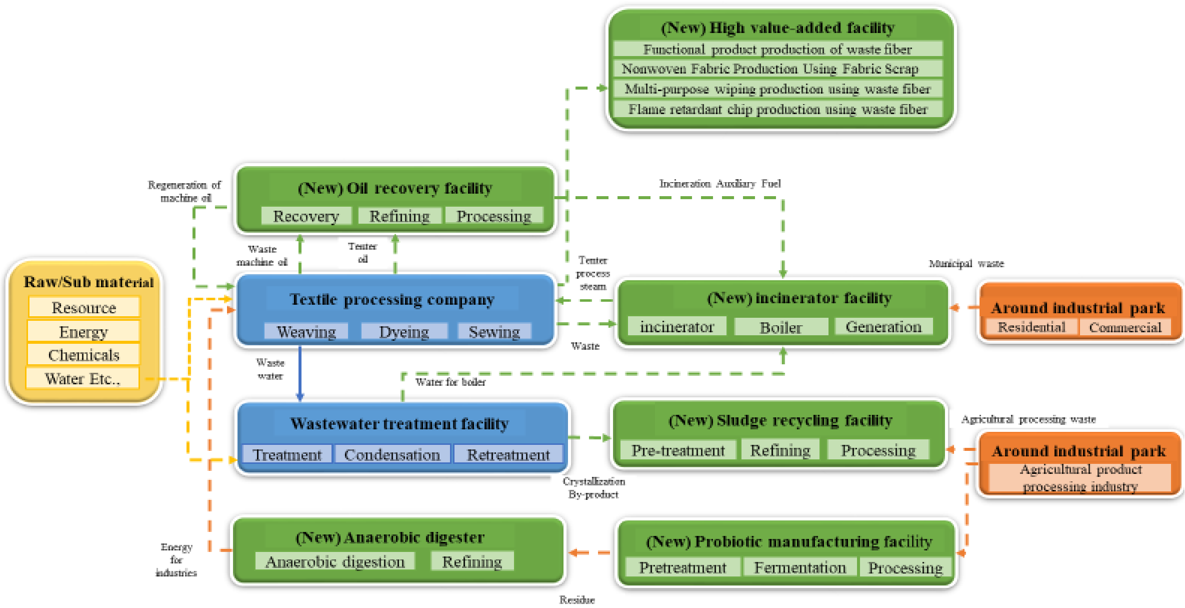

Figure 6.5: Potential RECP and IS network application to textile centered EIP transition in Ethiopia [26]

Typically, in applying the Korean model to the HIP, we considered the procedures outlined in figure 6.6. Firstly, target IP, HIP was recommended as an EIP transition pilot park by the Government of Ethiopia. Secondly, IS items are derived, followed by the establishment of a road map of the target IP. Finally, a feasibility review on the status of target IS item for emerging new businesses.

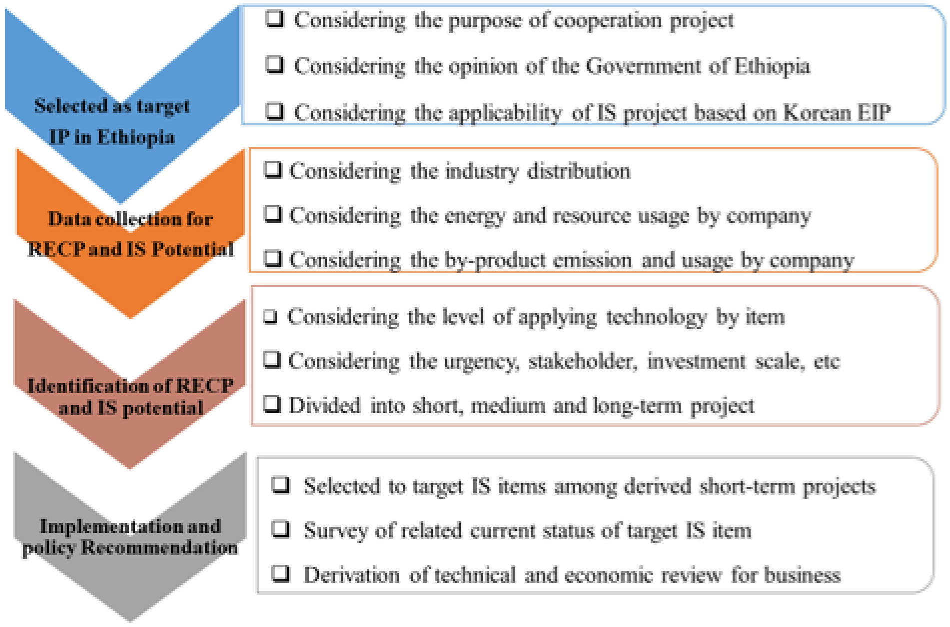

Figure 6.6: Procedure in applying Korean EIP model to HIP in Ethiopia

6.4 Results and Discussions

Selected government bodies and stakeholders play an integral role in facilitating HIP's transition. The IP development commission regulates the park's administration by selecting tenant companies and the Ethiopian investment commission (EIC) recruits foreign enterprises by carefully providing incentives that support them. Government policies, like the GTPI & GTP II, have as their main objective to transform Ethiopia into a middle-income economy by 2025, and as one of the pillars for reaching this target, is through the development of light manufacturing industries [3]. HIP is developed as a model IP, incorporating state of the art technologies, and meeting global standards in the industry. HIP's physical infrastructure includes 37 standard factory workshops, a 75 Megawatts power line, 11,000 inhabitant capacity, onsite facilitation service for tenant companies, fire prevention services, and a zero-liquid discharge (ZLD) facility. In total, HIP has approved 21 foreign companies (Figures 6.1 and 6.2) [26] and is instrumental in facilitating

EIP management in the park, by attracting partner companies as tenants with sustainable development agenda.

In the absence of an internationally accepted standard for EIP [12], this research seeks firstly, assess the general status of HIP in Ethiopia, then, identify the energy efficiency improvement opportunities at company level, wastewater treatment facility (WWTF) and finally propose environmental facility sharing IS business model of sludge treatment for HIP-EIP transition.

6.4.1 Energy efficiency improvement

As existing pumps are operating with low efficiency due to low life spans and low flow operations, there is need to apply the high efficiency circulation pump to reduce energy consumption levels in HIP [26]. Following are some analysis and measures to curb the energy efficiency scenarios.

a) Energy usage of HIP: Energy reduction can be achieved by introducing an external compressor and improving the operating methods. The issues pertaining to constant power loss due to load fluctuation of the air compressor can be improved by replacing the inverter air compressor and installing an external inverter. This power loss is due to unloading power generated during operation of a constant speed air compressor which can be improved through the installation of an external inverter with minimal investment cost, but additional improvement is needed to maximize efficiency [26]. In the case of the existing screw air compressor with 50HP, an external inverter is installed to take charge of the production of the main compressed air. It is advisable to improve the operation method that allows the existing reciprocating air compressor of 20HP to take care of the response to the product manufacturing load. Additionally, the existing reciprocating air compressor of 20HP should be equipped with a utility facility to enable the auto stop function, which contributes to the safety of the compressed air supply process [26]. The effect of reducing power consumption by improving the compressed air supply system is portrayed in figure 6.7.

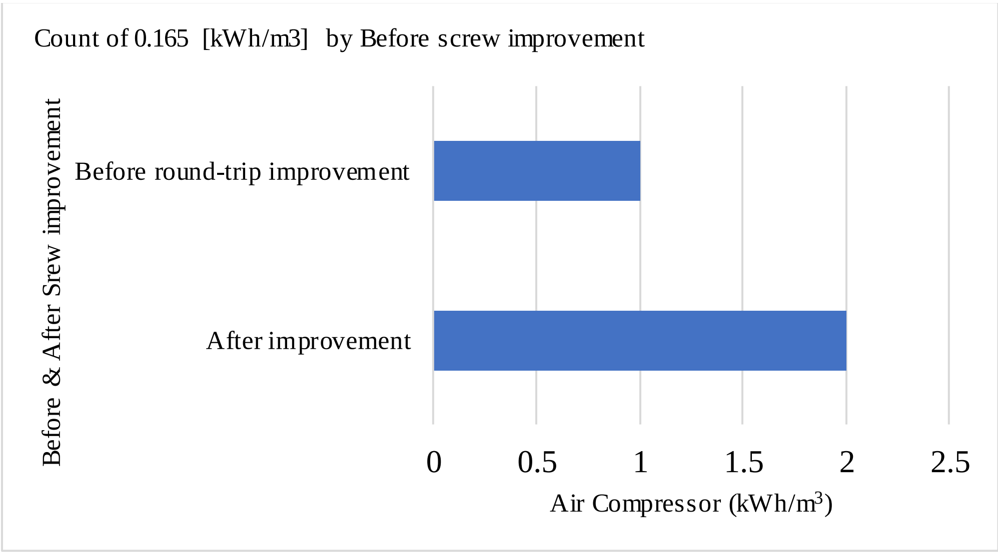

Figure 6.7: Hawassa industrial complex 'K' company air compressor operation [26]

b) Power consumption saving effect by improved compressed air supply system: With air compressors of 50HP and 20HP, power consumption is saved annually by (power consumption before improvement minus the power consumption after improvement multiplied by the annual operating time) (25.3 – 13.7) (kW) × 3,120 (hr/year) = 36,192(kWh/year). Following, the annual power savings reciprocating air compressors will be (14.5 – 8.25) (kW) × 3,120 (hr/year) = 19,500 (kWh/year). Hence, the total annual power saved will be 55,692 (kWh/year), and (55,692) (kWh/year) × 0.066 (USD/kWh) = 3,676 (USD/year). Estimated cost for 50HP external inverter installation stands at $15,000 and that of HP auto stop utility installation stands at $2,000 which is approximately 7 times lesser. See figure 6.8 for demonstration of reduced power consumption by using inverted air compressors [26].

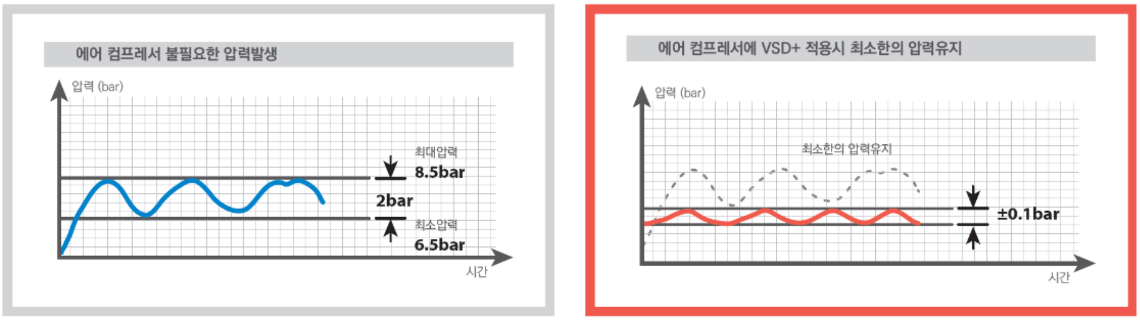

Figure 6.8: Reduction of power consumption by introducing high efficiency inverter air compressor [26].

Maximizing energy savings of the air compressor entails general improvement of the management sector by preventing leakage of compressed air and adjusting the discharge pressure. Hence the HIP can reduce its power consumption by adjusting discharge pressure of air compressors that are set higher than the actual required pressure of each process, so by reducing the discharge pressure by 1(kgf/cm^2), will reduce the air compressor to about 6%. For an existing compressor air of 8.5(kgf/cm^2) is lowered to 7.0(kgf/cm^2), the power savings will be as follows:

$$Lad_1 \propto \left\{ \left(\frac{8.5}{1} \right)^{\frac{0.4}{1.4}} - 1 \right\} = 0.8431$$

$$Lad_2 \propto \left\{ \left(\frac{7.0}{1} \right)^{\frac{0.4}{1.4}} - 1 \right\} = 0.7436$$

$$\epsilon = \frac{0.8431 - 0.7436}{0.8431} \times 100 = 11.8[\%]$$

c) Reduction of power consumption by high efficiency lighting equipment: improving maintenance cost with regards to lifespan of the lighting device while reducing its environmental externalities is of great concern. By replacing the lighting devices in workplaces, warehouses, and offices with high-efficiency LED lights, maintenance cost and power consumption can be reduced and hence less fatigue to field workers. Recommendations are made for the general fluorescent lamps to be replaced with highly efficient LED lamps and the mercury lamps be replaced with electrodeless lamps to reduce power consumption ass well [26].

Figure 6.9: Estimated power consumption of the lighting device before & after improvement [26]

Here the power saved (power consumption before improvement minus power consumption after improvement) (1,015,972(kWh/year) - 402,854(kWh/year) = 613,118(kWh/year) and the annual power saved (613,118(kWh/year) × 0.066(USD/kWh) = 40,466(USD/year). Estimated investment cost of LED 200W device per unit price is 250(USD/EA), for LED 40W device, unit price is 100(USD/EA), for LED 25W device, the unit price is 60(USD/EA) and 10,000(USD, LED 200W) + 92,000(USD, LED 40W) + 4,800(USD, LED 25W) gives a total of 106,800(USD) [26].

LED is a lighting facility that has a semiconductor device that emits light when current flows and has a conversion rate of over 90%. Energy conversion rate is simply the conversion rate that converts electricity input into light. Normally, energy conversion rate is 5% for incandescent bulbs and 40% for fluorescent lamps. Bulbs with low conversion rates give less eye fatigue as compared with those with high conversion rates. Hence fluorescent lamps give eye fatigue as compared to LED lamps. Fluorescent lamps blink 120 times per second to increase eye fatigue during long-term usage and LED fluorescent lamp has no flicker in ON/OFF mode which give less eye fatigue. LED lamps have a lifespan of 10 times when compared to fluorescent lamps. Due to the long service life during installation, replacement costs can be reduced and hence recommended for replacement of the existing fluorescent lamps [26].

d) Energy saving through insulation of dyeing process: In order to reduce heat loss on the surfaces of dyeing machines, it is recommended to apply insulation paint which is regarded as most practical method of heat containment. It is considered that the power consumption can be reduced through the insulation of dye. Considering reduction in power consumption of company 'J', with a dyeing machine surface temperature of 25 °C and the dyeing machine ambient temperature of 15°C, calculation of expected heat loss (based on one dyeing machine) will be.

- $\alpha_r = 4.88 \times [(\frac{Ts}{100})^4 - (\frac{Tr}{100})^4] \times \Sigma / (t_s - t_r)$

- $\alpha_r = 4.88 \times \frac{[(\frac{273+25}{100})^4 - (\frac{273+15}{100})^4] \times 1.0}{40-15}$ = 3.93 [kcal/(m^2·h·℃)]

- $\alpha_c = 2.2 \times \sqrt[4]{(25-15)}$ = 3.91 [kcal/(m^2·h·℃)]

- h = 3.93 + 3.91 = 7.84 [kcal/(m^2·h·℃)]

- $Q = h \times A \times (T_s - T_r)$

- 7.84 (kcal/m^2·h·℃) × 0.88 (㎡) × (25 - 15) (℃) = **138.0(kcal/h)**

Hence, the estimated power loss (based on 1 dyeing machine) is ((138.0(kcal/h) divided by 860(kcal/kWh)) which gives 0.160(kWh). The estimated power saving through 'J' company dyeing process insulation would be power loss before improvement (per year) which is 0.468(kWh). This is gotten from the power loss after improvement (per year) at 0.160(kWh), dyeing machine number, 16EA and process uptime is 7,488hr/year. Estimated annual power savings would be (power consumption before improvement minus power consumption after improvement) × Number of dyeing machines × Uptime (0.468(kWh)-0.160(kWh)) × 16EA × 7,488hr/year which is 36,901(kWh/year). And the annual saving amount ((36,901(kWh/year) × 0.066(USD/kWh)) is 2,435 (USD/year). Finally, the estimated investment cost for insulation paint (including other expenses such as construction) is 300(USA/EA) (300(USD/EA) × 16EA) which equals to 4,800(USD) [26].

e) Energy savings through introduction of humidity control system: considering the tenter machine of the "J" company in the HIP, operating an exhaust gas discharge by manual damper operating method, it is cumbersome to optimize its energy due to flue gas emission. The general exhaust gas temperature of the tenter is about 200°C based on the outlet temperature, and this high temperature exhaust gas leads to energy loss [26]. As an improvement plan to reduce such energy loss, it is regarded that the exhaust gas humidity management system and the inverter control of the exhaust fan which can discharge the proper amount of exhaust gas, are suitable and the criteria for calculating the absolute humidity of a tenter machine for a ‘J’ resident are as follows.

Basic information: (i) Exhaust gas dry bulb temperature (t) is 167 (℃), while the Exhaust gas wet bulb temperature (t) is 54 (℃). (ii) Dry bulb temperature Saturated water vapor pressure (es) is 5,523 (mmHg), while the Wet bulb temperature Saturated water vapor pressure (e_s) is 112.6 (mmHg), and the Standard pressure (P0) is 760 (mmHg) [26].

Actual vapor pressure (e); e_s (-0.000661 × P_o × (t – t') (112.6-0.000661 × 760 × (167 – 54)) is 55.8(mmHg). Relative Humidity (H); e/e_s × 100 (55.8/5,523 × 100 is 1.01 (%) and, Absolute Humidity (D); 0.622 × {e/(P_o-e)} (0.622 × {55.8/(760 – 55.8)}) is 49.3(gr-H2O/kg-dry air). Effective energy saving effect through introduction of absolute humidity control system for tenter exhaust gas company 'J' can be done by the following:

- **Reduced toast air after improvement:** Total toasted air volume × (absolute exhaust humidity after improvement - absolute exhaust humidity) ÷ exhaust absolute humidity after improvement (10,800 × (80 – 49.2) ÷ 80) and it gives 4,142(kg/h).
- **Reduced moisture during supply after improvement:** Reduced amount of toasted air after improvement × Absolute Supply Humidity ÷ 1000 (4,142 × 11.2 ÷ 1,000) which is 46.4(kg/h).
- **Calories saved per unit time:** Reduced air volume after improvement × Dry air specific heat × (Exhaust temperature-air supply temperature) + {Reduced air supply steam amount after improvement × (Exhaust Temperature-Air supply temperature)} × Margin) [{4,142 × 0.31 × (167 – 33)} + {46.4 × (167 – 33)}] × 0.5 is 89,138 (kcal/h).
- **Total saving calories:** Heat saving per unit time × Annual operating time (89,138 (kcal/h) × 7,488 (h/year) is 667,465,344 (kcal/year).

- **Estimated annual power savings:** (667,465,344 (kcal/year) ÷ 860 (kcal/kWh)) is 776,122 (kWh/year).
- **Annual savings and greenhouse gas reductions:** (776,122 (kWh/year) × 0.066 (USD/kWh)) is 51,224 (USD/year) and (776,122 (kWh/year) × 0.46625 (tCO2-eq/MWh) is 361.867 (tCO2-eq).
- **Estimated investment cost:** absolute humidity control system is USD 60,000 and payback period (estimated Investment Cost ÷ Annual Power Savings) (USD 60,000 ÷ 51,224(USD/year)) is 1.2(year) [26].

6.4.2 Wastewater treatment efficiency enhancement

HIP is the largest industrial park in Ethiopia and caters for textile and garments, consuming large amounts of water. HIP whose influent flow rate is 50% compared to the design capacity of the WWTF which is expected to treat 8,000tons/day. The textile industry uses various dyes and chemicals to treat the textiles and thus polluting the water. At Philips Van Heusen's Corporation (PVH's) encouragement, the government invested in a state-of-the-art zero-liquid-discharge (ZLD) treatment facility. With such technology, 90% of the water is recycled and reused, and the final waste is crystallized. The WWTF consists of primary treatment (chemical flocculation), secondary treatment (biological treatment) and tertiary treatment (physical adsorption). Process for reuse of effluent into industrial water, consisting of Ultrafiltration (UF) and Reverse Osmosis (RO) system. The treatment efficiency of ETP is lower than that of the Korea's textile WWTF. Inflow of high concentrations of organic matter into the UF system may lead to shortening of the life span of the industrial water reuse system (membrane) (Table 6.5). With the sewage treatment plant, sludge is supplied to WWTF bioreactor to improve the biological treatment efficiency wastewater from the textile. Mixed liquor Suspension Solids (MLSS) 4,000~8,000ppm, Dissolved

Oxygen (DO) 2~3ppm. General bioreactor conditions are; MLSS at 3,000ppm, DO at 1.5-2.0ppm. Sludge is generated from industrial wastewater treatment plant (ETP) and sewage treatment plant (STP) [26]. The amount of sludge produced is 3.8tons/day from ETP and 0.4tons/day from STP. The generated sludge which is quite small is being loaded into a container for containment. In the long-term, what would be the fate of the dry sludge store in the containers?

Table 6.5: Water quality of step by step process in a HIP-WWTF [26]

Process steps		Flux (m^3/day)	Chromaticity (Pt/Co)	TDS (Mg/l)	BOD (Mg/l)	Turbidity (Mg/l)	Hardness (Mg/l)	Alkaline (Mg/l)
Inflow		2,944	1,338	2,204	137	-	-	-
UF	inf.	-	168	2,118	-	9.4	18	-
	eff.	-	122	2,094	-	1.5	16	-
RO 1	inf.	-	125	2,036	-	1.8	66	213
	eff.	-	30	46	-	1.3	0	9
RO 2	inf.	-	436	11,029	-	17	508	1,353
	eff.	-	57	38	-	9	0	10
RO 3	inf.	-	668	16,063	-	5	815	2,116
	eff.	-	48	427	-	1.8	0	14
RO 4	inf.	-	1,136	27,398	-	4	1,415	2,994
	eff.	-	65	176	-	1.6	3	50
outflow (Water Supply)		1,636 (520)	-	92	1.0	-	-	-

Generally, the equalization tank is there to maintain and equalize the quantity and quality of influent in the WWTF and prevent accumulation of sedimentary substances by slow mixing with turbine mixer, or submerged pump. From the field survey, we found out that equalization tank is mixed by aeration in the HIP–WWTF [26]. Though, with excessive aeration being applied because of the dense installation of the aerator, the mixing efficiency decreases due to low water level. When surveying the quantity and quality of water at each step, it was noticed that the concentration of refractory organic substances in the influent is high, even though above 70% has been removed through the coagulation/precipitation process. A high level of refractory COD is still introduced into the bioreactor. There is need for an advance chemical treatment procedure consisting only of agglomeration before entering the bioreactor. However, it was seen that agitation time and energy for each step of rapid stirring and slow stirring in the coagulation process are not effectively managed. We also found that the T-N concentration in the effluent was higher than that of the influent due to the adding of STP sludge separately to maintain the concentration of microorganisms in the bioreactor [26]. In order to improve the treatment efficiency of the HIP-WWTF, the following improvements measures are recommended based on the current ZLD treatment plant processes and operation:

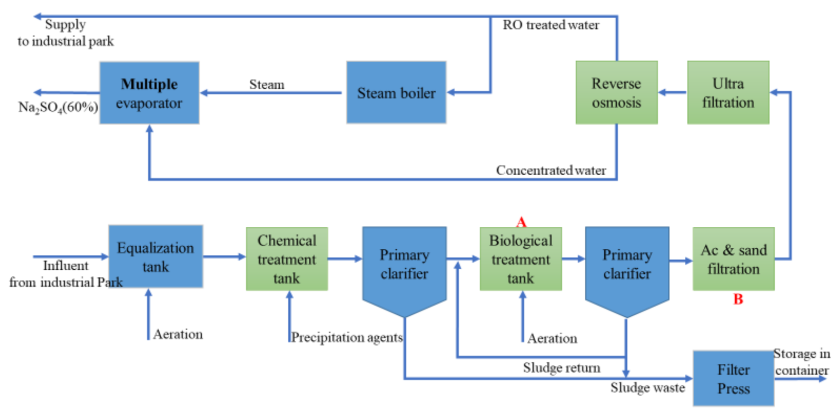

Figure 6.10: Treatment Efficiency Improvement in HIP-WWTF [26]

During the survey, a plan to reduce the amount of facility use considering the flow rate compared to the designed capacity will be to redesign the handling capacity of the WWTF. A total of 8,000tons/day and the actual amount of wastewater flowing into the WWTF is less than 4,000tons/day, which is 50% of the original handling capacity design. Only one of the two flow control tanks are used, and the circulation efficiency is increased by increasing the level of wastewater. The WWTF has two bioreactors, while using only one if the reactors, the hydraulic residence time (HRT) in the bioreactor reduces from 2.25 days to 1.125 days. Since the optimal hydraulic residence time (HRT) in the bioreactor is 6 to 8 hours, it is desirable to use only about 30% of one reactor if it can be further classified [26].

6.4.3 Environmental facility sharing IS business for wastewater sludge treatment [26]

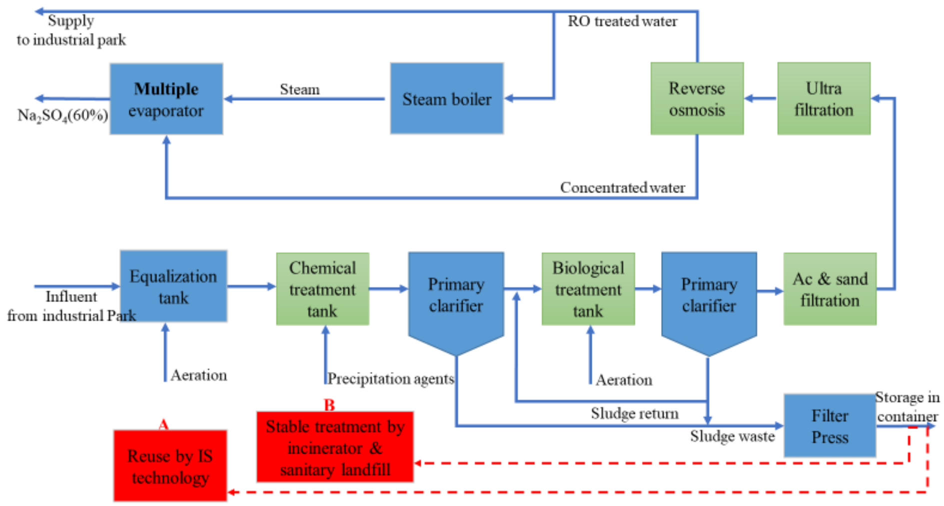

Figure 6.11: Stable treatment of wastewater sludge in WWTF [26]

For sustainable treatment of wastewater sludge in WWTF, environmental infrastructure sharing IS business can be developed by securing new landfills and incinerators (as B in Figure 6.11) or high value added IS technology of green construction, fuel and fertilizer can be used based on the quality and quantity of sludge.

1) Dehydrated Sludge Landfilling

Dehydrated sludge with a water content of 85 to 87% discharged from HIP-WWTF is generated in quantities of less than 5tons/day and is being loaded into containers located at the WWTF site. Regardless of the low quantities, it is very paramount to review items for stable treatment of sludge [26].

With not enough storage facilities, it is difficult to develop a separate recycling application and establish an independent recycling facility, so we focused on stable disposal and investigated a method of landfill disposal by proposals to build a landfill. With less than 5tons of wastewater sludge produced a day, and with view of a landfill operating for 20 years, and considering that sludge is currently loading at 1,000tons, the sludge generated for over 20 years will be about 36,500tons, requiring a landfill capacity of approximately 50,000m^3. With sludge density 1ton/m^3, cover ratio 30%, landfill required area will be 2,500m^2, with a landfill height 20m, and landfill slope not considered. Costing will be approximately USD 4,500,000USD (USD1 ~ KRW1,200) [26].

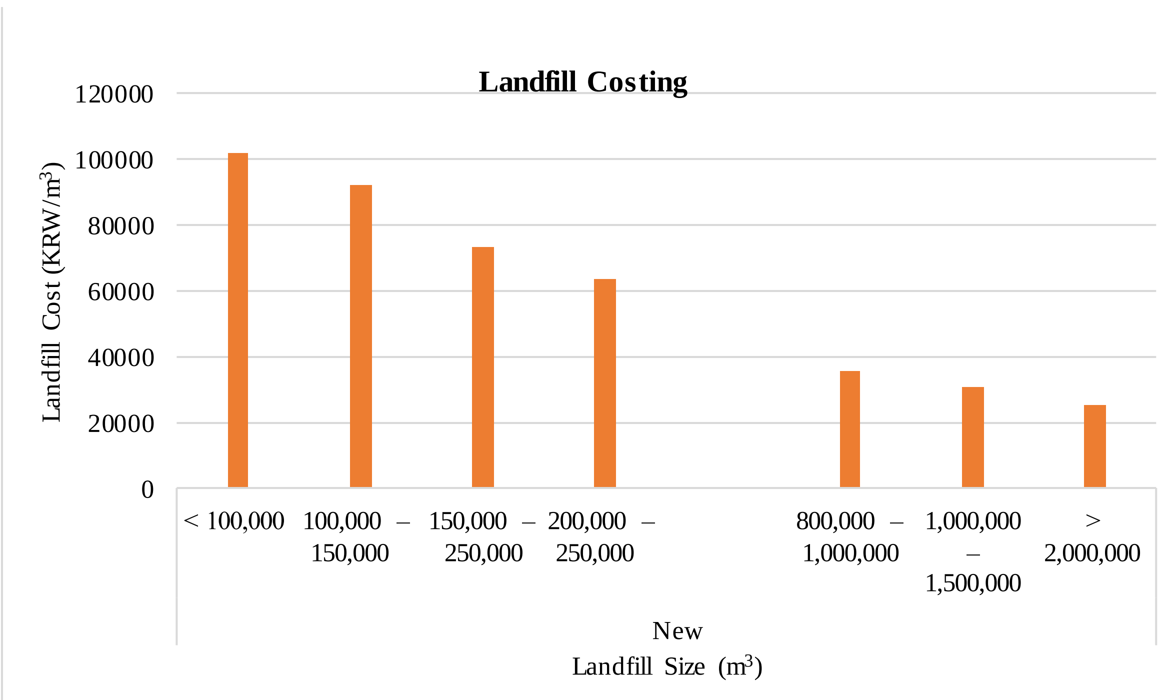

Figure 6.12: Landfill costing [26]

N/B: If the ratio of blasting rock construction volume (m^3) among the earthwork during the landfill is more than 25%, the construction cost may be additionally surcharged.

2) Waste to heat IS business

To secure the level of heat that can be incinerated and considering the low calorific value of the wastewater sludge produced, there is need to secure a small incinerator and floor ash reclamation capacity [26]. The composition of the wastewater sludge and facility procurement are as follows:

In order to maintain calorific value of mixed waste of more than 3,500Kcal/kg, textile scraps and biomass (assuming 4,000Kcal/kg) should be mixed in more than 29tons/day of sludge (600Kcal/kg), energy recovery is expected from incineration of waste and with the incineration scale expanded to 48tons/day to reflect energy demands of the industrial parks. With 48tons of incineration per day including wastewater sludge and landfill for incineration, under operating conditions of 20years, minimum heat generation will be 3,650Kcal/kg and sludge (assuming 600Kcal/kg) 5ton/day, textile scrap and biomass (assuming 4,000Kcal/kg) 43ton/day. Incineration amount of 48ton/day and incineration heat sales at 6ton/hr. Supply medium pressure (12kgf/cm^2) steam to multi-stage evaporative concentrator in wastewater treatment plant at 3ton/hr scale, supply 3ton/hr to nearby textile products manufacturing companies (JP TEXTILE) that require heat sources. Construction cost of incinerator is approximately 9,000,000 ~ 11,000,000USD [26].

The construction cost of incineration heat supply facility would be 17.000,000 ~ 20,000,000USD. Installation of incineration heat recovery boilers and pure water production facilities (reprocessing of effluent or UF/RO system using industrial water, recovery boiler 8ton/hr). Small ground medium pressure steam piping work (conveyance distance of 1km in industrial complex, support structure installation condition by ground piping, will cost about USD 1.8million/km). Incineration ash generation for 20 years for 10,200ton is 1.395ton/day (5ton/day * 0.3 * 0.5 + 43ton/day * 0.3 * 0.05. With a landfill capacity of about 17,000m^3, sludge density of

0.8ton/m^3, cover ratio would be about 30%. The landfill area required will be 900m^2 with height of 20m, and slope of landfill is not considered. Landfill cost will be USD1,500,000. Incineration plant, landfill site and steam supply facility construction cost will be estimated at 27,500,000 to USD32,500,000 (USD1 ~ KRW1,200) [26].

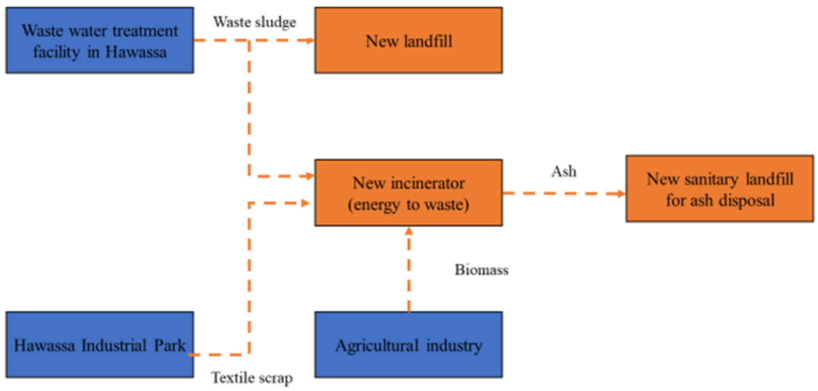

Figure 6.13: Sludge treatment method of HIP-WWTF [26]

Considering the amount of sludge loaded and generated in the WWTF, it would be more appropriate to have a stable disposal plan for a longer period of time than a plan for high value-addition by sludge recycling. Stable disposal methods include: a sanitary landfill for the disposal of generated sludge, and disposal of ash generated after incineration with industrial waste or agricultural waste.

6.5 Conclusions and Recommendations

6.5.1 Conclusions

Eco-industrial parks are effective tools towards the sustainable development of an economy. This chapter addresses the transitioning of HIP to EIP, with details of the status of the park, energy improvement opportunities at company level, improvements of the WWTF and proposed measures for IS business for the treatment of wastewater sludge. With all these addressed it will go a long way to greening of industries within the HIP in Ethiopia. HIP composed of 37 standard factories, 21 approved foreign companies and ZLD facility. Examining energy efficiency improvement issues can be handled by installing an external inverter to the 50HP screw air compressor and enabling an auto stop function to the 20HP screw air compressor. This auto stop function contributes to the safety of the compressed air supply process. These air compressors will save 36,192kWh of power consumption annually. Secondly to reduce power consumption, maintenance cost and environmental waste of lighting equipment can be done by introducing high-efficiency LED lights to replace the normal fluorescent lamps. Thirdly, USD 2,435 can be saved annually by applying insulation paint to dyeing machines which is most efficient method to reduce surface heat dissipation loss from these machines.

Functioning with full capacity of the HIP-WWTF, the amount of sludge produced is 3.8tons per day from ETP and 0.4tons per day from STP which is primarily stored in containers. Redesigning the facility to half handling capacity will increase circulation efficiency and using only one reactor will reduce the hydraulic residence time (HRT) in the bioreactor from 2.25 days to 1.125 days. Sustainable treatment of wastewater sludge in WWTF, environmental infrastructure sharing IS business can be developed by securing new landfills and incinerators. With all these achieved in HIP and replicated throughout all the industrial parks in Ethiopia will support Ethiopia as first to attain to the level of modern day EIP's for textile manufacture in Africa.

6.5.2 Recommendations

The following recommendations were made based on the results obtained.

a). Utility improvement of companies in the industrial park: Utility efficiency improvement of companies in the industrial park can be done by changing the lightening facilities. The use of improved energy efficiency by the use of LED lightening system is recommended. LED lamps have a lifespan of 10 times when compared to fluorescent lamps. Due to the long service life during installation, replacement costs and environmental waste can be reduced and hence recommended for replacement of the existing fluorescent lamps. Secondly, by installing external inverters on air compressors will minimize the cost of acquiring new compressors. Acquiring a compressed air public supply system that can used by all companies in the industrial park to supply compressed air, would improve overall energy efficiency in the entire industrial park.

b). Efficiency improvement in the water treatment facility: A plan to reduce the entire facility usage while considering the flow rate relative to the designed capacity will be to redesign the facility. The WWTF was designed to accommodate 8,000tons/day, and the actual amount of wastewater flowing into the treatment plant is less than 4,000tons/day, which is 50% of the design capacity. Redesigning to half its initial capacity is recommended. Also, usage of only one of the two flow control tanks will increase circulation efficiency and usage bioreactor will reduce the hydraulic residence time (HRT) in the bioreactor from 2.25 days to 1.125 days. Lastly, cleaner production item for efficiency improvement in sludge enhancement is done by adding nutrients such as cow manure to increase the microbial activity in the sludge.

c). Stable treatment of dry sludge from the water treatment facility: recommendations made by means of securing new sanitary landfills and incinerators for stable disposal of the dry sludge. Alternatively, the dry sludge can be improved by adding value to increase its calorific value and then supplied as raw material for construction and cement companies.

Implementation of these recommendations will definitely go a long way to usher the HIP to world first class EIP.

Acknowledgement

I acknowledge the Korea Energy Agency, GAIA Consulting, and the Ulsan EID Center for financial and data acquisition support. The data, presented in this chapter, is the property of Ulsan EID Center which was obtained through personal communication and used with permission.

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CHAPTER SEVEN

CONCLUSIONS AND POLICY IMPLICATIONS

7.1 Conclusions

Resource flows in countries and Industrial Parks towards achieving low-carbon economic growth has not had much attention till date, especially in the African context. Africa is greatly affected globally by adverse environmental externalities relative to other continents, though its emission contributions are not high. This dissertation was aimed at analyzing resource flows at national level and industrial park transitioning level. The main research objective was to assess the resource flow situations between countries, utilized the newly adopted tool (Dynamic approach) to monitoring industrial park progress and usher the transitioning of industrial parks to eco-industrial parks. All these are efforts to contribute to building knowledge on the subject matter "industrial ecology' as these are areas not thoroughly researched upon. Finally, at the end of it all this dissertation will also synthesize several policy directions for a sustainable low-carbon economic growth and eco-industrial transitioning for developing economies. So, this research focused its attention on some streamlined research questions:

(i) At the national level, what are the determining factors for energy-based CO_2 emissions in Ethiopia?

(ii) How can African states respond to rising materialization and carbonization levels? What are their coping mechanisms for low-carbon economic growth in the future?

(iii) At industrial level, how can we monitor and track progress efficiently in an eco-industrial park using the static and dynamic approach?

(iv) What does it take for an industrial park to transit into an eco-industrial park? And

(v) What are the sustainable policies to adapt for sustainable development low-carbon economic growth for resource flows at country level and at industry level?

This dissertation is designed in such a way that "national" and "industrial" level resource flows received almost equal attention. Thus, based on these five research questions, our main findings are presented below.

7.1.1. Dissertation outcomes

Dissertation began by introducing basic concepts pertinent to the research theme using existing knowledge and evidence from the industrial ecology literature (Chapter 1). After a thorough discussion, and evident that resource flows are rarely examined from an ecosystem's perspective in the African context. National level resource flows and industry transitioning are undistinctive from an environmental and industrial ecology preview. Following this research gap, crucial hot spots were identified, and fundamental research questions were synthesized. Based on the synthesized research questions, the contributions of national level resource flows and industrial park transitioning made enormous contributions towards sustainable low-carbon economic growth and industrial development. We have made our best attempt to address research questions to this dissertation.

Firstly, for resource flows in countries, Ethiopia, a fast-growing economy was analyzed. Due to huge industrial transformation and a boom in the Ethiopian economy, there are bound to be some adverse effects to the environment. Ethiopia has so far achieved a plausible economic growth especially in the last two decades. The environmental cost of economic progress is also quite high as well. we examined major drivers, based on Kaya identity, in rising CO_2 emissions from fossil fuel consumption in Ethiopia from 1990 till 2017. Important outcomes were, the population of Ethiopia grew by 122% from 1990–2017, its GDP grew by 385% while CO_2

emissions increased by 450% portraying a true picture of economic buoyancy at the cost of massive carbonization. Based on the decomposition analysis, major influencers of rising CO_2 emissions in Ethiopia included, the economy effect (49.1%), followed by population effect (42.7%) and by the fossil fuel mix effect (40.3%). However, emission intensity effect (14.5%) was four times less harmful than the economy effect. The only negative driver of CO_2 emissions was energy intensity effect which played the greatest role in mitigating rising carbon emissions in the country during 1990-2017. Based on the effect coefficient analysis, the shares of energy intensity effect and emission intensity effect have been declining in recent years, while the impact shares of population effect, economy effect, and fossil fuel mix effect have been on the rise meaning they could further cause carbon emissions to increase unless mitigation strategies are adopted.

Secondly, with targeting Ethiopia's material flows, and resource efficiency indicators in the African context, we conducted an in-depth analysis on MFA of Ethiopia and compared it with countries with huge economies in Africa. This enabled us to enrich the global MFA studies. As a basis, Ethiopia material flows from 1988 to 2017 and MFA indicators reflecting resource utilization intensity and efficiency were designed, analyzed, and compared with other typical African economies. Furthermore, dematerialization analysis based on modified Environmental Kuznets Curve (EKC) was applied to investigate the coupling statements and trends of resource consumption and economic growth. Finally, driving forces for the changes of material flows were investigated with decomposition approach based on IPAT in periods reflecting the key domestic development stages. Results highlighted a fluctuation of material flows from 1980s to early 2000s, which are in line with the domestic instability in Ethiopia, caused by international/domestic economic crisis and domestic political instability.

Thirdly, we made meaningful contributions to the economy-wide resource metabolism in Cameroon, Gabon and the Democratic Republic of Congo which are the top three economies in Central Africa from 1978-2017. Material Flow accounting indicators and various efficiency indicators were analyzed in the context of regional and global resource supply chain. The domestic drivers of material consumption, potential dematerialization of economic growth, policy impacts on resource efficiency were also analyzed. Decomposition analysis was used to examine drivers of material use and EKC hypothesis was tested to analyze undergoing dematerializing trends in the region. As per the results, DMC was greatest in Cameroon (3.54%), followed by Gabon (3.33%) and lastly the Democratic Republic of Congo (1.84%). Material intensity (per capita DMC) for 2017 was highest in Gabon in (5.87t), followed by Cameroon (4.09t) and lastly by the Democratic Republic of Congo (2.30t). Resource productivity in Gabon (1,567 USD/t) which was found to be very far ahead that of Cameroon (362 USD/t) and the Democratic Republic of Congo (178 USD/t), indicating that the economy of Gabon is high-end, high-value oriented with relatively low material intensity. As per the decomposition analysis, population factor was a major driver, economic affluence was a minor driver in all three countries, but however, technological advancement was on a rise in 2017 for all three countries.

Next, for industrial Parks, we expatiated on industrial symbiosis and EIP monitoring tool, by employing the static and dynamic approaches. Though EIP development strategies are well applied in many countries, systematic monitoring of EIP performance is still lacking, due to the difficulties faced in data collection, because of complex administrative procedures. This research delves into an industrial symbiosis and transition monitoring by using network efficiency in static and dynamic approaches. The dynamic approach tracks the performances faster and much more visible as compared to the static approach. Theoretically, if one company's waste would be accounted to a resource in another company, the traditional static approach increases network efficiency annually as 1/10, 2/10, 3/10, …9/10 for 5 years. Meanwhile, the dynamic approach would result in 1/2, 2/3, 3/4 … 9/10. This was then implemented with a simple five-step industrial symbiosis network approach for the Ulsan EIP; the dynamic approach measures the performance more visible than the static approach as seen in Step one of the symbiotic networks. The ratio of energy saved by the dynamic approach (0.17) compared to the static approach (0.02) is 9:1. Also for step 2, the energy-saving efficiency for dynamic approach was (0.18) which is three times higher than the energy saved by the static approach (0.05), with a ratio of 3:1. Thus, the dynamic approach of this research would effectively track EIP activities in an easy and more practical way than the static approach. This also saves time and reduces the administrative workload. The dynamic approach to monitor performance is strongly recommended as an indicator to be used to measure the performance of EIP's. It is a well-designed monitoring tool which is economically feasible, technological replicable, environmentally neutral, or positive, and socially adaptable.

Finally, the last chapter covers EIP transitioning in Ethiopia with lessons learned from the Korean research and development into business'(R&DB) framework for IS experience extended to the textile sector. The Korean integrated top down and bottom up approaches together with IS in the HIP in Ethiopia, this research presents and discusses the present IS potential opportunities in Hawassa industrial park (HIP) in Ethiopia by analyzing its demand for energy, utilization of its waste streams and locating potential symbiotic networks. Cleaner production item for stable treatment can be done by securing new landfills and incinerators for stable disposal and high value added to the sludge as raw material for cement factories. Lastly, by applying the high efficiency circulation pumps, average efficiency is expected to reduce by about 30% and hence a solution to energy consumption problems. This research proposes clean energy saving mechanisms and draws insightful policy recommendations for HIP and Ethiopia.

7.1.2. Potential contributions to the field

The dissertation provides innovative aspects of "resource flows" and their spatial analysis using a variety of industrial ecology concepts and environmental assessment tools. The dissertation potentially contributes in several ways to environmental engineering/management and industrial ecology. Firstly, the carbon emissions decomposition analysis for Ethiopia was done, this is the first five determinant study for the East African Region. Secondly, low-income developing countries are yet to ingress industrial ecology temperature due to their primitive industrialization stage, however, this dissertation analyzes the distinct resource flow metabolism in developing several African countries and synthesizes potential pathways for future dematerialization and decarbonization in Chapters 3 and 4, and most importantly, this dissertation introduces a new indicator tool to monitoring and tracking performance of EIP as seen in chapter 5. lastly, Ethiopia is becoming the major manufacturing hub in Africa with a lead in the textile sector. Green industrialization pathway in Ethiopia by employing tools and technologies, including the Korean research and development into business'(R&DB) framework for IS experience extended to the textile sector will go a long way to achieving economic buoyancy, sustainable industrial development, and an environmental appraisal. These research outcomes are expected to contribute to industrial ecology within countries and industry level through resource recovery and waste mitigation beyond the spatial boundaries of industrial ecosystems.

7.1.3 Study limitations and future recommendations

There is and will always be some room for improvement. First, the resource flows for countries was largely based on developing some African countries and on publicly available statistics that have been gathered using specific methodologies. It is recommended to use alternative methodologies such as sub-regional material flow accounts, physical input-output tables, and life cycle approaches to account for any discrepancies in the available data in the future and include more countries in the analysis. Second, limitations such as the unavailability of resource consumption data (e.g. raw material use, waste recycling, energy use) and environmental emission data (e.g. wastewater, waste, CO_2, CH_4, N_20), especially at the sectoral and sub-sectoral levels, needs to be addressed in the future. It is recommended to use alternative approaches to complement global databases with national and provincial level data to fill the missing links. The use of "big data" and artificial intelligence are greatly recommended. With IP transition to EIP in Ethiopia, it is recommended that all other countries in Africa should follow sought the transitioning and used the dynamic approach tool to monitor, track and measure EIP performances. Finally, with improvement in utility issues, energy usage, wastewater treatment facility and development of IS business are recommended for transition from IP to EIP as seen in the study on HIP in Ethiopia.

7.2 Policy Implications

For policy implications, at the country level, rising CO_2 emissions and air pollution issues have made it necessary for Ethiopia to draw up strategies to combat these environmental adversities. In addition, as the Government of Ethiopia has put in place a number of strategies and programs aimed at enhancing the adaptive capacity against climate change, reducing the vulnerability of the country to CO_2 emissions still remains a huge challenge. Policy initiatives such as CRGE and GTP are now greatly focusing on agriculture, forestry, renewable energy, and advanced technologies to developing a green economy. In addition, issues related to the environment, forests and climate change are being actively discussed at the national level. During the last two decades, emissions have been shifting their major sources; formerly the emissions were mainly from the agricultural sector (including livestock, soils, forestry etc.), but currently a huge portion of the emissions are coming from the industrial sector (including manufacturing and building construction). Secondly, the experiences and lessons from MFA analysis on Ethiopia can not only provide valuable policy insights to its resource management policies, but also enlighten African countries to find appropriate pathways on improving resource efficiency. Also, technology can significantly but not fully offset the pressures from domestic material consumption. Transforming into a greener lifestyle in CEMAC Zone is also essential. However, it will instead require an enormous amount of effort on some part of the countries policymakers to harness and guide technological improvement towards achieving sustainable development.

For industrial park level, the dynamic approach will be so beneficial to industries as it would attract policymakers, stakeholders, and businessmen in EIP transition activities. This is because it tracks the progress of an EIP faster, less cumbersome and saves time. For the Ethiopian EIP transitioning, recommendations made include: Application of high efficiency circulation pump to reduce energy consumption by over 30%. Securing new sanitary landfills and incinerators for stable disposal of dry sludge from the ZLD process, create an added value by supplying sludge as a raw material for construction and cement companies.

7.3. Scholarly contributions based on this dissertation

This dissertation was designed as a "manuscript-based work" and consisted of a collection of research contributions made by the author. All scholarly contributions, based on this dissertation, are presented below. Peer-reviewed article and conference presentations are listed below:

a) Peer-reviewed article:

Taka, G.N.; Huong, T.T.; Shah, I.H., Park, H. S., **2020.** Determinants of Energy-Based CO_2 Emissions in Ethiopia : A Decomposition Analysis from 1990 to 2017. Journal of Sustainability **2020**, 1–17.

b) International Oral Presentation:

Monitoring Eco-Industrial Park Performances by Static and Dynamic Approaches: A case on Ulsan eco-industrial park, Korea. 15^{th} International conference on waste Management and Technology (To build a zero-waste city systematically) (Beijing, China)

c) International Poster Presentation:

Eco-industrial park - An eco-innovation tool of circular economy transition in Korea. Korea). International Conference on Circular Economy for Agri-Food Resource Management (Seoul, Korea).

Appendix 1

2nd INTERNATIONAL CONFERENCE ON
BIORESOURCES, ENERGY, ENVIRONMENT, and
MATERIALS TECHNOLOGY

CERTIFICATE OF PRESENTATION

presented to

Gideon Taka
University of Ulsan

In recognition of the scientific presentation

The 2nd International Conference on Bioresources, Energy, Environment, and Materials Technology (BEEM2018)

held in Gangwon Province from June 10 to 13, 2018.

Prof. Yong Sik Ok Korea University	Prof. Sung-Eun Lee Kyungpook Nat'l University	Prof. Geonha Kim Hannam University	Prof. Eilhann E. Kwon Sejong University

BEEM2018
조직위원회

Appendix 2

International Conference on Resource Sustainability

In recognition of research contributions to the field of Resource Sustainability, the International Conference on Resource Sustainability hereby presents the

Most Welcomed Poster

to

Gideon Nkam Taka

Given at the International Conference on Resource Sustainability in Beijing on June 29, 2018.

icRS 2018 Conference Chair

icRS 2018 Award Committee Chair

icRS 2018 Award Committee Co-Chair

Appendix 3

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Certificate of acceptance for the manuscript (**sustainability-770721**) titled:

Determinants of energy-based CO2 emissions in Ethiopia: A Decomposition analysis from 1990 to 2017

Authored by:

Gideon Nkam Taka; Ta Thi Huong; Izhar Hussain Shah; Hung-Suck Park

has been accepted in *Sustainability* (ISSN 2071-1050) on 14 May 2020

MDPI Academic Open Access Publishing since 1996

Basel, May 2020