Addis Ababa University
College of Business and Economics
Department of Economics

A System Dynamic Analysis for Cement Production and Carbon Emissions in Ethiopia

Thesis Submitted to the Department of Economics in Partial Fulfillment of the Requirements for the Degree of Master of Science in Economics (Applied Economic Modeling)

By Shimelis Fikre

ID NO.: GSR/2850/14

Advisor: Alemu Lambamo (PhD)

Addis Ababa, Ethiopia

June, 2023

Approval

Addis Ababa University

School of Graduate Studies

Approval Sheet

This is to certify that the thesis prepared by Shimelis Fikre Chala, titled "**A System Dynamic Analysis for Cement Production and Carbon Emissions in Ethiopia**" and submitted to the Department of Economics, Addis Ababa University in partial fulfilment of the requirements for the Masters of Science in Economics (Applied Economic Modelling) complies with the regulations of the university and meets the accepted standards for originality and quality.

Signed/approved by;

Examiner ____________________________________ Signature ______ Date ________

Examiner ____________________________________ Signature ______ Date ________

Supervisor ____________________________________ Signature ______ Date ________

Acknowledgment

I would like to gratefulness is extended to all who have supported me during undertaking this thesis. My warmest thanks and appreciations to my supervisor **Dr. Alemu Lambamo** for his guidance and constructive comments as well as made me strong throughout the stage of writing this study.

Second, I want to express my deepest gratitude to **Dr. Abdurezack Husen,** who inspired me to complete this thesis. Thirdly, I would like to thank you my brilliant class mate students **Petros, Kaleab, Belay, Biruk, Demis, Yabetsega and Yimer**; no words to express my gratitude.

Finally, my profound thanks to all my co-worker colleagues for their supportive comments and moral supports.

Abstract

Cement production in Ethiopia is backbone for economic development by constructing large projects such as Grand Ethiopian Renaissance Dam (GERD), Mega Projects, road, etc. Conversely, the concentration of CO2 emissions from cement sector is challenging issue to future climate changes. Over time the demand for cement is increasing for housing and infrastructure development, while the productivity of cement production among the factory is yet poor. Most cement industry in Ethiopia use combustion of imported fossil fuels. However, these leads to high concentration of CO2 emission, productions inefficiency, high cost of operations, loss of productions due to various problem such as shortage of power, spare part, etc. and vulnerability to climate change severity in Ethiopia. This study simulates and develops System Dynamic Model for cement sector to explore endogenous behavior of variables within the model, using Causal Loop Diagram and Stock-Flow Diagram. According to simulation of this study, at end of 2030 the CO2 emission from cement industry is more than double, about 8.92mill. tonsCO2 as compared to 4.37 mill. tonsCO2 in 2022, as well cement production also doubles at the end of 2030 about 16.28 mill. tons. Thus, depict that the carbon emissions proportionally increasing with cement productions. Therefore, the study recommends to utilizes alternative renewable energy resource and modern technological kiln processor to improve their energy efficacy and more productive as well as cope environmental burden of carbon emissions from cement sector of Ethiopia.

Key words: *Cement Production, CO2 emission, Energy Consumption, System Dynamic Model, Causal Loop Diagram, Stock-Flow Diagram*

Table of Contents

List of Tables

List of Figure

ACRONYM

CLD - Causal Loop Diagram

CO_2 – Carbon Dioxide

CRGE – Climate Resilient Green Economy

ESS – Ethiopian Statistical Service

GDP – Gross Domestic Product

GHG – Greenhouse Gas

GJ – Gigajoules

$GtCO_2$ – Gigatons Carbon Dioxide.

GTP – Growth and Transformations Plan

IEA – International Energy Agency

IPCC – Intergovernmental Panel on Climate Changes

IPPU - Industrial Processes and Product Use sectors in Ethiopia

LCA - Life Cycle Assessment

NBE - National Bank of Ethiopia

NEP – United Nations Environmental Programme

RTS - Reference Technology Scenario

SDM - System Dynamic Model

SSA – Sub-Saharan Africa

UNFCCC - Third National Communication for the United Nations Framework Convention on Climate

VSK - vertical shaft kiln (VSK)

CHAPTER ONE

1 INTRODUCTION

1.1 Background of the study

Globally, climate change is one of the world's most serious issues, that threatening to plunge millions of people into poverty and famine, while also impeding economic progress by widening the inequality gap and triggering wars. Developing countries, particularly African, Asian, and Latin America, are vulnerable to climate change due to the susceptibility of their insignificant habitats to a fluctuating climate with variable rainfall, resulting in floods and droughts. In Africa, the challenges associated with rapid population increase, existing poverty, reliance on agriculture, and poor capacity to manage the problems created by climate change are exacerbated. Because the economy of Sub-Saharan Africa is heavily reliant on agriculture, thus, increase in global warming has caused more suffering than other regions due to fluctuation in rainfall and temperatures. Climate change is mostly caused by human activities such as the use of fossil fuels such as coal, oil, natural gas, and chemical processes during the manufacturing process of cement, iron steel, and other chemical processing (Ludwig et al., 2007).

In worldwide global carbon emissions have risen dramatically; since 1940 to 2021, CO2 increased from 4.85 billion tons to 37.12 billion metric tons. China and the USA are the main CO2 emitters, with 11.47 billion tons (GtCO2) and 5.01 billion tons (GtCO2), respectively. Emissions from industry due to utilizations of fossil fuel are increasing rapidly (Tiseo et al., 2023). South Africa and Egypt are the largest CO2 emitters in Africa, with 435.9 and 249.6 million MtCO2 emissions, respectively. The CO2 emissions increased with proportion of economic development. For instance, emissions during Covid-19 in 2020, global recessions in 2009, recessions in 1980, and World War II in 1945 were reduced by 5%, 2%, 2%, and 17%, respectively, due to slowdown economic of activities and reductions of energy consumptions (Aktar, et al., 2021). Despite the fact that economic progress necessitates a high level of energy consumption, shifting to renewable energy sources will result more competitive and sustainable economic development (Greenstone, et al., 2019).

According to the global energy review for 2021, CO2 emissions from energy increased to 36.3 Gt, which has never happened before. As a result, environmental issues are significant and critical concern all over the world (Newell, et al., 2021). Energy is mostly used for production in the industry, particularly in the cement sector. The cement industry is highly energy intensive, consuming around 54% of the world's total delivered energy (Jordan, 2014). In worldwide energy cost in cement is accounts for 30% to 40% (Kermeli et al., 2019; NEP, 2011); while, in Ethiopia is about 50% to 60% of total operational costs (Tesema & Worrell, 2015). Improving cement productivity through contemporary dry process technology, energy efficiency, and alternative energy consumption is an effective method for reducing a cement plant's energy needs in order to lessen the risks of climate change to the environment while, also lowering production costs (Cantini et al., 2021).

According to world data based on the global carbon emission projections by (Ritchie, et al., 2020), cement industries are responsible for 8% of CO2 emissions. China, India, Vietnam, Turkey, and the United States are the world's largest CO2 emitters, accounting for 853, 149, 54.1,44.4, and 41.2 million MtCO2 emissions, respectively (Tiseo et al., 2023). The CO2 emissions from the cement sector in Africa are approximately 77.7 million MtCO, whereas emissions in Ethiopia have climbed from 13 thousand metric tons in 1965 to 734 thousand metric tons in 2014, rising an average annual rate of 10.57% and reach 4.07 million metric tons in 2021. Ethiopia's CO2 emissions per capita were 0.17 tons in 2021, up from 0.03 tons in 1984.

According to (Ige, et al., 2022), African countries, particularly in SSA, are experiencing increased demand for cement products due to rapid population expansion, urbanization, and economic growth. According to International Finance Corporation (2017), the demand for cement in SSA is expected to rised over 50%, wanting additional cement kilns. Cement demand in Ethiopia is increasing overtime as well the cement production and consumption.

Cement sector in Ethiopia's is one of the largest in SSA, with significant expansion over the last decade, as well as one of the top cement producers in Sub Saharan Africa next to Nigeria and South Africa. In last two decade economic development of Ethiopia is experienced remarkable comparison to the major of African countries, and this trend is also projected to continue. Even though cement production increased, the per capita cement consumption does not increased proportionally, its low in comparison to the Sub-Saharan average of 165 kilograms, while cement consumption in Ethiopia increased from 39 kg to 62 kg in 2017 (Mulatu et al., 2018).

However, numerous solutions are being developed to reduce the anthropogenic greenhouse gas (GHG) emissions of cement sectors, with the goal of reaching net zero CO2 emissions by 2050 (Miller et al., 2021; Benhelal et al., 2013). Pathways to decarburization exist in many sectors, including most electrical generation (e.g., conversion from fossil fuels to renewable resources), reducing CO2 emissions through energy efficiency, alternative energy use (biomass), and modern dry process technology. Otherwise, rapid temperature rise causes economic losses by diminishing agricultural yields, labor productivity, industrial output and threatens human well-being in the future.

1.2 Statement of the problem

Several studies show that cement industry are a vital building component and the backbone of economic development. While CO2 emissions from cement industries are primarily related to the consumption of energy and chemical processes during the manufacturing process, there are global challenges due to environmental pollutions and ecological disturbances that affect many circumstances (Haggar, 2005; Twardowska, 2004; Berhe & Fortuin, 2014; Fayomi & Ayoola, 2019).

According to the energy and environmental global carbon emission report by (Tiseo et al., 2023), cement manufacturing was the third most emitter sector in the world, with over 1.7 billion metric tons at the end of 2021. Likewise, CO2 emissions of cement industry in Ethiopia is 4.07 million metric tons (51%) among Industrial Processes and Product Use (IPPU) sectors in Ethiopia of the third national communication report of FDRE (UNFCCC, 2022). The evolution of CO2 emissions in cement industries is approximately 40% from fossil fuel combustion during the production process, 50% from raw material utilization and manufacturing process, and 10% from indirect transportation emissions (Habert et al., 2010; Imbabi ,et al., 2012).

Ansari and Seifi (2013) studied the energy consumption and CO2 emissions of the Iranian cement industry under several scenarios using system dynamics model. The study creates the SD model for cement demand, production, energy consumption, and CO2 emissions, and projected the Iranian cement sector over 20 years. Anand et al. (2006); Nehdi, (2004) research used the SD model to estimate long-term CO2 emissions of India's cement sector over a 20-year period, as well as alternative scenarios such as population stability, energy savings, and structural management. Another study (Ige et al., 2022), assesses cement production in South Africa using an integrated Life Cycle Assessment (LCA) and SD model estimated the long-term environmental impact and future dynamics of cement production. According to the study, population expansion, urbanization, and development of economic growth all contribute to rising demand for cement, also increasing in Ethiopia. Due to increased cement demand, the number of cement manufacturers in Ethiopia has increased over time. According to Berhe et al. (2014), who studied on Messebo cement factory in Ethiopia, the number of cement factories is increasing, also the production capacity. As a result, clinker output, raw material input, raw material transportation all increasing and leading to increasing the CO2 emissions.

According to Sharma et al., (2021), the dust particles and greenhouse gases emitted by cement plants affect soil, air, vegetation, animal, and human health. Various studies in Ethiopia reveal that emissions from cement factories have an impact on the economy, the environment, and societal well-being. According to study by Estifanos (2012) the dust released by the cement production influences the physicochemical parameters of the soils in the surrounding area. Other studies by Beressa, et al., (2021); Tesema &Worrell, (2015) reveal that Ethiopian cement industry are very energy intensive, increasing production costs and environmental consequences. Energy consumption accounted for around 50% to 60% of total operational expenditures, making the industry very reliant on imported energy sources for manufacturing. However, no studies have been conducted in Ethiopia to quantify future cement productions and CO2 emissions using system dynamic models or other models, with the exception of the Ethiopian cement development strategy in 2015 and (Handiso, 2015), which examines ways of mitigating GHG emissions in Ethiopian industries using LCA and quantifying GHG emissions. However, these studies focus solely on environmental issues.

In Ethiopia, many plans have been undertaken to achieve net zero CO2 emissions by 2050 in short, medium and long-term development to make better economic development and poverty reduction through decarburization. The green economy and CRGE (EEPA, 2019) strategies and plans are linked to monitor environmental performance, such as increasing resilience to climate shocks, cutting GHG emissions, minimizing biodiversity loss, and assuring access to clean water and electricity. The CRGE strategy (FDRE, 2014) in sector development plans aids in the integration of climate change adaptations and mitigations. The Industry Ministry and USAID established a green manufacturing strategy and energy efficiency for Ethiopia's industrial sector, which encourages energy efficiency with low CO2 emissions. For example, the Ethiopian

Cement Associations (ECA) develops strategic plans for the cement industry's development, including identifying, selecting, and localizing key cement technologies, knowledge and technology transfer, environmental protection, and lobbying the government for adequate access to financial sources. Cement industry energy consumption strategies, such as substituting imported thermal cement supplies with local energy coal and alternative energy sources, energy efficiency, and the adoption of contemporary dry process technology, would cut cement production costs and CO_2 emissions.

The System dynamic model (SDM) that understands complex system behavior in cement sector linked to direct and indirect effect of economic, social, and environmental implications in system of behaviors was used to analyze cement industry production and CO_2 emissions in qualitative and quantitative representations. To reflect the positive and negative scope production system of cement sector demand, consumption, supply, economic consequences, raw material relation to energy consumptions and CO_2 emissions is quite extensive. As a result, no statistical method exists to capture or calibrate the complicated system behaviors. The dynamic system with uncertain boundaries of various elements and multiple feedback linkages can be considered in the context of a complex system. Common quantitative analysis approaches, such as the Time Series Method and the Regression Analysis Method, are effective in forecasting with large amounts of basic data (Lingli & Xingchen, 2018). On the other hand, SDM is distinguished by its ability to connect natural and social science with the dynamic behavior of complex feedback systems, i.e., the direct and indirect impacts. As a result, system dynamics can handle complex time-varying issues with higher orders and more interaction variables. As a result, this study employs System Dynamics Model and simulates cement production and CO_2 emissions among interactions of the variables that describe the productivity of cement sector.

Several studies in Ethiopia have focused on the economic development and cement demand implications (Mulatu et al., 2018; Gashahun, 2020), as well as the environmental repercussions of cement. So, most of studies focused on environmental aspects and positive implications, no studies in Ethiopia seen in aspect of economic, social and environmental impacts collectively. Also, no studies quantify future cement productions and CO_2 emission in Ethiopia; except CRGE of (FDRE, 2011). This governmental road map strategy was predicted the cement productions and CO_2 emissions until from 2010 to 2030 period, but it is more far from reality of current 2020 actual data and exagerated forecasted of 2030. Accordingly the forecasted value of

CRGE cement production in 2020 is >37mill.tons, while the actual is not above 8 mill.tons cement & 65.7 mill.tons in 2030, while the CO_2 emissions is 45mill.tonsCO_2 as forecasted in 2030.

However, system dynamic model is more effective than other models for several of reasons, the fact that forecasts derived from a calibrated SD model are better and more informative than other methods. The model is calibrated using historical data to predict future cement production, CO_2 emissions. Having a calibrated model leads to more precise, reliable and historical behavior forecast results, this lead to better decisions and can determine sensitives and policy scenarios. As a result, the purpose of this study is to build system dynamic model for cement sector as well forecast future development in Ethiopia. The application of this model is important to understand the complex and dynamic system of factors and making better decisions for policymakers' in cement sectors. This model can describe the cause-effect of variables, interactions of endogenous variables, non-linear behavior of systems social, environmental, and economic interconnections. As a result, projecting future CO_2 emissions and cement production, as well as creating alternative scenarios using the SD model, make this study different from others studies.

1.3 Objective of the Study

1.3.1 General objective of this study

The main objective of this research is to build and develop a system dynamic model for the cement sector in Ethiopia.

1.3.2 Specific objective of the study

Specific objective of this study is:

- To investigate the factors that influences the cement production system.
- To demonstrate the interactions effects of cement productions and environmental factors in cement sector.
- To forecast cement productions and CO_2 emissions in the long term.
- To find the highest leverage points that reducing CO_2 emissions in cement sector.

1.4 Significance of the Study

- It provides as additional information about CO_2 emissions among the manufacturers.
- Serve as reference for those who interested to study on the area of cement sector.
- Helps policy makers to give direction on alternative use in abatement of CO_2 emission.

1.5 Scope of the study

The main focus of this research paper is to analysis cement production and CO_2 emissions in Ethiopian. The emissions of carbon from cement industry have impact on social, economic and environmental change of the country. Due to these, the emissions of CO_2 from cement industry are national level, therefore, the scope of this research will all cement industry planted in Ethiopian are considered as part of my study.

1.6 Limitation of the study

The study have limitations related to data, inconsistency from report to report, confidentiality of data such as revenues, costs and other, no available information were documented manually, report and future plan strategy. In consistence of some basic input measurement with standard case and recent data with emission factors of energy intensity. Based on accessible information reports online because most factories do not have information, this study used information available online or literatures and not practical inspection in cement factories.

1.7 Organization of the study

The organizations of this study consist of the five chapters. The first chapter begins with background of the study, statement of the problem and objective of the study, the second chapter gives a brief overview of the cement productions, green economy and climate strategy, reviewing of related literature both theoretical and empirical, as well conceptual framework of my study. The third chapter deals with data and methodology, with application of system dynamic model, dynamic hypothesis, model structure and specification of the parameters. While, in fourth chapter result and discussions of sensitivity analysis and policy scenario were done. Finally, the study gives conclusions and policy implications for future implication were forwarded.

CHAPTER TWO

2. REVIEWS OF RELATED LITERATURE

2.1 Historical Overview of cement production in Ethiopia

The first Ethiopian cement factories was built in 1938 in Dire Dawa town by Italian fascist forces to boost infrastructure improvements for the colonial demands include Dire Dawa cement and lime factory with a capacity of 120 tons of clinker production per day. The second cement mill was constructed in Massawa (now in Eritrea), with a daily capacity of 45 tons of clinker output. Due to increased cement demand, the Ethiopian government erected two cement facilities in 1964 and 1965, each with 70,000 tons of clinker production capacity per year, in Addis Abeba and Massawa, respectively. In addition, two Mugher cement manufacturing lines were erected, initially with a capacity of 300,000 tons in 1984, and later in 1991, with a capacity of 600,000 tons per year of building of the second line stated from introduction to Ethiopian cement market essays24.com (2011,01).

Mulatu et al., (2018) the Ethiopian cement industry after millennium development, notably after 2000 period, blooming of economic expansion, and the industry sectors highly demanding cement. Increasing of cement consumption and the fast-developing building sector, while, lack of construction materials, particularly cements, has resulted in the construction of additional cement factories in Ethiopia. To alleviate the shortage of cement demand, the Ethiopian government implemented various measures such as importing cement from Egypt, the United Arab Emirates, India, Pakistan, and China, as well as planting additional cement factories domestically and increasing the production capacity level of existing factories.

In Ethiopia, 21 cement manufacturers are now functioning, including National cement, Mugher cement, Dangote cement, Ture cement, Messobo cement, Capital cement, Derba Midroc cement, Habesh cement, and others are among large capacity in the sector. Despite the fact that Ethiopia's existing cement plants are producing below capacity, the Ethiopian government planned to build cement factories and boost cement production capacity to meet cement demand.

2.2 Green economy and climate change

According to the United Nations Environment Programme (UNEP,2011), green economy is a global policy plan that aims to increase human well-being and social fairness, while also considerably lowering environmental burdens and ecological scarcity. Because the green economy approach is to reduce carbon emissions, use resources more efficiently, and create socially inclusive and innovative development to foster economic growth and development while protecting natural assets. Global warming is becoming more severe over time, affecting economic growth, productivity loss, social welfare, and environmental issues in society. The primary policy problem of the twenty-first century is climate change, which disrupts society, challenges economic progress, and alters the natural environment (Kanianska, 2017).

According to the UN, human activities are the primary cause of climate change and increased carbon emissions. Many industrialized and emerging countries' economic growth is dependent on the industrial sector. While industrial sectors are highly energy intensive, the GHGs from energy consumption are higher; for example, cement is the world's third largest emitter of GHGs (Bernstein et al., 2007). According to worldwide cement studies, production and cement demand have increased over time, as have CO2 emissions, which will account for around 7% of global emissions in 2021 and more than 8% in 2022. Thus, climate change or temperature rise causes severe droughts, water scarcity, terrible fires, increasing sea levels, flooding, melting polar ice, health, dwindling biodiversity, and so on (Ige, et al., 2022).

Many economists and policymakers believe that the only way to solve climate change is to implement a green growth/green economy policy plan (Antal & Van Den Bergh, 2016). The goal of green growth strategies is to ensure that natural assets can deliver maximum economic potential on a long-term basis. Both green economy and sustainable development address economic, social, and environmental development at the same time (Allen, 2012). Understanding green economy policies, thus, can make it easier to achieve goals of sustainable development that improve environmental, social, and economic resource issues. System dynamic models (SDM) proposed by (Forrester, 1958) were created to overcome and imply future policy direction.

2.3 Application of System Dynamic Modeling on Environmental issues

System dynamics models are commonly used due to problems are complex and dynamic and cannot be understood without integrated and simulation-based modeling (Tedeschi, et a., 2011). System dynamics is helpful that contains social, economic, and environmental factors within the same system of study (Bassi & Costantini, 2020). Particularly, environmental sustainability challenges have been extensively studied using system dynamics (Barbrook-Johnson & Penn, 2022), Environmental challenges are dynamic, with numerous interrelated components interacting with one another. Environmental challenges are also characterized by nonlinearities, geographical lags, and temporal lags (Costanza & Ruth, 1998).

However, Strong interactions between sectors, state changes over time, delayed system responses, feedback interactions, interaction multiplicity and nonlinearity, and behaviors that spontaneously emerged from the problem's patterns and structure are all factors contributing to the system's dynamic complexity. The human-environment relationship, in particular, is complicated and dynamic. In the case of situations with dynamic complexity, the system dynamics method would be employed to analyze the dynamic behavior and derive reasonable and valuable insights for policy analysis (Sweeney & Sterman, 2000).

2.4 Global Cement Production and Consumption

Cement output and consumption have expanded dramatically over time, with global cement production predicted to exceed 4.37 billion tons in 2021, while cement consumption is estimated to be 4.27 billion tons. According to Garside (2023), global cement production has climbed from 1.39 billion tons in 1995. According to these reports, the world's leading cement producers are China, India, the United States, South Korea, Russia, Egypt, and others. China produces about 55% of the world's cement, with India producing 8% share in 2021. The cement industry is expanding rapidly, particularly in developing Asian, Eastern European, Latin American, and African countries. Cement consumption is increasing because it is an important building material. The expanding worldwide population and urbanization patterns, together with the need for infrastructure development, drive up demand for cement and concrete (Chen, & Wei, 2018). Infrastructural projects and construction demand in metropolitan areas are increasing. Government infrastructure development and social welfare are more available than rural area people were asking to migrate to urban, which reduces deagriculturalization process (Fry, 2011; Aldred, 2012).

Despite covid-19 working paper by IMF, the output and demand for cement in Africa, particularly in Sub-Saharan Africa, has been consistently favorable (Schlorke, et al., 2020); (Ganum & Thakoor, 2021). The COVID-19 pandemic has been unprecedented and astounding, with decreased predicted cement demand across all regions compared to the pre-pandemic cement sector, according to a Fortune Business study. The COVID-19 epidemic had a significant impact on several countries' operations and productions, as well as the cement market, because government regulations restricted the flow of both people and goods around the world.

According to the most recent African cement industry trend data, African cement capacity has expanded dramatically from 262.0 Mt/a in 2014 to 386.1 Mt/a by the end of 2020. As a result, Africa's cement capacity utilization has fallen from 70.0% in 2014 to 55.1% by 2020. According to a World Bank analysis, Africa's population, urbanization, and gross national income are all rising faster than in other areas. As a result, cement consumption and output levels in Africa are extremely high. North Africa consumed 553 kg of cement per capita, while Sub-Saharan Africa consumed just 102 kg and Ethiopia consumed 62kg.

2.5 Production and consumption of cement industry in Ethiopia

The production and consumption of cement industry in Ethiopia is massively increasing sector. Even though the cement production in Ethiopia is below capacity of estimated production, in 2022 about 15.38 million tons increased from 3.69 million tons in 2011, 70,000 tons in 1960. The average global per capital consumption of cement is 500kg, the average per capital in Sub-Saharan Africa countries is 165kg it is below optimal global per capital consumption. While, in Ethiopia the average per capital consumption of cement is increased from 39kg in 2010 to 62kg in 2017, even it is below SSA and Ethiopia is expected to increase per capital of cement consumption to 179kg in 2025 (Mulatu, et al., 2018). While, to increase per capital consumption of cement in Ethiopia the policy makers expected to 179kg by 2025.

Cement industry sector in Ethiopia is one of the largest markets and changed from being imported to exporting to some neighboring countries such as South Sudan, Djibouti, Somalia, Kenya and other Sub-Saharan Africa region (Tesema and Worrell, 2015; Mulatu et al., 2018). The major factors that are causing demand for cement are heavy investments on housing projects, real state, different universities, infrastructures, power generation plants like building of the Grand Ethiopian Renaissance dam and irrigation, industrial zones, airport fields, railways and road construction projects. This increase cement consumption which is triggered by huge projects in the construction sector has led to extensive. So, the contributions in economic development in generating foreign currency, creating employees, role in building of construction sector which among the main contribution to economic growth in Ethiopia.

2.5.1 Impact of cement industry on climate change

Ethiopia's cement industry is rapidly expanding in terms of both production and consumption. Despite the fact that Ethiopian cement output is below capacity, it is expected to expand to 15.38 million tons by 2022, up from 3.69 million tons in 2011 and 70,000 tons in 1960. The average global per capita cement consumption is 500kg, but the average per capita consumption in Sub-Saharan African countries is 165kg, which is less than the optimal global per capita consumption. While Ethiopia's average per capita cement consumption climbed from 39kg in 2010 to 62kg in 2017, it is still lower than the SSA average, and Ethiopia is predicted to raise per capita cement consumption to 179kg in 2025 ((Mulatu et al., 2018).

The cement industry uses a lot of energy and emits a lot of pollution (Mossie, et al., 2021) Cement making is an energy-intensive process that necessitates a huge number of raw material resources. The cement industry is the third largest industrial emitters and energy user, accounting for 7% of worldwide industrial energy consumption in 2021 (Borenstein, 2022), but some sources estimate that global cement emissions will be over 8% in 2022. Cement manufacture involves the disintegration of limestone (calcium carbonate), which accounts for roughly two-thirds of the total CO2 emissions generated in the process, with the remainder being attributable to fuel burning. Global cement production is expected to increase by 12-23% by 2050 from its current level. Under the IEA Reference Technology Scenario (RTS), direct CO2 emissions from the cement industry are anticipated to rise by 4% globally by 2050, despite a 12% increase in global cement production (Chen et al., 2018).

The cement industry's emissions are increasing faster than those of other carbon-emitting businesses. The emissions in the cement industry are 50% due to chemical processing, 40% due to the combustion of fossil fuels, and 10% due to indirect emissions during transportation. According to the international energy report (Citaristi, 2022), the emissions of direct CO2 intensity from cement manufacturing grew by 1.5% every year from 2015 to 2021. The cement industry has an impact on the environment at every level of the manufacturing process. Dust, air pollution, water pollution, solid waste pollution, noise pollution, ground vibration, and resource depletion due to raw material extraction are the primary pollutants of cement manufacture.

Climate change is currently one of the most serious concerns confronting many developing countries, as well as a major source of concern for our society and environment. According to the

Ethiopian Panel on Climate Change (IPCC, 2015), GHG emissions are the leading causes of climate change and are increasing globally, not only in Ethiopia. According to the report, the main source of GHG emissions is tied to the development of the industrial sector, which emits through energy use as well as industrial processes. Because cement industry use a lot of energy and heat during manufacturing, they contribute the most to emissions in Ethiopia. CO2 emissions in the cement industry are caused by the combustion of fossil fuels and limestone calcination operations or raw materials processes, as well as clinker production activities. The impact of these emissions includes landscape damage, air pollution, water pollution, ground vibration, and resource depletion as a result of raw material extraction or disruption of local biodiversity from limestone quarrying.

2.5.2 Strategic Policy to reduce CO2 emissions from cement industry in Ethiopia

The International Energy Agency (IEA) road map aims to reduce emissions by 3% per year until 2030, with the goal of reaching net zero emissions by 2050 (Citaristi, 2022). According to Ethiopian climate resilient green economy (FDRE, 2011), combating the negative effects of climate change and resilience necessitates collaborative efforts from diverse stakeholders including as the industrial and agricultural sectors. Ethiopian CRGE GTP-I and GTP-II targets, domestic strategic policy goal to reach or attempt net zero or reduce carbon emissions by 2030.

According to Ethiopia's updated nationally determined contribution on climate resilience green strategy (Dupar, et a., 2021), the main strategic policy to reduce carbon emissions from the cement sector is clinker substitution with adequate and available materials, alternative fuels/biomass, and energy efficiency in cement production processes. This method was also recommended by the cement sustainability initiative (CSI) and the International Energy Agency (IEA) (Barcelo, et al., 2014). In Ethiopia, the cement industry is challenged by power outages, a lack of replacement parts, a lack of foreign cash, and some cement plants still employ the oldest technology, vertical kilns.

Various studies and organizations recommend that cutting carbon emissions in cement production include improving energy efficiency, using lower carbon fuels, promoting material efficiency (reducing clinker-to-cement ratio and total demand), and advancing innovative near-zero emission production routes as a key strategy. Alignment with this scenario will necessitate the creation and deployment of previously unavailable technology.

2.6 Empirical Review

Biswas et al., 2020 found that raw material use, managerial skill, motivation, skilled labor shortage, and other factors influence cement output. Process performance, marketing and supply chain, management and technological, human and safety issues, and government and political issues have been identified as the primary factors of productivity. Businesses' production success is essentially determined by productivity, which is typically determined by a number of various factors. It also displays how an industry or organization converts its inputs into outputs effectively and successfully (Syverson, 2011). Dasanayaka and Sardana (2017) attempted to discover the factors influencing the productivity of Sri Lanka's small and medium-sized rubber manufacturing firms. They revealed that technological adoption, innovation, human factors, raw material cost, and raw material quality all had a substantial impact on rubber production productivity. Islam and Khadem (2013) researched the productivity determinants of the Oman construction industry and discovered that professionalism, the fairness of financial transactions, the skill of supervisors, the availability of materials, and the availability of comprehensive drawings are the most important factors of productivity.

According to Coito, et al., (2007), the production schedule, plant operations and maintenance, product quality, energy usage, and efficient resource use all have a significant impact on the productivity of the California cement sector. Muthukrishnan (2011) examined the productivity-related variables in the Indian cement business and discovered that effective management, proper resource utilization, infrastructure facilities, and optimum human resource extraction led to increased productivity and better results. Capacity utilization, effective raw material use, maintenance, competition, incentive, and experienced employees are all highlighted as productivity factors of the Indian cement business (Burange and Yamini, 2009). According to Avami and Sattari (2007), energy use, production planning, and new technology all have a substantial impact on the Iranian cement industry's productivity.

Cement production is critical for economic development in the building sector and is widely used, but it consumes a lot of energy and produces a lot of pollutants, notably SO2 and CO2 emissions. The environmental damage caused by exponential expansion in cement production has gotten substantially worse in recent decades. While predicting the dangers of environmental, social, and economic consequences are not major issues. Cement is the third largest CO2 generating sector in the world, after steel manufacturing and chemical operations processes (Kim et al., 2007; Tong et al., 2021), with annual emissions ranging from 3.0 to 3.6Gt. According to (Gartner, 2004), 1kg of cement manufacturing released 0.5 to 0.9kg of CO2 emissions.

Additionally, cement manufacture has both positive and negative major implications at all levels of processing. Positive benefits include the creation of jobs and economic opportunities for local populations, while negative impacts include the disturbance of the landscape, dust and noise, and disturbances to local biodiversity caused by limestone quarrying, including CO2 emissions. The greenhouse gas emissions were generated directly by the generation of CO2 when generating lime and carbon dioxide about 50% of the time and indirectly by the use of energy, which was derived from the combustion of fossil fuels about 40% of the time and 10% through transportation and other means. Cement industry CO2 emissions are 900kg per 1000kg of cement (Subramanian, 2016).

Uwasu et al. (2014) investigate research to understand what factors influence cement production. They found that the amount of cement produced per person differs by country and investigated the factors influencing cement output in each country. This established the presence of an inverted U-shaped relationship between per capita GDP and cement production also known as the environmental Kuznets curve. Concerning the environmental implications, the most important thing is to control cement demand, while taking China's peculiarities and effects into account. Excess cement production in China has the potential to reach extraordinarily high levels, and halting production would drastically cut CO2 emissions as well as regional pollutants like mercury and particulate matter without negatively impacting the country's economic progress. These findings highlight the significance of demand management and technical transfer in addressing challenging global and local resource and environmental concerns.

Study in India by (Anand et al.,2006) predict CO2 emissions for the next 20 years using a system dynamic model. The report also presents three possible scenarios for reducing cement emissions. The first scenario assumes a baseline with the existing population growth rate (baseline), a second scenario in which the population growth rate is zero by 2020, and choices for steady population growth based on 2011 figures. Energy efficiency management and structural management were added as the third alternative policy option. Under a scenario that includes population stabilization, structural modifications, a 25% contribution from renewable energy sources, and the adoption of energy efficient process specific energy consumption, the environmental load of greenhouse gases might be reduced by 42% by 2020. The indirect CO_2 emissions from truck transportation of finished cement and raw materials (coal and limestone) are higher than those from rail transportation. As a result, shifting from using trucks to trains will result in lower CO_2 emissions.

The study (Ansari & Seifi, 2013) used SDM to analyze the energy consumption and CO_2 emissions in the Iranian cement sector under various production and export scenarios. The study calculated prospective energy demand across 20 periods and discovered that eliminating energy subsidies and implementing corrective policies in cement companies may save 29% of natural gas and 21% of electricity consumption, resulting in a 22% reduction in CO_2 emissions. The study by (Zhang et al., 2013 in China estimated cement production emissions based on technology development and tightening emission limits. The study's findings suggest that replacing outdated shaft kilns with precalciner kilns minimizes specific matter emissions.

Ige et al., (2022) used an integrated life cycle assessment (LCA) and a system dynamics (SDs) model to anticipate the long-term environmental impact and future dynamics of cement manufacturing in South Africa. A system dynamics model was created and parameterized using data from 2000 to 2017, as well as scenarios simulated over a 40-year period beginning in 2000. The study discovered that cement output increased from 2018 to 2040, contributing to increased global warming and environmental consequences. Increases in cement output are primarily driven by urbanization, economic activity or GDP growth, and industrialization. The report also suggests that environmental implications from cement CO_2 emissions can be minimized by enacting environmental legislation through government agencies, encouraging the cement industry to use new technology by encouraging policies, and managing population growth.

Handiso (2015) studied on cement sector by application of a life cycle assessment (LCA) model that reduce Ethiopian greenhouse gas emissions. In the model, the study included three mitigation option scenarios: alternative fuel use, clinker substitution, and thermal energy efficiency. The findings revealed that clinker substitution and alternative fuels played an important impact in reducing GHG emissions while also lowering operating costs. Using energy efficient kiln technology, which minimizes the quantity of thermal energy used, has the lowest GHG emissions reduction intensity and the highest implementation cost when compared to the other scenarios. The combined mitigation potential of GHG emissions and other selected mitigation scenarios might be at least 48.9% per ton of cement produced.

The study by (Gashahun, 2020) examines cement production practices and prospective cement replacement materials in Ethiopia. According to the study, the economic and construction cycle linkages between cement production and consumption generate fluctuations in operational costs and income. Growing cement demand has resulted in an increase in extra production capacity as well as a need to investigate new cement replacement alternatives. Ethiopia has an insufficient supply of cement as well as a wide variety of replacement cements for traditional cementation materials such as coffee husk ash.

However, government policy is also planting cement factories and attempting to meet domestic cement demand, rather than focusing on the negative effects of CO_2 emissions on society, the environment, and the economy. The CO_2 emissions from cement in Ethiopia have steadily increased overtime, while cement production has steadily increased until 2016, after which the emissions have not decreased despite output slightly reducing. Nonetheless, Ethiopia is subject to climatic unpredictability and environmental consequences as a result of CO_2 emissions from the cement sector. In the long run, this worsens economic development by reducing the contribution of the industrial, agricultural, and service sectors. In general, climate change and GHG emissions, particularly from industrial sectors such as cement, which are the largest emitters, have received less attention, and studied with exception of a few studies conducted by international organizations.

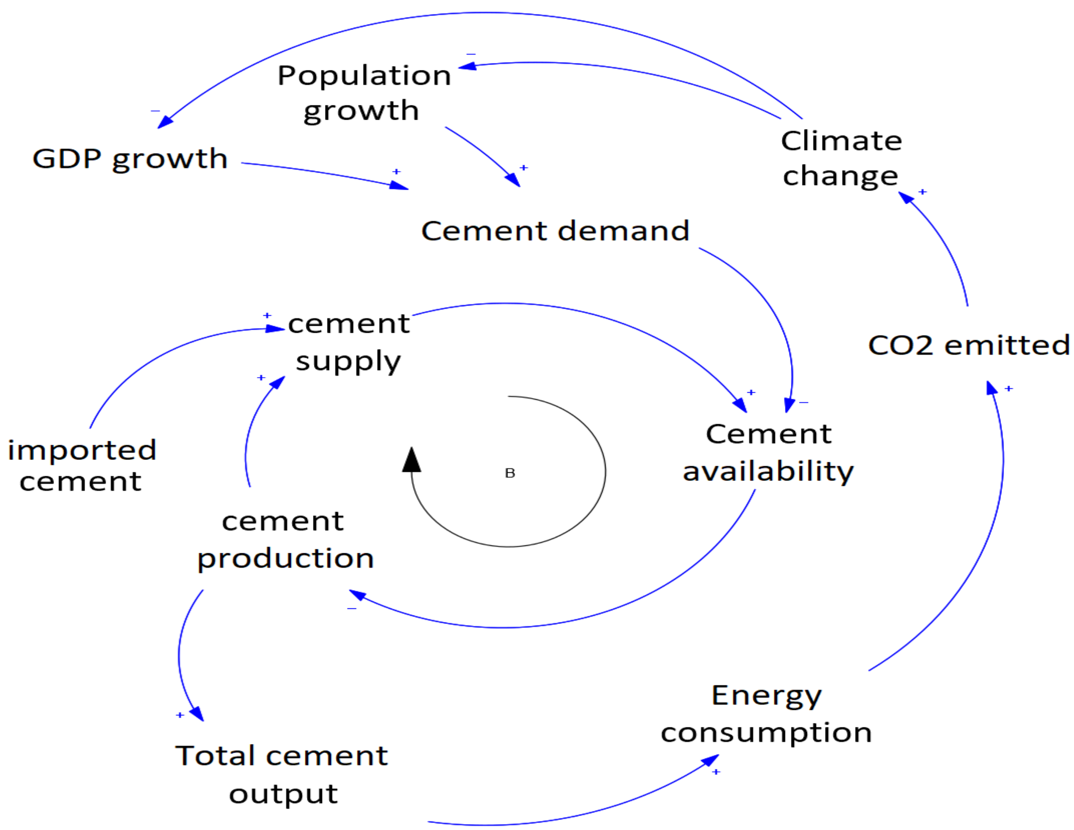
Several studies in the cement industry were conducted utilizing simple descriptive analysis or model-based analysis. Those studies were not particularly relevant to my research because they did not cover all aspects of social, environmental, and economic variables. Engineers conducted the majority of the investigations, which focused on material technology, chemical preparations, and quality control. Some of the studies employed primary data to investigate environmental and societal issues. The majority of the studies were likewise conducted at the industrial level and focused on the impact of that local area. In terms of economic impacts, however, few research have been conducted. Particularly in Ethiopia, there has been little research focus on the cement sectors; even those that have been conducted have focused on the capacity of production level on those largest producers of cement factories rather than CO_2 emissions at the national level; they have also focused on the positive economic consequences of cement and demand. My investigations, on the other hand, will use a system dynamic model to capture all aspects of economic, social, and environmental repercussions. Despite the fact that SD models have been utilized in several research on cement sectors, no studies have been conducted in Ethiopian cement sectors to anticipate and interact with these sectors.

2.7 Conceptual Framework of the Study

Cement production system are affected by various factors either directly or indirectly. Such as raw materials (energy and other materials), foreign currency, demand, economic activities, concentrations of CO2 of emissions, etc. The direct and indirect endogenous interaction variables that affect cement productivity were revised based on a review of theoretical and empirical literature. As a result, the study includes various of factors that describe cement sector in Ethiopia challenging issues. Cement industries are complex systems that influence social, economic, and environments. The carbon emissions during cement productions affects local environment that impacts to poor productivity in agriculture or social health. As a result of their interaction, these sub models produce complicated or non-linear causal effect relationships and feedback loops. To solve such issues, it is preferable to use a system dynamic model application to make better policy decisions.

Based on the examined literature, the conceptual framework for cement production system of the study were developed. Considering the application of system dynamic models (SDM) in the study, the following that we take to cope with it steps are identification and specification of problems, conceptualization of systems, model formulation, model testing and evaluation, model use, implementation (Forrester & Albin, 1997). The study developed the conceptual framework by designing of mental qualitative causal loop diagram (CLD) representations and based on the reviewed literature of the cement production system in the Ethiopia.

Figure 1: Conceptual Framework of CLD for cement production sector.



The graphic representation of the above depicts the conceptual framework for the overall model. For instance, the production and import of cement were related to cement supply this also has direct causal effect with cement availability that represented as ratio of cement supply to cement demand. Population and economic growth have direct relationship with cement demand which also have negative causal with availability of cements. As representations of balancing loop, the availability of cement has negative relationship with cement productions this has positive causal with cement supply this also leads to positive causal with availability of cements. Productions of cement leads to positive effect on total accumulation of cement output, the accumulation leads to rise the energy consumption positively. Thus, absolutely increase the concentrations of carbon emissions which widen the burden of climate change extensively, this either directly or indirectly affects economic growth and population density. Therefore, the visual representations of complex or interaction effects of various endogenous variables in cement sector of Ethiopia shown on the figure.

CHAPTER THREE

3. DATA AND METHOGOLOGY

3.1 Data Source and Methodology

The study covers all cement factory planted in Ethiopia because CO2 emissions from the sector are not available at factory level, using all cement factories, it is a better way to illustrate the environmental problem of emissions from the cement industry. However, the study includes a large number of variables gathered from various institutions or periodicals data to forecast more trustworthy outcomes and confirm the model behavior. The analysis covers the entire cement factory planted in Ethiopia because CO2 emissions from these industries are economically and environmentally affects at a national level. Furthermore, because there is no data at the disaggregated or factory level, so using all cement factories is a better way to reflect the environmental problem of emissions from the cement industry. However, in order to forecast more reliable outcomes and evaluate the model behavior, the study combines several factors.

Data used in this study is collected from various sources. Such as from Global Carbon emission projection report of CO2, cement productions are from Ministry of Mines, populations from Ethiopian Statistical Service (ESS) and economic variables such as GDP from National Bank of Ethiopia (NBE). Others data are collected from existing literature, reports, own computation based on take assumption from literature, etc. are sources for my study.

3.2 Application of System Dynamic Model

The use of system dynamic models is advantageous in explaining nonlinear, dynamic, and complex system behavior in cement production. Forrester, (1994) created the SDM first to comprehend complex systems, non-linear behavior, and in general entire reality system behavior methods. When the emphasis is on links between modeling and the analysis of the numerous variables in the system rather than on a single transaction, an SD technique is often utilized for big and complex systems (Koelling & Schwandt, 2005). Similarly, it is vital to select the best policy action that might productively cement manufacturing, maintain CO2 emissions, and preserve environmental climate changes. As a result, a dynamic simulation model based on a system dynamics model will be used to capture a complete grasp of the sector's complexity and dynamicity.

The development of the system dynamics model for the issue is based on an investigation and knowledge of the driving factors behind the cement production system and the environmental implications. A system dynamics model can be used to investigate and simulate the dynamicity, feedback interaction, and prospects of current activities, as well as to evaluate an alternative policy situation. The model additionally considers the causal relationship between the model's structure, non-linearity, and dynamic behavior delays (Bala et al., 2017).

The SDs method integrates qualitative and quantitative problem-solving methodologies by allowing the use of verbal and numerical data in conjunction with mental models in order to better understand the underlying structure and feedback loops responsible for system behavior. Combining data available at various degrees of detail helps in revealing different features of the system that may be relevant to various stakeholders. A system dynamics model is used to assist policymakers with CO2 reduction. The SD approach can also generate time step simulations to illustrate major changes in GHG emission trends. The SDs models analyzing the cement production process may give researchers with a better knowledge of long-term patterns in environmental, economic, or social repercussions by providing potential solutions for the development of cement sustainability.

3.3 Dynamic Hypothesis

Despite the fact that Ethiopian cement production below capacity, demand is increasing over time. The availability of cements to consumers has been difficult in recent years due to increased domestic demand and a scarcity of cement manufacturing. In fact, Ethiopia has experienced remarkable economic development over the last two decades, importance of cement to expand various infrastructural developments such as road construction, building construction, mega projects or dams, commercial building, and housing projects, as well as an increase in population and urbanization. On the other hand, most cement places are producing below capacity, due to a lack of foreign currency availability or other problems. Most machinery, including clinker, replacement parts, and energy (fuel, coal), is imported from other countries, posing an issue for Ethiopian cement availability and causing price volatility on production cements.

However, cement manufacturing process is characteristically energy intensive. In the manufacture of cement, raw materials such as limestone, clay, marl, and so on are taken from quarries by blasting or ripping with heavy machinery, resulting in a high heat temperature.

During these processes, the use of energy such as fuel oil, coal, and electricity increases, while CO_2 emissions from energy consumption are limitless. Not only that, but automobiles emit a lot of CO_2s as they transport goods or raw materials. Currently, CO_2 emissions from cement factories in Ethiopia are increasing likely or proportionally to cement output levels. As a result, the pattern of CO_2 emissions becomes exponentially growing, with no end in sight.

3.4 Structure of the Model

System dynamics modeling is the process of producing diagrams with feedback loops to illustrate how various factors interact within a system over time. The model allows for parameter estimation and adjustment, that helps in the improving of model predictions and the identification of paths leading to diverse the results. Overall, system dynamics modeling is an effective tool for investigating complex or uncertain systems through visualization, simulation, and scenario analysis. The structure of the model is consisting of two sections. The first section is a causal loop diagram (CLD), which conceptually illustrates the concepts or idea as well as a set of simplified cause and effect relationships between the various systems of the structure, during qualitative representation of the model. The second section is a stock & flow diagram (STD) that depicts the quantitative notions of the relationship between the variables (Coyle, 2000).

The production of cement is a complex system which influenced by economic growth and population density as well as the interactions of the endogenous variables. As shown on of the Figure 1 the conceptual framework of causal feedback loop diagram model. The model is consisting of some main variables population, economic growth, CO_2 emissions, and cement production output systems. When these sub models or variables are interacted, they produce nonlinear behavior causal effects or feedback loops systems. Population growth, expansion of different infrastructure and economic growth are key factors to determine the cement demand (Ansari & Seifi, 2013; Anand, 2006). Ansari & Seifi as implicate the demand of many countries population and GDP is key factors that determines the business market, particularly developing countries such as Ethiopia are poor policy strategy rather increasing the productivity of sector, they built other cement manufacture, which in turn requiring of additional energy consumption in the sectors. And, increasing the concentrations of CO_2 emissions and challenges for future climate changes.

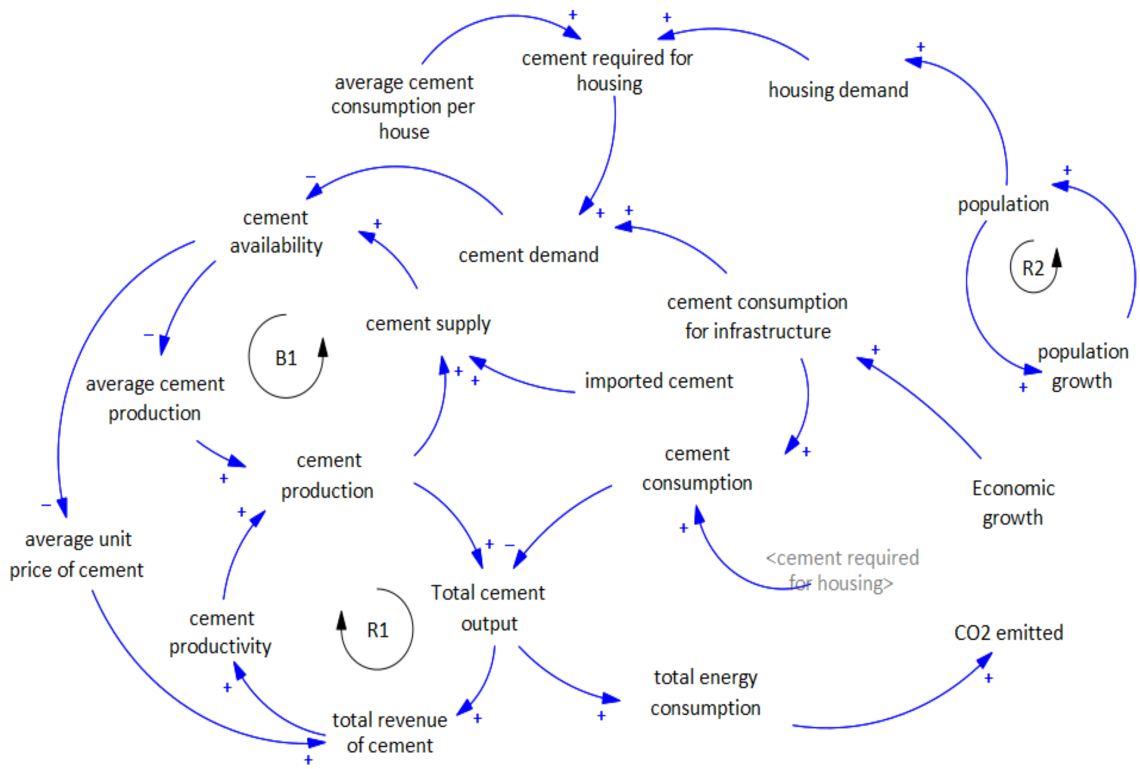
However, in Ethiopia trend of cement productions and CO_2 emission are increasing pattern and new cement factories is planted time to time. This indicate that, due to increase of population, infrastructural development the cement productions are rising, at the same time, the concentrations of CO_2 emission are also proportionally. As a result, cement demand, cement productions, CO_2 emissions, economic growth, and population growth are modeled by system dynamic model with realistic assumptions of both mental model causal loop diagram and visual model stock-flow diagrams to capture endogenous and exogenous variable interaction and non-linear complex system behavior of model structure.

3.4.1 Causal Loop Diagram (CLD)

A causal loop diagram is a conceptual framework that depicts a causal closed diagram which visualizes how various variables in a system are causally interrelated. It demonstrates how the feedback system is structured and how the dynamic factors of behavior are captured. In the causal loop diagram, there are also feedback loops that balance and reinforce each other. The reinforcing loop explains how the system increases, whereas, the balancing loop demonstrates how the system develops goal-seeking or self-regulating behaviors (Lannon, 2012; Bala, et al., 2017).

The causal loop structure can be developed to build links between each predefined variable, based on the dynamic hypothesis to investigate and simulate problem behavior. Each relationship illustrates how these variables are causally related. Each relationship has a polarity that indicates how these variables affect one another and might be positive (+) or negative (-). The causal loop diagram below attempts to explain the system structure of cement production and its interactions with environmental issues such as CO_2 emissions and economic values of cement sector. To form CLD model, how the production of cement system interacts with economic and social impacts interactions of the variables. The diagram will have constructed based on stated dynamic hypothesis statement or as shown on Figure 2.

Figure 2: Causal Loop Diagram (CLD) representation model for cement production & CO2 emission in Ethiopia.



The causal loop diagram (CLD) shown in Figure 2 comprises of reinforcing (Ri) and balancing (Bi) feedback loops between the interaction of economic, environmental, and social variables connected to CO2 emission impact during cement production. In any economic situation, the initial phases of investment are determined by the demand for that specific sector to be invested in. As a result of increased population growth, urbanization, and infrastructure development or expansion of buildings, cement demand rises, attracting various companies to participate in Ethiopian cement manufacturing. Positive or negative loop relationship or cause effect among factors during production.

Reinforcing loop R1: indicate that an increase in cement productions will increase accumulated total cement output, cement revenues this leads to increase or improve productivity of cement productions.

Re-enforcing loop R2: depict that; population is exponentially growing.

Balancing loop B1: indicate that cement productions have positive relationships with cement supply, the higher producing cement output, the more cement supply to consumers. While, cement supply has positive relationship with availability of cement which formulated as ratio of supply to demands. Availability of cement has negative relationship between average cement productions.

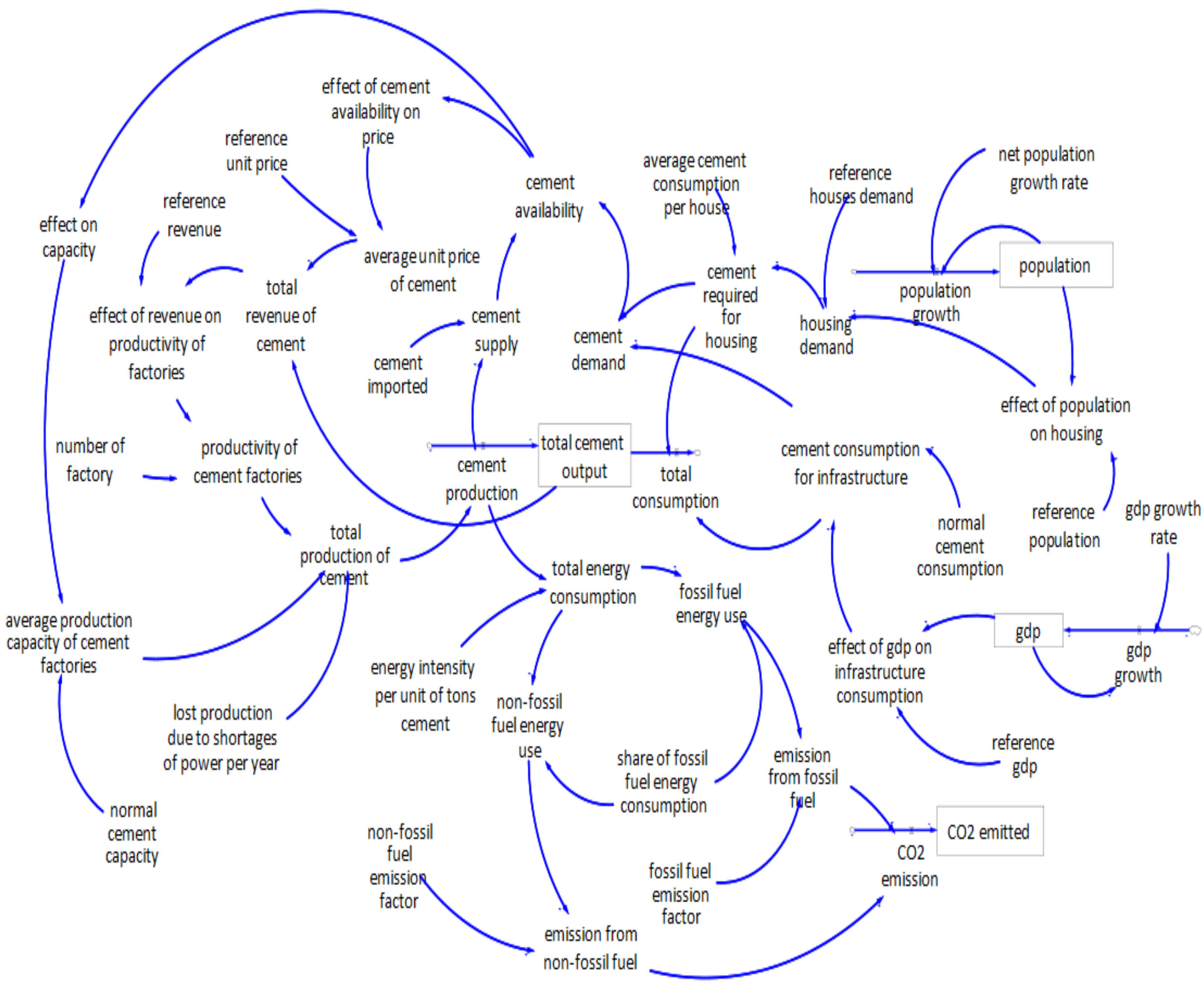
3.4.2 Stock and Flow Diagram

Stock and flow diagrams are more visual or quantitative communication languages in system dynamic models than mental causal loop diagrams (CLD) representations of the model. It is the cornerstone of the SD model and is composed of the stock and flow realities, which reflect quantitative visual or numerical values in the behavior system. Stock is accumulated or value at a given point in time based on the system's past behavior, which we gain by adding up of all the changes in the systems of historical data. On the other hand, flow, is a movement of anything over time or the rate at which a particular stock changes at any given moment of inflow or outflow with respect to increasing or decreasing the stock variables respectively. The stock and flow diagram represents integral finite difference equations with a variety of feedback loop structure variables and mimics the dynamics effects of the behavior over time (Sweeney & Sterman, 2000). Total cement output is the major stock variable in the model in this study that has both inflow and outflow behavior of the system, and as depicted as below diagram. This total cement output stock variable has an inflow of cement productions and an outflow of total cement consumption, which increase the stock accumulation as a result of productions and decrease the cement output due to the system of behavior's consuming behavior, respectively.

Other stock variables are total CO_2 emitted, GDP, and population. Even though this variable has no outflow behavior, it does have inflow behavior system of the variables. The other major variables are total CO_2 emitted from cement sectors, as a result of high energy consumption from fossil fuels and less concentration of CO_2 emission in cement sector due to the use of renewable energy resources. While, as a result of these two combination energy consumption sources is accumulated to stock variables of CO_2 emitted in cement sector of Ethiopia.

Economic and social stock variables of GDP and population are affected by inflow of their growth. An increasing of inflow of GDP growth and population growth affects to increase the demand of cement output, which in turn increases to concentration of CO_2 emissions and degradation of the environment as a result of climate change. This has ramifications for future economic development and population well-being.

Figure 3: Stock and Flow Diagram (SFD) visual representations for cement productions and CO_2 emission



In general, unlike of cement production and CO_2 emissions is determined by demand. Population and economic development are the key factors for cement demand or consumption. Then to produce cement energy is the main input. However, intensive of energy consumption sectors are high and used as primary production of cement. Hence, high consumption of energy leads to a concentration of CO2 emissions and climate changes. This has an adversely affect the economy and human well-being.

3.4.2.1 Specification of Parameters

Before performing the simulation model the stock and flow model requires formulation or specifications of the equations and parameterization of the variables. The below Table summarizes the values of the model's variables and parameters, as well as information on the unit of measurement and sources.

Table 1: List of Parameter with initial value or median value for the parameters

List of Parameters	Value of the parameters	Measurement of units	Source
Cement production	680,252.00	Tons	Ministry of Mines, Ethiopia
CO2 emission	365,200.00	TonsCO2	Tiseo, (2023)
Population	63,495,000.00	Person	Ethiopian Statistical Service (Gashahun)
GDP	364,984,334,372.08	Birr	National Bank of Ethiopia (NBE)
Average productions of cement factories	217,899	Tons	Ministry of Industry, Ethiopia
Average loss of cement production per year	64,524.1	Tons	Ministry of Industry, Ethiopia; Oqubay, (2015)
Average unit price in tons	500	Birr	Ministry of Industry, Ethiopia; Oqubay, (2015)
Intensity of energy consumption per tons cement	4.215	Giga Joule (GJ)	International Finance Corporation. (2017); (Mossie et al., 2021)
Share of fossil fuel consumptions	0.90	Percent	Tesema & Worrell, (2015) Ababa, (2013).
Share of non-fossil fuel consumptions	0.1	Percent	Tesema & Worrell, (2015) Ababa,

Number of cement factories	4	Factories	Ministry of Industry, Ethiopia & Oqubay, (2015)
Housing demand	100,000	Houses	Matsumoto & Crook, (2015); Ministry of Urban Development and Housing ((MUDH, 2017),
Average cement consumptions per house	2.431	Tons/100sqm (One house)	Oqubay, (2015)
Fossil fuel CO2 emission factors	0.513	tonsCO2/GJ	(Brander, et al, 2015; Mossie, 2021)
Non-fossil fuel CO2 emission factors	0.084	tonsCO2/GJ	(Brander, et al, 2015; Mossie, 2021)
Imported cement	10,000	Tons	Ministry of Industry, Ethiopia, Ababa, (2013).

We can see the formula and equations in appendix (Appendix A:)

NOTE: All Figure in this thesis are own computations using Vensim Software (Figure 1-17)

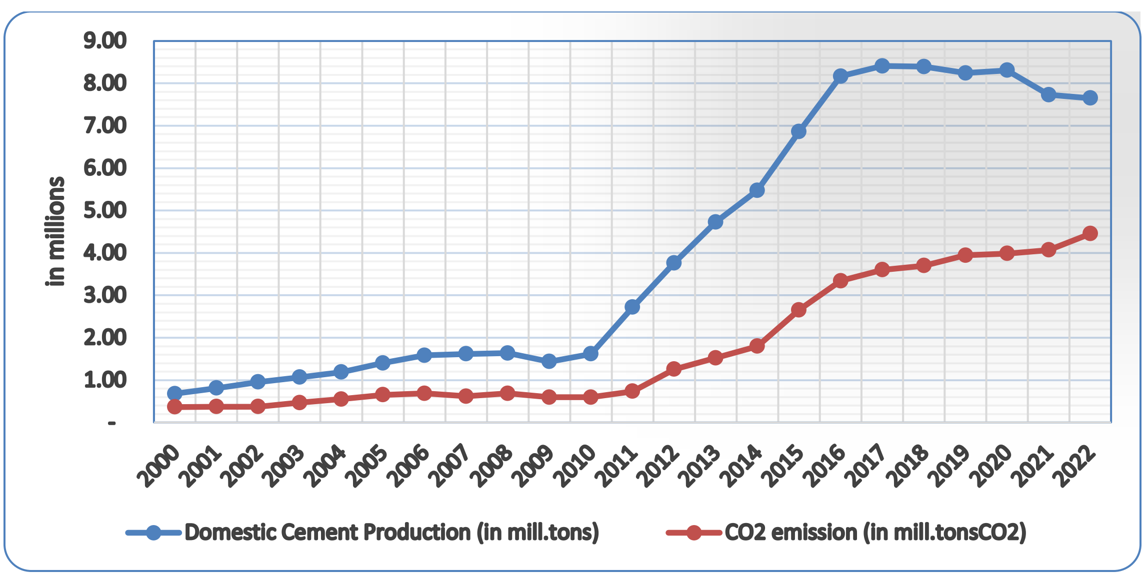
CHAPTER FOUR

4. RESULT AND DISCUSSIONS

4.1 Descriptive Statistics

The Figure 3 below depict that historical trend of cement productions in quantity of tons and amount of CO2 emissions in tonsCO2 in cement industry of Ethiopia. The two variables proportionally going rising pattern. However, unlike of the two variables in the same directions is not normal, in the sense of economic stance and environmental problems. In terms of productions has positive implications in economic development, while, in sense of concentration of carbon has negative implication on economy or environmental burden in future developments. As business interview by Ashenafi Endale (2020), the trend of cement output has been declining from the end of 2016, due to power problems during the dry rainy season of 2016, but power supply from Ethiopian electric utilities was begin after 2018, and then all cement resumed of producing. Aklilu, (2021) the COVID-19 affects cement industry of Ethiopia due to cement sector is consuming imported energy from abroad the restrictions of policy of different countries reduce production of cements. Therefore, the below figure gives as an entry point of pattern of production and carbon emissions in cement sectors in Ethiopia.

Figure 4: Trend of cement productions and CO2 emissions of Ethiopia



Source: Own computation using excel

4.2 Model Validation

Model validation is a key step in system dynamic approach since it establishes confidence in the model's output. It also the validation of the model evaluates whether the simulated model accurately fitted with behavioral or historical data of the model. Test of system dynamic model is based on reflections of reality, understanding, and importance of the system. The fundamental goal of system dynamics model validation is to build validation for the structure of the system in the model. When there is sufficient confidence in the structure of the model, the precision of the model behavior is evaluated (Barlas, 1996). Based on this literature the sequence for assessing the validity of the structure model is well perceived as below.

4.2.1 Direct Structure Tests

The direct structural test evaluates the validity of model equations individually by comparing them to available information with no simulation model. The empirical or theoretical structural test is used in this test. The empirical structural test compares model equations to a real system of knowledge. Theoretical structure compare model equations of general knowledge systems against existing the literature (Barlas, 1996), and both tests are employed as direct structure validation tests. According to Barlas, there are several sub direct structure tests such as structure verification tests, parameter verification tests, direct extreme condition tests, and dimensional consistency.

Structural verification tests compare theoretical structure tests to on literature knowledge. In general, the model's structure corresponds to the existing knowledge of the system, the literature or existing document report, books, media, other, etc. on the sector. The parameter verification test compares existing parameters to knowledge of the real system gathered from the literature, both conceptually and numerically (Senge & Forrester, 1980). The model's initial settings and parameters are based on real-world knowledge of the industry. Forrester and Senge (1980) define direct extreme condition testing as evaluating the model equations under extreme conditions and assessing acceptability of the result values against knowledge or anticipation of what will happen under similar conditions of a real-life system. The values are tested to ensure that the real relationship exists. Zero values are considered to ensure that the variables do not have unrealistic values. Setting the share energy of fossil fuel to zero, for example, and detecting the values that important variables are taking. It is normal to occur under typical operating conditions and is easy to foresee (see detail zero extreme condition test for some parameters appendix B). The final structure test is the dimensional consistency test, which is used to validate the dimensional analysis of model equations, unit specifications, and variable relationships. For simulations to be relevant and correct, units of each variable are introduced into the model. The dimensionality test for unit and model is satisfied in this model.

4.2.2 Structure Oriented Behavioral Tests

This behavioral test is used to indirectly validate the structure by applying certain behavior tests to model generated behavior patterns. Extreme conditions behavior testing involves assigning extreme values to parameters and comparing model generated behavior to real system observed behavior under the same extreme situations. Behavioral sensitivity test, modified behavioral prediction and boundary adequacy test (Barlas, 1996; Senge & Forrester, 1980). In this test when general modified behavior model is similar with simulated model the model become passes.

4.3.3 Model Behavioral Pattern Tests

Based on the two above mentioned tests, we may assess the validity of the model structure and gain enough or sufficient confidence in its structure. Accordingly, how the major historical or behavior patterns are observed in behavior of real system. To validate this structure of the model behavior data oriented used from 2000 to 2022 has simulated from historical data. The reference for data of cement productions is from Ministry of Mines, 2022 and CO2 emissions from global CO2 emission (Tiseo et al., 2023).

As Figure 4 depicted in below graph for simulated and historical data from 2000 to 2022 is shown. The main variables trying to show is cement productions and CO2 emissions as well as GDP and population which illustrated as below. Thus, the graph of historical and simulated model values almost the similar trends, when we compare it is likely, hence that we can proceed to next to step of model such as sensitivity analysis and scenario analysis.

Figure 5: Historical and simulated behavioral test for cement productions and CO_2 emission.

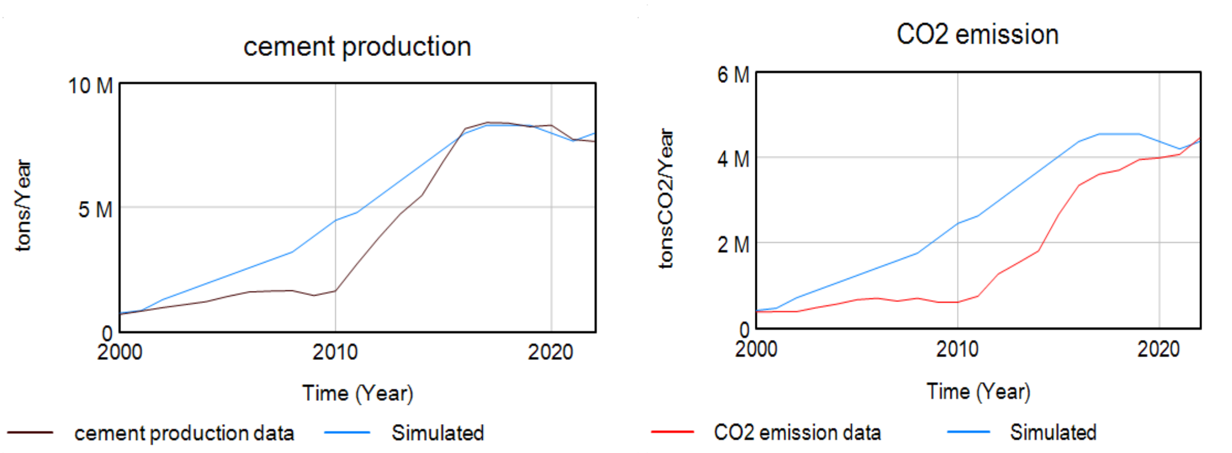
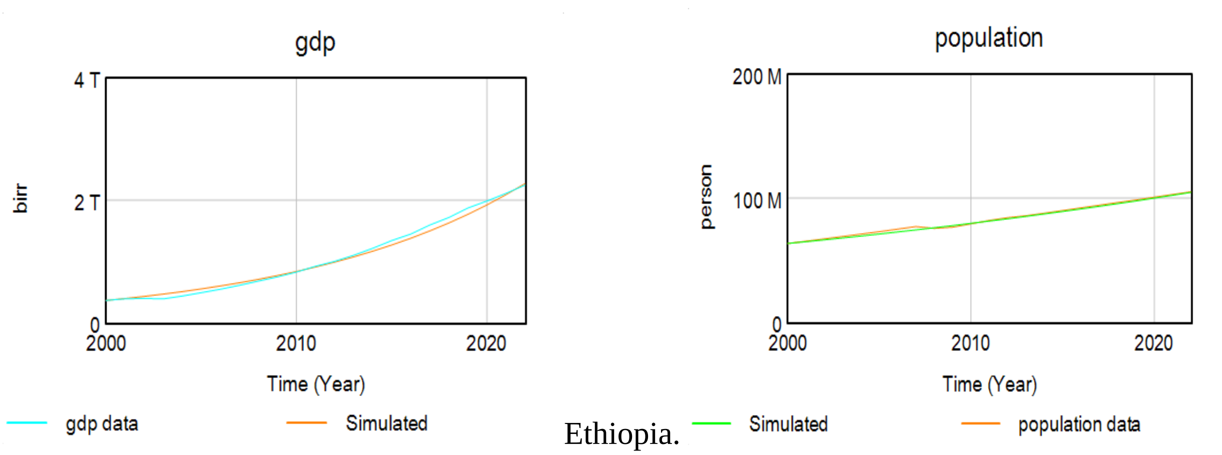


Figure 6: Historical and simulated behavioral test for GDP and population data of Ethiopia.



4.3 Sensitivity Analysis

In system dynamic model parameters are prone to uncertainty due to this testing sensitivity analysis is a crucial activity for ensuring the reliability and simulated result of the model (Hekimoğlu & Barlas, 2010). i.e., it determines how the results are sensitive to change the parameters and explore the effects of parameter uncertainty on the behavioral patterns of historical data by decreasing uncertainty of the parameter values. It also sensitivity analysis, is allows to determine which parameters are more important for simulation of output and desirable to existing policy by finding the highest leverage points among policy variables in the model (Bala et al., 2017). To determine the distribution range of the parameter values in sensitivity analysis, recommendable ranges used is between -20% and +20% distribution (Sweeney & Sterman, 2000).

Even though that, most studies taken with a 50% of the below or above the base case parameter value depicted in the simulated behavior of variables. Accordingly, sensitivity analysis of chosen variables is shown as below:

Figure 7: Sensitivity analysis for total energy consumption, fossil fuel energy, non-fossil fuel energy and CO_2 emission due to change in intensity of energy efficiency per tons.

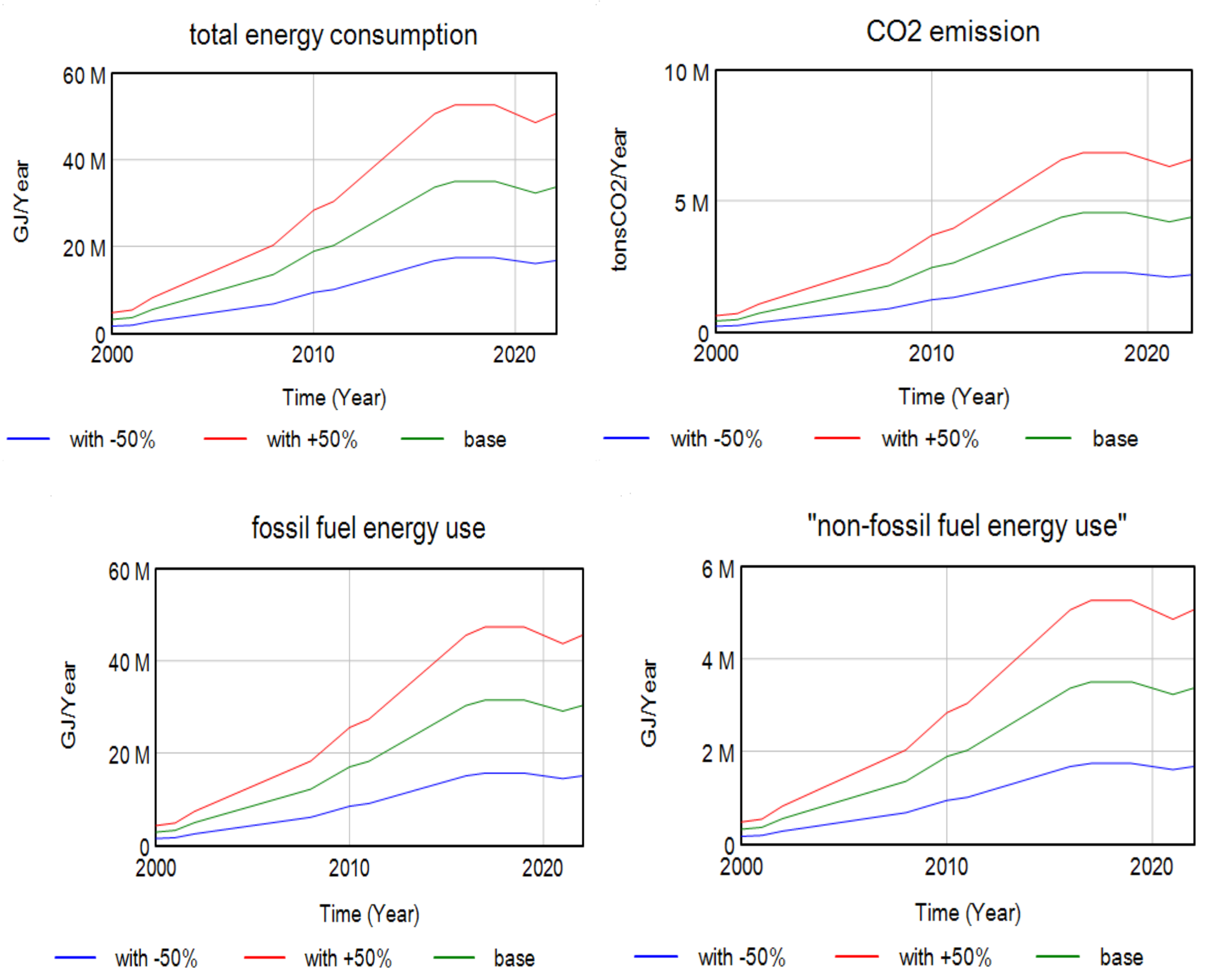


Figure 8: Sensitivity analysis of fossil fuel energy use, non-fossil fuel energy use, emission from fossil fuel, emission from non-fossil fuel and total CO2 emission due to change share of fossil fuel energy use.

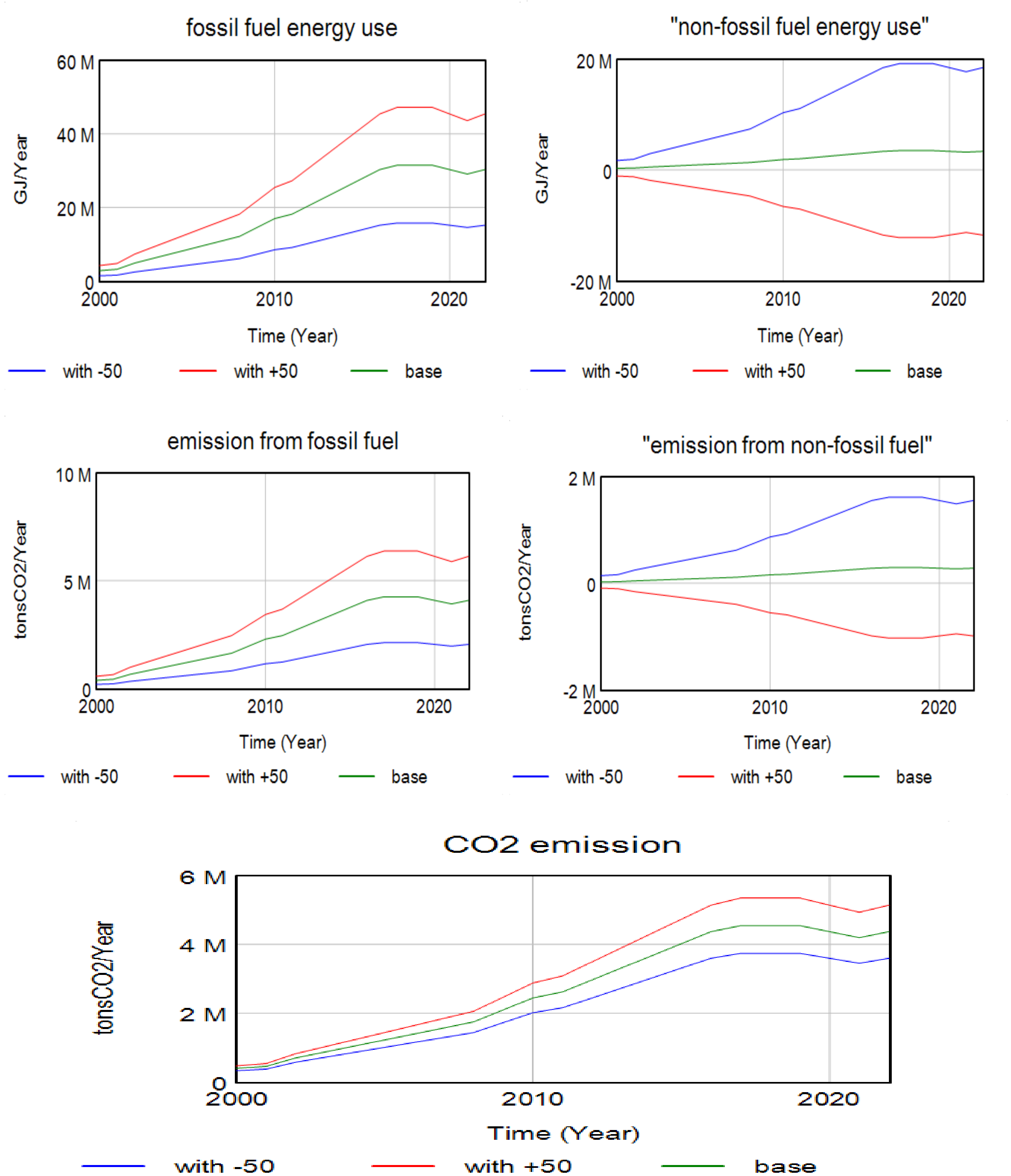
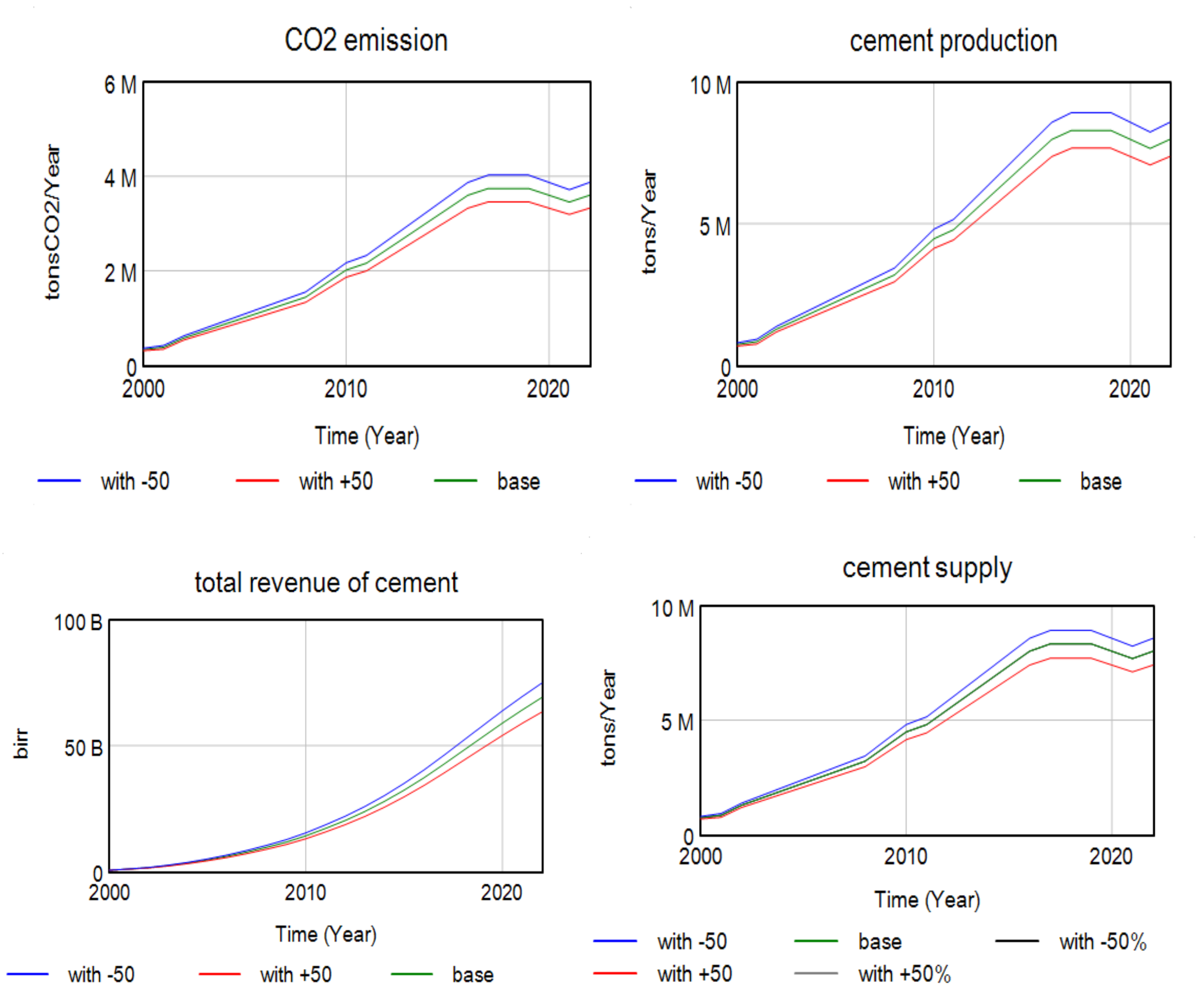


Figure 9: Sensitivity analysis of cement production, total CO2 emission, total revenue of cement industry and cement supply concentration to loss of production due to shortage of power per year.



As shown on the above Figure, sensitivity analysis for parameter of energy use/intensity, share of fossil fuel energy use and loss of productions due to shortage of power are the main parameters. The, parameter of energy intensity, share of fossil fuels energy use, losing of productions are policy scenario parameters that depicts the sensitivity of the cement productions, CO2 emissions, energy consumptions as well as demand of cement due to these parameters. While, variables cement productions are less sensitive parameter of productions loss due to various problem. In sensitivity analysis the parameter values determine how sensitive a model to change in structural of the model. So, analyzing the sensitivity of the parameter values used to find the leverage point for policy scenario implications. Hence, selected parameters are highly sensitive in affecting main variables of cement productions, carbon emissions, and also others wide size band of variables shown on the graph are indicate how they sensitive to the parameters.

4.4 Policy Scenario Analysis

Policy scenario analysis is the expectation of future prospective tasks to assist policy makers by investigating various policy options. Prior to future or upcoming developments of real-world policy implementations, policy possibilities were studied in system dynamic modeling analysis within simulations of alternative practice frameworks. Designing of policy is based on, when and how the policy scenario affects the problems in the system. For instance, when the cement productions and CO2 emissions are affected in strategic policy formulations by assessing trend performance of baseline scenario in this sector. In this context, baseline scenarios are used to examine the trend performance of cement productions and CO2 emissions in strategic policy formulations. Secondly, policy implications of how we influence problems in cement productivity and lowering CO2 emissions are generated. As a result, the purpose of this research is to simulate the interactions of cement sectors with economic, environmental, and social factors. Mainly, also the study aims to give a possible policy option that improves the productions system of cement, at the same time abatement of carbon emissions and quantitative forecasting in the sector.

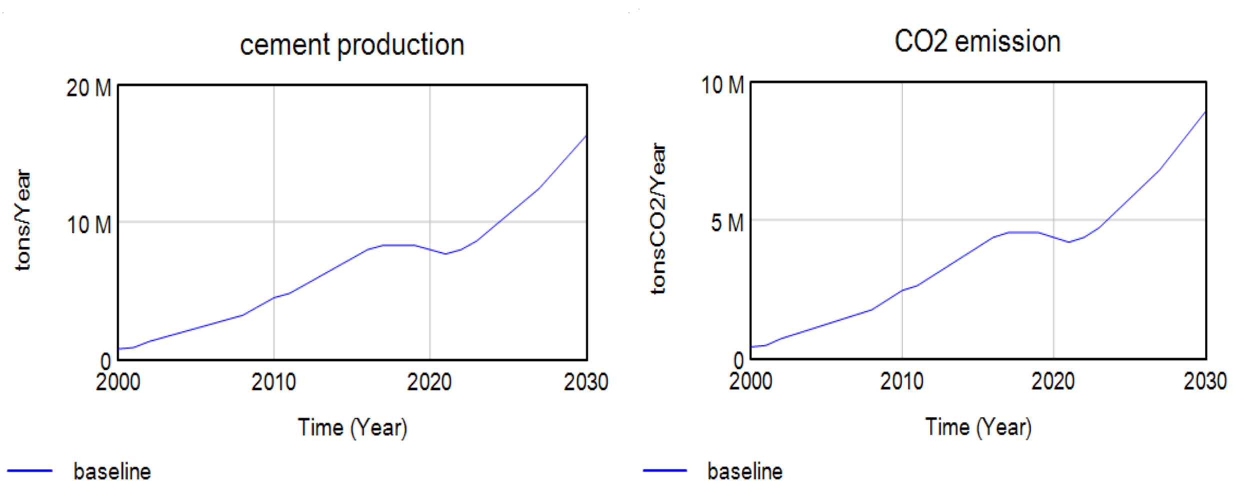
Accordingly, this study generates baseline and scenario for some important variables. The time span of simulated policy scenario for cement productions and CO2 emissions are ranges from 2022 to 2030 periods, whereas the actual simulated data are covered from 2000 to 2022. As shown below the policy scenarios are listed likely from baseline: -

4.4.1 Baseline Scenario

Baseline scenario is also known as reference or bench mark for other policy scenarios. The graph or data in baseline scenario follows past performance of the data trends. There are no policy intervention that influences with regard to analysis of baseline scenario, with respect to main variables of this study, the historical of total cement productions or CO2 emissions follow past or previous trend performance pattern of behavior. i.e. the baseline scenario of cement productions and CO2 emissions whether expecting increasing or decreasing, the data is allied to historical base year data.

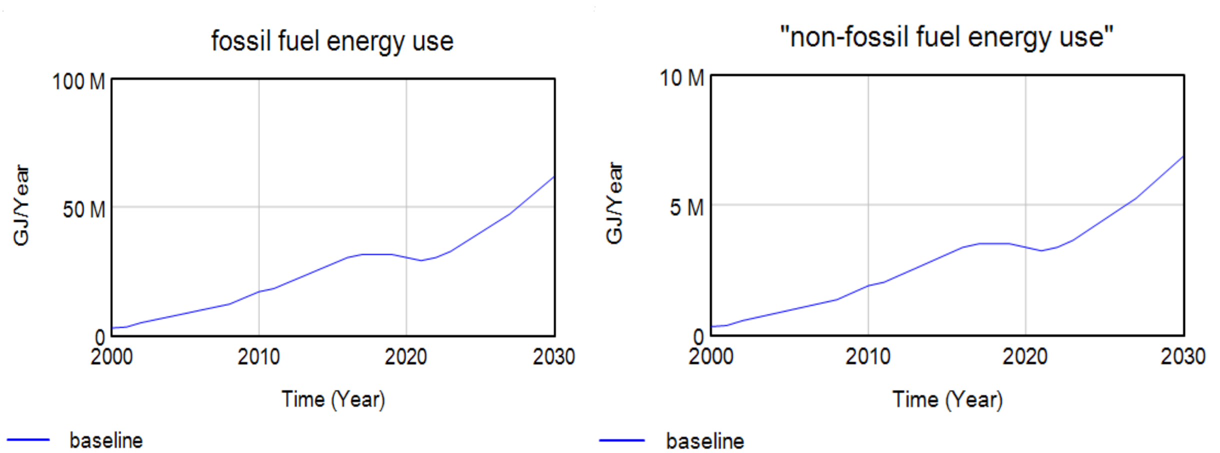
The below Figure 10 depict that, simulation model for cement production and CO2 emission under base case. Thus, the simulated data for two variables are forecasted until end of 2030 period and the graph is increasing trend patterns. This implicate that, when there are no policy interventions the concentration of CO2 emissions from cement sector is tremendously rising, it is 8.9 million tonsCO2 and 16.3 million tons of the Ethiopian cement productions at the end of 2030. This implicate that the concentrations CO2 emission become double as compared to current concentration of CO2 from cement industries, likely the productions also double. Therefore, increasing or improving the production of cement is better mode of economic system, likely by reducing the concentrations of CO2 emissions due to severe challenges in future climate changes. Hence, increasing productivity of cement sector is policy options to go further and why this study planning to state policy scenarios. It also the average annual growth rate of cement productions and CO2 emissions are equal for both 8.8%, it is growing simultaneously, since from 2022. About 104%, of CO2 emissions since 2022 to 2030, this makes a challenge for sustainability of environment, economic and social circumstances in Ethiopia as well as in world wide.

Figure 10: Baseline scenario tests for simulated of cement productions and CO emissions variables.



The below Figure 11, indicate that as above context it is baseline scenario for energy use of fossil fuels and non-fossil fuels which used as input for cement productions. The intensity of energy in cement sectors is more common, while shifting from higher CO2 concentrations of fossil fuels to non-fossil fuels or efficiently use of energy is important, in Ethiopia cement sectors. In Ethiopia the share of combustion of fossil fuels used an input in cement sectors are higher than non-fossil fuels as well as, about 60% total operational costs is energy, particularly fossil fuels about 90% (Ababa, 2013; Beressa & Saradhi, 2021; Tesema & Worrell, 2015). According to this simulation data, at end of 2030 also, the total energy consumption by cement sector is 68.6 million GJ, 61.8 million (90%) is combustion of fossil fuels and 6.9% million GJ (10%) is non-fossil fuels like electricity or alternative energy use.

Figure 11: Baseline scenario tests for simulated share of fossil fuel and non-fossil fuel energy use in cement sector.

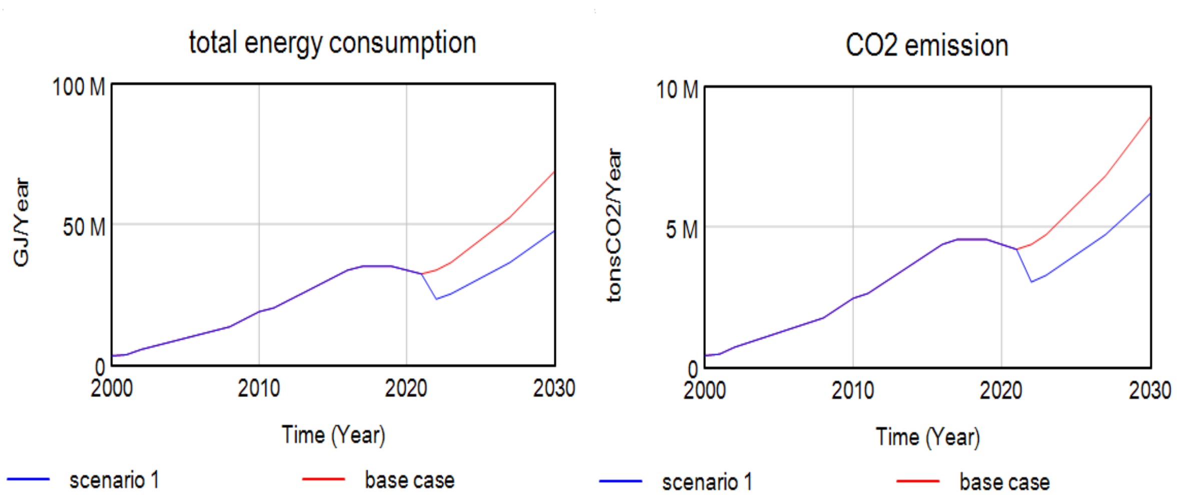


4.4.2 Policy Scenario 1: Intensity Energy Efficiency

Energy intensity of cement sector in Ethiopia is higher. Due to these the concentrations of CO2 emissions from cement industry is leading sector among Industrial Processes and Product Use (IPPU) sectors in Ethiopia (UNFCCC, 2022) about 51%. While, utilizing energy efficiency makes better by increasing the cement production, contrary reducing concentration of CO2 in Ethiopia (Melkie, 2022). According to Industrial energy efficiency and benchmarking report for cement sector by (Safarzadeh, Rasti-Barzoki, & Hejazi, 2020). The same like to this study, the policy scenario of parameter values used is reducing intensity of energy consumptions per tons of cement changes from 4.215GJ to 2.92GJ is made better to draw policy analysis. Utilizing energy efficiency in processing of cement manufacture is good as compared to effectiveness, costs, availability, environmental, economic and health impacts (Fadayini et al., 2021).

Energy consumptions in cement sector of Ethiopia is imported from abroad such as coal mostly imported from South Africa, fuel from other countries, this needs to have enough foreign exchange reserve availability, as well in terms of total operational costs, energy has higher share of costs. While, also due to saving energy consumptions, we can reduce concentrations of CO2 emissions and cost of energy consumptions (Tesema & Worrell, 2015). In other means, intensity of energy efficiency is adopting of modern dry processor technology in cement sector rather utilizing of old vertical shaft kiln (VSK) that process limestone is decomposed into calcium oxide of cement clinker particles under high temperature of cement productions and in which different reactions were made to form calcium carbonate or other reactions. The modern technology and mitigation of environmental pollution cement sector currently replacing VSK is using rotary kiln shaft manufacturing which consume less energy or energy save, environmental protections, and reliable in their (Mossie et al., 2023).

Figure 12: Simulated policy scenario 1 for energy efficiency impacts on energy consumptions and CO2 emissions.



Policy scenario 1 in this study is efficiently use of energy in cement sector of Ethiopia. As depicted on figure 12 above shifting energy from 4.215 GJ to 2.92 GJ per tons of cement consumptions made the above difference line. Implying that adopting of different modern technology among cement industry make them to save higher energy consumptions, which decrease the cost of productions indirectly, increase or improve productivity of cement and reduce the concentrations of CO2 emissions. As shown figure of the above when we applying scenario 1 consumptions of energy is the below base case line. Thus, they consume or with less energy intensity in producing of one ton's cement, the CO2 emissions are reduced. Quantitative value of total energy consumptions per year, at scenario 1 is 23.31million GJ to 47.55million GJ at end of 2022 and 2030 respectively. It is very less energy consumption than at baseline scenario of 33.65million GJ and 68.64 million GJ at the end of 2022 and 2030 respectively with the same amount of producing cement output in base case scenario. The increment of energy consumption from 2022 to 2030 at base case is 34.99 million GJ and 24.24 million GJ at scenario 1, almost 10 million GJ energy has to be savable energy.

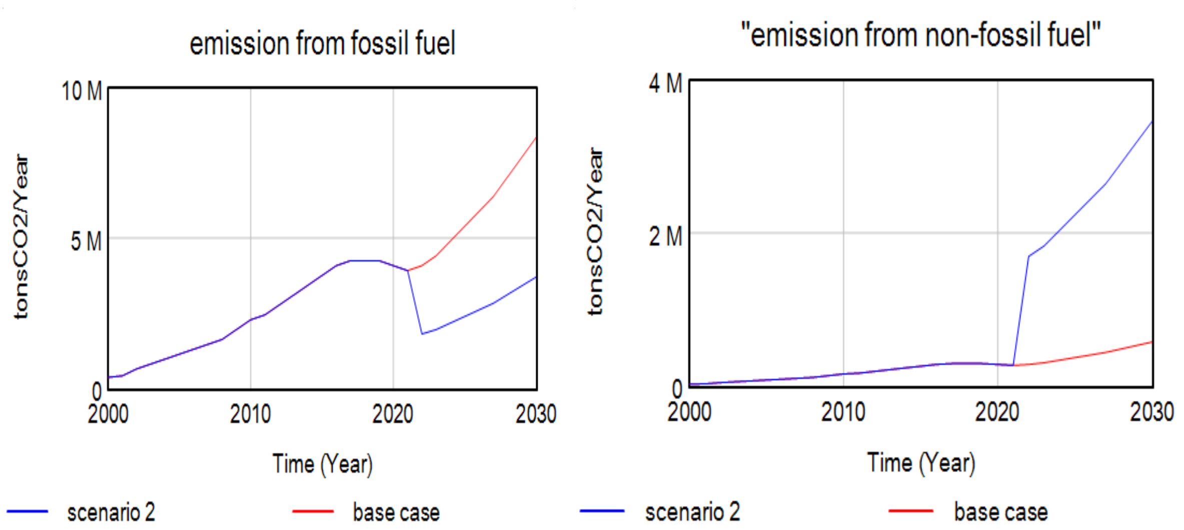
The second graph is concentration of CO2 emissions, it is obvious the higher energy saver or the one utilizes energy efficiently could emit less as compared to high energy intensive industries. This implies that, as depicted on the graph of CO2 emissions, the emission line for scenario 1 is less than base case of upper line. Yet there are higher concentrations of CO2 emissions in applying scenario 1, when compared to other stated scenarios. The CO2 emissions at scenario 1 are 4.37 million tonsCO2 and 8.92 million tonsCO2 in 2022 and at end of 2030 respectively. While, in base case 4.37 million tonsCO2 and 8.92 million tonsCO2 in 2022 and at end of 2030 respectively. The increment of the emissions is less in scenario 1 about 3.15 million tonsCO2 and 4.55million tonsCO2 in base. It will make almost 1.5 million tonsCO2 emission difference at end of 2030 when scenario 1 is implemented.

4.4.3 Policy Scenario 2: Alternative Energy Use

The second scenario is drawing of alternative energy use among cement industries in Ethiopia. In this scenario share of combustion of fossil fuels is almost 90%, while, other less percentage are electricity or biomass energy. Well known that combustion of fossil fuels is higher concentration of CO2 emissions and climate pollutant, so via shifting from utilizing of fossil fuels energy to non-fossil fuels or alternative energy use is an important. According to this scenario shifting of 90% of energy of fossil fuel combustion to non-fossil fuels, that means reducing current share of fossils fuels by less than half of current share about (40%) of fossil fuels combustion impacts on CO2 emission of cement sector in Ethiopia. According to Scandrett blog on January 04, 2017 impacts of renewable energy sources on environmental, the greenhouse gas (GHG) emissions from renewable energy of electricity 90% - 99% is less as compared to non-renewable energy of coal and causes 70% - 90% less pollutions. The non-renewable conventional energy sources of coal, fuel oil, and natural gas are crucial in economic development, despite the negative ecological effects. Unlikely, utilizing renewable energy sources can help to solve social, economic, and environmental problems with emitting less CO2. As a result, using of renewable energy sources in the cement industry can have a valuable on social, economic, and environmental benefit. For example, using of biomass, which originates from combustion of natural plants, solar or electricity use in cement sector is advantageous in terms of creating opportunities of labor or job creation, better health, income development, and demographic impacts (Ejiofor et al., 2020). In Ethiopia major cement factories utilizes combustions of fuels, this leads to high total operational costs of energy fuels by spending a million of dollar rather utilizing of energy efficiency or alternative energy effectively (Mossie, 2016). While, major is utilizing combustion of fossil fuels and some of them are partially use alternative energy sources. Therefore, the manufacturing cement sector in Ethiopia will adopt the utilizing of renewable energy by shifting from fossil fuel to alternative energy usage.

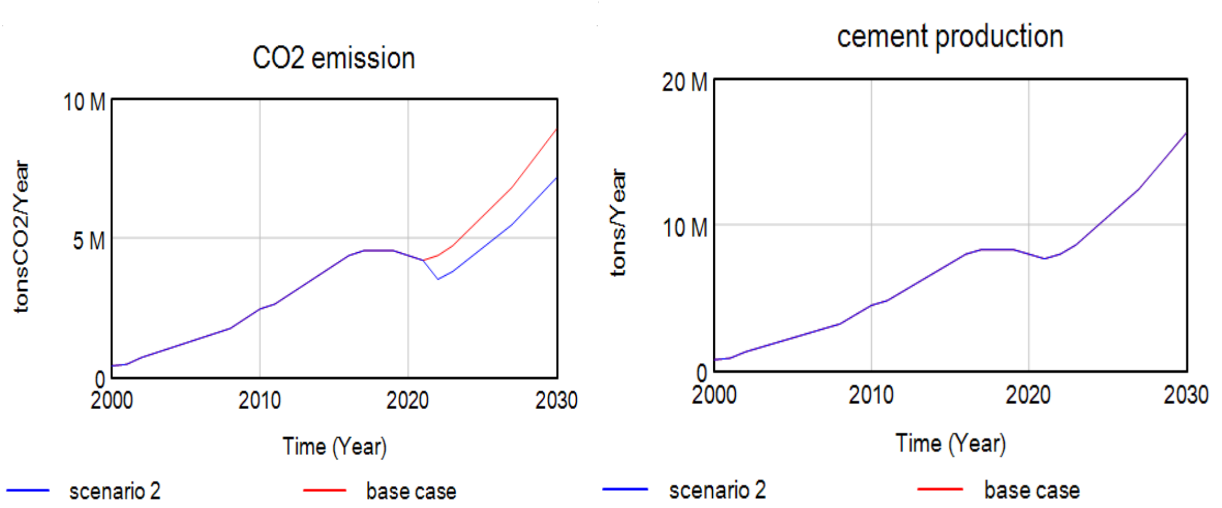
The second policy scenario is utilizing of alternative energy consumptions instead of combustion of fossil fuels among cement sectors in Ethiopia. Despite to the concentration to CO2 emissions in utilizing of fossil fuels, the costs they spend for fossil fuels is higher due to import energy fuels from other countries. While, utilizing of alternative renewable energy will make them to have less costs due available domestically, it also reduces concentrations of CO2 emissions and improve their productivity. So, shifting utilization of the large share of fossil fuels in Ethiopia cement sector (40%) to non-fossil fuels or alternative energy share (60%) will make a difference on CO2 emissions and cement productivity as well as impacts on other variables. Let we see further the difference on CO2 emissions in below Figure 13.

Figure 13: Simulated policy scenario 2 for alternative energy use impacts on share of fossil fuels and non-fossil fuels of CO2 emissions.



Application of alternative energy share of non-fossil fuels or renewable energy about 60% (0.6) share or 0.4% share for utilizing fossil fuel in cement sector of Ethiopia will made huge difference on concentrations of CO2 emissions. Accordingly, Figure 14 illustrates the concentration of CO2 emissions; it is less than base case scenario. In CO2 emissions figure scenario 2 is less CO2 concentrations than any other scenario stated. The concentrations of CO2 emissions are 2.55million tonsCO2 at 2022 and 5.21million tonsCO2 at the end of 2030 in this scenario. While, 4.37, 3.03 million tonsCO2 in 2022 base case & scenario 1 and 8.92, 6.18 million tonsCO2 in 2030 base case & scenario 1 respectively. The increment values of CO2 concentrations from base case and scenario 2 is 4.55 and 2.65 million tonsCO2 respectively difference. When we compare them scenario 2 is less CO2 concentration increment from 2022 to 2030 periods, with the same production of cement in base case.

Figure 14: Simulated policy scenario 2 for alternative energy use impacts on cement productions and CO2 emissions.



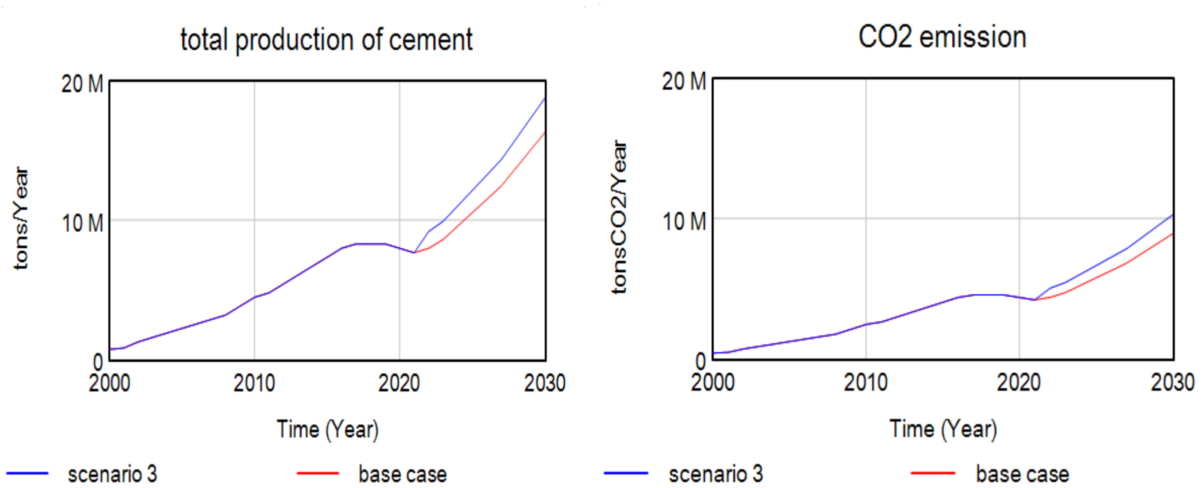
Therefore, in Ethiopian cement sector utilizing of alternative energy is more productive to improve the productions and reduce CO2 emissions. Having alternative energy such as electricity, biomass, other natural renewable energy, etc in turn by reducing the concentrations of CO2 emissions relative to in utilizing fossil fuels, it be possible to produce the same amount of quantity of base case.

4.4.4 Policy Scenario 3: Reducing Loss of Productions

The third important scenario is reducing loss of productions. This scenario is based Mughar cement factory (MCF) which is largest cement manufacture sector in Ethiopia, the loss of productions mainly due to shortage of power, due to spare part or an input, other problems, averagely they loss about 64,524.1 tons per year (Oqubay, 2015) this used as reference for all cement factories. In line with this, the policy scenario is making loss of productions due to various factor in production capacity of the factory is zero loss. i.e., zero loss, if there is no loss of productions among cement factory, then what will be happen on availability or supply of cement, revenue/profit in the factory, production capacity of the factories.

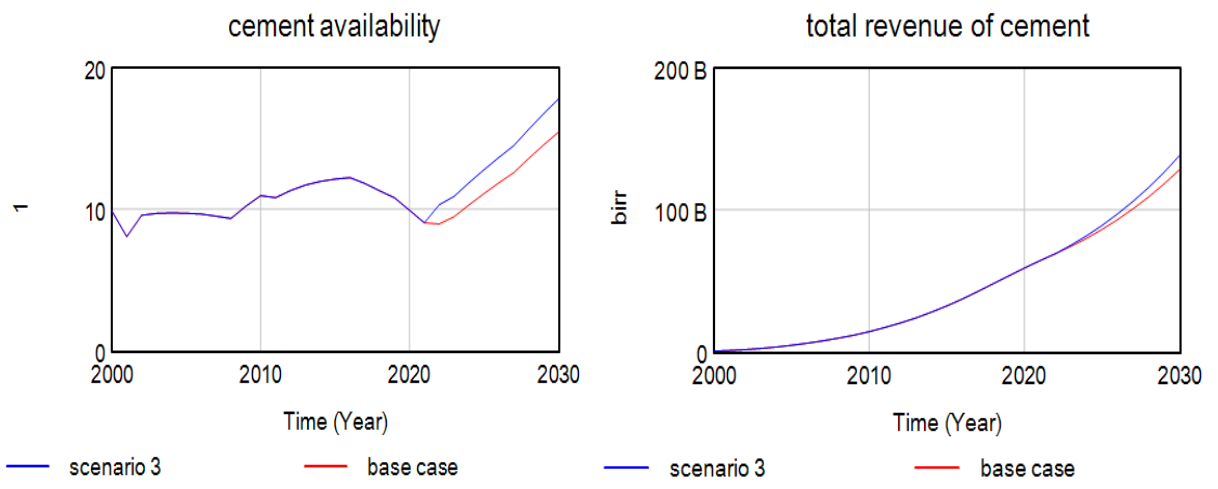
No doubt that the role of cement output in Ethiopia is higher and positive for economic development. Particularly, in construction sectors and infrastructure development as well for housing boundless significance. Despite that, due to increasing the demand for cement in both private and public consumptions the shortage of cement is anchor problem for infrastructure development and housing, likely due to shortage the impact on unit price of cement in Ethiopia sensitive issues. Therefore, to improve the shortage of cement, the factory will have to produce by full capacity, with almost zero or no loss of productions.

Figure 15: Simulated policy scenario 3 for reducing loss of cement productions impacts on total cement output and cement supply.



Reducing of loss of productions due to various problems such as shortage of power and other activity has negative impact on cement productivity. This scenario stated by making zero loss of cement productions and what impacts on total cement productions or cement supply, availability of cement and total revenue of cement industries as well as other variables. Reducing or zero loss of cement productions among cement indicate capacity or strength of the manufactures easily delivered or available of cement products and cement supply. As depicted in Figure 15 the scenario 3 is upper line in base case line. It increases the production output from 9.19 million tons to 18.75 million tons at end of 2030. It is higher as compared to base case or scenario 1, 2 cement outputs and the increments is 9.56 million tons. While, the other 8.30 million tons increment from 2022 to 2030.

Figure 16: Simulated policy scenario 3 for reducing loss of cement productions impacts on cement availability and total income.

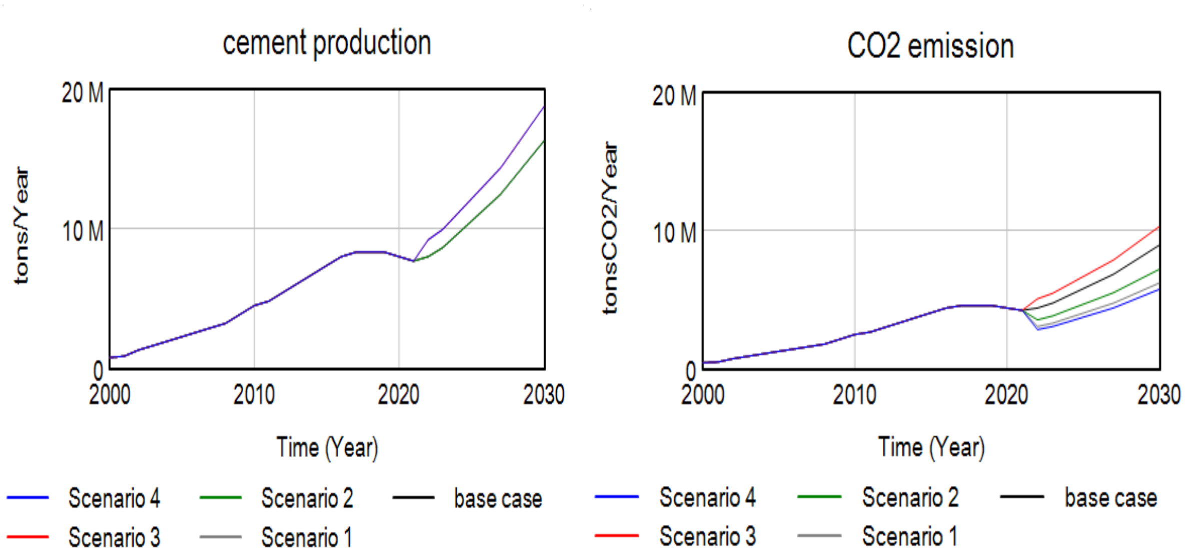


Availability of cement due to reducing loss of productions is made the increase the cement output into the market. As well as the income of cement productions become increasing. It will increase from 80.64 billion birr in 2022 to 149.71 billion birr in 2030, while it is 69.13 billion birrs in 2022 and 128.38 billion birr by end of 2030 in other scenarios. The increments 69.07 billion birr in scenario 3 and 59.25 billion in other scenarios, it is huge different about 10-billion-birr difference due to reducing or almost zero loss of their productions.

4.4.5 Policy Scenario 4: All Policy Scenarios:

Combining all of the above policy scenarios (scenarios 1, 2, and 3) will get a feasible and reliable outcome by affecting the main variables modeled in this study, either directly or indirectly. Utilizing of energy intensity efficiently, shifting to non-fossil fuels of energy resource/alternative energy use, reducing loss of production and controlling population growth rate policy variables either directly or indirectly it will affect CO2 emissions, improve productivity of cement, controlling of cement demand, increase availability of cement and increase the total income of cement factories.

Figure 17: A combinations of all policy scenarios to impact cement productions and concentration of CO2 emissions.



The above Figure 17 show that when all policy scenario applied what happened on main variables of cement productions and concentrations of CO2 emission in cement sector. Cement production under combination of all policy (scenario 4) is better than scenario base case, 1 and 2, while likely with scenario 3 (with zero losing of productions policy), because except scenario 4 & 3 all line is overlapped on lower line. While, the concentrations of CO2 emissions with scenarios 4 (combined) are also better than each applied of policy scenarios. That means, the reduction of the concentration cement sector in Ethiopia become significant, when scenario 4 policy is implemented, as evidenced by figure above the lowest blue line for variable of CO2 emission. Therefore, application of scenario 4 (combined all scenario policy) is significant in both productions of cements improvements and at the same time reducing of CO2 emissions in cement sector of Ethiopia (see numerically detail in below Tables).

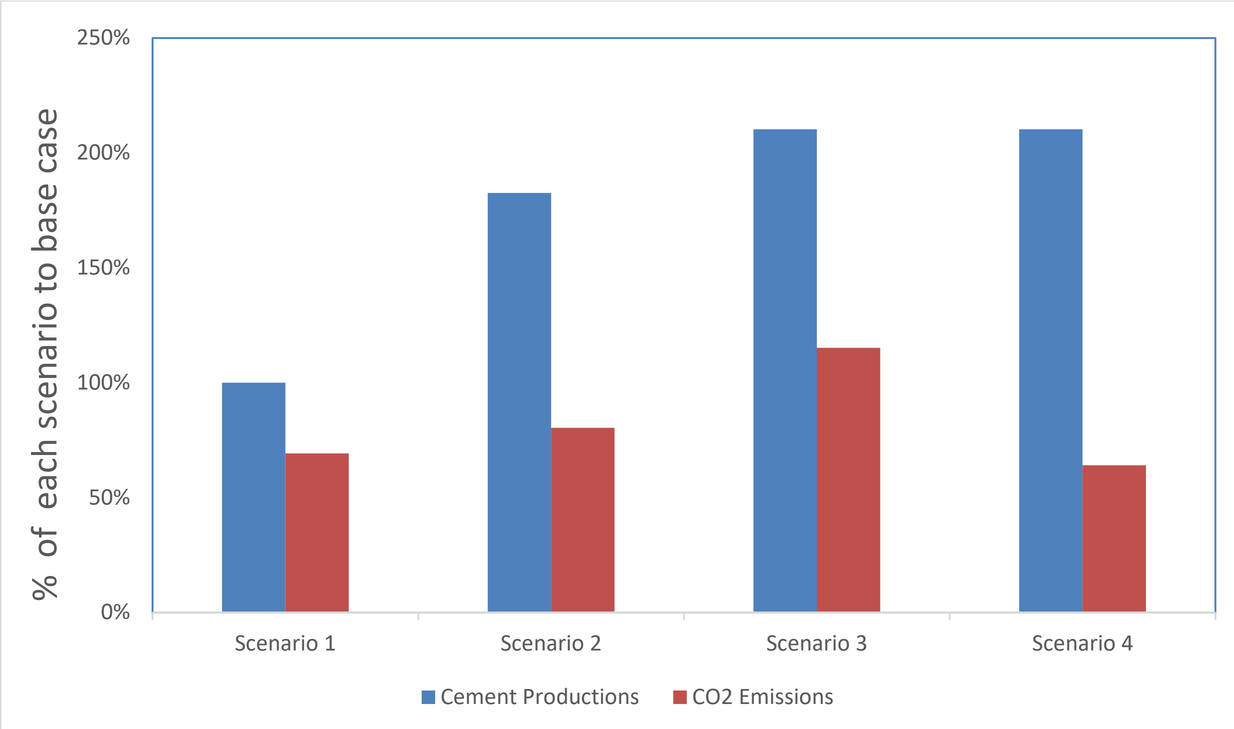
Table 2: Summary of all combinations of policy scenarios

Policy Options	Variables	Actual		Forecasted		Growth rate		
		2000	2022	2025(F)	2030(F)	2000 to 2022	2000 to 2030	2022 to 2030
Scenario Base case	Cement Production (in tons)	732,896	7,982,790	10,537,300	16,284,900	989%	2122%	104%
	CO2 Emission (in tonsCO2)	401,281	4,370,800	5,769,460	8,916,440			
Scenario 1	Cement Production (in tons)	732,896	7,982,790	10,537,300	16,284,900			
	CO2 Emission (in tonsCO2)	277,993	3,027,940	3,996,870	6,176,990			
Scenario 2	Cement Production (in tons)	732,896	7,982,790	10,537,300	16,284,900			
	CO2 Emission (in tonsCO2)	322,508	3,512,790	4,636,890	7,166,100			
Scenario 3	Cement Production (in tons)	843,970	9,192,610	12,134,300	18,752,900			
	CO2 Emission (in tonsCO2)	462,097	5,033,220	6,643,850	10,267,800			
Scenario 4	Cement Production (in tons)	843,970	9,192,610	12,134,300	18,752,900			
	CO2 Emission (in tonsCO2)	257,282	2,802,350	3,699,100	5,716,790			

Source: Own computation based on excel

For other selected variables, introducing of policy scenario (1, 2, 3, 4) impacts on other selected variables such as supply of cement, availability of cement, total revenue of cement sector, etc (See detail on appendix C).

Figure 18: Percentage share of each scenario to the base case scenario for Comparision.



Source: Own computation based on excel

As we realized with all policy scenarios, introduced on the above Figures and Tables all policy scenarios have significant sight to improve cement productions and reducing concentration CO2 emissions in cement sector. As shown on Histogram Figure 18 above for comparision of Scenarios, a combined policy of scenario 4 will better as compared to others policy scenarios 1, 2 and 3 that improve cement productions; at the same time, it reduces CO2 emission of cement sector in Ethiopia. Secondly, applications of policy scenario 2, which lifting consumptions of fossil fuels energy in cement sector to non- fossil fuels energy utilization has higher leverage point to reduce concentration of CO2 emissions and also scenario 3 and 1 are ranked from best to least.

According to the Ethiopian Panel on Climate Change (2015; Ansari, et al., 2013), improving of energy performance and productivity, while reducing environmental and climate change impact via the implementation of energy management system standards policy issues that can include; specific energy consumption per unit of production, energy system optimization. Improving energy efficiency should be handled in variety of aspects. For example, cross-cutting equipment and technologies such as compressed air and motors, which are used in the majority of plants and industrial industries, present well-documented prospects for improvement. Even more savings can be realized by fine-tuning the manufacturing process. Use of alternative fuels such as natural gas, biomass, and waste generated fuels such as tires, sewage sludge, and municipal solid wastes can minimize indirect emissions from using fossil fuels to heat the kiln. The country possesses an abundance of agricultural waste, such as coffee husk, which has yet to be properly utilized. These less carbon-intensive fuels have the potential to lower overall cement emissions by 18-24%.

Cement manufactures are one of ingredient for construction sector and positive to infrastructure developments in Ethiopia, while the concentration of CO2 emissions among industry sector in Ethiopia is higher, its over 50% shares of CO2 emissions due to high energy intensive(Melkie, 2022). Energy consumptions in manufacturing sectors of Ethiopia are over 85% utilizing fossil fuels, oil products and coal, while, 15% use renewable energy such as electricity, geothermal (Tiruye et al., 2021) as well as ministry of trade and industry on energy efficiency strategy for Ethiopian manufacturing by (sigra group, 2019). In cement sector of Ethiopia averagely 4.21GJ energy intensity used for producing one tons cement from both fossil fuels and non-fossil fuels energy (International Finance Corporation, 2017; Mossie et al., 2021). While, utilizing of energy efficiently, average standard is 2.92 GJ in industrial benchmarking report of cement use energy efficiency by (Osama, 2014; Safarzadeh, et al., 2020), it reduces concentrations of CO2 emissions. Energy efficiency in cement sectors of Ethiopia has various advantage such as reduce cost of energy, in reductions of Co2 emissions as well as improving of productivity.

Gashahun, (2020); the practice and potential replacing resource in Ethiopia that reduce high cost of operations as well as reduce CO2 emissions are utilizing of alternative energy resources in cement sectors such as coffee husk ash. As Mulatu, et al., (2018) cement sectors in Ethiopia technological very poor, they use vertical shaft kiln (VSK) for clinker production, this impacts on consuming of high energy imported and environmental pollutions changes. It reduces imported energy of cement sectors by domestically available energy resources that reduce costs, environmental burdens by promoting production of green cement.

International Finance Corporation, (2017); By re-processing waste from fuels, it is conceivable in SSA to replace fuels such as coal and natural gas in cement sectors. Increasing energy alternative fuels created from municipal solid waste, wood biomass and agricultural residue, sewage sludge (made from waste water), used tires and tire derived fuel possibilities in SSA to satisfy this high demand for cement.

According to Mossie (2016) study on Mugher cement in Ethiopia about 15%-20% of cost of energy due to in efficient of energy loss (high energy cost), not competitive with world market, causes environmental pollution, products with incomparable costs. So, improve of technology efficiency of energy is productive to more productive reduce CO2 emissions in Ethiopia (Tesema and Worrell, 2015). Use of alternative energy in cement sector is significant impact on improving productivity and in reductions of CO2 emissions.

CHAPTER FIVE

5. CONCLUSIONS AND POLICY IMPLICATIONS

5.1 Conclusions

The purpose of this study is to explore a key factor of cement productions and concentration of CO_2 emissions. Cement productions is an important construction sectors that have positive implications in economic, and social contributions by creating opportunity of job creations and others. Economically, it is a backbone of economic development such as to build Dam, roads, real state, built commercial property as well as for residential of housing. While, the concentration of CO_2 emission from cement sector has negative impacts on social and economic developments by polluting the CO_2 emission to climate. Cement sector is adversely affecting economic growth of many countries like Ethiopia, due to the economy of developing like Ethiopia is dependent on agricultural sectors. In real world the concentrations of CO_2 during manufacturing or processing of cement comes due to energy intensive process industries especially during clinker productions. So, it requires to lift to the modern technology which reduce energy intensity in clinker productions or other processing that break down different raw material into small scale such as limestone, clay and marl this made high temperature by using consuming high energy.

Therefore, with application of system dynamic model, the direct and indirect effect of endogenous variables that quantify both conceptually/qualitative and quantitative interactions of various effects. In cement sector increasing of productivity by adopting of different policy system, conversely, reducing of the CO_2 emissions is core issue. Cement sector in Ethiopia has problem of energy consumptions, old processing machine and other processing material, loss of the productions, etc. The study model based on the causal loop diagram and stock-flow diagram of the model captures cement demand, energy consumptions, cement supply and demand, cement output, makes feedback loop.

System dynamics modeling that captures the dynamicity and complexity has been applied to the cement industry and the environment, in particular the CO_2 emissions. In cement sector consumptions of fossil fuel combustion fully utilizing energy, increase of cement demand, loss of productions, energy intensity has some variables that affects the productivity and concentrations of CO_2 emissions. The study also simulates the actual or historical data model and simulated model, which used to model validation behavioral tests. This test used pre steps to model or find sensitivity analysis and policy scenario has been adopted that improves productivity of cement and reductions of CO2 emissions.

The model has passed the step of the validations of behavioral tests using structure model. sensitivity analysis for parameter values also tested to find policy variables or find the leverage points for policy experiment. Finally, after analysis of sensitivity, different policy scenario is assumed to implicate, that improves cement output and at the same time reducing of CO2 emissions. Four policy scenarios were adopted including combinations of all policy scenario.

Based on scenario policy cement output and CO2 emission until 2030 were simulated or forecasted as well as for other variables. Energy efficiency, alternative renewable energy use, reducing or zero loss of cement production was adopted. But, the highest leverage point among the policy scenario is use of alternative energy use in cement sector of Ethiopia improve the productivity of cement and abatement of CO2 emissions. While, the higher cement productivity, the less CO2 emissions at scenario 4 were significant policy stance. Accordingly, applying of all scenario policy has improved productivity of cement and reduces concentration of CO2 emissions in cement sector of Ethiopia.

5.2 Policy Implications

This study will forward policy based on scenario introduced: -

- Encourage cement manufacturing sector to use of waste materials as alternative fuel and waste heat recovery for electricity generation. i.e., increasing electricity generation from renewable energy sources for cement manufacturing sectors due to electric power emits is very less. For instance, reduce VAT tax, giving priority to get credit from finance sectors. i.e., Government has to give incentive scheme financially (credit, foreign currency) or non-financially (award, privilege or recognitions).
- Leapfrogging to modern technology and efficient energy utilization in cement manufacturing industry.

Generally, Ethiopia has natural resource availability, so using of renewable energy resource such as biomass, with the ability to generate electricity from hydropower, wind, solar, and geothermal sources, they can reduce environmental burden of carbon emission comes from cement sector, reduce high costs of energy in cement sectors, improve productivity of cement as well as reduce production loss due to shortage of power or imported energy problems. In general energy efficiency or alternative energy sources have economic and environmental benefit by producing of no greenhouse gas emissions from fossil fuels and energy. As a result, a combination of all policy scenario options, will more benefits to improve productivity of cement and reduce concentrations of CO_2 emissions in cement sector of Ethiopia.

References

Aboul-Atta, T. A. L., & Rashed, R. H. (2021). Analyzing the relationship between sustainable development indicators and renewable energy consumption. *Journal of Engineering and Applied Science*, *68*(1), 1-16.

Aklilu, T. (2021). *Effect Of Covid-19 On Cement Industry Economic Performance: The Case of Dangote Cement (Ethiopia) Plc* (Doctoral Dissertation, St. Mary's University).

Aktar, M. A., Alam, M. M., & Al-Amin, A. Q. (2021). Global economic crisis, energy use, CO2 emissions, and policy roadmap amid COVID-19. *Sustainable Production and Consumption*, *26*, 770-781..

Aldred, D. (2012). Urbanization: A major driver of infrastructure spending. *Citi Perspectives*, *6*, 36-39..

Allen, C., & Clouth, S. (2012). Green economy, green growth, and low-carbon development–history, definitions and a guide to recent publications. *Division for Sustainable Development, Department of Economic and Social Affairs, United Nations, New York, August. Division for Sustainable Development, Department of Economic and Social Affairs, United Nations, New York, August.,(1)*, 1-63..

Anand, S., Vrat, P., & Dahiya, R. P. (2006). Application of a system dynamics approach for assessment and mitigation of CO2 emissions from the cement industry. *Journal of environmental management*, *79*(4), 383-398.

Ansari, N., & Seifi, A. (2013). A system dynamics model for analyzing energy consumption and CO2 emission in Iranian cement industry under various production and export scenarios. *Energy Policy*, *58*, 75-89..

Antal, M. and J. C. J. C. p. Van Den Bergh (2016). "Green growth and climate change: conceptual and empirical considerations." 16(2): 165-177.

Ashenafi Endale, 2020; "Regulation Banning New Investments in the Cement Industry under Amendment"bussines interview/ September 30 2020 No. 90.

Bala, B. K., Arshad, F. M., Noh, K. M., Bala, B. K., Arshad, F. M., & Noh, K. M. (2017). Systems thinking: system dynamics. *System Dynamics: Modelling and Simulation*, 15-35.

Barbrook-Johnson, P., & Penn, A. S. (2022). *Systems Mapping: How to build and use causal models of systems* (p. 186). Springer Nature.

Barcelo, L., Kline, J., Walenta, G., & Gartner, E. (2014). Cement and carbon emissions. *Materials and structures*, *47*(6), 1055-1065.

Barlas, Y. (1996). Formal aspects of model validity and validation in system dynamics. *System Dynamics Review: The Journal of the System Dynamics Society*, *12*(3), 183-210.

Bassi, A. M., & Costantini, V. (2020). Roma Tre), Giorgia Sforna (SEEDS and ENEA).

Benhelal, E., Zahedi, G., Shamsaei, E., & Bahadori, A. (2013). Global strategies and potentials to curb CO2 emissions in cement industry. *Journal of cleaner production*, *51*, 142-161.

Beressa, L., & Saradhi, B. V. (2021). Life Cycle Assessment of Ethiopian Cement Manufacturing: A Potential Improvement on the Use of Fossil Fuel in Mugher Cement Factory. *Applied Environmental Research*, *43*(4), 100-112.

Berhe, A., Alemayehu, T., & Fortuin, K. J. P. (2014). Environmental impact study of cement factory using a multi-criteria analysis: Evidence from Messebo Cement Factory, Ethiopia. *Developing Country Studies*, *4*(24), 151-161.

Bernstein, L., Roy, J., Delhotal, K. C., Harnisch, J., Matsuhashi, R., Price, L., ... & Sheinbaum Parado, C. (2007). *Industry* (No. LBNL-814E). Lawrence Berkeley National Lab.(LBNL), Berkeley, CA (United States).

Biswas, P. K., Kibria, M. H., Hasan, J., & Khan, M. M. A. (2020). Productivity determinants of cement industries and their impacts assessment: a survey-based approach. *Journal of Production Systems and Manufacturing Science*, *1*(2), 11-22.

Borenstein, M. (2022). Comprehensive meta-analysis software. *Systematic reviews in health research: meta-analysis in context*, 535-548.

Brander, M., Sood, A., Wylie, C., Haughton, A., & Lovell, J. (2011). Technical Paper| Electricity-specific emission factors for grid electricity. *Ecometrica, Emissionfactors. com*.

Brown, G. S., & Campbell, D. P. (1948). *Principles of servomechanisms: dynamics and synthesis of closed-loop control systems*. J. Wiley.

Burange, L. G., & Yamini, S. (2009). Performance of the Indian cement industry: The competitive landscape. *Artha Vijnana*, *51*(3), 209.

Cantini, A., Leoni, L., De Carlo, F., Salvio, M., Martini, C., & Martini, F. (2021). Technological energy efficiency improvements in cement industries. *Sustainability*, *13*(7), 3810.

CHANGE, E. P. O. C. (2015). FIRST ASSESSMENT REPORT WORKING GROUP II-CLIMATE CHANGE IMPACT, VULNERABILITY, ADAPTATION AND MITIGATION V.

Chen, C., Habert, G., Bouzidi, Y., & Jullien, A. (2010). Environmental impact of cement production: detail of the different processes and cement plant variability evaluation. *Journal of Cleaner Production*, *18*(5), 478-485.

Chen, J. M., Yu, B., & Wei, Y. M. (2018). Energy technology roadmap for ethylene industry in China. *Applied Energy*, *224*, 160-174.

Citaristi, I. (2022). International Energy Agency—IEA. In *The Europa Directory of International Organizations 2022* (pp. 701-702). Routledge.

Coito, F., & Allen, D. (2007). Why industrial customers don't implement cost-effective energy efficiency opportunities: A closer look at California'cement industry. *Saving energy-just do it*.

Costanza, R., & Ruth, M. (1998). Using dynamic modeling to scope environmental problems and build consensus. *Environmental management*, *22*, 183-195.

Coyle, G. (2000). Qualitative and quantitative modelling in system dynamics: some research questions. *System Dynamics Review: The Journal of the System Dynamics Society*, *16*(3), 225-244.

Dasanayaka, S. W. S. B., & Sardana, G. D. (2017). Identification of factors affecting productivity of small and medium scale enterprises in Sri Lanka: a case study on rubber manufacturing sector. *World Review of Entrepreneurship, Management and Sustainable Development*, *13*(4), 389-417.

Dupar, M., Lovell, E., Walmsley, O., Diwakar, V., Balcou, C., Tesfaye, B., & Krishnan, V. (2021). Resilient Generation: supporting young people's prospects for decent work in the drylands of east and west Africa.

Dr. Amr Osama, (2014); Industrial Energy Efficiency: Benchmarking Report for Cement Sector.

Ejiofor, O. S., Okoro, P. A., Ogbuefi, U. C., Nnabuike, C. V., & Okedu, K. E. (2020). Off-grid electricity generation in Nigeria based on rice husk gasification technology. *Cleaner Engineering and Technology*, *1*, 100009.

El Haggar, S. M. (2005). Rural and developing country solutions. In *Environmental solutions* (pp. 313-400). Academic Press.

Estifanos, S., & Degefa, A. (2012). Assessing the effect of cement dust emission on the physicochemical nature of soil around Messebo area, Tigray, North Ethiopia. *International Journal of Economic and Environmental Geology*, *3*(2), 12-20.

Ethiopian panel on Climate Change (2015), First Assessment Report, Working Group II Industry, Transport and Infrastructure, Published by the Ethiopian Academy of Sciences.

Fadayini, O. M., Madu, C., Oshin, T. T., Obisanya, A. A., Ajiboye, G. O., Ipaye, T. O., ... & Kingsley, N. A. (2021). Energy and Economic Comparison of Different Fuels in Cement Production. *Cement Industry-Optimization, Characterization and Sustainable Application*.

Fayomi, G. U., Mini, S. E., Fayomi, O. S. I., & Ayoola, A. A. (2019, September). Perspectives on environmental CO2 emission and energy factor in Cement Industry. In *IOP Conference Series: Earth and Environmental Science* (Vol. 331, No. 1, p. 012035). IOP Publishing.

Forrester, J. W. (1994). System dynamics, systems thinking, and soft OR. *System dynamics review*, *10*(2-3), 245-256.

Forrester, J. W., & Albin, S. (1997). Building a System Dynamics Model Part 1: Conceptualization. *Massachusetts Institute of Technology: Cambridge, MA, USA*.

Fry, M. (2011). From crops to concrete: urbanization, deagriculturalization, and construction material mining in Central Mexico. *Annals of the Association of American Geographers*, *101*(6), 1285-1306.

Ganum, M. P., & Thakoor, M. V. V. (2021). *Post-Covid-19 Recovery and Resilience: Leveraging Reforms for Growth and Inclusion in Sub-Saharan Africa*. International Monetary Fund.

Gartner, E. (2004). Industrially interesting approaches to "low-CO2" cements. *Cement and Concrete research*, *34*(9), 1489-1498.

Gashahun, A. D. (2020). Assessment on cement production practice and potential cement replacing materials in Ethiopia. *Assessment*, *12*(1).

Greenstone, M., Reguant, M., Ryan, N., & Dobermann, T. (2019). Evidence paper.

Habert, G., Billard, C., Rossi, P., Chen, C., & Roussel, N. (2010). Cement production technology improvement compared to factor 4 objectives. *Cement and Concrete Research*, *40*(5), 820-826.

Handiso, B. (2015). The Possibility of Greenhouse Gas Mitigation in Ethiopian Cement Industry.

Hannah Ritchie, Max Roser and Pablo Rosado (2020) - "CO_2 and Greenhouse Gas Emissions". Published online at OurWorldInData.org. Retrieved from: 'https://ourworldindata.org/co2-and-greenhouse-gas-emissions' [Online Resource].

Hekimoğlu, M., & Barlas, Y. (2010). Sensitivity analysis of system dynamics models by behavior pattern measures. *Retrieved on March*, *18*, 2015.

Ige, O. E., Duffy, K. J., Olanrewaju, O. A., & Collins, O. C. (2022). An Integrated System Dynamics Model and Life Cycle Assessment for Cement Production in South Africa. *Atmosphere*, *13*(11), 1788.

Imbabi, M. S., Carrigan, C., & McKenna, S. (2012). Trends and developments in green cement and concrete technology. *International Journal of Sustainable Built Environment*, *1*(2), 194-216.

International Finance Corporation. (2017). *Increasing the use of alternative fuels at cement plants: International best practice*. World Bank.

Introduction to the Ethiopian Cement Market. Essays24.com. Retrieved 01, 2011, fromhttps://www.essays24.com/essay/Introduction-To-The-Ethiopian-Cement Market/30724.html.

Islam, M. A., & Khadem, M. M. R. K. (2013). Productivity determinants in Oman construction industry. *International Journal of Productivity and Quality Management*, *12*(4), 426-448.

Jordan, P. G. (2014). *Solar energy markets*. Elsevier, Incorporated.

Jordan, P. G. (2014). *Solar energy markets*. Elsevier, Incorporated.

Kanianska, R. (2017). Green growth and green economy. *Banská Bystrica, Blianum*, 11-20.

Kermeli, K., Edelenbosch, O. Y., Crijns-Graus, W., van Ruijven, B. J., Mima, S., van Vuuren, D. P., & Worrell, E. (2019). The scope for better industry representation in long-term energy models: Modeling the cement industry. *Applied Energy*, *240*, 964-985.

Kim, J. K., Kim, J. S., Ha, G. J., & Kim, Y. Y. (2007). Tensile and fiber dispersion performance of ECC (engineered cementitious composites) produced with ground granulated blast furnace slag. *Cement and concrete research*, *37*(7), 1096-1105.

Koelling, P., & Schwandt, M. J. (2005, December). Health systems: A dynamic system-benefits from system dynamics. In *Proceedings of the Winter Simulation Conference, 2005.* (pp. 7-pp). IEEE.

Lannon, C. J. S. T. (2012). Causal loop construction: the basics. *The Systems Thinker*, *23*(8), 7-8.

Lei, Yu and others, 'Primary Air Pollutants and CO2 Emissions from Cement Production in China', in Chris P. Nielsen, and Mun S. Ho (eds), *Clearer Skies Over China: Reconciling Air Quality, Climate, and Economic Goals* (Cambridge, MA, 2013; online edn, MIT Press Scholarship Online, 23 Jan. 2014), https://doi.org/10.7551/mitpress/9780262019880.003.0005, accessed 19 June 2023.

Liu, J., Tong, D., Zheng, Y., Cheng, J., Qin, X., Shi, Q., ... & Zhang, Q. (2021). Carbon and air pollutant emissions from China's cement industry 1990–2015: trends, evolution of technologies, and drivers. *Atmospheric chemistry and physics*, *21*(3), 1627-1647.

Ludwig, F., van Scheltinga, C. T., Verhagen, J., Kruijt, B., van Ierland, E., Dellink, R., ... & de Bruin, K. (2007). Climate change impacts on developing countries-EU accountability.

Macmillan, R. H. (2016). *An introduction to the theory of control in mechanical engineering*. Cambridge University Press.

Matsumoto, T., & Crook, J. (2021). Sustainable and inclusive housing in Ethiopia: a policy assessment.

Melkie, M. E. (2022). Green Industrialisation in Ethiopia.

Miller, S. A., Habert, G., Myers, R. J., & Harvey, J. T. (2021). Achieving net zero greenhouse gas emissions in the cement industry via value chain mitigation strategies. *One Earth*, *4*(10), 1398-1411.

Mossie, A. T. (2016). Energy Utilization Assessment In Ethiopian Industries (Case Study At Mughar Cement Factory (Mcf)). *International Journal Of Engineering Research*.

Mossie, A. T., Khatiwada, D., Palm, B., & Bekele, G. (2023). Investigating energy saving and climate mitigation potentials in cement production–A case study in Ethiopia. *Energy Conversion and Management*, *287*, 117111.

Mossie, A. T., Wolde, M. G., Beyene, G. B., Palm, B., & Khatiwada, D. (2021, October). A Comparative Study of the Energy and Environmental Performance of Cement Industries in Ethiopia and Sweden. In *2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)* (pp. 1-5). IEEE.

Mulatu, D., Habte, L., & Ahn, J. W. (2018). The Cement Industry in Ethiopia. *에너지공학*, *27*(3), 68-73.

Muthukrishnan, A. (2011). Productivity in cement industry A study with special reference to Tamilnadu. *Master Degree Thesis. University Madurai Tamil Nadu, India*.

Nehdi, M., Rehan, R., & Simonovic, S. P. (2004). System dynamics model for sustainable cement and concrete: novel tool for policy analysis. *Materials Journal*, *101*(3), 216-225.

NEP, 2011, Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication - A Synthesis for Policy Makers, www.unep.org/greeneconomy

Newell, R., Raimi, D., Villanueva, S., & Prest, B. (2021). Global energy outlook 2021: pathways from Paris. *Resources for the Future*, *8*.

Oqubay, Arkebe, 'Cementing Development? Uneven Development in an Import-Substitution Industry', *Made in Africa: Industrial Policy in Ethiopia* (Oxford, 2015; online edn, Oxford Academic, 20 Aug. 2015)https://doi.org/10.1093/acprof:oso/9780198739890.003.0004, accessed 19 June 2023.

Ritchie, H., Roser, M., & Rosado, P. (2020). CO_2 and greenhouse gas emissions. *Our world in data*.

Safarzadeh, S., Rasti-Barzoki, M., & Hejazi, S. R. (2020). A review of optimal energy policy instruments on industrial energy efficiency programs, rebound effects, and government policies. *Energy Policy*, *139*, 111342.

Samdariya, N., Sharma, A., & Shukla, R. K. Impact of Cement Plant on Rural Economy: A Review.

Sattari, S., & Avami, A. (2007). Assessment of energy-saving opportunities of cement industry in Iran. In *Proceeding of the 3rd IASME/WSEAS International Conference on Energy, Environment, Ecosystems and Sustainable Development* (pp. 585-593).

Scandrett G.blog on January 04, (2017) : https://www.adecesg.com/resources/blog/environmental-impacts-of-renewable-energy-sources/.

Schlorke, S., Tu, L., Stec, M., Villar Mallagray, J., & Kaleem, H. (2020). The impact of covid-19 on the cement industry.

Senge, P. M., & Forrester, J. W. (1980). Tests for building confidence in system dynamics models. *System dynamics, TIMS studies in management sciences*, *14*, 209-228.

Subramanian Narayanan, (2016); Environmental and Social Impacts of Cement Industries.

Sweeney, L. B., & Sterman, J. D. (2000). Bathtub dynamics: initial results of a systems thinking inventory. *System Dynamics Review: The Journal of the System Dynamics Society*, *16*(4), 249-286.

Syverson, C. (2011). What determines productivity?. *Journal of Economic literature*, *49*(2), 326-365.

Tedeschi, L. O., Nicholson, C. F., & Rich, E. (2011). Using System Dynamics modelling approach to develop management tools for animal production with emphasis on small ruminants. *Small Ruminant Research*, *98*(1-3), 102-110.

Tesema, G., & Worrell, E. (2015). Energy efficiency improvement potentials for the cement industry in Ethiopia. *Energy*, *93*, 2042-2052.

Tiruye, G. A., Besha, A. T., Mekonnen, Y. S., Benti, N. E., Gebreslase, G. A., & Tufa, R. A. (2021). Opportunities and challenges of renewable energy production in Ethiopia. *Sustainability*, *13*(18), 10381.

Tiseo, G., Barbieri, C., Galfo, V., Occhineri, S., Matucci, T., Almerigogna, F., ... & Falcone, M. (2023). Efficacy and safety of nirmatrelvir/ritonavir, molnupiravir, and remdesivir in a real-world cohort of outpatients with COVID-19 at high risk of progression: the PISA Outpatient Clinic Experience. *Infectious Diseases and Therapy*, *12*(1), 257-271.

Tiseo, I. (2021). Annual co2 emissions worldwide from 1940 to 2020.

Twardowska, I., Allen, H. E., Kettrup, A. F., & Lacy, W. J. (2004). *Solid waste: assessment, monitoring and remediation*. Gulf Professional Publishing.

United Nations Environment Programme. International Resource Panel, United Nations Environment Programme. Sustainable Consumption, & Production Branch. (2011). *Decoupling natural resource use and environmental impacts from economic growth*. UNEP/Earthprint.

United Nations Framework Convention on Climate Change. Secretariat. (1992). *United Nations framework convention on climate change*. UNFCCC.

Uwasu, M., Hara, K., & Yabar, H. (2014). World cement production and environmental implications. *Environmental Development*, *10*, 36-47.

Wang, W., Sun, Y., Liu, J., Wang, J., Li, Y., Li, H., ... & Liao, H. (2012). Protective effect of theaflavins on cadmium-induced testicular toxicity in male rats. *Food and chemical toxicology*, *50*(9), 3243-3250.

Wang, L., & Zhang, X. (2017). System dynamic model for simulating demand-supply interaction of railway express freight system. *Mathematical Problems in Engineering*, *2017*.

List of Appendix

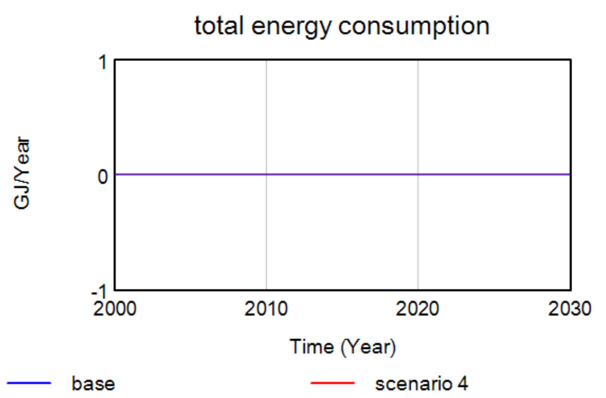
Appendix A:

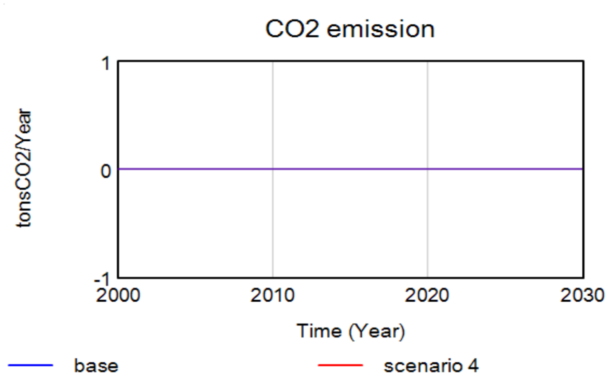
1) Average cement consumption per house = 2.431; Units: tons/house.
2) Average production capacity of cement factories= SIMULTANEOUS (effect on capacity*normal cement capacity, 113375); Units: tons/factories/Year.
3) Cement availability= SIMULTANEOUS (cement supply/cement demand, 0.0799) Units: 1
4) Cement consumption for infrastructure=normal cement consumption*effect of GDP on infrastructure consumption; Units: tons/Year
5) cement demand= cement consumption for infrastructure +cement required for housing; Units: tons/Year
6) Cement imported=100,000; Units: tons/Year
7) Cement production= total production of cement; Units: tons/Year
8) Cement required for housing= average cement consumption per house*housing demand; Units: tons/Year
9) Cement supply=cement imported +cement production; Units: tons/Year
10) CO_2 emission= (emission from fossil fuel +emission from non-fossil fuel) = Units: tonsCO_2/Year
11) CO_2 emitted= INTEG (CO_2 emission, 365200); Units: tonsCO_2
12) Emission from fossil fuel=fossil fuel emission factor*fossil fuel energy use; Units: tonsCO_2/Year
13) Emission from non-fossil fuel= non-fossil fuel emission factor*non-fossil fuel energy use; Units: tonsCO_2/Year
14) Energy intensity per unit of tons cement = 4.215; Units: GJ/tons
15) Fossil fuel emission factor = 0.513; Units: tonsCO_2/GJ
16) Fossil fuel energy use = total energy consumption*share of fossil fuel energy consumption; Units: GJ/Year
17) GDP = INTEG (GDP growth,3.64984e+11); Units: birr
18) GDP growth = GDP*GDP growth rate; Units: Birr/Year
19) GDP growth rate = 0.0867; Units: 1/Year
20) Housing demand = effect of population on housing*reference houses demand; Units: house/Year
21) Lost production due to shortages of power per year = 64524.1; Units: tons/factories/Year
22) Net population growth rate = 0.023; Units: 1/Year
23) Non-fossil fuel emission factor = 0.084; Units: tonsCO_2/GJ
24) Non-fossil fuel energy use = total energy consumption*(1-share of fossil fuel energy consumption); Units: GJ/Year
25) Normal cement capacity = 217899; Units: tons/(Year*factories)
26) Normal cement consumption = 250000; Units: tons/Year
27) Number of cement factories = reference number of factory*effect of revenue factories growth; Units: factories
28) Population = INTEG (population growth, 6.3495e+07); Units: person
29) Population growth = population*net population growth rate; Units: person/Year
30) Reference GDP = 3.64984e+11; Units: birr

31) Reference population = 6.3495e+07; Units: person
32) Reference revenue = 3.40126e+08; Units: birr
33) Reference unit price = 500; Units: birr/tons
34) Share of fossil fuel energy consumption = 0.9 Units: 1
35) Total cement output= INTEG (cement production-total consumption, 680252); Units: tons
36) Total consumption = (cement consumption for infrastructure+ cement required for housing); Units: tons/Year
37) Total energy consumption = energy intensity per unit of tons cement*cement production;
38) Units: GJ/Year
39) Total production of cement = (average production capacity of cement factories-lost production due to shortages of power per year) *number of cement factories; Units: tons/Year
40) total revenue of cement = unit price of cement*total cement output, Units: birr
41) Unit price of cement = effect of cement availability on price*reference unit price; Units: birr/tons

Appendix B: Extreme condition tests

a) When energy intensity per ton of cement is zero what happen total energy consumptions and CO2 emissions.

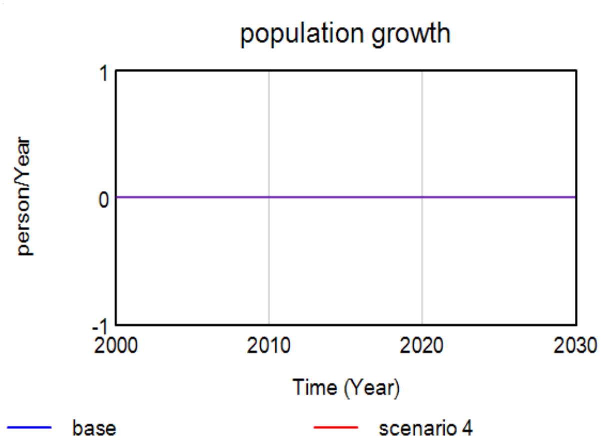


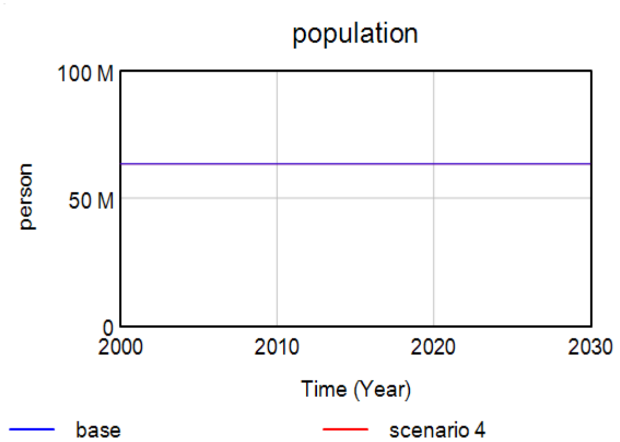


When there is zero energy intensity, has no total energy consumptions, cement production and zero CO2 emissions. This satisfies the assumption of zero extreme condition tests. It is not contradicted to the reality.

b) When population growth rate is zero what happen on population growth and total population.

The figure indicates that when no population growth rate it is zero population growth, while stock of total populations remains constant having the base year of population 63 million base year. Hence, the assumptions of extreme zero condition test is satisfied not oppose to the reality.





Appendix C: Summary for policy scenario with respect to selected variables

Policy at:-	Year	Cement output (in mill. tons)	Total energy consumptions (in mill. GJ)	Fossil fuel energy use (in mill. GJ)	Non-fossil fuel energy use (in mill.	CO2 emission (in mill. tonsCO2)	CO2 emissions from fossil fuel (in mill.	CO2 emissions from non-fossil (in mill.	cement supply (in mill. tons)	Population (in mill.)	GDP (in bill. birr)	Total income (in bill. birr)	Cement availability (ss/dd:dmnl)
Baseline	2022	7.98	33.65	30.28	3.36	4.37	4.09	0.28	7.98	104.71	2273.46	69.13	1.00
	2030	16.28	68.6	61.86	6.86	8.92	8.34	0.58	16.29	125.61	4421.44	128.38	1.72
	Amount of increment from 2022 to 2030	8.30	34.99	31.58	3.50	4.55	4.25	0.30	8.30	20.89	2147.98	59.25	0.63
	Growth (%)	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**107%**	**104%**	**20%**	**94%**	**86%**	**63%**
Scenario 1	2022	7.98	23.31	20.98	2.33	3.03	2.83	0.20	7.98	104.71	2273.46	69.13	1.00
	2030	16.28	47.55	42.80	4.76	6.18	5.78	0.40	16.29	125.61	4421.44	128.38	1.72
	Amount of increment from 2022 to 2030	8.30	24.24	21.82	2.42	3.15	2.95	0.20	8.30	20.89	2147.98	59.25	0.63
	Growth (%)	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**20%**	**94%**	**86%**	**63%**
Scenario 2	2022	7.98	33.65	13.46	20.19	3.51	1.82	1.70	7.98	104.71	2273.46	69.13	1.00
	2030	16.28	68.64	27.46	41.18	7.17	3.71	3.46	16.29	125.61	4421.44	128.38	1.72
	Amount of increment from 2022 to 2030	8.30	34.99	14.00	21.00	3.65	1.89	1.76	8.30	20.89	2147.98	59.25	0.63
	Growth (%)	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**20%**	**94%**	**86%**	**63%**
Scenario 3	2022	7.98	38.75	34.87	3.87	5.03	4.71	0.33	9.19	104.71	2273.46	80.64	1.00
	2030	16.28	79.04	71.14	7.90	10.27	9.60	0.66	18.75	125.61	4421.44	149.71	1.72
	Amount of increment from 2022 to 2030	8.30	40.30	36.27	4.03	5.23	4.90	0.34	9.56	20.89	2147.98	69.07	0.63
	Growth (%)	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**20%**	**94%**	**86%**	**63%**
Scenario 4	2022	9.19	26.84	10.74	16.11	2.80	1.45	1.35	9.19	79.03	2273.46	82.82	1.00
	2030	18.75	54.76	21.90	32.86	5.72	2.96	2.76	18.75	85.58	4421.44	153.70	1.83
	Amount of increment from 2022 to 2030	9.56	27.92	11.17	16.75	2.92	1.51	1.41	9.56	6.55	2147.98	70.88	0.72
	Growth (%)	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**104%**	**8%**	**94%**	**86%**	**72%**