

# Universidad de Huelva

Departamento de Física Aplicada



## **Carbon emissions, energy consumption and sustainable development in Ecuador (1980-2025) : system dynamics modelling, decomposition analysis and the Environmental Kuznets Curve**

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presentada por:**

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Bajo la dirección de los doctores:

José Enrique García Ramos

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UNIVERSITY OF HUELVA

**CARBON EMISSIONS, ENERGY  
CONSUMPTION AND SUSTAINABLE  
DEVELOPMENT IN ECUADOR (1980-2025):  
SYSTEM DYNAMICS MODELLING,  
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*Dedicated to people who believes that We must stand together...*

*[1]*



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June 2014



## **Abstract**

The energy consumption and the growth of the CO<sub>2</sub> emissions related with the growth of the economy represents a challenge requiring a deep analysis and the development of appropriated policies. Several analysis of future changes of the economy of particular countries rely on quantitative point forecasts for which is difficult to achieve a reasonable accuracy. In this dissertation a System Dynamics (SD) model, combined with the design of a set of scenarios, has been developed and applied to Ecuador within a medium term (up to 2025), allowing to estimate the Gross Domestic Product (GDP) and the CO<sub>2</sub> emissions, among other variables.

This research applied a combination of the so called decomposition analysis with a scenario analysis to identify and determine the driving forces of change of CO<sub>2</sub> emissions in Ecuador. A historical, from 1980 to 2010, and a forecast period, from 2011 to 2025, have been considered. Logarithmic Mean Divisia Index (LMDI) to carry out the decomposition analysis has been applied to both the historical and forecast periods, using in the latter case different plausible scenarios of development.

The historical analysis provides insights at both macro and sectoral level, allowing to establish the driving forces of the system: structure, scale, energy mix and, energy intensity. The macro decomposition was based on an extended Kaya identity while the sectoral decomposition tried to offer deeper insights of each productive sector. In addition, the formation of a GDP that depends on renewable energy, which introduces a feedback mechanism in the model, has been introduced to

build the model, which allows to generate a non-trivial evolution of the system.

The four considered scenarios show different emission trajectories, based on the different alternative development paths. In particular, special attention was paid to the effect of a reduction of the share of fossil energy, as well as of an improvement in the efficiency of the fossil energy use. The estimated values (for CO<sub>2</sub> emission and GDP, among others) are given in an aggregate way as well as in terms of sectoral contributions.

In a deeper analysis of the model outcome, we have studied the Environmental Kuznets Curve (EKC) hypothesis for Ecuador in a forthcoming period, 2011-2025 using the proposed scenarios. Our proposal goes a step further than previous contributions, and intends to see under which conditions a country could approach the fulfilment of this hypothesis in the medium term. The results do not support the fulfilment of the EKC, nevertheless, the estimations show that Ecuador could be on the way to achieving environmental stabilization in the near future. Indeed, our estimates show that Ecuador could be able to enter the area of environmental stability (second stage of the EKC) in the medium term (2019-2021). However, to achieve this goal it is essential to implement policies that allow the diversification of energy sources and to increase the energy efficiency in the productive sectors in order to get a more sustainable development.

The final conclusion of this work suggests that emissions can evolve with values higher or lower than the present ones and they will be determined not only by the evolution of the economic growth but also by the development path. Within the development path, economic growth interacts with governance, societal choices and other driving forces.

## Resumen

El consumo de energía y el aumento de las emisiones de CO<sub>2</sub> relacionadas con el crecimiento económico suponen un desafío para el desarrollo sostenible que requiere un análisis profundo y el desarrollo de políticas apropiadas. Muchos de los análisis de los futuros cambios en la economía de países o de regiones concretas se basan en predicciones cuantitativas para las cuales es complicado garantizar una precisión adecuada. En la presente investigación, se ha construido un modelo utilizando para ello la técnica de Dinámica de Sistemas (DS) en base a un enfoque de escenarios que permiten realizar estimaciones, a medio plazo (hasta 2025), del Producto Interno Bruto (PIB) y de las emisiones de CO<sub>2</sub>, entre otras variables, para el caso de Ecuador.

Esta investigación aplica una combinación del análisis de descomposición y del análisis de escenarios para identificar y analizar las fuerzas impulsoras que provocan el cambio de las emisiones de CO<sub>2</sub> en Ecuador. Se ha considerado para ello el periodo histórico de 1980 a 2010 y una proyección hasta el año 2025. Para el análisis de descomposición se usó el método de Índice de Divisia de la Media Logarítmica (IDML), aplicándolo tanto al periodo de datos (1980-2010) como al periodo de proyección (2011-2025), para el cual se emplearon diferentes escenarios que permitían explorar diferentes formas de desarrollo en Ecuador.

El análisis histórico da una visión a nivel macro a la vez que sectorial, permitiendo diferenciar diferentes fuentes de cambio: estructurales, de escala, de mix energético, y de la intensidad energética. La descomposición a nivel macroeconómico se basa en una identidad Kaya extendida, mientras que el análisis sectorial intenta ofrecer una visión más

profunda de cada sector productivo. Además, se ha considerado en el modelo un enfoque de la formación del PIB que depende de la energía renovable, lo que introduce un mecanismo de retroalimentación en el modelo y nos permite generar una evolución no trivial del sistema.

Los cuatro escenarios que se consideran muestran diferentes patrones de evolución de las emisiones de CO<sub>2</sub>, basados en los diferentes caminos de desarrollo alternativo considerados. En particular, se prestó especial atención al efecto de la reducción de la cuota de energía fósil, así como a la mejora en la eficiencia del uso de este tipo de energía. Los resultados se dan tanto en forma global para el país, como también referidos a cada una de los sectores productivos. Se observó que el efecto de la reducción de uso de energía fósil puede ser igual de efectivo que el aumento de su eficiencia de uso.

En un análisis más profundo de los resultados del modelo, se ha estudiado la hipótesis de la Curva de Kuznets Ambiental (CKA), utilizando para ello los mismos escenarios referidos anteriormente. Nuestra propuesta va un paso más allá de las contribuciones anteriores presentes en la literatura revisada, y tiene la intención de ver en qué condiciones un país podría acercarse al cumplimiento de esta hipótesis en el medio plazo. Los resultados no apoyan el cumplimiento de la CKA, sin embargo, las estimaciones muestran que Ecuador podría estar en el camino de lograr la estabilización de las emisiones de CO<sub>2</sub> (en relación al crecimiento del PIB) en un futuro relativamente cercano. De hecho, nuestras estimaciones muestran que Ecuador podría entrar en el ámbito de la estabilidad ambiental (segunda etapa de la CKA) en torno a 2019-2021. Sin embargo, para lograr dicho objetivo, es necesario implementar políticas que permitan la diversificación de las fuentes de energía y aumentar la eficiencia energética en los sectores productivos con el fin de conseguir un desarrollo más sostenible.

La conclusión final de este trabajo sugiere que las emisiones de CO<sub>2</sub> pueden evolucionar a lo largo de diferentes trayectorias, con niveles

de emisiones superiores o inferiores a los actuales, que vendrán determinados no sólo por la evolución del crecimiento económico, sino también por la vía de desarrollo seleccionada. En el camino hacia el desarrollo, el crecimiento económico interactúa con la gobernanza, las opciones sociales y las otras fuerzas impulsoras.



## Outcomes of the research

### Publications in scientific journal:

- *System dynamics modeling for renewable energy and CO<sub>2</sub> emissions: A case study of Ecuador.*

A. Robalino-López, A. Mena-Nieto, J.E. García-Ramos.

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- *System dynamics modelling and the environmental Kuznets curve in Ecuador (1980–2025).*

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### Submitted to publication in scientific journal:

- *Dynamic modelling of the relationship between Economic growth, CO<sub>2</sub> emissions, and Kuznets Curve verification in Venezuela (1980-2025)*

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Submitted to Renewable and Sustainable Energy Reviews.

- *CO<sub>2</sub> emissions convergence among South American countries. A study of Kaya components (1980-2010)*

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### Participation in international conferences and post graduate programs:

- *Emissions related to energy consumption and sustainable development, a system dynamics approach.*

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- *Energetic Forecast: Automation of the Weather Research and Forecast Model (WRF) to improve energy production.*

II Forum of Ecuadorian students in Europe - Guest Speaker - Milan-2013.

- *Modeling of energy consumption and CO<sub>2</sub> emissions using system dynamics: Ecuador Case Study.*

II Forum of Ecuadorian students in Europe - Guest Speaker - Milan-2013.

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## ACRONYMS

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- bbl Oil Barrel
- CO Carbon Monoxide
- COE Compensation of Employees
- CSP Concentrated Solar Power
- EFOM Energy Flow Optimization Model
- EKC Environmental Kuznets Curve
- EU European Union
- EEA European Environment Agency
- FDI Foreign Direct Investment
- FTP Feed-in Tariff Policies
- gCO<sub>2</sub>e Grams of Carbon Dioxide Equivalent
- GDI Gross Domestic Income
- GDP Gross Domestic Product
- GED Global Environmental Degradation
- GIGO Garbage Input Garbage Output
- GMI Gross Mixed Income
- GNP Gross National Product
- GOS Gross Operating Surplus
- GHG Greenhouse Gas Gases
- HDI Human Development Index
- ICTs information and communication
- IPAT Human Impact, Population, Affluence, Technology

## ACRONYMS

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- ISIC International Standard Industrial Classification of All Economic Activities
- kWh kilowatt hour
- LEAP Long range Energy Alternatives Planning
- LMDI Logarithmic mean Divisia index
- MB Marginal Benefit
- MC Marginal Cost
- MARKAL Market Allocation
- MEDEE Model for Long-Term Energy Demand Evaluation
- NAFTA North American Free Trade Agreement
- NO<sub>x</sub> Nitrogen Oxides
- PPP Purchasing power parity
- PSM Productive Sectors Matrix
- PV Photovoltaics
- REN21 Renewable Energy Policy for the 21st Century
- RGSR Renewables Global Status Report
- RPS Renewable Portfolio Standards
- SEM Structural Equation Modeling
- SD System Dynamics
- $S_{P\&M}$  Subsidies on Production and Imports
- SO<sub>x</sub> Sulfur Oxides
- TB Trade Balance
- $T_{P\&M}$  Taxes on Production and Import

## ACRONYMS

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- UK United Kingdom
- US United States
- USD United States Dollar-2005-PPP

*The beginning is the most important part of the work.*

Plato

CHAPTER

# 1

## Introduction

### 1.1 The challenges of sustainable development and energy

Climate change, energy and sustainable development is nowadays a key issue in the global scientific and political agendas. These issues have important implications for the development process and national policy in all regions of the planet. Through Kyoto Protocol, most industrialized nations have committed to reduce their emissions. In particular, *The climate and energy package* in European Union (EU) which is a set of binding legislation aims to ensure that the region meets its ambitious climate and energy targets for 2020<sup>1</sup> [9] and most recently, in May 2014, the United States (U.S.) Global Change Research Program released the *Third National Climate Assessment* (Melillo, 2014) [10], the authoritative and comprehensive report on climate change and its impacts in U.S. where Obama's administration showed its concern on climate change and on its effects.

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<sup>1</sup>These targets, known as the "20-20-20" targets, set three key objectives for 2020:

- i*) A 20% reduction in EU greenhouse gas (GHG) emissions from 1990 levels;
- ii*) Raising the share of EU energy consumption produced from renewable resources to 20%;
- iii*) A 20% improvement in the EU's energy efficiency [9].

## 1. INTRODUCTION

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Political debates and policy decisions with respect to energy and emissions involve a wide spectrum of fields and competences. National planning and policy processes, including: national development policy, sustainable development, environment, energy, climate and technology in fields such as spatial development, economic development, societal well-being and public education are relevant. Many of these spheres require an enhancement of its knowledge.

The United Nations Conference on Environment and Development, also known as the Earth Summits held in Stockholm (Sweden) in 1972, Rio de Janeiro (Brazil) in 1992 and Johannesburg (South Africa) in September 2002. In 2012, the United Nations Conference on Sustainable Development was also held in Rio (commonly called Rio+20 or Rio Earth Summit 2012). These meetings had a very outstanding outcome and guidance on arrangements for the signatory states in activities related with the environment.

The Rio Declaration on Environment and Development 1992 (UN, 1992) [11] establish that: *Human beings are at the centre of concerns for sustainable development (Principle 1). States have the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction (Principle 2). In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it (Principle 4). To achieve sustainable development and a higher quality of life for all people, States should reduce and eliminate unsustainable patterns of production and consumption and promote appropriate demographic policies (Principle 8). States shall facilitate and encourage public awareness and participation by making information widely available (Principle 10). States shall enact effective environmental legislation (Principle 11). Environmental impact assessment, as a national instrument, shall be undertaken by States (Principle 17) and that indigenous people, their communities and other local communities, have a vital role in environmental management and development because of their knowledge and traditional practices. States should recognize and duly support their identity, culture and interests and enable their effective participation in the achievement of sustainable development (Principle 22).*

## 1.1 The challenges of sustainable development and energy

On the other hand, one of the most interesting definitions of *Sustainable Development* refers to *the development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (Principle 3).

A key factor of economic development in countries and the transition from subsistence agricultural economies to modern industrial societies which are oriented to services, is to have an adequate supply of *affordable energy*. Energy is essential to enhance the social and economic welfare and, in most cases, it is essential to attract industrial and commercial wealth. It is a condition, *sine qua non*, to support poverty alleviation, generalize social protection and raise living standards. Note that no matter how essential energy<sup>1</sup> can be for the development, energy is just a medium, it is not the *final goal*, while the *final goal* of sustainable development is to achieve good health, a high standard of living, sustainable energy and a clean environment.

As already mentioned, energy consumption is one of the greatest measures of progress and well-being of a society. The concept of *energy crisis* appears when the energy sources of the society are depleted. An economic model as the present, whose operation depends on continued growth, also requires an equally growing demand for energy. Since fossil energy sources are finite, it is inevitable that at some point the demand can not be supplied and all the system will collapse unless new sources of energy would be discovered or new techniques are developed, as would be the case of renewable energy.

The energy obtained from virtually inexhaustible natural sources is called renewable energy, because this kind of sources contain a vast amount of energy, and also they are able to be regenerated by natural means in relatively short times.

The potential of renewable energy has a great capacity to help meet global energy demand. Furthermore, this type of clean energy has a rapid growth due to the remarkable technical advances that have taken place in recent years and of society.

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<sup>1</sup> It is worthy to note that there are no form of energy: coal, solar, nuclear, wind or any other type, that is inherently good or bad, and each is valid only to the extent that meets the purpose for which it was created.

## 1. INTRODUCTION

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The commitment to promote this type of development and the rational use of energy, involves setting goals at national and regional levels and define a policy according with these goals.

### 1.2 Trends in technology of renewable energy

Climate change, peak oil and energy security are the trends that are setting the pace of the global energy transition. New types of technologies are required to supply the growing energy demand and thus stop the historical dependence on fossil fuels. Faced with this challenge, the technologies related to renewable energy are receiving strong incentives and stimuli, leading to a global development. Some of these technologies has become competitive alternatives to traditional energy generation and start having a display and commercial use.

Indeed the last three decades of investment in renewable energy sources have enabled cost reductions close to 40% in technologies related to biomass, 70% in geothermal and 90% in wind, solar photovoltaic and solar thermal (Arent et al. 2011) [2]. Therefore, it is important to interpret the state of the global trends in development and dissemination of technologies of renewable energy.

This section is intended to show the level of technological development of the main renewable energy technologies. Note that these technologies should be in an advanced stage of its development (deployment and marketing) to have the potential to be used in developing countries such as Ecuador.

#### 1.2.1 Wind energy

Wind power is one of the more mature renewable energy sources in the world and the fastest growing in the last three decades (IEA, 2011a [12], WEC, 2010 [13]). This development has focused on wind turbines on land (onshore) with the three-bladed rotors model. The overall trend of the average cost <sup>1</sup> of wind power shows a marked reduction in the last years and in 2025 is projected to be less than 5

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<sup>1</sup>Average costs refer to the total incurred for the operation of a power plant. These include the costs of investment, operation, maintenance and financing. They are expressed in terms of the energy produced by the power plant during its life cycle (*e.g.* US/kWh) (Wiser et al, 2011) [14].

## 1.2 Trends in technology of renewable energy

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USD-cents/kWh (see Figure 1.1) (Arent et al., 2011) [2]. Although wind energy is a technology already being marketed and widespread disseminated, it is expected that there would be incremental advances and improvements in its design, more efficient use of materials, reliability and energy capture, reduction of operating and maintenance costs and longer life of the components.

Technological advances may lead to further cost reductions, facilitating its deployment and adoption in developing countries. Wind power prices are competitive compared to traditional energy systems based on fossil fuel. (Wiser et al, 2011 [14]; Arent et al. 2011 [2]). It is estimated that the average cost of onshore turbine technologies will be reduced between 10% and 30% for 2020 and ranges between 15% and 35% by 2030, regardless of cost reductions and incentive policies to facilitate the adoption of these systems (*e.g.* feed in tariff-FIT<sup>1</sup>) (Wiser et al., 2011) [14].

The technological development of other kind of wind energy such as wind turbines (offshore) and even floating turbines at sea are already a reality in developed countries (especially in Europe) (Wiser et al., 2011) [14]. The costs of these technologies are still higher than onshore turbines, since this kind of technology have a lower level of overall development. However, future reductions are also expected in the average costs of these technologies, ranging between 10% and 40% by 2020 and 20% to 45% by 2030 (Wiser et al., 2011) [14].

### 1.2.2 Solar energy

There are a wide range of solar energy technologies for use in heating, lighting, electricity, among others. These technologies have varying degrees of maturity and development. Since the 2000s the fastest growing of renewable energy are solar photovoltaic modules (Arvizu et al., 2011) [16].

Among solar technologies, the most competitive prices compared to traditional energy sources are solar thermal systems for heating and water heating. Others which are at the stage of deployment and use, at an increasing rate, are photovoltaic (PV) systems for electricity generation. Most installations of photovoltaic systems

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<sup>1</sup>FIT is a policy mechanism designed to accelerate investment in renewable energy technologies. It achieves this by offering long-term contracts to renewable energy producers, typically based on the cost of generation of each technology (Couture, 2011) [15].

## 1. INTRODUCTION

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correspond to panels on roofs of houses and connected to the grid of the city (Arvizu et al., 2011) [16]. Note that a trend of decentralized solar energy systems is also starting to be developed.

Other technological options are developing solar power generation systems based on concentrated solar power (CSP) used in some power plants. Designs include dyes sensitized to capture solar energy and solar cells from organic materials. Also, they are developing solar technologies for producing fuels such as hydrogen or hydrocarbons and to store a greater amount of energy in efficient carriers (Arvizu et al., 2011) [16].

Advances in solar thermal technologies for heating show developments enabling longer life of the systems, lower installation costs and higher temperatures. The trend is that these systems may be essential components of all the roofs of houses and buildings. In addition, recent designs in storage and conversion of heat and cold allow use the walls of buildings as active systems of air conditioning and heating (Arvizu et al., 2011) [16].

In PV panel technologies, future developments aimed at improving the performance (efficiency) and environmental and sustainability profiles in the manufacture of the modules. Advances aim to improve not only the panel that captures energy but the entire system (power inverter, battery, control and network) to convert that energy into electricity according to the standards used in end use appliances in houses.

The technological evolution during last four decades in solar energy has allowed a cost reductions of nearly 80% in PV systems. Indeed, since the PV systems reach further deployment in the market, their costs are projected to continue to decline rapidly. Based on these trends of technological development and the increase in the world market, it is projected the average cost of PV systems to be reduced by more than 50% and may reach an average of 7.3 USD-cents/kWh in 2020 (Arvizu et al., 2011) [16].

### 1.2.3 Bioenergy

Bioenergy production is an option to diversify the energy sources in the world (Kammen, 2004) [17] due to its large energy efficiency, clean and cost-competitive.

## **1.2 Trends in technology of renewable energy**

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Commercial available technologies are: heating and electricity generation through combustion of biofuels. Biofuels come from oil crops, such as biodiesel, and sugars and starches, such as ethanol (Chum et al., 2011) [18].

There are also small-scale systems that use bioenergy to provide heat for cooking, anaerobic digestion systems for treating solid waste and produce methane gas for burning (heating, cooking) and gasifiers.

These technologies use a wide range of agricultural products. Most existing bioenergy systems are mainly based on wood and agricultural residues for the production of heat and electricity, and agricultural crops for the production of liquid biofuels. The energy performance of these systems vary due to the conversion technology and material used (crop residues, pulp). Charcoal is one of the most frequent uses of bioenergy in developing countries, especially in rural areas, however, production can be improved with cleaner and more efficient furnaces (Chum et al., 2011) [18].

Another technology still in development status and still holding high costs is second-generation biofuel. These are manufactured from non-food biomass which crops require less both water and land for its production, or from agricultural and forest residues. It is under investigation and in its early stages of production, biofuels based inedible lignocellulosic biomass, including crop residues and wood production (such as rice husk, corn husk or sawdust), inedible plant crops in which whole plant is used (such as switchgrass) and vegetable oils crops that do not compete for land use (such as biodiesel from microalgae) (Carriquiri et al., 2011) [19]. Biomass is the only renewable energy where can be obtained liquid high energy density fuels to replace fossil fuels in transport by land, air and maritime (Chum et al., 2011) [18].

Trends in bioenergy costs are varied and depend on the prices of agricultural raw materials and on applied technology for conversion and energy use. Hence, the main factors affecting costs are the costs of bioenergy crop production, transportation to processing centers (these two may represent between 20 and 50% of the total average cost) and technical specificities the used technology (Chum et al. 2011) [18].

The cost projections for bioenergy are subject of uncertainty. However, based on the trends of improvement and maturity of the technology, can be estimated

## 1. INTRODUCTION

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a cost reductions close to 40% for the production of ethanol from sugarcane in countries like Brazil and 20% for corn ethanol in U.S. by 2020. Second-generation biofuels based on lignocellulosic materials also have the potential to reduce its cost production in medium term, which could compete with the prices of gasoline and diesel from a barrel of oil at USD 60- 70/bbl<sup>1</sup> (0.38 to 0.44 USD per liter of ethanol) by 2030 (Chum et al., 2011) [18].

### 1.2.4 Wave and tidal energy

This type of technology is still at an embryonic stage and is not commercially available yet. The industry dedicated to the development of this technology is focused in the design and evaluation of prototypes for harnessing wave and tidal energy (REN 21, 2011 [20] and Lewis et al, 2011 [21]). The only exception is the use of tidal energy through dams, similar to hydroelectric dams design, located in the sea estuaries (Lewis et al., 2011) [21].

Prototypes so far do not converge to a unique design as in the case of wind turbines where the consensus has resulted in a three-bladed model. Due to this fact, there are several options for energy use and a unique design is not likely in this technology. The investment cost and the average cost of electric generation is not yet competitive (between 12 and 22 USD/ kWh) compared to other renewable energy sources, even worse when compared with traditional sources (Lewis et al., 2011) [21].

### 1.2.5 Geothermal energy

Geothermal is one of the most promising alternatives for energy supply in the long term. A technological option is the use of high temperature fluids to generate electricity through turbines. To this end, there are two alternatives: use the natural hot spring pools or enhanced geothermal systems with the use of artificial fluids (Goldstein et al, 2011) [22].

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<sup>1</sup>An oil barrel (abbreviated as bbl) is a unit of volume whose definition has not been universally standardized. In the U.S. and Canada, an oil barrel is defined as 42 U.S. gallons, which is about 159 liters or 35 imperial gallons, and it can also be defined in those units, depending on the context.

### **1.3 Integration of renewable energies in energy systems**

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Thermal water reservoir is a mature and reliable technology (it has over 100 years of operation). Enhanced geothermal systems are still in demonstration phase. Geothermal energy has a great potential to generate electricity due to the high levels of efficiency that can be achieved (load factor<sup>1</sup>). This feature is an advantage over other renewables such as solar, wind and hydroelectric, because these technologies, by their variable and intermittent nature, have a fickle electricity production based on the availability of the source that use. Indeed, the global average load factor of geothermal systems for power generation is 74.5%. The new geothermal plants reach higher ground factors 90% (Goldstein et al., 2011) [22].

The power plants based on geothermal reservoirs of hot springs have high initial investment costs, because it is necessary to explore and drill similarly to those of the oil industry wells. However, operating costs are low and do not use fuels. Therefore, the average cost of electricity from these systems is competitive. Depending on the level of utilization of the resource, the range is between 0.03 and 0.17 USD/kWh. The cost of enhanced geothermal systems is still greater than this traditional source (Goldstein et al., 2011) [22].

Technological advances point to improve the reliability and energy recovery as well as increase the life cycle of plants. Therefore, research and development in the exploration of hidden geothermal resources is required. This type of geothermal resource is characterized by not showing water reservoirs, so they are exploited by improved systems. As a result of technological improvements, it is expected that the average cost of generation from geothermal water reservoirs decrease by 7% in 2020 (Goldstein et al., 2011) [22].

### **1.3 Integration of renewable energies in energy systems**

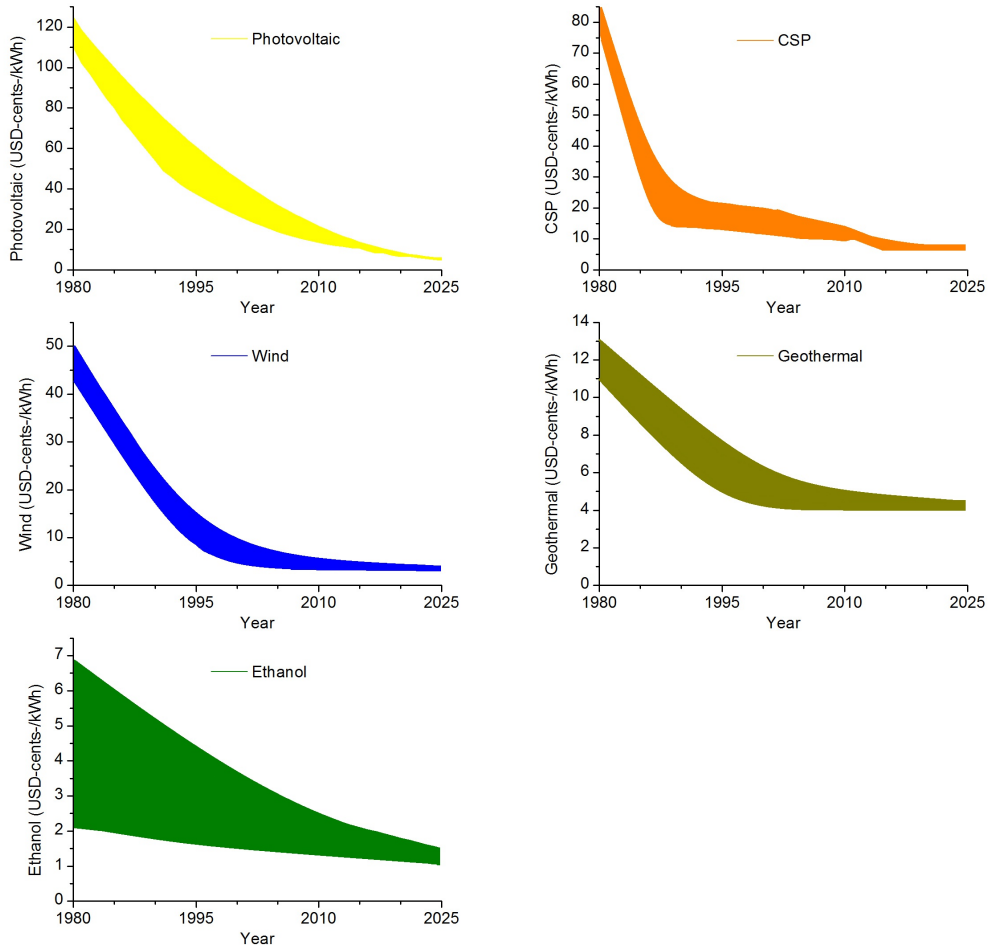
The analysis of the potential of renewable energy for changing the energy matrix is done on the basis of treating them as energy systems rather than from the perspective of technical and economic parameters of each technology (Kriegler, 2011)

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<sup>1</sup>In electrical engineering the load factor is defined as the average load divided by the peak load in a specified time period.

# 1. INTRODUCTION

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**Figure 1.1:** Historical trends and projected price of renewable energy based on Arent et al, 2011 [2] data.

### 1.3 Integration of renewable energies in energy systems

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[23].

In order to minimize the risks inside an energy system and to have greater reliability in the provision of energy is needed: diversification of energy sources, flexibility and complementarity between adopted technologies, extent of energy infrastructure (interconnection, transmission and distribution), the use of energy storage technologies and mainly of institutional and market mechanisms to improve security and energy supply (Sims et al., 2011) [24]. It is needed well-diversified energy sources to face the challenge of replacing fossil fuels as a primary energy source worldwide, in Latin America and in Ecuador.

According to IPCC (2011) [25], in the best case, about 77% of the world energy matrix can be supplied from the use of renewable resources. Some countries are exploring the possibility of having an energy matrix based 100% on renewable energy sources. Such is the case in Denmark, where by 2030 is aiming to achieve 50% and 100% by 2050. The energy matrix of each country should be based on the resources with the greatest potential in each nation (Lund and Mathiesen, 2009) [26].

Planning for an energy system based 100% on renewable energy sources is physically possible in allocation terms of energy resources. Some authors describe three scenarios regarding the reorganization of the energy systems around the replacement of fossil fuels worldwide. The first is the extensive use of bioenergy to supply the non-electric energy demand (*e.g.*, transportation fuels), in particular the use of biofuels. In this scenario, the biggest challenge is how to organize a sustainable coexistence between agriculture for food, conservation of ecosystems and bioenergy production. The second generation biofuels can make a significant contribution in reducing pressure, using waste water and marginal land, but their development still requires competitive costs (Kriegler, 2011) [23].

The second scenario suggests the production of fuels and energy storage with renewable technologies (other than biomass). The limitations of renewable energy sources, *e.g.*, intermittency, geographic dispersion and electrical use are removed when used for the production of fuels such as hydrogen. The challenges for this scenario are the massive changes in energy infrastructure in order to use hydrogen at large-scale. However, there are criticisms about cost and efficiency of hydrogen

## 1. INTRODUCTION

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as fuel and energy storage, but certainly this type of energy can be transported to end-uses (*e.g.*, fuel cells in cars) (Kriegler, 2011) [23].

The third scenario considers electrify transport and heating. This scenario requires technologies such as hybrid electric vehicles (plug in), among others, and may be feasible since there is already infrastructure to provide electric energy to end users. Extra advantage is the high efficiency of electric engines. However, it is required to improve battery technology for electric vehicles and the electric transmission grid to incorporate decentralized generation (Kriegler, 2011) [23].

Another challenge is to incorporate decentralized generation systems to the energy matrix. Traditionally, electrical systems were designed to transport energy from large scale power plants (hydroelectric, thermoelectric and nuclear) with high voltages to local distribution networks, with lower voltages. However, due to the disperse distribution of renewable energy sources, energy transition to a greener matrices requires that the grid transmission manage several medium and small generators connected to distribution systems (Bayod-Rújula, 2009) [27].

With the increasing demand of energy and the necessity of decarbonised energy systems, the world is beginning to understand that diversified and decentralized systems make a energy matrix more robust. This robustness has several advantages: lower concentration in few sources, lower risk of natural disasters and climate change effects and greater diversification of energy sources (Ebinger and Vergara, 2011 [28]; Bouffard and Kirschen, 2008 [29]; Nair and Zhang, 2009 [30]).

Decentralized energy systems involves challenges for transmission infrastructure. The management of electricity distribution networks by information, communication and control infrastructure is required, in order to manage the increasing complexity of having several generators connected to the system. In this sense, there are new concepts and perspectives as micro grids, virtual power plants (Bayod-Rújula, 2009) [27] and smart grid (Lindley, 2010) [31].

Smart grid is a concept that involves electrical transmission systems that incorporate the new information and communication technologies (ICTs) with transmission lines and distribution channels (Nair and Zhang, 2009) [30]. The purpose of smart grids is to optimize the operation of the electricity market and create a reliable and affordable transmission. This system would allows multiple options for managing electricity demand in order to reduce the peaks, to have greater efficiency

## 1.4 Methodological issues and exploration of future changes

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and to interconnect between communities and households to exchange information and energy flows (Lindley, 2010) [31].

### 1.4 Methodological issues and exploration of future changes

The understanding of future changes in energy and emissions for both policy and reporting in the areas under study start from official data sources such as the World Bank, the International Energy Agency, Central Banks and Institutes of Statistics and Census of a given country or region. To carry out projections of energy use and emissions can be problematic, due to inertia in infrastructure, technology and even culture of each country or region. Note that short term decisions can have long term consequences. They can embed a long term development path that limits or prevents emission reductions and hence an environmental protection. According to Van't Klooster and Van Asselt (2006) [32], studies on the future of a system is complex, as many relations *that may seem to have been continuously developed in retrospect, often follow a non-linear model in future*. Those authors propose that it may be legitimate to hold different and often conflicting perspectives on how the future can reveal. Armstrong (2001) [33] discusses two key sources of uncertainty in forecasting in general. These are overconfidence in forecast due to uncertainty in the causal variables in an econometric model and assumptions about relationships that may not hold over the forecast horizon. Agnolucci et al. (2009) [34] suggest that the past is not necessarily a good guide to the future in the context of energy and emissions. The predictability of energy and emissions and the accuracy of the predictions have been questioned even in the short term.

It is often not possible to make an assessment and ex-post forecast on energy or emissions with high accuracy. Linderoth (2002) [35] among others, described large forecast errors in determining future energy consumption in countries member of IEA. These sometimes conceal the sum of considerable positive and negative forecast errors in the sectors, particularly in industry and transport. This author indicates that the underestimate of transport can have particular consequences for emission reduction policy. Winebrake and Sakva (2005) [36] found a low mean

## 1. INTRODUCTION

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percentage error for total energy consumption concealing an average 5.9% overestimate for the industry sector and 4.5% underestimate for the transport sector in U.S.. O'Neill and Desai (2005) [37] noted that the errors occur not only in absolute values and sectoral consumption, but in GDP growth rates, energy intensity improvement and in fuel mix. This reduces the potential accuracy of forecast of GHG emissions and, as they are an input into policy processes, has potential further consequences. Errors can occur even on short time-scales. Linderoth (2002) [35] concluded that large forecast error can occur even when the forecast year is close to the review year.

Pilavachi et al. (2008) [38] state that the *Energy 2000* study of the European Community in 1985 underestimated consumptions of oil and gas and overestimated solid fuels and renewable energy in 2000 of most of the EU countries. The author found a substantial forecast error over the EU and outlined three areas of uncertainty: *i*) unanticipated *strong* political decisions, *ii*) unanticipated energy requirements and *iii*) data definition and availability. In this context, the potential significance of such *overestimations/underestimations* is not just in meeting targets in environmental protection but also in cost effectiveness and cost benefit analysis of measures to meet targets.

On the short and medium term there is a clear benefit in using sectorally disaggregated scenarios. These can show variation in absolute totals of energy consumption and emissions. They can also illustrate potential divergent trends in, for example, sectoral contribution, economic growth rates and energy intensity change. de Jouvenel (2000) [39] stated that simulation models based on observations of the past are favoured by economists, econometrists, statisticians and forecasters. In addition, the accuracy or scientific quality of forecasts is not guaranteed where results may be arbitrary and subjective because can be subject to the GIGO effect (Garbage In Garbage Out), This method has long been opposed to the scenario method, which is more developed and used by futurists for one simple reason: better a rough but fair estimations than a refined yet incorrect forecast (de Jouvenel, 2000) [39]. In addition, technological and economic realities are implicitly embedded in energy modelling apparatus while results are often promoted as *objective* (Nielsen and Karlsson, 2007) [40]. Middtun and Baumgartner (1986) [41] termed

## 1.5 Data sources and data pre-processing

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this combination of modelling and politics as *the scientific negotiation of energy futures*. It increases the need for not only reproducible results and published models, but transparent assumptions and dynamics in studies related to energy and emissions modelling.

Note that, even in a short period, uncertainty in emissions projections can arise. This uncertainty is a challenge to probabilistic and predictive methodologies and suggests that scenarios are useful to delimit uncertainty. While forecasts are useful, it can also give an illusion of certainty. The continual revision of the CO<sub>2</sub> and energy projections for different countries and regions by the most of authors illustrates some of the methodological difficulties encountered by forecasting.

### 1.5 Data sources and data pre-processing

Data sources and statistics collected by an officially recognized national body are usually the most appropriate and accessible data. In some countries, however, those charged with the task of compiling inventory information may not have ready access to the entire range of data available within their country and may wish to use data specially provided by their country to the international organizations. In regard to this dissertation two main types of data sources will be distinguished, on one hand, population and economic activity and on the other, energy and fuels.

#### 1.5.1 Population and economic activity data

Currently, there are two main international sources about population and economic activity statistics: the World Bank (WB), and the International Monetary Fund (IMF). Both international organizations collect population and economic statistics from the national administrations of their member countries through systems of questionnaires.

In the case of WB, this database presents population and other demographic estimates and projections from 1960 to 2050. They are disaggregated by age-group and gender and cover approximately 200 economies.

Economic data here covers measures of economic growth, such as gross domestic product (GDP) and gross national income (GNI). It also includes indicat-

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ors representing factors known to be relevant to economic growth, such as capital stock, employment, investment, savings, consumption, government spending, imports, and exports.

### 1.5.2 Energy and fuel data

The main international sources related to energy and fuel statistics are: the International Energy Agency (IEA), the United Nations (UN) and in particular in Latin-America the Latin American Energy Organization (OLADE). All these organizations collect energy data from the national administrations of their member countries through systems of questionnaires, thus, data gathered are *official*.

Many countries have long time series about energy statistics that can be used to derive time series about GHG emissions. However, in many cases statistical practices (including definitions of fuels, of fuel use by sectors) will have changed over time and recalculations of the energy data in the latest set of definitions is not always feasible. In compiling time series about emissions from fuel combustion, these changes might give rise to time series inconsistencies, which should be dealt using the methods provided in Time Series Consistency Chapter 5 of Volume 1 of the 2006 IPCC Guidelines [42].

### 1.5.3 Data pre-processing

Data pre-processing is an important step in the data analysis and model building. The phrase *GIGO* is particularly applicable in these kind projects. Data-gathering methods are often loosely controlled, resulting in out-of-range values (*e.g.*, negative values in population data), impossible data combinations (*e.g.*, Sex: Male, Pregnant: Yes), missing values, etc. Analyzing data that has not been carefully screened for such problems can produce misleading results. Thus, the representation and quality of data is first and foremost before running an analysis (Pyle, D., 1999) [43].

When there is much irrelevant and redundant information present or noisy and unreliable data, the knowledge discovery during the training phase is more difficult. Data preparation and filtering steps can take considerable amount of processing

## 1.5 Data sources and data pre-processing

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time. Data pre- processing includes cleaning, normalization, transformation, filtering, feature extraction and selection, etc. The product of data pre- processing is the input to analysis and model building phases. Kotsiantis et al. (2006) [44] present a well-known algorithm for each step of data pre-processing.

In modelling and forecasting works, to remove the effect of seasonal, cyclical and irregular components from observed data and work only with the trend part is important. Therefore, decomposition methods in time series to determine the trends, are required. The Hodrick- Prescott (HP) filter is a method to extract the trend component of a time series, proposed in 1980 by Robert J. Hodrick and Edward C. Prescott (Hodrick and Prescott (1980)) [45]. It decomposes the observed series into two components: *i*) the trend component and *ii*) the cyclical component. The sensitivity setting of the trend to short-term fluctuations is obtained by modifying a multiplier called  $\lambda$ . It is currently one of the most widely used techniques in research on business cycles to calculate the trend of the time series, as it gives more consistent results with the observed data than other methods.

According to Hodrick and Prescott (1980) [45], HP filter has its origin in the method of *Whittaker-Henderson Type A*, which was first used by actuaries to smooth life tables, but also has been useful in studies of astronomy and ballistics. Kydland and Prescott (1990) justify the use of this filter for its linearity, being well defined without subjective elements, independent of the series to which it applies and easy to replicate to find *the trend that one could draw freehand* (Kydland, E, and Prescott E, 1990) [46].

The reasoning for the methodology uses ideas related to the decomposition of time series. Let  $y_t$ , for  $t = 1, 2, \dots, T$ , denote the time series variable. The series  $y_t$ , is made up of a trend component, denoted by  $\tau$ , and a cyclical component, denoted by  $c$ , such that  $y_t = \tau_t + c_t$  (Kim, H 2004) [47]. Given an adequately chosen, positive value of  $\lambda$ , there is a trend component that will solve the following equation:

$$\min \left( \sum_{t=1}^T (y_t - \tau_t)^2 + \lambda \sum_{t=2}^{T-1} [(\tau_{t+1} - \tau_t) - (\tau_t - \tau_{t-1})]^2 \right) \quad (1.1)$$

The first term of Equation 1.1 is the sum of the squared deviations  $d_t = y_t - \tau_t$  which penalizes the cyclical component. The second term, which is multiple by  $\lambda$

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corresponds to the sum of the squares of the trend component's second differences. This second term penalizes variations in the growth rate of the trend component. The larger the value of  $\lambda$ , the higher is the penalty. Hodrick and Prescott suggest 1600 as a value of  $\lambda$  for quarterly data under the assumption of disturbances having effects during at least 8 years or more permanent. For monthly series is usually used  $\lambda = 14400$  and for annual series a value of  $\lambda = 100$  is recommended.

### 1.6 Decomposition of the driving forces of change

It is well known that humans have dramatically altered the global environment, but there is a limited understanding of the driving forces of these impacts. The absence of a refined set of analysis tools is cited as a fundamental limitation (York et al., 2003) [48]. Analysis methodologies and tools have been developed in the field of analysis of decomposition, including sustainability framework known as the IPAT<sup>1</sup> (Commoner, 1972 [49] and Ehrlich and Holdren, 1972 [50]). The decomposition of changes in an aggregate environmental impact and of its driving forces has become popular to unravel the relationship of society and economy with the environment.

The specific application in energy consumption and CO<sub>2</sub> emissions is the so called *Kaya identity* (Kaya, 1990) [51]. The Kaya identity is a linking expression of factors that determine the level of human impact on environment, in the form of CO<sub>2</sub> emissions. It states that total emission level can be expressed as the product of four inputs: population, GDP per capita, energy use per unit of GDP, carbon emissions per unit of energy consumed. The Kaya identity<sup>2</sup> plays a core role in the development of future emissions scenarios in the IPCC Special Report on Emissions Scenarios [52]. The scenarios set out a range of assumed conditions for future development of each of the four inputs. Population growth projections are available independently from demographic research; GDP per capita trends are available from economic statistics and econometrics; similarly for energy intensity

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<sup>1</sup>Human Impact (I) on the environment equals the product of P= Population, A= Affluence, T= Technology. This describes how our growing population, affluence, and technology contribute toward our environmental impact.

<sup>2</sup>Note that, a limitation of this equation is that it does not account for *i*) the direct release of carbon dioxide by deforestation through burning *ii*) the loss of the carbon sink due to that deforestation.

## 1.6 Decomposition of the driving forces of change

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and emission levels. The projected carbon emissions can drive carbon cycle and climate models to predict future CO<sub>2</sub> concentration and climate change.

Some similar conceptual bases can be found in the field of index decomposition analysis (IDA). In particular, with the advent of the global oil crisis in 1973 and 1974, special attention was given to the use of energy in industry among policy-makers because energy in industrial constituted most of the primary energy demand in most countries. Therefore, researchers focused on the mechanisms of change in industrial energy use. This new area of research emerged to quantify the impact of a structural change in industrial production on the total energy demand. These initial studies showed a significant impact of structural changes on the trends of energy demand. The need to identify and quantify its impact became an imperative for policy-making. This line of research was expanded considerably in the methodology and in its application, *it is now a widely accepted tool for the formulation of national policies on energy and environment analysis* (Ang, 2004) [53]. It is particularly useful to provide the analysis of contributing factors, such as structural changes and changes in energy intensity. Steenhof et al., (2006) [54] manifested that decomposition of a predefined set of factors helps to understand the progression of the driving forces, the consequences of the processes occurring and the political dimensions associated with these processes. Steenhof et al., (2006) [54] also proposed that this would allow a rationalisation for possible progression into the future.

The scope of the IDA was expanded beyond the analysis of industrial energy demand, now being used in the analysis, at country level, of fields such as energy or environment<sup>1</sup>.

The need for *political views*<sup>2</sup> of the IDA has mainly focused on historical analysis of the driving forces. While decomposition techniques such as IPAT can be used to predict future changes in the driving forces of a given system (Waggoner and Ausubel, 2002) [55], IDA is on the cusp of a new scenario analysis techniques

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<sup>1</sup>Energy efficiency measures are required by several international and national policies as the EU directive 2006/32/EC and while these can be executed using tools like IDA and LMDI (Logarithmic Mean Divisia Index) techniques (Ang, 2004) [53].

<sup>2</sup>The development of policy, reporting and monitoring of progress depends on the right as the index decomposition analysis analytical tools.

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and forecasting. For defining areas of future research in IDA, Ang and Zhang (2000) [56] suggests its use in projecting energy demand and emissions in short and medium term. Sun (2001) [57] used a complete decomposition method to forecast GHG emissions in the EU-15 up to 2010. Sorrell et al. (2009) [58] recommended more research in the use of the decomposition framework for scenario development. Although both, IDA in energy and emissions, as well as scenario analysis in the context of energy emissions are often based on the framework of Kaya, the combination of these approaches has often not applied. In this line some studies have combined these approaches; Kwon (2005) [59], Steenhof et al. (2006) [54], Steenhof (2007) [60] and Agnolucci et al. (2009) [34].

Agnolucci et al. (2009) [34] used a retrospective approach to scenarios and projection ratios decomposition. This approach was used to generate a predefined result in 2050 to discuss how relationships can be altered to achieve future goals through public policy. Kwon (2005) [59] used scenario analysis to quantify future CO<sub>2</sub> emissions from car travel in the United Kingdom (UK) until 2030 using the IPAT framework. This author built a Business as usual (BAU) scenario and alternatives scenarios to make assumptions about the forecast of each of the factors of the identity used. Steenhof (2007) [60] uses the IDA approach of Laspeyre to build baselines for the electricity sector in China by 2020. This author uses a BAU, conservative and optimistic scenarios with the analysis of time series decomposition (every two years instead of at the beginning and end of year). Steenhof et al. (2006) [54] also combines the decomposition analysis and the use of scenarios to project the burden of GHG in the short term (up to 2012) in Canada. Decomposition analysis was performed on the historical pattern to understand impact of the driving forces, while the scenario analysis provided the means to manipulate these forces in the future. Again BAU scenarios, optimistic and pessimistic have been employed.

In the research present in this dissertation about income growth, energy use and CO<sub>2</sub> emissions for Ecuador in medium term (up to 2025), the specific combination of techniques such as IDA (specifically LMDI approach), the use of exploratory scenarios and the Kaya identity (Kaya, 1993) [51] is trying to help to fill the gap in the regional literature in this topic. This study joins the study of the driving forces of change across both analysis decomposition and scenario analysis.

### 1.7 Background of scenario analysis

Scenario analysis has a wide history in a large number of sectors and disciplines (Van Notten et al, 2003) [61]. It is an approach to deal with uncertainty that may exist in organizations and governments (Nielsen and Karlsson, 2007) [40]. This type of analysis has been increasingly applied in the field of energy and environment, due to difficulties in providing accurate forecasts (Silberglitt et al., 2003) [62], and to the need for tools to imagining, discuss, and create future scenarios equally plausible. Specifically in the analysis of environmental settings including energy and emissions, there are two currents that could be described respectively as *i) inquiry-driven* and *ii) strategy-driven* (Alcamo et al., 2009) [63]. Inquiry-driven scenario analysis is conducted to meet the needs of the scientific community through expanding the knowledge and as an input to policy analysis. Strategy-driven scenario analysis is mainly due to the business community for corporate planning. The scientific credibility about scenarios theory has been increased due to the wide spectrum of opportunities for study and analysis that this technique offered in different fields.

The scenario analysis allows having a structured view of the future of development in areas such as driving forces, trends, themes, events and the logic of cause and effect. The objective of the scenario-based analysis is not prediction, but the construction and articulation of several different futures and the paths leading to them (Borjeson et al, 2006) [64]. In particular climate change depends in part on the evolution of humans factors such as anthropogenic GHG emissions, population, economy, etc. Given the uncertainty of future development, the scenarios have been used in the Special Report on Emissions Scenarios (SRES) of the Intergovernmental Panel on Climate Change (IPCC, 2000) [52] as the most suitable tool for exploring the future evolution of global emissions of GHG by the year 2100.

To study the evolution of complex systems where elements with behaviour not fully understood exists, the use of scenarios could be compulsory. The scenarios are not predictions or forecasts, but they are used to explore the equally plausible images of future developments (Nakicenovic et al, 2000) [65]. Besides, scenarios have been used as tools to link qualitative and quantitative arguments in modelling.

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The scenarios are also used by intergovernmental bodies such as the IEA and the European Environment Agency (EEA).

Certain works based on the use of scenarios have tended to focus on the long term in a world of great uncertainty (Nielsen and Karlsson, 2007) [40]. However, as indicated above, even in the short and medium-term, the application of the scenario methodology has scientific credibility and potential usefulness in policy development. In this dissertation a set of plausible scenarios for the evolution of CO<sub>2</sub> emissions and energy consumption in Ecuador in a medium term (2025) are carry out. These scenarios explore the evolution of the driving forces, both qualitatively and quantitatively. The delimitation of uncertainty in response to questions related to forecast accuracy provides insights into the driving forces of change and explores the potential contribution of different sectors to the total change of emissions.

### 1.8 Background of analysis models

The economics and environmental models can be divided in two general groups according to their structure: *i*) *top-down* and *ii*) *bottom-up* models (Great Britain. Department of Energy. Economics and Statistics Division, 1978) [66].

The top-down analysis method is based on a macroeconomic approach and considers the price of the energy and the elasticity as the main economic indicators to model the relationship between energy consumption and energy production. The top-down method is mainly applicable to the analysis of macroeconomics and to research on development of energy policies. However, this approach cannot control the impact on the economy of advances in technology. Some examples of this approach are the computable general equilibrium (CGE) model<sup>1</sup> based on General Equilibrium Theory and the Input-Output model.

The bottom-up analysis is a technique to build a model in more detailed way. Mainly it aims the construction of models of energy consumption and production for supply-demand forecast and environment impact analysis (Toshihiko, 2004) [68]. The bottom-up model has two branches in terms of research, which were

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<sup>1</sup>CGE models are a class of economic models that use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors. CGE models are also referred to as AGE (applied general equilibrium) models [67].

described by Wei (2005) [69]. The first is based on energy supply and conversion, it is frequently used for the analysis of the introduction of efficient techniques into energy systems and for the analysis on its effects. Typical examples of this approach are MARKAL model, developed by the IEA and EFOM (Energy Flow Optimization Model <sup>1</sup>) model developed by EU [71]. The second branch analyzes and calculates in detail the change in energy demand and consumption caused by the human activities. Representative models are MEDEE (Model for Long-Term Energy Demand Evaluation) model, developed by France and LEAP (Long range Energy Alternatives Planning) model, developed by Stockholm Environment Institute.

Now, we will mention briefly the most relevant models related to energy and emissions, then we will focus on the approach used in this research, System Dynamics (see Section 1.9 in this Chapter).

### 1.8.1 Input-Output model

Wassily Leontief is credited with developing the Input-Output (I/O model) analysis [72] and he was awarded the Nobel Prize in Economics in 1973 for his development of this model [73], which is still considered as one of the most effective theories to solve the problem of balanced economic growth, as was shown by William (1980) [74]. This approach could help working out the chessboard type of input-output statement and setting up the corresponding linear algebraic equation set to form an economic mathematical model, which could imitate the structure of the actual national economic system and the social production process, to analyze and confirm, comprehensively, the complex relationship among all the sectors in the national economic system and the key production proportional relationship.

### 1.8.2 LEAP model

LEAP is an integrated modeling tool that can be used to track energy consumption, production and resource extraction in all sectors of an economy. This model has

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<sup>1</sup>The Energy Flow Optimization Model (EFOM) is the supply part of the energy model complex of the Commission of the European Communities which has been used for a number of studies during the last decade [70].

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been developed by the Stockholm Environment Institute and the Tellus Institute [75]. The model follows the sequence of *resource*, *transition* and *demand*, to assess the energy demand and supply balance at certain region. This model is used to design the energy consumption mode in various development scenarios on the base of the current energy demand of each productive sector. This model also is useful to perform the forecast of social and economic development in the medium and long term with different policy packages and techniques selection modes. The combination of various development modes and their comparison could provide a reference for decision-making about economic and energy development planning in a given country or region.

LEAP model is considerate as *terminal energy consumption model*. It is mainly focuses on the achievement of the balance in demand and resource transition (Joost, 2004) [76]. Moreover, LEAP uses the existing energy technology and environmental databases to analyze the balance program in terms of cost and pollutant yield. Therefore, LEAP model is suitable to be applied to scenario analysis. It is possible to set up various policies to draft cases of study and then analyze the advantages and shortcomings of them.

### 1.8.3 MARKAL model

In 1976, the IEA developed MARKAL (Market Allocation) model and promoted many nation initiatives for its use. MARKAL model is an energy system analysis tool based on multi-objective linear planning method. The model is a partial equilibrium model mainly composed of an energy database and a linear planning software. It pays great attention to the energy technologies, uses 21 kinds of constraint equations to assure supply-demand balance and economic growth, and sets up an objective function to get an energy program which aim is to get the lowest cost or the minimum pollutant emission. The model is able to be used for optimization and solving, as was shown by Naughten (2003) [77] and Evasio (2004) [78].

### 1.8.4 SD model

The System Dynamics (SD) is a computer-aided approach to policy analysis and design developed by J. Forrester at Massachusetts Institute of Technology (MIT) in

## 1.9 The system dynamics approach

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1956, applicable to modelling and simulating complex systems. SD allows to study the *cause-and-effect* relationship among the factors inside the system and depends on a computer simulation to conduct a quantitative analysis. SD is characterized for dependence on the inherent mechanism of a large complex system to complete the simulation. Thus, once the model is calibrated, it could be used to rightly forecast the system state. SD is also an approach to understanding the behaviour of complex systems over time. It deals with internal feedback cycles and time delays that affect the behaviour of the overall system. What makes different SD from other approaches, to study complex systems, is the use of *feedback-loops, stocks and flows*. These elements, which are described as deceptively simple systems display a bewildering nonlinearity.

Since this work try to model, in macro and sectoral basis, the production system of a given country, the use of primary energy and fossil fuel. In addition, this research attempts to use a formation approach of the GDP that includes the effect of renewable energies, which introduces a feedback mechanism. SD is an ideal tool to carry out such a task. Therefore this approach will allow us to draw robust conclusions about the behavior of the individual components as well as of the whole system.

## 1.9 The system dynamics approach

SD is an approach to system theory as a method for understanding the dynamic behaviour of complex systems. The basis of the method is the recognition that the structure of any system: the many circular, interlocking, sometimes *time-delayed* relationships among its components, is often just as important, in determining its behaviour, as the individual components themselves. Examples are chaos theory and social dynamics. It is also claimed that because there are often *properties-of-the-whole* which cannot be found among the properties of its *elements*, in some cases the behaviour of the whole cannot be explained in terms of the behaviour of the parts.

SD is currently being used throughout the public and private sector for policy analysis and design (Radzicki and Taylor, 2008) [79]. The best known SD model is probably *The Limits to Growth* (Meadows, Donella H., 1972) [80]. This model

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predicts that exponential growth would lead to economic collapse during the 21st century under a wide variety of growth scenarios. The use of SD methodology for the understanding of complex environmental systems has increased significantly in the last decades. SD has been used to study climate change policies and the evolution of the economy (Naill, 1992 [81]; Nordhaus, 1996 [82]; Fiddman, 2002 [83]; Feng, 2012 [84]). Bassi and Baer (2009) [85] carried out an SD study trying to answer whether an annual investment of 1% of GDP to mitigate the negative economic impacts of climate change, would allow for the reduction of GHG emissions in Ecuador.

SD approach involves, in general, the following aspects:

- Defining problems dynamically, in terms of graphs over time.
- Striving for an endogenous, behavioural view of the significant dynamics of a system, a focus inward on the characteristics of a system that themselves generate or exacerbate the perceived problem.
- Thinking in all concepts of the real system as continuous quantities interconnected in loops of information feedback and circular causality.
- Identifying independent stocks or accumulations (levels) in the system and their inflows and outflows (rates).
- Formulating a behavioural model capable of reproducing, by itself, the dynamic problem of concern. The model is usually a computer simulation model expressed in nonlinear equations, but it is occasionally left unquantified as a diagram capturing the stock-and-flow/causal feedback structure of the system.
- Deriving understandings and applicable policy insights from the resulting model.
- Implementing changes resulting from model-based understandings and insights.

The theory about SD is extensive, we will follow the introduction given by System Dynamics Society [86]. Further information can be found in Garcia (2011) [87].

### 1.9.1 Modelling and simulation

Mathematically, the basic structure of a formal SD computer simulation model is a system of coupled, nonlinear, first-order differential (or integral) equations,

$$\frac{d}{dt}x = f(x, p) \quad (1.2)$$

where  $x$  is a vector of levels (stocks or state variables),  $p$  is a set of parameters, and  $f$  is a nonlinear vector-valued function.

Simulation of such systems is easily accomplished by partitioning simulated time into discrete intervals of length  $d_t$  and stepping the system through time one  $d_t$  at a time. Each state variable is computed from its previous value and its net rate of change  $x'(t) : x(t) = x(t - d_t) + d_t * x'(t - d_t)$ . The computation interval  $d_t$  is selected small enough to have no discernible effect on the patterns of dynamic behaviour exhibited by the model. In more recent simulation environments, more sophisticated integration schemes are available.

In present dissertation, the main use of SD, apart that for calculation the evolution of the system, is for *understanding* the dynamics of complex systems for the purpose of policy analysis and design. The conceptual tools and concepts given by SD, including feedback thinking, stocks and flows, the concept of feedback loop dominance, and an endogenous point of view, are as important as its simulation methods.

### 1.9.2 Feedback thinking

The feedback concept is at the heart of the SD approach. Diagrams with feedback and causality loops are tools for conceptualizing the structure of a complex system and for communicating model-based insights. Intuitively, a feedback loop exists when information resulting from some action *travels* through the system and eventually returns in some form to its point of origin, potentially influencing future action. If the tendency in the loop is to reinforce the initial action, the loop is called a *positive* or reinforcing feedback loop<sup>1</sup>; if the tendency is to oppose the

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<sup>1</sup>Reinforcing loops are sources of growth or accelerating collapse; they are disequilibrating and destabilizing.

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initial action, the loop is called a *negative* or balancing feedback loop<sup>1</sup>. The sign of the loop is called the polarity. Combined, reinforcing and balancing circular causal feedback processes can generate all manner of dynamic patterns.

### 1.9.3 Loop dominance and nonlinearity

The loop concept underlying feedback and circular causality by itself is not enough, however. The explanatory power and insightfulness of feedback understandings also rest on the notions of active structure and loop dominance. Complex systems change over time. A crucial requirement for a powerful view of a dynamic system is the ability of a mental or formal model to change the strength of influences as conditions change, that is to say, the ability to shift active or dominant structure. This ability to shift loop dominance comes about endogenously from nonlinearities in the system. Only nonlinear models can endogenously alter their active or dominant structure and shift loop dominance. From a feedback perspective, the ability of nonlinearities to generate shifts in loop dominance and capture the shifting nature of reality is the fundamental reason for advocating nonlinear models of social system behaviour.

#### 1.9.3.1 The endogenous point of view

The concept of endogenous change is fundamental to the system dynamics approach. It dictates aspects of model formulation: exogenous disturbances are seen at most as triggers of system behaviour (like displacing a pendulum); the causes are contained within the structure of the system itself (like the interaction of a pendulum's position and momentum that produces oscillations). Corrective responses are also not modeled as functions of time, but are dependent on conditions within the system. Time by itself is not seen as a cause.

But more importantly, theory building and policy analysis are significantly affected by this endogenous perspective. Taking an endogenous view exposes the natural compensating tendencies in social systems that conspire to defeat many

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<sup>1</sup>Balancing loops can be variously characterized as goal-seeking, equilibrating, or stabilizing processes. They can sometimes generate oscillations, as when a pendulum seeking its equilibrium goal gathers momentum and overshoots it.

policy initiatives. Feedback and circular causality are delayed, devious, and deceptive. For understanding, system dynamics practitioners strive for an endogenous point of view. The effort is to uncover the sources of system behaviour that exist within the structure of the system itself.

### 1.9.3.2 System structure

These ideas are captured in Forrester's (1969) [88] organizing framework for system structure:

- Closed boundary
  - Feedback loops
    - \* Levels
    - \* Rates
      - Goal
      - Observed condition
      - Discrepancy
      - Desired action

The closed boundary signals the endogenous point of view. The word *closed* here does not refer to open and closed system in the general system sense, but rather refers to the effort to view a system as causally *closed*. The modeller's goal is to assemble a formal structure that can, by itself, without exogenous explanations, reproduce the essential characteristics of a dynamic problem.

The causally *closed* system boundary at the head of this organizing framework identifies the endogenous point of view as the feedback view pressed to an extreme. Feedback thinking can be seen as a consequence of the effort to capture dynamics within a closed causal boundary. Without causal loops, all variables must trace the sources of their variation ultimately outside a system. Assuming, instead, that the causes of all significant behaviour in the system are contained within some *closed* causal boundary forces causal influences to feed back upon themselves, forming causal loops. Feedback loops enable the endogenous point of view and give it structure.

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### 1.9.3.3 Levels and rates

Stocks (levels) and the flows (rates) that affect them are essential components of system structure. A map of causal influences and feedback loops is not enough to determine the dynamic behaviour of a system. A constant inflow yields a linearly rising stock; a linearly rising inflow yields a stock rising along a parabolic path, and so on. Stocks (accumulations, state variables) are the memory of a dynamic system and are the sources of its disequilibrium and dynamic behaviour.

Forrester (1961) [88] placed the operating policies of a system among its rates (flows), many of which assume the classic structure of a balancing feedback loop striving to take action to reduce the discrepancy between the observed condition of the system and a goal. The simplest rate structure results in an equation of the form  $NETFLOW = (GOAL - STOCK) / (ADJTIM)$ , where  $ADJTIM$  is the time over which the level adjusts to reach the goal.

### 1.9.3.4 Behaviour is a consequence of system structure

The importance of levels and rates appear most clearly when one takes a continuous view of structure and dynamics. Although a discrete view, focusing on separate events and decisions, is entirely compatible with an endogenous feedback perspective, the system dynamics approach emphasizes a continuous view. The continuous view strives to look beyond events to see the dynamic patterns underlying them.

Moreover, the continuous view focuses not on discrete decisions but on the policy structure underlying decisions. Events and decisions are seen as surface phenomena that ride on an underlying tide of system structure and behaviour. It is that underlying tide of policy structure and continuous behaviour that is the focus of system dynamicity.

There is thus a distancing inherent in the system dynamics approach, not so close as to be confused by discrete decisions and myriad operational details, but not so far away as to miss the critical elements of policy structure and behaviour. Events are deliberately blurred into dynamic behaviour. Decisions are deliberately blurred into perceived policy structures. Insights into the connections between system structure and dynamic behaviour, which are the goal of the system dynamics approach, come from this particular distance of perspective.

## 1.10 Hypothesis of environmental Kuznets curve

The Environmental Kuznets Curve (EKC) hypothesis postulates an *inverted-U-shaped* relationship between different pollutants and per capita income, *i.e.*, CO<sub>2</sub> emission of an economy could increased up to a certain level as the income of the economy goes up, after that, this relationship could show a significant change. The EKC actually reveals how a technically specified measurement of environmental quality changes as the income of a country changes. A rich literature on EKC has grown in recent years. The common point of all the studies is the assertion that the environmental quality deteriorates at the early stages of economic development/growth and subsequently improves at the later stages. In other words, environmental pressure increases faster than income at early stages of development and slows down relative to income growth at higher income levels (see Figure 1.2).

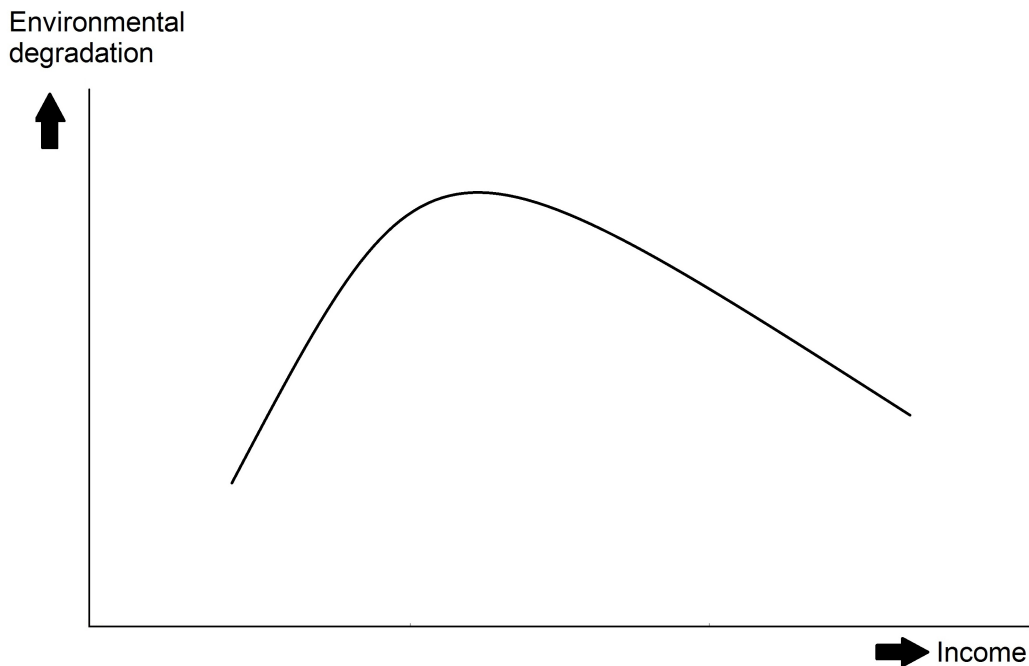


Figure 1.2: Environmental Kuznets Curve.

The name EKC of the *inverted-U* relationship comes from of the work of Kuznets (1955) [89] who postulated a *inverted-U* relationship between income in-

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equality and economic development. The logic of EKC hypothesis follows the general intuition. In the first stage of industrialization process, pollution grows rapidly because high priority is given to increase material output, and the economy is more interested in create jobs and income than to maintain clean air and water (Dasgupta et al., 2002) [90]. The rapid growth due to a industrialization process inevitably results in greater use of natural resources and emission of pollutants, which in turn put more pressure on environment. The country are too poor to pay for abatement, and/or disregard environmental consequences of growth. In a later stage of industrialization, as income rises, the government and people value the environment more, regulatory institutions become more effective, green energy and energy efficiency are more frequent and pollution level declines. Thus, EKC hypothesis posits a well-defined relationship between level of economic activity and environmental pressure (defined as the level of concentration of pollution or flow of emissions, depletion of resources, etc.). The EKC reveals how a technically specified measurement of environmental quality changes as the income of a country.

In brief, Environmental Kuznets Curves are statistical tool that summarize a important aspects of collective human behavior in two dimensional space where pollution indicators are plotted against income per capita.

### 1.10.1 Policy implication for EKC

Nowadays EKC has become standard fare in technical conversations about environmental policy. Understanding the impact of economic growth on environmental quality is becoming increasing important as environmental concerns are making their way into main public policy agenda (Anderson and Cavandish, 2001) [91]. The policy implication of EKCs is that promoting economic growth is a sufficient criteria to safeguard the environment. In the long run, the surest way to improve the environment is to *become rich* (Beckerman, 1992) [92]. But environmental policies may or may not be implemented when economy develops (Shafik and Bandyopadhyay, 1992) [93]. There are several points that obstruct a clear policy conclusion derived from the EKCs. The work of Dinda (2004) [94] collects some questions about related policies with EKC, such as:

## 1.10 Hypothesis of environmental Kuznets curve

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- *Is EKC valid for all types of environmental pressure?* Empirical evidences suggest that environmental problems may be solved at higher levels of income only for some environmental quality indicators. This is true when there is a direct link between environmental quality and human health impacts (Gangadharan and Valenzuela, 2001) [95]. The EKC applies only to environmental problems that are easy to solve and which are well documented and well known.
- *Is EKC permanent?* The EKC hypothesis assumes that the initial increases in environmental pressure are temporary, but that the subsequent decreases in environmental pressure are permanent. Only a few number of authors have questioned whether these observed decreases could also be a temporary phenomenon due to technological limitation (Dinda et al., 2000) [96]. Grossman and Krueger (1995) [97], de Bruyn and Opschoor (1997) [98] and Sengupta 1997 [99] among other found *N*-shaped curve evidence. An upswing of EKC can be explained by the difficulty of keeping up efficiency improvements (innovation) with continuing growth of production.
- *Is EKC valid both for individual countries and for the World?* In general, EKC estimates use cross-section panel of countries. Such estimates do not guarantee that over time, individual countries will move along the estimated relationship (de Bruyn et al., 1998) [100]. The results of panel countries and that of individual or sub-sample countries vary widely (Dijkgraaf and Vollebergh, 1998 [101]; Stern and Common, 2001 [102]). Developed countries are often associated with lower emission reductions but in developing countries, the environmental pressure increases over time. Developing countries have not yet reached income levels high enough to be able to derive their turning points (TP). The worldwide emission prospects are not optimistic as it might be expected on the basis of EKC results. According to EKC hypothesis, the improvements in environmental quality are not attainable for the majority of the world population that has the standards of living substantially below the estimated turning points (Stern et al., 1996) [103]. Therefore, worldwide emissions are expected to continue to increase due to economic growth (Selden and Song, 1995) [104].

## 1. INTRODUCTION

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- *Does EKC follow a sustainable development path?* EKCs represent the patterns of flows of pollutants, whereas environmental impacts are often characterized as a stock problem (Arrow et al., 1995) [105]. The EKC, therefore, does not necessarily reflect a sustainable time path of pollution (Dinda, 2003a [106]; Ekins, 1998 [107]; Gruver, 1976 [108]; Zang, 1998 [109]). Maximum level of pollution depends on costs and benefits of pollution abatement, which differ among countries. Differences in absorptive capacities, social preferences and discount rates give rise to different cost–benefit structures, which implies different optimal levels of pollution among countries. This limits the policy relevance of an estimated collective turning point for a whole sample of countries. There is no guaranty that the rising part and top of EKC bypass ecological thresholds and sustainability constraints beyond which environmental deterioration will become irreversible (Arrow et al., 1995 [105]; Panayotou, 1997 [110]). Note that a positive answers to these questions would grant the EKC policy relevance. Negative answers would indicate that the validity and policy relevance of EKCs is partial with respect to countries, indicators, time and cost-effectiveness.

Restructuring the environment may become unnecessarily expensive, and it may be less costly to prevent or abort today than in future (Dinda, 2004) [94]. Most of authors agree that environmental policies are key determinants of the future path of income–environment relationship. The environmental policy is a function of the preferences of society. Actual levels of environmental quality depend on weights placed on various heterogeneous societal preferences by policy makers, which can be generally characterized as the policy regime. One major determinant of environmental policy is the socio-political regime of a particular country.

### 1.10.2 A critique of EKC

It is clear that EKC can take shape from a multiplicity of possible outcomes of economic development. The EKC model has elicited conflicting reactions from researchers and policymakers. The stakes in the EKC debate are high for both developing and developed countries. Therefore, a special attention is required for multiple factors that form the economic–environmental system, rather than a single

## 1.10 Hypothesis of environmental Kuznets curve

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dominant one (Ezzati et al., 2001) [111]. It is a very hard task to determine the factors that may dominate and govern the EKC shape due to that these factors are interdependent. The uses of reduced form models deny any insight into the underlying causes of EKCs. Since both income and environmental quality are endogenous variables, *i.e.*, the impact each other, therefore, the estimation of a single equation relationships where simultaneity exists will produce biased and inconsistent estimates (Hung and Shaw, 2002) [112]. The lack of information on the process causing the down-turn in the curve of pollution beyond a particular income level, makes a very difficult task, the design of a specific policy from EKC study. The EKC analysis thus has significant deficiencies. There are increasing grounds to be cautious about EKC hypothesis [94].

### 1.10.2.1 A conceptual critique

It is clear from the existing literature that most of the world's population lies on the upward sloping portion of EKCs. Therefore the environmental quality may also deteriorate as population pressure increases more and more. This implies that, even if the EKC exists, income growth across the global population will increase environmental damage (Ekins, 1998) [107]. Such damage is considered to be the main obstacle or hindrance to attaining sustainable development (O'Neill et al., 1996) [113]. Thus, economic growth may not automatically lead to a higher environmental quality and only strong pressure for environmental policy may help in this regard (Grossman and Krueger, 1995) [97]. Better policies and institutional setup can help to flatten the EKC (Panayotou, 1997) [110].

Environmental policy is designed on the basis of empirical findings, which actually depends on the choice of appropriate variables (measured in terms of relative or absolute level). Empirical studies have mostly used absolute measure of pollution like amount of emission or pollution rather than a relative measure (like pollution or emission per unit of output or per square kilometer, etc.). Use of a relative measure of pollution or emission, *i.e.*, pollution intensity, may reveal a *U*-shape or a monotonic relation with income rather than an inverted-*U*-shape (which may be true for absolute level). For example, incorporating spatial intensity of economic activity may turn the relationship between per capita income and atmospheric concentration of SO<sub>2</sub> upside down (Kaufmann et al., 1998) [114]. It should be noted

## 1. INTRODUCTION

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in this context that the effect of income on pollution intensity tends to be negative in open economies, but positive in the closed ones (Dinda, 2002 [115]).

The objective of an empirical study is not only to find the existing relationship but also to help predict the future. Forecasting (or predictions) of environmental quality actually depends on the estimated income-environment relationship (which is based on observed data). Prediction will be meaningful and correct if the existing relations hold in future. Predictive success is really a very limited conception over a longer period of time. For example, the immediate past has allowed much growth and technological progress that does not mean the same holds for an indefinite period of time into the future. The existence of EKC does not ensure to exist in future because of pressures of global competitions for environmental standards and regulations. The EKC analysis does not yet establish the channels through which economic globalization affects the pollution levels or existing environmental quality (Tisdell, 2001) [116].

### 1.10.2.2 A methodological critique

As previously mentioned, several authors have applied various methodologies in their empirical studies. Most of the studies have used cross-section data to examine the EKC hypothesis for group of countries and enough attention has not been given to country-specific EKC. The basic assumption behind pooling the data of different countries in one panel is that economic development trajectory would be the same for all. This assumption should be criticized because wide cross-country variations are observed in social, economical, political and biophysical factors that may affect environmental quality. (For example, the quantity and quality of natural resources varies from country to country.) Under such heterogeneity of conditions, the use of random effect model may be appropriate for examining shape of economic growth–environment relationship based on cross-country, cross-sectional data (Koop and Tole, 1999) [117].

It should be noted that empirical support for the existence of a global EKC for CO<sub>2</sub> emissions has not been found, although some meaningful relationships between income and CO<sub>2</sub> emissions in individual countries have been observed

## 1.10 Hypothesis of environmental Kuznets curve

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(Dijkgraaf and Vollebergh, 1998) [101]. The coefficient estimates for carbon emissions<sup>1</sup> for a panel of OECD countries differ from those obtained for individual country-specific time series that constitute the panel. Little attention has been paid to time series properties of the data, whether variables used in EKC are stationary or/and integrated (Perman and Stern, 1999 [121]; Coondoo and Dinda, 2002 [122]).

A number of relevant factors have so far been omitted in the EKC studies, such as transboundary and intergenerational externalities (Ansuategi et al., 1998 [123]; Copeland, 1995 [124]). Trade is supposed to be an important explanatory factor for EKC relationship. As argued above, high-income countries have greater emission reduction possibilities because they may shift polluting industries to other countries through trade. The export and import of manufactured goods are likely to be much stronger determinants of the level of energy consumption than income (Suri and Chapman, 1998) [125]. The amount of energy consumption depends on its prices. Thus, the energy price may be a relevant variable for explaining EKC (Agras and Chapman, 1999) [126].

The non-availability of actual data on environmental quality is the major limitation of all EKC studies. Truly speaking, environmental quality is something that is not easy to be measured accurately. Therefore, an index of environmental quality, which could be better measurement, should be developed and used to examine the EKC hypothesis (Fare et al., 2001) [127].

The empirical robustness of EKC relation still remains an open issue (Grossman and Krueger, 1996) [128]. The reduced form rather than structural form equations have been used in most of the EKC studies. Actually, environmental outcomes are related to endowments of individual countries but (economic measures in) reduced forms are silent about causal mechanisms. More structural forms may warrant exploration, for some interdependence in our environmental indicators is probable (Dinda and Coondoo, 2001) [129].

In sum, the criticisms collected show some of the weaknesses of both the EKC hypothesis itself and the empirical studies that have been conducted to contrast it.

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<sup>1</sup>In this case, non-parametric, Bayesian or/and agent based approach can fit the data better than regression models (Taskin and Zaim, 2000 [118]; Halkos and Tsionas, 2001 [119]; Bartoszezuk et al., 2001 [120]).

## 1. INTRODUCTION

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Therefore it is important to advance in the research of the relationship between income and environment. Precisely for the need to provide more detailed information than that provided by global EKC studies, is recommended the EKC studies by specific country such as we will carry out in Chapter 5.

### 1.10.3 Lessons from the EKC studies

Dinda (2004) [94] states that the outcome of EKC inspired a large amount of research. A number of important lessons for the EKC debate are already emerging from the literature.

**Local versus global pollution:** The EKC relationships are more likely to hold for certain types of environmental damage, *e.g.*, pollutants with more short-term and local impacts, rather than those with more global, indirect and long-term impacts (Arrow et al., 1995 [105]; Cole et al., 1997 [130]; John et al., 1995 [131]).

**The role of national and local policy:** Most of the EKC studies have concluded that income–environmental degradation relationship is likely to be affected significantly by national and local policies. Several studies in this issue have attempted to estimate the influence of policy explicitly. The strong policies and institutions in the form of more secure property rights, better enforcement and effective environmental regulations can help to *flatten* the EKC (Panayotou, 1997) [110].

**Country specific effects:** A more productive approach to the analysis of the relationship between economic growth and environmental impact would be the examination of historical experience of individual countries, using econometric and also qualitative historical analysis (Stern et al., 1996) [103].

**Structural change:** Some authors have attempted to explore empirically which structural factors are responsible for EKC. The scale and the composition of economic activity, and techniques of production (Grossman and Krueger, 1991 [132]; Vukina et al., 1999 [133]; Xiaoli and Chatterjee, 1997 [134]), which may lend explanatory power to the observed relationships between income levels and measures of environmental impacts. Although structural change is a very intuitive notion, empirical evidence is found for the impact of difference in the structure of production on polluter manufacturing emissions (Lucas et al., 1992) [135].

## 1.10 Hypothesis of environmental Kuznets curve

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**Technological progress:** In general, technological progress leads to greater efficiency in the use of energy and materials. Therefore, a given amount of goods can be produced with successively reduced burdens on natural resources and environment. One aspect of this progress may be better and more efficient reuse and recycling of materials, which (coupled with greater efficiency in use) can yield large resource savings [94].

**Research and development:** As income grows, people can adopt better and more efficient technology that provide cleaner environment. This preferential behaviour of people should be reflected through their income elasticity. The income elasticity of public research and development funding for environmental protection is positive (Komen et al., 1997) [136]. The effect of economic growth on pollution/emissions differs substantially among high-income countries. Relative income and political framework in which policy decisions are taken determine the emergence of downward sloping segment of EKC. This also depends on the adoption of new technology.

**Innovation and adoption:** New technologies, unambiguously, improve productivity but create potential dangers to the society such as new hazardous wastes, risk and other human problems. These effects are unknown in the early phase of diffusion of technology, in later stages regulation becomes warranted to address it. Once the technology is regulated, this may stimulate the gradual phase out of existing technology. Then, a cyclical pattern arises in technologies, which first diffuse, after become regulated and finally are phased out by next generation of technologies (Smulder and Bretschger, 2000) [137].

**Technological and organizational change:** Improved technology not only significantly increases productivity in the manufacture of old products but also the development of new ones. There is a growing trend among industries to reconsider their production processes and thereby take environmental consequences of production into account. This concerns not only traditional technological aspects but also the organization of production as well as the design of products. Technological changes associated with the production process that may also result in changes in the input mix of materials and fuels (Lindmark, 2002) [138]. Material substitution may be an important element of advance economics (Labys and Wadell, 1989) [139] that may result in lower environmental impacts. The economy-wide reforms

## 1. INTRODUCTION

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often contribute simultaneously to the economic, social and environmental gains (Anderson and Cavandish, 2001 [91]; Pasche, 2002 [140]).

The EKC approach seeks to relate the stages of economic development of a country to that of environmental degradation. Developing countries could learn from the experiences of already industrialized countries, and restructure growth and development to tunnel through (Munasinghe, 1999) [141] any potential EKC- thereby avoiding going through the same stages of growth that involve relatively high (and even irreversible) levels of environmental harm.

However, it is not clear which effective environmental policies should cover to reduce pollution. But, almost all studies investigating EKCs have alluded to the important policy implications of their work [94].

### 1.11 The goals of the dissertation

The general objective of this research is create a useful methodology to estimate CO<sub>2</sub> emissions for a given country, in particular for Ecuador, and to understand the driving forces that guide this process, such as economic growth, energy use, energy mix structure, and fuel use in the productive sectors. The proposed methodology tries to be easily transferable to other countries, regions, and time periods and to be used as a *pedagogical tool* for explaining to policymakers the possible ways to design a policy for reducing CO<sub>2</sub> emissions in a medium term horizon.

A multi-scenarios approach is used to analyze the evolution of energy consumption and energy-related emissions and its implications in the socio-economic and environmental development of the study area. This study could help the development and implementation of proactive policies to the challenge of sustainable development.

The application of *scenario analysis-modelling* in the short-to-medium term is intended to develop insights into plausible future changes with green goals in the driving forces of the national policies. While the decomposition analysis gives insights into historical change. The combination of scenario analysis-modelling, decomposition analysis and EKC hypothesis in this study gives rise to the following specific research objectives:

## 1.11 The goals of the dissertation

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1. To identify and analyse the historical pattern of income, energy use and the related CO<sub>2</sub> emissions in Ecuador (1980-2010) by applying decomposition analysis in sectoral level.
2. To study in detail the way the changes in the energy matrix and in the Gross Domestic Product (GDP) will affect CO<sub>2</sub> emissions of the country. In particular, we will pay special attention to the effect of a reduction of the share of fossil energy, as well as of an improvement in the efficiency of the fossil energy use.
3. To develop a set of integrated qualitative and quantitative baseline scenarios at both macro and sectoral level to explore plausible alternative development of income, energy use and CO<sub>2</sub> emissions in a medium term (2025) in Ecuador.
4. To test the existence of the EKC hypothesis in Ecuador in the different proposed scenarios. Our proposal goes a step further than previous contributions, and intends to see under which conditions the country could approach the fulfilment of this hypothesis in the medium term.
5. To fill the gap in the literature of studies on the relationship between emissions, energy consumption and income growth in Latin American countries in general, and in Ecuador in particular.

This study combines decomposition analysis with scenario modelling to create a baseline prevision as guidance for possible new policies. This allowed the development of a model with a set of integrated exploratory scenarios about income growth, energy use and CO<sub>2</sub> emissions for Ecuador in a medium term (2025). The scenarios show plausible more *environmental-friendly* trends that the country could take like pathways to get closer to a sustainable development. The study offers potential *longer-term insights* through the exploration of changes in to the driving forces to evaluate the fulfilment of the EKC hypothesis.

### 1.12 Overview of thesis chapters

The thesis is organized into six chapters and seven appendices. Chapter 1 (presented earlier) shows the introduction of the most important aspects of the methodology and aims of the research, the following, Chapter 2 shows the main figures in economy, productive sectors, energy use, etc., in Ecuador since 1980 until 2010; also it discusses about critical factors for the adoption of renewable technologies in the country.

Chapter 3 presents a System Dynamic (SD) model approach of CO<sub>2</sub> emissions in Ecuador in the upcoming years, up to 2025. In this chapter, the way the changes in the energy matrix and in the Gross Domestic Product (GDP) will affect the CO<sub>2</sub> emissions in the country is studied. In particular, it will pay special attention to the effect in emissions of a reduction of the share of fossil energy, as well as of an improvement in the efficiency of the fossil energy use. The results obtained with the model are the starting point for the decomposition analysis in Chapter 4 and for the study of Environmental Kuznets Curve (EKC) in Chapter 5.

Chapter 4 presents a decomposition analysis of income and energy-consumption related CO<sub>2</sub> emissions. Also a review of the main decomposition techniques is shown. Since one of the goals of this research is to analyze the effects of scale, structure and intensity on CO<sub>2</sub> emissions in Ecuador, LMDI approach for this case study has been selected. Note that, the kind and level of desegregation of the data available for the country are supporting the LMDI approach used. We use three periods of 16 years to perform the analysis, two within the set of historical data (1980-1995 and 1995-2010) and the last one corresponds to the estimates (2010-2025). This analysis will allow us to determine the relative importance of each term related with CO<sub>2</sub> emission.

In Chapter 5 we try to respond *if is it possible for a country in the process of development to comply with the EKC hypothesis in the medium term?*. This chapter uses the model that has been developed previously to analyze whether the EKC hypothesis holds within the period 1980-2025 under four different scenarios. We used co-integration techniques [142] to test the existence of the EKC hypothesis in Ecuador in the medium term using the Jaunky's specification [143]. Our proposal goes a step further than previous contributions, and intends to see under

## **1.12 Overview of thesis chapters**

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which conditions a country could approach the fulfilment of this hypothesis in the medium term. Results do not support the fulfilment of the EKC, nevertheless, our estimations show that Ecuador could be on the way to achieving environmental stabilization in the near future if economic growth is combined with an increase in the use of renewable energies, an improvement of the productive sectoral structure, and the use of a more efficient fossil fuel technology.

Finally, in Chapter 6 summary and conclusions are drawn from research findings. Scopes for further research and limitations are also discussed.



*The indifferent men to the misfortunes of the nation, whether privately laborious, are auxiliary unaware of corruption and misery of the people.*

Eloy Alfaro

CHAPTER

# 2

## **Ecuador in figures (1980-2010)**

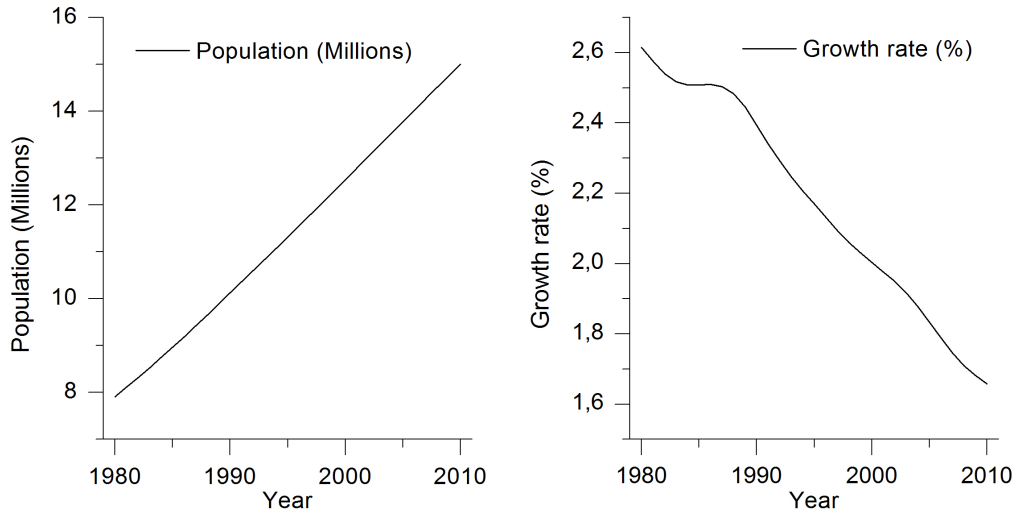
### **2.1 Overview**

Ecuador (officially the Republic of Ecuador) has an area of 272046 km<sup>2</sup> and a population of more than 15.49 million (2012) (WB, 2012) [144]. The population growth rate has shown a downward trend since 1980. During the period 1981-1995, the growth rate was 2.42% and the population multiplied by 1.39, while in the period 1996-2010, the growth rate was 1.25% and the population grew by 1.25 (see Figure 2.1). Ecuadorian territory, which includes the Galapagos Islands, 1000 km off the west coast, has the planet's densest biodiversity. This species diversity makes Ecuador one of the 17 mega-diverse countries in the world (CI, 2012) [145]. The new Ecuadorian constitution of 2008 is the first one in the world to recognize legally enforceable rights of Nature, or ecosystem rights (TCELDF, 2011)[146].

Ecuador is a medium-income country with a Human Development Index score of 0.724 in 2012 (UN Development Program, 2012) [147] and about 35.1% of its population lives below the poverty threshold (IM, 2014) [148]. Its economy is the eighth largest in Latin America and experienced an average annual growth of 6.48% in the period 2011-2012 (WB, 2014) [149].

## 2. ECUADOR IN FIGURES (1980-2010)

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**Figure 2.1:** Left: Evolution of population in Ecuador 1980-2010. Right: Growth rate.

The Ecuadorian income was multiplied by 2.35 times between 1980 and 2010, and the GDP reached a value of around 131 billion US- 2005-PPP<sup>1</sup> dollars (USD) in 2012 (WB, 2014) [149]. Note that the country's public finances are healthy, but they have recognized that the Achilles heel of the Ecuadorian economy is the external sector, due to the deficit, without including oil exports, in the trade balance [150]. Since the late 1960s oil extraction increased. Proven reserves of the country in 2013 are estimated at around 8 billion barrels (IEA, 2013 [151]; Ecuadorian Central Bank, 2012 [150]).

The extreme poverty<sup>2</sup> rate has declined significantly between 2000 and 2010. In 2000, the estimate was approximately 20.7% of the population, while by 2010 this number has dropped down to 4.6% of the total population. This is largely explained by emigration and the economic stability achieved after the dollarization of the economy. Poverty rates were higher for indigenous peoples, afro-descendants and rural areas, reaching 44% of the native population (WB, 2012) [144].

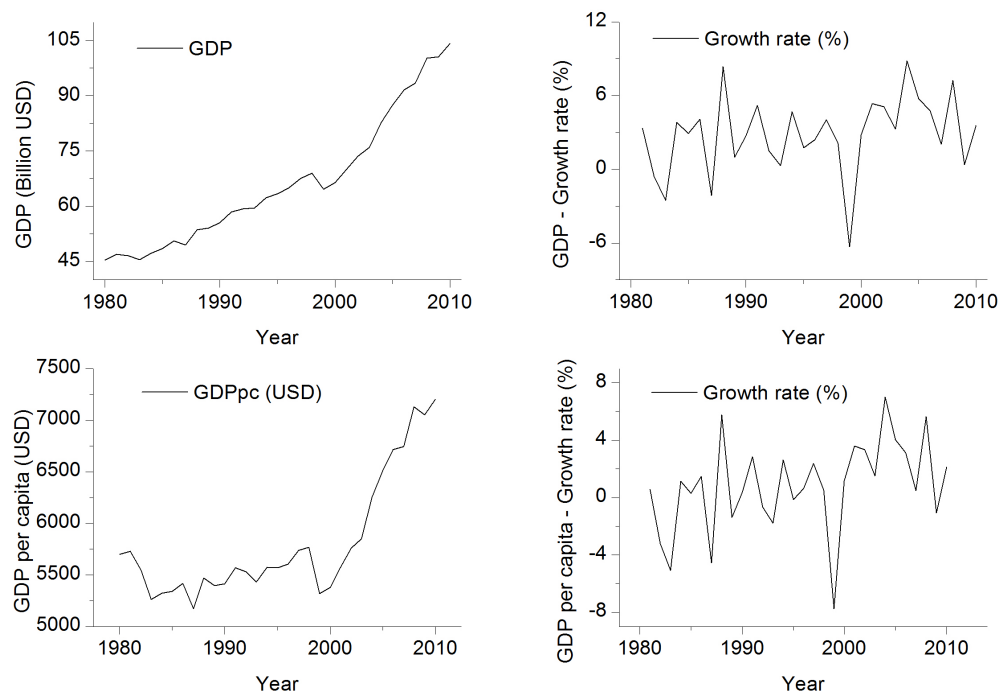
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<sup>1</sup>Purchasing power parity. An international dollar has the same purchasing power over GDP as a U.S. dollar has in the United States.

<sup>2</sup>Population below 1.25 USD a day is the percentage of the population living on less than 1.25 USD a day at 2005 international prices.

## 2.2 Economic figures

Ecuador is substantially dependent on its petroleum resources, which have accounted for more than half of the country's export earnings and approximately two-fifths of public sector revenues in recent years. The average growth rate of GDP in the period 1980-1997 was 2.40 % (see Figure 2.2), with an income per capita around of 5500 USD (WB, 2012) [144]. In 1998-1999, the economy of Ecuador suffered a banking crisis, with GDP contracting by 6.3% and poverty increasing significantly. Per capita income went back to values of a decade earlier (around 5300 USD) (WB, 2012) [144]. In March 2000, the Congress approved a series of structural reforms that including for the adoption of the U.S. dollar as legal tender. Dollarization stabilized the economy, and positive growth returned in the country, helped by high oil prices, remittances, and by increased non-traditional exports (TCELDF, 2011) [146].



**Figure 2.2:** Left: Evolution of GDP and GDP per capita in Ecuador 1980-2010. Right: Growth rate.

## 2. ECUADOR IN FIGURES (1980-2010)

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Between 2002 and 2006 the economy grew an average of 5.54% per year, the highest five-year average in last 25 years and is the first time that the per capita income exceeds 6000 USD (see Figure 2.2). After moderate growth in 2007 (2.04%), the economy reached a growth rate of 7.24% in 2008 and per capita income breaks the barrier of 7000 USD (WB, 2012) [144], buoyed by high global petroleum prices and increased public sector investment. Present President Rafael Correa (who took office in January 2007) defaulted sovereign debt of Ecuador in December 2008, which with a total face value of approximately 3.2 billion USD, represented about 30% of public external debt of the country. In May 2009, Ecuador bought back 91% of its "defaulted" bonds via an international reverse auction (IM, 2014) [148].

Some economic policies under Correa administration to cancel a number of international treaties, which in the opinion of the government are not beneficial to the country<sup>1</sup>, have generated economic uncertainty and discouraged private investment. The Ecuadorian economy slowed to under 1% growth in 2009 due to the global financial crisis and to the sharp decline in world oil prices and remittance flows. Growth picked up to 3.58% in 2010 with an income per capita of 7200 USD (WB, 2012) [144] and nearly 8% in 2011, before falling to 5% in 2012 [149]. China has become Ecuador's largest foreign lender since Ecuadorian government defaulted in 2008, allowing the government to maintain a high rate of social spending; Ecuador contracted with the Chinese government for more than 9 USD billion in oil for cash and project loans in December 2012 (IM, 2014) [148].

Given the availability of data and following the division of the productive sectors of Ecuadorian government (Mosquera, 2008) [152], the productive sectors matrix (PSM) used in this study consists of 5 sections: *i*) Agriculture, fishing and mining, *ii*) industry, *iii*) construction, *iv*) trade and public services and *v*) transport. Note that this is not the standard division of the productive sectors, but it is the most appropriate according to the structure of the available data-set and to the goal of this work<sup>2</sup>. In Figure 2.3 can be observed that the largest sector is Trade

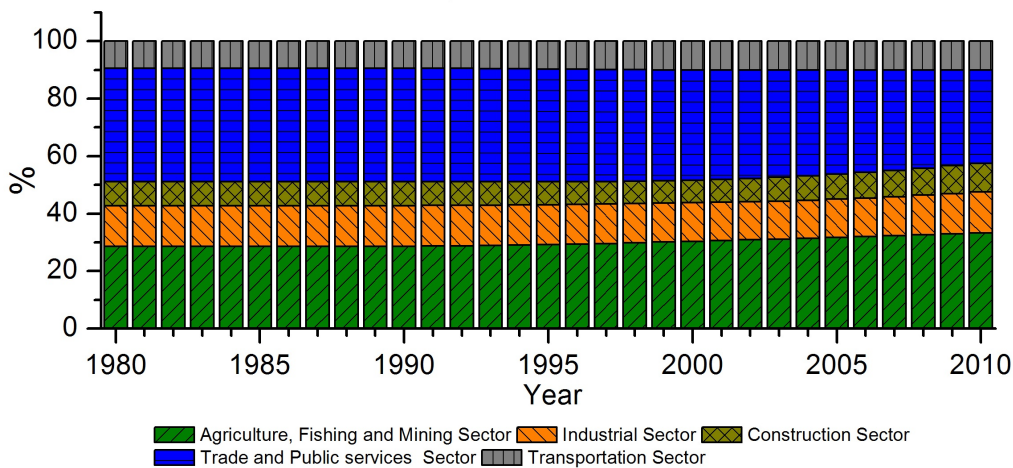
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<sup>1</sup>For example, an announcement in late 2009 of its intention to terminate 13 bilateral investment treaties, including one with U.S.

<sup>2</sup>The usual standard division of productive sectors follows the ISIC specification (International Standard Industrial Classification of All Economic Activities, Rev.4). In particular, the aggregate classification of different economic activities of the same level is: Primary Sector (agriculture, hunting, fishing, ...), Secondary Sector (manufacturing, mining and quarrying, electricity, gas and

## 2.2 Economic figures

and Public services that represented around 38% of GDP in the period 1980-2010, followed by the Agriculture, Fishing and Mining sector (includes income from petroleum) (30%), Industry sector (14%), Transport sector (10%) and Construction Sector (8%).

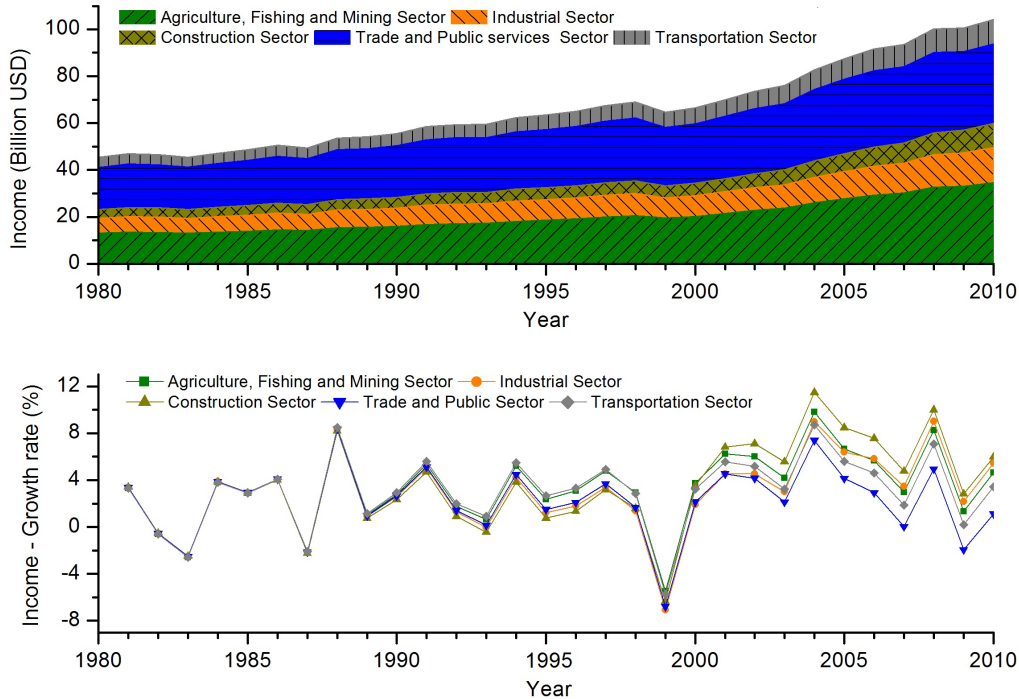


**Figure 2.3:** Productive Sectors Matrix in Ecuador 1980-2010.

Regarding the agriculture, fishing and mining sector, it is seen that has grown by 2.66, from 12.99 billion USD in 1980 to 34.60 billion USD in 2010 with an average growth rate of 3.37%. Industrial sector was multiplied by 2.33, growing from 6.41 to 14.95 billion USD with an average growth rate of 2.92% during the same period. While the construction sector was multiplied by 2.72, growing from 3.79 to 10.29 billion USD with an average growth rate of 3.46% during the period 1980-2010. In the trade and public services sector, the growth rate was the smallest of all sectors, multiplying by 1.90 with an average growth rate of 2.20% and growing from 17.90 to 33.92 billion USD between 1980 and 2010. Finally, in the transport sector the average growth has been 3.07%, growing from 4.26 to 10.41 billion USD, multiplying by 2.04 the value between 1980 and 2010 (see Figure 2.4).

water supply and construction) and Tertiary Sector (services, trade, residential and transportation) (UN, 2008) [153].

## 2. ECUADOR IN FIGURES (1980-2010)



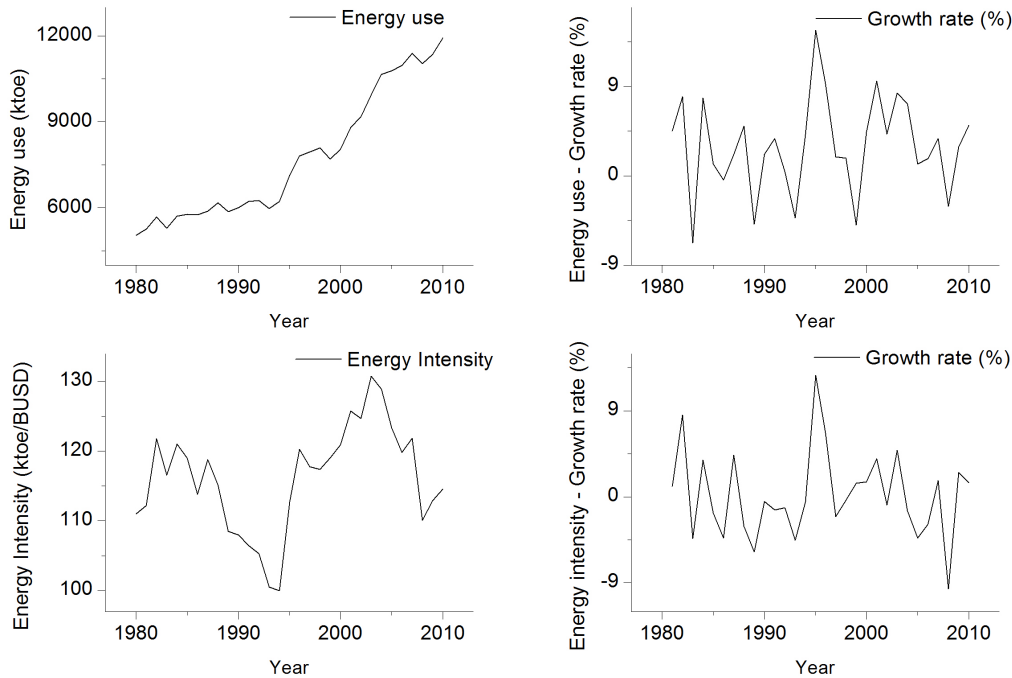
**Figure 2.4:** Top: Evolution of income by productive sector in Ecuador 1980-2010. Bottom: Growth rate.

### 2.3 Energy figures

The analyzed historical data (1980-2010) indicate that Ecuador has become a net exporter of energy but not self-sufficient. The structure of the processing plants, refineries specifically, is inadequate in relation to the composition of the local market, preventing meet energy needs. The request is subject to population growth, economic development and technological advancement. Ecuador, like other countries in the region, does not have complete information and data of its energy potential.

The country energy transition has followed, in general terms, the global trends. The substitution of primary energy supply registered a loss of penetration of the wood on fossil fuels and moderate growth of hydropower. The choice of oil as the main source of energy supply makes the country very vulnerable energetically. The relative abundance of this resource has reduced the prospects for increasing the use of other technologies and diversification of the energy matrix. Despite the high

## 2.3 Energy figures



**Figure 2.5:** Left: Evolution of primary energy consumption and energy intensity in Ecuador 1980-2010. Right: Growth rate. BUSD correspond to billion USD

hydropower potential, a little progress in the effort to transform this potential into an installed capacity for energy generation has been developed. Also, geothermal, wind and solar potential has not been exploited, except in small projects that are developed with international cooperation in specific locations.

Changes in lifestyles and advances in technology have led to changing consumer preferences for energy sources with a increased yield, quality and lower cost. Note that energy consumers are not interested in the sources of the energy they spend, but in a reliable, quality and appropriate service for their machines and devices.

The efficiency of the machines and devices is a decisive factor to reduce fuel consumption, as well as the rational use of the energy. In recent years the concern is evidenced by the use of more efficient equipment which use cheaper energy such as liquefied petroleum gas (LPG) and efficient light bulbs, among others.

## **2. ECUADOR IN FIGURES (1980-2010)**

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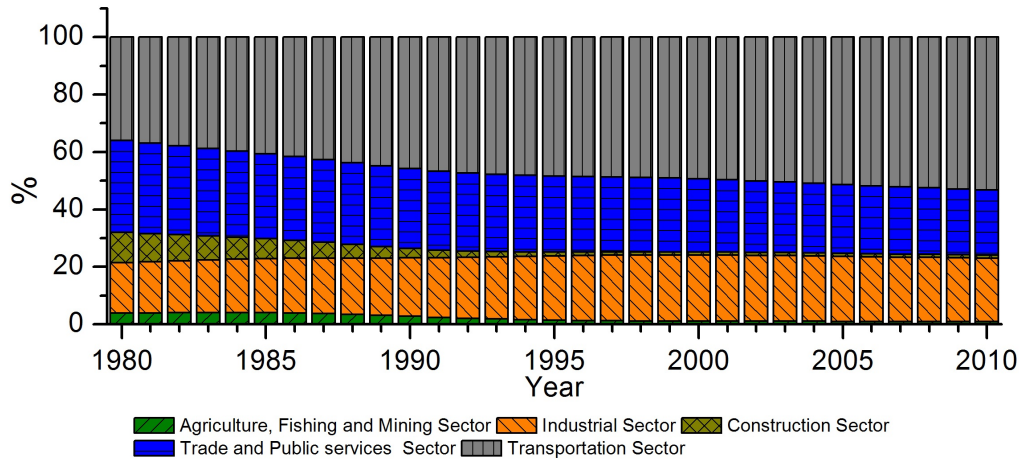
The consumption of primary energy by the country have increased by 2.37 between 1980 and 2010, going from 5032 to 11931 kt of oil equivalent (ktoe) (see Figure 2.5). Global energy intensity has a fluctuating evolution and the average value is 116 ktoe/BUSD in the period 1980-2010 (see Figure 2.5).

### **2.3.1 Energy matrix and energy intensity by sectors**

Agriculture, fishing and mining sector uses mainly gasoline and diesel [152] and historically is the least energy-intensive sector. It represents less than 5% within the energy matrix by sector (see Figure 2.6), showed decreasing trend in the 1980s, with a subsequent stabilization in the following years. The average growth rate is 1.14% but the historical data shows a decline in the use of energy going from 151 ktoe in 1980 to 123 ktoe in 2010 (see Figure 2.7). The energy intensity in the sector is the lowest of all sectors, with a clear downward trend that leds its value from 11.6 to 3.57 ktoe/BUSD between 1980 and 2010 (see Figure 2.8).

In the industrial sector, energy consumption appears less concentrated (regarding the source), due to the characteristics of each production process in various industries. In the first decade of the 21st century, the use of fuel oil predominates (35%), followed by the use of diesel oil (21%), cane products (20%) and finally electricity (15%), while the wood lost penetration (Mosquera, 2008) [152]. Fossil fuels and electricity are used to provide power to industrial cycles for generating prime mover and heat. However, these activities have low productivity per unit of energy, derived from the technologies used, which affects the competitiveness of Ecuadorian products in the international market.

Energy consumption in the industrial sector accounts for about 21% of the energy matrix by sector (see Figure 2.6). The amount of energy used by the sector increased from 856 to 2565 ktoe between 1980 and 2010 (see Figure 2.7). Energy intensity of the sector indicates a fluctuating evolution around an upward trend with a peak of 250 ktoe/BUSD in 2004 that was originated because the fuel mix and the lower efficiency of the technologies used. Since 2005 the sector has shown a shift in energy intensity, leading this intensity to a much lower value in 2010, 172 ktoe/BUSD (see Figure 2.8).



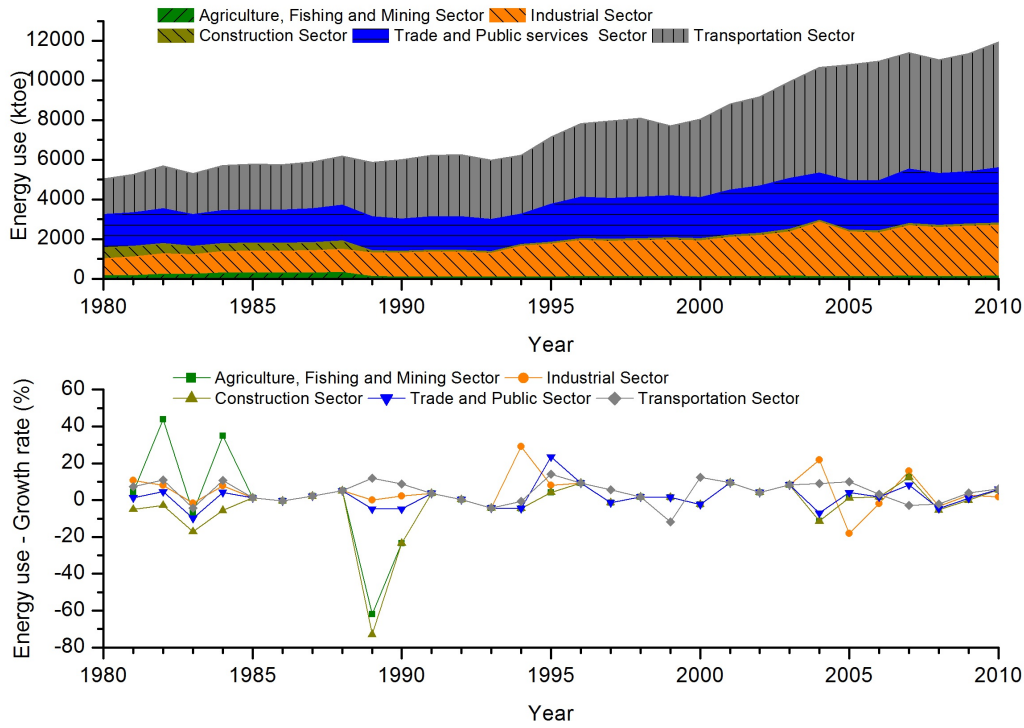
**Figure 2.6:** Evolution of Energy Matrix by productive sectors in Ecuador 1980-2010.

Note that the industrial sector, whose indicators are based on large aggregates, includes a set of very different situations in terms of generating value added. It is necessary to consider features and updated technology as well as energy consumption.

Construction sector mainly uses electricity [152]. It is the second least energy-intensive sector and represents less than 5% of the energy matrix by sector (see Figure 2.6). The average growth rate of energy use is negative with a value of 2.80% in the period 1980-2010. Therefore, the energy use in the sector passed from 554 to 123 ktoe in the same period (see Figure 2.7). The energy intensity shows a clear downward trend, passing from 146 to 12.0 ktoe/BUSD between 1980 and 2010 (see Figure 2.8).

The use of electricity for lighting in trade and public services sector is predominant, which in turn, replaced the diesel oil and gasoline in prime mover. LPG also increased but at a slower pace [152]. It is the second most energy intensive sector after transport sector and represents 27% of the energy matrix by sector (see Figure 2.6). The average growth rate of energy use is 1.93% between 1980 and 2010 passing the energy use from 1661 ktoe in 1980 to 2788 ktoe in 2010 (see Figure 2.7). Energy intensity shows a relatively stable value, which in average has been 81.5 ktoe/BUSD with a small downward trend, passing from 92.8 to 82.2

## 2. ECUADOR IN FIGURES (1980-2010)



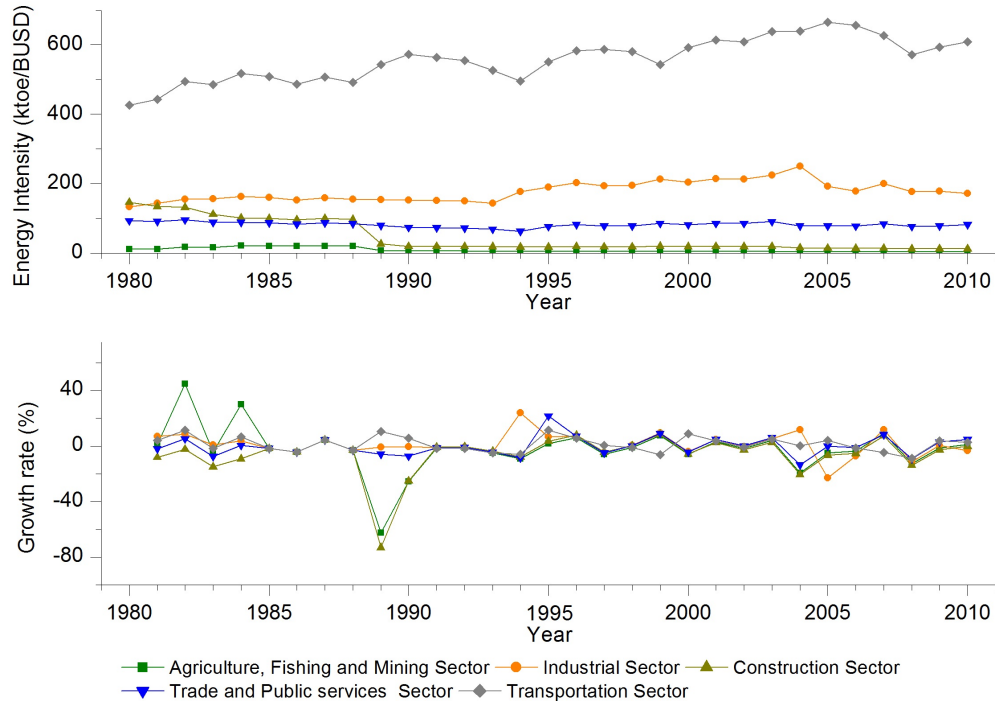
**Figure 2.7:** Top: Evolution of energy use by productive sectors in Ecuador 1980-2010. Bottom: Growth rate.

ktoe/BUSD between 1980 and 2010 (see Figure 2.8).

The residential energy consumption that is included in this sector, shows a significant drop in firewood consumption and an increase in penetration of the LPG and electricity. LPG is dominant in houses for various uses such as water heating and cooking, especially in isolated areas without electricity. The downward trend in the average energy intensity of the residential sector is a reflection of a historical process of improvement in household equipment that has allowed the replacement of inefficient energy sources by others more efficient [152].

The transport is the most energy-intensive sector, accounting for nearly 50% of the country's energy use (see Figure 2.6). With a clear upward trend and it has increased its consumption by 3.50 going from 1812 ktoe in 1980 to 6332 ktoe in 2010 (see Figure 2.7). It is also the largest consumer of liquid fuels. There is a significant fall in the use of gasoline in favor of oil diesel, as a result of the increase use of

## 2.3 Energy figures



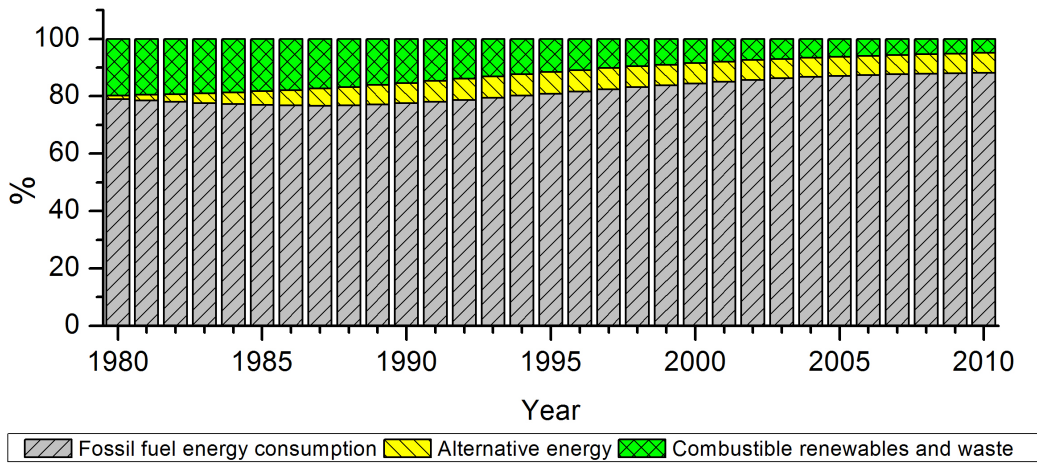
**Figure 2.8:** Top: Evolution of energy intensity by productive sectors in Ecuador 1980-2010. Bottom: Growth rate.

internal combustion engines in freight transport (trucks) and passenger (buses) for middle and long distance (Mosquera, 2008) [152]. The growth of the national fleet has given increasing consumption of gasoline and diesel oil, helped by subsidized prices of these fuels, which are still below the average values of the region. On the other hand, it is observed that energy intensity fluctuates around 550 ktoe/BUSD, with a slightly increasing trend and much higher levels than in the case of industry (see Figure 2.8).

As mentioned above, this sector is the largest energy consumer in the country (about 50% of energy consumption), but it represents only 10% in the generation of income. Transport sector is intensive in the use of energy and shows signs of inefficiency arising from inadequate modal distribution to meet the demand of passengers and freight transport.

## 2. ECUADOR IN FIGURES (1980-2010)

### 2.3.2 Energy matrix by sources



**Figure 2.9:** Evolution of Energy Matrix by energy source in Ecuador 1980-2010.

The energy matrix by sources is composed by the following primary energy sources: *i*) Fossil fuel comprising coal, oil, petroleum, and natural gas products, *ii*) Alternative and nuclear energy, refers to clean energy that is non-carbohydrate energy and does not produce carbon dioxide when generated. It includes hydro-power, geothermal, and solar power, among others, *iii*) Combustible renewables and waste that comprise solid biomass, liquid biomass, biogas, industrial waste, and municipal waste (WB, 2012) [144].

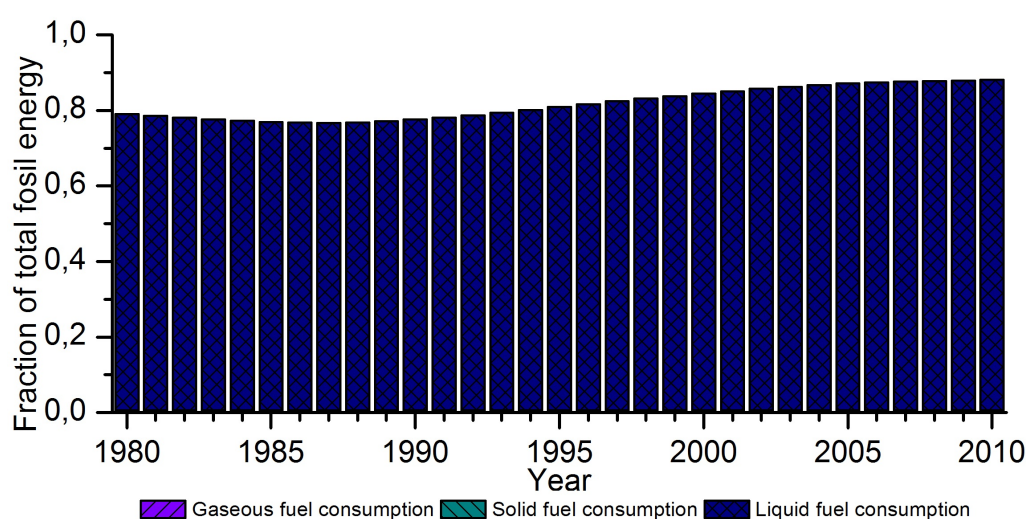
Following the trend of the region and most of the world, in Ecuador there is a strong dependence on fossil fuels, which represent more than 80% of the energy matrix in the period from 1980 to 2010 and have reached a peak of 88% in 2010 (see Figure 2.9).

The use of alternative energy sources has had a very poor increase going from 1.22% to 7.06% (see Figure 2.9) in the national energy matrix between 1980 and 2010.

Furthermore, renewable and waste fuel have presented a considerable reduction passing from 19.7% in 1980 to only 4.9% of the energy matrix in 2010 (see Figure

2.9). This decrease is mainly due to the replacement of firewood by more modern fuels such as LPG within different sectors.

### 2.3.3 Fuel matrix by sources



**Figure 2.10:** Evolution of Fuel Matrix by source in Ecuador 1980-2010.

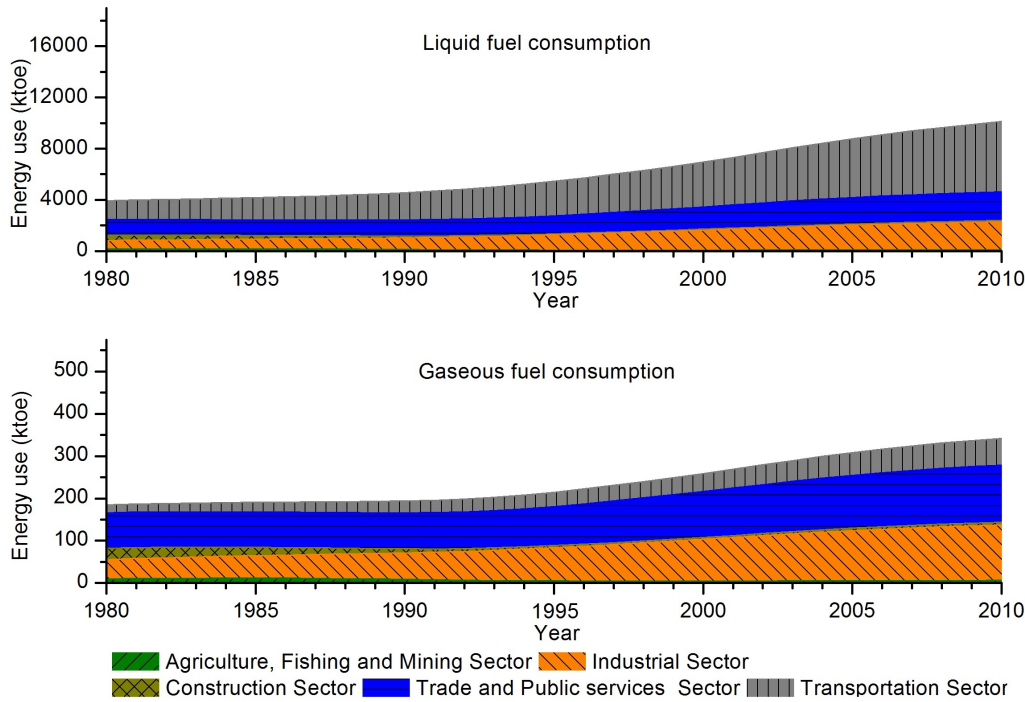
The Fuel Matrix (FM-Sou) refers to the different types of fossil fuels: *i*) Gaseous fuel mainly from natural gas, *ii*) Solid fuel mainly by use of coal, *iii*) Liquid fuel mainly from petroleum-derived fuels. In Ecuador, the use of liquid fuel is predominant in the fuel matrix, over 95% between 1980 and 2010. The rest comes from the use of gaseous fuels and do not have the contribution of solid fuels (see Figure 2.10).

In regard to the use of liquid fuels, the most intensive sector is the transport sector with an average consumption of 3031 ktoe in the period 1980-2010, followed by commerce, public services and residential sector with 1570 ktoe, industry sector with 1306 ktoe, construction sector with 157 ktoe and agriculture, fishing and mining industry with 111 ktoe (see Figure 2.11).

The most intensive sector in gaseous fuel consumption is trade, public services and residential sector with an average consumption of 101 ktoe during the period 1980-2010, followed by the industrial sector with 196 ktoe, transport sector with 37

## 2. ECUADOR IN FIGURES (1980-2010)

ktoe, construction sector with 10 ktOE and agriculture, fishing and mining industry with 7 ktOE (see Figure 2.11).



**Figure 2.11:** Evolution of Fuel consumption by productive sectors in Ecuador 1980-2010. Top: Liquid fuel consumption. Down: Gaseous fuel consumption. Note that there is not consumption of solid fuel in the country.

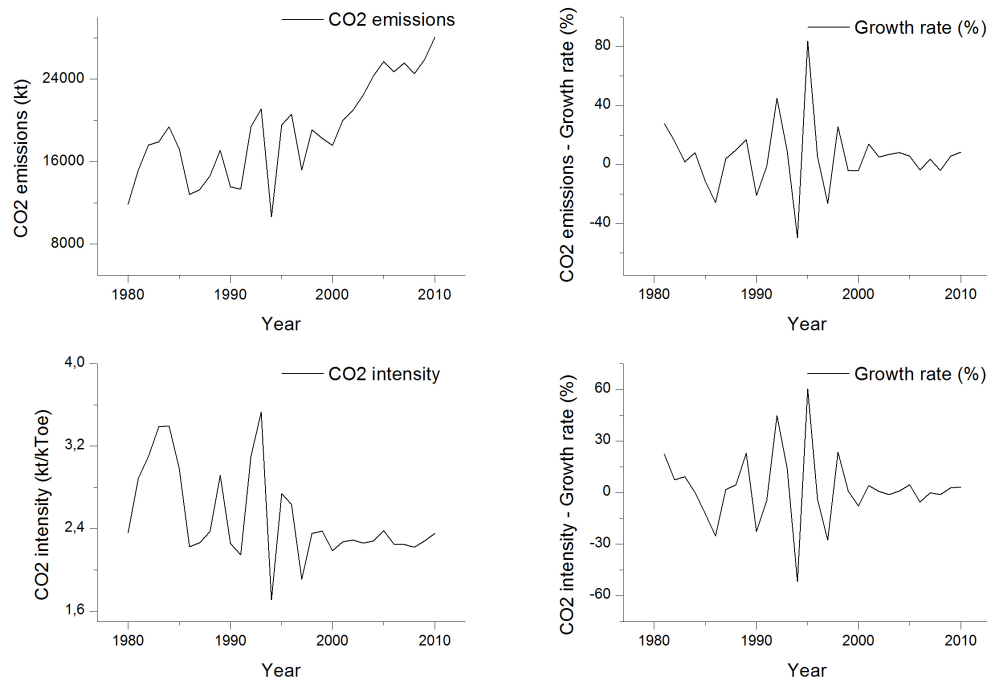
### 2.4 Emissions figures

Ecuador has had a modest but steady increase in CO<sub>2</sub> emissions<sup>1</sup>, mainly due to the increase of population and the growth of the economy, changing habits and more frequent use of devices that require more energy in the different productive sectors of the country. Emissions have increased by 2.37 between 1980 and 2010, passing

<sup>1</sup>CO<sub>2</sub> represents 76.7% of the GHG emissions (approximately 56.6% is from fossil fuels, 17.3% from deforestation, and 2.8% from other sources) (IPCC, 2007) [154], in this dissertation all CO<sub>2</sub> data correspond to burning of fossil fuels

## 2.4 Emissions figures

from 12 to 28 Mtonnes (Mt). Global CO<sub>2</sub> intensity, defined as CO<sub>2</sub> emissions over energy, has a fluctuating evolution and the average value is 2.51 kt/ktoe in the period 1980-2010 (see Figure 2.12).

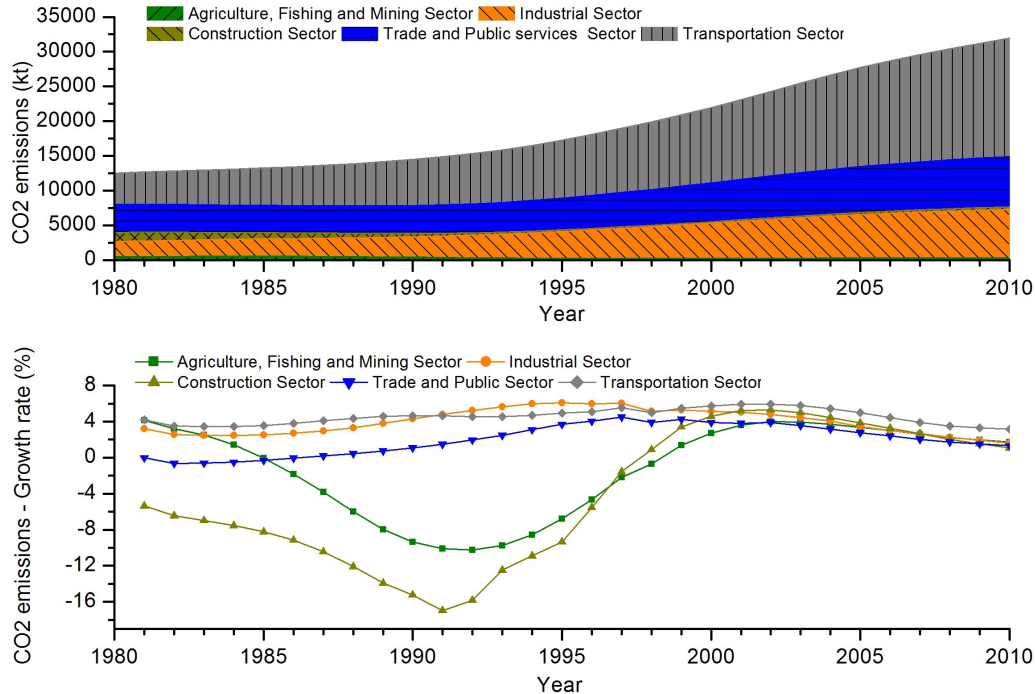


**Figure 2.12:** Left: Evolution of CO<sub>2</sub> emissions and CO<sub>2</sub> intensity in Ecuador 1980-2010. Right: Growth rate.

The sector that reported more emissions is transport which represents more than 50% of emissions in the period 1980-2010, increasing by 3.79, passing from 4.50 Mt in 1980 to 17.1 Mt in 2010 (see Figure 2.13). CO<sub>2</sub> intensity has a clear growing trend and it was multiplied by 3 passing from 19.81 to 59.5 kt/ktoe in this period (see Figure 2.14).

Trade and public services represents more than 20% of emissions between 1980 and 2010. The emissions of this sector has been multiplied by 1.81, going from 3.99 Mt in 1980 to 7.22 Mt in 2010 (see Figure 2.13). CO<sub>2</sub> intensity has a growing trend and it was multiplied by 6.31 passing from 22.3 to 141 kt/ktoe in the same period 1980-2010 (see Figure 2.14).

## 2. ECUADOR IN FIGURES (1980-2010)

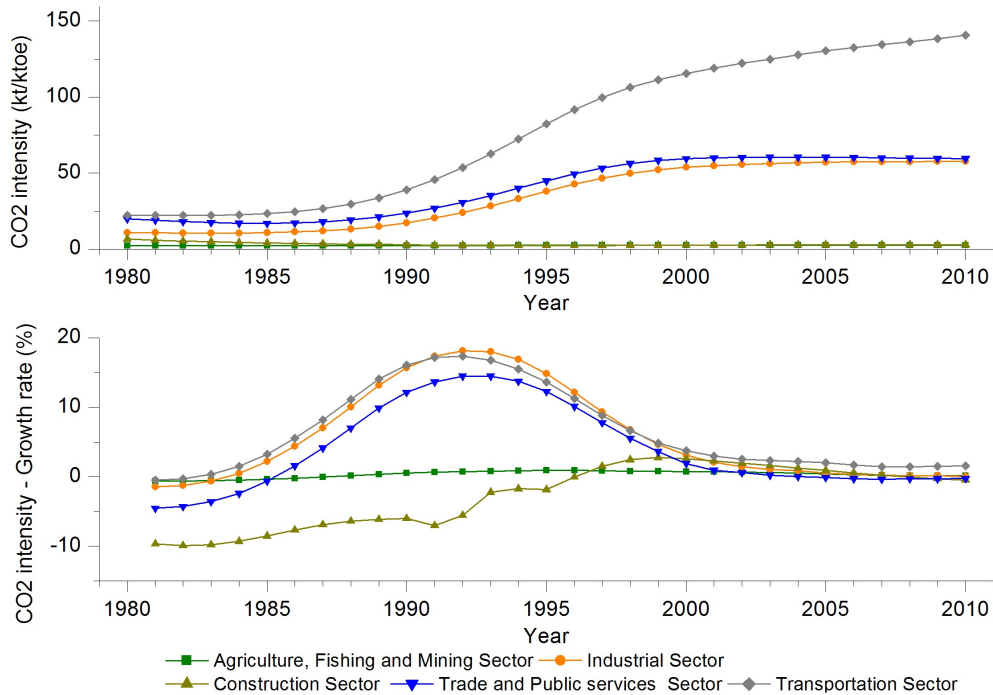


**Figure 2.13:** Top: Evolution of CO<sub>2</sub> emissions by productive sectors in Ecuador 1980-2010. Bottom: Growth rate.

Industry sector represents accounts for about 20% of emissions between 1980 and 2010. This sector has increased by 3.20, going from 2.19 Mt in 1980 to 6.99 Mt in 2010 (see Figure 2.13). This sector has the second largest growth after transportation. CO<sub>2</sub> intensity also has a growing trend and was multiplied by 5.32 passing from 10.8 to 57.6 kt/ktoe between 1980 and 2010 ( see Figure 2.14).

The aggregation of agriculture, fishing and mining sector and construction sector both represents less 10% of emissions between 1980 and 2010. In addition, both sectors have decreased their emissions. Agriculture, fishing and mining sector emissions were multiplied by 0.67 and construction sector by 0.26, going from 0.49 to 0.32 Mt and from 1.32 to 0.34 Mt respectively in the same period (see Figure 2.13). In CO<sub>2</sub> intensity, there is a significant difference between both sectors, while the agriculture, fishing and mining sector has keep an almost constant intensity of 2.48 kt/ktoe for the period 1980-2010, the construction sector has shown a clear

downward trend, from 6.53 to 2.78 in the same period. (see Figure 2.14).

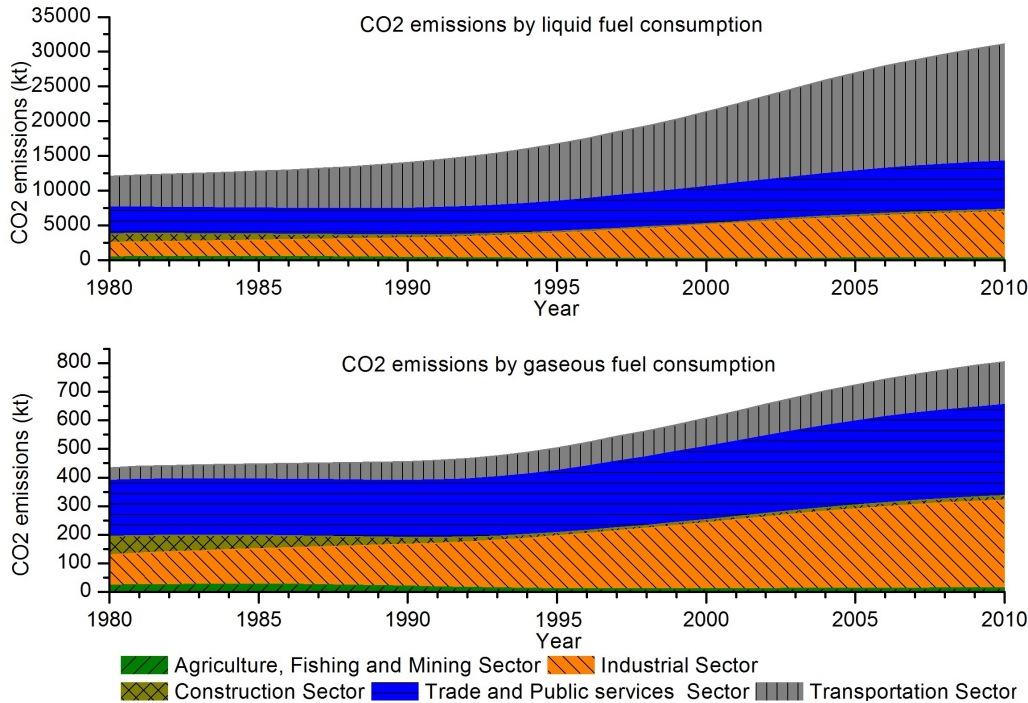


**Figure 2.14:** Top: Evolution of CO<sub>2</sub> intensity in Ecuador 1980-2010. Bottom: Growth rate.

Now we disaggregated emissions by type of fossil fuel and by sector. Regarding emissions from gaseous fuel, the most intensive sector is trade, public services and residential sector with an average emission of 237 kt during the period 1980-2010, followed by the industrial sector with 196 kt, transport sector with 87.1 kt, construction sector with 20.2 kt and agriculture, fishing and mining industry with 15.5 kt (see Figure 2.15).

In regard to emissions by liquid fuels, the most intensive sector is the transport sector with an average emission of 5306 kt in the period 1980-2010, followed by trade, public services and residential sector with 4819 kt, industry sector with 4009 kt, construction sector with 483 kt and agriculture, fishing and mining industry with 17.1 kt (see Figure 2.15).

## 2. ECUADOR IN FIGURES (1980-2010)



**Figure 2.15:** Top: Evolution of CO<sub>2</sub> emissions by fuel in Ecuador 1980-2010. Bottom: Growth rate.

### 2.5 Renewable energy figures

The Ecuadorian government has, among its goals, the development of strategies to guarantee the energy supply, increase energy cost efficiency, and last, but not least, to minimize the negative impact of economic development on the environment (Mosquera, 2008) [152].

Renewable energy sources could play an important role in the diversification of the energy matrix in Ecuador. In particular, CONELEC-004 /11 regulation (Conelec, 2011) [155] establishes the conditions for selling electricity from renewable sources to the national grid, which is encouraging new projects. Below we summarize projects and potential sources that could increase the use of renewable energy in Ecuador in the upcoming years.

### 2.5.1 Bioenergy

Ecuador has a good potential to use modern, clean and efficient bioenergy technologies using diverse crop and livestock production to generate waste energy. The type of animal waste can be harnessed through anaerobic digestion to produce biogas (methane) (Conelec, 2009) [3].

The country has about 71 thousand ha (2009) of sugarcane mostly concentrated in the cost region, near Guayaquil (MAG, 2011) [156]. A fuel ethanol pilot program has been planned in Guayaquil and Quito, initially consisting of 5% ethanol blend with gasoline [157]. If it is successful, this could set the ground for a nation-wide ethanol fuel program. The use of this kind of fuel will generate savings of about 32 million USD a year, as the country would stop importing about 320 thousand of barrels of high octane naphtha<sup>1</sup> (15%) (MEER, 2011) [157].

On the other hand, the total area planted with African palm in Ecuador is 240 thousand ha, with about 200 thousand ha currently being harvested [156]. Ecuador could potentially plant up to 760 thousand ha of African palm according to Ecuador's Association of African Palm Growers (ANCUPA, 2013) [158]. Based on projections from the sector in terms of production, domestic consumption and export surplus of red oil, the surplus could grow significantly and reach more than 850 kt of red oil in 2025 (USDA, 2011) [159].

In Ecuador, more than 300 thousand tonnes of husk is produced annually. A tonne of this residue has the ability to displace the consumption of 90 gallons of diesel used in steam generation for both processing and food production. So the 300 thousand tonnes would reduce the use of about 27 million gallons of diesel a year, besides avoiding the emission of CO<sub>2</sub> and other primary pollutants (Neira et al., 2006) [160].

Note that, according to the cycle of sugar cane harvest, these plants operate with variability in their production. The annual average load factor in 2010 was 29%. During the months of August to November has come to be greater than 60% while between January and April has not been operated for lack of waste (Conelec, 2011) [155]. The implementation of these initiatives require institutional efforts and that

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<sup>1</sup>Naphtha is used primarily as feedstock for producing high octane gasoline.

## **2. ECUADOR IN FIGURES (1980-2010)**

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the market offers the conditions for collection and storage of husk, combined with incentives to the diffusion of technology in rural areas.

### **2.5.2 Geothermal energy**

Ecuador is a country with active volcanism that is part of the Pacific Ring of Fire and has a great geothermal potential. This is illustrated by the presence of around 180 hot springs in the country and a geothermal potential of 534 MW (CEPAL, 2010) [161]. Studies have identified 17 potential geothermal exploitation for production of electrical, industrial and agricultural energy (Conelec, 2009) [3].

Three sites, Tufiño-Chiles (139 MW), Chachimbiro (113 MW) and Barges (282 MW) in which has been quantified an installable power of 534 MW. The Chalupas geothermal project has been determined like priority. This project is in the feasibility stage (2011) and it require further geophysical exploratory work to bring it to the next stage. The cost of exploration and feasibility stage representing 10% of the total budget. When is confirmed this feasibility, additional drilling are required. Then, stages of design, construction and installation should continue. These stages would be the most expensive, around 90% of the budget (Conelec, 2009) [3].

The loading factors at the global level are between 60% and 90%; which are considered efficient levels of use of the resource (levels of basic energy source). Geothermal has an advantage over other renewable: short term variable technologies (solar, wind, wave and tidal), and hydroelectricity where load factors are between 40% and 80% (Bruckner et al., 2011) [4].

### **2.5.3 Hydropower**

As was mentioned above, Ecuador has a huge hydroelectric potential unexploited, despite that hydropower is the renewable resource more exploited in the country. In 2011 Ecuador had 2, 215 MW of installed hydropower capacity and another 2, 756 MW under construction (Conelec, 2013) [162]. The biggest hydroelectric project is called Coca Codo Sinclair and has a capacity of 1500 MW and an estimated cost of 2.25 billion USD (the overall project progress is 27.4% up to November 2012). Other hydroelectric projects are: Deisitanisagua with 115 MW, Maduriacu with 60

MW, Mazar Dudas with 21 MW, Minas de San Francisco with 270 MW, Quijos with 50 MW, Sopladora with 487 MW, and Toachi Pilatón with 253 MW [157].

### 2.5.4 Solar energy

The potential of this energy in Ecuador is not among the highest in the world, compared to countries with high desert irradianations (*e.g.* North Africa); however, it is at an appropriate level to become a significant source of national power. Note that solar radiation is uniform throughout the year in Ecuador, which reduces the problem of variations, and makes the use of technology more reliable (Conelec, 2009) [3].

Most of the Ecuadorian territory has an average annual potential of 4.4 to 4.7 kWh/m<sup>2</sup>/day solar radiation. Among the places with the most potential are Quito (5.1 kWh/m<sup>2</sup>/day), Sigchos and Pedernales (5.25 kWh/m<sup>2</sup>/day), southern (5.25 kWh/m<sup>2</sup>/day) and west (5.4 kWh/m<sup>2</sup>/day) of Zapotillo and Macara (5.5 kWh/m<sup>2</sup>/day) (CIE, 2008) [163]. Considering that it requires direct radiation of at least 5 kWh/m<sup>2</sup>/day in order to be able to generate electricity from concentrated solar power (CSP) (WB, 2010a), there are few places in the country to exploit this technology as is the case of Macara in the south of Loja (5.1 kWh/m<sup>2</sup>/day direct sunlight) (CIE, 2008) [163].

In addition, Through Rural Electrification and Urban Marginal Funds (Fondos de Electrificación Rural y Urbano Marginal-FERUM), Ecuador initiated in 2004 a program of electrification in the countryside using PV generation units. This program started in zones near the border with Peru and in the Amazonian region. Another program using PV (Photovoltaic) panels is executed in the Galapagos Islands to generate a power of 2.1 MW (MEER, 2011) [157].

### 2.5.5 Wave and tidal energy

There are no reviews or studies in Ecuador about the potential of this energy. The Expansion Master Plan 2009-2020 states that a wind and tidal potential in the country could be and it can be used as an energy option in places close to the coast. Global information estimated a moderate potential of this type of energy for the

## 2. ECUADOR IN FIGURES (1980-2010)

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Ecuadorian coast (between 15 and 16 kW per meter of wave), which is low compared to sites with high potential as southern Chile with 74 kW/m.

Load factors of this energy are between 22.5% and 28.5%, which shows its variable nature. Note that, the useful life of tide dams is about 40 years. In order to integrate these energies to the system, it is required to expand the transmission infrastructure near the coast, or even a few kilometers off to the coast if the generators are located offshore. The electrical characteristics of the power plants of both waves and tides is similar to those of wind energy technologies, therefore, the technical connection requirements are often similar (Sims et al., 2011) [24].

### 2.5.6 Wind energy

A challenge for the integration of wind energy to electrical systems is their intermittent nature for the energy generation (Arent, 2011) [2]. That is, the wind is a variable resource so that the generation fluctuates according to weather conditions and wind in a given plant or wind turbine. When wind electricity generation represents more than 20% of country's electricity matrix, it requires technical and institutional adjustments by the authority (Wiser et al, 2011 [14]; Taylor, 2004 [164]).

Although latitudes located on the equator are not rich in winds, the presence of the Andes Mountains and the Pacific Ocean provide thermal gradients that allow the existence of areas of high wind interest in Ecuador. To determine the potential of wind generation site, it is required to evaluate different parameters such as wind speed, daily, monthly and seasonal variations. Wind energy is one of the most variable renewable sources in the short term (Sims et al., 2011) [24], and even more than solar, because the wind varies dramatic and randomly.

The areas with the highest wind potential in Ecuador are at the tops of the mountains and coastal sites. Among these sites Villonaco hill located in the province of Loja in the south of the country is recognized, with a cost of 41.8 million USD, a power capacity of 16.5 MW and considered in the Plan of Expansion of Generation 2009-2020 of Ecuador. There are some other identified sites with wind generation potential, such as The Angel in Carchi, Salinas in Imbabura, Tixán in Chimborazo

## **2.6 Cost of the adoption of renewable energy**

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and Huascachaca in Azuay. A specific technical evaluation, both national and local levels to get a full wind atlas of the country is still required (Conelec, 2009) [3].

Programs for using wind energy started in 2004. Other important program, promoted by the Ministry of Electricity and Renewable Energy (MEER), aim at replacing the existing thermal generation plant by wind and PV plants in the Galapagos Islands. With the new facilities, 5.7 MW of wind power (plus 2.1 MW of PV power) will substitute most of the 8.8 MW of the thermal generation installed (MEER, 2011 [157]; Conelec, 2013 [162]).

## **2.6 Cost of the adoption of renewable energy**

The cost of renewable energy is an important factor in determining the competitiveness of a given technology in the energy sector. Thus, if a technology generates electricity at below market price, estimated for the long term, this technology would be selected by investors for future expansion (Casparly, 2009) [165]. Costs are still a critical factor, then, it is most feasible and likely to adopt technologies that have competitive costs compared to the traditional electricity sector.

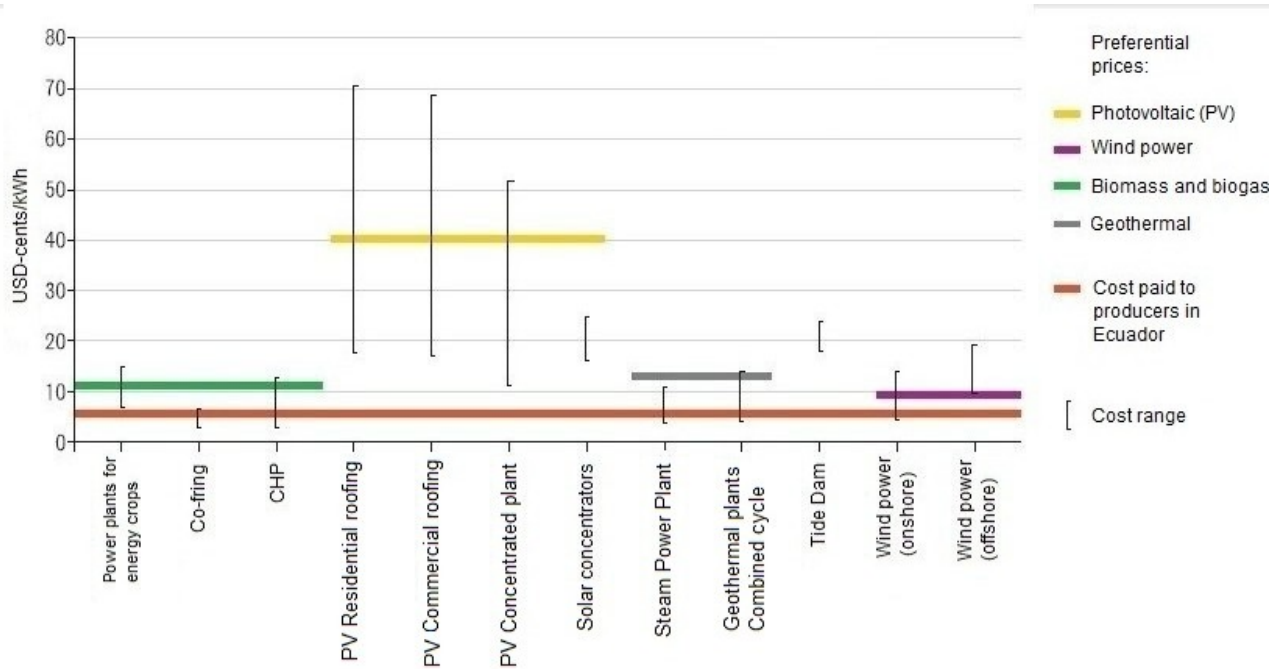
This section compares overall average technology costs ranges of renewable energy with the costs paid to electricity generators in Ecuador. The average costs of renewable energy generation technologies are taken from IPCC<sup>1</sup>. The data correspond to the global aggregate costs of renewable energy technologies commercially available.

Further, costs are not the only factor used but also the commercial availability of technologies. These cost ranges are constructed based on information from countries where there are projects, studies and information on these technologies. Also, are listed the natural and technological factors affecting the feasibility of using each type of renewable source such as load factor (which expresses the variability and natural availability of a source), life-cycle and size of the plant, and costs incurred in investment, operation, maintenance and fuel (for bioenergy).

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<sup>1</sup>The average costs of technologies for renewable energy sources given by the IPCC are calculated for the life-cycle of each of the technologies and are calculated at present value with a discount rate of 7%. None of these average costs include effects of energy subsidies granted in different countries (Bruckner et al 2011) [4].

## 2. ECUADOR IN FIGURES (1980-2010)



**Figure 2.16:** International average cost range versus preference prices for renewable energy in Ecuador based on (Conelec 2009) [3] and (Bruckner et al 2011) [4].

The comparison of cost is a first step in the analysis of the feasibility of incorporating renewable technologies in the energy matrix of the country. Moreover, the comparative cost used is the generation of electricity in Ecuador determined by Conelec<sup>1</sup> (Conelec, 2009)[3].

Figure 2.16 shows that four technologies of renewable energy would have incentives to be adopted without the support of preferential prices<sup>2</sup>. These technologies show a global average cost range lower than the recognized power generation

<sup>1</sup> In 2011 a new regulation of Conelec (Regulation No. CONELEC-004/11) was approved for the treatment of the price of energy produced from non-conventional renewable energy resources, which seeks to encourage the spread of these technologies in Ecuador through the payment of preferential prices to allow greater competitiveness thereof. The costs of electricity generation of Conelec are average values of domestic industries (Conelec 2009) [3]

<sup>2</sup> The Conelec's regulation (feed in tariff) contributes to the adoption of technologies of renewable energy in Ecuador's electricity market. These regulations provide for different preferential prices for different technologies (see the different lines in Figure 2.16). Technologies that have their range of prices below these ceilings become economically viable energy in Ecuador.

## 2.6 Cost of the adoption of renewable energy

in Ecuador (range of cost below the red line in the graph) cost. These technologies are: bioenergy for electricity generation by combined combustion (co-firing), gasification of biomass for heat and power generation (combined heat and power, CHP); geothermal flash steam technologies (flash condensing plants) and binary cycle plants.

The regulation of preferential prices govern the payment of costs for a period of 15 years, after which the authority will conduct a review. With this time horizon and with the downward trend in the cost of renewable technologies is likely that more options will become financially viable in the medium and long term.

The energy generation based on fossil fuels produces global effects such as GHG and local effects such as the emission of primary pollutants (eg  $SO_x$ ,  $NO_x$ , etc.). If these effects are incorporated, the real cost of power generation from these sources will be higher. Then, renewable technologies produces least amount and less intense effects, especially in GHG. This option would become more competitive in front of polluter energy generation.

Since the incorporation of these effects are not included in the price of energy generation in Ecuador, we can only refer to the financial costs. Note that this financial cost of energy generation is not the actual cost, because the energy sector (especially the thermoelectric generation) use subsidized fuel. These factors, subsidies for fossil fuels and non-inclusion of external environmental costs make the price of conventional energy generation technologies in Ecuador cheaper than renewable energy sources. However, the low price is not based on real and sustainable benefits in the long term.

Regarding energy costs for transportation, there is a global downward trend in the prices of first generation biofuels (see Figure 2.16). Particularly in Latin America, Brazil is the leader in biofuels production, and is achieving lower cost and not requiring subsidies to be competitive (Chum et al., 2011) [18]. But in Ecuador, gasoline and diesel have costs below the world average price and even below that of its Andean neighbors, Peru and Colombia, because of subsidies.



*Education is the most powerful  
weapon which you can use to  
change the world.*

Nelson Mandela

CHAPTER

# 3

## **System dynamics modelling for renewable energy and CO<sub>2</sub> emissions in Ecuador (1980-2025)**

### **3.1 Overview**

It is a very complicated task to predict how much the economy will grow in the near future. This growth will strongly modulate CO<sub>2</sub> emissions of any country and therefore it will be crucial to make a realistic estimate of this emissions. On the other hand, the different *feedback-mechanisms*, both in the climatic and in the economic system make any prediction highly questionable beyond 5-10 years (Fiddman, 2002) [83]. However, it is critical to provide accurate information to policymakers in order to design appropriate energy policies for the near future (Bahrman, 2007) [166].

This Chapter explores the relationship between economic growth, productive sectors, energy consumption, changes in the use of renewable energy, improvements in the efficiency of fossil energy, and CO<sub>2</sub> emissions of Ecuador. To estimate

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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CO<sub>2</sub> emissions in the near future we will define different scenarios in both income and energy use.

The model is based on a variation of the Kaya identity (Kaya, 1993) [167] and on an approach of formation of GDP which includes a contribution from renewable energy (Chien and Hu) [5]. The model has been implemented using a SD technique (Forrester, 1961) [168] on a Vensim platform (Vensim, 2011) [169]. The considered data corresponds to the period 1980-2010 and it has been extracted from the official data sources such as: Ecuadorian Institute of Statistics and Census (INEC, 2012) [170], Central Bank of Ecuador (BCE) [150], World Bank<sup>1</sup> (WB) [144], and International Energy Agency (IEA) [151]. The raw data has been processed using a Hodrick-Prescott filter (HP) (Hodrick and Prescott, 1997) [171] which allows to generate a smooth representation of a time series.

The Kaya identity is commonly used as an analytical tool to explore the main driving forces that control the amount of carbon dioxide emissions (Alcantara, 2005 [172]; Mena, 2009 [173]). According to this identity, CO<sub>2</sub> emissions of a given country could be broken down into the product of four factors: carbon intensity (defined as the CO<sub>2</sub> emitted per unit of energy consumed), energy intensity (defined as the consumed energy per unit of GDP), economic rent (defined as GDP per capita), and population.

The technique was originally proposed by J. Forrester to understand how systems change as a function of time (Begueri, 2001) [174]. SD is a method for modeling, simulating and analyzing complex systems. A system is defined as a collection of elements in which interactions are modeled as flows between reservoirs in time steps, and in which the rate of change depends on the value of the variables that define the system (feedback mechanisms). Therefore, the main goal of SD is to *understand* how a given system evolves, and even more importantly, to understand the causes that govern its evolution (Garcia, 2011) [87]. The basis of SD has been analyzed in detail in Radzicki (2009) [175] and Tan (2010) [176], in addition a brief review are in Section 1.9 of Chapter 1.

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<sup>1</sup>Economic official data set used is given in constant 2005 PPP international dollars.

### 3.2 Formulation of model

The model uses a variation of the Kaya identity, where the amount of CO<sub>2</sub> emissions from industry and from other energy uses may be studied quantifying the contributions of five different factors: *i*) global industrial activity, *ii*) industry activity mix, *iii*) sectoral energy intensity, *iv*) sectoral energy mix and *v*) CO<sub>2</sub> emission factors. Moreover, we consider different sub-categories concerning the industrial sectors and the fuel type. The CO<sub>2</sub> emissions can be written as,

$$C = \sum_{ij} C_{ij} = \sum_{ij} Q \frac{Q_i}{Q} \frac{E_i}{Q_i} \frac{E_{ij}}{E_i} \frac{C_{ij}}{E_{ij}} = \sum_{ij} Q \cdot S_i \cdot EI_i \cdot M_{ij} \cdot U_{ij}, \quad (3.1)$$

where  $C$  is the total CO<sub>2</sub> emissions (in a given year);  $C_{ij}$  is the CO<sub>2</sub> emission arising from fuel type  $j$  in the productive sector  $i$  (note that the index  $i$  runs over five productive sectors and the index  $j$  over five type of energy sources);  $Q$  is the total GDP of the country;  $Q_i$  is the GDP generated by the productive sector  $i$ ;  $E_i$  is the energy consumption in the productive sector  $i$ ;  $E_{ij}$  is the consumption of fuel  $j$  in the productive sector  $i$ , verifying that the total consumed energy,  $E = \sum_{ij} E_{ij}$ ;  $S_i \left( \frac{Q_i}{Q} \right)$  is the share of sector  $i$  in the total GDP; the energy intensity of sector  $i$  is given by  $EI_i \left( \frac{E_i}{Q_i} \right)$ ; the energy matrix is given by  $M_{ij} \left( \frac{E_{ij}}{E_i} \right)$  and the CO<sub>2</sub> emission factor by  $U_{ij} \left( \frac{C_{ij}}{E_{ij}} \right)$ . Throughout this work, as a convention, we will always refer to the productive sector with the  $i$  index and to the type of energy source with the  $j$  index.

This equation is an extension of the Kaya identity because we disaggregate in type of productive sector and kind of fuel used, while in the original formulation only aggregated terms are considered:  $C$ ,  $Q$ , and  $E$ .

The raw data to perform the model correspond to the official available data on Ecuador, provided by the INEC<sup>1</sup>, the BCE<sup>2</sup>, the WB<sup>3</sup>, and the International Energy Agency<sup>4</sup>. The subsequent data analysis and the preprocessing of the time series was performed using the Hodrick-Prescott (HP) filter [171], which allows isolation

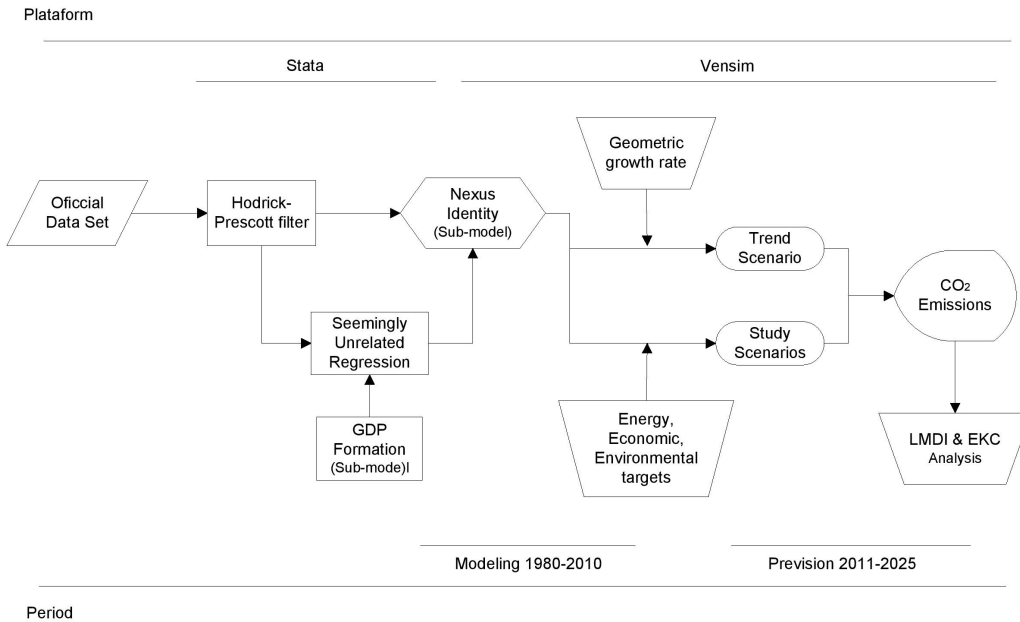
<sup>1</sup><http://www.inec.gob.ec/estadisticas/>, <http://www.ecuadorencifras.com/>

<sup>2</sup><http://www.bce.fin.ec/indicador.php>

<sup>3</sup><http://data.worldbank.org/country/ecuador>

<sup>4</sup><http://www.iea.org/countries/non-membercountries/ecuador/>

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)



**Figure 3.1:** Schematic diagram of the methodology used to build the model.

of outliers (economic crises, random behavior of markets, etc) of the time series under study. After that, it is possible to get the trend component of a time series and to perform more adequate estimations<sup>1</sup>. Indeed, all time series used in this work have been computed using the HP filter with a  $\lambda$  value of 100.

The simulation period extends from 1980 to 2025, where 1980-2010 is used to fix the parameters of the model and 2011-2025 corresponds to the forecast period, under the assumption of different scenarios concerning the evolution of the income, the evolution of the energy mix, and the efficiency of the used technology. The geometric growth rate (Rowland, 2003 [177]; Jin et al., 2009 [178]) has been used to extrapolate the trends into the forecast period. The Seemingly Unrelated Regression (SUR) (Zellner, 1962) [179] in STATA software platform (Stata, 2012) [180] has been used to parameterize the GDP formation. The validation of the model has

<sup>1</sup> The smoothing parameter  $\lambda$  of the filter, which penalizes acceleration in the trend relative to cycle component, needs to be specified. Most of the business cycle literature use past data and a value of the smoothing parameter  $\lambda$  equal to 100 (Hodrick and Prescott) [171] (see Section 1.5.3 in Chapter 1).

been done with the mean absolute percentage error (MAPE).

Figure 3.1 shows in a schematic way how the calculations have been performed using the different techniques described in previous paragraphs.

## 3.3 Economic model approach

### 3.3.1 Introduction of economic approach

The promotion of renewable energy is a well accepted solution to the mitigation of CO<sub>2</sub> emission. Furthermore, Chien and Hu (2007) [181] show that increasing the use of renewable energy improves the macroeconomic efficiency of economies.

Energy, labor, and capital stock are key inputs to produce the economic output-GDP (Hu and Kao, 2007 [182]; Hu and Wang, 2006 [183]). It is desirable for an economy to increase its income and to decrease its inputs in order to maximize production efficiency.

It is worth noting that increasing the input of traditional energy decreases technical efficiency. To improve the technical efficiency of an economy, it is important not to increase the total input of energy. By substituting traditional energy with renewable energy, technical efficiency can be improved (Hu and Kao, 2007) [181].

Renewable energy systems are considered to be environmentally superior to traditional technologies from the viewpoint of CO<sub>2</sub> mitigation and the effective utilization of resources. Several studies show that substitution of conventional fossil fuels by biomass, for energy production results, in both a net reduction of GHG and in the replacement of non-renewable energy sources (Schneider and McCarl, 2003 [184]; Dowaki and Mori, 2005 [185]; Caputo et al., 2005[186]).

Abulfotuh (2007) [187] suggests that one possible solution to the environmental risks brought by the escalating demand for energy is to consider immediate change in the composition of the energy resource portfolio. It is expected that renewables have great potential to solve a major part of global energy sustainability. Increasing the use of renewables in power industries has already been seriously reviewed in some countries.

Various new policies to achieve the national goals of a renewables ratio in the energy portfolio are adopted in different economies. Lund (2007) [188] groups

### **3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)**

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policies on renewable energy and efficient energy use into subsidy type and catalyzes measures based on the use the public financial resources according to REN21 (Renewable Energy Policy for the 21st Century, 2012) [189] in Renewables Global Status Report (RGSR, 2012) [189] at least 118 countries, more than half of which are developing countries, had renewable energy targets in place, and 109 countries have policies to support renewables in the power sector by early 2012. Renewable energy targets and support policies continued to be a driving force behind increasing markets for renewable energy, despite some setbacks resulting from a lack of long-term policy certainty and stability in many countries.

Renewable power generation policies remain the most common type of support policy; at least 109 countries had some type of renewable power policy by early 2012, up from the 96 countries reported in the RGSR 2012 [189]. Feed-in-tariffs (FITs) and renewable portfolio standards<sup>1</sup> (RPS) are the most commonly used policies in this sector. FIT policies were in place in at least 65 countries by early 2012 (REN, 2012) [189].

Renewables are currently accepted as one of the key solutions to climate change and escalating energy demand. Many economies have adopting policies to promote the use of renewables. However, the mechanism of how renewables improve GDP is still unknown (Chien and Hu, 2008) [181].

#### **3.3.2 Theory of the impact of renewables on GDP**

In this section, we will review the work of Chien and Hu (2008) [5] that broadens the perspective of environmental economics to include an analysis of renewable usage directly contributing to the important elements of economies or regional development. Domac et al. (2005) [190] suggest that renewable energy increases the macroeconomic efficiency by the following process: *i*) The business expansion and new employment brought by renewable energy industries result in economic

---

<sup>1</sup>RPS is a regulation that requires the increased production of energy from renewable energy sources, such as wind, solar, biomass, and geothermal. The RPS mechanism generally places an obligation on electricity supply companies to produce a specified fraction of their electricity from renewable energy sources. Certified renewable energy generators earn certificates for every unit of electricity they produce and can sell these along with their electricity to supply companies.

### 3.3 Economic model approach

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growth. *ii*) The import substitution of energy has direct and indirect effects in increasing income of the economy and trade balance.

Measured by expenditures, GDP is the sum of goods and services produced during a given period. Total output comprises four groups' purchases of final goods and services: *i*) households purchase consumption goods; *ii*) businesses purchase investment goods (and retain unsold production as inventory increases); *iii*) governments purchase goods and services used in public administration and *iv*) welfare transfers; and foreigners purchase (net) exports. There is substantial uniformity in the shares of consumption and investment (the sum of capital expenditures and inventories) across nations with quite disparate income levels (Mack, 2008) [191]<sup>1</sup>. It is important to note that if one counts some major activities such as child-rearing (generally unpaid) as production, GDP ceases to be an accurate indicator of production. Similarly, if there is a long term shift from non-market provision of services (for example cooking, cleaning, child rearing, do-it yourself repairs) to market provision of services, then this trend toward increased market provision of services may mask a dramatic decrease in actual domestic production, resulting in overly optimistic and inflated reported GDP. This is particularly a problem for economies which have shifted from production economies to service economies.

The expenditure approach estimates GDP by the following equation:

$$GDP = C + I + G + X - M, \quad (3.2)$$

where:

- *C* (consumption) is normally the largest GDP component in the economy, consisting of private (household final consumption expenditure) in the economy. These personal expenditures fall under one of the following categories: durable goods, non-durable goods, and services. Examples include food, rent, jewelry, gasoline, and medical expenses but does not include the purchase of new housing.

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<sup>1</sup>Note that, if you knit yourself a socks, it is production but does not get counted as GDP because it is never sold.

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- $I$  (investment) includes, for instance, business investment in equipment, but does not include exchanges of existing assets. Examples include construction of a new mine, purchase of software, or purchase of machinery and equipment for a factory. Spending by households (not government) on new houses is also included in investment. In contrast to its colloquial meaning, *investment* in GDP does not mean purchases of financial products.
- $G$  (government spending) is the sum of government expenditures on final goods and services. It includes salaries of public servants, purchases of weapons for the military and any investment expenditure by a government. It does not include any transfer payments, such as social security or unemployment benefits.
- $X$  (exports) represents gross exports. GDP captures the amount a country produces, including goods and services produced for other nations' consumption, therefore exports are added.
- $M$  (imports) represents gross imports. Imports are subtracted since imported goods will be included in the terms  $G$ ,  $I$ , or  $C$ , and must be deducted to avoid counting foreign supply as domestic.

The deduction of imports from exports ( $X-M$ ) is the trade balance ( $TB$ ).

Another way of measuring GDP is to measure total income (Income approach). This way of counting is sometimes called gross domestic income (GDI<sup>1</sup>) and should provide the same amount as the expenditure method described previously<sup>2</sup>

Following to Chien and Hu (2008) [5] the impact of renewables on GDP has evaluated by the expenditure approach, because the import substitution effect of renewables seems to have a direct impact on trade balance.

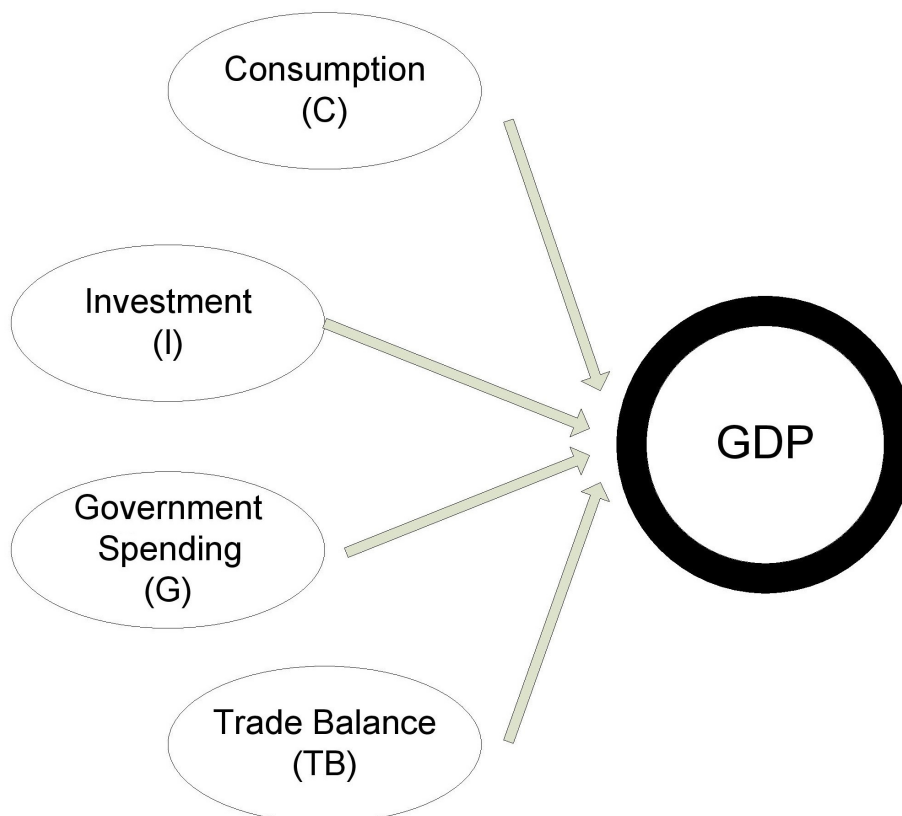
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<sup>1</sup>This method measures GDP by adding incomes of salaries for labour, interest for capital, rent for land and profits for entrepreneurship.

<sup>2</sup>By definition,  $GDI = GDP$ . In practice, however, measurement errors will make the two figures slightly off when reported by national statistical agencies.

#### 3.3.3 Path analysis of the impacts of renewables on GDP

The influences of renewables on GDP are illustrated by Figure 3.2. This represents the original constitution of GDP by household consumption, government consumption, capital formation, and trade balance.

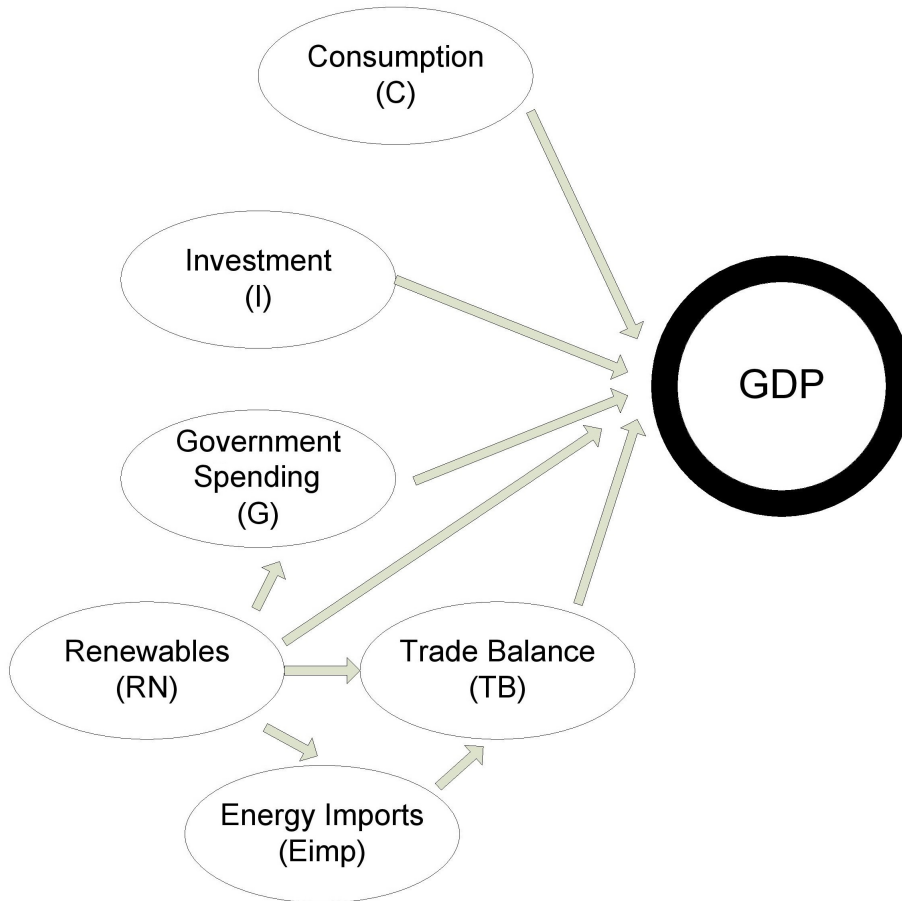


**Figure 3.2:** Conceptual framework of GDP constitution in Chien and Hu (2008) [5]

Closely following Chien and Hu (2008) [5], in Figure 3.3, the diagram shows that the use of renewables influences GDP through two paths: *i*) the emergence of renewable energy industries brings about business expansion, which results in increased capital formation; and *ii*) the import substitution of traditional energy by locally produced renewables has direct and indirect effects on increasing trade balance in an economy. The increases of capital formation and trade balance would lead to the increase of the GDP.

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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**Figure 3.3:** Conceptual framework of the influences of renewables on GDP in Chien and Hu (2008) [5]

Policy makers have to choose from different policy instruments to identify the most effective instrument. This became very important issue and therefore the mechanism for renewables to create economic impacts should be first identified.

Chien and Hu (2008) [5] use the path analysis of Structural Equation Modeling (SEM) to test the conceptual model, specifying causal relationships between renewables and the other relevant variables<sup>1</sup>. The output of path analysis in Chien and Hu (2008) [5] work provides significance tests for specific causal paths. The

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<sup>1</sup>Path analysis can be used to determine whether the theoretical model accounts for the actual relationships in the observed data.

### 3.3 Economic model approach

significant links point out where the policies should be executed.

In the work of Chien and Hu (2008) [5], the sample profile contains 116 economies. The results of this work show that technical efficiency is higher in developed economies than in developing economies. The share of renewable energy in total energy supply is higher in developing economies than in developed economies due to the widespread biomass use in the residential sector of developing economies. The share of geothermal, solar, tide and wind fuels in renewable energy is higher in developed economies than in developing economies.

In this research, we apply the model of Chien and Hu (2008) [5] for the case of Ecuador. We also conduct an analysis performed using the correlation matrix (Table 3.1).

**Table 3.1:** Summary of descriptive statistics for the Economic model.

| Measure           | Means  | Stan.Dev | GDP   | I     | TB    | C     | Eimp  | RN    |
|-------------------|--------|----------|-------|-------|-------|-------|-------|-------|
| GDP <sup>a</sup>  | 7.54   | 1.97     | 1.00  | 0.93  | -0.12 | 0.97  | -0.86 | -0.86 |
| I <sup>b</sup>    | 1.71   | 0.54     | 0.93  | 1.00  | -0.24 | 0.85  | -0.67 | -0.70 |
| TB <sup>c</sup>   | -0.10  | 0.24     | -0.12 | -0.24 | 1.00  | 0.22  | -0.05 | 0.02  |
| C <sup>d</sup>    | 5.00   | 1.37     | 0.97  | 0.85  | -0.22 | 1.00  | -0.89 | 0.87  |
| Eimp <sup>e</sup> | -12.72 | 3.81     | -0.86 | -0.67 | -0.05 | -0.89 | 1.00  | 0.87  |
| RN <sup>f</sup>   | 3.81   | 0.18     | -0.86 | -0.70 | 0.02  | -0.90 | 0.87  | 1.00  |

<sup>a</sup> GDP in 10<sup>10</sup> USD.

<sup>b</sup> I in 10<sup>10</sup> USD.

<sup>c</sup> TB in 10<sup>10</sup> USD.

<sup>d</sup> C in 10<sup>10</sup> USD.

<sup>e</sup> Eimp in 10<sup>6</sup> toe.

<sup>f</sup> RN in 10<sup>6</sup> toe.

On the other hand, according to these authors the government spending  $G$  ( $G = GDP - C - I - (X - M)$ ) is eliminated from the model estimation to avoid multicollinearity. To avoid the problems of inputting raw data, a rescaling of the smoothed time series has been used so that they are all on approximately the same scale. The system of theoretical GDP formation model is made up by the following equations:

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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$$Q = a_1 \cdot I + a_2 \cdot TB + a_3 \cdot C + a_4 \cdot Eimp + a_5 \cdot RN + \epsilon_1, \quad (3.3)$$

$$I = b_1 \cdot RN + b_2 \cdot C + \epsilon_2, \quad (3.4)$$

$$TB = c_1 \cdot Eimp + c_2 \cdot RN + \epsilon_3, \quad (3.5)$$

$$Eimp = d_1 \cdot RN + \epsilon_4, \quad (3.6)$$

$$C = f_1 \cdot Eimp + f_2 \cdot TB + \epsilon_5, \quad (3.7)$$

where  $Q$  refers to GDP of the country,  $Eimp$  is the energy import,  $RN$  is the renewable energy and  $\epsilon_1 \dots \epsilon_5$  are residuals. Note that Equations 3.3-3.7 form the model for the formation of GDP. Coefficients appearing in these equations are determined using SUR technique<sup>1</sup> in the datasets of 1980-2010 period and therefore their values are a consequence of the data. The SEM model is present in Figure 3.4.

In Equation 3.3, income ( $Q$ ) is influenced by invest ( $I$ ), trade balance ( $TB$ ), and consumption ( $C$ ). Chien and Hu (2007) [181] suggested that energy inputs may affect income, therefore, energy imports ( $Eimp$ ) and renewable energy ( $RN$ ) are included as well Equation (3.3). Note the negative value of coefficient  $a_5$  in Table 3.2.

In Equation 3.4 investment is influenced by renewable energy, since theory predicts that increasing the use of renewable energy will result in business expansion and thus capital could be accumulated in long term, but its implementation (infrastructure and incentives in early stages, see Section 2.6 in Chapter 2) is expected

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<sup>1</sup> A single model may contain a number of linear equations. In such a model it is often unrealistic to expect that the equation errors would be uncorrelated. A set of equations that has contemporaneous cross-equation error correlation (*i.e.* the error terms in the regression equations are correlated) is called a seemingly unrelated regression (SUR) system (Zellner, 1962) [179]. At first look, the equations seem unrelated, but the equations are related through the correlation in the errors. The model can be estimated equation by equation using standard ordinary least squares (OLS). Such estimates are consistent, however generally not as efficient as the SUR method, which amounts to feasible generalized least squares with a specific form of the variance-covariance matrix. Two important cases when SUR is in fact equivalent to OLS, are: either when the error terms are in fact uncorrelated between the equations (so that they are truly unrelated), or when each equation contains exactly the same set of regressors on the right-hand-side.

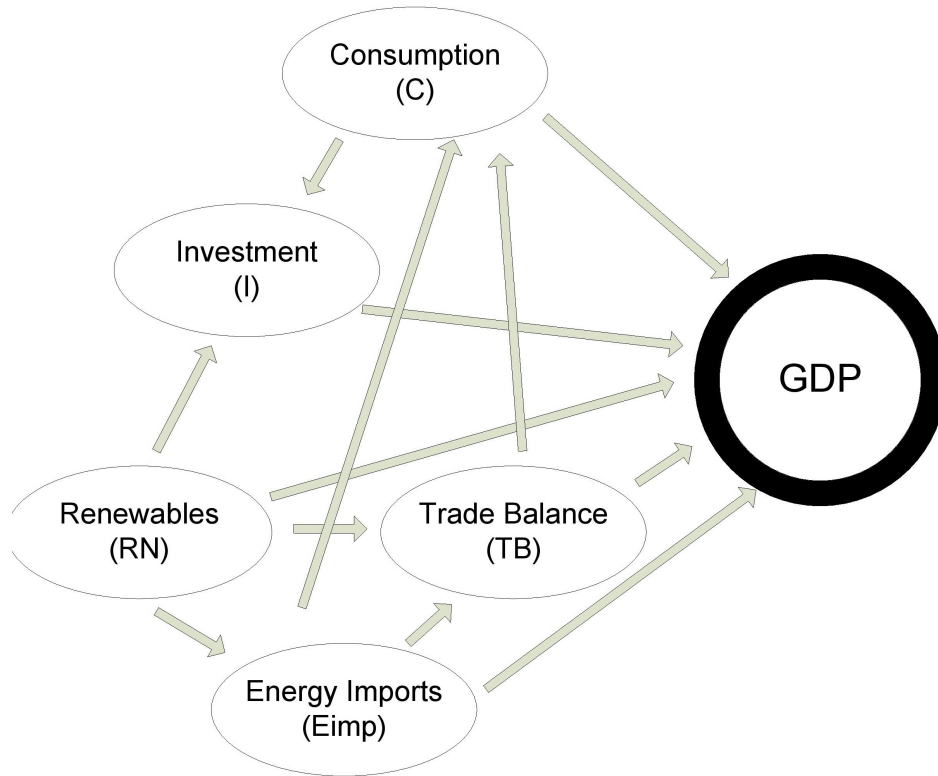


Figure 3.4: SEM model in Chien and Hu (2008) [5]

to have a negative short term effect over income (this is confirmed with a negative value of  $b_1$  in Table 3.2).

In Equation 3.5 energy imports and renewable energy influence trade balance (both coefficients,  $c_1$  and  $c_2$ , have positive values in Table 3.2). The theory proposed by Domac et al. (2005) [190] suggests that the use of renewable energy results in import substitution by domestic-produced renewable energy, and thus trade balance will increase by the use of renewable energy. Furthermore, if renewable energy could cause import substitution, then the imports of energy should be reduced by the increase of renewable energy (in Equation 3.6 the value of the coefficient  $d_1$  is negative). Although Ecuador is a net exporter of fossil energy, the use of renewable energy can help diversify its energy matrix and reduce emissions.

In Equation 3.7, according to international trade theories, the domestic price

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**Table 3.2:** Estimated coefficients for the GDP formation equations (see Eqs. 3.3-3.7)<sup>a</sup>.

| Variable                      | GDP <sup>b</sup>    | I                   | TB                | C                     | Eimp                 |
|-------------------------------|---------------------|---------------------|-------------------|-----------------------|----------------------|
| I <sup>c</sup>                | 1.16***<br>(5.11)   |                     |                   | -6.07***<br>(-41.44)  |                      |
| TB <sup>d</sup>               | 0.99***<br>(3.46)   |                     |                   |                       |                      |
| C <sup>e</sup>                | 1.21***<br>(7.70)   | 0.50***<br>(100.40) |                   |                       |                      |
| E <sub>imp</sub> <sup>f</sup> | 0.05***<br>(2.66)   |                     | 0.01***<br>(4.14) | -0.27***<br>(-100.17) |                      |
| RN <sup>g</sup>               | -0.50***<br>(-4.44) | -0.84***<br>(-5.40) | 0.04<br>(0.28)    |                       | -36.79***<br>(-5.47) |

<sup>a</sup> \*\*\* represents significance at the 1% level and numbers in parentheses are *t*-statistics.

Estimation Method: SUR. Sample: 1980-2010. Included observations: 155.

<sup>b</sup> GDP in 10<sup>10</sup> USD.

<sup>c</sup> I in 10<sup>10</sup> USD.

<sup>d</sup> TB in 10<sup>10</sup> USD.

<sup>e</sup> C in 10<sup>10</sup> USD.

<sup>f</sup> Eimp in 10<sup>6</sup> toe.

<sup>g</sup> RN in 10<sup>6</sup> toe.

of goods increases as the same kind of goods are exported, while it decreases as the same kind of goods are imported. Thus, trade balance influences consumption through changes in domestic prices. The imports of energy influence domestic energy prices and the consumption of energy. As a result, consumption of energy-related products is also affected. Ecuador exports crude oil and imports refined products, such as diesel and liquid petroleum gas (LPG) which affects the value of *TB* and *Eimp* in Equation 3.3.

The results obtained after the fitting of the smoothed series of data is depicted in Table 3.2. Note that the error terms are correlated through the equations of formation of GDP, because the variables in Equation 3.3 are not fully statistically independent. All the coefficients are individually significant at the 0.01 level except

### **3.4 Energy consumption and productive sectoral structure submodel**

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the coefficient between  $E_{imp}$  and  $TB$ .

According to the results of Table 3.2 renewable energy generates a reduction on income ( $Q$ ) and on invest ( $I$ ) in the short term, however they have a positive impact on the trade balance ( $TB$ ) and a large negative effect on the energy imports ( $E_{imp}$ ).

### **3.4 Energy consumption and productive sectoral structure submodel**

Energy consumption refers to the use of primary energy before transformation into any other end-use energy, which is equal to the local production of energy plus imports and stock changes, minus the exports and the amount of fuel supplied to ships and aircraft engaged in international transport. It is given in kt of oil equivalent (ktoe). Energy intensity is defined as the ratio of energy consumption and GDP [144].

The energy demand analysis starts from an analytical method that is based on energy end use, in order to model the requirements of consumption in the different productive sectors. Economic, demographic and energy use information applies to build different scenarios, in order to determine how the total and disaggregated energy sources consumption evolve over time in each industry and in each scenario. The energy demand analysis is a starting point for assessing the energetic area in integrated form, since all processing calculations and use of resources are determined by the calculated levels of final demand.

In general, sectoral structure comprises households, industry, transport, trade, agriculture, etc.. In turn, each sector can be divided into different sub-sectors, final consumption and equipment that use energy. However, given the availability of data in Ecuador, it is only possible to identify the primary energy consumption by source and type in each of the sectors mentioned previously.

As was already mentioned in Section 2.2 in Chapter 2, the usual standard division of productive sectors follows the ISIC specification (International Standard Industrial Classification of All Economic Activities, Rev.4), but taking in account the availability of data, we follow the division of the productive sectors given in

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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Mosquera (2008) [152]: *i*) agriculture, fishing and mining (sec-1), *ii*) industry (sec-2), *iii*) construction (sec-3), *iv*) trade and public services (sec- 4), and *v*) transportation (sec-5).

Sectors will be represented inside the model by their contribution to the country's economy ( $S_i$ ), by their energy intensity<sup>1</sup> ( $EI_i$ ) and by their energy mix ( $M_{ij}$ ). Index  $i$  runs over each sector of the productive sectoral structure and index  $j$  runs over each kind of fuel: *i*) natural gas ( $j = 1$ ), *ii*) coal ( $j = 2$ ), *iii*) petroleum ( $j = 3$ ), *iv*) renewable ( $j = 4$ ), and *v*) alternative energy ( $j = 5$ ).

#### 3.5 CO<sub>2</sub> intensity and energy matrix submodel

CO<sub>2</sub> intensity ( $CO2_{int}$ ) of a given country corresponds to the ratio of CO<sub>2</sub> emissions and the total consumed energy written in terms of mass of oil equivalent.

$$CO2_{int} = \frac{\sum_{ij} C_{ij}}{\sum_{ij} E_{ij}} \quad (3.8)$$

The value of the  $CO2_{int}$  in a given year depends on the particular energy mix during that year.  $M_{ij}$  gives the energy matrix, but it is more convenient to sum over the different sectors and aggregate the fossil fuel contributions, therefore, we define:

$$M_j = \frac{\sum_i E_{ij}}{\sum_{ij} E_{ij}} \quad (3.9)$$

On one hand,  $M_1$ ,  $M_2$ , and  $M_3$  correspond to the energy consumption from natural gas, coal, and petroleum, respectively. Therefore, the share of fossil energy in the total consumption will be  $M_1+M_2+M_3$ . On the other hand,  $M_4$  and  $M_5$  stand for the energy consumption from renewable and alternative sources, respectively. Therefore:

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<sup>1</sup>Energy intensity measures the amount of energy required per unit of consumption or product, expressed in terms of a value which is determined by the used sources which have different caloric powers and by the equipment used with different technologies and efficiency levels (WB, 2012) [144]. Note that the different economic sectors have different intensive use of energy (Cancelo, 2002) [192]. Two factors explain the differences in energy intensity between each sector: *i*) differences in the efficiency of the energy used in each sector and *ii*) differences in the economic activity of each sector.

$$M_1 + M_2 + M_3 + M_4 + M_5 = 100\% \quad (3.10)$$

In order to simplify the description, we assume that  $M_4$  and  $M_5$  do not contribute to the CO<sub>2</sub> emissions. Following the methodology recommended by the IPCC, that is, the *Reference method* (IPCC, 2006) [42], the approach of the first level for the fossil energy mix was used. The emission factors,  $U_{ij}$ , are taken from the *IPCC* methodology to estimate the CO<sub>2</sub> emission of each fuel (IPCC, 2006) [42].

### 3.6 CO<sub>2</sub> emission factors

Following the IPCC Guidelines for National Greenhouse Gas Inventories (2006), Volume 2: Energy [6], combustion processes are optimized to derive the maximum amount of energy per unit of fuel consumed, hence delivering the maximum amount of CO<sub>2</sub>. Efficient fuel combustion ensures oxidation of the maximum amount of carbon available in the fuel. CO<sub>2</sub> emission factors for fuel combustion are therefore relatively insensitive to the combustion process itself and hence are primarily dependent only on the carbon content of the fuel.

The carbon content may vary considerably both among and within primary fuel types on a per mass or per volume basis:

- For natural gas, the carbon content depends on the composition of the gas which, in its delivered state, is primarily methane, but can include small quantities of ethane, propane, butane, and heavier hydrocarbons. Natural gas flared at the production site will usually contain far larger amounts of non-methane hydrocarbons. The carbon content will be correspondingly different.
- Carbon content per unit of energy is usually less for light refined products such as gasoline than for heavier products such as residual fuel oil.
- For coal, carbon emissions per tonne vary considerably depending on the coal's composition of carbon, hydrogen, sulphur, ash, oxygen, and nitrogen.

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

| TABLE 1.4 (CONTINUED)<br>DEFAULT CO <sub>2</sub> EMISSION FACTORS FOR COMBUSTION <sup>1</sup> |   |                                 |  |                         |         |         |
|---|---|---------------------------------|--|-------------------------|---------|---------|
| Fuel type English description   | Default carbon content (kg/GJ)            | Default carbon oxidation Factor | Effective CO <sub>2</sub> emission factor (kg/TJ) <sup>2</sup> |                         |         |         |
|   |   |                                 | Default value  | 95% confidence interval |         |         |
|   | A   | B                               | $C=A*B*44/12*1000$   | Lower                   | Upper   |         |
| Natural Gas   | 15.3                                      | 1                               | 56 100   | 54 300                  | 58 300  |         |
| Municipal Wastes (non-biomass fraction)   | 25.0                                      | 1                               | 91 700   | 73 300                  | 121 000 |         |
| Industrial Wastes   | 39.0                                      | 1                               | 143 000  | 110 000                 | 183 000 |         |
| Waste Oil   | 20.0                                      | 1                               | 73 300   | 72 200                  | 74 400  |         |
| Peat  | 28.9                                      | 1                               | 106 000  | 100 000                 | 108 000 |         |
| Solid Biofuels  | Wood/Wood Waste                           | 30.5                            | 1  | 112 000                 | 95 000  | 132 000 |
|   | Sulphite lyes (black liquor) <sup>5</sup> | 26.0                            | 1  | 95 300                  | 80 700  | 110 000 |
|   | Other Primary Solid Biomass               | 27.3                            | 1  | 100 000                 | 84 700  | 117 000 |
|   | Charcoal                                  | 30.5                            | 1  | 112 000                 | 95 000  | 132 000 |
| Liquid Biofuels   | Biogasoline                               | 19.3                            | 1  | 70 800                  | 59 800  | 84 300  |
|   | Biodiesels                                | 19.3                            | 1  | 70 800                  | 59 800  | 84 300  |
|   | Other Liquid Biofuels                     | 21.7                            | 1  | 79 600                  | 67 100  | 95 300  |
| Gas biomass   | Landfill Gas                              | 14.9                            | 1  | 54 600                  | 46 200  | 66 000  |
|   | Sludge Gas                                | 14.9                            | 1  | 54 600                  | 46 200  | 66 000  |
|   | Other Biogas                              | 14.9                            | 1  | 54 600                  | 46 200  | 66 000  |
| Other non-fossil fuels  | Municipal Wastes (biomass fraction)       | 27.3                            | 1  | 100 000                 | 84 700  | 117 000 |

Notes:

<sup>1</sup> The lower and upper limits of the 95 percent confidence intervals, assuming lognormal distributions, fitted to a dataset, based on national inventory reports, IEA data and available national data. A more detailed description is given in section 1.5

<sup>2</sup> TJ = 1000GJ

<sup>3</sup> The emission factor values for BFG includes carbon dioxide originally contained in this gas as well as that formed due to combustion of this gas.

<sup>4</sup> The emission factor values for OSF includes carbon dioxide originally contained in this gas as well as that formed due to combustion of this gas

<sup>5</sup> Includes the biomass-derived CO<sub>2</sub> emitted from the black liquor combustion unit and the biomass-derived CO<sub>2</sub> emitted from the kraft mill lime kiln.

**Figure 3.5:** Default CO<sub>2</sub> emission factors for combustion - Table 1.4 in IPCC Guidelines for National Greenhouse Gas Inventories (2006), Volume 2: Energy [6].

By converting to energy units this variability is reduced. A small part of the fuel carbon entering the combustion process escapes oxidation. This fraction is usually small (99 to 100 percent of the carbon is oxidized) and so the default emission factors in Figure 3.5 (Table 1.4 in IPCC Guidelines for National Greenhouse Gas Inventories (2006), Volume 2: Energy [6]) are derived on the assumption of 100 percent oxidation. For some fuels, this fraction may in practice not be negligible and where representative country-specific values, based on measurements are available, they should be used. In other words: the fraction of carbon oxidised is assumed to be 1 in deriving default CO<sub>2</sub> emission factors.

Figures 3.6 and 3.7 (Table 1.3 in IPCC Guidelines for National Greenhouse

### 3.6 CO<sub>2</sub> emission factors

| Fuel type English description | Default carbon content <sup>1</sup><br>(kg/GJ) | Lower | Upper |
|-------------------------------|--|-------|-------|
| Crude Oil                     | 20.0   | 19.4  | 20.6  |
| Orimulsion                    | 21.0   | 18.9  | 23.3  |
| Natural Gas Liquids           | 17.5   | 15.9  | 19.2  |
| Motor Gasoline                | 18.9   | 18.4  | 19.9  |
| Aviation Gasoline             | 19.1   | 18.4  | 19.9  |
| Jet Gasoline                  | 19.1   | 18.4  | 19.9  |
| Jet Kerosene                  | 19.5   | 19    | 20.3  |
| Other Kerosene                | 19.6   | 19.3  | 20.1  |
| Shale Oil                     | 20.0   | 18.5  | 21.6  |
| Gas/Diesel Oil                | 20.2   | 19.8  | 20.4  |
| Residual Fuel Oil             | 21.1   | 20.6  | 21.5  |
| Liquefied Petroleum Gases     | 17.2   | 16.8  | 17.9  |
| Ethane                        | 16.8   | 15.4  | 18.7  |
| Naphtha                       | 20.0   | 18.9  | 20.8  |
| Bitumen                       | 22.0   | 19.9  | 24.5  |
| Lubricants                    | 20.0   | 19.6  | 20.5  |
| Petroleum Coke                | 26.6   | 22.6  | 31.3  |
| Refinery Feedstocks           | 20.0   | 18.8  | 20.9  |
| Refinery Gas <sup>2</sup>     | 15.7   | 13.3  | 19.0  |
| Paraffin Waxes                | 20.0   | 19.7  | 20.3  |
| White Spirit & SBP            | 20.0   | 19.7  | 20.3  |
| Other Petroleum Products      | 20.0   | 19.7  | 20.3  |
| Anthracite                    | 26.8   | 25.8  | 27.5  |
| Coking Coal                   | 25.8   | 23.8  | 27.6  |
| Other Bituminous Coal         | 25.8   | 24.4  | 27.2  |
| Sub-Bituminous Coal           | 26.2   | 25.3  | 27.3  |
| Lignite                       | 27.6   | 24.8  | 31.3  |
| Oil Shale and Tar Sands       | 29.1   | 24.6  | 34    |
| Brown Coal Briquettes         | 26.6   | 23.8  | 29.6  |

**Figure 3.6:** Default values of carbon content - Table 1.3 in IPCC Guidelines for National Greenhouse Gas Inventories (2006), Volume 2: Energy [6].

Gas Inventories (2006), Volume 2: Energy [6]) give carbon contents of fuels from which emission factors on a full molecular weight basis can be calculated (Figure 3.5). These emission factors are default values that are suggested only if country-specific factors are not available. More detailed and up-to-date emission factors may be available at the IPCC [6].

Note that CO<sub>2</sub> emissions from biomass fuels are not included in the national total but are reported as an information item, also peat is treated as a fossil fuel and not as a biofuel and emissions from its combustion are therefore included in the national total.

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

| TABLE 1.3 (CONTINUED)<br>DEFAULT VALUES OF CARBON CONTENT |  |       |       |
|---|--|-------|-------|
| Fuel type English description                             | Default carbon content <sup>1</sup><br>(kg/GJ) | Lower | Upper |
| Municipal Wastes (non-biomass fraction) <sup>8</sup>      | 25.0   | 20.0  | 33.0  |
| Industrial Wastes   | 39.0   | 30.0  | 50.0  |
| Waste Oils <sup>9</sup>                                   | 20.0   | 19.7  | 20.3  |
| Peat  | 28.9   | 28.4  | 29.5  |
| Wood/Wood Waste <sup>10</sup>                             | 30.5   | 25.9  | 36.0  |
| Sulphite lyes (black liquor) <sup>11</sup>                | 26.0   | 22.0  | 30.0  |
| Other Primary Solid Biomass <sup>12</sup>                 | 27.3   | 23.1  | 32.0  |
| Charcoal <sup>13</sup>                                    | 30.5   | 25.9  | 36.0  |
| Biogasoline <sup>14</sup>                                 | 19.3   | 16.3  | 23.0  |
| Biodiesels <sup>15</sup>                                  | 19.3   | 16.3  | 23.0  |
| Other Liquid Biofuels <sup>16</sup>                       | 21.7   | 18.3  | 26.0  |
| Landfill Gas <sup>17</sup>                                | 14.9   | 12.6  | 18.0  |
| Sludge Gas <sup>18</sup>                                  | 14.9   | 12.6  | 18.0  |
| Other Biogas <sup>19</sup>                                | 14.9   | 12.6  | 18.0  |
| Municipal Wastes (biomass fraction) <sup>20</sup>         | 27.3   | 23.1  | 32.0  |

Notes:

<sup>1</sup> The lower and upper limits of the 95 percent confidence intervals, assuming lognormal distributions, fitted to a dataset, based on national inventory reports, IEA data and available national data. A more detailed description is given in section 1.5

<sup>2</sup> Japanese data; uncertainty range: expert judgement;

<sup>3</sup> EFDB; uncertainty range: expert judgement

<sup>4</sup> Coke Oven Gas; uncertainty range: expert judgement

<sup>5</sup> Japan & UK small number data; uncertainty range: expert judgement

<sup>6</sup> 7. Japan & UK small number data; uncertainty range: expert judgement

<sup>8</sup> Solid Biomass; uncertainty range: expert judgement

<sup>9</sup> Lubricants ; uncertainty range: expert judgement

<sup>10</sup> EFDB; uncertainty range: expert judgement

<sup>11</sup> Japanese data; uncertainty range: expert judgement

<sup>12</sup> Solid Biomass; uncertainty range: expert judgement

<sup>13</sup> EFDB; uncertainty range: expert judgement

<sup>14</sup> Ethanol theoretical number; uncertainty range: expert judgement

<sup>15</sup> Ethanol theoretical number; uncertainty range: expert judgement

<sup>16</sup> Liquid Biomass; uncertainty range: expert judgement

<sup>17-18</sup> Methane theoretical number; uncertainty range: expert judgement

<sup>20</sup> Solid Biomass; uncertainty range: expert judgement

**Figure 3.7:** Default values of carbon content - Table 1.3 (Continued) in IPCC Guidelines for National Greenhouse Gas Inventories (2006), Volume 2: Energy [6].

The data presented in Figures 3.6 and 3.7 is used to calculate default emission factors for each fuel on a per energy basis. If activity data is available on a per mass basis, a similar approach can be applied to these activity data directly. Obviously the carbon content then should be known on a per mass basis.

### 3.7 Model equations

Below we summarize the difference equations that are used in each submodel:

$$Q_{(t)} = a_1 I_{(t)} + a_2 TB_{(t)} + a_3 C_{(t)} + a_4 Eimp_{(t)} + a_5 RN_{(t-1)}, \quad (3.11)$$

$$E_{j(t)} = \sum_i S_{i(t)} \cdot EI_{i(t)} \cdot M_{ij(t)} \cdot GDP_{(t)}, \quad (3.12)$$

$$RN_{(t)} = E_{4(t)} + E_{5(t)}, \quad (3.13)$$

$$y_{(t)} = y_{(t-1)} \cdot (1 + r_y), \quad (3.14)$$

where  $S_{i(t)}$ ,  $EI_{i(t)}$ ,  $M_{ij(t)}$ ,  $I_{(t)}$ ,  $TB_{(t)}$ ,  $C_{(t)}$ , and  $Eimp_{(t)}$  evolve following Equation 3.14 while the parameters  $a_i$  have constant values. Note that index  $j$  runs over the type of energy sources, while  $i$  on the industrial sectors;  $j = 4$  and  $j = 5$  corresponds to renewable and alternative energy, respectively.  $t = 0$  corresponds to the base year and  $t$  is given in number of years since 1980. The value of  $r_y$  is fixed through the definition of the used scenario,

$$r_y = \left( \frac{y_{(tf)}}{y_{(0)}} \right)^{1/tf} - 1, \quad (3.15)$$

where  $tf$  is the future time for which we establish the goal ( $y_{(tf)}$ ), and  $y_0$  is the starting value of the function. According to Rowland (2003) [177] and Jin et al., [178], to extrapolate the trend of the period 1980-2010 in the base scenario (trend), one should use a value of  $r_y$  that depends on the time,

$$r_{y(t)} = \left( \frac{y_{(t-1)}}{y_{(t-n)}} \right)^{1/n} - 1, \quad (3.16)$$

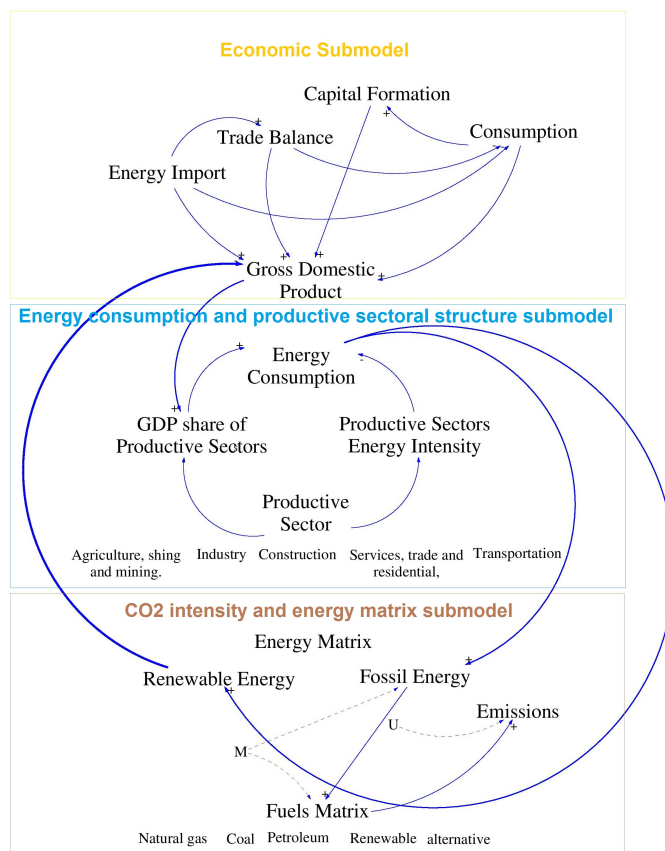
where  $n$  is the number of years of the dataset period, *i.e.*, 30 in our case. The feedback mechanism is provided through the inclusion of  $RN_{(t-1)}$  in the calculation of the income ( $Q$ ) (Equation 3.11). As  $a_5 < 0$  (see Table 3.2) the feedback mechanism is negative. This fact induces a decrease of the GDP for the *SC-3* and *SC-4* scenarios with respect to *SC-2* (see section 3.10.1 in this Chapter) for increasing of renewable energy use. In general, any increase of the terms  $\sum_i S_{i(t)} \cdot EI_{i(t)} \cdot M_{ij(t)}$  for  $j = 4$  and  $j = 5$  will induce a reduction, though moderate, of the income.

In Figure 3.8 we present the schematic view of the whole model. It is worth noting the *feedback* mechanism between renewable energy and GDP. This is one of the keys of the model, which allows us to generate a non-trivial evolution of

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

the system. In this Figure, we can identify the economic submodel, the energy consumption and productive sectoral submodel, as well as the CO<sub>2</sub>intensity and energy matrix submodel.

#### 3.8 Causal diagram of CO<sub>2</sub> emissions



**Figure 3.8:** Causal diagram for the model. Continuous lines stand for the relationship between variables, while dashed ones correspond to control terms (S:productive sectoral structure, M: energy matrix, U:emission factors). Bold line represents a feedback mechanism.

To understand why and how CO<sub>2</sub> emissions change over time, we need to know the factors that separately affect or control CO<sub>2</sub> emissions. In particular, it is extremely useful to represent the driving forces of CO<sub>2</sub> emissions in a hierarchical

way, showing the causality relationship between the different variables. All this information constitutes the causal diagram. In this work the variables that will determine the amount of CO<sub>2</sub> emissions are: GDP (formation components), share of the different productive sectors in the GDP, energy intensity of each sector, energy consumption, energy matrix, and carbon dioxide intensity. They are all represented schematically in Figure 3.8. It can be observed that the CO<sub>2</sub> emitted into the atmosphere has several connections with the variables of the model: economic growth and its different productive activities demand more energy, this increase in energy consumption induces higher CO<sub>2</sub> emissions that could be regulated by changes in the energy matrix and in the productive sectoral structure of the country.

It is worth to note the presence of a feedback mechanism associated to the influence of renewable energy on the GDP (see bold line in Figure 3.8).

### 3.9 Model validation and verification

Official dataset from 1980 to 2010 and the output of the model for the same period can be compared to test the reliability and robustness of the model. This analysis can be carried out calculating the mean absolute percentage error (MAPE) that is a measure of accuracy of a method for constructing fitted time series values in statistics, specifically in trend estimation. MAPE is most commonly used to evaluate cross-sectional forecasts (Ahlburg, 1995 [193]; Campbell, 2002 [194]; Hyndman and Koehler, 2006 [195]; Isserman, 1977 [196]; Miller, 2001 [197]; Murdock et al., 1984 [198]; Rayer, 2007 [199]; Sink, 1997 [200]; Smith, 1987 [201]; Smith and Sincich, 1990 [202]; Smith and Sincich, 1992 [203]; Smith, Tayman, and Swanson, 2001 [204]; Tayman, Schaffer, and Carter, 1998 [205]; Wilson, 2007 [206]).

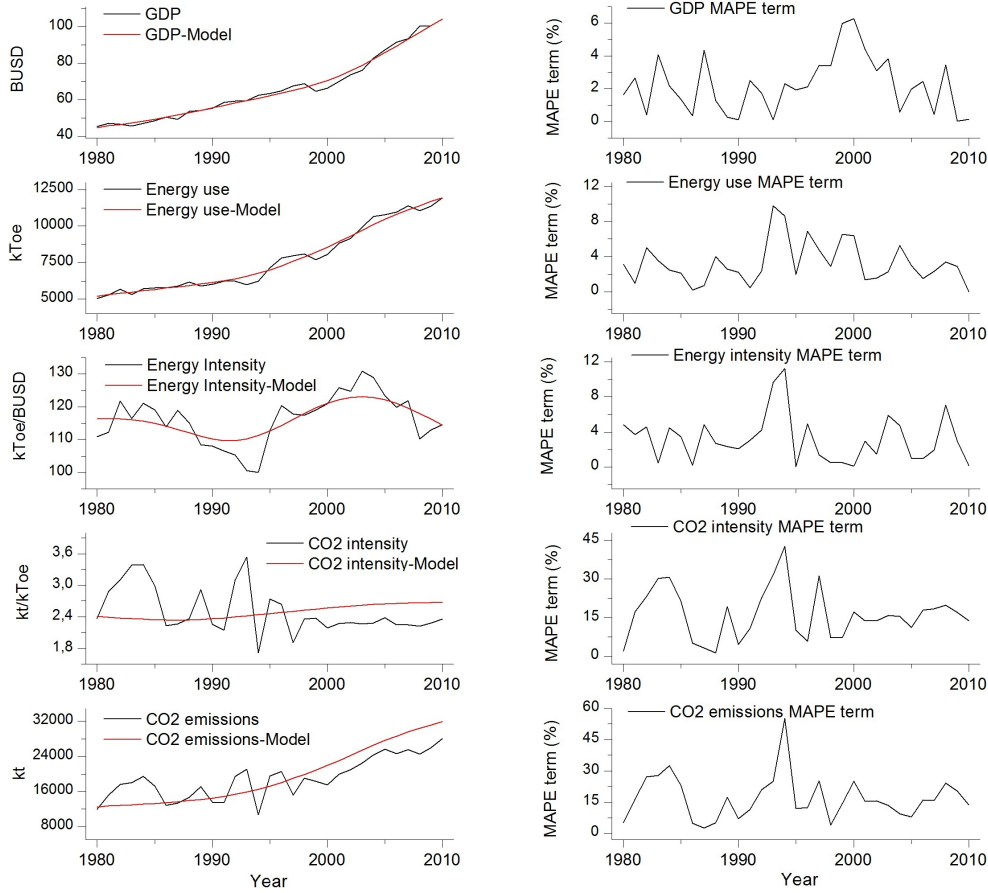
It usually expresses accuracy as a percentage, and is defined by the formula:

$$\text{MAPE}(\%) = \frac{1}{n} \sum_{t_1}^n \left| \frac{A_t - F_t}{A_t} \right| \times 100, \quad (3.17)$$

where,  $A_t$ ,  $F_t$ , and  $n$  are the real data, the calculated values, and the number of data, respectively.

In table 3.3 the corresponding MAPE values for some selected variables are given. These results indicate the robustness of the model.

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)



**Figure 3.9:** Left: Comparative of model result vs. historical data. Right: Time series of MAPE term at time  $t$ , see Equation 3.17.

Note that in this work, we consider that CO<sub>2</sub> emissions come only from the burning of fossil fuels and we do not include the contribution coming from the production of cement, because the lack of official data. Therefore, our projections will consider CO<sub>2</sub> emissions only. This fact, together with the process of smoothing (HP filter) of the raw dataset and the use of general emission factors [42] justify the somehow large deviations observed in table 3.3 for the CO<sub>2</sub> intensity and CO<sub>2</sub> emissions (see Figure 3.9).

**Table 3.3:** Mean absolute percentage error (MAPE) for selected variables.

| VARIABLE                  | MAPE(%) |
|---------------------------|---------|
| GDP                       | 2.2     |
| Energy consumption        | 3.3     |
| Energy intensity          | 3.2     |
| CO <sub>2</sub> intensity | 16      |
| CO <sub>2</sub> emission  | 17      |

## 3.10 Scenarios

### 3.10.1 Scenario analysis to income, energy and emissions

As mentioned in Section 1.7 in Chapter 1, scenario analysis is used in a wide range of purposes in the literature. The primary function of the scenario approach in economy growth, energy consumption and emission in this research is to respond to uncertainty and potentially to develop strategic insights for policy.

Sometimes the terminology used to describe possible future conditions in the context of income, energy and emissions is often interchangeable in the literature. Holmes (2007) [207] notes some important distinctions. Whereas projections, forward historical data or past trends and forecasts, all of them are predictive and seek to determine the most likely future, scenarios look at diverging trends and the potential unfolding of new dynamics.

Rather than prediction, scenario approach seeks to describe a *spectrum of possibilities*. This is a bounded package of probability that could cover the range of plausible outcomes. Economic and environmental scenarios are used in contexts where dynamic complex systems are subject to uncertainties.

These uncertainties include inadequate scientific understanding, data gaps and inherent uncertainties on future events (Nakicenovic, 2000) [65]. Sometimes forecasts and projections are based on producing *Business As Usual* (BAU) or central *best guess* estimates and the high/low or optimistic/pessimistic variants of these.

According to Nakicenovic (2000) [65], the formulation of a range of emission scenarios is an appropriate technique to encompass uncertainties and deliver

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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policy insights. With the use of scenario approach, some concern of *decision-makers* about the quantitative point forecasts of single *most likely* estimates arises. While this can reflect an ease of understanding of single estimates, or simply what decision-makers are accustomed to, these forecasts can also reflect a particular set of values or interests promoted as *objective* information. This concern with forecasts may not be appropriate to either scientific inquiry or to strategic thinking in decision-making, but it is a practice issue for scenarios.

Nielsen and Karlsson (2007) [40] note a science-policy nexus issue as technological and economic rationalities are implicitly embedded in models. This opens the question of the worldview, values and philosophy underpinning supposedly *objective* scientific information. This information can reflect specific futures that are profitable or preferable to certain interests or can be used to legitimise results rather than guide policy. The use of scenarios offers an approach to make world views more explicit, through the description of underlying themes in narratives. It can also be used to document assumptions used in modelling.

#### 3.10.2 Proposal of scenarios for Ecuador 2010-2025

The goals that will be considered to define the different scenarios that will be proposed, under the general purpose of *improve the quality of life of people with the least environmental impact* are:

- *Goal 1*, by 2025 the GDP per capita will reach the international average ( $\approx$  15000 USD according to our estimates based on World Bank data) through a process of industrialization and improvement of the productive sectoral structure of the country;
- *Goal 2*, in regard to the *Goal 1*, the use of renewable energy will be increased up to almost 30% of the total energy consumption;
- *Goal 3*, in regard to *Goal 1* and *Goal 2*, the energy efficiency will be enlarged by a reduction of the energy intensity and by changes in the productive sectoral structure.

Taking into account the latter goals, we propose four scenarios concerning the growth of the income, the evolution of the energy matrix and of the productive sectoral structure for the period 2011-2025.

1. *Baseline scenario (BS)*: the GDP, the energy matrix and the productive sectoral structure will evolve through the smooth trend of the period 1980-2010 extrapolated to 2011-2025 using the geometric growth rate method.
2. *Increasing GDP scenario (SC-2)*: GDP will increase approximately up to be double of reference GDP (2010) by 2025. To generate this scenario a constant annual growth of GDP formation components ( $I$ ,  $TB$ ,  $C$ ,  $E_{imp}$ , see Section 3.3.3 in this Chapter) of 7% per year between 2011 to 2025 will be assumed and a structural change in the productive sectoral structure will be implemented through a growth of 1% per year in the GDP share ( $S_i$ ) in the sectors with more profit in the country economy: industry sector (sec-2) and trade and public service sector (sec-4). The rest of the variables will evolve as in the *BS* scenario. This scenario clearly corresponds to a situation where the economy is growing rapidly and no mitigation measurements to reduce the CO<sub>2</sub> emissions are carried out.
3. *Increasing GDP and share of renewable energies scenario (SC-3)*: increasing GDP and change in productive sectoral structure as in the *SC-2* scenario is considered, however the share of fossil energy, will be reduced approximately one point per year, passing from a 88% in 2011 to 67% in 2025 due to a constant annual growth of share in renewable and alternative energy ( $M_4$  and  $M_5$ ). This scenario shows a first measure of environmental responsibility in order to try to reduce dependence of fossil energy.
4. *Increasing GDP and share of renewable energies and improvement in energy efficiency scenario (SC-4)*: increasing GDP, change in productive sectoral structure and change in share of fossil energy as in *SC-3* scenario is carried out. Moreover, an improvement in energy efficiency is implemented with a 1% reduction of energy intensity in industry sector (sec-2), in trade and public services sector (sec-4) and in transportation sector (sec-5). This scenario takes a step towards improving the country's environmental responsibility

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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and sustainable development by supporting their energetic saving measures and energy efficiency.

Both *SC-3* and *SC-4* scenarios goals are realistic considering the state of development and evolution of energy technology in various energy projects implemented by the Ecuadorian government, and the trends in the use of renewable energies in the country [152] (see Section 2.5 and Section 2.6 in Chapter 2).

#### 3.11 Empirical findings and discussion of the model

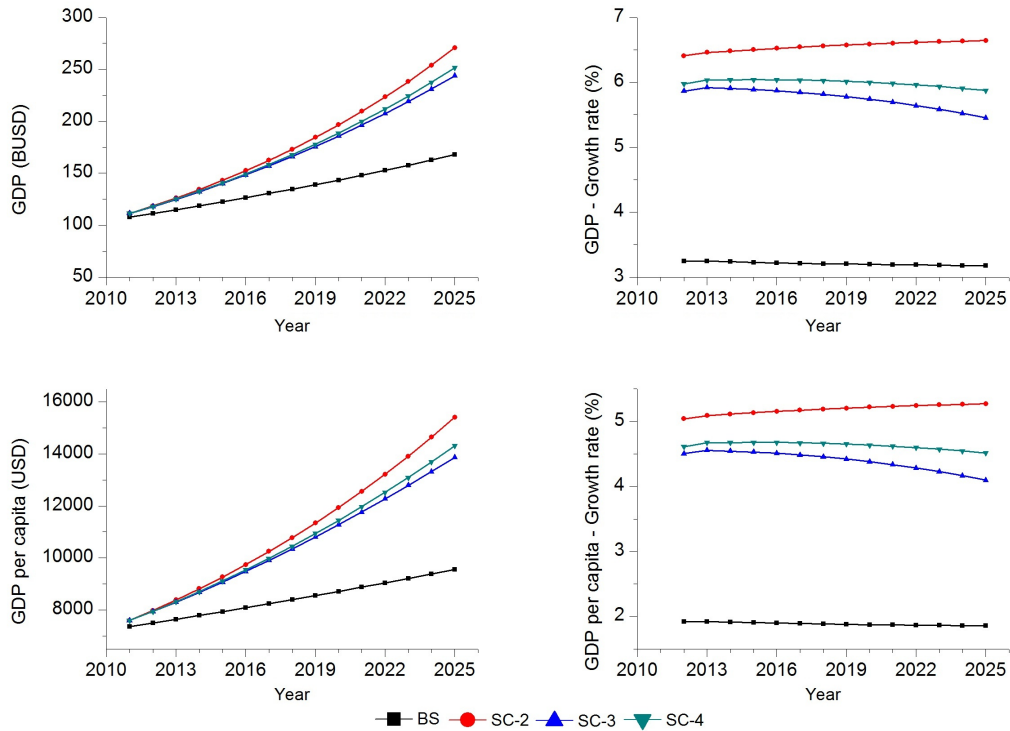
This section includes the estimations and respective discussion for the period 2011-2025 in each studied scenarios of the main considerate variables, such as: income and income per capita, energy consumption and CO<sub>2</sub> emissions, among others.

##### 3.11.1 Economic estimates

GDP estimates for the two economic scenarios considered (on the one hand the *BS* and on the other hand *SC-2*, *SC-3* and *SC-4*) are presented in Figure 3.10, where one can see that the estimated GDP for the *SC-2* scenario will be around 271 billion USD in 2025 (61% higher than for *BS* scenario) and its average growth rate is 6.6% while in *BS* scenario is 3.2%. Note that the projected GDP is not a forecast but a consequence of the considered scenarios. Assuming an annual increase of the population of 1.2%, the population will pass from 14.5 million in 2010 to 17.6 million in 2025, thus GDP per capita in 2025 will be around 15000 USD (see Figure 3.10), which is roughly the prevision that has been considerate as the international average of GDP per capita.

In *SC-3* and *SC-4* scenarios, GDP would be lower than in *SC-2* scenario with a reduction of 27 and 20 billion USD, reaching 244 and 251 billion USD (BUSD) in 2025, respectively, due to the promotion of renewable energy and energy efficiency (see Figure 3.10). The nexus between GDP and renewable energy is obtained through the feedback mechanism of the model (see Section 3.7 in this Chapter). In *SC-4* scenario the reduction in GDP is slightly smaller (about 7 billion USD regarding the reduction in *SC-3*) because of the improvement in the energy intensity. Note that the tiny deviations between *SC-2*, *SC-3* and *SC-4* scenarios are due to the

### 3.11 Empirical findings and discussion of the model



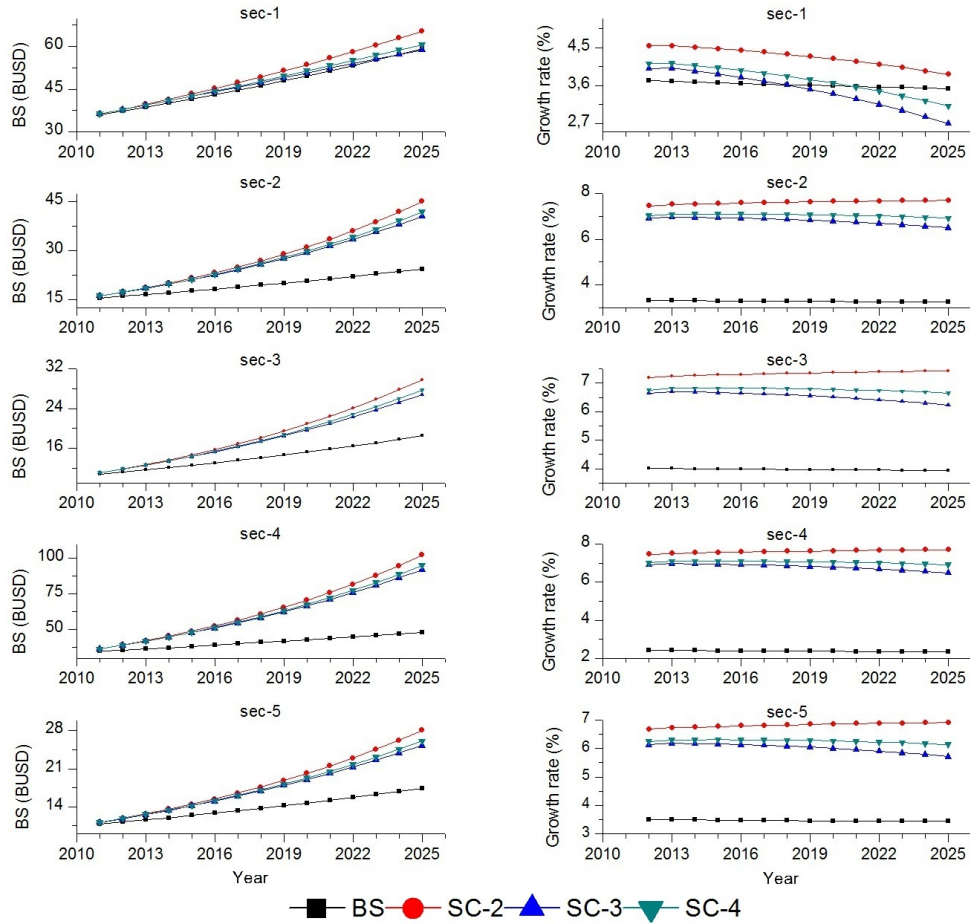
**Figure 3.10:** Left: Estimation of GDP and GDP per capita for the period 2011-2025 in Ecuador. Right: Growth rate.

feedback mechanism between GDP and renewable energy. This can be seen in the different average growth rates for these scenarios, *SC-2* with 6.6%, *SC-3* with 5.8% and *SC-4* with 6.0% (see Figure 3.10).

Regarding the evolution of each sector, in *sec-1* a very similar growth is observed in all scenarios (see Figure 3.11), about 3.8%. The reason is that its growth is not primarily affected by changes in the energetic matrix since this sector is less energetically intensive and its revenues depend greatly on the oil production of the country (see Section 2.2 in Chapter 2).

In *sec-2* and *sec-4*, a significant increase is observed in the growth rate of the *SC-2*, *SC-3* and *SC-4* scenarios with respect to the growth rate of the *BS* scenario (see Figure 3.11). In the case of *sec-2*, *BS* grows at a rate of 3.3% while *SC-2* average growing is 7.6%. This growth is diminished in the remaining two scenarios, *SC-3* with 6.5% and *SC-4* with 6.9%. Similarly, in the *sec-4*, *BS* grows at a rate of

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)



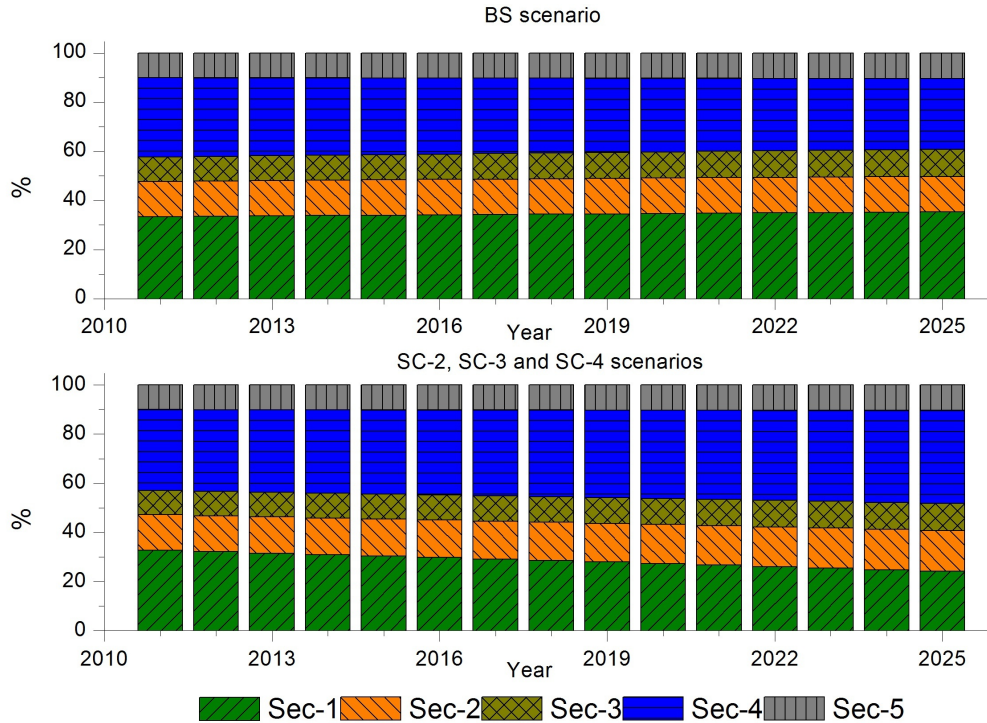
**Figure 3.11:** Left: Estimation of GDP by sector for the period 2011-2025 in Ecuador. Right: Growth rate.

2.4% while the *SC-2* grows at a rate of 7.6%, this growth also is diminished in *SC-3* with a rate of 6.9% and in *SC-4* with a rate of 7.1%. The reason for this decrease is the application of the policy of reducing the use of fossil fuels and the improvement of energy efficiency.

In the case of *sec-3* and *sec-5*, an increase in the growth rate is also observed in the *SC-2*, *SC-3* and *SC-4* scenarios with respect to *BS* but with less intensity. Note that the *sec-5* (transport), in the *BS*, grows with a rate of 3.4% and the *SC-2*, *SC-3* and *SC-4* grow with an average value of 6.4% (see Figure 3.11).

Figure 3.12 shows the estimation of the Productive Sectorial Matrix (PSM) for

### 3.11 Empirical findings and discussion of the model



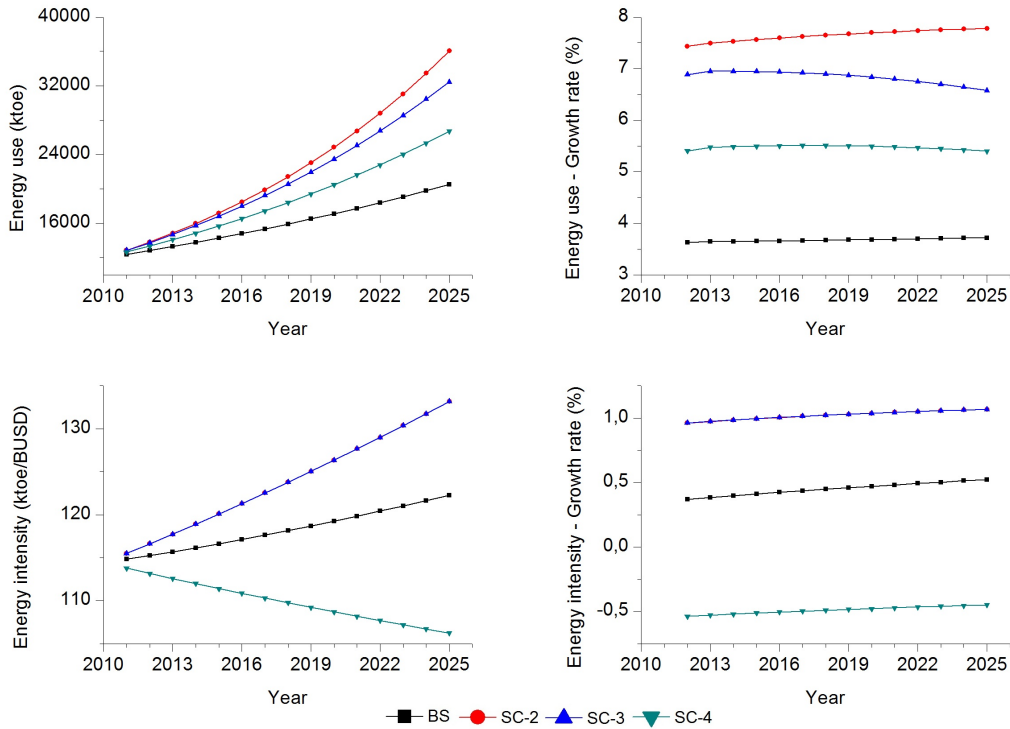
**Figure 3.12:** Estimation of Productive Sectors Matrix in Ecuador 2011-2025.

the *BS* and for the alternative scenarios (*SC-2*, *SC-3* and *SC-4*). In *BS* case, we can observe that the largest sector is sec-1 (includes income from petroleum) that represented around 34% of GDP in the period 2011-2025, reinforcing the country's oil dependence, followed by sec-4 (31%), sec-2 (14%), sec-3 (11%) and sec-5 (10%). In the alternative scenarios, we can observe a change in the shares of PSM and Sec-4 is now the largest sector (35%), following by sec-1 but with a less share that in previous case (28%), sec-2 (industry) growth up to 16%, sec-3 (11%) and sec-5 (10%). Note that the share of sec-5 (transportation) keeps constant.

#### 3.11.2 Energy estimates

Energy consumption is calculated through the product of the energy intensity of each productive sector ( $EI_i$ ) and the corresponding share of the GDP ( $Q_i$ ) of every sector. The values of the energy consumption for the period 2011-2025 are represented in Figure 3.13. In 2025 the *BS* scenario generates a consumption of 20520

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

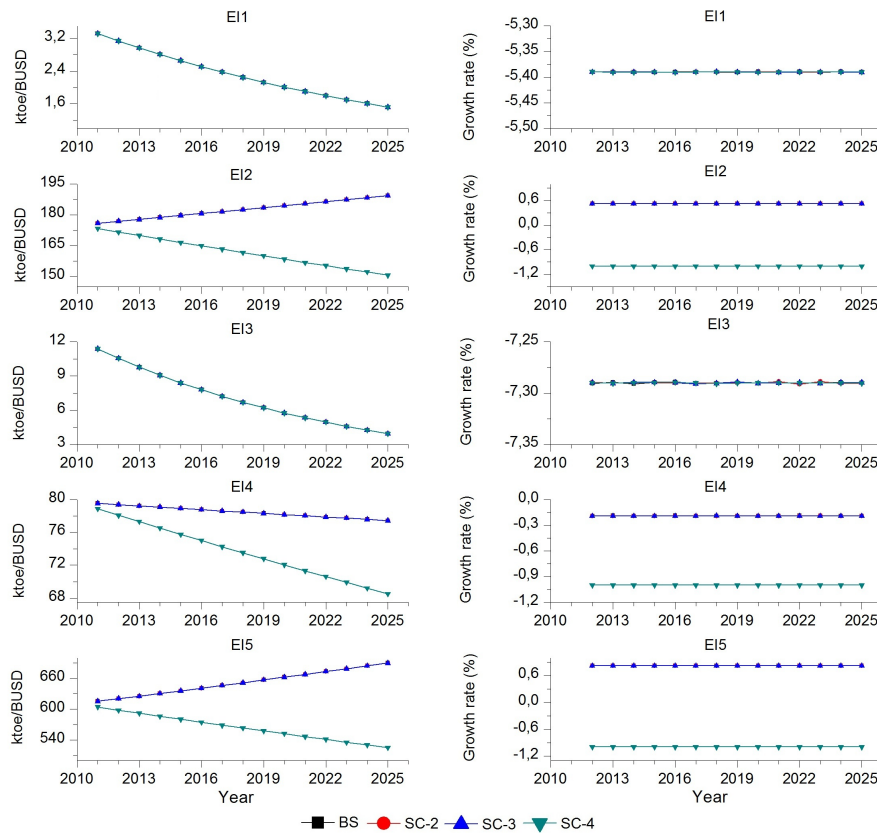


**Figure 3.13:** Lefth: Estimation of energy consumption and energy intensity for the period 2011-2020 in Ecuador. Right: Growth rate.

ktoe, the *SC-2* scenario about 36040 ktoe (76% higher than the *BS* scenario), and the *SC-3* scenario generates a consumption of 32425 ktoe (58% higher than the *BS* scenario). These two last scenarios show the growth of the energy consumption due to the increase of GDP and to the changes of the productive sectoral structure. Finally, *SC-4* scenario generates a consumption of 26740 ktoe (only 30% higher than in the *BS* scenario). It clearly shows the benefits of the reduction of the energy intensity.

In Figure 3.13, we can see that there are three pathways followed by the different proposed scenarios, the most energetically intensive is the path followed by *SC-2* and *SC-3* (indistinguishable in the used scale), due to its larger energy consumption and low energy efficiency goal. Indeed, in these scenarios the energy intensity increases more than 15% (period 2011-2025). The path taken by *SC-4* is clearly the most energetically efficient, with a reduction of 6% in energy efficiency,

### 3.11 Empirical findings and discussion of the model



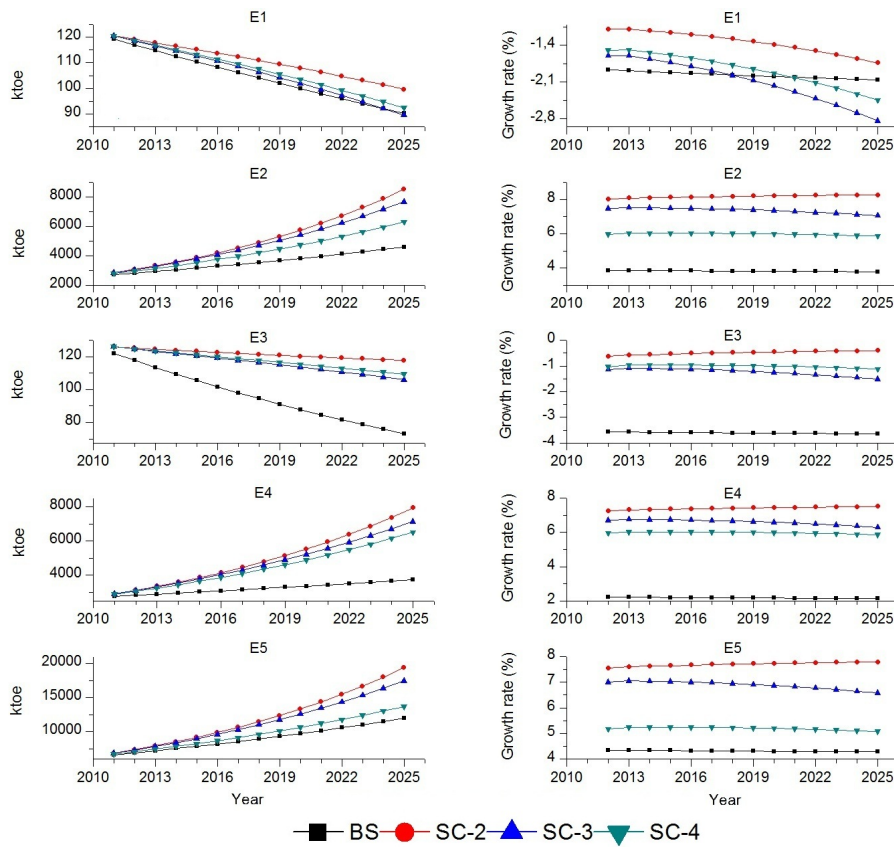
**Figure 3.14:** Left: Estimation of energy intensity in each productive sector for the period 2011-2025 in Ecuador. Right: Growth rate.

while *BS* follow the trend path with a increase of 7% in the whole period.

The estimated values of energy intensity and energy consumption in each productive sector till 2025 are shown in Figure 3.14 and Figure 3.15, respectively to illustrate the differences between sectors. In Figure 3.14, one can clearly see the results of the implementation of energy efficiency goals set for each sector (especially for sec-2, sec-4 and sec-5) in scenario SC-4 (see Section 3.10.2 in this Chapter). Indeed, sec-5 in *SC-4* scenario has a reduction in its energy intensity value of almost 165 points (ktoe/BUSD) respect to the value in the rest of scenarios in 2025<sup>1</sup>, while sec-2 and sec-4 reach a reduction of 40 and 10 points respectively

<sup>1</sup> Note that, in *SC-4* sec-5 sector there is a reduction in the energy consumption of more than 5600 ktoe in 2025 respect to *SC-2* (see Figure 3.15).

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)



**Figure 3.15:** Left: Estimation of energy consumption in each productive sector for the period 2011-2025 in Ecuador. Right: Growth rate.

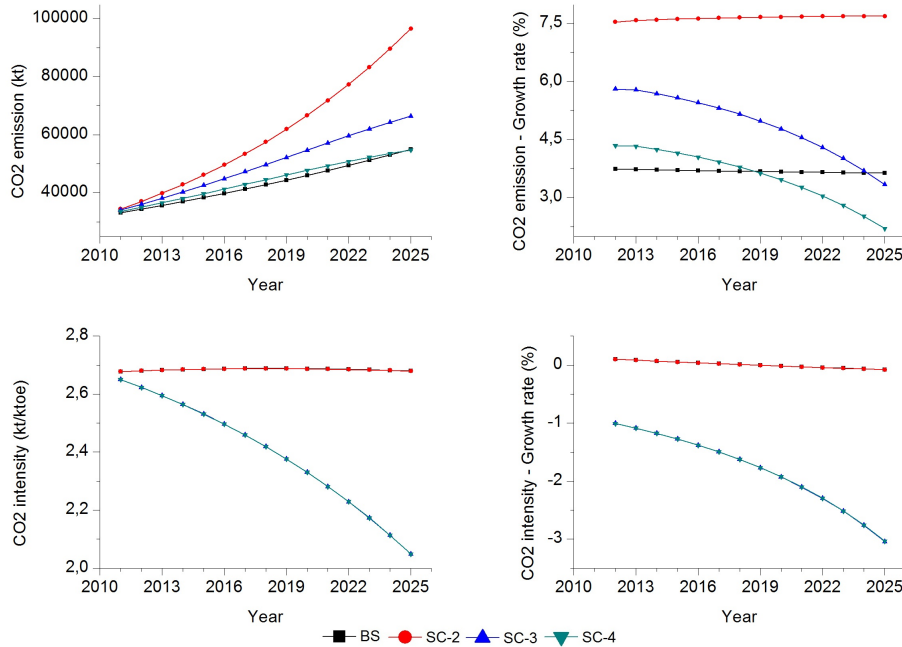
in the same case<sup>1</sup>.

Regarding energy matrix, two types of evolution have been taken into account in the calculations, in particular, for the share of fossil energy inside of the energy matrix and its components ( $M_1$ ,  $M_2$ , and  $M_3$ ). In the first case (scenarios *BS* and *SC-2*), the evolution of fossil energy keeps the tendency of the period 1980-2010. In the second case (scenarios *SC-3* and *SC-4*), a continuous drop of the use of fuel energy down to 67% in 2025 due to an approx increase of one point per year of renewable energy share (see Figure 3.16).

<sup>1</sup> Note that, in *SC-4* scenario there are more than 2200 and 1400 ktoe of reduction in the energy consumption in 2025 for sec-2 and sec-4, respectively with respect to *SC-2* (see Figure 3.15).



### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

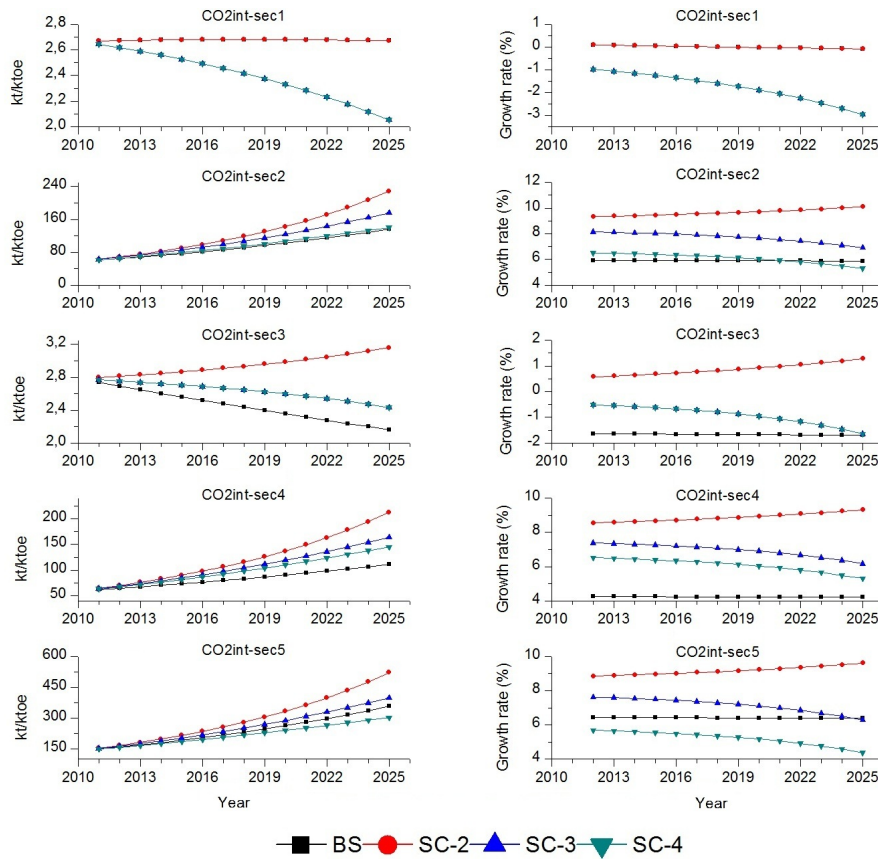


**Figure 3.17:** Left: Estimation of CO<sub>2</sub> and CO<sub>2</sub> intensity for the period 2011-2025 in Ecuador. Right: Growth rate.

in 2025 CO<sub>2</sub> emissions would reach 97 thousand kt in *SC-2* scenario, and only 55 thousand kt in *BS* scenario. With the reduction of fossil energy, down to 67% in *SC-3* scenario, without modifying the energy intensity, one reaches 66 thousand kt, while implementing energy efficiency measures in the productive sectoral structure (*SC-4* scenario) emissions are reduced down to 54 thousand kt.

The *BS* scenario presents CO<sub>2</sub> emissions in 2025, 1.7 times higher than in 2010, while the *SC-2* scenario gives rise to an increase of 2.8 times. This implies that the amount of CO<sub>2</sub> emissions in the *SC-2* scenario during the period 2011-2020 will be 260 thousand kt higher than in the *BS* scenario. Scenarios where renewable energy and efficiency goals are implemented show that it is possible to increase the GDP in a constant way, mitigating, at the same time, the CO<sub>2</sub> emissions, therefore reducing the rise of the emissions due to the higher economic activity. In particular, the most efficient scenario, *SC-4*, presents a remarkable reduction. In 2025 CO<sub>2</sub> emissions will be 43% lower than in the *SC-2* scenario. Furthermore, the *SC-3*

### 3.11 Empirical findings and discussion of the model

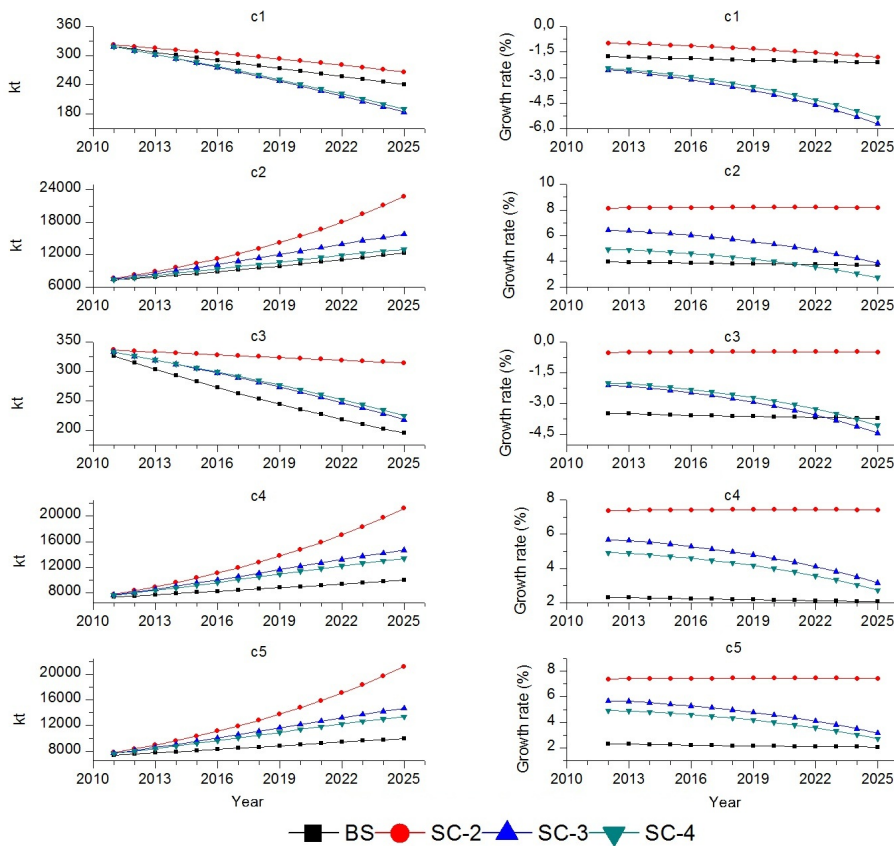


**Figure 3.18:** Left: Estimation of CO<sub>2</sub> intensity in each productive sector for the period 2011-2025 in Ecuador. Right: Growth rate.

scenario generates 115 thousand kt more than *BS* scenario during the 2011-2025 period, which supposes a reduction of 30 thousand kt with respect to *SC-2* scenario. Finally, the *SC-4* scenario generates 300 kt less than *BS* scenario during the same period, which supposes a large reduction of 41 thousand kt with respect to the *SC-2* scenario.

The estimated values of CO<sub>2</sub> intensity and CO<sub>2</sub> emissions in each productive sector till 2025 are shown in Figure 3.18 and Figure 3.19 respectively to illustrate the differences between sectors. In Figure 3.18, we can see the results of the implementation of green goals set for each sector (especially for sec-2 and sec-5) in scenario *SC-4* (see Section 3.10.2 in this Chapter). Indeed, sec-5 in *SC-4* scenario presents a reduction in its CO<sub>2</sub> intensity value of 55, 220 and 95 points (kt/ktoe)

### 3. SYSTEM DYNAMICS MODELLING FOR RENEWABLE ENERGY AND CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)



**Figure 3.19:** Left: Estimation of CO<sub>2</sub> in each productive sector for the period 2011-2025 in Ecuador. Right: Growth rate.

respect to the value of *BS*, *SC-2* and *SC-3* in 2025, respectively. Note that, in *SC-4* scenario there are more than 4, 24 and 7 thousand kt of reduction in emissions of transport sector (sec-5) in 2025 respect to *BS*, *SC-2* and *SC-3* scenarios, respectively (see Figure 3.19). While sec-2 in *SC-4* reach a reduction of 88 and 136 points with respect to *SC-2* and *SC-3*, respectively, and only has 4 point more than the value of CO<sub>2</sub> intensity in *BS* scenario. Note that, in *SC-4* scenario there are almost 10 and 3 thousand kt of reduction in emissions of industry sector (sec-2) in 2025 respect to *SC-2* and *SC-3*, respectively and only 600 kt more than in the *BS* scenario (see Figure 3.19).

## 3.12 Summary and conclusions of the chapter

This Chapter presents a model based on a variation of the Kaya Identity and on an approach of GDP formation which is supported with the use of renewable energy. The official data set (1980-2010) was used to parameterize the model, while with the second part of the period (2011-2025) an estimation of different variables, including the CO<sub>2</sub> emissions, was carried out. To this end, the GDP and the energy intensity have been modeled. Moreover, different scenarios that present the evolution of the energy matrix and the productive sectoral structure have been defined.

First, a *BS* scenario (baseline scenario) has been defined, in which the variables of the model were parameterized according to the observed tendency during the period 1980-2010, assuming a geometric growth rate during the period 2011-2025. The second scenario, called *SC-2*, is characterized by the increasing (relative to 2010) of the GDP during the period 2011-2025 (with the goal of reaching the estimated international average GDP per capita in 2025). In the third scenario, called *SC-3* scenario, besides assuming the increasing of the GDP, we impose the decreasing of the fossil energy share ( $ES_1$ ) up to 67%. Finally, in the fourth one, *SC-4* scenario, we complement the *SC-3* scenario including changes in the productive sectoral structure to achieve a reduction of energy intensity, which supposes a lower CO<sub>2</sub> intensity.

The main outcome of this chapter are the estimates of CO<sub>2</sub> emissions by the period 2011-2025 in each scenario (see Section 3.11.3 in this Chapter). By 2025 the *BS* scenario reaches 55 thousand kt, in the *SC-2* scenario it corresponds to 97 thousand kt, in *SC-3* scenario to 66 thousand kt, and in the *SC-4* scenario to 55 thousand kt of CO<sub>2</sub>. Note that the *BS* scenario corresponds to a modest GDP increase, while in the others the GDP increases heavily. The highest emissions are for the *SC-2* scenario where no mitigation measures are taken. The other two scenarios show us that it is possible a sizable reduction of the emissions, promoting the renewable energy (*SC-3* scenario) and on top of that modifying the productive sectoral structure, therefore, reducing the energy and the CO<sub>2</sub> intensities, as in the *SC-4* scenario. It is worth to note that both promotion of renewable energy and improvement of the energy intensity are equally effective attenuating CO<sub>2</sub> emissions.



*Adapt or perish, now as ever, is  
nature's inexorable imperative.*

H. G. Wells

CHAPTER

# 4

## **Decomposition analysis in income and energy consumption related with CO<sub>2</sub> emissions in Ecuador (1980-2025)**

### **4.1 Overview**

In the present chapter, we discuss the decomposition analysis (DA) methodology applied within this research. This section presents the used technique, the applied mathematical methodology and the construction of an appropriate identity to measure the change of CO<sub>2</sub> emission in Ecuador during the period 1980-2025. Change is measured at both macro and disaggregated sectoral level. Specific aspects related to the application of DA to both the historical period (1980-2010) and in medium term prevision (2011-2025) for the proposed scenarios are discussed.

DA is widely applied in understanding changes in economic, energy consumption, environmental, employment and other socio-economic indicators (Hoekstra

#### 4. DECOMPOSITION ANALYSIS IN INCOME AND ENERGY CONSUMPTION RELATED WITH CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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and van den Bergh, 2003) [208]. Several DA methodologies have been developed specifically to analyze changes in energy and emissions. Two main streams of inquiry have evolved under the concept of DA: *i*) Index Decomposition Analysis (IDA) and *ii*) Structural Decomposition Analysis (SDA).

These techniques have been used for both temporal and cross country/region analysis. IDA is formulated using concepts similar to the *index numbers* used in economics and statistics. This technique is more popular in the literature than SDA which is based on an input-output model (Ang, 2004a) [209]. At first sight, the advantages of IDA over SDA include the requirement for less data (Hatzigeorgiou et al., 2008) [210]. In IDA, absolute, structural and elasticity indicators have been analysed in contrast to SDA which has generally been restricted to absolute indicators. In many countries input-output tables are not constructed annually. IDA also permits the exploration of a share effect in industry or transport, indeed, this methodology has a great development and application studies in the literature. In contrast, SDA can distinguish between technological and demand effects which is not possible in IDA. Zhou and Ang, (2008) [211] propose that IDA is more flexible for aggregate data studies, Hatzigeorgiou (2008) [210] points the requirement for less data and the use of three indicator forms as comparative advantages of IDA approach, while Ang (2004a) [209] states its simplicity and flexibility.

Since late 1970s IDA methods have undergone several deep changes in scope of application. The reason is the expanding from applications in industry to energy demand and emission analysis across various sectors. Key to the application of IDA is the decomposition of change as an indicator, using a governing function to a number of predefined factors of interest to the analysis (Zhou, 2008) [211]. This idea can be used to get insight into the effect of the driving forces<sup>1</sup> or determinants that underlie changes. IDA approach is now a widely accepted analytical tool for energy and carbon emissions analysis (Ang, 2004) [53]. The technique has direct policy implications as it can be used to accurately quantify effects including evaluation of energy conservation programs and the outcome may provide a basis for

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<sup>1</sup>In DA, the driving forces are determined by the governing function designed and are quantitative. In scenario analysis, driving forces can potentially overlap with those described by the DA approach, but they also encompass qualitative aspects that sometimes cannot be captured by modelling.

## 4.2 Decomposition techniques in explanatory factors - Aggregate data decomposition

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forecasting (Ang, 2004a) [209].

### 4.2 Decomposition techniques in explanatory factors - Aggregate data decomposition

Proops et al (1993) [212] decompose the growth rate of CO<sub>2</sub> emissions considering aggregate an economic activity, that is, without taking into account the relative weights of the different productive sectors. They identified three variables that influence the temporal evolution of CO<sub>2</sub> emissions, which are:

- The ratio of CO<sub>2</sub>( $C$ ) and energy used ( $E$ ):  $\frac{C}{E}$ ,
- The ratio of energy use in the economy ( $E$ ) and GDP ( $Q$ ):  $\frac{E}{Q}$ ,
- The GDP of the economy ( $Q$ ).

These variables are related in the following identity:

$$C = \left(\frac{C}{E}\right) \left(\frac{E}{Q}\right) Q. \quad (4.1)$$

Taking logarithms of the identity 4.1 and differentiating<sup>1</sup> respect to time:

$$\frac{C'}{C} = \left(\frac{(C/E)'}{C/E}\right) + \left(\frac{(E/Q)'}{E/Q}\right) + \frac{Q'}{Q}. \quad (4.2)$$

Considering that time series are in discrete time and taking into account that  $x' = \frac{dx}{dt} \approx \frac{\Delta x}{\Delta t}$  and assuming that  $\Delta t = 1$ , then  $\frac{x'}{x} \approx \frac{\Delta x}{x}$ , Equation 4.2 can be approached as,

$$\frac{\Delta C}{C} \approx \frac{\Delta(C/E)}{C/E} + \frac{\Delta(E/Q)}{E/Q} + \frac{\Delta Q}{Q}. \quad (4.3)$$

As Equation 4.3 is a discrete approximation, the result in both sides of the equation do not match and always will exist a residue.

Therefore, according to equation 4.3, the variation of CO<sub>2</sub> will be influenced by the following variables:

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<sup>1</sup>Wherein the ' represents the first derivative with respect to time,  $x' = \frac{dx}{dt}$ .

#### 4. DECOMPOSITION ANALYSIS IN INCOME AND ENERGY CONSUMPTION RELATED WITH CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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- The variation of the ratio  $\frac{C}{E}$ : this variation would be picking the modification of the fuel mix, so as to provide the same amount of energy a different quantity of CO<sub>2</sub> is emitted. Another possibility is that technologies that reduce emissions at the end of the process are applied.
- The variation of the ratio  $\frac{E}{Q}$ : it is the modification of the energy requirements to produce one unit of GDP. The variation of the ratio  $\frac{E}{Q}$  could take place either because it increases the efficiency of energy production or because the structure is modified to sectors with lower energy requirements.
- The variation of Q: is the change in the GDP of the economy.

If we consider the three effects of first level mentioned in Grossman and Krueger (1991) [132] (effect scale, composition and technology, see Section 5.2.2 in Chapter 4). CO<sub>2</sub> change in Equation 4.3 can be explained through three terms: *i*) the first is the technological effect, *ii*) the second refer to the rest of the technological effect (related to the improved efficiency in the use of resources), and the composition effect; the third is the scale effect. Although Proops et al (1993) [212] proposed this decomposition to be used for CO<sub>2</sub>, it could be used for any contaminant associated with energy use.

This decomposition, some times called aggregate data decomposition, precisely because it does not incorporate information neither on the behavior of the different sectors nor introduce specific information on the fuel mix used, this approach represent the economic system as a whole. Since we need to incorporate information about productive sectors and energy mix to understand their behavior and effect on emission (disaggregated data) and because this will be introduce a *sum term* inside of Equation 4.3 a new approach is needed.

### 4.3 Index decomposition analysis (IDA)

These methods began to be used to decompose the energy consumption and energy intensity but later extended its use to the decomposition of pollutant emissions related to energy (notably CO<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub>).

### 4.3 Index decomposition analysis (IDA)

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According to Ang and Zhang (2000) [56], the most two used IDA methods in the literature have been the Laspeyres and arithmetic mean Divisia index. Following Ang and Zhang (2000) [56] and Ang (1994) [213], we choose as an indicator to decompose the *energy intensity* of the industry, to *shorten the explanation*, since it involves only two factors decomposition whereas if decompose *e.g.* emissions related to energy, we have to work with four factors. Also, we will introduce some reference to the decomposition of CO<sub>2</sub> emissions that will be used in the case of study in Section 4.5 in this Chapter.

We define the following variables for year  $t$ :

- $E_t$ : total energy consumption in the industry.
- $E_{it}$ : energy consumption in the industrial sector  $i$ .
- $Y_t$ : total industry output.
- $Y_{it}$ : production of industrial sector  $i$ .
- $S_{it}$ : share of the industrial sector  $i$  ( $Y_{it}/Y_t$ ).
- $I_t$ : aggregate energy intensity ( $E_t/Y_t$ ).
- $I_{it}$ : energy intensity of sector  $i$  ( $E_{it}/Y_{it}$ ).

The aggregate energy intensity can be expressed as:

$$I_t = \sum_i S_{it} I_{it}, \quad (4.4)$$

where the sum is taken over all industrial sectors ( $i$ ). In Equation 4.4 the aggregate energy intensity is expressed in terms of the production structure and the sectoral energy intensities.

To analyze the variation of  $I_t$  as a function of changes of its components, *i.e.*,  $S_{it}$  and  $I_{it}$ , we will differentiate Equation 4.4 with respect to time, one gets,

$$I'_t = \sum_i (I_{it} S'_{it} + I'_{it} S_{it}). \quad (4.5)$$

Following Ang and Zhang (2000) [56], if we assume that the aggregate energy intensity varies from  $I_0$  at time 0 to  $I_T$  at time  $T$ , this change can be expressed

#### 4. DECOMPOSITION ANALYSIS IN INCOME AND ENERGY CONSUMPTION RELATED WITH CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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in two ways:  $D_{tot} = \frac{I_T}{I_0}$  and  $\Delta I_{tot} = I_T - I_0$ . The first is called multiplicative decomposition since the estimated impact of structural change ( $D_{str}$ ) and sectoral intensity ( $D_{int}$ ) appear as multiplicative:

$$D_{tot} = D_{str}D_{int}. \quad (4.6)$$

The second form is called additive decomposition, the same two effects now called  $I_{str}$  (structural change) and  $I_{int}$  (sectoral intensity), appear additively:

$$\Delta I_{tot} = \Delta I_{str} + \Delta I_{int}. \quad (4.7)$$

In order to short the explanation, we present only the additive decomposition according to Ang and Zhang (2000) [56], which has been the most used in the literature.

##### 4.3.1 Laspeyres index

This method isolates the impact of one variable, allowing it to vary while keeping the rest of the variables at their base year values (Ang and Zhang, 2000) [56].

Returning to Equation 4.5, which was in continuous time and converting it into a discrete time, keeping the variables that do not vary in their base year values, we approach the variation of  $I$  from year 0, to year  $T$  with the follow expression:

$$I_T - I_0 = \sum_i I_{i0}(S_{iT} - S_{i0}) + \sum_i (I_{iT} - I_{i0})S_{i0}. \quad (4.8)$$

The effects shown in the second member of Equation 4.8 can also be expressed as:

$$\Delta I_{str} = \sum_i S_{iT}I_{i0} - \sum_i S_{i0}I_{i0}, \quad (4.9)$$

$$\Delta I_{int} = \sum_i S_{i0}I_{iT} - \sum_i S_{i0}I_{i0}, \quad (4.10)$$

$$\Delta I_{rsd} = (I_T - I_0) - (\Delta I_{str} + \Delta I_{int}), \quad (4.11)$$

where  $\Delta I_{rsd}$  is the residual that has been produced by the above approach in time discreet.

### 4.3.2 Arithmetic mean Divisia index

The Divisia index can be defined as a weighted average of growth rates in which the components are weighted in proportion to their share to the total value.

Following Ang (1994) [213], we integrate Equation 4.5 on both sides with respect to time  $t$ , from year 0 to year  $T$ , Ang (1994) obtained the following expression:

$$\Delta I_{tot} = \int_0^T \sum_i I_{it} S'_{it} dt + \int_0^T \sum_i I'_{it} S_{it} dt. \quad (4.12)$$

Taking into account that:

$$I_{it} = \frac{E_{it}}{Y_{it}} = \frac{E_{it}}{Y_t} \frac{Y_t}{Y_{it}} = \frac{E_{it}}{Y_i} \frac{1}{S_{it}}. \quad (4.13)$$

Now, we reformulate Equation 4.12 to obtain the following expression<sup>1</sup>,

$$\Delta I_{tot} = \int_0^T \sum_i \frac{E_{it}}{Y_t} \frac{S'_{it}}{S_{it}} dt + \int_0^T \sum_i \frac{E_{it}}{Y_t} \frac{I'_{it}}{I_{it}} dt = \Delta I_{str} + \Delta I_{int} \quad (4.14)$$

The integral of Equation 4.14 is converted into a parametric problem. To do this, we consider the first term of Equation 4.14 under the following conditions,

$$\min \{E_{i0}/Y_0, E_{iT}/Y_T\} \leq E_{it}/Y_t \leq \max \{E_{i0}/Y_0, E_{iT}/Y_T\}, \quad (4.15)$$

$$\min \{S_{i0}, S_{iT}\} \leq S_{it} \leq \max \{S_{i0}, S_{iT}\}. \quad (4.16)$$

One can find a set of parameters,  $\beta_i$ , satisfying the following equation [213]:

$$\Delta I_{str} = \sum_i \left[ \frac{E_{i0}}{Y_0} + \beta_i \left( \frac{E_{iT}}{Y_T} - \frac{E_{i0}}{Y_0} \right) \right] \times \ln \left( \frac{S_{iT}}{S_{i0}} \right). \quad (4.17)$$

The same can be done with the second term of Equation 4.14,

$$\Delta I_{int} = \sum_i \left[ \frac{E_{i0}}{Y_0} + \tau_i \left( \frac{E_{iT}}{Y_T} - \frac{E_{i0}}{Y_0} \right) \right] \times \ln \left( \frac{I_{iT}}{I_{i0}} \right), \quad (4.18)$$

---

<sup>1</sup>Indeed, Ang (1994) [213] obtained two different expressions for the same decomposition, allowing deduce two parametric Divisia methods for additive decomposition. The presented here is the method of parametric Divisia 1 for additive decomposition. The expression from where starts the method of parametric Divisia 2 is simply the Equation 4.12 without restating. It also has two parametric Divisia methods for multiplicative decomposition.

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where  $0 \leq \beta, \tau \leq 1$

If we take  $\beta_i = \tau_i = 0.5$ , Equations 4.17 and 4.18 would be as follows,

$$\Delta I_{str} = \sum_i \left[ \frac{\frac{E_{iT}}{Y_T} + \frac{E_{i0}}{Y_0}}{2} \right] \times \ln \left( \frac{S_{iT}}{S_{i0}} \right), \quad (4.19)$$

$$\Delta I_{int} = \sum_i \left[ \frac{\frac{E_{iT}}{Y_T} + \frac{E_{i0}}{Y_0}}{2} \right] \times \ln \left( \frac{I_{iT}}{I_{i0}} \right), \quad (4.20)$$

$$\Delta I_{rsd} = \Delta I_{tot} - (\Delta I_{str} + \Delta I_{int}). \quad (4.21)$$

Equations 4.19 to 4.21 constitute the arithmetic mean Divisia index formulas in its additive form as they appear in the work by Ang and Zhang (2000) [56]. The term  $\Delta I_{rsd}$  includes the residual resulting from the discrete approximation made. The expression in brackets in Equations 4.19 and 4.20 would act as a weight for sector  $i$  in the summation.

To obtain the multiplicative form, Equation 4.5 is divided between  $I_t$  and then integrated, as in the additive form, between year 0 to year  $T$ , obtaining:

$$\ln \left( \frac{I_T}{I_0} \right) = \int_0^T \left( \sum_i \frac{I_{it} S'_{it}}{I_t} \right) dt + \int_0^T \left( \sum_i \frac{I'_{it} S_{it}}{I_t} \right) dt. \quad (4.22)$$

If we set  $D_{tot} = \frac{I_T}{I_0}$ , Equation 4.22 can be expressed as:

$$D_{tot} = \exp \left\{ \int_0^T \sum_i \left( \frac{E_{it}}{E_t} \right) \left( \frac{S'_{it}}{S_{it}} \right) dt \right\} \times \exp \left\{ \int_0^T \sum_i \left( \frac{E_{it}}{E_t} \right) \left( \frac{I'_{it}}{I_{it}} \right) dt \right\}, \quad (4.23)$$

$$D_{tot} = D_{str} \times D_{int}, \quad (4.24)$$

where:

$$D_{str} = \exp \left\{ \int_0^T \sum_i \left( \frac{E_{it}}{E_t} \right) \left( \frac{S'_{it}}{S_{it}} \right) dt \right\}, \quad (4.25)$$

$$D_{int} = \exp \left\{ \int_0^T \sum_i \left( \frac{E_{it}}{E_t} \right) \left( \frac{I'_{it}}{I_{it}} \right) dt \right\}, \quad (4.26)$$

In Equation 4.23, we can transform the integrated problem into a parametric problem in the same way that was done in the additive case. (See Ang, 1994 [213]).

### 4.3 Index decomposition analysis (IDA)

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In contrast to Ang and Zhang (2000) [56]<sup>1</sup>, we used the general parametric Divisia methods to arrive at the Equations 4.19 - 4.24 in the manner described by Ang (1994) [213]. We selected the parametric Divisia methods because they allowed Ang (1994) [213] to classify all decomposition methods used until 1995, both additives and multiplicative, simply by varying the value given to the parameters  $\beta_i$  and  $\tau_i$ . As has been mentioned in Ang (1994) [213]: *The values of the parameters can also be treated as weights assigned to the corresponding variables in year 0 and year T in the decomposition.* Because the weights can be assigned in an infinite number of ways, there may be an infinite number of decomposition methods, each corresponding to a specific set of weights.

For example, if we take  $\beta_i = \tau_i = 0.5$ , the equations of the method of arithmetic mean Divisia index are obtained, as we have shown for the additive form. By giving the value of 0.5 to the parameters, it is being assigned the same weight (0.5) at year 0 and year  $T$ . But if  $\beta_i = \tau_i = 0$ , then we would be in the case of Laspeyres index because all weights are assigned to year 0<sup>2</sup>.

Ang (1994) [213] states that the term *adaptive* in the adaptive mean Divisia method, indicate that the parameters are not fixed a priori by the researcher but are determined, in the energy intensity case by the energy consumption and by the industrial production levels in the year 0 and in the year  $T$  [213].

The methods described can be applied to the decomposition between two given years, but may be also applied to a time series so that the decomposition will take place between  $t$  and  $t + 1$ , with  $t$  varying from 1 to  $N$ . As will be  $(N - 1)$  decomposition sets which are used to calculate the cumulative effect [213].

Note that, all the methods used until 1995 and classified by Ang (1994) [213] presents as major drawback that they leave a residue on decomposition. Also note that the presence of logarithms, create a problem of zero, *i.e.*, problems that appear when the data set values appear 0.

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<sup>1</sup>These authors use the theorem of the instantaneous growth rate and discrete approach based on call Törnqvist formula to arrive at the same equations.

<sup>2</sup>The equations that we presented for the Laspeyres index decomposition, Equations 4.9 and 4.10, are obtained exactly by the method of parametric Divisia 2 for the case additive (see Ang, 1994 [213]) when a value of 0 is given to the parameters.

#### 4. DECOMPOSITION ANALYSIS IN INCOME AND ENERGY CONSUMPTION RELATED WITH CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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In Ang and Zhang (2000) [56] accurate methods were proposed and solved the above problems. Those methods are: the logarithmic mean Divisia index (LMDI) method and refined Laspeyres index method. Note that these new methods can not be integrated in the general framework of parametric Divisia methods that allowed Ang (1994) [213] to classify the methods used until 1995.

##### 4.3.3 Logarithmic mean Divisia index (LMDI)

This method does not give residue in the decomposition, but still has the problem of zero, it can be solved by replacing zero values with small positive numbers (Ang, 2000) [56]. This method weights using the logarithmic mean rather than the arithmetic mean, *i.e.*, the arithmetic mean in brackets in Equations 4.19 and 4.20 is replaced by the logarithmic mean. It applies to both additive and multiplicative form.

Following Ang (2005) [214], let  $V$  be an energy-related aggregate composed of  $n$  factors contributing to changes in  $V$  over time and each one is associated with a quantifiable variable,  $x_1, x_2, \dots, x_n$ . Let subscript  $i$  be a sub-category of the aggregate for which structural change is to be studied. At the sub-category level the relationship  $V_i = x_{1,i}x_{2,i} \cdots x_{n,i}$  holds. Then, the general index decomposition analysis (IDA) for  $V$  is given by:

$$V = \sum_i V_i = \sum_i x_{1,i}x_{2,i} \cdots x_{n,i}, \quad (4.27)$$

the aggregate changes from  $V^0 = \sum_i x_{1,i}^0 x_{2,i}^0 \cdots x_{n,i}^0$  in period 0 to  $V^T = \sum_i x_{1,i}^T x_{2,i}^T \cdots x_{n,i}^T$  in period  $T$ .

In additive decomposition we decompose the difference as,

$$\Delta V_{tot} = \Delta V^T - \Delta V^0 = \Delta V_{x_1} + \Delta V_{x_2} + \cdots + \Delta V_{x_n}. \quad (4.28)$$

While in multiplicative decomposition as,

$$D_{tot} = \frac{V^T}{V^0} = D_{x_1} D_{x_2} \cdots D_{x_n}. \quad (4.29)$$

The subscript *tot* represents the total or overall change and the terms on the right-hand side give the effects associated with the respective factors in Equation 4.27.

### 4.3 Index decomposition analysis (IDA)

In the logarithmic mean Divisia index (LMDI) approach<sup>1</sup>, the general formula for the effect of the  $k$ th factor on the right hand side of Equations 4.28 and 4.29 are respectively:

$$\Delta V_{x_k} = \sum_i L(V_i^T, V_i^0) \ln \left( \frac{x_{k,i}^T}{x_{k,i}^0} \right). \quad (4.30)$$

$$D_{x_k} = \exp \left[ \sum_i \frac{L(V_i^T, V_i^0)}{L(V^T, V^0)} \ln \left( \frac{x_{k,i}^T}{x_{k,i}^0} \right) \right], \quad (4.31)$$

where  $L(a, b) = (a - b)/(\ln a - \ln b)$  as defined in Ang (2004) [53].

#### 4.3.4 Refined Laspeyres index

In the case of methods based on the Laspeyres index the problem of zero does not exist, but as Ang and Zhang (2000) shown, these methods leave large residues after decomposition. To address these residues, Sun (1998) proposed the method called the refined Laspeyres index, in which residues (interactions) are equally distributed between the different effects (structural effect and intensity effect) decomposition. This method can only be applied to the additive form. Following Laspeyres index method, Equations 4.19 and 4.20 would be replaced by [56]:

$$\Delta I_{str} = \sum_i (S_{iT} - S_{i0}) I_{i0} + \frac{1}{2} \sum_i (S_{iT} - S_{i0}) (I_{iT} - I_{i0}), \quad (4.32)$$

$$\Delta I_{int} = \sum_i (I_{iT} - I_{i0}) S_{i0} + \frac{1}{2} \sum_i (S_{iT} - S_{i0}) (I_{iT} - I_{i0}), \quad (4.33)$$

where  $\sum_i (S_{iT} - S_{i0})$  is the residue of the decomposition.

Ang and Zhang (2000) [56] conclude that residues obtained by the employment of basic Laspeyres approach are far from the ideal values (1 in the multiplicative form and 0 in the additive form), whereas the arithmetic mean Divisia method is very close to these ideal values. The two Divisia methods (arithmetic and logarithmic mean) would provide similar results when changes in the variables between year 0 and year  $T$  are not so important. In the event that this does not happen, the arithmetic mean Divisia method in its additive form has significant residue.

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<sup>1</sup>The LMDI is used here to refer to the logarithmic mean Divisia method I (LMDI I). A related version, the LMDI II, has a weighting scheme slightly more complex than LMDI I (Ang et al., 2003) [215].

## 4. DECOMPOSITION ANALYSIS IN INCOME AND ENERGY CONSUMPTION RELATED WITH CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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### 4.4 Structural decomposition analysis (SDA)

Rose and Chen defined the SDA as *the analysis of economic change through a set of comparative static changes in key parameters in an input-output table* (Rose and Chen, 1991) [216]. According to Rose and Casler (1996) [217], the basic rationale of the SDA is to break an identity into its components. This division can be as simple as three parts or as complex as desired. For these authors, the reasons that may explain the popularity of this methodology are:

- This methodology overcomes many of the features of the static input-output models and allows us to examine changes over time in the technical coefficients and sectoral participation. Although it has been used mainly for historical analysis, this technique can also be used as a predictive tool. It also allows examine the responses to changes in prices, which are only implicit even in the input-output tables based on values.
- Another reason is that it is a pragmatic alternative to the econometric estimation. To analyze the same issues, econometric studies require time series of fifteen years or more and not just the outputs and primary factors of production, but also the intermediate inputs. The SDA only require two input-output tables: one for the initial year and one for the final one.
- An additional reason is that it allows to consider all inputs used in production, including intermediate. This is especially interesting for studies related to the environment and natural resources, and to analyze the causes of pollution and resource depletion.

Hoekstra and van den Bergh (2002) [218] conducted a review of the literature on the implementation of the SDA to the physical flows in an economy (*e.g.*, emissions). These authors consider that the input-output framework is suitable for environmental analysis because it is able to integrate data on the economic situation and data on physical flows. They point to two methods of input-output analysis that combine monetary and physical data that are relevant to the SDA:

#### 4.4 Structural decomposition analysis (SDA)

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- The input-output analysis using the method of "hybrid units". This method allows the use of different units in different rows of the input-output table (for example, replace the monetary units in the sectors of primary energy production by corresponding physical unit of CO<sub>2</sub> emissions). Thus, the data from the monetary input-output table and physical input-output table can be integrated into a hybrid units input-output table.
- The input-output analysis using the method of factor intensity. In this method the monetary input-output model is associated ( multiplying) a vector of material intensity per unit of output (or value added) in each sector. This method requires less data than the previous one. According to Miller and Blair (1985) [219], this method is equivalent to the hybrid units only if the prices of the products are uniform for all industries and consumers. If prices are not uniform, the method of hybrid units works better. For example, if the price of fuel varies between sectors, a monetary unit of fuel purchased by different sectors may result in different amounts of fuel and also in different emissions, so that the correct variation in emissions would not result. This does not happen in the method of hybrid units.

Following Hoekstra and van den Bergh (2002) [218], the input-output model can be written as,

$$x = L \cdot y \tag{4.34}$$

where  $L = (I - A)^{-1}$  is the Leontief inverse matrix<sup>1</sup> and  $y$  is the vector of final demand. This equation can be decomposed into two effects: *i) the effect coefficients input-output*, which is produced by changes in the structure of the intermediate inputs and *ii) the final demand effect*, which reflects the changes in  $y$ :

$$\Delta x = \Delta L \cdot y + L \cdot \Delta y. \tag{4.35}$$

These two effects may in turn be analyze separately:

*i)* On one hand, the input-output coefficients can be decomposed into the change due to the technological substitution of inputs (changes between inputs) and productivity changes (changes in the efficiency with which an input is used).

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<sup>1</sup>Note that, If the inverse  $(I - A)^{-1}$  exists, then a unique solution to the Equation 4.34 exists.

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Following Hoekstra and see Bergh (2002) [218], the decomposition of the input-output coefficients can be:

- Additive:  $\Delta L = (I - \Delta A)^{-1}$ .
- Multiplicative:  $\Delta L = L \cdot \Delta A \cdot L$ .

The next step in the decomposition is to break down changes in the coefficient matrix,  $A$ , into changes in the underlying structure of the inputs. To do this there are two ways:

- Divide the matrix into individual coefficients:  $\Delta A = \Delta A_{11} + \Delta A_{12} + \dots + \Delta A_{ij} + \Delta A_{nn}$ .
- Use a method based on the RAS<sup>1</sup> approach:  $\Delta A = \Delta r \cdot \Delta A^{t-1} \cdot s + r \cdot A^{t-1} \cdot \Delta s + \epsilon$ , where  $r$  and  $s$  are RAS multipliers.

*ii*) On the other hand, final demand can be decomposed into several effects: the effect of product participation (changes in the participation of  $n$ -products consumed); the effect category (changes between  $p$ -categories in final demand) and the effect of the level of final demand (the effect of growth in total final demand). If sufficient information is available, the decomposition of final demand is able to determine the impact on environmental indicators of changes in domestic consumption or changes in foreign transactions.

Final demand can be decomposed into (Hoekstra and van den Bergh, 2002) [218]:

$$\Delta Y = \Delta B \cdot c \cdot f + B \cdot \Delta c \cdot f + B \cdot c \cdot \Delta f, \quad (4.36)$$

where  $B$  is a matrix whose elements are equal to the elements of the matrix in final demand divided by the corresponding column sums; coefficients  $c$  indicate the share of each category in final demand in total final demand; the scalar  $f$  represents the total final demand.

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<sup>1</sup>The RAS method is an iterative method of biproportional adjustment of rows and columns that has been independently developed by various researchers, such as Kruithoff and Sheleikhovski in the 1930s. In 1961, Stone adapted the technique for use in updating IO tables from the work of Deming and Stephan [220].

#### 4.4 Structural decomposition analysis (SDA)

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Taking reference exposed decomposition, the decomposition model of hybrid units would be identical to the Equation 4.35 except that the variables would be hybrid units.

In the case of the method of factor intensity, we should calculate the total physical flow  $m$ :

$$m = i \cdot L \cdot y, \quad (4.37)$$

where  $i$  collect the intensity (physical use per unit of output) for each sector.

The decomposition of the Equation 4.35 would lead to the following expression:

$$\Delta m = \Delta i \cdot L \cdot y + i \cdot \Delta L \cdot y + i \cdot L \cdot \Delta y, \quad (4.38)$$

where the second and third term would be the effects of input-output coefficients and final demand and the first term is the intensity effect, that would include the influence of changes in the physical flows per unit of output (the output in monetary terms).

SDA requires choosing an index to carry out the decomposition since each index produces different results and residues. No conclusive results have been reached on what is the most appropriate index (Hoekstra and van den Bergh, 2002) [218].

Hoekstra and van den Bergh (2003) [208] conducted a comparative analysis between SDA and IDA methods. The main advantage of the IDA is that it requires less data than SDA. However, the SDA allows a more detailed breakdown, in which a set of technological effects and final demand is included that can not be obtained with the IDA. In addition, SDA can capture the indirect effects of demand.

Hoekstra and van den Bergh (2003) [208] pointed out the different effects that can be captured with each of the two methods:

- Production effect (SDA and IDA), measures the effect of the change in total output on indicator.
- Structure effect (IDA), pick up the effect of a change in the share of the productive sectors in the economy.

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- Leontief effect (SDA) assesses the effects of changes in the Leontief inverse matrix and can be interpreted as a technological effect of changes in the structure of intermediate inputs.
- Intensity effect (SDA and IDA) estimates changes in the use of the indicator in each sector per unit of output.
- Final demand effect (SDA), measures the effect of changes in final demand products of each sector.

Therefore, each method allows to estimate different effects but the SDA enables a more detailed analysis of demand and technological effects while IDA study allows to study the structure effects together with the intensity effect.

Since one of the goals of this research is to analyze the effects of scale, structure and intensity on CO<sub>2</sub> emissions in Ecuador, LMDI approach for this case study has been selected. Another reason for this choice is because the kind and level of desegregation of the data available for the country.

#### 4.5 LMDI analysis for Ecuador 1980-2025

As was already explained, Ang (2004) [53] compared various index decomposition analysis methods and concluded that the multiplicative and additive logarithmic mean Divisia index (LMDI) method is the preferred method due to their theoretical foundation, adaptability, ease of use and result interpretation, and some other desirable properties in the context of decomposition analysis..

In this section we will carry out a decomposition analysis based on the LMDI (Ang, 2005) [214]. This analysis will allow us to determine the relative importance of each term conforming the CO<sub>2</sub> emission (see Equation 3.1). Indeed, it is very enlightening to write down the increase on CO<sub>2</sub> emission relative to the value of a given period, and to decompose it as the sum or product of the terms corresponding to the different driving forces that conform the CO<sub>2</sub> emission. Therefore we can use (Ang, 2005) [214]:

In the case of the additive decomposition:

$$\Delta C_{tot} = C^T - C^0 = \Delta C_{act} + \Delta C_{str} + \Delta C_{int} + \Delta C_{mix} + \Delta C_{emf}, \quad (4.39)$$

where  $C_{tot}$  is the CO<sub>2</sub> emission (relative to the base year),  $C^0$  and  $C^T$  represent the emission in the base and final year respectively,  $C_{act}$  is the GDP term,  $C_{str}$  is the structure term (the share of the different sectors to the GDP),  $C_{int}$  the energy intensity term,  $C_{mix}$  the energy mixing term, and  $C_{emf}$  the emission factor term. Note that because the emission factors, given by the IPCC, do not change over the time,  $C_{emf} = 0$  all the time and therefore it will not be shown in the tables. The other option is,

In the case of the multiplicative decomposition:

$$D_{tot} = C^T / C^0 = D_{act} \times D_{str} \times D_{int} \times D_{mix} \times D_{emf}, \quad (4.40)$$

where  $D_{tot}$  is the CO<sub>2</sub> emission (relative to the base year),  $D_{act}$  is the GDP term,  $D_{str}$  is the structure term (the share of the different sectors to the GDP),  $D_{int}$  the energy intensity term,  $D_{mix}$  the energy mixing term, and  $D_{emf}$  the emission factor term. As said before  $D_{emf} = 1$  all the time and therefore it will not be shown in the tables.

Applying as indicated in Section 4.3.3 of this Chapter for the case of CO<sub>2</sub> emissions (see Equation 4.39 and 4.40 ) the following formulas are obtained for decomposing changes in each of the terms involved in Equation 3.1, for both additive and multiplicative forms:

LMDI formula additive decomposition:

$$\Delta C_{act} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln \left( \frac{Q^T}{Q^0} \right), \quad (4.41)$$

$$\Delta C_{str} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln \left( \frac{S_i^T}{S_i^0} \right), \quad (4.42)$$

$$\Delta C_{int} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln \left( \frac{EI_i^T}{EI_i^0} \right), \quad (4.43)$$

$$\Delta C_{mix} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln \left( \frac{M_{ij}^T}{M_{ij}^0} \right), \quad (4.44)$$

$$\Delta C_{emf} = \sum_{ij} \frac{C_{ij}^T - C_{ij}^0}{\ln C_{ij}^T - \ln C_{ij}^0} \ln \left( \frac{U_{ij}^T}{U_{ij}^0} \right). \quad (4.45)$$

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LMDI formula multiplicative decomposition:

$$D_{act} = exp \left( \sum_{ij} \frac{(C_{ij}^T - C_{ij}^0) / (\ln C_{ij}^T - \ln C_{ij}^0)}{(C^T - C^0) / (\ln C^T - \ln C^0)} \ln \left( \frac{Q^T}{Q^0} \right) \right), \quad (4.46)$$

$$D_{str} = exp \left( \sum_{ij} \frac{(C_{ij}^T - C_{ij}^0) / (\ln C_{ij}^T - \ln C_{ij}^0)}{(C^T - C^0) / (\ln C^T - \ln C^0)} \ln \left( \frac{S_i^T}{S_i^0} \right) \right), \quad (4.47)$$

$$D_{int} = exp \left( \sum_{ij} \frac{(C_{ij}^T - C_{ij}^0) / (\ln C_{ij}^T - \ln C_{ij}^0)}{(C^T - C^0) / (\ln C^T - \ln C^0)} \ln \left( \frac{EI_i^T}{EI_i^0} \right) \right), \quad (4.48)$$

$$D_{mix} = exp \left( \sum_{ij} \frac{(C_{ij}^T - C_{ij}^0) / (\ln C_{ij}^T - \ln C_{ij}^0)}{(C^T - C^0) / (\ln C^T - \ln C^0)} \ln \left( \frac{M_{ij}^T}{M_{ij}^0} \right) \right), \quad (4.49)$$

$$D_{emf} = exp \left( \sum_{ij} \frac{(C_{ij}^T - C_{ij}^0) / (\ln C_{ij}^T - \ln C_{ij}^0)}{(C^T - C^0) / (\ln C^T - \ln C^0)} \ln \left( \frac{U_{ij}^T}{U_{ij}^0} \right) \right), \quad (4.50)$$

**Table 4.1:** Aggregate data for Ecuador for the period 1980-2025.

| Year             | CO <sub>2</sub> emissions<br>(Mt) | Income<br>(BUSD) | Energy consumption<br>(ktoe) |
|------------------|-----------------------------------|------------------|------------------------------|
| <i>Data</i> 1980 | 11.9                              | 45.4             | 5032                         |
| <i>Data</i> 1995 | 19.6                              | 63.4             | 7143                         |
| <i>Data</i> 2010 | 28.1                              | 104              | 11931                        |
| <i>BS</i> 2025   | 55.0                              | 167              | 20516                        |
| <i>SC-2</i> 2025 | 96.6                              | 271              | 36042                        |
| <i>SC-3</i> 2025 | 66.5                              | 244              | 32425                        |
| <i>SC-4</i> 2025 | 54.7                              | 251              | 26700                        |

We will use three periods of 16 years to perform the analysis, two within the set of historical data (1980-1995 and 1995-2010) and the last one corresponding to the forecast period (2010-2025). This analysis will allow us to determine the relative importance of each term related with CO<sub>2</sub> emission. The aggregate CO<sub>2</sub>

## 4.5 LMDI analysis for Ecuador 1980-2025

**Table 4.2:** Results of the CO<sub>2</sub> emission additive decomposition factors for the period 1980-2025.

| Scenario              | $\Delta C_{tot}$ (kt) | $\Delta C_{act}$ | $\Delta C_{str}$ | $\Delta D_{int}$ | $\Delta C_{mix}$ |
|-----------------------|-----------------------|------------------|------------------|------------------|------------------|
| <i>Data</i> 1980-1995 | 5470                  | 4780             | 194              | 196              | 292              |
| <i>Data</i> 1995-2010 | 14800                 | 12300            | -637             | 1160             | 1990             |
| <i>BS</i> 2010-2025   | 22600                 | 20100            | -82              | 2500             | 96               |
| <i>SC-2</i> 2010-2025 | 62100                 | 55600            | 3020             | 3300             | 192              |
| <i>SC-3</i> 2010-2025 | 32500                 | 39900            | 2400             | 2640             | -12400           |
| <i>SC-4</i> 2010-2025 | 23200                 | 37100            | 2200             | -5040            | -11100           |

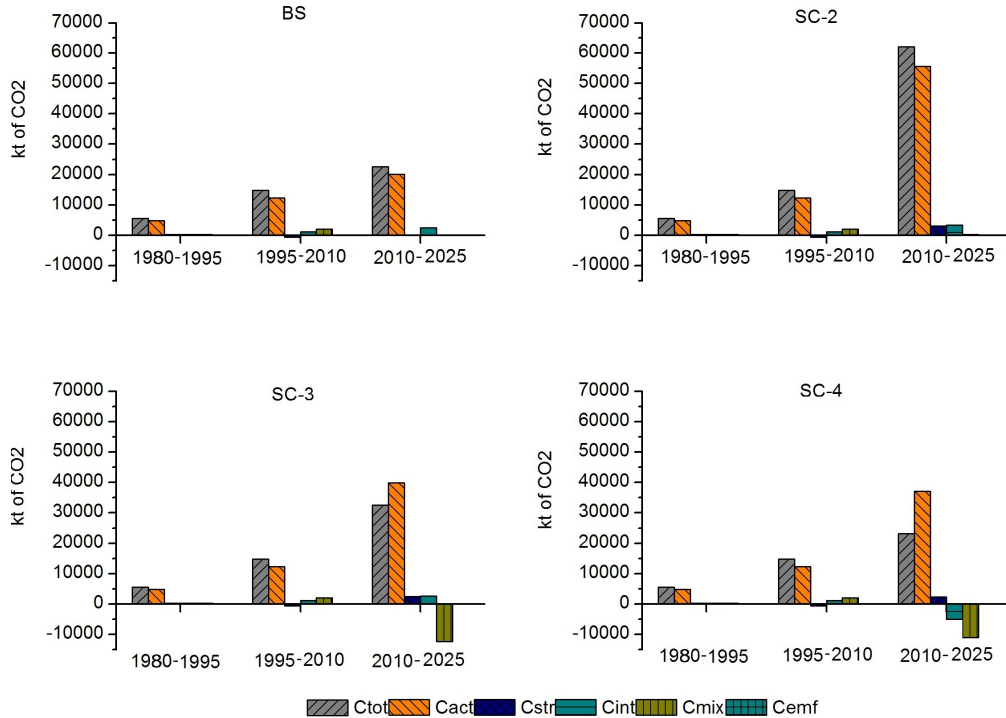
**Table 4.3:** Results of the CO<sub>2</sub> emission multiplicative decomposition factors for the period 1980-2025.

| Scenario              | $D_{tot}$ | $D_{act}$ | $D_{str}$ | $D_{int}$ | $D_{mix}$ |
|-----------------------|-----------|-----------|-----------|-----------|-----------|
| <i>Data</i> 1980-1995 | 1.35      | 1.38      | 1.01      | 0.95      | 1.02      |
| <i>Data</i> 1995-2010 | 1.85      | 1.68      | 0.98      | 1.04      | 1.09      |
| <i>BS</i> 2010-2025   | 1.72      | 1.61      | 1.00      | 1.07      | 1.00      |
| <i>SC-2</i> 2010-2025 | 3.03      | 2.59      | 1.09      | 1.07      | 1.00      |
| <i>SC-3</i> 2010-2025 | 2.08      | 2.33      | 1.09      | 1.07      | 0.77      |
| <i>SC-4</i> 2010-2025 | 1.71      | 2.41      | 1.09      | 0.85      | 0.77      |

emissions in million tonnes of CO<sub>2</sub> (Mt), income in billion of USD (BUSD) and energy consumption (ktoe) are shown in Table 4.1.

The findings (see Figures 4.1 and 4.2) show that in the period 1980-1995 there was an increase in emissions by 35% (see Table 4.3) or equivalently of more than 5400 kt (see Table 4.2). The LMDI analysis show that the activity effect led to an increases just 3 percent points (38%) that the margin in emission increase. The effect of structural change ( $D_{str} = 1.01$ ) in productive sectors and change in energy mix ( $D_{mix} = 1.02$ ) does not have significant impact over the emission in this period. Actual growth in emissions was lower because of the reduction of the sectoral energy intensity ( $D_{int} = 0.95$ ), see a pictorial view in Figure 4.3. Note

#### 4. DECOMPOSITION ANALYSIS IN INCOME AND ENERGY CONSUMPTION RELATED WITH CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)



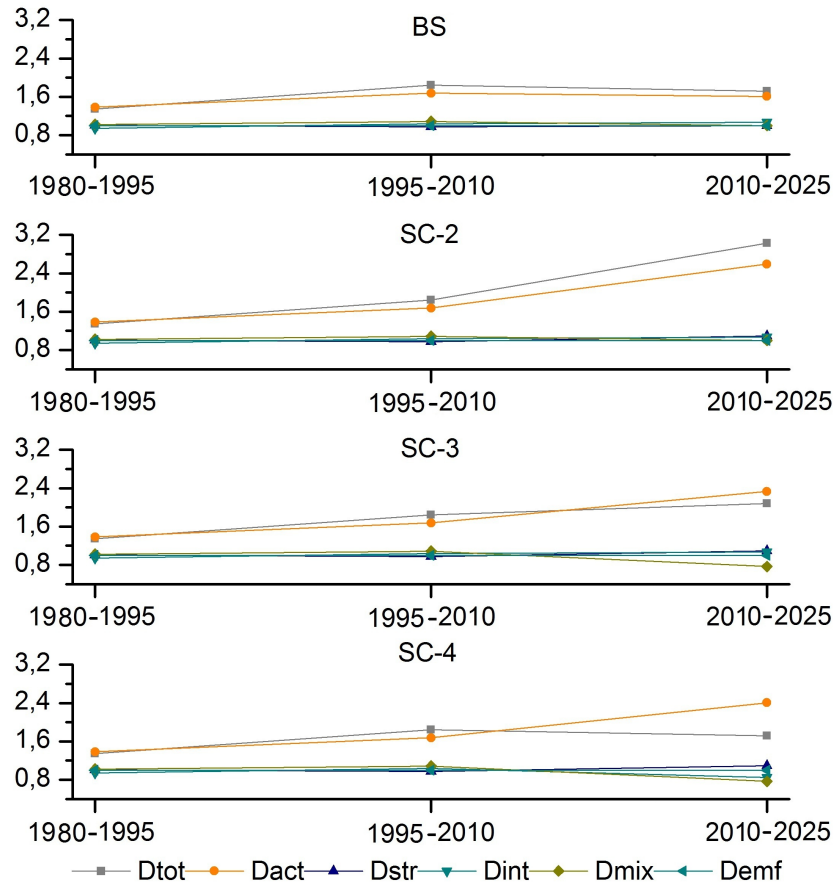
**Figure 4.1:** Bar view of the CO<sub>2</sub> emission additive decomposition factors for the period 1980-2025 in Ecuador.

that the ratio  $D_{tot}/D_{act}$  is almost 1 and is a proxy of that country emissions in this period grow in the same factor that the income (see Figures 4.1).

The period 1995-2010 reflected a greater increase in emissions (85%) or equivalently of more than 14800 kt (see Tables 4.2 and 4.3). The LMDI analysis show that the activity effect led to an increase of 0.80 times (68%) that the margin in emissions increase. In addition, changes in energy intensity ( $D_{int} = 1.04$ ) and in energy mix ( $D_{int} = 1.09$ ) led to an additional increase in emissions. The impact of structural change ( $D_{str} = 0.98$ ) in productive sectors has a reduction effect in emission. Note that the ratio  $D_{tot}/D_{act}$  equal to 1.10 is a proxy of that the higher economic growth in this period (regarding to the previous one) accelerated the emission growth of the country (see Figures 4.3).

Regarding the forecast period, the findings shows that in 2025 the CO<sub>2</sub> emissions increase by 72% or equivalently of more than 22000 kt in the BS scenario. The

#### 4.5 LMDI analysis for Ecuador 1980-2025

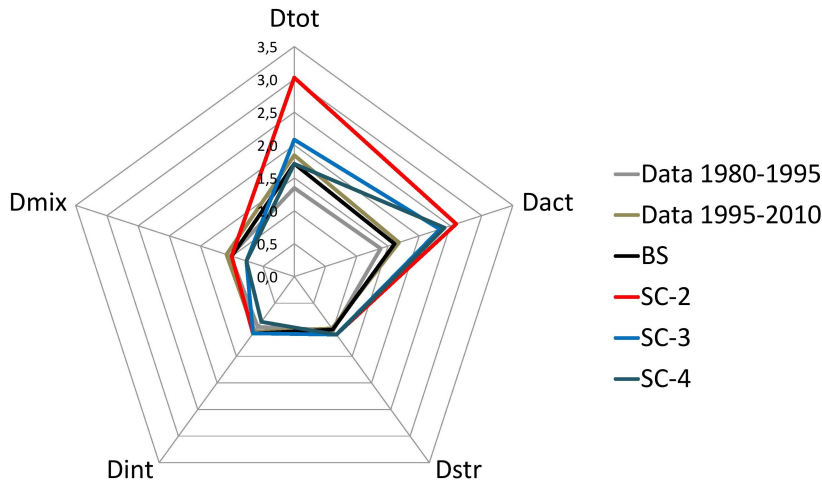


**Figure 4.2:** View of the CO<sub>2</sub> emission multiplicative decomposition factors for the period 1980-2025 in Ecuador.

LMDI analysis show that the activity effect led to an increase of 0.85 times (61%) that the margin in emissions increase. The effect of structural change ( $D_{str} = 1.00$ ) in productive sectors and change in energy mix ( $D_{mix} = 1.00$ ) does not have impact on the emission in this period. Actual growth in emissions was higher because of increase in sectoral energy intensity ( $D_{int} = 1.07$ ), as an pictorial view of Figure 4.3. Note that the ratio  $D_{tot}/D_{act}$  is almost the same that for the previously period (1.07) (see Figure 4.4) and is a proxy of that the grow in emissions depends mainly on the scale term ( $D_{act}$ ) in *BS* scenario.

The *SC-2* scenario presents an amount of emissions in 2025 that is more than 3 times that in 2010 (3.03 times) or equivalently of more than 62000 kt. The LMDI

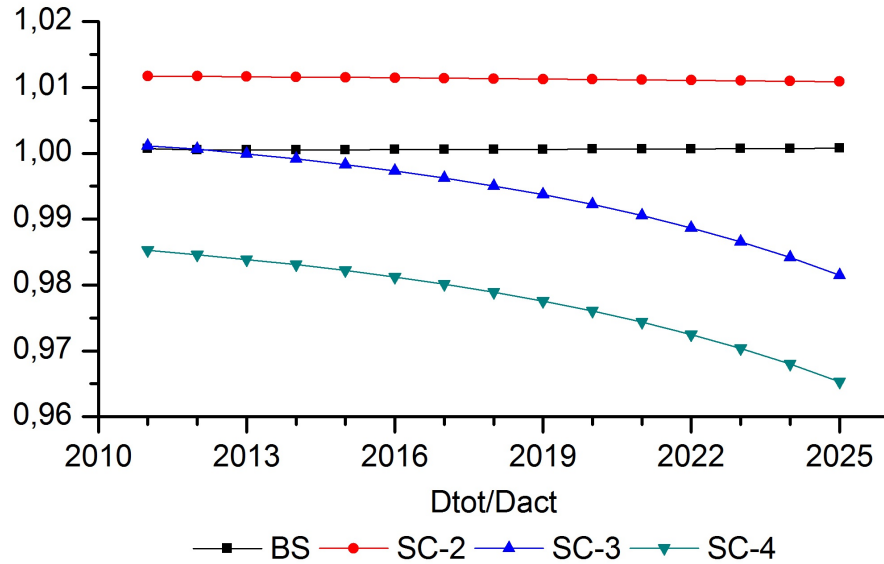
#### 4. DECOMPOSITION ANALYSIS IN INCOME AND ENERGY CONSUMPTION RELATED WITH CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)



**Figure 4.3:** Pictorial view of the CO<sub>2</sub> emission multiplicative decomposition factors for the period 1980-2025 in Ecuador.

analysis show that the activity effect led to an increase of 0.57 times (2.49 times) that the margin in emissions increase. The effect of energy mix ( $D_{mix} = 1.00$ ) does not have impact on the emission during this period. As in *BS* scenario, actual growth in emissions was higher because the increase in sectoral energy intensity ( $D_{int} = 1.07$ ) and by the impact of the structural change ( $D_{str} = 1.09$ ), as an in the pictorial view of Figure 4.3. Note that the ratio  $D_{tot}/D_{act}$  is 1.17 (higher than *BS* scenario) (see Figure 4.4) and is a proxy of that the higher economic growth achieved in this scenario is because an increase in the economic scale and in the energy intensity, arising from the shift in the composition of industry output towards energy-intensive sectors of the country as has been considered in this scenario (see Section 3.10.2 in Chapter 3).

The *SC-3* scenario presents an amount of emissions in 2025 that is more than 2 times in 2010 (2.08 times) or equivalently of more than 32000 kt. The LMDI analysis show that the activity effect led to an increase of 1.23 times ( $D_{tot} = 2.33$ ) that the margin in emissions increase. In addition, impact of structural change ( $D_{str} = 1.09$ ) in productive sectors changes and in energy intensity ( $D_{int} = 1.07$ ) led to a increase in emissions. The impact of energy mix ( $D_{str} = 0.77$ ) used in productive sectors has a reduction effect in emissions as has been considered in



**Figure 4.4:**  $D_{tot}/D_{act}$  for the period 2011-2025 in Ecuador.

this scenario (see Section 3.10.2 in Chapter 3), see a pictorial view in Figure 4.3. Note that the ratio  $D_{tot}/D_{act}$  is lower than 1 (0.89) (see Figure 4.4) and is a proxy of that for first time in the country (in the analyzed period), the economic growth is higher than emission growth. The reason is that in addition of the growth in the economic scale, the impact of energy mix change leads to a reduction of this ratio.

Finally, in the *SC-4* scenario the emissions just increase by a factor of 1.71 or equivalently more than 23000 kt. The LMDI analysis shows that the activity effect led to an increase almost 2 times ( $D_{tot} = 2.33$ ) that the margin in emission increase. As in previous scenarios, the impact of structural change ( $D_{str} = 1.09$ ) in productive sectors changes led to an increases in emissions. However, actual growth in emissions was lower than in rest of scenarios because the impact of energy mix ( $D_{str} = 0.77$ ) and the reduction in sectoral energy intensity ( $D_{int} = 0.85$ ) has a reduction effect in emission as has been considered in this scenario (see Section 3.10.2 in Chapter 3), see a pictorial view in Figure 4.3. Note that in this scenario the ratio  $D_{tot}/D_{act}$  is the lowest (0.71) (see Figure 4.4) and as in the *SC-3* scenario, in addition to the growth in the economic scale, the impact energy mix are present and adding the impact of the reduction of energy intensity considered

#### 4. DECOMPOSITION ANALYSIS IN INCOME AND ENERGY CONSUMPTION RELATED WITH CO<sub>2</sub> EMISSIONS IN ECUADOR (1980-2025)

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in this scenario (see Section 3.10.2 in Chapter 3) is reducing even more this ratio.

All the coefficients are summarized in Table 4.2 and 4.3 and in a pictorial way in Figure 4.3. In this figure five axes are depicted corresponding to the five columns appearing in table 4.3. The value of the vertical axis,  $D_{tot}$ , corresponds to the product of the five remaining variables,  $D_{act}$ ,  $D_{str}$ ,  $D_{int}$ ,  $D_{mix}$  and  $D_{emf}$ .

### 4.6 Summary and conclusions of the chapter

This Chapter presents a decomposition analysis of CO<sub>2</sub> related to income growth and energy consumption bases on LMDI (see Section 4.5 in this Chapter) for Ecuador in the period 1980-2025. For this purpose three periods have been selected, the first sub-period is 1980-1995 where the LMDI analysis findings suggest that the country emissions in this period almost grow (38%) in the same factor that the income (35%), see Figures 4.1. The second sub-period is 1995-2010 and the evidence suggest that a higher economic growth (68%) led to even greater emissions growth (85%) in the country.

The third sub-period is 2010-2025 and includes the analysis for the different scenarios proposed in Chapter 3. To see more clearly how the income-CO<sub>2</sub> relationship behaves as a function of time, it is very enlightening to depict the ratio  $D_{tot}/D_{act}$  as a function of the time (see Figure 4.4). The first striking thing is the very different behaviour for each scenario. On one hand, it is somehow surprising the almost flat curve corresponding to the *BS* scenario which implies a *trend-growth* GDP scenario, however the CO<sub>2</sub> emission increases steadily because of the absence of attenuation measurements. A similar behaviour, although slightly sloping down, is observed for *SC-2*, where a rapid growth of the GDP is assumed without any attenuation action regarding CO<sub>2</sub> emission. It is worth noting a certain decrease of the ratio  $D_{tot}/D_{act}$  in the final part of the period under study. The other two scenarios, *SC-3* and *SC-4*, show a steady reduction of the ratio  $D_{tot}/D_{act}$  due to the changes in the sectoral structure and in the energy mix, which allows compensation of rapid GDP growth.

This preliminary analysis suggests that, with the appropriate changes in the energy mix, the sectoral structure, and the share of renewable energies, Ecuador

#### **4.6 Summary and conclusions of the chapter**

can move into a more environmentally sustainable situation. All these results encourages us to perform a more rigorous analysis in regard to income and emission relationship. The EKC analysis to study in which stage of the process Ecuador is currently in, and will be in the coming future is carried out in Chapter 5.



*You must be the change you wish to  
see in the world.*

Mahatma Gandhi

CHAPTER

# 5

## **System dynamics modelling and the environmental Kuznets curve in Ecuador (1980-2025)**

### **5.1 Overview**

Kuznets (1955) stated that the changing relationship between per capita income and income inequality is an *inverted-U-shaped* curve. As per capita income increases, income inequality also increases at first and then starts declining after a *turning point* (TP). In other words, the distribution of income becomes more unequal in early stage of income growth and then the distribution moves towards greater equality as economic growth continues (Kuznets, 1955) [89]. This observed empirical phenomenon is popularly known as the Kuznets curve. In the 1990s and onwards, the Kuznets curve took a new existence. There were evidences that the level of environmental degradation and the per capita income follows the same inverted-U-shaped relationship as does income inequality and per capita income in the original

## 5. SYSTEM DYNAMICS MODELLING AND THE ENVIRONMENTAL KUZNETS CURVE IN ECUADOR (1980-2025)

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Kuznets curve. Now, Kuznets curve has become a tool for describing the relationship between measured levels of environmental quality (for example, emissions of CO<sub>2</sub>) and per capita income. This inverted-*U*-shaped relationship between economic growth and measured pollution indicators (environmental quality) is known as the Environmental Kuznets curve (EKC).

First empirical EKC studies appeared independently in three working papers: an NBER<sup>1</sup> working paper as part of a study of the environmental impacts of NAFTA<sup>2</sup> (Grossman and Krueger, 1991) [132], the World Bank's 1992 World Development Report (Shafik and Bandyopadhyay, 1992) [93] and a Development Discussion paper as part of a study for the International Labour Organisation (Panayotou, 1993) [221]. Grossman and Krueger which was later published in 1993 (Grossman and Krueger, 1993) [132], first pointed out an inverted-*U* relationship between pollutants (SO<sub>2</sub> and smoke) and income per capita. The name of Kuznets was attached to the inverted-*U* relationship between pollution and economic development later due to its resemblance with the inverted-*U* relationship between income inequality and economic development proposed by Kuznets. However, Panayotou (1993) [221] first coined it as the Environmental Kuznets curve or EKC. At this point we will follow the review that Dinda (2004) [94] conducted about the EKC hypothesis.

### 5.2 Explanations for the EKC

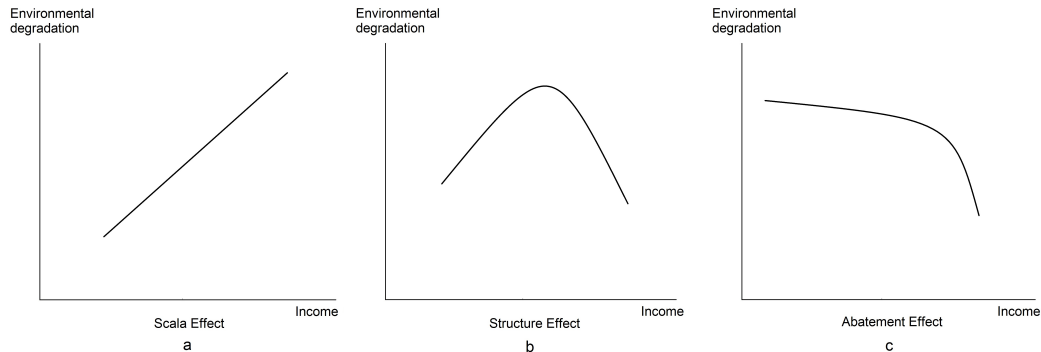
EKC hypothesis actually summarizes an essentially dynamic process of change. As income of an economy grows over time, emission level grows first, reaches a peak and then starts declining after a threshold level of income has been crossed. However, the statement of the hypothesis makes no explicit reference to time. Dinda (2004) [94] states that EKC can be considered as a long run phenomenon. In other words, it is a development trajectory for a single economy that grows through different stages over time. Empirically, this development trajectory can be observed in *cross-country* or *cross-sectional* data, which represents countries with different

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<sup>1</sup>The National Bureau of Economic Research is an American private nonprofit research organization committed to undertaking and disseminating unbiased economic research among public policymakers, business professionals, and the academic community.

<sup>2</sup>North American Free Trade Agreement.

## 5.2 Explanations for the EKC



**Figure 5.1:** Different effects of income on environmental degradation as presented in Islam et al. (1999) [7]

level of income (low, middle and high) groups corresponding to their emission levels. The author also said that assuming that all countries follow one EKC, then at any cross-section of time, it should be observed that some countries are poor, shaping the initial stage of EKC, some others are developing countries approaching towards the peak or starting to decline and others are rich, lying on the final stage of the EKC. Evidently, thus, under the null hypothesis of EKC and under the assumption of invariance of the *income–emission* relationship, for a given set of cross-country or cross-sectional data on income and emission, the emission on income regression line should be an *inverted-U-shaped* empirical EKC [94].

Therefore, according to the EKC hypothesis the relationship between income per capita and some types of pollution is approximately an inverted-*U*. This behaviour states that as the per capita income grows, environmental damage increases, reaches a maximum, and then declines. The reason for this behaviour is that when income reaches a certain threshold the economy moves into a different regime, where the rate of emissions with respect to income can be reduced with respect to the initial regime.

There is thus a unidirectional causality running from income to environmental degradation. The theoretical explanations of the EKC hypothesis are based on three effects: the scale effect, the structure effect and the abatement effect (Grossman and Krueger, 1991; Islam et al., 1999) [7, 132] (see Figure 5.1).

## 5. SYSTEM DYNAMICS MODELLING AND THE ENVIRONMENTAL KUZNETS CURVE IN ECUADOR (1980-2025)

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### 5.2.1 Environmental quality demand and income elasticity

As income grows, society achieve a higher standard of living and care more for the quality of environment they live in and demand for better environment induces structural changes in economy that tends to reduce environmental degradation. The most common explanation for the shape of an EKC (see Figure 5.2) is the notion that when a country achieves a sufficiently high standard of living, people attach increasing value to environmental amenities (Pezzey, 1989 [222]; Selden and Song, 1994 [223]; Baldwin, 1995 [224]). When a particular level of income is reached, the willingness to pay for a clean environment rises by a greater proportion than income (Roca, 2003) [225]. This will be reflected through changes in habits and in choice of less environmentally damaging products by people. Thus, people with a high standard of living can value and pay (at the same time) for a cleaner environment and to preserve it. Generally, it is recognized that income elasticity of environmental quality demand and resource goods is in excess of unity, *i.e.*, clean environment and preservation are *luxury goods* [94]. But major indicators of environmental degradation are monotonically rising in income though the income elasticity is less than one and is not a simple function of income alone [94]. However, Dinda (2004) survey [94] states that most of the EKC models have emphasized the role of income elasticity of environmental quality demand (Beckerman, 1992 [92]; Carson et al., 1997 [226]; Chaudhuri and Pfaff, 1998 [227]; McConnell, 1997 [228]) and this elasticity is often invoked in the literature as the main reason to explain the reduction of emission level. An adequate explanation of observed EKC relationships for some pollutants, are consistent with the high-income elasticity of environmental quality demand (McConnell, 1997 [228]; Shafik, 1994 [229]). Poor countries have little demand for environmental quality, however, as a society reaches high levels of living, its members may intensify their demands for a more healthy and cleaner environment. Societies with higher incomes are not only willing to spend more for green products but also create pressure for environmental protection and regulations. In most cases where emissions have declined with rising income, the reductions have been due to local and national institutional reforms, such as environmental legislation and *market-based* incentives to reduce environmental degradation.

### 5.2.2 Scale, technological and composition effects

There are three different channels where economic growth affects the quality of environment: scale effects, technological effects and composition effects (Grossman and Krueger, 1991) [132]. Increasing output requires more input and thus more natural resources are used in production process. More output also implies more wastes and emissions by product, which also contributes to degrade environmental quality. Therefore, economic growth exhibits a scale effect that has a negative impact on environment. However, economic growth also has a positive impact on environment through the composition effect: income grows, the structure of the economy tends to change and gradually cleaner activities increase with reduces pollution [94].

Environmental degradation tends to increase as structure of the economy changes from rural to urban, or from agricultural to industrial, but it starts to fall with another structural change from energy intensive industry to services and knowledge based technology intensive industry. As a wealthy nation can afford to spend more on research and technical development (Komen et al., 1997) [136], technological progress occurs with economic growth and the dirty and obsolete technologies are replaced by upgraded new and cleaner technology, which improves environmental quality. This is the so called technique effect of economic growth. Vukina et al., (1999) [133] state that EKC suggests that the negative impact on environment of the scale effect, that tends to prevail in initial stages of growth, will be eventually outweighed by the positive impact of the composition and technique effects that will tend to lower the emission level.

### 5.2.3 International trade

International trade is one of the most important factors that envelope the EKC [94]. Trade leads to increase the size of the economy increasing pollution, thus, trade can be considerate as a cause of environmental degradation. However, many authors have long argued that trade is not the root cause of environmental damage (Birdsall and Wheeler, 1993 [230]; Lee and Roland-Holst, 1997 [231]; Jones and Rodolfo, 1995 [232]). Free trade has the contradictory impacts on environment, on one hand,

## 5. SYSTEM DYNAMICS MODELLING AND THE ENVIRONMENTAL KUZNETS CURVE IN ECUADOR (1980-2025)

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increasing pollution and, on the other hand, motivating reductions in it. Environmental quality could decline through the scale effect as increase the trade volume (especially export) up to the size of the economy, which increases pollution. On the other hand, trade can improve the environment through the composition effect and/or the technique effect (*i.e.*, as income rises through trade, environmental regulation is tightened which spurs pollution reducing innovation) [94].

Pollution from the production of pollution-intensive goods declines in a given country as it increases in another via international trade. This composition effect is attributed to two related hypotheses: *i*) Displacement Hypothesis and *ii*) Pollution Haven Hypothesis. These hypotheses are basically the same with respect to comparative advantage in international trade. *Displacement Hypothesis* expects that trade liberalization or openness will lead more rapid growth of pollution-intensive industries in less developed economies as developed economies enforce strict environmental regulations (Harrison, 1996 [233]; Rock, 1996 [234]; Tobey, 1990 [235])<sup>1</sup>. *Pollution Haven Hypothesis* refers to the possibility that multinational industries, particularly those engaged in highly polluting activities, relocate to countries with lower environmental standards. Also this hypothesis argues that low environmental standards become a source of comparative advantage, and thus shifts in trade patterns. This theory suggests that high regulation countries will lose all the *dirty industries* and low regulation countries will get them all.

Most of the developing countries rely on technology transfer through foreign direct investment from developed countries as a primary means of technology acquisition. In the case of Pollution Haven Hypothesis, these clean and upgraded technologies could reduce pollution level. Also the diffusion of technology prevents economic latecomers from requiring the same levels of materials and energy inputs per unit of income than older industrialized countries needed in past. Some authors suggest that international trade enhances diffusion of clean technology (Martin and Wheeler, 1992 [236]; Reppelin-Hill, 1999 [237]) and another authors have suggested that this might allow developing countries to *dive through* the EKC.

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<sup>1</sup>Note that, the changes in the structure of production in developed economies are not accompanied by equivalent changes in the structure of consumption, therefore, EKC actually records displacement of dirty industries to less developed economies (Copeland and Taylor, 1995) [124].

Other scenario could be the so called *race to bottom*: relatively high environmental standards in developed economies impose high costs on polluters. Therefore, polluting activities in high-income economies face higher regulatory costs than their counterparts in developing countries (Wheeler, 2000 [238] and Jaffe et al., 1995 [239]; Mani, 1998 [240]). Wheeler (2000) [238] states that globalization could trigger the environmental *race to bottom*, in which competition increases for investment and jobs. Indeed, the bottom rises with economic growth. Less developed economies improve their environmental quality as investment increases income and employment. This has led some authors to argue that globalization is compatible with pollution reduction (Robinson, 1988 [241]; Dessus and Bussolo, 1998 [242]; Grether and Melo, 2002 [243]).

### 5.3 Theoretical analysis of EKC

A basic comparative static analysis of the costs and benefits associated with a better environmental quality provides an interesting conceptual insight as to how the EKC may arise. The EKC is derived from the interaction points of marginal cost (MC) and marginal benefit (MB) curves (Munasinghe, 1999) [141]. An EKC can be derived directly from the technological link between consumption of a desired good and abatement of its undesirable by product (Andreoni and Levinson, 2001) [244]. It is also consistent with either Pareto<sup>1</sup> efficient policy or a decentralized market economy. If pollution is not priced, companies will use it until its marginal product is zero, when pollution is considered as a factor of production, but not the stock of environmental capital. Extending this model, stock of environmental quality is included as a factor of production (Lopez, 1994) [245], then the predictions of this model depend crucially on the existence of property rights. The EKC emerges from a dynamic process, as a part of capital goes for development of the environmental sectors. Total capital is divided into two parts, one is used in production process that creates pollution and damage the existing environment and the other is used to clean up environment or improve it (Dinda, 2002) [115].

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<sup>1</sup>Pareto efficiency, or Pareto optimality, is a state of allocation of resources in which it is impossible to make any one individual better off without making at least one individual worse off.

## 5. SYSTEM DYNAMICS MODELLING AND THE ENVIRONMENTAL KUZNETS CURVE IN ECUADOR (1980-2025)

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The role of abatement expenditure is crucial to reduce the pollution in production side (Selden and Song, 1994 [223]; Dessus and Bussolo, 1998 [242]; Jaeger, 1998 [246]). But the abatement expenditure may not be a determining factor behind the EKC for long-lived pollutants like hazardous waste sites that are neither easily abated nor shifted elsewhere. A theoretical model of the EKC based on perfect mobility of household and labour is developed, and a general equilibrium model that emphasizes spatial separation on the consumer side as the reason behind the EKC for hazardous waste sites (Gawande et al., 2001) [247]. Under various conditions, the EKC relationship between pollution and income can be obtained theoretically (John and Pecchenino, 1994 [248]; Jones and Rodolfo, 1995 [232]; Selden and Song, 1995 [104]; Beltratti, 1997 [249]; Stokey, 1998 [250]; Kadekodi and Agarwal, 1999 [251]; Bulte and van Soest, 2001 [252]; Dinda, 2002 [115]). Note that the EKC relationship may also take shape from the interaction between ecological and economic factors (Ezzati et al., 2001) [111].

The empirical evidence for the existence of an EKC has been found in various studies. These studies share some common characteristics with respect to the data and methods employed. Most of the data used in these studies are cross-sectional panel data [94]. The following reduced form model is used to test the various possible relationships between pollution level/environmental pressure and income:

$$y_i = \alpha_i + \beta_1 x_{it} + \beta_2 x_{it}^2 + \beta_3 x_{it}^3 + \beta_4 z_{it} + \epsilon_{it}, \quad (5.1)$$

where  $y$  is an environmental indicator,  $x$  is income and  $z$  relates to other variables of influence on environmental degradation. The subscript  $i$  stands for the country,  $t$  for time,  $\alpha_i$  is a constant,  $\beta_k$  are the coefficient of the  $k$  explanatory variables. Equation 5.1 allows us to test several forms of environment–economic development/growth relationships:

- (i)  $\beta_1 = \beta_2 = \beta_3 = 0$ .  
A flat pattern or no relationship between  $x$  and  $y$ .
- (ii)  $\beta_1 > 0$  and  $\beta_2 = \beta_3 = 0$ .  
A monotonic increasing relationship or a linear relationship between  $x$  and  $y$ .

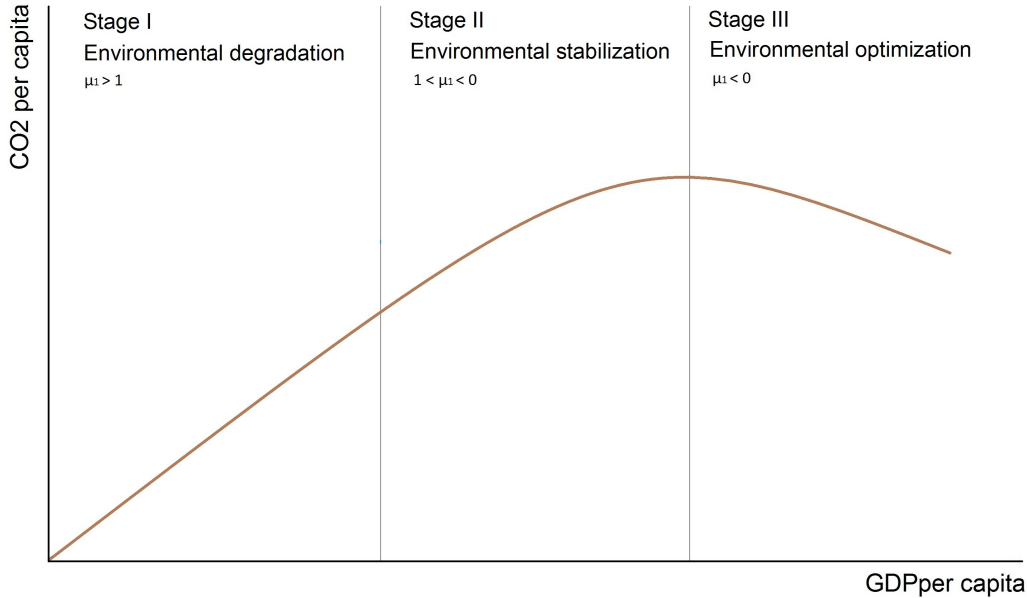
- (iii)  $\beta_1 < 0$  and  $\beta_2 = \beta_3 = 0$ .  
A monotonic decreasing relationship between  $x$  and  $y$ .
- (iv)  $\beta_1 > 0$ ,  $\beta_2 < 0$  and  $\beta_3 = 0$ .  
An inverted-U-shaped relationship, i.e., EKC.
- (v)  $\beta_1 < 0$ ,  $\beta_2 > 0$  and  $\beta_3 = 0$ .  
A U-shaped relationship.
- (vi)  $\beta_1 > 0$ ,  $\beta_2 < 0$  and  $\beta_3 > 0$ .  
A cubic polynomial or N-shaped figure.
- (vii)  $\beta_1 < 0$ ,  $\beta_2 > 0$  and  $\beta_3 < 0$ .  
Opposite to the N-shaped curve.

## 5.4 Empirical findings of EKC in Ecuador

The inverted  $U$ -shaped relationship between  $\text{CO}_2$  emissions and GDP is an empirical observation. In this respect there are many studies where quadratic and cubic models are used to fit the emissions to income (Canas, 2003 [253]; Shen, 2004 [254]; Cole, 2005 [255]; Galeotti, 2006 [256]; Esteve, 2012a [257]). However, in many cases the evidences of the EKC hypothesis is weak. Another way to test the validity of the EKC assumption is to compare the long and the short run impact of income on emissions (Nara, 2010 [258], Jaunky, 2011 [143]). Whatever approach is used or set of countries studied, analysis always uses past data and there are no studies where the EKC hypothesis has been tested in a forthcoming period. To do this, a detailed model of the connection between GDP and  $\text{CO}_2$  emissions is needed, as well as a set of plausible scenarios that could describe a possible evolution (income, energy matrix, and sectoral structure) of a given country.

As the theory predicts a long-run relationship linking emissions and economic growth, there is a wide stream of recent research that has assessed this relationship employing co-integration techniques. The empirical evidence suggests that pollution levels and GDP may be jointly determined, so that any constraint put on energy consumption, to help in reducing emissions, will have effects on economic growth. In the initial stage, as in the developing countries,  $\text{CO}_2$  emissions

## 5. SYSTEM DYNAMICS MODELLING AND THE ENVIRONMENTAL KUZNETS CURVE IN ECUADOR (1980-2025)



**Figure 5.2:** Schematic plot of the relationship between the per capita income and the CO<sub>2</sub> emission: 1) linear growth of the pollution with the GDP, 2) stabilization, and 3) reduction of the emissions with the increase of the income. Figure adapted from Iglesias et al. (2013) [8].

scale with the *size* of the economy because the industries are relatively rudimentary, unproductive, and polluting. In the second stage, the impact of the economy in environmental degradation is reduced through the *structure and composition effect*, because the economy growth induces structural changes. In particular, that happens as an agricultural based economy shifts into a manufacturing services based economy. Finally, the third stage appears when nations invest intensively in research and development and the dirty and obsolete technologies are replaced by clean ones. At this point the pollution starts to decrease as a function of the income. The different phases of the EKC are depicted schematically in Figure 5.2.

Some authors, (Soytas, 2001 [259]; Soytas, 2003 [260]; Lee, 2005 [261]; Lise, 2006 [262]; Chontanawat, 2008 [263]; Halicioglu, 2009 [264]; Ozturk, 2010 [265]; Esteve, 2012a [257]; Esteve, 2012b [266]; Fosten, 2012 [267]) among others, use cointegration procedures to examine the CO<sub>2</sub> and GDP nexus, however these studies analyze past evidence. Our proposal goes a step further and intends to see under

## 5.4 Empirical findings of EKC in Ecuador

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what conditions a country could approach the fulfilment of the EKC hypothesis in the medium term.

To this end, we will use the model proposed in Chapter 3 and the findings of Chapter 4 ((see Section 4.6 in Chapter 4) as starting point (see Section 3.10.1 in Chapter 3).

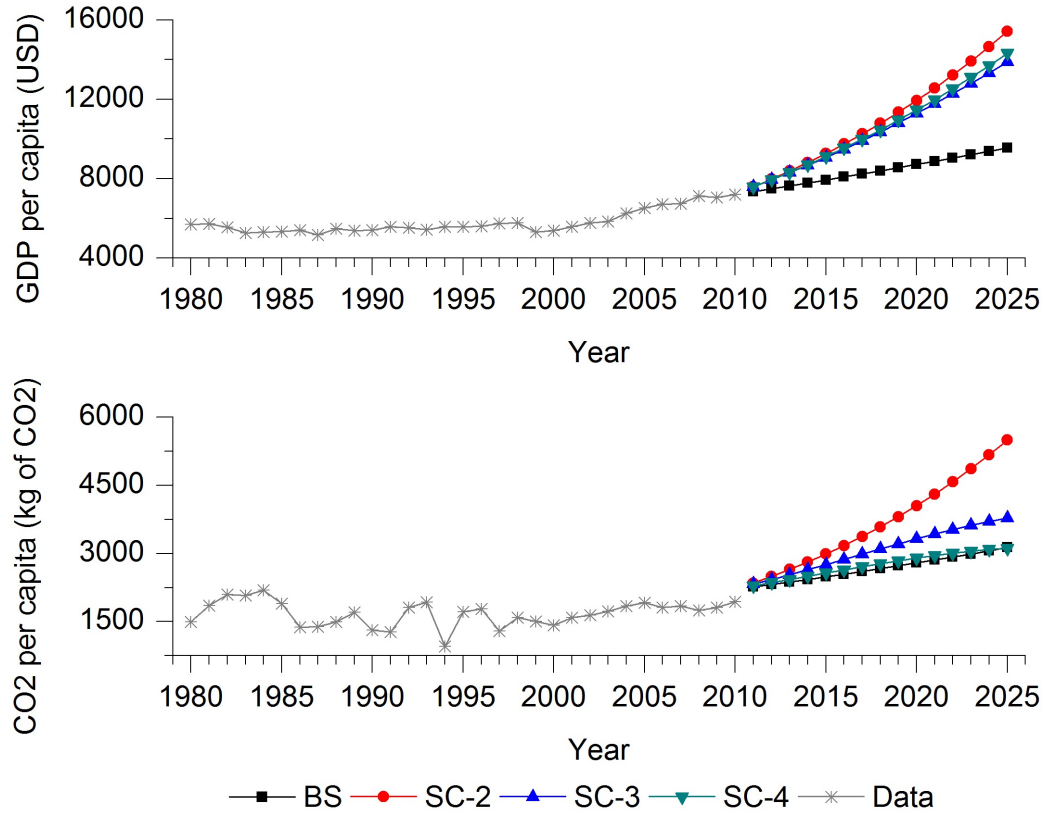
The followings sections are an effort to fill the gap in the literature of studies on the relationship between emissions and GDP in Latin American countries in general, and in Ecuador in particular. In addition, studies of a single country help policy makers improve comprehensive policies to control environmental degradation. Moreover, it represents a step forward in the study of the EKC hypothesis following Jaunky's specification [143], due to the inclusion of a forthcoming (2011-2025) and not a past period of time.

In Jaunky (2011) the author tries to test the EKC hypothesis in a set of high-income countries for the period 1980-2005. The lower long-run income elasticity does not provide evidence for the EKC, but it indicates that CO<sub>2</sub> emissions are stabilizing in developed countries. Therefore, the extension of this work to other countries and to a forthcoming period is of interest.

### 5.4.1 EKC hypothesis verification

The EKC hypothesis supposes that from a given moment onward the relationship between CO<sub>2</sub> emission and income is no longer proportional and that, even the first can be reduced as GDP increases. To get the first insight about the relationship between GDP and CO<sub>2</sub> we plot the per capita GDP and CO<sub>2</sub> emission as a function of the year in Figure 5.3, using the data set of the period 1980-2010 and the model calculation for the four considered scenarios (2011-2025). To calculate the value of the population, needed for any per capita quantity, we use the geometric-growth rate (Equation (3.14)) to extrapolate its value into the forecast period. Regarding GDP, one can observe two clearly distinct behaviours in the forecast period, on one hand the *BS* scenario, with a moderate increase of the GDP per capita, and on the other hand, the rest of scenarios that present a large increase of the GDP. For CO<sub>2</sub> emissions *BS* and *SC-4* scenarios show the same value, while *SC-3* shows a slightly higher one, and *SC-2* scenario presents, by far, the largest increase of CO<sub>2</sub>

## 5. SYSTEM DYNAMICS MODELLING AND THE ENVIRONMENTAL KUZNETS CURVE IN ECUADOR (1980-2025)



**Figure 5.3:** Top: Estimation of GDP per capita for the period 2011-2025 in Ecuador. Bottom: Estimation of CO<sub>2</sub> emission per capita for the period 2011-2025 in Ecuador.

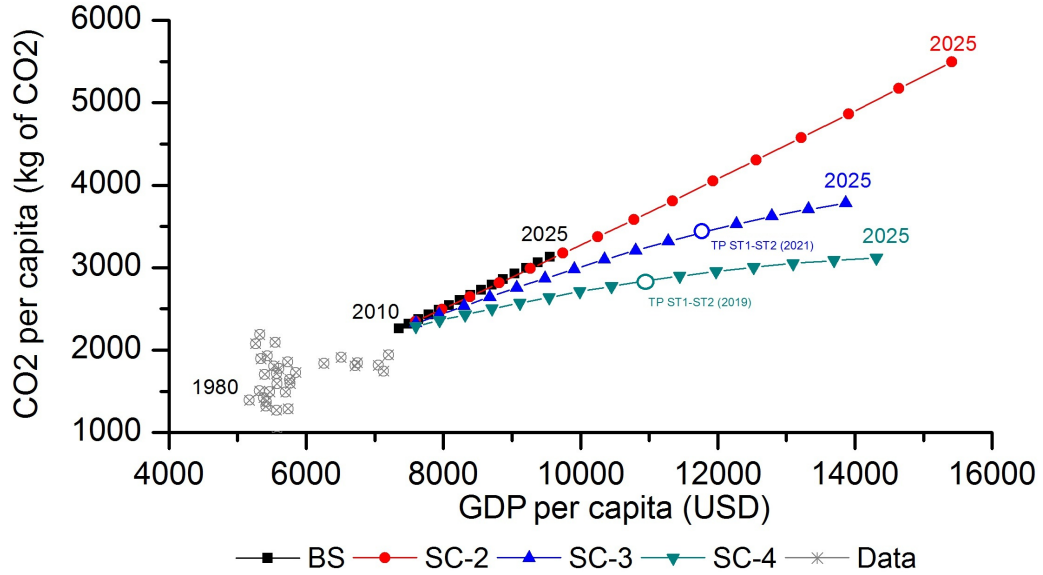
emissions. In Figure 5.4 we combine both pieces of information in a single picture, where we plot CO<sub>2</sub> emission per capita as a function of GDP per capita. According to this figure it seems that the different scenarios generate different regimes and the environmental impact is attenuated in some cases, specially for SC-3 and SC-4 scenarios.

We follow the Jaunky's specification [143] for testing the EKC hypothesis in Ecuador. A reduced form equation for the relationship between the per capita income and the CO<sub>2</sub> emission is assumed:

$$LCO2_t = \mu_0 + \mu_1 LGDP_t + \epsilon_t, \quad (5.2)$$

where  $LCO2$  is the natural logarithm of the CO<sub>2</sub>,  $LGDP$  is the natural logarithm

## 5.4 Empirical findings of EKC in Ecuador



**Figure 5.4:** GDP per capita *versus* CO<sub>2</sub> emission per capita for the period 2011-2025 in Ecuador. Marks TP-ST1-ST2 stand for the year of the turning points (the scenario passes from stage 1 to state 2) of the EKC (see Figure 5.5).

of the GDP,  $\epsilon$  is the error term,  $\mu_0$  is the term constant, and  $\mu_1$  estimates the CO<sub>2</sub>-GDP elasticity.

In the first region of the simplified Kuznets curve (Figure 5.2), as the elasticity  $\mu_1 > 1$  there is a high responsiveness of GDP to changes in CO<sub>2</sub> emissions. Therefore a change in GDP generates a more than proportional increase in CO<sub>2</sub> emission. This phase involves little environmental responsibility and also implies that the country is in the early stage of environmental sustainability (*environmental degradation*). If  $0 < \mu_1 < 1$ , then an income increase leads to a less than proportional increase in CO<sub>2</sub> emissions and, as a consequence, it implies that the country enters into the second stage of the EKC with *environmental stabilization*<sup>1</sup>. Finally, for  $\mu_1 < 0$  a negative relationship occurs between GDP and CO<sub>2</sub> emission. This is the final stage of the EKC and mean that the country enters into a phase with intensive use of green technology and *environmental optimization*<sup>2</sup>.

<sup>1</sup>Note that, we define turning point of change from the first to the second stage (TP-ST1-ST2( $t$ )) to the time  $t$  where  $\mu_1 > 1$  pass to  $0 < \mu_1 < 1$ ).

<sup>2</sup>Note that, we define turning point of change from the second to the third stage (TP-ST2-ST3( $t$ ))

## 5. SYSTEM DYNAMICS MODELLING AND THE ENVIRONMENTAL KUZNETS CURVE IN ECUADOR (1980-2025)

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### 5.4.2 EKC verification

We start the analysis testing the order of integration of both variables  $LGDP_t$  and  $LCO2_t$  using the tests of Ng and Perron (2001) [268]. These authors proposed using test statistics which are a efficient modified versions of Phillip-Perron (PP) and Augmented Dickey-Fuller (ADF) tests. Such modifications improve the tests do not exhibit the severe size distortions of the PP tests for errors with large negative MA or AR roots, and they can have substantially higher power than the PP tests.

Using the GLS detrended data  $y_T^d$ , the efficient modified PP tests are defined as:

$$\bar{M}Z_{\alpha}^{GLS} = (T^{-1}y_T^d - \lambda^2) \left( 2T^{-2} \sum_{t=1}^T y_{t-1}^d \right)^{-1}, \quad (5.3)$$

$$\bar{M}SB^{GLS} = \left( T^{-2} \sum_{t=1}^T \frac{y_{t-1}^d}{\lambda^2} \right)^{1/2}, \quad (5.4)$$

$$\bar{M}Z_t^{GLS} = \bar{M}Z_{\alpha}^{GLS} \times \bar{M}SB^{GLS}, \quad (5.5)$$

$$\bar{M}SB^{GLS} = \left[ T^{-2} \left( y_{t-1} \frac{2}{s^2} \right) \right]^{1/2}, \quad (5.6)$$

where  $[y_t]_1^T$  represents the realization of the time series,  $T$  denotes the sample size,  $\lambda^2$  is a consistent estimate of the long-run variance parameter  $\lambda^2$  and  $s^2$  is the variance.

The statistics  $\bar{M}Z_{\alpha}^{GLS}$  and  $\bar{M}Z_t^{GLS}$  are efficient versions of the PP  $Z_{\alpha}$  and  $Z_t$  tests that have much smaller size distortions in the presence of negative moving average errors. Note that those tests should be performed for the whole dataset.

The results are shown in Table 5.1, and according to them, the null hypothesis of no stationarity cannot be rejected, independently of the statistic used, for both series,  $LGDP_t$  and  $LCO2_t$ . Accordingly, both series would be concluded to be I(1).

Once the order of integration of the series is analyzed, we will estimate the long-run regression model [143] using the Dynamic Ordinary Least Squares (DOLS)<sup>1</sup> to the time  $t$  where  $0 < \mu_1 < 1$  pass to  $\mu_1 < 0$ ).

<sup>1</sup>Least squares estimation of equation might suffer two problems: endogeneity bias in the explanatory variables and nuisance parameter dependencies due to serial correlation in the residuals.

## 5.4 Empirical findings of EKC in Ecuador

**Table 5.1:** Ng-Perron unit root test.

| Variable | $\bar{M}Z_{\alpha}^{GLS}$ | $\bar{M}Z_t^{GLS}$ | $\bar{M}SB^{GLS}$ | $\bar{M}P_T^{GLS}$ |
|----------|---------------------------|--------------------|-------------------|--------------------|
| $LGDP_t$ | -3.488                    | -1.268             | 0.364             | 25.197             |
| $LCO2_t$ | -4.827                    | -1.532             | 0.317             | 18.750             |

estimation method of Stock and Watson (2010) [142], following the methodology proposed by Shin (1994)<sup>1</sup> [269]. This approach is similar to the KPSS<sup>2</sup> tests, which are implemented in two stages for the case of cointegration.

The first step in our estimation strategy would therefore consist of the estimation of the coefficients of a long-run dynamic equation [143] including leads and lags of the explanatory variables (GDP) in the long-run regression model, *i.e.*, the so-called DOLS regression:

$$LCO2_t = \mu_0 + \mu_1 LGDP_t + \sum_{j=-q}^q \mu_j \Delta LGDP_{t-j} + \epsilon_j. \quad (5.7)$$

The second step is to use the statistic  $C_{\mu}$ <sup>3</sup> that is a LM-type<sup>4</sup> test designed by Shin (1994) [269], to test the null hypothesis of cointegration against the alternative of no cointegration in a DOLS regression.

$$C_{\mu} = T^{-2} \sum \frac{\tilde{S}_{\mu t}^2}{\tilde{s}_{\mu}^2(l)}, \quad (5.8)$$

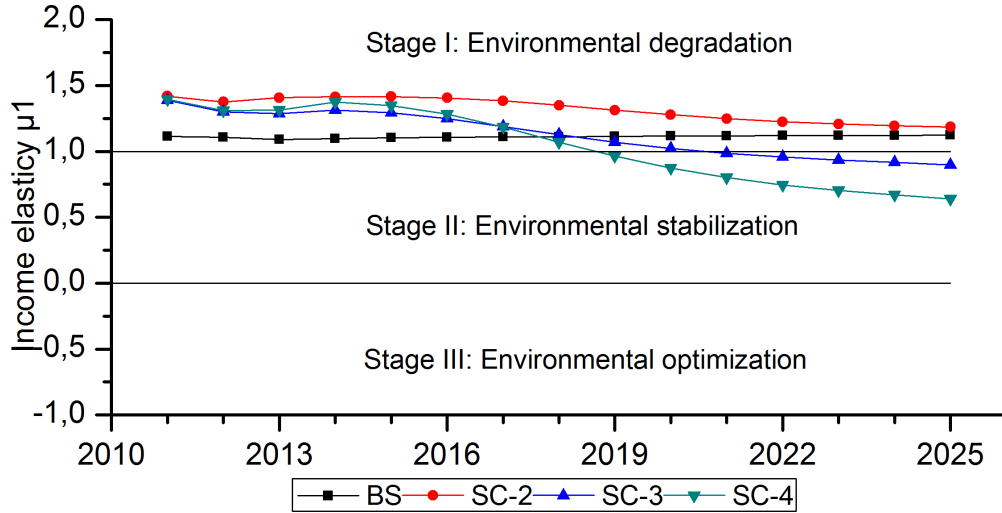
<sup>1</sup>In order to overcome the problem of the low power of the classical cointegration tests in the presence of persistent roots in the residuals of the cointegration regression, Shin (1994) [269] suggests a new test where the null hypothesis is that of cointegration.

<sup>2</sup>These tests are called the Kwiatkowski et al. (1992) [270] tests, and assume the null hypothesis of stationarity.

<sup>3</sup> $C_{\mu}$  is the test statistic for deterministic cointegration, *i.e.*, when no trend is present in the regression.

<sup>4</sup>Lagrange multiplier (LM) test is a statistical test of a simple null hypothesis that a parameter of interest  $\theta$  is equal to some particular value  $\theta_0$ . It is the most powerful test when the true value of  $\theta$  is close to  $\theta_0$ . The main advantage of this test is that it does not require an estimate of the information under the alternative hypothesis or unconstrained maximum likelihood. This makes testing feasible when the unconstrained maximum likelihood estimate is a boundary point in the parameter space.

## 5. SYSTEM DYNAMICS MODELLING AND THE ENVIRONMENTAL KUZNETS CURVE IN ECUADOR (1980-2025)



**Figure 5.5:** Evolution of CO<sub>2</sub>-GDP elasticity for the period 2010-2025 in Ecuador.

where  $\tilde{S}_{\mu t}^2$  and  $\tilde{s}_{\mu}^2$  are semiparametric consistent estimators of the long-run variance.

In table 5.2 (Full sample column), we report the estimates from the DOLS regression and the results from Shin's test (Shing, 1994) [269]. Results show evidence of linear cointegration between CO<sub>2</sub> emissions and GDP, because we cannot reject the null hypothesis of cointegration, being the estimated value of the income elasticity of CO<sub>2</sub> emissions,  $\mu_1 = 1.185$  which denotes little environmental responsibility, *i.e.*, Ecuador in 2010 is still in the first stage of the EKC.

Our final aim is to verify whether the EKC applies to Ecuador in the medium term (up to 2025), or to know the EKC stage that the country fulfills. To carry out this task, we perform the same process described above using the time series obtained in our model (see Chapter 3). The results are shown in table 5.2. The results show that in any scenario Ecuador fulfills the EKC hypothesis. However, in *SC-3* and *SC-4* scenarios the income elasticity of CO<sub>2</sub> emissions is below 1, which means, that in these cases, Ecuador has reached a new stage of environmental responsibility. In particular, stage 2 of the EKC is closer in the 2020s decade than in first decade of the 21th century. Figure 5.5 clearly illustrates this, where the  $\mu_1$  elasticity is plotted as a function of the year for the four scenarios under investigation. It is important to point out that Ecuador switches from the first to the second

## 5.4 Empirical findings of EKC in Ecuador

**Table 5.2:** Stock -Watson-Shin's DOLS <sup>a,b,c,d</sup> estimation of linear cointegration.

| Parameter       | Full sample       | BS                  | SC-2              | SC-3                | SC-4                |
|-----------------|-------------------|---------------------|-------------------|---------------------|---------------------|
| estimates       | 1980-2010         | 1980-2025           | 1980-2025         | 1980-2025           | 1980-2025           |
| $\mu_0$         | -19.9***<br>(1.7) | -18.4***<br>(0.2)   | -19.7**<br>(2.5)  | -12.7<br>(2.4)      | -6.50<br>(3.5)      |
| $\mu_1$         | 1.19***<br>(0.07) | 1.123***<br>(0.009) | 1.19***<br>(0.10) | 0.898***<br>(0.099) | 0.641***<br>(0.056) |
| $R^2$           | 0.998             | 0.999               | 0.995             | 0.989               | 0.982               |
| Test: $C_\mu^c$ | 0.132             | 0.071               | 0.113             | 0.131               | 0.152               |
| $\sigma^2$      | 0.013             | 0.011               | 0.046             | 0.053               | 0.071               |

<sup>a</sup> Standard Errors (in brackets) are adjusted for long-run variance. The long-run variance of the cointegrating regression residual is estimated using the Barlett window which is approximately equal to  $\text{INT}(T^{1/2})$  as proposed in Newey and West (1987) [271].

<sup>b</sup> We choose  $q=\text{INT}(T^{1/3})$  as proposed by Stock and Watson (2010) [142].

<sup>c</sup>  $C_\mu$  is a LM statistic for cointegration using the DOLS residuals from deterministic cointegration, as proposed Shin (1994) [269]. \*, \*\* and \*\*\* denote significance at the 10%, 5% and 1% levels, respectively.

<sup>d</sup> The critical values are taken from table 1 and  $m = 1$  of Shin (1994) [269]:  $C_\mu$  0.231 (10%) 0.314 (5%) 0.533 (1%)

stage in 2019 and 2021 for scenarios *SC-4* and *SC-3*, respectively.

In conclusion, the changes introduced in the *SC-3* and *SC-4* scenarios, which suppose an increase in energy efficiency, changes in the energy matrix, the productive sectoral structure, and in the share of renewable energy to the total consumption (see Section 3.10.2 in Chapter 3), have induced a more environmentally sounding scenario. The impact of GDP growth is somehow attenuated and the country moves towards a situation where the increase of the GDP will not lead to an unavoidable and uncontrolled increase of CO<sub>2</sub> emissions.

### 5.5 Summary and conclusions of the chapter

In this Chapter we have studied the EKC hypothesis for Ecuador in a forthcoming period, 2011-2025, using the model proposed in Chapter 3 under four different scenarios (see Section 3.10.1 in Chapter 3). The model allows us to estimate the CO<sub>2</sub> emission as a function of global productive activity, the energy mix and industry sectoral structure, using the system dynamics (SD) methodology. In addition we use a GDP formation presented in Chien and Hu (2008) [5] that depends on the renewable energy which creates a *feedback* mechanism that makes the model more reliable and allows us to obtain *non-trivial* conclusions in the analysis. The generated data under four different scenarios closely followed Jaunky's specification [143] and allowed us to see whether the EKC is fulfilled, or not, in Ecuador and to calculate the elasticity between GDP and CO<sub>2</sub> emission.

In the analysis of the EKC hypothesis we conclude that in any case Ecuador fulfills this hypothesis, but the value of the CO<sub>2</sub>-GDP elasticity allows us to separate the proposed scenarios in two families, on one hand *BS* and *SC-2*, and, on the other, *SC-3* and *SC-4* scenarios. In the first case, the elasticity is larger than one, while in the second case it is lower than one. Therefore, the first family implies little environmental respect, while the second family corresponds to a situation where the impact of the GDP growth is attenuated.

Our estimates do indeed show that Ecuador will be able to enter the area of environmental stability (second stage of the EKC) in the medium term (2019-2021). Therefore, to achieve this goal it is essential to implement policies that allow the diversification of energy sources and to increase energy efficiency in the productive sectors in order to get more sustainable development.

This Chapter intended to fill the gap in the literature of studies on energy and CO<sub>2</sub> emissions in Latin American countries in general, and in Ecuador in particular. On the other hand, this kind of study may help policymakers create more comprehensive and reliable policies for control of environmental degradation. Moreover this work contributes to the EKC literature with a case study of Ecuador using time series data for the period 1980-2010 and goes a step further with the study of a forthcoming period, up to 2025.

*Our species needs, and deserves, a citizenry with minds wide awake and a basic understanding of how the world works.*

Carl Sagan

CHAPTER

# 6

## Summary and conclusions

Globally, CO<sub>2</sub> is by far the main contributor to anthropogenic greenhouse gas (GHG) emissions (IPCC, 2007) [154, Fig. 2.1]: CO<sub>2</sub> represents 76.7% of the GHG emissions (approximately 56.6% is from fossil fuels, 17.3% from deforestation, and 2.8% from other sources). Ecuador has a relatively low level of CO<sub>2</sub> emissions (2100 kg per capita per year) while Qatar, the world's largest CO<sub>2</sub> emitter per capita in 2009, emitted 44000 kg per capita. At the same time Venezuela, the largest CO<sub>2</sub> emitter in Latin America (LA), emitted annually 6500 kg per capita (WB, 2012) [144]. It is expected that social and economic development in the coming years could significantly increase Ecuador's emissions. Observations show that global CO<sub>2</sub> emissions, far from stabilizing, have experienced significant growth in recent years.

Several international organizations, notably, the Intergovernmental Panel on Climate Change (IPCC), are warning about the need of stabilizing the CO<sub>2</sub> and others anthropogenic GHG emissions in order to avoid a catastrophic warming of the climatic system during this century (IPCC, 2007) [154]. The IPCC has developed several methods to estimate GHG emissions, such as the *Reference Method* (IPCC, 2006) [42], which is a *top-down* technique that uses data from the country's energy supply (mainly from the burning of fossil fuels), land use, and deforestation rate, among others, to calculate CO<sub>2</sub> emissions. It is a straightforward method that

## 6. SUMMARY AND CONCLUSIONS

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can be applied on the basis of the available energy supply statistics (IPCC, 2006) [42]. However, the problem arises when it is necessary to conduct more detailed studies and find the driving forces that are behind the emissions, but the data is not available or is not sufficiently disaggregated for use with this method.

A key factor of economic development in countries and the transition from subsistence agricultural economies to modern industrial societies which are oriented to services, is to have an adequate supply of *affordable energy*. Energy is essential to enhance the social and economic welfare and, in most cases, it is essential to attract industrial and commercial wealth. It is a condition, *sine qua non*, of poverty alleviation, generalize social protection and raise living standards. Note that no matter how essential energy can be for the development, energy is just a medium, it is not the *final goal*, and the *final goal* of sustainable development is to achieve good health, a high standard of living, sustainable energy and a clean environment.

As already mentioned, energy consumption is one of the greatest measures of progress and well-being of a society. The concept of *energy crisis* appears when the energy sources of the society supplies are depleted. An economic model like the present, whose operation depends on continued growth, also requires an equally growing demand for energy. Since fossil energy sources are finite, it is inevitable that at some point the demand can not be supplied and all system will collapse; unless new sources of energy would be discovered or new techniques are developed, as would be the case of renewable energy.

The potential of renewable energy has a great capacity to help meet global energy demand. Furthermore, this type of clean energy has a rapidly growing due to the remarkable technical advances that have taken place in recent years and by the strong support of the various national governments and the enormous social support.

The commitment to promote this type of development and the rational use of energy, involves setting goals at national and regional levels and define a policy according with these goals.

The general objective of this research was create a useful methodology to estimate CO<sub>2</sub> emissions of a given country, in particular for Ecuador, and to understand the driving forces that guide this process, such as economic growth, energy use,

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energy mix structure, and fuel use in the productive sectors. The proposed methodology try to be easily transferable to other countries, regions, and time periods and to be used as a *pedagogical tool* for explaining to policymakers the possible ways to design a policy for reducing CO<sub>2</sub> emissions in a medium term horizon.

This study combines decomposition analysis with scenario modelling to create a baseline prevision as guidance for possible new policies. This allowed the development of a model with a set of integrated exploratory scenarios about income growth, energy use and CO<sub>2</sub> emissions for Ecuador in a medium term (2025). The scenarios show plausible more *environmental-friendly* trends that the country could take like pathways to get closer to a sustainable development.

The application of *scenario analysis-modelling* in the short-to-medium term is intended to develop insights into plausible future changes with additional green goals in the driving forces in national policies. While the decomposition analysis gives insights into historical change. The study offers potential *longer-term insights* through the exploration of changes in to the driving forces to evaluate the fulfillment of the Environmental Kuznets Curve (EKC) hypothesis.

The thesis was organized into six chapters and seven appendices. Chapter 1 presents the introduction of the most important aspects of the methodology and objectives of the research. Chapter 2 introduce the main figures in economy, productive sectors, energy use, etc., about Ecuador since 1980 until 2010; also it discusses about critical factors for the adoption of renewable technologies in the country.

Chapter 3 presents a model approach of CO<sub>2</sub> emissions in Ecuador in the upcoming years, up to 2025. The main goal here is to study in detail the way the changes in the energy matrix and in the Gross Domestic Product (GDP) will affect the CO<sub>2</sub> emissions in the country. In particular, special attention to the effect of a reduction of the share of fossil energy will be paid, as well as of an improvement in the efficiency of the fossil energy use. In this chapter, we have developed a System Dynamic (SD) model based on a relationship, which is a variation of the *Kaya identity* (Kaya, 1993) [167], and on a formation of GDP approach that depends on renewable energy (Chien and Hu) [5], which introduces a *feedback mechanism* in the model and allows us to generate a *non-trivial* evolution of the system. Therefore, the GDP and the energy intensity have been modeled with different scenarios that present the evolution of the energy matrix and the productive

## 6. SUMMARY AND CONCLUSIONS

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sectoral structure have been defined. First, a *BS* scenario (baseline scenario) has been defined, in which the variables of the model were parameterized according to the observed tendency during the period 1980-2010 (see Chapter 2), assuming a geometric growth rate during the period 2011-2025. The second scenario, called *SC-2*, is characterized by the increasing (relative to 2010) of the GDP during the period 2011-2025 (with the goal of reaching the estimated international average GDP per capita in 2025). In the third scenario, called *SC-3* scenario, besides assuming the increasing of the GDP, we impose the decreasing of the fossil energy share ( $ES_1$ ) up to 67%. Finally, in the fourth one, *SC-4* scenario, we complement the *SC-3* scenario including changes in the productive sectoral structure to achieve a reduction of energy intensity, which supposes a lower CO<sub>2</sub> intensity.

The main outcome of this chapter are the estimates of CO<sub>2</sub> emissions by the period 2011-2025 in each scenario (see Section 3.11.3 in this Chapter). By 2025 the *BS* scenario reaches 55 thousand kt, in the *SC-2* scenario it corresponds to 97 thousand kt, in *SC-3* scenario to 66 thousand kt, and in the *SC-4* scenario to 55 thousand kt of CO<sub>2</sub>. Note that the *BS* scenario corresponds to a modest GDP increase, while in the others the GDP increases heavily. The highest emissions are for the *SC-2* scenario where no mitigation measures are taken. The other two scenarios show us that it is possible a sizable reduction of the emissions, promoting the renewable energy (*SC-3* scenario) and on top of that modifying the productive sectoral structure, therefore, reducing the energy and the CO<sub>2</sub> intensities, as in the *SC-4* scenario. It is worth to note that both promotion of renewable energy and improvement of the energy intensity are equally effective attenuating CO<sub>2</sub> emissions.

After the study that has been carried out in this chapter, the main conclusions are:

- Energy and emissions analysis, the development of policy and the reporting of progress require insight into the driving forces of change and potential future evolution.
- Energy and emissions are both dependent on, and influenced by, a wider development domain which is complex in evolution and uncertain in outcome.

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- Qualitative and quantitative exploratory scenario analysis was implemented for baseline quantification of future CO<sub>2</sub> emissions as *scientific inquiry* to improve the *strategic planning*.
  - The exploratory scenarios are not predictions but are plausible descriptions of alternative future worlds. These involve not only technical and economic parameters but explicitly represent the evolution of social, political and cultural aspects.
  - The emissions increase under all scenarios studied but the composition of this growth and the total growth by 2025 are divergent and suggest that it is possible to control the CO<sub>2</sub> emissions even under a scenario of continuous increase of the income. To do this, it is needed an increase of the use of renewable energy and the support of the use of more efficient fossil fuel technologies.
  - The methodology presented is useful to estimate the CO<sub>2</sub> emissions of a given country and to understand the driving forces that guide this process.
  - This methodology is easily transferable to other countries, regions, and time periods. Moreover, it can be pedagogically useful for explaining to *policy-makers* the possible ways to design a policy for reducing CO<sub>2</sub> emissions in a medium term horizon.
  - This study offers useful lessons for developing countries, and it could be used as a *policy-making* tool since it is easily transferable to any other time period or region.

The results obtained with the model are the starting point for the decomposition analysis in Chapter 4 and for the study of Environmental Kuznets Curve (EKC) in Chapter 5.

In Chapter 4, a decomposition analysis of CO<sub>2</sub> related to income growth and energy consumption bases on LMDI (see Section 4.5 in this Chapter) for Ecuador in the period 1980-2025 is carried out. For this purpose three periods have been selected, the first period is 1980-1995 where the LMDI analysis findings suggest that the country emissions in this period almost grow (38%) in the same factor that

## 6. SUMMARY AND CONCLUSIONS

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the income (35%). The second period is 1995-2010 and the evidence suggests that a higher economic growth (68%) led to even greater emissions growth (85%) in the country.

The third period is 2010-2025 and includes the analysis for the different scenarios proposed in Chapter 3. To see more clearly how the income-CO<sub>2</sub> relationship behaves as a function of time, it is very enlightening to depict the ratio  $D_{tot}/D_{act}$ <sup>1</sup> as a function of the time. The first striking thing is the very different behaviour for each scenario. On one hand, it is somehow surprising the almost flat curve corresponding to the *BS* scenario which implies a *trend-growth* GDP scenario, however the CO<sub>2</sub> emission increases steadily because of the absence of attenuation measurements. A similar behaviour, although slightly sloping down, is observed for *SC-2*, where a rapid growth of the GDP is assumed without any attenuation action regarding CO<sub>2</sub> emission. It is worth noting a certain decrease of the ratio  $D_{tot}/D_{act}$  in the final part of the period under study. The other two scenarios, *SC-3* and *SC-4*, show a steady reduction of the ratio  $D_{tot}/D_{act}$  due to the changes in the sectoral structure and in the energy mix, which allows compensation of the rapid GDP growth.

The main conclusions of this chapter are:

- The application of decomposition analysis was implemented towards insight at macro and sectoral level both historically and as alternative future evolution in the scenarios. This can enhance knowledge of the driving forces that control in CO<sub>2</sub> emissions. It is demonstrated by, *e.g.*, the insight into change in industry and transport emissions which is of key importance in Ecuador.
- In general, economic growth is the most significant in determining future emissions, thus the scale growth in economic output of the sectors acted to increase emissions. Patterns of energy intensity saw a deeper decrease in industry, trade and public service sector as well as in transport in the greener scenario (*SC-4*), one can clearly see the results of the implementation of energy efficiency goals set for each sector in this scenario.
- The key of the alternative evolution scenarios is the complex array of driving forces in the development path, which can be driven by governance and

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<sup>1</sup>Terms of LMDI formula in Multiplicative decomposition case (see Figure 4.4).

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society. These driving forces in particular can influence the evolution of technological change and the development models applied but can also be represented by lifestyles and societal preferences.

- This preliminary analysis suggests that, with the appropriate changes in the energy mix, the sectoral structure, and the share of renewable energies, Ecuador can move into a more environmentally sustainable situation.

In Chapter 5 we try to respond *if is it possible for a country in the process of development to comply with the EKC hypothesis in the medium term?*. This chapter has studied the EKC hypothesis for Ecuador in a forthcoming period, 2011-2025, using the model proposed in Chapter 3 under four different scenarios (see Section 3.10.1 in Chapter 3). We used co-integration techniques (Stock and Watson) [142] to test the existence of the EKC hypothesis in Ecuador in the medium term using the Jaunky's specification (Jaunky, 2011) [143]. Our proposal goes a step further than previous contributions, and intends to see under which conditions a country could approach the fulfilment of this hypothesis in the medium term. Results do not support the fulfilment of the EKC, nevertheless, our estimations show that Ecuador could be on the way to achieving environmental stabilization in the near future if economic growth is combined with an increase in the use of renewable energies, an improvement of the productive sectoral structure, and the use of a more efficient fossil fuel technology.

After the analysis that has been carried out in this chapter we can conclude that:

- Lower emissions are not necessarily associated with lower economic growth, as the economy expands demand for the supply of energy and energy intensive goods increases. At the same time, economic growth can drive technological change, increased efficiency, institutional change and preferences more towards reducing emissions
- In any case Ecuador fulfills this hypothesis, but the value of the CO<sub>2</sub>-GDP elasticity allows us to separate the proposed scenarios in two families, on one hand *BS* and *SC-2*, and, on the other, *SC-3* and *SC-4* scenarios. In the first case, the elasticity is larger than one, while in the second case it is lower than

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one. Therefore, the first family implies little environmental respect, while the second family corresponds to a situation where the impact of the GDP growth is attenuated.

- Our estimates do indeed show that Ecuador will be able to enter the area of environmental stability (second stage of the EKC) in the medium term (2019-2021). Therefore, to achieve this goal it is essential to implement policies that allow the diversification of energy sources and to increase energy efficiency in the productive sectors in order to get more sustainable development.
- This chapter intended to fill the gap in the literature of studies on energy and CO<sub>2</sub> emissions in Latin American countries in general, and in Ecuador in particular. On the other hand, this kind of study may help policymakers create more comprehensive and reliable policies for control of environmental degradation. Moreover this work contributes to the EKC literature with a case study of Ecuador using time series data for the period 1980-2010 and goes a step further with the study of a forthcoming period, up to 2025.

In summary, to explore the influence of policy and *decision-making* on the development path and the complex array of driving forces it entails governance represents a more broad conception than *government*. Ultimately, the evolution of governance is dependent on society. The development path arising from governance and society can involve stronger or weaker processes of *sustainability* that encourage stronger or weaker processes of immaterialisation, dematerialisation and decarbonisation (Tapio et al., 2007) [272]. Emissions can evolve on higher or lower emissions trajectories based not only on the evolution of economic growth but on the evolution of the development path. Within the development path, economic growth interacts with governance and societal choices and the other driving forces. This can drive potential lock-in to a higher emissions trajectory.

### 6.1 Limitations

As with most research, the lack of data, poor quality and level of detail as well as the little disaggregation and accessibility have been the main limitation of this

study. The data used to build the model has been taken from published sources and additional estimates have been made on base of the literature. In completing the data set for different variables, data are probably underestimate or overestimate.

The lack of more disaggregated data has avoided a more fully develop of the sub-systems, such as the productive sectors. The lack of this *sectoral-vision* weakens the *macro-vision* and the insight about the dynamics of the system that may provide the model. In addition, the decomposition analysis framework does not explicitly consider the effect of price on energy consumption. The general level of prices is also important in explaining growth in GDP but can not be explicitly considered in the analysis. It also can not explore how high inflation reduces growth in output. Goodwin et al. (2003) [273] suggests that income is a stronger determinant of fuel consumption than fuel price and consumption is price inelastic. Despite these limitations, in the scenarios a range of income growth rates are explored which allows the analysis of alternative evolutions of the economy and its relationship with energy and emissions.

Scenario analysis is a method for structuring thinking on the future but the future is by its nature complex and uncertain. Known factors can evolve in unknown ways and unknown factors can have a substantial impact and alter outcomes. In general, the scenarios attempt to bound uncertainty of the known factors while unknown factors or wildcards have been excluded and would be the subject of strategic planning exercises (Nakicenovic et al., 2000) [65]. Note that the scenario analysis has been made based on assumptions and generalizations used in the literature.

The top-down methodology for building models maybe have a bias in the estimation and analysis at sector level. In addition, the identity that has been used (an extension of Kaya identity) may suggest direct causality and simple linear relationships between variables. The factors described in the identity maybe are not directly driving forces in themselves.

Due to the high complexity involved in environmental, economic and energy systems there is no methodology or model to make an accurate forecast and as mentioned above, the scenario analysis not even try to make a prediction, therefore, our study outcomes should be taken as estimates of potential future for the accomplishment of policies.

## 6. SUMMARY AND CONCLUSIONS

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### 6.2 Areas for further research

In order to get more accurate estimates and realistic scenarios, future research would expand the model within different sectors and economic activities of the country. Each sector could contain their own causal relationships and driving forces, in order to achieve deeper insight on their dynamics. The priority should be to develop transport and construction sectors, as these are the most energetically intensive and therefore they are calls for achieving improved in energy intensity and in emissions reduction.

In responding to data gaps, further research both on transport and industry activity data for Ecuador would be beneficial to both policy and analysis. Further data research could also examine the disaggregation of energy data for different types of transport (passenger/ freighter) or industrial activity. For the residential sector, further disaggregation could be extended to different branches of housing by including by age and dwelling type or by energy service or technology type *e.g.* lighting, space heating etc. where data permits.

The use of the model with other indicators (economic and environmental) and another type pollutants ( $\text{SO}_2$ ,  $\text{CH}_4$ , etc.) could also be recommended for future research. Note that, the use of the model and the methodology can also be transferred to other countries or similar zones.

The most comprehensive and holistic vision of growth, energy consumption and emissions issue is another line that future research should continue. In light of the results, insights into convergence processes at local and regional level, about income, energy use and emissions are necessary for the development of new and more effective policies. The long-term impact of energy infrastructure investment and alternative approaches to curb future demand is meritorious of further analysis.

CHAPTER

7

# Appendix

## 7. APPENDIX

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### 7.1 Appendix A

Appendix A presents the historical data that was used to build and validate the model. The considered data corresponds to the period 1980-2010 and it has been extracted from the official data sources such as: Ecuadorian Institute of Statistics and Census (INEC, 2012) [170], Central Bank of Ecuador (BCE) [150], World Bank<sup>1</sup> (WB) [144], and International Energy Agency (IEA) [151].

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<sup>1</sup>Economic official data set used is given in constant 2005 PPP international dollars.

## 7.1 Appendix A

Appendix A

Historical Data (1980-2010)

| Year | Population (Total) | GDP, PPP (constant 2005 international \$) | GDPpc (USD) | Agriculture, Fishing and Mining Sector (% of GDP) | Industrial Sector (% of GDP) |
|------|--------------------|---|-------------|---|------------------------------|
| 1980 | 7957811            | 45348387571                               | 5698,60     | 28,66   | 14,13                        |
| 1981 | 8178948            | 46874315322                               | 5731,09     | 28,65   | 14,14                        |
| 1982 | 8403034            | 46607486519                               | 5546,51     | 28,64   | 14,15                        |
| 1983 | 8629832            | 45427603706                               | 5264,02     | 28,63   | 14,15                        |
| 1984 | 8859125            | 47170328792                               | 5324,49     | 28,62   | 14,16                        |
| 1985 | 9090592            | 48546166408                               | 5340,26     | 28,61   | 14,16                        |
| 1986 | 9323745            | 50522364562                               | 5418,68     | 28,60   | 14,16                        |
| 1987 | 9557974            | 49438373617                               | 5172,47     | 28,60   | 14,16                        |
| 1988 | 9792658            | 53574220063                               | 5470,86     | 28,60   | 14,16                        |
| 1989 | 10027109           | 54099539802                               | 5395,33     | 28,62   | 14,15                        |
| 1990 | 10260587           | 55550422486                               | 5413,96     | 28,65   | 14,14                        |
| 1991 | 10493498           | 58435507851                               | 5568,73     | 28,70   | 14,12                        |
| 1992 | 10725281           | 59319377193                               | 5530,80     | 28,77   | 14,08                        |
| 1993 | 10953182           | 59494485196                               | 5431,71     | 28,88   | 14,04                        |
| 1994 | 11173647           | 62292016560                               | 5574,90     | 29,02   | 13,98                        |
| 1995 | 11384506           | 63384349640                               | 5567,60     | 29,19   | 13,90                        |
| 1996 | 11584074           | 64906106323                               | 5603,05     | 29,38   | 13,82                        |
| 1997 | 11774005           | 67536871819                               | 5736,10     | 29,59   | 13,73                        |
| 1998 | 11959586           | 68963769795                               | 5766,40     | 29,83   | 13,63                        |
| 1999 | 12148188           | 64619429726                               | 5319,26     | 30,09   | 13,52                        |
| 2000 | 12345023           | 66430642294                               | 5381,17     | 30,36   | 13,40                        |
| 2001 | 12552036           | 69975853579                               | 5574,86     | 30,61   | 13,30                        |
| 2002 | 12767415           | 73552710360                               | 5760,97     | 30,88   | 13,22                        |
| 2003 | 12987992           | 75960473417                               | 5848,52     | 31,15   | 13,19                        |
| 2004 | 13208869           | 82663204609                               | 6258,16     | 31,43   | 13,21                        |
| 2005 | 13426402           | 87411173006                               | 6510,39     | 31,70   | 13,29                        |
| 2006 | 13639708           | 91564517585                               | 6713,08     | 31,98   | 13,43                        |
| 2007 | 13849721           | 93430326328                               | 6746,01     | 32,26   | 13,62                        |
| 2008 | 14056740           | 100196254255                              | 7127,99     | 32,57   | 13,84                        |
| 2009 | 14261566           | 100558832906                              | 7051,04     | 32,89   | 14,09                        |
| 2010 | 14465000           | 104160450566                              | 7200,86     | 33,22   | 14,35                        |

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Appendix A

Historical Data (1980-2010)

| Year | Construction Sector (% of GDP) | Trade and Public services Sector (% of GDP) | Transportation Sector (% of GDP) | Energy use (kt of oil equivalent) | Agriculture, Fishing and Mining Sector (% of Energy use) | Industrial Sector (% of Energy use) |
|------|--------------------------------|---|----------------------------------|-----------------------------------|--|-------------------------------------|
| 1980 | 8,35                           | 39,46                                       | 9,39                             | 5032,22                           | 3,00   | 17,00                               |
| 1981 | 8,35                           | 39,47                                       | 9,39                             | 5259,13                           | 3,00   | 18,00                               |
| 1982 | 8,35                           | 39,48                                       | 9,38                             | 5677,75                           | 4,00   | 18,00                               |
| 1983 | 8,36                           | 39,49                                       | 9,38                             | 5293,44                           | 4,00   | 19,00                               |
| 1984 | 8,36                           | 39,49                                       | 9,37                             | 5708,26                           | 5,00   | 19,00                               |
| 1985 | 8,36                           | 39,50                                       | 9,37                             | 5775,48                           | 5,00   | 19,00                               |
| 1986 | 8,35                           | 39,51                                       | 9,37                             | 5750,92                           | 5,00   | 19,00                               |
| 1987 | 8,35                           | 39,51                                       | 9,38                             | 5874,32                           | 5,00   | 19,00                               |
| 1988 | 8,33                           | 39,51                                       | 9,39                             | 6169,54                           | 5,00   | 19,00                               |
| 1989 | 8,31                           | 39,51                                       | 9,40                             | 5869,94                           | 2,00   | 20,00                               |
| 1990 | 8,29                           | 39,50                                       | 9,43                             | 5997,20                           | 1,50   | 20,00                               |
| 1991 | 8,25                           | 39,47                                       | 9,46                             | 6221,86                           | 1,50   | 20,00                               |
| 1992 | 8,20                           | 39,44                                       | 9,51                             | 6244,76                           | 1,50   | 20,00                               |
| 1993 | 8,14                           | 39,38                                       | 9,57                             | 5979,53                           | 1,50   | 20,00                               |
| 1994 | 8,07                           | 39,30                                       | 9,64                             | 6228,28                           | 1,38   | 24,77                               |
| 1995 | 7,99                           | 39,20                                       | 9,72                             | 7143,29                           | 1,25   | 23,33                               |
| 1996 | 7,91                           | 39,08                                       | 9,81                             | 7806,35                           | 1,25   | 23,33                               |
| 1997 | 7,84                           | 38,94                                       | 9,89                             | 7954,64                           | 1,21   | 22,58                               |
| 1998 | 7,80                           | 38,78                                       | 9,97                             | 8095,33                           | 1,21   | 22,58                               |
| 1999 | 7,80                           | 38,57                                       | 10,03                            | 7693,42                           | 1,29   | 24,14                               |
| 2000 | 7,85                           | 38,32                                       | 10,07                            | 8033,32                           | 1,21   | 22,58                               |
| 2001 | 7,96                           | 38,04                                       | 10,09                            | 8800,79                           | 1,21   | 22,58                               |
| 2002 | 8,11                           | 37,69                                       | 10,10                            | 9169,46                           | 1,21   | 22,58                               |
| 2003 | 8,29                           | 37,27                                       | 10,09                            | 9933,56                           | 1,21   | 22,58                               |
| 2004 | 8,49                           | 36,78                                       | 10,08                            | 10653,78                          | 1,00   | 25,64                               |
| 2005 | 8,71                           | 36,22                                       | 10,07                            | 10782,45                          | 1,00   | 20,73                               |
| 2006 | 8,95                           | 35,59                                       | 10,06                            | 10970,65                          | 1,00   | 20,00                               |
| 2007 | 9,19                           | 34,89                                       | 10,04                            | 11383,24                          | 1,08   | 22,31                               |
| 2008 | 9,42                           | 34,14                                       | 10,02                            | 11030,69                          | 1,06   | 22,25                               |
| 2009 | 9,65                           | 33,36                                       | 10,01                            | 11351,79                          | 1,03   | 22,19                               |
| 2010 | 9,87                           | 32,56                                       | 9,99                             | 11931,70                          | 1,03   | 21,50                               |

## 7.1 Appendix A

Appendix A

Historical Data (1980-2010)

| Year | Construction Sector (% of Energy use) | Trade and Public services Sector (% of Energy use) | Transportation Sector (% of Energy use) | Energy Intensity (kToe/BUSD) | Energy Intensity in Agriculture, Fishing and Mining Sector (kToe/BUSD) | Energy Intensity in Industrial Sector (kToe/BUSD) |
|------|---------------------------------------|--|---|------------------------------|--|---|
| 1980 | 11,00                                 | 33,00  | 36,00                                   | 110,97                       | 11,61  | 133,47  |
| 1981 | 10,00                                 | 32,00  | 37,00                                   | 112,20                       | 11,75  | 142,82  |
| 1982 | 9,00                                  | 31,00  | 38,00                                   | 121,82                       | 17,01  | 155,01  |
| 1983 | 8,00                                  | 30,00  | 39,00                                   | 116,52                       | 16,28  | 156,45  |
| 1984 | 7,00                                  | 29,00  | 40,00                                   | 121,01                       | 21,14  | 162,43  |
| 1985 | 7,00                                  | 29,00  | 40,00                                   | 118,97                       | 20,79  | 159,63  |
| 1986 | 7,00                                  | 29,00  | 40,00                                   | 113,83                       | 19,90  | 152,71  |
| 1987 | 7,00                                  | 29,00  | 40,00                                   | 118,82                       | 20,77  | 159,39  |
| 1988 | 7,00                                  | 29,00  | 40,00                                   | 115,16                       | 20,13  | 154,51  |
| 1989 | 2,00                                  | 29,00  | 47,00                                   | 108,50                       | 7,58   | 153,33  |
| 1990 | 1,50                                  | 27,00  | 50,00                                   | 107,96                       | 5,65   | 152,72  |
| 1991 | 1,50                                  | 27,00  | 50,00                                   | 106,47                       | 5,56   | 150,86  |
| 1992 | 1,50                                  | 27,00  | 50,00                                   | 105,27                       | 5,49   | 149,50  |
| 1993 | 1,50                                  | 27,00  | 50,00                                   | 100,51                       | 5,22   | 143,19  |
| 1994 | 1,38                                  | 24,77  | 47,71                                   | 99,99                        | 4,74   | 177,20  |
| 1995 | 1,25                                  | 26,67  | 47,50                                   | 112,70                       | 4,83   | 189,15  |
| 1996 | 1,25                                  | 26,67  | 47,50                                   | 120,27                       | 5,12   | 203,03  |
| 1997 | 1,21                                  | 25,81  | 49,19                                   | 117,78                       | 4,81   | 193,68  |
| 1998 | 1,21                                  | 25,81  | 49,19                                   | 117,39                       | 4,76   | 194,46  |
| 1999 | 1,29                                  | 27,59  | 45,69                                   | 119,06                       | 5,12   | 212,58  |
| 2000 | 1,21                                  | 25,81  | 49,19                                   | 120,93                       | 4,82   | 203,76  |
| 2001 | 1,21                                  | 25,81  | 49,19                                   | 125,77                       | 4,97   | 213,56  |
| 2002 | 1,21                                  | 25,81  | 49,19                                   | 124,67                       | 4,88   | 212,88  |
| 2003 | 1,21                                  | 25,81  | 49,19                                   | 130,77                       | 5,08   | 223,85  |
| 2004 | 1,00                                  | 22,36  | 50,00                                   | 128,88                       | 4,10   | 250,14  |
| 2005 | 1,00                                  | 23,00  | 54,27                                   | 123,35                       | 3,89   | 192,39  |
| 2006 | 1,00                                  | 23,00  | 55,00                                   | 119,81                       | 3,75   | 178,44  |
| 2007 | 1,08                                  | 23,99  | 51,53                                   | 121,84                       | 4,09   | 199,59  |
| 2008 | 1,06                                  | 23,63  | 52,00                                   | 110,09                       | 3,58   | 176,95  |
| 2009 | 1,03                                  | 23,20  | 52,56                                   | 112,89                       | 3,53   | 177,71  |
| 2010 | 1,03                                  | 23,36  | 53,07                                   | 114,55                       | 3,57   | 171,61  |

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Appendix A

Historical Data (1980-2010)

| Year | Energy Intensity in Construction Sector (kToe/BUSD) | Energy Intensity in Trade and Public services Sector (kToe/BUSD) | Energy Intensity in Transportation Sector (kToe/BUSD) | Fossil fuel energy consumption (% of total) | Alternative and nuclear energy (% of total energy use) | Combustible renewables and waste (% of total energy) |
|------|---|--|---|---|--|--|
| 1980 | 146,20  | 92,80  | 425,44  | 79,04                                       | 1,22   | 19,74  |
| 1981 | 134,34  | 90,96  | 442,32  | 78,57                                       | 1,95   | 19,49  |
| 1982 | 131,24  | 95,66  | 493,44  | 78,09                                       | 2,68   | 19,24  |
| 1983 | 111,55  | 88,53  | 484,61  | 77,63                                       | 3,40   | 18,96  |
| 1984 | 101,35  | 88,86  | 516,34  | 77,24                                       | 4,11   | 18,65  |
| 1985 | 99,65   | 87,34  | 507,71  | 76,94                                       | 4,78   | 18,28  |
| 1986 | 95,38   | 83,55  | 485,73  | 76,76                                       | 5,39   | 17,85  |
| 1987 | 99,65   | 87,21  | 506,83  | 76,73                                       | 5,93   | 17,35  |
| 1988 | 96,72   | 84,52  | 490,72  | 76,85                                       | 6,38   | 16,76  |
| 1989 | 26,10   | 79,64  | 542,34  | 77,15                                       | 6,76   | 16,10  |
| 1990 | 19,54   | 73,80  | 572,58  | 77,58                                       | 7,05   | 15,37  |
| 1991 | 19,37   | 72,83  | 562,62  | 78,13                                       | 7,27   | 14,61  |
| 1992 | 19,26   | 72,07  | 553,62  | 78,74                                       | 7,42   | 13,83  |
| 1993 | 18,53   | 68,90  | 525,34  | 79,42                                       | 7,51   | 13,06  |
| 1994 | 17,05   | 63,02  | 494,89  | 80,15                                       | 7,55   | 12,30  |
| 1995 | 17,63   | 76,67  | 550,55  | 80,92                                       | 7,53   | 11,55  |
| 1996 | 19,02   | 82,07  | 582,37  | 81,68                                       | 7,48   | 10,85  |
| 1997 | 18,17   | 78,05  | 585,73  | 82,41                                       | 7,41   | 10,18  |
| 1998 | 18,21   | 78,12  | 579,47  | 83,11                                       | 7,33   | 9,56   |
| 1999 | 19,75   | 85,15  | 542,60  | 83,78                                       | 7,23   | 8,99   |
| 2000 | 18,63   | 81,43  | 590,85  | 84,44                                       | 7,12   | 8,44   |
| 2001 | 19,11   | 85,33  | 613,16  | 85,09                                       | 6,99   | 7,92   |
| 2002 | 18,59   | 85,36  | 607,35  | 85,70                                       | 6,87   | 7,42   |
| 2003 | 19,08   | 90,54  | 637,30  | 86,27                                       | 6,77   | 6,96   |
| 2004 | 15,17   | 78,35  | 639,02  | 86,74                                       | 6,71   | 6,55   |
| 2005 | 14,16   | 78,33  | 664,68  | 87,12                                       | 6,69   | 6,19   |
| 2006 | 13,39   | 77,43  | 655,30  | 87,40                                       | 6,72   | 5,88   |
| 2007 | 14,38   | 83,78  | 625,34  | 87,61                                       | 6,79   | 5,61   |
| 2008 | 12,37   | 76,20  | 571,09  | 87,77                                       | 6,88   | 5,35   |
| 2009 | 12,03   | 78,50  | 592,86  | 87,92                                       | 6,97   | 5,11   |
| 2010 | 12,00   | 82,19  | 608,43  | 88,08                                       | 7,06   | 4,86   |

## 7.1 Appendix A

Appendix A

Historical Data (1980-2010)

| Year | Gaseous fuel consumption (% Total Fossil Energy) | Solid fuel consumption (% Total Fossil Energy ) | Liquid fuel consumption (% Total Fossil Energy) | CO2int (kt/kToe) | CO2pc- (kgCO2) | CO2-Total |
|------|--|---|---|------------------|----------------|-----------|
| 1980 | 0,01   | 0,00  | 0,78  | 2,36             | 1491,63        | 11870,08  |
| 1981 | 0,01   | 0,00  | 0,78  | 2,89             | 1855,70        | 15177,71  |
| 1982 | 0,01   | 0,00  | 0,77  | 3,10             | 2095,11        | 17605,27  |
| 1983 | 0,01   | 0,00  | 0,77  | 3,39             | 2077,87        | 17931,63  |
| 1984 | 0,01   | 0,00  | 0,77  | 3,40             | 2188,00        | 19383,76  |
| 1985 | 0,01   | 0,00  | 0,76  | 2,98             | 1893,89        | 17216,57  |
| 1986 | 0,01   | 0,00  | 0,76  | 2,23             | 1372,61        | 12797,83  |
| 1987 | 0,01   | 0,00  | 0,76  | 2,26             | 1391,91        | 13303,88  |
| 1988 | 0,01   | 0,00  | 0,76  | 2,37             | 1493,36        | 14624,00  |
| 1989 | 0,01   | 0,00  | 0,77  | 2,91             | 1706,03        | 17106,56  |
| 1990 | 0,01   | 0,00  | 0,77  | 2,26             | 1318,76        | 13531,23  |
| 1991 | 0,01   | 0,00  | 0,77  | 2,15             | 1272,01        | 13347,88  |
| 1992 | 0,01   | 0,00  | 0,78  | 3,10             | 1806,27        | 19372,76  |
| 1993 | 0,01   | 0,00  | 0,79  | 3,53             | 1928,05        | 21118,25  |
| 1994 | 0,01   | 0,00  | 0,80  | 1,71             | 952,39         | 10641,63  |
| 1995 | 0,01   | 0,00  | 0,80  | 2,74             | 1717,46        | 19552,44  |
| 1996 | 0,01   | 0,00  | 0,81  | 2,64             | 1776,51        | 20579,20  |
| 1997 | 0,01   | 0,00  | 0,82  | 1,91             | 1289,09        | 15177,71  |
| 1998 | 0,01   | 0,00  | 0,82  | 2,36             | 1594,10        | 19064,73  |
| 1999 | 0,01   | 0,00  | 0,83  | 2,37             | 1503,85        | 18268,99  |
| 2000 | 0,01   | 0,00  | 0,84  | 2,19             | 1422,54        | 17561,26  |
| 2001 | 0,01   | 0,00  | 0,84  | 2,27             | 1592,77        | 19992,48  |
| 2002 | 0,01   | 0,00  | 0,85  | 2,29             | 1644,02        | 20989,91  |
| 2003 | 0,01   | 0,00  | 0,86  | 2,26             | 1728,47        | 22449,37  |
| 2004 | 0,01   | 0,00  | 0,86  | 2,28             | 1838,65        | 24286,54  |
| 2005 | 0,01   | 0,00  | 0,86  | 2,38             | 1912,10        | 25672,67  |
| 2006 | 0,01   | 0,00  | 0,87  | 2,25             | 1810,69        | 24697,25  |
| 2007 | 0,01   | 0,00  | 0,87  | 2,25             | 1846,25        | 25569,99  |
| 2008 | 0,01   | 0,00  | 0,87  | 2,22             | 1744,19        | 24517,56  |
| 2009 | 0,01   | 0,00  | 0,87  | 2,28             | 1815,81        | 25896,35  |
| 2010 | 0,01   | 0,00  | 0,87  | 2,35             | 1941,11        | 28078,22  |

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Appendix A

Historical Data for Economic Model (1980-2010)

| Indicator Name | GDP (USD-2005) | Investment (% GDP) | Trade balance (% GDP) | Consumption (% GDP) | Energy Use (ktoe) | Energy import(% Energy Use) | Renewables (% Energy Use) |
|----------------|----------------|--------------------|-----------------------|---------------------|-------------------|-----------------------------|---------------------------|
| 1980           | 49062851650    | 25,37              | -0,73                 | 57,06               | 5032,22           | -133,54                     | 19,50                     |
| 1981           | 51816682846    | 25,83              | -0,68                 | 58,98               | 5259,13           | -129,14                     | 18,05                     |
| 1982           | 52135275313    | 21,76              | -3,10                 | 64,00               | 5677,75           | -110,26                     | 18,60                     |
| 1983           | 51959647851    | 20,67              | 0,24                  | 63,70               | 5293,44           | -157,95                     | 19,91                     |
| 1984           | 53323730597    | 18,78              | 1,69                  | 63,32               | 5708,26           | -161,81                     | 19,22                     |
| 1985           | 55422020148    | 18,95              | 3,65                  | 62,64               | 5775,48           | -176,65                     | 18,37                     |
| 1986           | 57342272613    | 23,57              | -1,85                 | 62,67               | 5750,92           | -185,70                     | 17,56                     |
| 1987           | 57193699525    | 25,41              | -7,00                 | 66,31               | 5874,32           | -79,71                      | 18,40                     |
| 1988           | 60562675687    | 26,11              | -4,65                 | 62,27               | 6169,54           | -177,34                     | 18,01                     |
| 1989           | 61171801723    | 27,09              | -4,55                 | 63,78               | 5869,94           | -173,12                     | 18,35                     |
| 1990           | 63422871451    | 24,07              | 0,93                  | 62,69               | 6021,20           | -173,60                     | 13,71                     |
| 1991           | 66144564024    | 22,05              | 2,15                  | 64,46               | 6343,80           | -172,47                     | 13,55                     |
| 1992           | 67543065602    | 22,67              | 3,46                  | 63,93               | 6499,21           | -182,42                     | 12,71                     |
| 1993           | 68875837583    | 21,08              | -3,10                 | 71,42               | 5992,01           | -228,60                     | 13,87                     |
| 1994           | 71808743259    | 21,29              | -3,22                 | 70,98               | 6380,95           | -236,77                     | 12,26                     |
| 1995           | 73426270226    | 19,82              | -3,34                 | 72,30               | 7162,49           | -208,93                     | 10,89                     |
| 1996           | 74697827835    | 18,54              | 0,33                  | 70,26               | 7787,15           | -181,13                     | 10,21                     |
| 1997           | 77930648806    | 20,31              | -1,95                 | 70,37               | 7888,39           | -178,55                     | 8,35                      |
| 1998           | 80476276364    | 24,00              | -7,61                 | 72,52               | 8320,97           | -157,66                     | 9,54                      |
| 1999           | 76662195157    | 19,63              | 3,55                  | 65,05               | 7801,91           | -174,85                     | 10,28                     |
| 2000           | 77499194203    | 21,28              | 4,79                  | 64,58               | 8034,28           | -181,94                     | 8,68                      |
| 2001           | 80611275017    | 22,35              | -4,30                 | 72,50               | 8800,79           | -161,21                     | 8,29                      |
| 2002           | 83913738916    | 23,70              | -6,39                 | 72,86               | 9206,90           | -141,14                     | 7,91                      |
| 2003           | 86198607096    | 19,59              | -2,04                 | 71,74               | 9927,80           | -138,81                     | 6,49                      |
| 2004           | 93276392755    | 20,20              | -1,56                 | 70,47               | 10349,74          | -183,17                     | 5,59                      |
| 2005           | 98211934236    | 21,64              | -0,86                 | 68,51               | 10986,88          | -167,77                     | 5,21                      |
| 2006           | 102536722721   | 22,46              | 0,96                  | 65,98               | 10922,56          | -173,64                     | 5,30                      |
| 2007           | 104782342544   | 22,70              | 1,28                  | 65,09               | 11332,31          | -155,15                     | 6,42                      |
| 2008           | 111443492905   | 26,39              | 0,27                  | 61,51               | 11027,43          | -158,87                     | 5,93                      |
| 2009           | 112074810922   | 25,64              | -1,61                 | 62,24               | 11461,86          | -138,39                     | 5,37                      |
| 2010           | 115268445163   | 26,98              | -3,98                 | 63,88               | 12096,90          | -126,22                     | 5,35                      |

## **7.2 Appendix B**

Appendix B presents the outcomes of the model in the period 1980-2010. We use this results in the model validation.

## 7. APPENDIX

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Appendix B

Model Outcomes (1980-2010)

| Year | Population<br>(Total) | GDP, PPP (constant<br>2005 international \$) | GDPpc<br>(USD) | Energy use<br>(kt of oil<br>equivalent) |
|------|-----------------------|--|----------------|---|
| 1980 | 7946890               | 44600000000                                  | 5612,26        | 5189,16                                 |
| 1981 | 8178140               | 45628900000                                  | 5579,37        | 5307,11                                 |
| 1982 | 8409590               | 46418100000                                  | 5519,66        | 5394,86                                 |
| 1983 | 8640850               | 47268300000                                  | 5470,33        | 5482,41                                 |
| 1984 | 8872430               | 48192300000                                  | 5431,69        | 5568,89                                 |
| 1985 | 9104000               | 49206000000                                  | 5404,89        | 5653,96                                 |
| 1986 | 9336150               | 50342400000                                  | 5392,21        | 5741,98                                 |
| 1987 | 9567680               | 51575500000                                  | 5390,59        | 5831,78                                 |
| 1988 | 9798260               | 52882700000                                  | 5397,15        | 5923,81                                 |
| 1989 | 10028500              | 54241600000                                  | 5408,73        | 6021,75                                 |
| 1990 | 10256200              | 55614600000                                  | 5422,55        | 6129,50                                 |
| 1991 | 10481800              | 56973300000                                  | 5435,45        | 6250,26                                 |
| 1992 | 10704000              | 58289300000                                  | 5445,56        | 6392,86                                 |
| 1993 | 10923500              | 59564900000                                  | 5452,94        | 6564,17                                 |
| 1994 | 11138600              | 60839900000                                  | 5462,06        | 6766,50                                 |
| 1995 | 11350300              | 62152800000                                  | 5475,89        | 7001,93                                 |
| 1996 | 11559100              | 63537300000                                  | 5496,72        | 7266,77                                 |
| 1997 | 11764900              | 65219500000                                  | 5543,58        | 7577,54                                 |
| 1998 | 11969600              | 66634200000                                  | 5566,96        | 7862,07                                 |
| 1999 | 12173100              | 68488600000                                  | 5626,24        | 8196,14                                 |
| 2000 | 12377600              | 70607300000                                  | 5704,46        | 8546,77                                 |
| 2001 | 12583000              | 73059600000                                  | 5806,19        | 8920,27                                 |
| 2002 | 12789400              | 75827500000                                  | 5928,93        | 9313,19                                 |
| 2003 | 12997900              | 78877000000                                  | 6068,46        | 9706,86                                 |
| 2004 | 13207100              | 82183000000                                  | 6222,62        | 10092,60                                |
| 2005 | 13417100              | 85680400000                                  | 6385,90        | 10459,40                                |
| 2006 | 13627800              | 89311900000                                  | 6553,66        | 10802,60                                |
| 2007 | 13837600              | 93015000000                                  | 6721,88        | 11118,30                                |
| 2008 | 14048000              | 96745800000                                  | 6886,81        | 11406,70                                |
| 2009 | 14258700              | 100509000000                                 | 7048,96        | 11677,80                                |
| 2010 | 14468300              | 104288000000                                 | 7208,06        | 11931,70                                |

## 7.2 Appendix B

Appendix B

Model Outcomes (1980-2010)

| Year | Energy Intensity (kToe/BUSD) | Energy Intensity in Agriculture, Fishing and Mining Sector (kToe/BUSD) | Energy Intensity in Industrial Sector (kToe/BUSD) | Energy Intensity in Construction Sector (kToe/BUSD) | Energy Intensity in Trade and Public services Sector (kToe/BUSD) | Energy Intensity in Transportation Sector (kToe/BUSD) |
|------|------------------------------|--|---|---|--|---|
| 1980 | 116,35                       | 15,79  | 144,16  | 147,11  | 94,46  | 446,10  |
| 1981 | 116,31                       | 16,17  | 146,25  | 136,83  | 92,83  | 457,44  |
| 1982 | 116,22                       | 16,51  | 148,24  | 126,54  | 91,18  | 468,55  |
| 1983 | 115,98                       | 16,72  | 149,98  | 116,21  | 89,49  | 479,09  |
| 1984 | 115,56                       | 16,72  | 151,40  | 105,88  | 87,74  | 488,91  |
| 1985 | 114,90                       | 16,43  | 152,51  | 95,52   | 85,96  | 497,91  |
| 1986 | 114,06                       | 15,80  | 153,39  | 85,05   | 84,15  | 506,32  |
| 1987 | 113,07                       | 14,84  | 154,24  | 74,45   | 82,33  | 514,37  |
| 1988 | 112,02                       | 13,59  | 155,22  | 63,82   | 80,54  | 522,09  |
| 1989 | 111,02                       | 12,14  | 156,60  | 53,49   | 78,84  | 529,45  |
| 1990 | 110,21                       | 10,66  | 158,59  | 44,13   | 77,34  | 536,02  |
| 1991 | 109,71                       | 9,28   | 161,38  | 35,70   | 76,16  | 541,65  |
| 1992 | 109,67                       | 8,06   | 165,11  | 29,32   | 75,40  | 546,52  |
| 1993 | 110,20                       | 7,03   | 169,83  | 25,09   | 75,11  | 551,00  |
| 1994 | 111,22                       | 6,21   | 175,44  | 21,88   | 75,31  | 555,41  |
| 1995 | 112,66                       | 5,58   | 181,48  | 19,43   | 75,95  | 560,24  |
| 1996 | 114,37                       | 5,13   | 187,52  | 17,98   | 76,85  | 565,67  |
| 1997 | 116,19                       | 4,81   | 193,31  | 17,24   | 77,85  | 571,61  |
| 1998 | 117,99                       | 4,60   | 198,76  | 16,98   | 78,88  | 578,13  |
| 1999 | 119,67                       | 4,46   | 203,73  | 16,96   | 79,84  | 585,24  |
| 2000 | 121,05                       | 4,37   | 207,99  | 16,95   | 80,37  | 593,08  |
| 2001 | 122,10                       | 4,31   | 211,19  | 16,88   | 80,65  | 601,27  |
| 2002 | 122,82                       | 4,26   | 212,99  | 16,69   | 80,93  | 608,90  |
| 2003 | 123,06                       | 4,19   | 213,00  | 16,38   | 80,98  | 615,36  |
| 2004 | 122,81                       | 4,11   | 211,26  | 15,95   | 80,83  | 619,97  |
| 2005 | 122,07                       | 4,02   | 207,54  | 15,42   | 80,58  | 622,40  |
| 2006 | 120,95                       | 3,93   | 202,41  | 14,83   | 80,32  | 622,52  |
| 2007 | 119,53                       | 3,83   | 196,30  | 14,21   | 80,10  | 620,65  |
| 2008 | 117,90                       | 3,72   | 189,47  | 13,56   | 79,92  | 617,48  |
| 2009 | 116,19                       | 3,61   | 182,31  | 12,91   | 79,80  | 613,91  |
| 2010 | 114,41                       | 3,50   | 175,07  | 12,28   | 79,69  | 610,16  |

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Appendix B

Model Outcomes (1980-2010)

| Year | CO2 in Agriculture, Fishing and Mining Sector (kTons) | CO2 in Industrial Sector (kTons) | CO2 in Construction Sector (kTons) | CO2 in Trade and Public services Sector (kTons) | CO2 in Transportation Sector (kTons) |
|------|---|----------------------------------|------------------------------------|---|--------------------------------------|
| 1980 | 485,28  | 2185,27                          | 1317,22                            | 3997,66   | 4496,64                              |
| 1981 | 505,32  | 2255,78                          | 1246,48                            | 3996,49   | 4686,24                              |
| 1982 | 521,56  | 2313,32                          | 1166,17                            | 3971,07   | 4851,44                              |
| 1983 | 534,73  | 2370,88                          | 1084,86                            | 3947,20   | 5020,04                              |
| 1984 | 542,41  | 2428,98                          | 1003,00                            | 3927,37   | 5194,91                              |
| 1985 | 541,99  | 2489,66                          | 920,33                             | 3914,81   | 5379,86                              |
| 1986 | 531,98  | 2556,75                          | 836,19                             | 3912,76   | 5584,70                              |
| 1987 | 511,59  | 2633,02                          | 748,96                             | 3920,88   | 5812,43                              |
| 1988 | 481,03  | 2720,72                          | 658,32                             | 3938,73   | 6065,02                              |
| 1989 | 442,62  | 2823,87                          | 566,64                             | 3968,50   | 6342,93                              |
| 1990 | 401,21  | 2944,99                          | 480,26                             | 4011,97   | 6638,37                              |
| 1991 | 360,69  | 3085,62                          | 398,80                             | 4072,12   | 6945,41                              |
| 1992 | 323,75  | 3246,90                          | 335,63                             | 4152,17   | 7261,30                              |
| 1993 | 292,20  | 3429,99                          | 293,74                             | 4255,38   | 7591,33                              |
| 1994 | 267,18  | 3634,84                          | 261,67                             | 4387,36   | 7947,47                              |
| 1995 | 249,07  | 3855,70                          | 237,24                             | 4549,73   | 8340,51                              |
| 1996 | 237,45  | 4085,56                          | 224,09                             | 4733,95   | 8766,71                              |
| 1997 | 232,27  | 4332,16                          | 220,62                             | 4947,90   | 9251,69                              |
| 1998 | 230,60  | 4554,32                          | 222,59                             | 5141,78   | 9713,00                              |
| 1999 | 233,81  | 4795,49                          | 230,18                             | 5361,55   | 10248,28                             |
| 2000 | 240,17  | 5041,18                          | 240,73                             | 5570,74   | 10837,63                             |
| 2001 | 248,87  | 5294,65                          | 253,30                             | 5783,42   | 11481,21                             |
| 2002 | 258,86  | 5549,27                          | 266,76                             | 6010,27   | 12163,21                             |
| 2003 | 269,14  | 5795,00                          | 280,11                             | 6224,97   | 12865,58                             |
| 2004 | 279,11  | 6029,38                          | 292,60                             | 6422,21   | 13566,68                             |
| 2005 | 288,47  | 6239,25                          | 303,91                             | 6601,09   | 14242,85                             |
| 2006 | 297,11  | 6427,98                          | 313,78                             | 6760,10   | 14874,22                             |
| 2007 | 304,96  | 6597,89                          | 322,07                             | 6898,42   | 15455,44                             |
| 2008 | 311,80  | 6746,53                          | 328,60                             | 7018,09   | 15997,75                             |
| 2009 | 317,95  | 6877,05                          | 333,62                             | 7124,76   | 16526,24                             |
| 2010 | 323,44  | 6987,95                          | 337,23                             | 7218,57   | 17045,04                             |

## 7.2 Appendix B

Appendix B

Model Outcomes (1980-2010)

| Year | CO2int<br>(kt/kToe) | CO2pc-<br>(kgCO2) | CO2-Total |
|------|---------------------|-------------------|-----------|
| 1980 | 2,41                | 1570,69           | 12482,07  |
| 1981 | 2,39                | 1551,73           | 12690,30  |
| 1982 | 2,38                | 1524,87           | 12823,56  |
| 1983 | 2,36                | 1499,59           | 12957,71  |
| 1984 | 2,35                | 1476,11           | 13096,67  |
| 1985 | 2,34                | 1455,04           | 13246,64  |
| 1986 | 2,34                | 1437,68           | 13422,38  |
| 1987 | 2,34                | 1424,26           | 13626,89  |
| 1988 | 2,34                | 1414,93           | 13863,82  |
| 1989 | 2,35                | 1410,43           | 14144,54  |
| 1990 | 2,36                | 1411,52           | 14476,80  |
| 1991 | 2,38                | 1417,95           | 14862,65  |
| 1992 | 2,40                | 1431,22           | 15319,74  |
| 1993 | 2,42                | 1452,16           | 15862,64  |
| 1994 | 2,44                | 1481,20           | 16498,53  |
| 1995 | 2,46                | 1518,22           | 17232,24  |
| 1996 | 2,48                | 1561,35           | 18047,77  |
| 1997 | 2,51                | 1613,67           | 18984,63  |
| 1998 | 2,53                | 1659,40           | 19862,30  |
| 1999 | 2,55                | 1714,38           | 20869,31  |
| 2000 | 2,57                | 1771,78           | 21930,44  |
| 2001 | 2,59                | 1832,75           | 23061,44  |
| 2002 | 2,60                | 1895,97           | 24248,36  |
| 2003 | 2,62                | 1956,84           | 25434,81  |
| 2004 | 2,63                | 2013,31           | 26589,98  |
| 2005 | 2,65                | 2062,71           | 27675,57  |
| 2006 | 2,65                | 2104,02           | 28673,19  |
| 2007 | 2,66                | 2137,57           | 29578,78  |
| 2008 | 2,67                | 2164,21           | 30402,77  |
| 2009 | 2,67                | 2186,71           | 31179,62  |
| 2010 | 2,67                | 2205,67           | 31912,23  |

## 7. APPENDIX

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Appendix B

Outcomes of Economic Model (1980-2010)

| Year | QT     | IT    | TBT   | CHT   | EIMPT     | RNT     |
|------|--------|-------|-------|-------|-----------|---------|
| 1980 | 48,96  | 11,52 | -0,27 | 28,96 | -6502,31  | 1057,57 |
| 1981 | 50,27  | 11,71 | -0,33 | 30,18 | -6949,82  | 1113,64 |
| 1982 | 51,57  | 11,91 | -0,39 | 31,39 | -7399,51  | 1167,91 |
| 1983 | 52,89  | 12,14 | -0,46 | 32,58 | -7851,97  | 1219,57 |
| 1984 | 54,25  | 12,43 | -0,53 | 33,78 | -8296,42  | 1266,46 |
| 1985 | 55,67  | 12,79 | -0,63 | 34,99 | -8727,15  | 1306,45 |
| 1986 | 57,14  | 13,18 | -0,75 | 36,24 | -9147,86  | 1338,32 |
| 1987 | 58,66  | 13,58 | -0,85 | 37,54 | -9576,98  | 1361,30 |
| 1988 | 60,25  | 13,95 | -0,90 | 38,91 | -10048,30 | 1374,62 |
| 1989 | 61,88  | 14,26 | -0,91 | 40,36 | -10546,61 | 1379,32 |
| 1990 | 63,56  | 14,49 | -0,89 | 41,91 | -11065,68 | 1377,25 |
| 1991 | 65,26  | 14,67 | -0,88 | 43,53 | -11595,39 | 1371,02 |
| 1992 | 66,97  | 14,81 | -0,91 | 45,21 | -12119,53 | 1362,52 |
| 1993 | 68,67  | 14,94 | -0,98 | 46,89 | -12615,32 | 1353,88 |
| 1994 | 70,38  | 15,08 | -1,05 | 48,53 | -13057,34 | 1347,09 |
| 1995 | 72,08  | 15,26 | -1,12 | 50,09 | -13431,03 | 1343,37 |
| 1996 | 73,79  | 15,49 | -1,16 | 51,56 | -13742,29 | 1343,43 |
| 1997 | 75,53  | 15,79 | -1,19 | 52,95 | -14012,40 | 1346,34 |
| 1998 | 77,36  | 16,17 | -1,19 | 54,29 | -14266,23 | 1351,19 |
| 1999 | 79,31  | 16,62 | -1,17 | 55,64 | -14529,42 | 1355,36 |
| 2000 | 81,49  | 17,17 | -1,17 | 57,07 | -14816,08 | 1356,80 |
| 2001 | 83,97  | 17,85 | -1,19 | 58,61 | -15131,48 | 1354,76 |
| 2002 | 86,76  | 18,66 | -1,20 | 60,23 | -15478,90 | 1350,15 |
| 2003 | 89,86  | 19,61 | -1,16 | 61,88 | -15852,16 | 1344,46 |
| 2004 | 93,23  | 20,73 | -1,11 | 63,53 | -16220,26 | 1340,32 |
| 2005 | 96,80  | 22,01 | -1,06 | 65,14 | -16531,47 | 1339,58 |
| 2006 | 100,49 | 23,43 | -1,06 | 66,71 | -16761,46 | 1342,91 |
| 2007 | 104,25 | 24,97 | -1,12 | 68,24 | -16904,88 | 1348,46 |
| 2008 | 108,04 | 26,57 | -1,27 | 69,76 | -16978,46 | 1352,48 |
| 2009 | 111,83 | 28,21 | -1,47 | 71,27 | -17005,68 | 1352,29 |
| 2010 | 115,61 | 29,86 | -1,70 | 72,80 | -17015,43 | 1348,21 |

## **7.3 Appendix C**

Appendix C presents the outcomes of the model in the forecast period 2011-2025 for the four considered scenarios. We use these results in both decomposition analysis (Chapter 4) and EKC study (Chapter 5).

## 7. APPENDIX

Appendix C

Model Outcomes (2011-2025)

| Year | Pop.     | GDP, PPP (constant 2005 international \$) |              |              |              |
|------|----------|---|--------------|--------------|--------------|
|      |          | BS  | SC-2         | SC-3         | SC-4         |
| 2011 | 14656400 | 107814000000                              | 111344000000 | 111344000000 | 111344000000 |
| 2012 | 14846900 | 111316000000                              | 118476000000 | 117873000000 | 117994000000 |
| 2013 | 15039900 | 114929000000                              | 126125000000 | 124847000000 | 125113000000 |
| 2014 | 15235500 | 118650000000                              | 134295000000 | 132216000000 | 132664000000 |
| 2015 | 15433500 | 122481000000                              | 143024000000 | 140001000000 | 140674000000 |
| 2016 | 15634200 | 126426000000                              | 152350000000 | 148216000000 | 149166000000 |
| 2017 | 15837400 | 130491000000                              | 162312000000 | 156877000000 | 158163000000 |
| 2018 | 16043300 | 134678000000                              | 172953000000 | 165996000000 | 167691000000 |
| 2019 | 16251800 | 138992000000                              | 184319000000 | 175587000000 | 177773000000 |
| 2020 | 16463100 | 143437000000                              | 196459000000 | 185661000000 | 188436000000 |
| 2021 | 16677100 | 148018000000                              | 209424000000 | 196228000000 | 199704000000 |
| 2022 | 16893900 | 152738000000                              | 223270000000 | 207294000000 | 211603000000 |
| 2023 | 17113600 | 157604000000                              | 238054000000 | 218865000000 | 224159000000 |
| 2024 | 17336000 | 162618000000                              | 253841000000 | 230944000000 | 237397000000 |
| 2025 | 17561400 | 167787000000                              | 270696000000 | 243531000000 | 251341000000 |

Appendix C

Model Outcomes (2011-2025)

| Year | GDPpc (USD) |          |          |          |  |  |
|------|-------------|----------|----------|----------|--|--|
|      | BS          | SC-2     | SC-3     | SC-4     |  |  |
| 2011 | 7356,10     | 7596,96  | 7596,96  | 7596,96  |  |  |
| 2012 | 7497,56     | 7979,86  | 7939,22  | 7947,38  |  |  |
| 2013 | 7641,61     | 8386,01  | 8301,04  | 8318,73  |  |  |
| 2014 | 7787,73     | 8814,66  | 8678,19  | 8707,59  |  |  |
| 2015 | 7936,02     | 9267,13  | 9071,22  | 9114,84  |  |  |
| 2016 | 8086,55     | 9744,68  | 9480,29  | 9541,02  |  |  |
| 2017 | 8239,41     | 10248,60 | 9905,47  | 9986,69  |  |  |
| 2018 | 8394,66     | 10780,40 | 10346,80 | 10452,40 |  |  |
| 2019 | 8552,38     | 11341,40 | 10804,20 | 10938,70 |  |  |
| 2020 | 8712,62     | 11933,30 | 11277,40 | 11445,90 |  |  |
| 2021 | 8875,48     | 12557,50 | 11766,30 | 11974,70 |  |  |
| 2022 | 9041,00     | 13216,00 | 12270,30 | 12525,40 |  |  |
| 2023 | 9209,28     | 13910,30 | 12789,00 | 13098,30 |  |  |
| 2024 | 9380,36     | 14642,40 | 13321,60 | 13693,80 |  |  |
| 2025 | 9554,32     | 15414,20 | 13867,40 | 14312,10 |  |  |

## 7.3 Appendix C

Appendix C

Model Outcomes (2011-2025)

| Year | Agriculture, Fishing and Mining Sector (% of GDP) |       |       |       |  |  |
|------|---|-------|-------|-------|--|--|
|      | BS  | SC-2  | SC-3  | SC-4  |  |  |
| 2011 | 33,38   | 32,65 | 32,65 | 32,65 |  |  |
| 2012 | 33,53   | 32,08 | 32,08 | 32,08 |  |  |
| 2013 | 33,68   | 31,50 | 31,50 | 31,50 |  |  |
| 2014 | 33,83   | 30,92 | 30,92 | 30,92 |  |  |
| 2015 | 33,97   | 30,33 | 30,33 | 30,33 |  |  |
| 2016 | 34,11   | 29,74 | 29,74 | 29,74 |  |  |
| 2017 | 34,25   | 29,14 | 29,14 | 29,14 |  |  |
| 2018 | 34,39   | 28,53 | 28,53 | 28,53 |  |  |
| 2019 | 34,52   | 27,92 | 27,92 | 27,92 |  |  |
| 2020 | 34,66   | 27,30 | 27,30 | 27,30 |  |  |
| 2021 | 34,78   | 26,68 | 26,68 | 26,68 |  |  |
| 2022 | 34,91   | 26,05 | 26,05 | 26,05 |  |  |
| 2023 | 35,03   | 25,42 | 25,42 | 25,42 |  |  |
| 2024 | 35,16   | 24,78 | 24,78 | 24,78 |  |  |
| 2025 | 35,27   | 24,13 | 24,13 | 24,13 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | Industrial Sector (% of GDP) |       |       |       |  |  |
|------|------------------------------|-------|-------|-------|--|--|
|      | BS                           | SC-2  | SC-3  | SC-4  |  |  |
| 2011 | 14,36                        | 14,49 | 14,49 | 14,49 |  |  |
| 2012 | 14,37                        | 14,64 | 14,64 | 14,64 |  |  |
| 2013 | 14,38                        | 14,78 | 14,78 | 14,78 |  |  |
| 2014 | 14,39                        | 14,93 | 14,93 | 14,93 |  |  |
| 2015 | 14,40                        | 15,08 | 15,08 | 15,08 |  |  |
| 2016 | 14,41                        | 15,23 | 15,23 | 15,23 |  |  |
| 2017 | 14,42                        | 15,38 | 15,38 | 15,38 |  |  |
| 2018 | 14,43                        | 15,54 | 15,54 | 15,54 |  |  |
| 2019 | 14,44                        | 15,69 | 15,69 | 15,69 |  |  |
| 2020 | 14,45                        | 15,85 | 15,85 | 15,85 |  |  |
| 2021 | 14,46                        | 16,01 | 16,01 | 16,01 |  |  |
| 2022 | 14,47                        | 16,17 | 16,17 | 16,17 |  |  |
| 2023 | 14,48                        | 16,33 | 16,33 | 16,33 |  |  |
| 2024 | 14,49                        | 16,49 | 16,49 | 16,49 |  |  |
| 2025 | 14,50                        | 16,66 | 16,66 | 16,66 |  |  |

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Appendix C

Model Outcomes (2011-2025)

| Year | Construction Sector (% of GDP) |       |       |       |  |  |
|------|--------------------------------|-------|-------|-------|--|--|
|      | BS                             | SC-2  | SC-3  | SC-4  |  |  |
| 2011 | 9,95                           | 9,95  | 9,95  | 9,95  |  |  |
| 2012 | 10,02                          | 10,02 | 10,02 | 10,02 |  |  |
| 2013 | 10,10                          | 10,10 | 10,10 | 10,10 |  |  |
| 2014 | 10,17                          | 10,17 | 10,17 | 10,17 |  |  |
| 2015 | 10,25                          | 10,25 | 10,25 | 10,25 |  |  |
| 2016 | 10,32                          | 10,32 | 10,32 | 10,32 |  |  |
| 2017 | 10,40                          | 10,40 | 10,40 | 10,40 |  |  |
| 2018 | 10,47                          | 10,47 | 10,47 | 10,47 |  |  |
| 2019 | 10,55                          | 10,55 | 10,55 | 10,55 |  |  |
| 2020 | 10,63                          | 10,63 | 10,63 | 10,63 |  |  |
| 2021 | 10,71                          | 10,71 | 10,71 | 10,71 |  |  |
| 2022 | 10,79                          | 10,79 | 10,79 | 10,79 |  |  |
| 2023 | 10,87                          | 10,87 | 10,87 | 10,87 |  |  |
| 2024 | 10,95                          | 10,95 | 10,95 | 10,95 |  |  |
| 2025 | 11,03                          | 11,03 | 11,03 | 11,03 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | Trade and Public services Sector (% of GDP) |       |       |       |  |  |
|------|---|-------|-------|-------|--|--|
|      | BS  | SC-2  | SC-3  | SC-4  |  |  |
| 2011 | 32,30                                       | 32,89 | 32,89 | 32,89 |  |  |
| 2012 | 32,04                                       | 33,22 | 33,22 | 33,22 |  |  |
| 2013 | 31,78                                       | 33,55 | 33,55 | 33,55 |  |  |
| 2014 | 31,52                                       | 33,89 | 33,89 | 33,89 |  |  |
| 2015 | 31,27                                       | 34,22 | 34,22 | 34,22 |  |  |
| 2016 | 31,01                                       | 34,57 | 34,57 | 34,57 |  |  |
| 2017 | 30,76                                       | 34,91 | 34,91 | 34,91 |  |  |
| 2018 | 30,51                                       | 35,26 | 35,26 | 35,26 |  |  |
| 2019 | 30,27                                       | 35,61 | 35,61 | 35,61 |  |  |
| 2020 | 30,02                                       | 35,97 | 35,97 | 35,97 |  |  |
| 2021 | 29,78                                       | 36,33 | 36,33 | 36,33 |  |  |
| 2022 | 29,54                                       | 36,69 | 36,69 | 36,69 |  |  |
| 2023 | 29,30                                       | 37,06 | 37,06 | 37,06 |  |  |
| 2024 | 29,06                                       | 37,43 | 37,43 | 37,43 |  |  |
| 2025 | 28,82                                       | 37,81 | 37,81 | 37,81 |  |  |

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Model Outcomes (2011-2025)

| Year | Transportation Sector (% of GDP) |       |       |       |  |  |
|------|----------------------------------|-------|-------|-------|--|--|
|      | BS                               | SC-2  | SC-3  | SC-4  |  |  |
| 2011 | 10,02                            | 10,02 | 10,02 | 10,02 |  |  |
| 2012 | 10,04                            | 10,04 | 10,04 | 10,04 |  |  |
| 2013 | 10,07                            | 10,07 | 10,07 | 10,07 |  |  |
| 2014 | 10,09                            | 10,09 | 10,09 | 10,09 |  |  |
| 2015 | 10,12                            | 10,12 | 10,12 | 10,12 |  |  |
| 2016 | 10,14                            | 10,14 | 10,14 | 10,14 |  |  |
| 2017 | 10,17                            | 10,17 | 10,17 | 10,17 |  |  |
| 2018 | 10,19                            | 10,19 | 10,19 | 10,19 |  |  |
| 2019 | 10,22                            | 10,22 | 10,22 | 10,22 |  |  |
| 2020 | 10,24                            | 10,24 | 10,24 | 10,24 |  |  |
| 2021 | 10,27                            | 10,27 | 10,27 | 10,27 |  |  |
| 2022 | 10,30                            | 10,30 | 10,30 | 10,30 |  |  |
| 2023 | 10,32                            | 10,32 | 10,32 | 10,32 |  |  |
| 2024 | 10,35                            | 10,35 | 10,35 | 10,35 |  |  |
| 2025 | 10,37                            | 10,37 | 10,37 | 10,37 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | Energy use (kt of oil equivalent) |          |          |          |  |  |
|------|-----------------------------------|----------|----------|----------|--|--|
|      | BS                                | SC-2     | SC-3     | SC-4     |  |  |
| 2011 | 12378,80                          | 12859,80 | 12859,80 | 12669,30 |  |  |
| 2012 | 12828,00                          | 13815,10 | 13744,70 | 13353,90 |  |  |
| 2013 | 13295,20                          | 14850,00 | 14699,60 | 14084,80 |  |  |
| 2014 | 13780,10                          | 15967,60 | 15720,40 | 14857,10 |  |  |
| 2015 | 14283,50                          | 17174,60 | 16811,50 | 15673,50 |  |  |
| 2016 | 14806,00                          | 18478,10 | 17976,80 | 16535,80 |  |  |
| 2017 | 15348,60                          | 19885,80 | 19219,90 | 17446,00 |  |  |
| 2018 | 15912,10                          | 21406,00 | 20545,00 | 18406,30 |  |  |
| 2019 | 16497,30                          | 23047,60 | 21955,80 | 19418,60 |  |  |
| 2020 | 17105,00                          | 24820,20 | 23456,10 | 20485,00 |  |  |
| 2021 | 17736,30                          | 26734,30 | 25049,70 | 21607,70 |  |  |
| 2022 | 18392,10                          | 28801,00 | 26740,20 | 22788,60 |  |  |
| 2023 | 19073,30                          | 31032,40 | 28530,90 | 24029,70 |  |  |
| 2024 | 19781,10                          | 33441,40 | 30425,00 | 25333,00 |  |  |
| 2025 | 20516,40                          | 36042,20 | 32425,40 | 26700,40 |  |  |

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Model Outcomes (2011-2025)

| Year | Agriculture, Fishing and Mining Sector (% of Energy) |      |      |      |  |  |
|------|--|------|------|------|--|--|
|      | BS   | SC-2 | SC-3 | SC-4 |  |  |
| 2011 | 0,96   | 0,94 | 0,94 | 0,95 |  |  |
| 2012 | 0,91   | 0,86 | 0,86 | 0,89 |  |  |
| 2013 | 0,86   | 0,79 | 0,79 | 0,83 |  |  |
| 2014 | 0,82   | 0,73 | 0,73 | 0,77 |  |  |
| 2015 | 0,77   | 0,67 | 0,67 | 0,72 |  |  |
| 2016 | 0,73   | 0,62 | 0,62 | 0,67 |  |  |
| 2017 | 0,69   | 0,56 | 0,56 | 0,63 |  |  |
| 2018 | 0,65   | 0,52 | 0,52 | 0,58 |  |  |
| 2019 | 0,62   | 0,47 | 0,47 | 0,54 |  |  |
| 2020 | 0,58   | 0,43 | 0,43 | 0,51 |  |  |
| 2021 | 0,55   | 0,40 | 0,40 | 0,47 |  |  |
| 2022 | 0,52   | 0,36 | 0,36 | 0,44 |  |  |
| 2023 | 0,49   | 0,33 | 0,33 | 0,40 |  |  |
| 2024 | 0,47   | 0,30 | 0,30 | 0,37 |  |  |
| 2025 | 0,44   | 0,28 | 0,28 | 0,35 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | Industrial Sector (% of Energy use) |       |       |       |  |  |
|------|-------------------------------------|-------|-------|-------|--|--|
|      | BS                                  | SC-2  | SC-3  | SC-4  |  |  |
| 2011 | 22,01                               | 22,08 | 22,08 | 22,07 |  |  |
| 2012 | 22,06                               | 22,20 | 22,20 | 22,19 |  |  |
| 2013 | 22,10                               | 22,33 | 22,33 | 22,31 |  |  |
| 2014 | 22,14                               | 22,45 | 22,45 | 22,42 |  |  |
| 2015 | 22,18                               | 22,56 | 22,56 | 22,53 |  |  |
| 2016 | 22,22                               | 22,68 | 22,68 | 22,65 |  |  |
| 2017 | 22,26                               | 22,80 | 22,80 | 22,76 |  |  |
| 2018 | 22,29                               | 22,91 | 22,91 | 22,87 |  |  |
| 2019 | 22,32                               | 23,02 | 23,02 | 22,98 |  |  |
| 2020 | 22,34                               | 23,13 | 23,13 | 23,08 |  |  |
| 2021 | 22,37                               | 23,24 | 23,24 | 23,19 |  |  |
| 2022 | 22,39                               | 23,35 | 23,35 | 23,30 |  |  |
| 2023 | 22,41                               | 23,46 | 23,46 | 23,40 |  |  |
| 2024 | 22,42                               | 23,57 | 23,57 | 23,51 |  |  |
| 2025 | 22,44                               | 23,68 | 23,68 | 23,61 |  |  |

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Model Outcomes (2011-2025)

| Year | Construction Sector (% of Energy use) |      |      |      |  |  |
|------|---------------------------------------|------|------|------|--|--|
|      | BS                                    | SC-2 | SC-3 | SC-4 |  |  |
| 2011 | 0,99                                  | 0,98 | 0,98 | 1,00 |  |  |
| 2012 | 0,92                                  | 0,91 | 0,91 | 0,93 |  |  |
| 2013 | 0,85                                  | 0,84 | 0,84 | 0,88 |  |  |
| 2014 | 0,79                                  | 0,78 | 0,78 | 0,82 |  |  |
| 2015 | 0,74                                  | 0,72 | 0,72 | 0,77 |  |  |
| 2016 | 0,69                                  | 0,66 | 0,66 | 0,73 |  |  |
| 2017 | 0,64                                  | 0,61 | 0,61 | 0,68 |  |  |
| 2018 | 0,59                                  | 0,57 | 0,57 | 0,64 |  |  |
| 2019 | 0,55                                  | 0,52 | 0,52 | 0,60 |  |  |
| 2020 | 0,51                                  | 0,48 | 0,48 | 0,56 |  |  |
| 2021 | 0,48                                  | 0,45 | 0,45 | 0,53 |  |  |
| 2022 | 0,44                                  | 0,41 | 0,41 | 0,50 |  |  |
| 2023 | 0,41                                  | 0,38 | 0,38 | 0,47 |  |  |
| 2024 | 0,38                                  | 0,35 | 0,35 | 0,44 |  |  |
| 2025 | 0,36                                  | 0,33 | 0,33 | 0,41 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | Trade and Public services Sector (% of Energy use) |       |       |       |  |  |
|------|--|-------|-------|-------|--|--|
|      | BS   | SC-2  | SC-3  | SC-4  |  |  |
| 2011 | 22,37  | 22,65 | 22,65 | 22,80 |  |  |
| 2012 | 22,07  | 22,61 | 22,61 | 22,92 |  |  |
| 2013 | 21,77  | 22,58 | 22,58 | 23,04 |  |  |
| 2014 | 21,46  | 22,54 | 22,54 | 23,16 |  |  |
| 2015 | 21,16  | 22,50 | 22,50 | 23,28 |  |  |
| 2016 | 20,86  | 22,45 | 22,45 | 23,39 |  |  |
| 2017 | 20,57  | 22,41 | 22,41 | 23,51 |  |  |
| 2018 | 20,27  | 22,36 | 22,36 | 23,62 |  |  |
| 2019 | 19,97  | 22,31 | 22,31 | 23,73 |  |  |
| 2020 | 19,68  | 22,26 | 22,26 | 23,85 |  |  |
| 2021 | 19,39  | 22,21 | 22,21 | 23,96 |  |  |
| 2022 | 19,10  | 22,16 | 22,16 | 24,07 |  |  |
| 2023 | 18,82  | 22,10 | 22,10 | 24,18 |  |  |
| 2024 | 18,54  | 22,05 | 22,05 | 24,28 |  |  |
| 2025 | 18,26  | 21,99 | 21,99 | 24,39 |  |  |

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Model Outcomes (2011-2025)

| Year | Transportation Sector (% of Energy use) |       |       |       |  |  |
|------|---|-------|-------|-------|--|--|
|      | BS                                      | SC-2  | SC-3  | SC-4  |  |  |
| 2011 | 53,67                                   | 53,35 | 53,35 | 53,18 |  |  |
| 2012 | 54,04                                   | 53,41 | 53,41 | 53,06 |  |  |
| 2013 | 54,42                                   | 53,46 | 53,46 | 52,94 |  |  |
| 2014 | 54,78                                   | 53,51 | 53,51 | 52,82 |  |  |
| 2015 | 55,14                                   | 53,55 | 53,55 | 52,69 |  |  |
| 2016 | 55,50                                   | 53,59 | 53,59 | 52,56 |  |  |
| 2017 | 55,85                                   | 53,62 | 53,62 | 52,43 |  |  |
| 2018 | 56,20                                   | 53,65 | 53,65 | 52,29 |  |  |
| 2019 | 56,54                                   | 53,67 | 53,67 | 52,15 |  |  |
| 2020 | 56,88                                   | 53,69 | 53,69 | 52,00 |  |  |
| 2021 | 57,21                                   | 53,70 | 53,70 | 51,85 |  |  |
| 2022 | 57,54                                   | 53,71 | 53,71 | 51,70 |  |  |
| 2023 | 57,87                                   | 53,72 | 53,72 | 51,55 |  |  |
| 2024 | 58,19                                   | 53,73 | 53,73 | 51,40 |  |  |
| 2025 | 58,51                                   | 53,73 | 53,73 | 51,24 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | Energy Intensity (kToe/BUSD) |        |        |        |  |  |
|------|------------------------------|--------|--------|--------|--|--|
|      | BS                           | SC-2   | SC-3   | SC-4   |  |  |
| 2011 | 114,82                       | 115,50 | 115,50 | 113,79 |  |  |
| 2012 | 115,24                       | 116,61 | 116,61 | 113,17 |  |  |
| 2013 | 115,68                       | 117,74 | 117,74 | 112,58 |  |  |
| 2014 | 116,14                       | 118,90 | 118,90 | 111,99 |  |  |
| 2015 | 116,62                       | 120,08 | 120,08 | 111,42 |  |  |
| 2016 | 117,11                       | 121,29 | 121,29 | 110,86 |  |  |
| 2017 | 117,62                       | 122,52 | 122,52 | 110,30 |  |  |
| 2018 | 118,15                       | 123,77 | 123,77 | 109,76 |  |  |
| 2019 | 118,69                       | 125,04 | 125,04 | 109,23 |  |  |
| 2020 | 119,25                       | 126,34 | 126,34 | 108,71 |  |  |
| 2021 | 119,83                       | 127,66 | 127,66 | 108,20 |  |  |
| 2022 | 120,42                       | 129,00 | 129,00 | 107,70 |  |  |
| 2023 | 121,02                       | 130,36 | 130,36 | 107,20 |  |  |
| 2024 | 121,64                       | 131,74 | 131,74 | 106,71 |  |  |
| 2025 | 122,28                       | 133,15 | 133,15 | 106,23 |  |  |

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Model Outcomes (2011-2025)

| Year | Energy Intensity in Agriculture, Fishing and Mining |      |      |      |  |  |
|------|---|------|------|------|--|--|
|      | BS  | SC-2 | SC-3 | SC-4 |  |  |
| 2011 | 0,03  | 0,03 | 0,03 | 0,03 |  |  |
| 2012 | 0,03  | 0,03 | 0,03 | 0,03 |  |  |
| 2013 | 0,03  | 0,03 | 0,03 | 0,03 |  |  |
| 2014 | 0,02  | 0,02 | 0,02 | 0,03 |  |  |
| 2015 | 0,02  | 0,02 | 0,02 | 0,02 |  |  |
| 2016 | 0,02  | 0,02 | 0,02 | 0,02 |  |  |
| 2017 | 0,02  | 0,02 | 0,02 | 0,02 |  |  |
| 2018 | 0,02  | 0,02 | 0,02 | 0,02 |  |  |
| 2019 | 0,02  | 0,02 | 0,02 | 0,02 |  |  |
| 2020 | 0,02  | 0,02 | 0,02 | 0,02 |  |  |
| 2021 | 0,02  | 0,01 | 0,01 | 0,02 |  |  |
| 2022 | 0,01  | 0,01 | 0,01 | 0,02 |  |  |
| 2023 | 0,01  | 0,01 | 0,01 | 0,02 |  |  |
| 2024 | 0,01  | 0,01 | 0,01 | 0,02 |  |  |
| 2025 | 0,01  | 0,01 | 0,01 | 0,01 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | Energy Intensity in Industry Sector (kToe/BUSD) |      |      |      |  |  |
|------|---|------|------|------|--|--|
|      | BS  | SC-2 | SC-3 | SC-4 |  |  |
| 2011 | 1,53  | 1,52 | 1,52 | 1,52 |  |  |
| 2012 | 1,54  | 1,52 | 1,52 | 1,52 |  |  |
| 2013 | 1,54  | 1,51 | 1,51 | 1,51 |  |  |
| 2014 | 1,54  | 1,50 | 1,50 | 1,50 |  |  |
| 2015 | 1,54  | 1,50 | 1,50 | 1,49 |  |  |
| 2016 | 1,54  | 1,49 | 1,49 | 1,49 |  |  |
| 2017 | 1,54  | 1,48 | 1,48 | 1,48 |  |  |
| 2018 | 1,54  | 1,47 | 1,47 | 1,47 |  |  |
| 2019 | 1,55  | 1,47 | 1,47 | 1,46 |  |  |
| 2020 | 1,55  | 1,46 | 1,46 | 1,46 |  |  |
| 2021 | 1,55  | 1,45 | 1,45 | 1,45 |  |  |
| 2022 | 1,55  | 1,44 | 1,44 | 1,44 |  |  |
| 2023 | 1,55  | 1,44 | 1,44 | 1,43 |  |  |
| 2024 | 1,55  | 1,43 | 1,43 | 1,43 |  |  |
| 2025 | 1,55  | 1,42 | 1,42 | 1,42 |  |  |

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Model Outcomes (2011-2025)

| Year | Energy Intensity in Construction Sector |      |      |      |  |  |
|------|---|------|------|------|--|--|
|      | BS                                      | SC-2 | SC-3 | SC-4 |  |  |
| 2011 | 0,10                                    | 0,10 | 0,10 | 0,10 |  |  |
| 2012 | 0,09                                    | 0,09 | 0,09 | 0,09 |  |  |
| 2013 | 0,08                                    | 0,08 | 0,08 | 0,09 |  |  |
| 2014 | 0,08                                    | 0,08 | 0,08 | 0,08 |  |  |
| 2015 | 0,07                                    | 0,07 | 0,07 | 0,08 |  |  |
| 2016 | 0,07                                    | 0,06 | 0,06 | 0,07 |  |  |
| 2017 | 0,06                                    | 0,06 | 0,06 | 0,07 |  |  |
| 2018 | 0,06                                    | 0,05 | 0,05 | 0,06 |  |  |
| 2019 | 0,05                                    | 0,05 | 0,05 | 0,06 |  |  |
| 2020 | 0,05                                    | 0,05 | 0,05 | 0,05 |  |  |
| 2021 | 0,04                                    | 0,04 | 0,04 | 0,05 |  |  |
| 2022 | 0,04                                    | 0,04 | 0,04 | 0,05 |  |  |
| 2023 | 0,04                                    | 0,04 | 0,04 | 0,04 |  |  |
| 2024 | 0,03                                    | 0,03 | 0,03 | 0,04 |  |  |
| 2025 | 0,03                                    | 0,03 | 0,03 | 0,04 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | Energy Intensity in Trade and Public services Sector |      |      |      |  |  |
|------|--|------|------|------|--|--|
|      | BS   | SC-2 | SC-3 | SC-4 |  |  |
| 2011 | 0,69   | 0,69 | 0,69 | 0,69 |  |  |
| 2012 | 0,69   | 0,68 | 0,68 | 0,69 |  |  |
| 2013 | 0,68   | 0,67 | 0,67 | 0,69 |  |  |
| 2014 | 0,68   | 0,67 | 0,67 | 0,68 |  |  |
| 2015 | 0,68   | 0,66 | 0,66 | 0,68 |  |  |
| 2016 | 0,67   | 0,65 | 0,65 | 0,68 |  |  |
| 2017 | 0,67   | 0,64 | 0,64 | 0,67 |  |  |
| 2018 | 0,66   | 0,63 | 0,63 | 0,67 |  |  |
| 2019 | 0,66   | 0,63 | 0,63 | 0,67 |  |  |
| 2020 | 0,66   | 0,62 | 0,62 | 0,66 |  |  |
| 2021 | 0,65   | 0,61 | 0,61 | 0,66 |  |  |
| 2022 | 0,65   | 0,60 | 0,60 | 0,66 |  |  |
| 2023 | 0,64   | 0,60 | 0,60 | 0,65 |  |  |
| 2024 | 0,64   | 0,59 | 0,59 | 0,65 |  |  |
| 2025 | 0,63   | 0,58 | 0,58 | 0,65 |  |  |

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Model Outcomes (2011-2025)

| Year | Energy Intensity in Transportation Sector |      |      |      |  |  |
|------|---|------|------|------|--|--|
|      | BS  | SC-2 | SC-3 | SC-4 |  |  |
| 2011 | 5,36                                      | 5,33 | 5,33 | 5,31 |  |  |
| 2012 | 5,38                                      | 5,32 | 5,32 | 5,28 |  |  |
| 2013 | 5,41                                      | 5,31 | 5,31 | 5,26 |  |  |
| 2014 | 5,43                                      | 5,30 | 5,30 | 5,23 |  |  |
| 2015 | 5,45                                      | 5,29 | 5,29 | 5,21 |  |  |
| 2016 | 5,47                                      | 5,28 | 5,28 | 5,18 |  |  |
| 2017 | 5,49                                      | 5,27 | 5,27 | 5,16 |  |  |
| 2018 | 5,51                                      | 5,26 | 5,26 | 5,13 |  |  |
| 2019 | 5,53                                      | 5,25 | 5,25 | 5,10 |  |  |
| 2020 | 5,55                                      | 5,24 | 5,24 | 5,08 |  |  |
| 2021 | 5,57                                      | 5,23 | 5,23 | 5,05 |  |  |
| 2022 | 5,59                                      | 5,22 | 5,22 | 5,02 |  |  |
| 2023 | 5,61                                      | 5,20 | 5,20 | 4,99 |  |  |
| 2024 | 5,62                                      | 5,19 | 5,19 | 4,97 |  |  |
| 2025 | 5,64                                      | 5,18 | 5,18 | 4,94 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | Fossil fuel energy consumption (% of total) |       |       |       |  |  |
|------|---|-------|-------|-------|--|--|
|      | BS  | SC-2  | SC-3  | SC-4  |  |  |
| 2011 | 88,18                                       | 88,18 | 87,24 | 87,24 |  |  |
| 2012 | 88,27                                       | 88,27 | 86,35 | 86,35 |  |  |
| 2013 | 88,35                                       | 88,35 | 85,39 | 85,39 |  |  |
| 2014 | 88,41                                       | 88,41 | 84,37 | 84,37 |  |  |
| 2015 | 88,45                                       | 88,45 | 83,28 | 83,28 |  |  |
| 2016 | 88,49                                       | 88,49 | 82,11 | 82,11 |  |  |
| 2017 | 88,51                                       | 88,51 | 80,85 | 80,85 |  |  |
| 2018 | 88,51                                       | 88,51 | 79,51 | 79,51 |  |  |
| 2019 | 88,51                                       | 88,51 | 78,08 | 78,08 |  |  |
| 2020 | 88,49                                       | 88,49 | 76,54 | 76,54 |  |  |
| 2021 | 88,46                                       | 88,46 | 74,90 | 74,90 |  |  |
| 2022 | 88,42                                       | 88,42 | 73,15 | 73,15 |  |  |
| 2023 | 88,37                                       | 88,37 | 71,27 | 71,27 |  |  |
| 2024 | 88,31                                       | 88,31 | 69,25 | 69,25 |  |  |
| 2025 | 88,24                                       | 88,24 | 67,10 | 67,10 |  |  |

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Appendix C

Model Outcomes (2011-2025)

| Year | Alternative and nuclear energy (% of total energy) |      |       |       |  |  |
|------|--|------|-------|-------|--|--|
|      | BS   | SC-2 | SC-3  | SC-4  |  |  |
| 2011 | 7,20   | 7,20 | 7,55  | 7,55  |  |  |
| 2012 | 7,35   | 7,35 | 8,08  | 8,08  |  |  |
| 2013 | 7,50   | 7,50 | 8,65  | 8,65  |  |  |
| 2014 | 7,65   | 7,65 | 9,25  | 9,25  |  |  |
| 2015 | 7,81   | 7,81 | 9,90  | 9,90  |  |  |
| 2016 | 7,97   | 7,97 | 10,59 | 10,59 |  |  |
| 2017 | 8,13   | 8,13 | 11,34 | 11,34 |  |  |
| 2018 | 8,30   | 8,30 | 12,13 | 12,13 |  |  |
| 2019 | 8,47   | 8,47 | 12,98 | 12,98 |  |  |
| 2020 | 8,64   | 8,64 | 13,89 | 13,89 |  |  |
| 2021 | 8,82   | 8,82 | 14,86 | 14,86 |  |  |
| 2022 | 9,00   | 9,00 | 15,90 | 15,90 |  |  |
| 2023 | 9,18   | 9,18 | 17,01 | 17,01 |  |  |
| 2024 | 9,37   | 9,37 | 18,20 | 18,20 |  |  |
| 2025 | 9,56   | 9,56 | 19,48 | 19,48 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | Combustible renewables and waste (% of total) |      |       |       |  |  |
|------|---|------|-------|-------|--|--|
|      | BS  | SC-2 | SC-3  | SC-4  |  |  |
| 2011 | 4,61  | 4,61 | 5,20  | 5,20  |  |  |
| 2012 | 4,38  | 4,38 | 5,57  | 5,57  |  |  |
| 2013 | 4,15  | 4,15 | 5,96  | 5,96  |  |  |
| 2014 | 3,94  | 3,94 | 6,38  | 6,38  |  |  |
| 2015 | 3,74  | 3,74 | 6,82  | 6,82  |  |  |
| 2016 | 3,54  | 3,54 | 7,30  | 7,30  |  |  |
| 2017 | 3,36  | 3,36 | 7,81  | 7,81  |  |  |
| 2018 | 3,19  | 3,19 | 8,36  | 8,36  |  |  |
| 2019 | 3,03  | 3,03 | 8,94  | 8,94  |  |  |
| 2020 | 2,87  | 2,87 | 9,57  | 9,57  |  |  |
| 2021 | 2,72  | 2,72 | 10,24 | 10,24 |  |  |
| 2022 | 2,58  | 2,58 | 10,96 | 10,96 |  |  |
| 2023 | 2,45  | 2,45 | 11,72 | 11,72 |  |  |
| 2024 | 2,32  | 2,32 | 12,54 | 12,54 |  |  |
| 2025 | 2,20  | 2,20 | 13,42 | 13,42 |  |  |

## 7.3 Appendix C

Appendix C

Model Outcomes (2011-2025)

| Year | Gaseous fuel consumption (% Total Fossil Energy) |      |      |      |
|------|--|------|------|------|
|      | BS   | SC-2 | SC-3 | SC-4 |
| 2011 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2012 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2013 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2014 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2015 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2016 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2017 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2018 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2019 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2020 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2021 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2022 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2023 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2024 | 0,01   | 0,01 | 0,01 | 0,01 |
| 2025 | 0,01   | 0,01 | 0,01 | 0,01 |

Appendix C

Model Outcomes (2011-2025)

| Year | Solid fuel consumption (% Total Fossil Energy ) |      |      |      |
|------|---|------|------|------|
|      | BS  | SC-2 | SC-3 | SC-4 |
| 2011 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2012 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2013 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2014 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2015 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2016 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2017 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2018 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2019 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2020 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2021 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2022 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2023 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2024 | 0,00  | 0,00 | 0,00 | 0,00 |
| 2025 | 0,00  | 0,00 | 0,00 | 0,00 |

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Appendix C

Model Outcomes (2011-2025)

| Year | Liquid fuel consumption (% Total Fossil Energy) |      |      |      |  |  |
|------|---|------|------|------|--|--|
|      | BS  | SC-2 | SC-3 | SC-4 |  |  |
| 2011 | 0,88  | 0,88 | 0,87 | 0,87 |  |  |
| 2012 | 0,88  | 0,88 | 0,86 | 0,86 |  |  |
| 2013 | 0,88  | 0,88 | 0,85 | 0,85 |  |  |
| 2014 | 0,88  | 0,88 | 0,84 | 0,84 |  |  |
| 2015 | 0,88  | 0,88 | 0,83 | 0,83 |  |  |
| 2016 | 0,88  | 0,88 | 0,81 | 0,81 |  |  |
| 2017 | 0,88  | 0,88 | 0,80 | 0,80 |  |  |
| 2018 | 0,88  | 0,88 | 0,79 | 0,79 |  |  |
| 2019 | 0,88  | 0,88 | 0,77 | 0,77 |  |  |
| 2020 | 0,88  | 0,88 | 0,76 | 0,76 |  |  |
| 2021 | 0,88  | 0,88 | 0,74 | 0,74 |  |  |
| 2022 | 0,88  | 0,88 | 0,72 | 0,72 |  |  |
| 2023 | 0,88  | 0,88 | 0,71 | 0,71 |  |  |
| 2024 | 0,88  | 0,88 | 0,69 | 0,69 |  |  |
| 2025 | 0,88  | 0,88 | 0,66 | 0,66 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | CO2 in Agriculture, Fishing and Mining Sector |        |        |        |  |  |
|------|---|--------|--------|--------|--|--|
|      | BS  | SC-2   | SC-3   | SC-4   |  |  |
| 2011 | 318,20  | 321,50 | 318,20 | 318,20 |  |  |
| 2012 | 312,56  | 318,30 | 310,03 | 310,35 |  |  |
| 2013 | 306,93  | 315,06 | 301,83 | 302,47 |  |  |
| 2014 | 301,30  | 311,72 | 293,39 | 294,39 |  |  |
| 2015 | 295,67  | 308,26 | 284,73 | 286,10 |  |  |
| 2016 | 290,05  | 304,68 | 275,83 | 277,59 |  |  |
| 2017 | 284,46  | 300,98 | 266,67 | 268,86 |  |  |
| 2018 | 278,89  | 297,15 | 257,26 | 259,88 |  |  |
| 2019 | 273,35  | 293,17 | 247,58 | 250,66 |  |  |
| 2020 | 267,86  | 289,05 | 237,64 | 241,19 |  |  |
| 2021 | 262,40  | 284,78 | 227,44 | 231,47 |  |  |
| 2022 | 256,99  | 280,36 | 216,98 | 221,49 |  |  |
| 2023 | 251,63  | 275,78 | 206,27 | 211,26 |  |  |
| 2024 | 246,33  | 271,02 | 195,33 | 200,78 |  |  |
| 2025 | 241,08  | 266,10 | 184,17 | 190,07 |  |  |

## 7.3 Appendix C

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Model Outcomes (2011-2025)

| Year | CO2 in Industrial Sector (kTons) |          |          |          |  |  |
|------|----------------------------------|----------|----------|----------|--|--|
|      | BS                               | SC-2     | SC-3     | SC-4     |  |  |
| 2011 | 7275,23                          | 7583,27  | 7505,36  | 7391,86  |  |  |
| 2012 | 7563,30                          | 8200,15  | 7987,11  | 7755,35  |  |  |
| 2013 | 7861,33                          | 8869,90  | 8497,19  | 8134,83  |  |  |
| 2014 | 8169,06                          | 9594,82  | 9030,72  | 8525,55  |  |  |
| 2015 | 8486,86                          | 10379,51 | 9587,19  | 8926,64  |  |  |
| 2016 | 8815,09                          | 11228,88 | 10165,33 | 9336,64  |  |  |
| 2017 | 9154,12                          | 12148,06 | 10763,33 | 9753,73  |  |  |
| 2018 | 9504,31                          | 13142,91 | 11378,65 | 10175,67 |  |  |
| 2019 | 9866,04                          | 14219,42 | 12008,20 | 10599,78 |  |  |
| 2020 | 10239,72                         | 15384,19 | 12647,93 | 11022,65 |  |  |
| 2021 | 10625,78                         | 16644,26 | 13292,67 | 11440,60 |  |  |
| 2022 | 11024,47                         | 18007,37 | 13936,45 | 11849,01 |  |  |
| 2023 | 11436,52                         | 19481,82 | 14571,80 | 12242,44 |  |  |
| 2024 | 11862,05                         | 21076,42 | 15189,73 | 12614,67 |  |  |
| 2025 | 12301,68                         | 22800,74 | 15779,97 | 12958,47 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | CO2 in Construction Sector (kTons) |        |        |        |  |  |
|------|------------------------------------|--------|--------|--------|--|--|
|      | BS                                 | SC-2   | SC-3   | SC-4   |  |  |
| 2011 | 325,98                             | 336,66 | 333,20 | 333,20 |  |  |
| 2012 | 314,65                             | 334,89 | 326,19 | 326,53 |  |  |
| 2013 | 303,66                             | 333,24 | 319,24 | 319,92 |  |  |
| 2014 | 292,98                             | 331,61 | 312,12 | 313,17 |  |  |
| 2015 | 282,61                             | 330,01 | 304,82 | 306,28 |  |  |
| 2016 | 272,54                             | 328,43 | 297,32 | 299,22 |  |  |
| 2017 | 262,78                             | 326,86 | 289,60 | 291,98 |  |  |
| 2018 | 253,32                             | 325,31 | 281,64 | 284,52 |  |  |
| 2019 | 244,16                             | 323,78 | 273,43 | 276,83 |  |  |
| 2020 | 235,28                             | 322,25 | 264,93 | 268,89 |  |  |
| 2021 | 226,69                             | 320,73 | 256,15 | 260,68 |  |  |
| 2022 | 218,37                             | 319,21 | 247,05 | 252,19 |  |  |
| 2023 | 210,33                             | 317,70 | 237,63 | 243,38 |  |  |
| 2024 | 202,56                             | 316,18 | 227,87 | 234,24 |  |  |
| 2025 | 195,04                             | 314,66 | 217,77 | 224,75 |  |  |

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Appendix C Model Outcomes (2011-2025)

| Year | CO2 in Trade and Public services Sector (kTons) |          |          |          |  |  |
|------|---|----------|----------|----------|--|--|
|      | BS  | SC-2     | SC-3     | SC-4     |  |  |
| 2011 | 7396,62   | 7778,20  | 7698,28  | 7635,80  |  |  |
| 2012 | 7568,04   | 8351,52  | 8134,55  | 8011,28  |  |  |
| 2013 | 7742,01   | 8969,84  | 8592,93  | 8403,28  |  |  |
| 2014 | 7918,00   | 9634,38  | 9067,96  | 8806,90  |  |  |
| 2015 | 8096,10   | 10348,70 | 9558,73  | 9221,24  |  |  |
| 2016 | 8276,40   | 11116,45 | 10063,56 | 9644,77  |  |  |
| 2017 | 8458,95   | 11941,51 | 10580,29 | 10075,62 |  |  |
| 2018 | 8643,83   | 12828,22 | 11106,21 | 10511,52 |  |  |
| 2019 | 8831,09   | 13780,91 | 11637,90 | 10949,57 |  |  |
| 2020 | 9020,80   | 14804,38 | 12171,22 | 11386,48 |  |  |
| 2021 | 9213,01   | 15903,89 | 12701,36 | 11818,22 |  |  |
| 2022 | 9407,79   | 17084,80 | 13222,48 | 12240,08 |  |  |
| 2023 | 9605,18   | 18353,18 | 13727,56 | 12646,43 |  |  |
| 2024 | 9805,25   | 19715,14 | 14208,74 | 13030,95 |  |  |
| 2025 | 10008,05  | 21177,49 | 14656,49 | 13386,21 |  |  |

Appendix C Model Outcomes (2011-2025)

| Year | CO2 in Transportation Sector (kTons) |          |          |          |  |  |
|------|--------------------------------------|----------|----------|----------|--|--|
|      | BS                                   | SC-2     | SC-3     | SC-4     |  |  |
| 2011 | 17831,44                             | 18415,35 | 18219,15 | 17890,24 |  |  |
| 2012 | 18626,94                             | 19825,21 | 19294,93 | 18623,73 |  |  |
| 2013 | 19454,23                             | 21349,38 | 20427,19 | 19382,05 |  |  |
| 2014 | 20313,11                             | 22991,69 | 21603,38 | 20153,22 |  |  |
| 2015 | 21204,80                             | 24761,42 | 22821,06 | 20934,48 |  |  |
| 2016 | 22130,60                             | 26668,48 | 24076,37 | 21721,74 |  |  |
| 2017 | 23092,04                             | 28723,14 | 25363,96 | 22510,32 |  |  |
| 2018 | 24090,23                             | 30936,62 | 26676,97 | 23294,65 |  |  |
| 2019 | 25126,78                             | 33321,03 | 28007,16 | 24067,94 |  |  |
| 2020 | 26203,21                             | 35889,28 | 29343,98 | 24822,51 |  |  |
| 2021 | 27320,94                             | 38655,21 | 30674,97 | 25549,67 |  |  |
| 2022 | 28481,48                             | 41633,66 | 31985,16 | 26238,96 |  |  |
| 2023 | 29686,64                             | 44840,68 | 33256,71 | 26878,77 |  |  |
| 2024 | 30938,06                             | 48293,12 | 34468,86 | 27455,73 |  |  |
| 2025 | 32237,44                             | 52009,47 | 35597,12 | 27954,56 |  |  |

## 7.3 Appendix C

Appendix C

Model Outcomes (2011-2025)

| Year | CO2int (kt/kToe) |      |      |      |  |  |
|------|------------------|------|------|------|--|--|
|      | BS               | SC-2 | SC-3 | SC-4 |  |  |
| 2011 | 2,68             | 2,68 | 2,65 | 2,65 |  |  |
| 2012 | 2,68             | 2,68 | 2,62 | 2,62 |  |  |
| 2013 | 2,68             | 2,68 | 2,59 | 2,59 |  |  |
| 2014 | 2,68             | 2,68 | 2,56 | 2,56 |  |  |
| 2015 | 2,69             | 2,69 | 2,53 | 2,53 |  |  |
| 2016 | 2,69             | 2,69 | 2,50 | 2,50 |  |  |
| 2017 | 2,69             | 2,69 | 2,46 | 2,46 |  |  |
| 2018 | 2,69             | 2,69 | 2,42 | 2,42 |  |  |
| 2019 | 2,69             | 2,69 | 2,38 | 2,38 |  |  |
| 2020 | 2,69             | 2,69 | 2,33 | 2,33 |  |  |
| 2021 | 2,69             | 2,69 | 2,28 | 2,28 |  |  |
| 2022 | 2,69             | 2,68 | 2,23 | 2,23 |  |  |
| 2023 | 2,68             | 2,68 | 2,17 | 2,17 |  |  |
| 2024 | 2,68             | 2,68 | 2,11 | 2,11 |  |  |
| 2025 | 2,68             | 2,68 | 2,05 | 2,05 |  |  |

Appendix C

Model Outcomes (2011-2025)

| Year | CO2pc-(kgCO2) |         |         |         |  |  |
|------|---------------|---------|---------|---------|--|--|
|      | BS            | SC-2    | SC-3    | SC-4    |  |  |
| 2011 | 2261,64       | 2349,48 | 2324,87 | 2290,42 |  |  |
| 2012 | 2316,00       | 2494,13 | 2428,31 | 2359,23 |  |  |
| 2013 | 2371,57       | 2648,78 | 2535,81 | 2429,71 |  |  |
| 2014 | 2428,17       | 2813,44 | 2645,63 | 2500,29 |  |  |
| 2015 | 2485,89       | 2988,82 | 2757,41 | 2570,69 |  |  |
| 2016 | 2544,72       | 3175,53 | 2870,53 | 2640,36 |  |  |
| 2017 | 2604,74       | 3374,33 | 2984,32 | 2708,81 |  |  |
| 2018 | 2665,95       | 3585,93 | 3097,91 | 2775,38 |  |  |
| 2019 | 2728,40       | 3811,17 | 3210,37 | 2839,36 |  |  |
| 2020 | 2792,11       | 4050,83 | 3320,50 | 2899,92 |  |  |
| 2021 | 2857,14       | 4305,84 | 3427,01 | 2956,19 |  |  |
| 2022 | 2923,49       | 4577,12 | 3528,38 | 3007,10 |  |  |
| 2023 | 2991,21       | 4865,67 | 3622,85 | 3051,51 |  |  |
| 2024 | 3060,35       | 5172,58 | 3708,50 | 3088,16 |  |  |
| 2025 | 3130,92       | 5498,90 | 3783,04 | 3115,59 |  |  |

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Appendix C Model Outcomes (2011-2025)

| Year | CO2-Total |          |          |          |  |  |
|------|-----------|----------|----------|----------|--|--|
|      | BS        | SC-2     | SC-3     | SC-4     |  |  |
| 2011 | 33147,48  | 34434,98 | 34074,18 | 33569,31 |  |  |
| 2012 | 34385,49  | 37030,08 | 36052,81 | 35027,23 |  |  |
| 2013 | 35668,15  | 39837,42 | 38138,37 | 36542,54 |  |  |
| 2014 | 36994,44  | 42864,22 | 40307,57 | 38093,23 |  |  |
| 2015 | 38366,03  | 46127,91 | 42556,53 | 39674,73 |  |  |
| 2016 | 39784,68  | 49646,92 | 44878,40 | 41279,96 |  |  |
| 2017 | 41252,35  | 53440,55 | 47263,85 | 42900,51 |  |  |
| 2018 | 42770,58  | 57530,22 | 49700,73 | 44526,25 |  |  |
| 2019 | 44341,42  | 61938,30 | 52174,27 | 46144,78 |  |  |
| 2020 | 45966,86  | 66689,16 | 54665,71 | 47741,72 |  |  |
| 2021 | 47648,81  | 71808,88 | 57152,58 | 49300,65 |  |  |
| 2022 | 49389,10  | 77325,40 | 59608,12 | 50801,72 |  |  |
| 2023 | 51190,31  | 83269,15 | 61999,96 | 52222,27 |  |  |
| 2024 | 53054,24  | 89671,89 | 64290,53 | 53536,37 |  |  |
| 2025 | 54983,30  | 96568,46 | 66435,51 | 54714,07 |  |  |

Appendix C Outcomes of Economic Model (2011-2025)

| Year | qt-bs  | IT    | TBT   | CHT    | EIMPT     | RNT     |
|------|--------|-------|-------|--------|-----------|---------|
| 2011 | 120,42 | 30,96 | -1,01 | 74,84  | -17380,48 | 1371,30 |
| 2012 | 124,76 | 32,14 | -0,98 | 77,14  | -17549,54 | 1377,58 |
| 2013 | 129,14 | 33,41 | -1,00 | 79,49  | -17791,30 | 1391,00 |
| 2014 | 133,76 | 34,78 | -1,02 | 81,88  | -17976,80 | 1406,31 |
| 2015 | 138,61 | 36,27 | -1,04 | 84,34  | -18172,25 | 1426,71 |
| 2016 | 143,72 | 37,87 | -1,07 | 86,85  | -18349,82 | 1450,47 |
| 2017 | 149,10 | 39,60 | -1,08 | 89,41  | -18526,96 | 1475,83 |
| 2018 | 154,75 | 41,47 | -1,09 | 92,04  | -18697,68 | 1503,57 |
| 2019 | 160,69 | 43,47 | -1,09 | 94,72  | -18865,76 | 1532,50 |
| 2020 | 166,91 | 45,61 | -1,07 | 97,45  | -19028,59 | 1563,21 |
| 2021 | 173,40 | 47,89 | -1,06 | 100,23 | -19185,72 | 1595,26 |
| 2022 | 180,01 | 50,31 | -1,12 | 103,05 | -19335,30 | 1628,48 |
| 2023 | 186,97 | 52,87 | -1,14 | 105,92 | -19475,94 | 1664,81 |
| 2024 | 194,19 | 55,56 | -1,15 | 108,84 | -19606,41 | 1703,33 |
| 2025 | 201,66 | 58,36 | -1,15 | 111,81 | -19727,30 | 1743,91 |

## 7.3 Appendix C

Appendix C Outcomes of Economic Model (2011-2025)

| Year | qt-SC-2 | IT    | TBT   | CHT    | EIMPT     | RNT     |
|------|---------|-------|-------|--------|-----------|---------|
| 2011 | 121,05  | 31,28 | -1,62 | 76,24  | -17820,16 | 1457,03 |
| 2012 | 126,83  | 32,76 | -1,55 | 79,85  | -18662,95 | 1574,61 |
| 2013 | 132,87  | 34,30 | -1,47 | 83,63  | -19545,60 | 1701,69 |
| 2014 | 139,19  | 35,93 | -1,40 | 87,58  | -20469,99 | 1839,08 |
| 2015 | 145,81  | 37,63 | -1,34 | 91,72  | -21438,10 | 1987,64 |
| 2016 | 152,72  | 39,41 | -1,27 | 96,06  | -22452,00 | 2148,33 |
| 2017 | 159,96  | 41,27 | -1,21 | 100,60 | -23513,85 | 2322,17 |
| 2018 | 167,52  | 43,22 | -1,16 | 105,36 | -24625,91 | 2510,28 |
| 2019 | 175,44  | 45,27 | -1,10 | 110,34 | -25790,57 | 2713,87 |
| 2020 | 183,72  | 47,41 | -1,05 | 115,56 | -27010,32 | 2934,28 |
| 2021 | 192,38  | 49,65 | -1,00 | 121,03 | -28287,75 | 3172,95 |
| 2022 | 201,44  | 52,00 | -0,95 | 126,75 | -29625,59 | 3431,45 |
| 2023 | 210,93  | 54,46 | -0,91 | 132,75 | -31026,71 | 3711,48 |
| 2024 | 220,86  | 57,03 | -0,86 | 139,03 | -32494,09 | 4014,91 |
| 2025 | 231,25  | 59,73 | -0,82 | 145,60 | -34030,87 | 4343,77 |

Appendix C Outcomes of Economic Model (2011-2025)

| Year | qt-SC-3 | IT    | TBT   | CHT    | EIMPT     | RNT     |
|------|---------|-------|-------|--------|-----------|---------|
| 2011 | 121,17  | 31,28 | -1,62 | 76,24  | -17820,16 | 1468,03 |
| 2012 | 127,08  | 32,76 | -1,55 | 79,85  | -18662,95 | 1593,72 |
| 2013 | 133,26  | 34,30 | -1,47 | 83,63  | -19545,60 | 1733,46 |
| 2014 | 139,73  | 35,93 | -1,40 | 87,58  | -20469,99 | 1885,50 |
| 2015 | 146,51  | 37,63 | -1,34 | 91,72  | -21438,10 | 2053,08 |
| 2016 | 153,60  | 39,41 | -1,27 | 96,06  | -22452,00 | 2237,38 |
| 2017 | 161,03  | 41,27 | -1,21 | 100,60 | -23513,85 | 2437,66 |
| 2018 | 168,81  | 43,22 | -1,16 | 105,36 | -24625,91 | 2658,04 |
| 2019 | 176,96  | 45,27 | -1,10 | 110,34 | -25790,57 | 2898,68 |
| 2020 | 185,50  | 47,41 | -1,05 | 115,56 | -27010,32 | 3162,69 |
| 2021 | 194,46  | 49,65 | -1,00 | 121,03 | -28287,75 | 3451,48 |
| 2022 | 203,84  | 52,00 | -0,95 | 126,75 | -29625,59 | 3767,57 |
| 2023 | 213,67  | 54,46 | -0,91 | 132,75 | -31026,71 | 4113,98 |
| 2024 | 223,99  | 57,03 | -0,86 | 139,03 | -32494,09 | 4493,14 |
| 2025 | 234,80  | 59,73 | -0,82 | 145,60 | -34030,87 | 4908,67 |

## 7. APPENDIX

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Appendix C Outcomes of Economic Model (2011-2025)

| Year | qt-SC-4 | IT    | TBT   | CHT    | EIMPT     | RNT     |
|------|---------|-------|-------|--------|-----------|---------|
| 2011 | 121,16  | 31,28 | -1,62 | 76,24  | -17820,16 | 1457,03 |
| 2012 | 127,05  | 32,76 | -1,55 | 79,85  | -18662,95 | 1574,61 |
| 2013 | 133,22  | 34,30 | -1,47 | 83,63  | -19545,60 | 1701,69 |
| 2014 | 139,68  | 35,93 | -1,40 | 87,58  | -20469,99 | 1839,08 |
| 2015 | 146,43  | 37,63 | -1,34 | 91,72  | -21438,10 | 1987,64 |
| 2016 | 153,50  | 39,41 | -1,27 | 96,06  | -22452,00 | 2148,33 |
| 2017 | 160,90  | 41,27 | -1,21 | 100,60 | -23513,85 | 2322,17 |
| 2018 | 168,64  | 43,22 | -1,16 | 105,36 | -24625,91 | 2510,28 |
| 2019 | 176,75  | 45,27 | -1,10 | 110,34 | -25790,57 | 2713,87 |
| 2020 | 185,24  | 47,41 | -1,05 | 115,56 | -27010,32 | 2934,28 |
| 2021 | 194,13  | 49,65 | -1,00 | 121,03 | -28287,75 | 3172,95 |
| 2022 | 203,45  | 52,00 | -0,95 | 126,75 | -29625,59 | 3431,45 |
| 2023 | 213,21  | 54,46 | -0,91 | 132,75 | -31026,71 | 3711,48 |
| 2024 | 223,43  | 57,03 | -0,86 | 139,03 | -32494,09 | 4014,91 |
| 2025 | 234,15  | 59,73 | -0,82 | 145,60 | -34030,87 | 4343,77 |

## **7.4 Appendix D**

Appendix D presents the outcomes of the LDMI analysis (Chapter 4) year by year for the four considered scenarios in the period 1980-2025.

## 7. APPENDIX

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Appendix D

LMDI (Additive decomposition)

| Time (year) | Cact    |         |         |         |
|-------------|---------|---------|---------|---------|
|             | BS      | SC-2    | SC-3    | SC-4    |
| 1980        |         |         |         |         |
| 1981        | 287,03  | 287,03  | 287,03  | 287,03  |
| 1982        | 218,74  | 218,74  | 218,74  | 218,74  |
| 1983        | 233,95  | 233,95  | 233,95  | 233,95  |
| 1984        | 252,18  | 252,18  | 252,18  | 252,18  |
| 1985        | 274,16  | 274,16  | 274,16  | 274,16  |
| 1986        | 304,42  | 304,42  | 304,42  | 304,42  |
| 1987        | 327,24  | 327,24  | 327,24  | 327,24  |
| 1988        | 343,98  | 343,98  | 343,98  | 343,98  |
| 1989        | 355,24  | 355,24  | 355,24  | 355,24  |
| 1990        | 357,65  | 357,65  | 357,65  | 357,65  |
| 1991        | 354,00  | 354,00  | 354,00  | 354,00  |
| 1992        | 344,55  | 344,55  | 344,55  | 344,55  |
| 1993        | 337,45  | 337,45  | 337,45  | 337,45  |
| 1994        | 342,63  | 342,63  | 342,63  | 342,63  |
| 1995        | 360,00  | 360,00  | 360,00  | 360,00  |
| 1996        | 388,55  | 388,55  | 388,55  | 388,55  |
| 1997        | 483,74  | 483,74  | 483,74  | 483,74  |
| 1998        | 416,74  | 416,74  | 416,74  | 416,74  |
| 1999        | 558,91  | 558,91  | 558,91  | 558,91  |
| 2000        | 651,84  | 651,84  | 651,84  | 651,84  |
| 2001        | 767,89  | 767,89  | 767,89  | 767,89  |
| 2002        | 879,43  | 879,43  | 879,43  | 879,43  |
| 2003        | 979,28  | 979,28  | 979,28  | 979,28  |
| 2004        | 1067,85 | 1067,85 | 1067,85 | 1067,85 |
| 2005        | 1130,62 | 1130,62 | 1130,62 | 1130,62 |
| 2006        | 1169,41 | 1169,41 | 1169,41 | 1169,41 |
| 2007        | 1183,17 | 1183,17 | 1183,17 | 1183,17 |
| 2008        | 1179,34 | 1179,34 | 1179,34 | 1179,34 |
| 2009        | 1174,93 | 1174,93 | 1174,93 | 1174,93 |
| 2010        | 1164,27 | 1164,27 | 1164,27 | 1164,27 |
| 2011        | 1081,51 | 2170,74 | 2159,21 | 2143,00 |
| 2012        | 1079,23 | 2217,49 | 1997,48 | 1989,30 |
| 2013        | 1118,67 | 2403,44 | 2131,72 | 2096,08 |
| 2014        | 1157,50 | 2594,22 | 2248,76 | 2186,58 |
| 2015        | 1197,25 | 2800,80 | 2369,83 | 2279,26 |
| 2016        | 1238,59 | 3023,57 | 2492,21 | 2372,24 |
| 2017        | 1282,14 | 3263,28 | 2615,84 | 2464,75 |
| 2018        | 1326,67 | 3521,67 | 2738,73 | 2556,78 |
| 2019        | 1373,14 | 3800,22 | 2860,63 | 2646,59 |
| 2020        | 1421,26 | 4100,41 | 2979,62 | 2734,21 |
| 2021        | 1471,37 | 4423,47 | 3094,31 | 2817,74 |
| 2022        | 1522,84 | 4771,65 | 3202,30 | 2896,51 |
| 2023        | 1576,98 | 5145,94 | 3302,25 | 2969,14 |
| 2024        | 1632,20 | 5549,76 | 3391,78 | 3033,94 |
| 2025        | 1690,13 | 5983,78 | 3468,41 | 3089,15 |

## 7.4 Appendix D

Appendix D

LMDI (Multiplicative decomposition)

| Time (year) | Dact       |            |            |            |
|-------------|------------|------------|------------|------------|
|             | BS         | SC-2       | SC-3       | SC-4       |
| 1980        |            |            |            |            |
| 1981        | 1,02306775 | 1,02306775 | 1,02306775 | 1,02306775 |
| 1982        | 1,01729471 | 1,01729471 | 1,01729471 | 1,01729471 |
| 1983        | 1,01831468 | 1,01831468 | 1,01831468 | 1,01831468 |
| 1984        | 1,0195464  | 1,0195464  | 1,0195464  | 1,0195464  |
| 1985        | 1,02103268 | 1,02103268 | 1,02103268 | 1,02103268 |
| 1986        | 1,0230925  | 1,0230925  | 1,0230925  | 1,0230925  |
| 1987        | 1,02449141 | 1,02449141 | 1,02449141 | 1,02449141 |
| 1988        | 1,02534176 | 1,02534176 | 1,02534176 | 1,02534176 |
| 1989        | 1,02569218 | 1,02569218 | 1,02569218 | 1,02569218 |
| 1990        | 1,02530825 | 1,02530825 | 1,02530825 | 1,02530825 |
| 1991        | 1,02442633 | 1,02442633 | 1,02442633 | 1,02442633 |
| 1992        | 1,02309533 | 1,02309533 | 1,02309533 | 1,02309533 |
| 1993        | 1,02188192 | 1,02188192 | 1,02188192 | 1,02188192 |
| 1994        | 1,02140375 | 1,02140375 | 1,02140375 | 1,02140375 |
| 1995        | 1,02157854 | 1,02157854 | 1,02157854 | 1,02157854 |
| 1996        | 1,02227516 | 1,02227516 | 1,02227516 | 1,02227516 |
| 1997        | 1,02647545 | 1,02647545 | 1,02647545 | 1,02647545 |
| 1998        | 1,02169123 | 1,02169123 | 1,02169123 | 1,02169123 |
| 1999        | 1,02782945 | 1,02782945 | 1,02782945 | 1,02782945 |
| 2000        | 1,03093492 | 1,03093492 | 1,03093492 | 1,03093492 |
| 2001        | 1,03473132 | 1,03473132 | 1,03473132 | 1,03473132 |
| 2002        | 1,03788529 | 1,03788529 | 1,03788529 | 1,03788529 |
| 2003        | 1,040216   | 1,040216   | 1,040216   | 1,040216   |
| 2004        | 1,04191305 | 1,04191305 | 1,04191305 | 1,04191305 |
| 2005        | 1,04255594 | 1,04255594 | 1,04255594 | 1,04255594 |
| 2006        | 1,04238399 | 1,04238399 | 1,04238399 | 1,04238399 |
| 2007        | 1,04146234 | 1,04146234 | 1,04146234 | 1,04146234 |
| 2008        | 1,04010946 | 1,04010946 | 1,04010946 | 1,04010946 |
| 2009        | 1,03889761 | 1,03889761 | 1,03889761 | 1,03889761 |
| 2010        | 1,0375984  | 1,0375984  | 1,0375984  | 1,0375984  |
| 2011        | 1,03380978 | 1,067658   | 1,06765799 | 1,06765819 |
| 2012        | 1,03248146 | 1,06405305 | 1,05863745 | 1,05972431 |
| 2013        | 1,03245676 | 1,06456094 | 1,05916476 | 1,06033309 |
| 2014        | 1,03237614 | 1,06477639 | 1,05902367 | 1,06035297 |
| 2015        | 1,03228788 | 1,06499812 | 1,05888038 | 1,06037764 |
| 2016        | 1,03220873 | 1,0652053  | 1,05867765 | 1,06036608 |
| 2017        | 1,03215286 | 1,0653884  | 1,05843451 | 1,06031492 |
| 2018        | 1,03208618 | 1,06555845 | 1,05812789 | 1,06024123 |
| 2019        | 1,03203165 | 1,06571684 | 1,05777807 | 1,06012207 |
| 2020        | 1,03197996 | 1,06586366 | 1,05737286 | 1,05998058 |
| 2021        | 1,03193708 | 1,06599303 | 1,05691516 | 1,05979708 |
| 2022        | 1,03188773 | 1,06611431 | 1,0563932  | 1,05958277 |
| 2023        | 1,03185821 | 1,06621545 | 1,05581889 | 1,05933712 |
| 2024        | 1,03181365 | 1,06631657 | 1,05518889 | 1,05905586 |
| 2025        | 1,03178589 | 1,06639954 | 1,054502   | 1,0587366  |

## 7. APPENDIX

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Appendix D

LMDI (Additive decomposition)

| Time (year) | Cint    |         |         |         |
|-------------|---------|---------|---------|---------|
|             | BS      | SC-2    | SC-3    | SC-4    |
| 1980        |         |         |         |         |
| 1981        | 62,22   | 62,22   | 62,22   | 62,22   |
| 1982        | 59,04   | 59,04   | 59,04   | 59,04   |
| 1983        | 47,28   | 47,28   | 47,28   | 47,28   |
| 1984        | 31,20   | 31,20   | 31,20   | 31,20   |
| 1985        | 11,38   | 11,38   | 11,38   | 11,38   |
| 1986        | -7,59   | -7,59   | -7,59   | -7,59   |
| 1987        | -23,41  | -23,41  | -23,41  | -23,41  |
| 1988        | -36,87  | -36,87  | -36,87  | -36,87  |
| 1989        | -44,03  | -44,03  | -44,03  | -44,03  |
| 1990        | -45,60  | -45,60  | -45,60  | -45,60  |
| 1991        | -38,22  | -38,22  | -38,22  | -38,22  |
| 1992        | -20,30  | -20,30  | -20,30  | -20,30  |
| 1993        | 7,78    | 7,78    | 7,78    | 7,78    |
| 1994        | 43,79   | 43,79   | 43,79   | 43,79   |
| 1995        | 85,11   | 85,11   | 85,11   | 85,11   |
| 1996        | 119,85  | 119,85  | 119,85  | 119,85  |
| 1997        | 145,13  | 145,13  | 145,13  | 145,13  |
| 1998        | 165,94  | 165,94  | 165,94  | 165,94  |
| 1999        | 180,58  | 180,58  | 180,58  | 180,58  |
| 2000        | 175,06  | 175,06  | 175,06  | 175,06  |
| 2001        | 171,92  | 171,92  | 171,92  | 171,92  |
| 2002        | 167,53  | 167,53  | 167,53  | 167,53  |
| 2003        | 131,34  | 131,34  | 131,34  | 131,34  |
| 2004        | 79,85   | 79,85   | 79,85   | 79,85   |
| 2005        | 23,83   | 23,83   | 23,83   | 23,83   |
| 2006        | -31,50  | -31,50  | -31,50  | -31,50  |
| 2007        | -80,46  | -80,46  | -80,46  | -80,46  |
| 2008        | -114,22 | -114,22 | -114,22 | -114,22 |
| 2009        | -125,83 | -125,83 | -125,83 | -125,83 |
| 2010        | -134,78 | -134,78 | -134,78 | -134,78 |
| 2011        | 112,97  | 114,91  | 114,30  | -267,80 |
| 2012        | 119,45  | 125,48  | 123,14  | -279,39 |
| 2013        | 126,15  | 136,71  | 131,95  | -290,28 |
| 2014        | 133,09  | 148,79  | 141,13  | -301,51 |
| 2015        | 140,32  | 161,85  | 150,69  | -312,97 |
| 2016        | 147,75  | 175,84  | 160,50  | -324,61 |
| 2017        | 155,56  | 191,03  | 170,71  | -336,31 |
| 2018        | 163,61  | 207,30  | 181,10  | -348,07 |
| 2019        | 171,94  | 224,81  | 191,66  | -359,82 |
| 2020        | 180,63  | 243,74  | 202,39  | -371,35 |
| 2021        | 189,62  | 264,07  | 213,12  | -382,60 |
| 2022        | 198,95  | 285,97  | 223,80  | -393,46 |
| 2023        | 208,69  | 309,62  | 234,35  | -403,71 |
| 2024        | 218,69  | 334,94  | 244,47  | -413,23 |
| 2025        | 229,19  | 362,36  | 254,21  | -421,78 |

Appendix D

LMDI (Additive decomposition)

| Time (year) | Cmix   |        |          |          |
|-------------|--------|--------|----------|----------|
|             | BS     | SC-2   | SC-3     | SC-4     |
| 1980        |        |        |          |          |
| 1981        | -67,92 | -67,92 | -67,92   | -67,92   |
| 1982        | -69,79 | -69,79 | -69,79   | -69,79   |
| 1983        | -67,76 | -67,76 | -67,76   | -67,76   |
| 1984        | -60,42 | -60,42 | -60,42   | -60,42   |
| 1985        | -47,07 | -47,07 | -47,07   | -47,07   |
| 1986        | -29,79 | -29,79 | -29,79   | -29,79   |
| 1987        | -7,48  | -7,48  | -7,48    | -7,48    |
| 1988        | 17,09  | 17,09  | 17,09    | 17,09    |
| 1989        | 44,32  | 44,32  | 44,32    | 44,32    |
| 1990        | 70,60  | 70,60  | 70,60    | 70,60    |
| 1991        | 91,62  | 91,62  | 91,62    | 91,62    |
| 1992        | 109,16 | 109,16 | 109,16   | 109,16   |
| 1993        | 124,18 | 124,18 | 124,18   | 124,18   |
| 1994        | 139,51 | 139,51 | 139,51   | 139,51   |
| 1995        | 153,13 | 153,13 | 153,13   | 153,13   |
| 1996        | 158,21 | 158,21 | 158,21   | 158,21   |
| 1997        | 160,51 | 160,51 | 160,51   | 160,51   |
| 1998        | 161,17 | 161,17 | 161,17   | 161,17   |
| 1999        | 160,17 | 160,17 | 160,17   | 160,17   |
| 2000        | 165,74 | 165,74 | 165,74   | 165,74   |
| 2001        | 170,23 | 170,23 | 170,23   | 170,23   |
| 2002        | 168,94 | 168,94 | 168,94   | 168,94   |
| 2003        | 159,60 | 159,60 | 159,60   | 159,60   |
| 2004        | 143,02 | 143,02 | 143,02   | 143,02   |
| 2005        | 118,49 | 118,49 | 118,49   | 118,49   |
| 2006        | 89,52  | 89,52  | 89,52    | 89,52    |
| 2007        | 67,98  | 67,98  | 67,98    | 67,98    |
| 2008        | 56,95  | 56,95  | 56,95    | 56,95    |
| 2009        | 54,60  | 54,60  | 54,60    | 54,60    |
| 2010        | 54,48  | 54,48  | 54,48    | 54,48    |
| 2011        | 39,19  | 42,80  | -302,02  | -300,55  |
| 2012        | 34,66  | 39,44  | -348,29  | -341,40  |
| 2013        | 30,09  | 35,99  | -398,89  | -385,48  |
| 2014        | 25,38  | 32,06  | -456,95  | -435,38  |
| 2015        | 20,45  | 27,54  | -523,44  | -491,82  |
| 2016        | 15,41  | 22,50  | -599,54  | -555,60  |
| 2017        | 10,13  | 16,74  | -686,57  | -627,64  |
| 2018        | 4,64   | 10,24  | -785,97  | -708,94  |
| 2019        | -1,06  | 2,92   | -899,65  | -800,84  |
| 2020        | -7,02  | -5,33  | -1029,33 | -904,48  |
| 2021        | -13,21 | -14,57 | -1177,22 | -1021,40 |
| 2022        | -19,68 | -24,95 | -1345,80 | -1153,29 |
| 2023        | -26,43 | -36,55 | -1537,76 | -1301,94 |
| 2024        | -33,53 | -49,60 | -1756,02 | -1469,33 |
| 2025        | -40,92 | -64,10 | -2004,23 | -1658,00 |

## 7. APPENDIX

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Appendix D

LMDI (Additive decomposition)

| Time (year) | Cemf |      |      |      |
|-------------|------|------|------|------|
|             | BS   | SC-2 | SC-3 | SC-4 |
| 1980        |      |      |      |      |
| 1981        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1982        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1983        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1984        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1985        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1986        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1987        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1988        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1989        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1990        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1991        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1992        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1993        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1994        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1995        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1996        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1997        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1998        | 0,00 | 0,00 | 0,00 | 0,00 |
| 1999        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2000        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2001        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2002        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2003        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2004        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2005        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2006        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2007        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2008        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2009        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2010        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2011        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2012        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2013        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2014        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2015        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2016        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2017        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2018        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2019        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2020        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2021        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2022        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2023        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2024        | 0,00 | 0,00 | 0,00 | 0,00 |
| 2025        | 0,00 | 0,00 | 0,00 | 0,00 |

Appendix D

LMDI (Additive decomposition)

| Time (year) | Ctot    |         |         |         |
|-------------|---------|---------|---------|---------|
|             | BS      | SC-2    | SC-3    | SC-4    |
| 1980        |         |         |         |         |
| 1981        | 279,64  | 279,64  | 279,64  | 279,64  |
| 1982        | 206,67  | 206,67  | 206,67  | 206,67  |
| 1983        | 212,07  | 212,07  | 212,07  | 212,07  |
| 1984        | 221,99  | 221,99  | 221,99  | 221,99  |
| 1985        | 238,01  | 238,01  | 238,01  | 238,01  |
| 1986        | 268,21  | 268,21  | 268,21  | 268,21  |
| 1987        | 298,98  | 298,98  | 298,98  | 298,98  |
| 1988        | 330,22  | 330,22  | 330,22  | 330,22  |
| 1989        | 365,87  | 365,87  | 365,87  | 365,87  |
| 1990        | 398,66  | 398,66  | 398,66  | 398,66  |
| 1991        | 430,62  | 430,62  | 430,62  | 430,62  |
| 1992        | 464,39  | 464,39  | 464,39  | 464,39  |
| 1993        | 509,53  | 509,53  | 509,53  | 509,53  |
| 1994        | 576,70  | 576,70  | 576,70  | 576,70  |
| 1995        | 659,06  | 659,06  | 659,06  | 659,06  |
| 1996        | 729,62  | 729,62  | 729,62  | 729,62  |
| 1997        | 848,92  | 848,92  | 848,92  | 848,92  |
| 1998        | 793,35  | 793,35  | 793,35  | 793,35  |
| 1999        | 933,02  | 933,02  | 933,02  | 933,02  |
| 2000        | 1004,48 | 1004,48 | 1004,48 | 1004,48 |
| 2001        | 1093,98 | 1093,98 | 1093,98 | 1093,98 |
| 2002        | 1173,53 | 1173,53 | 1173,53 | 1173,53 |
| 2003        | 1202,90 | 1202,90 | 1202,90 | 1202,90 |
| 2004        | 1200,22 | 1200,22 | 1200,22 | 1200,22 |
| 2005        | 1163,55 | 1163,55 | 1163,55 | 1163,55 |
| 2006        | 1098,95 | 1098,95 | 1098,95 | 1098,95 |
| 2007        | 1023,90 | 1023,90 | 1023,90 | 1023,90 |
| 2008        | 960,22  | 960,22  | 960,22  | 960,22  |
| 2009        | 928,74  | 928,74  | 928,74  | 928,74  |
| 2010        | 900,73  | 900,73  | 900,73  | 900,73  |
| 2011        | 1222,11 | 2441,63 | 2084,06 | 1686,51 |
| 2012        | 1222,43 | 2504,73 | 1892,39 | 1486,36 |
| 2013        | 1264,55 | 2707,82 | 1991,90 | 1543,69 |
| 2014        | 1306,16 | 2916,89 | 2067,52 | 1578,82 |
| 2015        | 1349,26 | 3143,37 | 2139,78 | 1609,88 |
| 2016        | 1393,67 | 3386,80 | 2203,80 | 1633,41 |
| 2017        | 1440,53 | 3648,58 | 2258,79 | 1648,29 |
| 2018        | 1488,70 | 3930,61 | 2301,23 | 1653,60 |
| 2019        | 1538,91 | 4234,33 | 2328,78 | 1646,18 |
| 2020        | 1591,02 | 4561,22 | 2337,63 | 1624,96 |
| 2021        | 1644,96 | 4912,33 | 2323,73 | 1586,39 |
| 2022        | 1700,43 | 5290,25 | 2282,28 | 1528,30 |
| 2023        | 1759,35 | 5697,00 | 2209,72 | 1448,21 |
| 2024        | 1818,77 | 6134,23 | 2099,14 | 1341,50 |
| 2025        | 1881,51 | 6604,27 | 1945,13 | 1204,64 |

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Appendix D

LMDI (Additive decomposition)

| Time (year) | Cstr    |         |         |         |
|-------------|---------|---------|---------|---------|
|             | BS      | SC-2    | SC-3    | SC-4    |
| 1980        |         |         |         |         |
| 1981        | -1,69   | -1,69   | -1,69   | -1,69   |
| 1982        | -1,32   | -1,32   | -1,32   | -1,32   |
| 1983        | -1,40   | -1,40   | -1,40   | -1,40   |
| 1984        | -0,96   | -0,96   | -0,96   | -0,96   |
| 1985        | -0,45   | -0,45   | -0,45   | -0,45   |
| 1986        | 1,16    | 1,16    | 1,16    | 1,16    |
| 1987        | 2,63    | 2,63    | 2,63    | 2,63    |
| 1988        | 6,01    | 6,01    | 6,01    | 6,01    |
| 1989        | 10,34   | 10,34   | 10,34   | 10,34   |
| 1990        | 16,00   | 16,00   | 16,00   | 16,00   |
| 1991        | 23,21   | 23,21   | 23,21   | 23,21   |
| 1992        | 30,99   | 30,99   | 30,99   | 30,99   |
| 1993        | 40,13   | 40,13   | 40,13   | 40,13   |
| 1994        | 50,78   | 50,78   | 50,78   | 50,78   |
| 1995        | 60,82   | 60,82   | 60,82   | 60,82   |
| 1996        | 63,01   | 63,01   | 63,01   | 63,01   |
| 1997        | 59,55   | 59,55   | 59,55   | 59,55   |
| 1998        | 49,49   | 49,49   | 49,49   | 49,49   |
| 1999        | 33,36   | 33,36   | 33,36   | 33,36   |
| 2000        | 11,84   | 11,84   | 11,84   | 11,84   |
| 2001        | -16,07  | -16,07  | -16,07  | -16,07  |
| 2002        | -42,37  | -42,37  | -42,37  | -42,37  |
| 2003        | -67,32  | -67,32  | -67,32  | -67,32  |
| 2004        | -90,51  | -90,51  | -90,51  | -90,51  |
| 2005        | -109,39 | -109,39 | -109,39 | -109,39 |
| 2006        | -128,47 | -128,47 | -128,47 | -128,47 |
| 2007        | -146,79 | -146,79 | -146,79 | -146,79 |
| 2008        | -161,85 | -161,85 | -161,85 | -161,85 |
| 2009        | -174,96 | -174,96 | -174,96 | -174,96 |
| 2010        | -183,24 | -183,24 | -183,24 | -183,24 |
| 2011        | -11,56  | 113,18  | 112,58  | 111,86  |
| 2012        | -10,91  | 122,31  | 120,05  | 117,85  |
| 2013        | -10,37  | 131,68  | 127,13  | 123,37  |
| 2014        | -9,80   | 141,82  | 134,57  | 129,13  |
| 2015        | -8,76   | 153,18  | 142,70  | 135,41  |
| 2016        | -8,07   | 164,90  | 150,62  | 141,38  |
| 2017        | -7,30   | 177,54  | 158,81  | 147,48  |
| 2018        | -6,22   | 191,39  | 167,38  | 153,83  |
| 2019        | -5,11   | 206,37  | 176,15  | 160,25  |
| 2020        | -3,86   | 222,40  | 184,94  | 166,59  |
| 2021        | -2,82   | 239,36  | 193,52  | 172,65  |
| 2022        | -1,68   | 257,58  | 201,99  | 178,55  |
| 2023        | 0,12    | 277,98  | 210,88  | 184,72  |
| 2024        | 1,41    | 299,13  | 218,91  | 190,11  |
| 2025        | 3,11    | 322,23  | 226,74  | 195,28  |

**7.5 Appendix E**

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Appendix E presents values of CO<sub>2</sub>-income elasticity for Ecuador (2011-2025).

Figure 5.5 in Chapter 5 is based on this data.

Appendix E Evolution of CO2-income elasticity for Ecuador (2011-2025)

| Year | BS     | SC-2  | SC-3  | SC-4  |
|------|--------|-------|-------|-------|
| 2011 | 1,1127 | 1,42  | 1,388 | 1,395 |
| 2012 | 1,107  | 1,376 | 1,3   | 1,31  |
| 2013 | 1,091  | 1,407 | 1,288 | 1,312 |
| 2014 | 1,096  | 1,415 | 1,314 | 1,373 |
| 2015 | 1,102  | 1,416 | 1,292 | 1,347 |
| 2016 | 1,106  | 1,406 | 1,248 | 1,282 |
| 2017 | 1,11   | 1,383 | 1,189 | 1,184 |
| 2018 | 1,112  | 1,35  | 1,126 | 1,071 |
| 2019 | 1,115  | 1,313 | 1,069 | 0,964 |
| 2020 | 1,116  | 1,278 | 1,023 | 0,873 |
| 2021 | 1,118  | 1,248 | 0,986 | 0,801 |
| 2022 | 1,12   | 1,225 | 0,958 | 0,745 |
| 2023 | 1,121  | 1,208 | 0,935 | 0,703 |
| 2024 | 1,122  | 1,194 | 0,916 | 0,669 |
| 2025 | 1,123  | 1,185 | 0,898 | 0,641 |

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### 7.6 Appendix F

Appendix F presents the programming of the model in Vensim platform. In addition the flow diagram, based on the causal diagram (see Figure 3.8 in Chapter 3) is shown. Note that the programming is based on the equation system of Section 3.7 in Chapter 3.

```

(001) c= INTEG (
           "c %",
           2.83148e+010)
(002) "c %"=
           IF THEN ELSE(Time<2010,c*c r/100,c*"esc-c"/100)
(003) c r = WITH LOOKUP (
           Time,
           ((1980,2)-(2025,4)),(1980,3.33),(1981,3.22),(1982,3.13),(1983,3.1),(1984
           ,3.09),(1985,3.07),(1986,2.99),(1987,2.86),(1988,2.71),(1989,2.55),(1990,2.41
           ),(1991,2.27),(1992,2.15),(1993,2.07),(1994,2.03),(1995,2.05),(1996,2.14),
           (1997,2.29),(1998,2.5),(1999,2.83),(2000,3.18),(2001,3.44),(2002,3.61),(2003
           ,3.71),(2004,3.75),(2005,3.77),(2006,3.77),(2007,3.76),(2008,3.73),(2009,3.63
           ),(2010,2.96),(2025,2.96) )
(004) c11=
           e11*uT1
(005) c12=
           e12*uT2
(006) c13=
           e13*uT3
(007) c21=
           e21*uT1
(008) c22=
           e22*uT2
(009) c23=
           e23*uT3
(010) c31=
           e31*uT1
(011) c32=
           e32*uT2
(012) c33=
           e33*uT3
(013) c41=
           e41*uT1
(014) c42=
           e42*uT2
(015) c43=
           e43*uT3
(016) c51=
           e51*uT1
(017) c52=
           e52*uT2
(018) c53=
           e53*uT3
(019) CO2=
           c11+c12+c13+c21+c22+c23+c31+c32+c33+c41+c42+c43+c51+c52+c53
(020) "CO2-s"=
           E*"co2int-s"
(021) "co2int-c"=
           CO2/E
(022) "co2int-s"=

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```
0.0303*es1
(023) E=
      (e1+e2+e3+e4+e5)
(024) e1=
      q1*i1/(10^11)
(025) e11=
      e1*m11
(026) e12=
      e1*m12
(027) e13=
      e1*m13
(028) e2=
      q2*i2/(10^11)
(029) e21=
      e2*m21
(030) e22=
      e2*m22
(031) e23=
      e2*m23
(032) e3=
      q3*i3/(10^11)
(033) e31=
      e3*m31
(034) e32=
      e3*m32
(035) e33=
      e3*m33
(036) e4=
      q4*i4/(10^11)
(037) e41=
      e4*m41
(038) e42=
      e4*m42
(039) e43=
      e4*m43
(040) e5=
      q5*i5/(10^11)
(041) e51=
      e5*m51
(042) e52=
      e5*m52
(043) e53=
      e5*m53
(044) ef51 r = WITH LOOKUP (
      Time,
      ((1980,10)-(2010,100)),(1980,0),(2010,0)))
(045) eimp= INTEG (
      "eimp %",
      -6490.22
      )
```

```

(046) "eimp %" =
      IF THEN ELSE(Time<2010,eimp*eimp r/100,eimp*"esc-eimp"/100)
(047) eimp r = WITH LOOKUP (
      Time,
      (((1980,0)-(2025,10)),(1980,6.96),(1981,6.54),(1982,6.18),(1983,5.73),(1984
,5.26),(1985,4.89),(1986,4.77),(1987,5),(1988,5.03),(1989,4.98),(1990,4.82
),(1991,4.52),(1992,4.06),(1993,3.45),(1994,2.79),(1995,2.24),(1996,1.89),
(1997,1.74),(1998,1.77),(1999,1.9),(2000,2.09),(2001,2.29),(2002,2.47),(2003
,2.45),(2004,2.13),(2005,1.68),(2006,1.23),(2007,0.89),(2008,0.69),(2009,0.63
),(2010,2.74),(2025,2.74) ))
(048) "es-m42 r" = WITH LOOKUP (
      Time,
      (((1980,10)-(2010,100)),(1980,0),(2010,0)))
(049) es1 =
      (100-(es2+es3))
(050) es11 = INTEG (
      es1/100*"es11%"/100,
      es1/100*0.8/100)
(051) es11 r = WITH LOOKUP (
      Time,
      (((1980,-100)-(2010,100)),(1980,40.31),(1981,12.39),(1982,14.68),(1983,-
10.7),(1984,8.22),(1985,36.45),(1986,-51.42),(1987,80.57),(1988,61.06),(1989
,73.87),(1990,18.52),(1991,-45.22),(1992,5.28),(1993,74.98),(1994,-46.2),(
1995,0.97),(1996,22.66),(1997,-17.88),(1998,-2.2),(1999,13.26),(2000,-10.47
),(2001,6.87),(2001,-5.32),(2002,78.43),(2003,12.08),(2004,-22.66),(2005,59.89
),(2006,-0.63),(2007,-27.28),(2008,6.87),(2009,5.84),(2010,6.84) ))
(052) "es11%" =
      IF THEN ELSE(Time<2010, es11*es11 r/100, es11*"esc-es11"/100)
(053) es12 = INTEG (
      es1/100*"es12%"/100,
      es1/100*0/100)
(054) es12 r = WITH LOOKUP (
      Time,
      (((1980,0)-(2010,0.2)),(1980,0),(2010,0) ))
(055) "es12%" =
      IF THEN ELSE(Time<2010, es12*es12 r/100, es12*"esc-es12"/100)
(056) es13 =
      es1/100-(es11+es12)
(057) es2 = INTEG (
      "es2%",
      1.22049
      )
(058) es2 r = WITH LOOKUP (
      Time,
      (((1980,-2)-(2020,60)),(1980,59.61),(1981,37.48),(1982,27.11),(1983,20.85
),(1984,16.23),(1985,12.76),(1986,9.96),(1987,7.69),(1988,5.84),(1989,4.33
),(1990,3.1),(1991,2.11),(1992,1.25),(1993,0.43),(1994,-0.26),(1995,-0.66)
,(1996,-0.92),(1997,-1.13),(1998,-1.32),(1999,-1.56),(2000,-1.74),(2001,-1.71
),(2002,-1.46),(2003,-0.96),(2004,-0.29),(2005,0.44),(2006,1.04),(2007,1.33
),(2008,1.32),(2009,1.31),(2010,1.31),(2011,2.04),(2020,2.04) ))

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```
(059) "es2%"=
      IF THEN ELSE(Time<2010, es2*es2 r/100, es2*"esc-e2"/100)
(060) es3= INTEG (
      "es3%",
      19.7351
      )
(061) es3 r = WITH LOOKUP (
      Time,
      (((1980,-8)-(2020,0)),(1980,-1.26),(1981,-1.29),(1982,-1.41),(1983,-1.65
      ),(1984,-1.98),(1985,-2.37),(1986,-2.82),(1987,-3.37),(1988,-3.96),(1989,-
      4.54),(1990,-4.95),(1991,-5.28),(1992,-5.57),(1993,-5.86),(1994,-6.05),(1995
      ,-6.12),(1996,-6.12),(1997,-6.08),(1998,-5.97),(1999,-6.1),(2000,-6.21),(2001
      ,-6.27),(2002,-6.21),(2003,-5.95),(2004,-5.5),(2005,-5),(2006,-4.63),(2007
      ,-4.52),(2008,-4.59),(2009,-4.76),(2010,-5.14),(2020,-5.14) ))
(062) "es3%"=
      IF THEN ELSE(Time<2010, es3*es3 r/100, es3*"esc-e3"/100)
(063) "esc-c"=
      2.96
(064) "esc-e2"=
      2.04
(065) "esc-e3"=
      -5.14
(066) "esc-eef31"=
      0
(067) "esc-eimp"=
      2.74
(068) "esc-es11"=
      5.86
(069) "esc-es12"=
      0
(070) "esc-i"=
      4.15
(071) "esc-i1"=
      -5.39
(072) "esc-i2"=
      0.52
(073) "esc-i3"=
      -7.29
(074) "esc-i4"=
      -0.19
(075) "esc-i5"=
      0.82
(076) "esc-m11"=
      0
(077) "esc-m12 r" = WITH LOOKUP (
      Time,
      (((1980,10)-(2010,100)),(1980,0),(2010,0) ))
```

```

(078) "esc-m12"=
      0
(079) "esc-m21"=
      0
(080) "esc-m22"=
      20
(081) "esc-m32"=
      0
(082) "esc-m41"=
      0
(083) "esc-m42"=
      80
(084) "esc-m51"=
      0
(085) "esc-m52"=
      0
(086) "esc-pob"=
      1.3
(087) "esc-s2"=
      0.07
(088) "esc-s3"=
      0.74
(089) "esc-s4"=
      -0.81
(090) "esc-s5"=
      0.25
(091) "esc-tb"=
      -4.12
(092) FINAL TIME = 2030
      Units: year
      The final time for the simulation.
(093) i= INTEG (
      "i %",
      8.92732e+009)
(094) "i %"=
      IF THEN ELSE(Time<2010,i*r/100,i*"esc-i"/100)
(095) i r = WITH LOOKUP (
      Time,
      (([1980,0)-(2025,10)],(1980,0.94),(1981,1.06),(1982,1.37),(1983,1.95),(1984
      ,2.53),(1985,3.2),(1986,3.47),(1987,3.41),(1988,3.15),(1989,2.83),(1990,2.66
      ),(1991,2.64),(1992,2.72),(1993,2.8),(1994,2.88),(1995,3.02),(1996,3.28),(
      1997,3.59),(1998,4.01),(1999,4.71),(2000,5.3),(2001,5.64),(2002,5.81),(2003
      ,5.97),(2004,5.99),(2005,5.89),(2006,5.7),(2007,5.4),(2008,5.12),(2009,4.89
      ),(2010,4.15),(2025,4.15) ))
      Units: 1/year
(096) i1= INTEG (
      "i1%",
      15.7858
      )

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```
(097) i1 r = WITH LOOKUP (
      Time,
      (((1980,-20)-(2030,20)),(1980,2.42),(1981,2.1),(1982,1.29),(1983,0.02),(
1984,-1.74),(1985,-3.82),(1986,-6.09),(1987,-8.46
),(1988,-10.66),(1989,-12.16),(1990,-12.98),(1991,-13.15),(1992,-12.71),(1993
,-11.69),(1994,-10.11),(1995,-8.18),(1996,-
6.19),(1997,-4.38),(1998,-2.96),(1999,-1.98),(2000,-1.43),(2001,-1.32),(2002
,-1.54),(2003,-1.88),(2004,-2.13),(2005,-2.34
),(2006,-2.54),(2007,-2.79),(2008,-2.97),(2009,-3.1),(2010,-3.1),(2020,-5)
))
(098) "i1%"=
      IF THEN ELSE(Time<2010, i1*i1 r/100, i1*"esc-i1"/100 )
(099) i2= INTEG (
      "i2%",
      144.164
      )
(100) i2 r = WITH LOOKUP (
      Time,
      (((1980,-8)-(2050,6)),(1980,1.45),(1981,1.36),(1982,1.17),(1983,0.95),(1984
,0.73),(1985,0.58),(1986,0.55),(1987,0.64),(1988,0.89),(1989,1.27),(1990,1.76
),(1991,2.31),(1992,2.86),(1993,3.3),(1994,3.44),(1995,3.33),(1996,3.09),(
1997,2.82),(1998,2.5),(1999,2.09),(2000,1.54),(2001,0.85),(2002,0.007),(2003
,-0.82),(2004,-1.76),(2005,-2.47),(2006,-3.02),(2007,-3.48),(2008,-3.78),(
2009,-3.97),(2010,-3.97),(2011,-1),(2020,-1),(2050,0) ))
(101) "i2%"=
      IF THEN ELSE(Time<2010, i2*i2 r/100, i2*"esc-i2"/100 )
(102) i3= INTEG (
      "i3%",
      147.112
      )
(103) i3 r = WITH LOOKUP (
      Time,
      (((1981,-20)-(2030,6)),(1980,-6.99),(1981,-7.52),(1982,-8.16),(1983,-8.89
),(1984,-9.79),(1985,-10.96),(1986,-12.46),(1987
,-14.28),(1988,-16.19),(1989,-17.5),(1990,-19.09),(1991,-17.87),(1992,-14.43
),(1994,-11.18),(1995,-7.47),(1996,-4.11),(1997
,-1.54),(1998,-0.11),(1999,-0.03),(2000,-0.45),(2001,-1.11),(2002,-1.85),(
2003,-2.65),(2004,-3.29),(2005,-3.83),(2006,-4.22
),(2007,-4.53),(2008,-4.77),(2009,-4.94),(2010,-4.77),(2020,-6.77) ))
(104) "i3%"=
      IF THEN ELSE(Time<2010, i3*i3 r/100, i3*"esc-i3"/100 )
(105) i4= INTEG (
      "i4%",
      94.462
      )
(106) i4 r = WITH LOOKUP (
      Time,
      (((1981,-4)-(2050,2)),(1980,-1.73),(1981,-1.77),(1982,-1.86),(1983,-1.95
),(1984,-2.03),(1985,-2.11),(1986,-2.16),(1987,-2.18),(1988,-2.11),(1989,-
1.9),(1990,-1.52),(1991,-1),(1992,-0.39),(1993,0.27),(1994,0.85),(1995,1.18
```

```

), (1996, 1.31), (1997, 1.32), (1998, 1.21), (1999, 0.67), (2000, 0.35), (2001, 0.35),
(2002, 0.06), (2003, -0.19), (2004, -0.31), (2005, -0.32), (2006, -0.28), (2007, -0.22
), (2008, -0.15), (2009, -0.14), (2010, -0.14), (2011, -1), (2020, -1), (2050, 0) ))
(107) "i4%"=
      IF THEN ELSE(Time<2010, i4*i4 r/100, i4*"esc-i4"/100)
(108) i5= INTEG (
      "i5%",
      446.103
      )
(109) i5 r = WITH LOOKUP (
      Time,
      ((1981,-4)-(2050,2)), (1980, 2.54), (1981, 2.43), (1982, 2.25), (1983, 2.05), (1984
, 1.84), (1985, 1.69), (1986, 1.59), (1987, 1.5), (1988, 1.41), (1989, 1.24), (1990, 1.05
), (1991, 0.9), (1992, 0.82), (1993, 0.8), (1994, 0.87), (1995, 0.97), (1996, 1.05), (1997
, 1.14), (1998, 1.23), (1999, 1.34), (2000, 1.38), (2001, 1.27), (2002, 1.06), (2003, 0.75
), (2004, 0.39), (2005, 0.02), (2006, -0.3), (2007, -0.51), (2008, -0.58), (2009, -0.61
), (2010, -0.61), (2011, -1), (2020, -1), (2050, 0) ))
(110) "i5%"=
      IF THEN ELSE(Time<2010, i5*i5 r/100, i5*"esc-i5"/100)
(111) INITIAL TIME = 1980
      Units: year
      The initial time for the simulation.
(112) m11= INTEG (
      ("m11%"/100)*es11,
      5/100)
(113) m11 r = WITH LOOKUP (
      Time,
      ((1980,10)-(2010,100)), (1980,0), (2010,0) ))
(114) "m11%"=
      IF THEN ELSE(Time<2010, m11*m11 r/100, m11*"esc-m11"/100)
(115) m12= INTEG (
      "m12%"/100*es12,
      0/100)
(116) "m12%"=
      IF THEN ELSE(Time<2010, m12*"esc-m12 r"/100, m12*"esc-m12"/100)
(117) m13=
      (1-(m11+m12))*es13
(118) m21= INTEG (
      ("m21%"/100)*es11,
      5/100)
(119) m21 r = WITH LOOKUP (
      Time,
      ((1980,10)-(2010,100)), (1980,0), (2010,0) ))
(120) "m21%"=
      IF THEN ELSE(Time<2010, m21*m21 r/100, m21*"esc-m21"/100)
(121) m22= INTEG (
      "m22%"/100*es12,
      0/100)
(122) m22 r = WITH LOOKUP (
      Time,

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```

((1980,10)-(2010,100)),(1980,20),(2010,20) ))
(123) "m22%"=
      IF THEN ELSE(Time<2010, m22*m22 r/100, m22*"esc-m22"/100)
(124) m23=
      (1-(m21+m22))*es13
(125) m31= INTEG (
      ("m31%"/100)*es11,
      5/100)
(126) m31 r = WITH LOOKUP (
      Time,
      ((1980,10)-(2010,100)),(1980,0),(2010,0) ))
(127) "m31%"=
      IF THEN ELSE(Time<2010, m31*m31 r/100, m31*"esc-eef31"/100)
(128) m32= INTEG (
      "m32%"/100*es12,
      0/100)
(129) m32 r = WITH LOOKUP (
      Time,
      ((1980,10)-(2010,100)),(1980,0),(2010,0) ))
(130) "m32%"=
      IF THEN ELSE(Time<2010, m32*m32 r/100, m32*"esc-m32"/100)
(131) m33=
      (1-(m31+m32))*es13
(132) m41= INTEG (
      ("m41%"/100)*es11,
      5/100)
(133) m41 r = WITH LOOKUP (
      Time,
      ((1980,10)-(2010,100)),(1980,0),(2010,0) ))
(134) "m41%"=
      IF THEN ELSE(Time<2010, m41*m41 r/100, m41*"esc-m41"/100)
(135) m42= INTEG (
      "m42%"/100*es12,
      0/100)
(136) "m42%"=
      IF THEN ELSE(Time<2010, m42*"es-m42 r"/100, m42*"esc-m42"/100)
(137) m43=
      (1-(m41+m42))*es13
(138) m51= INTEG (
      ("m51%"/100)*es11,
      1/100)
(139) "m51%"=
      IF THEN ELSE(Time<2010, m51*ef51 r/100, m51*"esc-m51"/100)
(140) m52= INTEG (
      "m52%"/100*es12,
      0/100)
(141) m52 r = WITH LOOKUP (
      Time,
      ((1980,10)-(2010,100)),(1980,0),(2010,0)))
```

```

(142) "m52%"=
      IF THEN ELSE(Time<2010, m52*m52 r/100, m52*"esc-m52"/100)
(143) m53=
      (1-(m51+m52))*es13
(144) pob= INTEG (
      "pob %",
      7.94689e+006)
(145) "pob %"=
      IF THEN ELSE(Time<2010,pob*pob r/100,pob*"esc-pob"/100)
(146) pob r = WITH LOOKUP (
      Time,
      (((1980,0)-(2025,4)),(1980,2.91),(1981,2.83),(1982,2.75),(1983,2.68),(1984
      ,2.61),(1985,2.55),(1986,2.48),(1987,2.41),(1988,2.35),(1989,2.27),(1990,2.2
      ),(1991,2.12),(1992,2.05),(1993,1.97),(1994,1.9),(1995,1.84),(1996,1.78),(
      1997,1.74),(1998,1.7),(1999,1.68),(2000,1.66),(2001,1.64),(2002,1.63),(2003
      ,1.61),(2004,1.59),(2005,1.57),(2006,1.54),(2007,1.52),(2008,1.5),(2009,1.47
      ),(2010,1.44),(2025,1.3) ))
(147) Q=
      1.20772*c + 1.15776*i + 0.997272*tb + 504457*eimp - 4.98877e+006*RN +
      9.63411e+009
      EXP(0.162483*LN(i)-0.005391*LN(tb)+0.961963*LN(c)-0.122869*LN(eim
      p)-0.166514*LN(RN))
(148) q1=
      Q*s1
(149) q2=
      Q*s2
(150) q3=
      Q*s3
(151) q4=
      Q*s4
(152) q5=
      Q*s5
(153) Qpc=
      Q/pob
(154) RN= INTEG (
      (es2+es3)*E/100 - RN,
      1087.42)
(155) s1=
      100-(s2+s3+s4+s5)
(156) s2= INTEG (
      "s2%",
      14.1344)
(157) s2 r = WITH LOOKUP (
      Time,
      (((1981,-1)-(2025,6)),(1980,0.04),(1981,0.04),(1982,0.04),(1983,0.03),(1984
      ,0.03),(1985,0.02),(1986,0.01),(1987,-0.02),(1988,-0.06),(1989,-0.1),(1990
      ,-0.16),(1991,-0.23),(1992,-0.32),(1993,-0.44),(1994,-0.53),(1995,-0.58),(
      1996,-0.65),(1997,-0.74),(1998,-0.82),(1999,-0.87),(2000,-0.77),(2001,-0.56
      ),(2002,-0.24),(2003,0.15),(2004,0.61),(2005,1.03),(2006,1.4),(2007,1.67),
      (2008,1.8),(2009,1.81),(2010,1.81),(2011,1),(2030,1),(2050,0) ))

```

## 7. APPENDIX

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```
(158) "s2%"=
      IF THEN ELSE(Time<2010, s2*s2 r/100, s2**"esc-s2"/100 )
(159) s3= INTEG (
      "s3%",
      8.34912)
(160) s3 r = WITH LOOKUP (
      Time,
      (((1981,-2)-(2030,6)),(1980,0.03),(1981,0.03),(1982,0.03),(1983,0.02),(1984
      ,-0.01),(1985,-0.04),(1986,-0.09),(1987,-0.15),(1988,-0.23),(1989,-0.34),(
      1990,-0.48),(1991,-0.6),(1992,-0.73),(1993,-0.85),(1994,-0.99),(1995,-1.03
      ),(1996,-0.83),(1997,-0.52),(1998,-0.05),(1999,0.71),(2000,1.4),(2001,1.9)
      ,(2002,2.21),(2003,2.44),(2004,2.58),(2005,2.68),(2006,2.67),(2007,2.56),(
      2008,2.45),(2009,2.31),(2010,2.31),(2020,0.85) ))
(161) "s3%"=
      IF THEN ELSE(Time<2010,s3*s3 r/100,s3**"esc-s3"/100)
(162) s4= INTEG (
      "s4%",
      39.4618
      )
(163) s4 r = WITH LOOKUP (
      Time,
      (((1981,-4)-(2050,6)),(1980,0.02),(1981,0.02),(1982,0.02),(1983,0.02),(1984
      ,0.02),(1985,0.02),(1986,0.01),(1987,0),(1988,-0.01),(1989,-0.03),(1990,-0.06
      ),(1991,-0.09),(1992,-0.14),(1993,-0.21),(1994,-0.26),(1995,-0.3),(1996,-0.35
      ),(1997,-0.43),(1998,-0.53),(1999,-0.64),(2000,-0.75),(2001,-0.91),(2002,-
      1.11),(2003,-1.32),(2004,-1.52),(2005,-1.74),(2006,-1.96),(2007,-2.15),(2007
      ,-2.15),(2008,-2.3),(2009,-2.38),(2010,-2.38),(2011,1),(2030,1),(2050,5) )
      )
(164) "s4%"=
      IF THEN ELSE(Time<2010,s4*s4 r/100,s4**"esc-s4"/100)
(165) s5= INTEG (
      "s5%",
      9.38983)
(166) s5 r = WITH LOOKUP (
      Time,
      (((1981,-0.2)-(2030,6)),(1980,-0.05),(1981,-0.04),(1982,-0.04),(1983,-0.03
      ),(1984,-0.02),(1985,0.01),(1986,0.04),(1987,0.1),(1988,0.17),(1989,0.26),
      (1990,0.37),(1991,0.48),(1992,0.61),(1993,0.76),(1994,0.88),(1995,0.89),(1995
      ,0.89),(1996,0.84),(1997,0.74),(1998,0.6),(1999,0.43),(2000,0.22),(2001,0.07
      ),(2002,-0.03),(2003,-0.1),(2004,-0.13),(2005,-0.15),(2006,-0.16),(2007,-0.16
      ),(2008,-0.16),(2009,-0.16),(2010,-0.16),(2020,0.23) ))
(167) "s5%"=
      IF THEN ELSE(Time<2010,s5*s5 r/100,s5**"esc-s5"/100)
(168) SAVEPER =
      TIME STEP
      Units: year [0,?]
      The frequency with which output is stored.
(169) tb= INTEG (
      "tb %",
      -8.6961e+008
```

```

)
(170) "tb %"=
      IF THEN ELSE(Time<2010,tb*tb r/100,tb**esc-tb"/100)
(171) tb r = WITH LOOKUP (
      Time,
      (((1980,-100)-(2025,2000)),(1980,-2.41),(1981,-2.35),(1982,-2.11),(1983,
      0.42),(1984,4.08),(1985,6.16),(1986,2.96),(1987,-4.64),(1988,-12.71),(1989
      ,-20.99),(1990,-26.61),(1991,-27.87),(1992,-22.77),(1993,-16.32),(1994,-9.21
      ),(1995,-0.28),(1996,-88.44),(1997,1147.95),(1998,26.33),(1999,36.89),(2000
      ,36.92),(2001,25.98),(2002,16.27),(2003,12.15),(2004,11.77),(2005,14.05),(
      2006,17.61),(2007,19.98),(2008,20.09),(2009,18.13),(2010,-4.12),(2025,-4.12
      )))
(172) TIME STEP = 1
      Units: year [0,?]
      The time step for the simulation.
(173) uT1=
      15.3*(44/12)*(0.041868)
(174) uT2=
      25.8*(44/12)*(0.041868)
(175) uT3=
      20*(44/12)*(0.041868)

```



## **7.7 Appendix G**

Appendix G presents the outcomes of the Seemingly Unrelated Regression (SUR) method that was used to solve the equation system in Section 3.7 in Chapter 3.

## 7. APPENDIX

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Appendix G

Estimation Method: Seemingly Unrelated Regression

Estimation Method: Seemingly Unrelated Regression

Date: 09/01/13 Time: 19:22

Sample: 1980 2010

Included observations: 31

Total system (balanced) observations 155

Linear estimation after one-step weighting matrix

|       | Coefficient | Std. Error | t-Statistic | Prob,  |
|-------|-------------|------------|-------------|--------|
| C(1)  | 1,411105    | 0,031502   | 44,79468    | 0      |
| C(2)  | 1,752995    | 0,146469   | 11,96841    | 0      |
| C(3)  | 1,208262    | 0,035874   | 33,68085    | 0      |
| C(4)  | 9,68E-04    | 1,04E-04   | 9,338675    | 0      |
| C(5)  | 0,001155    | 0,000616   | 1,874391    | 0,063  |
| C(13) | 3,310063    | 0,702734   | 4,710266    | 0      |
| C(6)  | 0,005679    | 0,002423   | 2,343685    | 0,0205 |
| C(7)  | 0,327665    | 0,020958   | 15,6341     | 0      |
| C(14) | -6,783069   | 3,187221   | -2,128208   | 0,0351 |
| C(8)  | 6,58E-05    | 7,27E-06   | 9,057015    | 0      |
| C(9)  | -0,00152    | 0,00034    | -4,47011    | 0      |
| C(15) | 1,869575    | 0,39524    | 4,730229    | 0      |
| C(10) | -30,54406   | 6,371385   | -4,793943   | 0      |
| C(16) | 27537,82    | 8409,2     | 3,274726    | 0,0013 |
| C(11) | -0,004048   | 1,28E-04   | -31,69594   | 0      |
| C(12) | 1,85435     | 0,945702   | 1,960819    | 0,0519 |
| C(17) | 0,353807    | 1,349733   | 0,262131    | 0,7936 |

Appendix G

Estimation Method: Seemingly Unrelated Regression

Determinant residual covari: 3,90E+02

Equation:  $QT=C(1)*IT+C(2)*TBT+C(3)*CHT+C(4)*EIMPXENT+C(5)*RNXENT+C(13)$

Observations: 31

|                 |          |                    |          |
|-----------------|----------|--------------------|----------|
| R-squared       | 0,999984 | Mean dependent var | 75,38    |
| Adjusted R-sq   | 0,999981 | S,D, dependent var | 19,47725 |
| S,E, of regress | 0,085893 | Sum squared resid  | 0,184442 |
| Durbin-Watson   | 0,351924 |                    |          |

Equation:  $IT=C(6)*RNXENT+C(7)*CHT+C(14)$

Observations: 31

|                 |          |                    |          |
|-----------------|----------|--------------------|----------|
| R-squared       | 0,861443 | Mean dependent var | 17,0929  |
| Adjusted R-sq   | 0,851546 | S,D, dependent var | 5,026978 |
| S,E, of regress | 1,936881 | Sum squared resid  | 105,0422 |
| Durbin-Watson   | 0,068576 |                    |          |

Equation:  $TBT=C(8)*EIMPXENT+C(9)*RNXENT+C(15)$

Observations: 31

|                 |          |                    |           |
|-----------------|----------|--------------------|-----------|
| R-squared       | 0,895226 | Mean dependent var | -0,970968 |
| Adjusted R-sq   | 0,887742 | S,D, dependent var | 0,326687  |
| S,E, of regress | 0,109456 | Sum squared resid  | 0,335459  |
| Durbin-Watson   | 0,374838 |                    |           |

Equation:  $EIMPXENT=C(10)*RNXENT+C(16)$

Observations: 31

|                 |          |                    |           |
|-----------------|----------|--------------------|-----------|
| R-squared       | 0,423466 | Mean dependent var | -12715,41 |
| Adjusted R-sq   | 0,403586 | S,D, dependent var | 3418,343  |
| S,E, of regress | 2639,913 | Sum squared resid  | 2,02E+08  |
| Durbin-Watson   | 0,050567 |                    |           |

Equation:  $CHT=C(11)*EIMPXENT+C(12)*TBT+C(17)$

Observations: 31

|                 |          |                    |          |
|-----------------|----------|--------------------|----------|
| R-squared       | 0,972547 | Mean dependent var | 50,02516 |
| Adjusted R-sq   | 0,970586 | S,D, dependent var | 13,53326 |
| S,E, of regress | 2,321005 | Sum squared resid  | 150,8378 |
| Durbin-Watson   | 0,091579 |                    |          |



# Bibliography

- [1] Nickelback. When We Stand Together. <http://www.youtube.com/watch?v=B5VM5aq4rmY>, 2011. i
- [2] Arent D., Alison W., and Rachel G. The status and prospects of renewable energy for combating global warming. *Energy Economics*: 33: 584–593, 2011. xvii, 4, 5, 10, 66
- [3] CONELEC (National Council for Electrification of Ecuador). Electrification Master Plan 2009-2020. <http://www.conelec.gob.ec/documentos.php?cd=4171&l=1>, 2009. xviii, 63, 64, 65, 67, 68
- [4] Bruckner T., Chum H., Jäger-Waldau A., Killingtveit Å., Gutiérrez-Negrín L., Nyboer J., Musial W., Verbruggen A., 2011: Annex III: Cost Table. In IPCC Special Report on Renewable Energy Sources Wiser R., Climate Change Mitigation [Edenhofer O., Pichs-Madruga R., Sokona Y., Seyboth K., Matschoss P., Kadner S., Zwickel T., Eickemeier P., Hansen G., Schlömer S., and von Stechow C. (eds)]. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 2011. xviii, 64, 67, 68
- [5] Chien T. and Hu Jin-Li. Renewable energy: An efficient mechanism to improve *gdp*. *Energy Policy* 36, 3045-3052, 2008. xviii, 72, 76, 78, 79, 80, 81, 83, 154, 157

## BIBLIOGRAPHY

---

- [6] IPCC (Intergovernmental Panel on Climate Change). *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Volume 2: Energy*. Cambridge University Press, 2006. xviii, 87, 88, 89, 90
- [7] Islam N., Vincent J., and Panayotou T. Unveiling the income–environment relationship: an exploration into the determinants of environmental quality. <http://www.cid.harvard.edu/hiid/701.pdf>, 1999. xx, 139
- [8] Iglesias J., Carmona M., Golpe A., and Martin J.M. La curva de Kuznets y la emission de CO<sub>2</sub> en Espana, 1850-2008. *Economía Industrial*, 2013. xx, 146
- [9] EC (European Commission). Climate action. The 2020 climate and energy package'. [http://ec.europa.eu/clima/policies/package/index\\_en.htm](http://ec.europa.eu/clima/policies/package/index_en.htm), May 2014. 1
- [10] Melillo Jerry M., Terese (T.C.) Richmond, and Gary W. Yohe. *Highlights of Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program*. U.S. Government Printing Office. ISBN 9780160924033, 2014. 1
- [11] United Nations (UN). Rio Declaration on Environment and Development 1992. Technical report, United Nations (UN), 1992. 2
- [12] IEA (International Energy Agency). Clean Energy Progress Report. [http://www.iea.org/publications/tcep\\_web.pdf](http://www.iea.org/publications/tcep_web.pdf), 2011. 4
- [13] WEC (World Energy Council). 2010 Survey of Energy Resources. [http://www.worldenergy.org/documents/ser\\_2010\\_report\\_1.pdf](http://www.worldenergy.org/documents/ser_2010_report_1.pdf), 2010. 4
- [14] Wisner R., Yang Z., Hand M., Hohmeyer O., Infield D., Jensen P. H., Nikolaev V., O'Malley M., Sinden G., 2011: Wind Energy. In IPCC Special Report on Renewable Energy Sources Zervos A., Climate Change Mitigation [Edenhofer O., Pichs-Madruga R., Sokona Y., Seyboth K., Matschoss P., Kadner S., Zwickel T., Eickemeier P., Hansen G., Schlömer S., and von Stechow

## BIBLIOGRAPHY

---

- C. (eds)]. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2011. 4, 5, 66
- [15] Couture T., Cory K., Kreycik C., and Williams E. *Policymaker's Guide to Feed-in Tariff Policy Design*. National Renewable Energy Laboratory, U.S. Dept. of Energy, 2010. 5
- [16] Arvizu D., Balaya P., Cabeza L., Hollands T., Jäger-Waldau A., Kondo M., Konseibo C., Meleshko V., Stein W., Tamaura Y., Xu H., 2011: Direct Solar Energy. In IPCC Special Report on Renewable Energy Sources Zilles R., Climate Change Mitigation [Edenhofer O., Pichs-Madruga R., Sokona Y., Seyboth K., Matschoss P., Kadner S., Zwickel T., Eickemeier P., Hansen G., Schlömer S., and von Stechow C. (eds)]. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 2011. 5, 6
- [17] Kammen D. Renewable Energy, Taxonomic Overview. *En Cutler J. Cleveland (Ed.), Encyclopedia of Energy, Berkeley, Elsevier, 2004. 6*
- [18] Chum H., Faaij A., Moreira J., Berndes G., Dhamija P., Dong H., Gabrielle B., Goss Eng A., Lucht W., Mapako M., Masera Cerutti O., McIntyre T., Minowa T., 2011: Bioenergy. In IPCC Special Report on Renewable Energy Sources Pingoud K., Climate Change Mitigation [Edenhofer O., Pichs-Madruga R., Sokona Y., Seyboth K., Matschoss P., Kadner S., Zwickel T., Eickemeier P., Hansen G., Schlömer S., and von Stechow C. (eds)]. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 2011. 7, 8, 69
- [19] Carriquiri M., Xiaodong D., and Govinda T. Second generation biofuels: Economics and policies. *Energy Policy 39: 4222–4234, 2011. 7*
- [20] REN 21 (Renewable Energy Policy Network for the 21st Century). *Renewables 2011 Global Status Report*. Paris, REN 21 Secretariat, 2011. 8

## BIBLIOGRAPHY

---

- [21] A. Lewis, Estefen S., Huckerby J., Musial W., Pontes T., 2011: Ocean Energy. In IPCC Special Report on Renewable Energy Sources Torres-Martinez J. and, Climate Change Mitigation [Edenhofer O., Pichs-Madruga R., Sokona Y., Seyboth K., Matschoss P., Kadner S., Zwickel T., Eickemeier P., Hansen G., Schlömer S., and von Stechow C. (eds)]. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 2011. 8
- [22] Goldstein B., Hiriart G., Bertani R., Bromley C., Gutiérrez-Negrín L., Huenges E., Muraoka H., Ragnarsson A., Tester J., 2011: Geothermal Energy. In IPCC Special Report on Renewable Energy Sources Zui V., Climate Change Mitigation [Edenhofer O., Pichs-Madruga R., Sokona Y., Seyboth K., Matschoss P., Kadner S., Zwickel T., Eickemeier P., Hansen G., Schlömer S., and von Stechow C. (eds)]. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA., 2011. 8, 9
- [23] Kriegler E. Comment. *Energy Economics* 33: 594–596, 2011. 11, 12
- [24] R. Sims, Mercado P., Krewitt W., Bhuyan G., Flynn D., Holttinen H., Jannuzzi G., Khennas S., Liu Y., O'Malley M., Nilsson L. J., Ogden J., Ogimoto K., Outhred H., Ulleberg Ø., 2011: Integration of Renewable Energy into Present van Hulle F., Future Energy Systems. In IPCC Special Report on Renewable Energy Sources, Climate Change Mitigation [Edenhofer O., Pichs-Madruga R., Sokona Y., Seyboth K., Matschoss P., Kadner S., Zwickel T., Eickemeier P., Hansen G., Schlömer S., and von Stechow C. (eds)]. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 2011. 11, 66
- [25] IPCC (Intergovernmental Panel On Climate Change). *Summary for Policymakers*. in von Stechow C. and Edenhofer O. and Pichs-Madruga R. and Sokona Y. and Seyboth K. and Matschoss P. and Kadner S. and Zwickel T.

## BIBLIOGRAPHY

---

- and Eickemeier P. and Hansen G. and Schlömer S.(Eds.), IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation. Cambridge, Cambridge University Press,, 2011. 11*
- [26] Lund H. and Mathiesen B. Energy system analysis of 100% renewable energy systems- The case of Denmark in years 2030 and 2050. *Energy 34: 524– 531*, 2009. 11
- [27] Bayod-Rújula A. Future development of the electricity systems with distributed generation. *Energy 34: 377-383*, 2009. 12
- [28] Ebinger J. and Vergara W. Climate Impacts on Energy Systems. Key Issues for Energy Sector Adaptation. Energy Sector Management Assistance Program (ESMAP). Technical report, Washington DC.,The World Bank, 2010. 12
- [29] Bouffard F. and Kirschen D. Centralised and distributed electricity systems. *Energy Policy 36: 4504-4508*, 2008. 12
- [30] Nair N. and Zhang L. SmartGrid: Future networks for New Zealand power systems incorporating distributed generation. *Energy Policy 37: 3418–3427*, 2009. 12
- [31] Lindley D. The Energy Storage Problem. *Nature. 463: 18-20*, 2010. 12, 13
- [32] Van't Klooster S.A. and van Asselt M.B.A. Practicing the scenario-axis technique. *Futures 38 (1), 15-30*, 2006. 13
- [33] J.S. Armstrong. *Principles of forecasting. A handbook for researchers and practitioners*. Springer science and business media, New York, New York, 2001. 13
- [34] Agnolucci P., Ekins P. abd Iacopini G., Anderson K., Bows A., Mander S., and S. Shackley. Different scenarios for achieving radical reduction in carbon emissions: a decomposition analysis. *Ecological Economics 68, 1652–1666*, 2009. 13, 20

## BIBLIOGRAPHY

---

- [35] Linderoth H. Forecast errors in IEA-countries' energy consumption. *Energy Policy* 30, 53-61, 2002. 13, 14
- [36] Winebrake J.J. and D. Savka. An evaluation of errors in US energy forecasts: 1982–2003. *Energy Policy* 34, 3475–3483, 2006. 13
- [37] O'Neill B.C. and Desai M. Accuracy of past projections of US energy consumption. *Energy Policy* 33 (8), 979-993, 1996. 14
- [38] Pilavachi P.A., Dalamaga T., Rossetti di Valdalbero D., and Guilmot J.F. Ex-post evaluation of European energy models. *Energy Policy* 36(5), 1726-1735, 2008. 14
- [39] H. de Jouvenel. A brief methodological guide to scenario building. *Technological Forecasting and Social Change* 65, 37–48, 2000. 14
- [40] Nielsen S. K. and Karlsson K. Energy scenarios: a review of methods, uses and suggestions for improvement. *International Journal Global Energy Issues* 27 (3), 2007. 14, 21, 22, 96
- [41] Middtun A. and Baumgartner T. Negotiating Energy Futures: The Politics of Energy Forecasting. *Energy Policy* 14, 219-41, 1986. 14
- [42] IPCC (Intergovernmental Panel on Climate-Change). *2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme*. Cambridge University Press, 2006. 16, 87, 94, 155, 156
- [43] Pyle D. *Data Preparation for Data Mining*. Morgan Kaufmann Publishers, Los Altos, California, 1999. 16
- [44] Kotsiantis S., Kanellopoulos D., and Pintelas P. Data Preprocessing for Supervised Learning. *International Journal of Computer Science*, 2006, Vol 1 N. 2, pp 111-117, 2006. 17
- [45] Hodrick R. and Prescott E. Postwar U.S. Business Cycles: an Empirical Investigation. *Carnegie-Mellon University; Discussion Papers 451, Northwestern University*, 1980. 17

## BIBLIOGRAPHY

---

- [46] Finn E. Kydland and Prescott E. Business Cycles: Real Facts and a Monetary Myth. *Quarterly Review* 14 (2): 3–18, Federal Reserve Bank of Minneapolis, 1990. 17
- [47] H. Kim. Hodrick–prescott filter. 2004. 17
- [48] York R., Rosa E. A., and Dietz T. STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts. *Ecological Economics* 46(3), 351–365, 2003. 18
- [49] Commoner B. A Bulletin Dialogue on The Closing Circle. *Response. Bulletin of the Atomic Scientists* 28 (17), 42-56, 1972. 18
- [50] Ehrlich P. R. and Holdren J.P. A Bulletin Dialogue on the Closing Circle: Critique. One-Dimensional Ecology. *Bulletin of the Atomic Scientists* 28:16-27, 1972. 18
- [51] Y. Kaya. Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios. *Paper presented to the IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris, (mimeo)*, 1990. 18, 20
- [52] IPCC (Intergovernmental Panel On Climate Change). *IPCC Special Reports. Emissions Scenarios*. Cambridge University Press, The Edinburgh Building Shaftesbury Road, Cambridge CB2 2RU England, 2000. 18, 21
- [53] Ang B.W. Decomposition analysis for policymaking in energy: which is the preferred method? *Energy Policy* 32, 2004. 19, 112, 121, 126
- [54] Steenhof P., Woudsma C., and Sparling E. *Greenhouse gas emissions and the surface transport of freight in Canada*. Transportation Research Part D-Transport and Environment 11 (5), 369–376, 2006. 19, 20
- [55] Waggoner P.E. and Ausubel J.H. A framework for sustainability science: a renovated IPAT identity. *Proceedings of the National Academy of Sciences* 99 (12), 7860-7865, 2002. 19

## BIBLIOGRAPHY

---

- [56] Ang B.W. and Zhang F.Q. A survey of index decomposition analysis in energy and environmental analysis. *Energy* 25, 1149-1176, 2000. 20, 115, 116, 118, 119, 120, 121
- [57] Sun J.W. Energy demand in the fifteen European Union countries by 2010 -A forecasting model based on the decomposition approach. *Energy* 26, 549-560, 2001. 20
- [58] Sorrell S., Lehtonen M., Stapleton L., J. Pujol, and T. Champion. Decomposing road freight energy use in the United Kingdom. *Energy Policy* 37 (8), 3115-3129, 2009. 20
- [59] Kwon T.H. A scenario analysis of CO<sub>2</sub> emission trends from car travel: Great Britain 2000-2030. *Transport Policy* 12 (2), 175-184, 2005. 20
- [60] P. Steenhof. Decomposition for emission baseline setting in China's electricity sector. *Energy Policy* 35 (1), 280-294, 2007. 20
- [61] Van Notten P., Rotmans J., van Asselt M., and Rothman D. An updated scenario typology. *Futures* 35 (5), 423-443, 2003. 21
- [62] Silbergliitt R., Hove A., and Shulman P. Silbergliitt R. and Hove A. and Shulman P. *Technological Forecasting and Social Change* 70 (4), 297-315, 2003. 21
- [63] Alcamo J. Environmental Futures. The practice of environmental scenario analysis. *Developments in Integrated Environmental Assessment 2. Elsevier, Amsterdam, the Netherlands*, 2009. 21
- [64] Borjeson L., Höjer M., Dreborg K., Ekvall T., and G. Finnveden. Scenario types and techniques: towards a user's guide. *Futures* 38, 723-739, 2006. 21
- [65] Nakicenovic N., Alcamo J. and Davis G., de Vries B., Fenham J., Gaffin S., Gregory K., Grübler A., Jung T.-Y., Kram T., La Rovere E.L., Michaelis L., Mori S., Morita T., Pepper W., Pitcher H., Price L., Riahi K., Reohl A., Rogner H.H., Sankovski A., Schlesinger M., Shukla P., Smith S., Swart

## BIBLIOGRAPHY

---

- R., van Rooijen S., Victor N., and Dadi Z. *Special report on emissions scenarios. Working Group III, Intergovernmental Panel on Climate Change (IPCC)*. Cambridge University Press, Cambridge, 2000. 21, 95, 163
- [66] Great Britain. Dept. of Energy. Economics and Statistics Division Great Britain. Dept. of Energy. *Energy Forecasting Methodology Número 29 de Energy paper*. Stationery Office, ISBN 0114106509, 9780114106508, 1978. 22
- [67] Johansen L. *A multi-sectoral study of economic growth*. North-Holland Pub. Co., 1974 - Business and Economics, 74. 22
- [68] Toshihiko N. Energy-economic models and the environment. *Progress in Energy and Combustion Science* 2004;30(4):417-475, 2004. 22
- [69] Wei Y.M., Wu G., Liu L.C., and Fan Y. Progress in modeling for energy-economy-environment complex system and its applications. *Chinese Journal of Management* 2005;3(2):159-170, 2005. 23
- [70] Grohnheit P. Economic interpretation of the EFOM model. *Butterworth-Heinemann Ltd-0140-9883/91/020143-10 1991*, 1991. 23
- [71] Van der Voort E., Donni E., Thonet C., Bois d'Enghien, Dechamps C., and Guilmot J. F. Energy Supply Modelling Package EFOM 12 C Mark I - Mathematical Description, CABAY,. Technical report, Commission of the European Communities, 1984., 1984. 23
- [72] Leontief W. *Input-output economics*. New York, Oxford University Press, 1966, 1966. 23
- [73] Thijs Ten Raa. *Input-output economics: theory and applications: featuring Asian economies*. World Scientific Publishing Co. Pte. Ltd., 2010. 23
- [74] William H.M. *Basic Theory of input-output analysis*. Beijing: China Social Sciences Press 1980, 1980. 23

## BIBLIOGRAPHY

---

- [75] Lazarus M., Heaps C., and von Hippel D. Methods for assessment of mitigation options Appendix IV: Mitigation Assessment Handbook. Technical report, Stockholm Environment Institute and Tellus Institute, 1994. 24
- [76] Joost S. The Long-range energy alternatives planning model (LEAP) and wood energy planning. [http://www.rwedp.org/p\\_leap.html](http://www.rwedp.org/p_leap.html), 2004. 24
- [77] Naughten B. Economic assessment of combined cycle gas turbines in Australia some effects of microeconomic reform and technological change. *Energy Policy* 2003;31(3):225–245, 2003. 24
- [78] Evasio L. Exploring energy technology perspectives. <http://www.etsap.org/markal/main.html>, March 2004. 24
- [79] Radzicki M.J. and Taylor R.A. *Origin of System Dynamics: Jay W. Forrester and the History of System Dynamics*. U.S. Department of Energy's Introduction to System Dynamics. Retrieved 23 Oktober 2008, 2008. 25
- [80] Meadows D.H., Meadows D.M., Randers J., and Behrens W. *Limits to Growth*. New York, Universe books. ISBN 0-87663-165-0, 1972. 25
- [81] Naill R.F., Gelanger S., Klinger A., and Petersen E. An analysis of cost effectiveness of US energy policies to mitigate global warming. *System Dynamics Review* 8, 111-118, 1992. 26
- [82] Nordhaus W. and Z Yang. A regional dynamic general-equilibrium model of Alternative climate-change strategies. *The American Economic Review* 86, 741-765, 1996. 26
- [83] Fiddaman Thomas S. Exploring policy with a behavioral climate-economy model. *System Dynamics Review*. 18, 243-267, 2002. 26, 71
- [84] Feng Y.Y., Chen S.Q., and Zhang L.X. System dynamics modeling for urban energy consumption and CO<sub>2</sub> emissions: a case study of Beijing, China. *Ecological Modelling* 2013;252:44–52, 2012. 26

## BIBLIOGRAPHY

---

- [85] A. Bassi and Baer A. Quantifying cross-sectoral impacts of investments in climate change mitigation in Ecuador. *Energy for Sustainable Development* 13, 116-123, 2009. 26
- [86] System Dynamics Society. Introduction to System Dynamics. <http://www.systemdynamics.org/what-is-s/>, January 2014. 26
- [87] García J. *Theory and Practical Exercises of System Dynamics*. Spain. ISBN 84-607-9304-4, Legal Deposit B-4958-2003, 2011. 26, 72
- [88] Forrester J.W. *Urban Dynamics*. Cambridge, MA: The MIT Press. Reprinted by Pegasus Communications, 1969. 29, 30
- [89] Kuznets P. and Simon P. Economic growth and income inequality. *American Economic Review* 45, 1– 28, 1955. 31, 137
- [90] Dasgupta S., Laplante B., Wang H., and Wheeler D. Confronting the Environmental Kuznets Curve. *Journal of Economic Perspectives* 16 (1), 147–168, 2002. 32
- [91] Anderson D. and Cavandish W. Dynamic simulation and environmental policy analysis: beyond comparative statics and environmental Kuznets curve. *Oxford Economic Papers* 53, 721– 746, 2001. 32, 40
- [92] Beckerman W. Economic growth and the environment: whose growth? Whose environment? *Development* 20, 481–496, 1992. 32, 140
- [93] Shafik N. and Bandyopadhyay S. Economic Growth and Environmental Quality: Time Series and Cross-Country Evidence. Background Paper for the World Development Reportk. Technical report, The World Bank, Washington, DC, 1992. 32, 138
- [94] Dinda S. Environmental Kuznets Curve Hypothesis: A Survey. *Ecological Economics* 49 (2004) 431–455, 2004. 32, 34, 35, 38, 39, 40, 138, 139, 140, 141, 142, 144

## BIBLIOGRAPHY

---

- [95] Gangadharan L. and Valenzuela M.R. Inter-relationships between income, health and the environment: extending the Environmental Kuznets curve hypothesis. *Ecological Economics* 36 (3), 513– 531, 2001. 33
- [96] Dinda S., Coondoo D., and Pal M. Air quality and economic growth: an empirical study. *Ecological Economics* 34 (3), 409– 423, 2000. 33
- [97] Grossman G.M. and Krueger A.B. Economic growth and the environment. *Quarterly Journal of Economics* 110 (2), 353– 377, 1995. 33, 35
- [98] de Bruyn S.M. and J.B. Opschoor. Developments in the throughput – income relationship: theoretical and empirical observations. *Ecological Economics* 20, 255– 268, 1997. 33
- [99] Sengupta R.P. CO<sub>2</sub> emission–income relationship: policy approach for climate control. *Pacific Asia Journal of Energy* 7 (2), 207– 229, 1997. 33
- [100] de Bruyn S.M., van den bergh J.C.J.M., and Opschoor J.B. Economic growth and emissions: reconsidering the empirical basis of Environmental Kuznets Curves. *Ecological Economics* 25, 161–175, 1998. 33
- [101] Dijkgraaf E. and Vollebergh H.R.S. Growth and environment— is there a Kuznets curve for carbon emissions? *University of Geneva*, 1998. 33, 37
- [102] Stern D.I. and Common M.S. Is there an environmental Kuznets curve for sulfur? *Journal of Environmental Economics and Management* 41 (2), 162– 178, 2001. 33
- [103] Stern D.I., Common M.S., and Barbier E.B. Economic growth and environmental degradation: a critique of the environmental Kuznets curve. *World Development* 24, 1151– 1160, 1996. 33, 38
- [104] Selden T. and Song D. Neoclassical growth, the J Curve for abatement, and the inverted-U Curve for pollution. *Journal of Environmental Economics and management* 29, 162– 168, 1995. 33, 144

## BIBLIOGRAPHY

---

- [105] Arrow K., Bolin B., Costanza R., Folke C., Holling C.S., Janson B., Levin S., K. Maler, Perrings C., and D. Pimental. *Economic growth, carrying capacity, and the environment*. *Science* 15, 91– 95 (reprint in *Ecological Economics*), 1995. 34, 38
- [106] Dinda S. Economic growth with environmental and physical capital: a convergence approach. *Mimeo*, 2003. 34
- [107] Ekins P. *Economic Growth and Environmental Sustainability*. 182– 214 (chap. 7), 1998. 34, 35
- [108] Gruver G.W. Optimal investment in pollution control capital in a neoclassical growth context. *Journal of Environmental Economics and Management* 5, 165– 177, 1976. 34
- [109] Zang H. The stability of the Kuznets Curve: some further evidence. *Application of Economics Letters* 5, 131– 133, 1998. 34
- [110] Panayotou T. Demystifying the environmental Kuznets curve: turning a black box into a policy tool. *Environment and Development Economics* 2, 465– 484, 1997. 34, 35, 38
- [111] Ezzati M., Singer B.H., and D.M. Kammen. Towards an integrated framework for development and environmental policy: the dynamics of Environmental Kuznets Curves. *World Development* 29 (8), 1421–1434, 2001. 35, 144
- [112] Hung M.F. and Shaw D. TEconomic growth and the Environmental Kuznets Curve in Taiwan: a simultaneity model analysis. *Department of Economics, National Cheng-Chi University. Mimeo*, 2002. 35
- [113] O’Neill R.V., Kahn J.R., Duncan J.R., Elliott S., Efrogmson R., Cardwell H., and D.W. Jones. Economic growth and sustainability: a new challenge. *Ecological Applications* 6 (1), 23–24, 1996. 35
- [114] Kaufmann R.K., Davidsdottir B., Garnham S., and P. Pauly. The determinants of atmospheric SO<sub>2</sub> concentrations: reconsidering the environmental Kuznets curve. *Ecological Economics* 25, 209– 220, 1998. 35

## BIBLIOGRAPHY

---

- [115] Dinda S. A theoretical basis for Environmental Kuznets Curve. *Economic Research Unit, Indian Statistical Institute, Kolkata. Mimeo*, 2002. 36, 143, 144
- [116] Tisdell C. Globalisation and sustainability: environmental Kuznets curve and the WTO. *Ecological Economics* 39, 185–196, 2001. 36
- [117] Koop G. and Tole L. Is there an environmental Kuznets curve for deforestation? *Journal of Development Economics* 58, 231–244, 1999. 36
- [118] Taskin F. and O. Zaim. Searching for a Kuznets Curve in environmental efficiency using kernel estimation. *Economics Letters* 68, 217–223, 2000. 37
- [119] Halkos G.E. and Tsionas E.G. Environmental Kuznets Curves: Bayesian evidence from switching regime models. *Energy Economics* 23, 191–210, 2001. 37
- [120] Bartoszezuk P., Ma T., and Y. Nakamari. Environmental Kuznets curve for some countries—regression and agent-based approach. *Japan Advance Institute of science and Technology (mimeo)*, 2001. 37
- [121] Perman R. and Stern D.I. The Environmental Kuznets Curve: implications of non-stationarity. *Australian National University. Mimeo*, 1999. 37
- [122] Coondoo D. and S Dinda. Causality between income and emission: a country group-specific econometric analysis. *Ecological Economics* 40 (3), 351–367, 2002. 37
- [123] Ansuategi A., Barbier E., and Perrings C. *The Environmental Kuznets Curve. In: van den Bergh, J.C.J.M., Hofkes, M.W. (Eds.). Theory and Implementation of Sustainable Development Modelling. Kluwer Academic, Dordrecht, 1998.* 37
- [124] Copeland B.R. and Taylor M.S. Trade and environment: a partial synthesis. *American Journal of Agricultural Economics* 77, 765–771, 1995. 37, 142

## BIBLIOGRAPHY

---

- [125] Suri V. and D. Chapman. Economic growth, trade and the environment: implications for the environmental Kuznets curve. *Ecological Economics* 25, 195–208, 1998. 37
- [126] Agras J. and Chapman D. A dynamic approach to the Environmental Kuznets Curve hypothesis. *Ecological Economics* 28 (2), 267–277, 1999. 37
- [127] Fare R., Grosskopt S., and O. Zaim. An index number approach to measuring environmental performance: an Environmental Kuznets Curve for the OECD countries, (mimeo). *Department of economics, Oregon State University, USA*, 2001. 37
- [128] Grossman G.M. and Krueger A.B. The inverted-U: what does it mean? *Environment and Development Economics* 1 (2), 119–122, 1996. 37
- [129] Dinda S. A note on global EKC in case of CO<sub>2</sub> emission. *Economic Research Unit, Indian Statistical Institute, Kolkata. Mimeo*, 2001. 37
- [130] Cole M.A., Rayner A.J., and Bates J.M. The Environmental Kuznets Curve : an empirical analysis. *Environment and Development. Economics* 2, 401–416, 1997. 38
- [131] John A., Pecchenino R., Schimmelpfenning D., and Schreft S. Short-lived agents and the long-lived environment. *Journal of Public Economics* 58, 127–141, 1995. 38
- [132] Grossman G.M. and Krueger A.B. Environmental impacts of the North American Free Trade Agreement. *NBER. Working paper 3914*, 1991. 38, 114, 138, 139, 141
- [133] Vukina T., Beghin J.C., and Solakoglu E.G. Transition to markets and the environment: effects of the change in the composition of manufacturing output. *Environment and Development Economics* 4 (4), 582–598, 1999. 38, 141

## BIBLIOGRAPHY

---

- [134] Xiaoli H. and Chatterjee L. Impact of growth and structural change on CO<sub>2</sub> emissions of developing countries. *World Development* 25 (3), 395–407, 1997. 38
- [135] Lucas R.E.B., Wheeler D., and Hettige H. Economic development, environmental regulation and the international migration of toxic industrial pollution: 1960 – 1988. In: *Low P. (Ed.) International Trade and the Environment, World Bank discussion paper 159*, 67– 87, 1997. 38
- [136] Komen R., Gerking S., and Folmer H. Income and environmental R and D: empirical evidence from OECD countries. *Environment and Development Economics* 2, 505–515, 1997. 39, 141
- [137] Smulder S. and Bretschger L. Explaining Environmental Kuznets Curves: how pollution induces policy and new technologies. *Center for Economic Research working paper No. 2000- 95, Tilburg University*, 2000. 39
- [138] Lindmark M. An EKC-pattern in historical perspective: carbon dioxide emissions, technology, fuel prices and growth in Sweden 1870– 1997. *Ecological Economics* 42, 333– 347, 2002. 39
- [139] Labys W.C. and Wadell L.M. Commodity lifecycles in US materials demand. *Resources Policy* 15, 238–252, 1989. 39
- [140] Pasche D. and Markus D. Technical progress, structural change, and the environmental Kuznets curve. *Ecological Economics* 42, 381– 389, 2002. 40
- [141] Munasinghe M. Is environmental degradation an inevitable consequence of economic growth: tunneling through the environmental Kuznets curve. *Ecological Economics* 29, 89– 109, 1999. 40, 143
- [142] Stock J. H. and Watson M. W. A simple estimator of cointegrating vectors in higher order integrated systems. *Econometrica* 61, 783-820, 2010. 42, 151, 153, 161

## BIBLIOGRAPHY

---

- [143] Jaunky V. C. The CO<sub>2</sub> emissions-income nexus: Evidence from rich countries. *Energy Policy*, 39 (3), 1228-1240, 2011. 42, 145, 147, 148, 150, 151, 154, 161
- [144] WB (World Bank). Data, statistics and National referents-Ecuador. <http://data.worldbank.org/country/ecuador>, July 2012. 45, 46, 47, 48, 56, 72, 85, 86, 155, 166
- [145] CI (Conservation International). Megadiversity: The 17 Biodiversity Superstars. <http://www.conservation.org/documentaries/Pages/megadiversity.aspx>, March 2012. 45
- [146] TCELDf (The Community Environmental Legal Defense Fund). About the New Constitution 2008. <http://www.Celdf.org>, October 2011. 45, 47
- [147] UNDP (United Nations Development Program). *Human Development Report 2011*. United Nations Development Programme (UNDP), ISBN: 9780230363311, 2012. 45
- [148] IM (IndexMundi). IndexMundi. <http://www.indexmundi.com>, April 2014. 45, 48
- [149] WB (World Bank). Data, statistics and National referents-Ecuador. <http://data.worldbank.org/country/ecuador>, April 2014. 45, 46, 48
- [150] BCE (Ecuadorian Central Bank). BCE indicators homepage. <http://www.bce.fin.ec/indicador.php>, March 2012. 46, 72, 166
- [151] IEA (International Energy Agency). Data Services homepage. <http://www.iea.org/>, 2013. 46, 72, 166
- [152] A. Mosquera-Rodríguez. *Policies and Strategies for Changing the Energy Matrix in Ecuador*. Ministry of Electricity and Renewable Energy, Ecuador, 2008. 48, 52, 53, 54, 55, 62, 86, 98

## BIBLIOGRAPHY

---

- [153] UN (United Nations). *ST/ESA/STAT/SER.M/4/Rev.4*. UNITED NATIONS PUBLICATION, ISBN: 978-92-1-161518-0, 2008. 49
- [154] IPCC (Intergovernmental Panel On Climate Change). *Synthesis Report. Contribution of Working Groups I, II, and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, 2007. 58, 155
- [155] CONELEC (National Council for Electrification of Ecuador). National Council for Electrification (Consejo Nacional de Electrificación). Treatment for energy produced from non-conventional renewable energy resources (CONELEC regulation no. 004/11). <http://www.conelec.gob.ec>, 2011. 62, 63
- [156] Aquaculture MAG (Ministry of Agriculture, Livestock and Fisheries of Ecuador). Major crops of Ecuador, total cropped area, historical series 2000–2011. <http://servicios.agricultura.gob.ec>, Dec 2011. 63
- [157] MEER (Ministry of Electricity and Renewable Energy of Ecuador). Flagship projects. <http://www.energia.gob.ec>, Dec 2011. 63, 65, 67
- [158] ANCUPA (Area national oil palm. Ecuador Association of African Palm Growers). Statistics. <http://www.ancupa.com>, 2013. 63
- [159] USDA (United States Department of Agriculture). Ecuador 2011 biofuels (biodiesel, biotethanol, biomass) sector policy development and outlook. <http://gain.fas.usda.gov>, 2011. 63
- [160] Neira D., Van Den Berg B., and De la Torre F. *The Clean Development Mechanism in Ecuador: A rapid diagnosis of the challenges and opportunities in the Carbon Market*. Interamerican Development Bank, 2006. 63
- [161] CEPAL (Comisión Económica para América Latina y el Caribe). *PROJECT OLADE/CEPAL/GTZ: Study for the Environmental Assessment of the Binational Geothermal Project Tufiño-Chiles-Cerro Negro, LC/R*. CEPAL, 2010. 64

## BIBLIOGRAPHY

---

- [162] CONELEC (National Council for Electrification of Ecuador). National statistics. <http://www.conelec.gob.ec/documentos.php?cd=4171&l=1>, 2009. 64, 67
- [163] CIE (Corporation for the Energy Research). Solar Atlas of Ecuador purposes Electricity Generation. [http://www.conelec.gob.ec/archivos\\_articulo/Atlas.pdf](http://www.conelec.gob.ec/archivos_articulo/Atlas.pdf), 2008. 65
- [164] Taylor D. *Wind Energy. En Godfrey Boyle (Ed.), Renewable Energy: Power for a sustainable future.* Cambridge, Oxford University Press, The Open University, 2011. 66
- [165] Caspary G. Gauging the future competitiveness of renewable energy in Colombia. *Energy Economics*, 31: 443-449, 2009. 67
- [166] Bahrman S., C. Lenker, and Michalek J. A Model Based Approach to Analyze the Effects of Automotive Air Emissions Policy on Consumers, Producers, and Air Quality. *Eco Design and Manufacturing*, 2007. 71
- [167] Kaya Y. and Yokobori K. *Environment, Energy, and Economy: strategies for sustainability.* Conference on Global Environment, Energy, and Economic Development (1993 : Tokyo, Japan)., 1993. 72, 157
- [168] Forrester J. Industrial Dynamics. *Pegasus Communications*, 1961. 72
- [169] Vensim. Simulation environment window. Version PLE. <http://www.vensim.com/>, October 2011. 72
- [170] INEC (Ecuadorian Institute of Statistics and Censuses). National statistics. <http://www.inec.gov.ec>, March 2012. 72, 166
- [171] Hodrick R. and Prescott E. Postwar U.S. Business Cycles: An Empirical Investigation . *Journal of Money, Credit and Banking*, Vol. 29, No. 1 (Feb., 1997), pp. 1-16, 1997. 72, 73, 74
- [172] Alcántara V. and Padilla E. Analysis of CO<sub>2</sub> and its explanatory factors in the different areas of the world. Technical report, Universidad Autonoma de Barcelona, Department of Economics Applied, Spain, 2005. 72

## BIBLIOGRAPHY

---

- [173] Mena-Nieto A., Menaca C., Barrero A., and Bellido M. Application of the system dynamics methodology for modeling and simulation of the greenhouse gas emissions in Cartagena de Indias (Colombia). *In: AEIPRO, editor. Selected proceedings from the 13th international congress on project engineering. Spain: Badajoz; 2009. p. 260–77, 2009.* 72
- [174] Begueri G. System Dynamics: A New Approach. Technical report, Universidad Nacional de San Juan, Argentina, 2001. 72
- [175] Radzicki M.J. and Tauheed L. In Defense of System Dynamics: A Response to Professor Hayden . *Journal of Economic Issues* 43 (4), 1043-1061, 2009. 72
- [176] Tan B., Anderson E.G.Jr., Dyer J.S., and Parker G.G. Evaluating system dynamics models of risky projects using decision trees: alternative energy projects as an illustrative example. *System Dynamics Review* 26 (1), 1-17, 2010. 72
- [177] Rowland D. *Demographic methods and concepts, chap 2, population growth and decline.* Oxford University Press Oxford University Press; 2003, 2003. 74, 91
- [178] Jin Y., Yumi T., Tatsuya T., Shigehide S., and Kei ichi T. Mathematical equivalence of geometric mean fitness with probabilistic optimization under environmental uncertainty. *Ecol Model* 2009;220:26112617, 2009. 74, 91
- [179] Zellner A. An Efficient Method of Estimating Seemingly Unrelated Regressions and Tests for Aggregation Bias. *Journal of the American Statistical Association, Vol. 57, No. 298,* 1962. 74, 82
- [180] StataCorp LP. StataCorp LP. <http://www.stata.com/>, 2012. 74
- [181] Chien T. and Hu J.L. Renewable energy and macroeconomic efficiency of OECD and non-OECD economies. *Energy Policy* 35, 3606–3615, 2007. 75, 76, 82

## BIBLIOGRAPHY

---

- [182] Hu J.L. and Kao C.H. Efficient Energy-saving Targets for APEC Economies. *Energy Policy* 35: 373–382, 2007. 75
- [183] Hu J.L. and Wang S.C. Total-factor energy efficiency of regions in China. *Energy Policy* 34 (17), 3206–3217, 2006. 75
- [184] Schneider U.A. and McCarl B.A. Economic potential of biomass based fuels for greenhouse gas emission mitigation. *Environmental and Resource Economics* 24, 291–312, 2003. 75
- [185] Dowaki K. and Mori S. Biomass energy used in a sawmill. *Applied Energy* 80, 327–339, 2005. 75
- [186] Caputo A. Economics of biomass energy utilization in combustion and gasification plants: effects of logistic variables. *Biomass and Bioenergy* 28, 35–51, 2005. 75
- [187] Abulfotuh F. Energy efficiency and renewable technologies: the way to sustainable energy future. *Desalination* 209, 275–282, 2007. 75
- [188] Lund P.D. Effectiveness of policy measures in transforming the energy system. *Energy Policy* 35, 627–639, 2007. 75
- [189] REN 21 (Renewable Energy Policy Network for the 21st Century). *Renewables 2012 Global Status Report*. Paris, REN 21 Secretariat, 2012. 76
- [190] Domac J., Richards K., and Risovic S. Socio-economic drivers in implementing bioenergy projects. *Biomass and Bioenergy* 28, 97–106, 2005. 76, 83
- [191] Mack Ott. National Income Accounts. Technical report, The Concise Encyclopedia of Economics. 2008. Library of Economics and Liberty. 12 May 2014., 2008. 77
- [192] Cancelo M. and Díaz M. CO<sub>2</sub> emissions and economic growth in EU countries. Journal of International Development Economic Research. Technical report, Universidad de Santiago de Compostela, Spain. JEL classification: O13, O14, O52., 2002. 86

## BIBLIOGRAPHY

---

- [193] Abulfotuh F. Simple versus Complex Models: Evaluation, Accuracy, and Combining. *Mathematical Population Studies* 5: 281-90, 1995. 93
- [194] Campbell P. Evaluating Forecast Error in State Population Projections Using Census 2000 Counts. *Population Division Working Paper Series No. 57. Washington, D.C.: U. S. Census Bureau, 2002.* 93
- [195] Hyndman R. and Koehler A. Another Look at Measures of Forecast Accuracy. *International Journal of Forecasting* 22: 679-688, 2006. 93
- [196] Isserman A. The Accuracy of Population Projections for Subcounty Areas. *Journal of the American Institute for Planners* 43: 247-59, 1977. 93
- [197] Miller E.R. Evaluation of the 1990 School District Level Population Estimates Based on the Synthetic Ratio Approach. *Population Division Working Paper No. 54. Washington D.C.: US Census Bureau, 2001.* 93
- [198] Murdock S., Leistritz L., Hamm R., Hwang S., and Parpia B. An Assessment of the Accuracy of a Regional Economic-Demographic Projection Model. *Demography* 21: 383- 404, 1984. 93
- [199] Rayer S. Population Forecast Accuracy: Does the Choice of Summary Measure of Error Matter? *Population Research and Policy Review* 26: 163-184, 2007. 93
- [200] Sink L. Race and Ethnicity Classification Consistency between the Census Bureau and the National Center for Health Statistics. *Population Division Working Paper No. 17. Washington, D.C.: U.S. Census Bureau, 1997.* 93
- [201] Smith S. Tests of Accuracy and Bias for County Population Projections. *Journal of the American Statistical Association* 82: 991-1003, 1987. 93
- [202] Smith S. and Sincich T. On the Relationship Between Length of Base Period and Population Forecast Errors. *Journal of the American Statistical Association* 85: 367-75, 1990. 93

## BIBLIOGRAPHY

---

- [203] Smith S. and Sincich T. Evaluating the Forecast Accuracy and Bias of Alternative Projections for States. *International Journal of Forecasting* 8: 495-508, 1992. 93
- [204] Smith S., Tayman J., and Swanson D.A. State and Local Population Projections: Methodology and Analysis. *New York: Kluwer Academic/Plenum Publishers*, 2001. 93
- [205] Tayman J., Schafer E., and Carter L. The Role of Population Size in the Determination of Population Forecast Errors: An Evaluation using Confidence Intervals for Subcounty Areas. *Population Research and Policy Review* 17: 1-20, 1998. 93
- [206] Wilson T. The Forecast Accuracy of Australian Bureau of Statistics National Population Projections. *Journal of Population Research* 24 (1): 91-117, 2007. 93
- [207] Holmes H.H. *Interpreting global energy and emission scenarios: methods for understanding and communicating policy insights*. Doctoral dissertation, Stanford University, 2007. 95
- [208] Hoekstra R. and Van der Bergh J.C.J.M. Comparing structural and index decomposition analysis. *Energy Economics* 25 (1), 39–64, 2003. 112, 125
- [209] Ang B.W. Decomposition analysis applied to energy. In: C.J. Cleveland, Editor, *Encyclopedia of Energy*, Elsevier, Amsterdam, pp. 761–769, 2004. 112, 113
- [210] Hatzigeorgiou E., Polatidis H., and Haralambopoulos D. A decomposition analysis and comparison of results using the Arithmetic Mean Divisia Index and Logarithmic Mean Divisia Index techniques. *Energy* 33 (3), 492-499, 2008. 112
- [211] Zhou P. and Ang B.W. CO<sub>2</sub> emissions: a production-theoretical approach. *Energy Economics* 30, 1054-1067, 2008. 112

## BIBLIOGRAPHY

---

- [212] Proops J., Faber M., and Wagenhals G. *Reducing CO2 emissions. A comparative Input-Output study for Germany and the UK*. Springer-Verlag, Berlin, 1993. 113, 114
- [213] Ang B.W. Decomposition of industrial energy consumption. The energy intensity approach. *Energy Economics*, 16(3), pp. 163-174, 1994. 115, 117, 118, 119, 120
- [214] Ang B.W. The LMDI approach to decomposition analysis: a practical guide. *Energy Policy* 33 (2005) 867–871, 2005. 120, 126
- [215] Ang B.W., Liu F.L., and Chew E.P. Perfect decomposition techniques in energy and environmental analysis. *Energy Policy* 31, 1561–1566, 2003. 121
- [216] Rose A. and Chen C.Y. Sources of change in energy use in the US economy, 1972-1982: a structural decomposition analysis. *Resources and Energy*, 13, 1991. 122
- [217] Rose A. and Casler S. Input-Output structural decomposition analysis: a critical appraisal. *Economic Systems Research*, 1996. 122
- [218] Hoekstra R. and van den Bergh J.C.J.M. Structural decomposition analysis of physical flows in the economy. *Environmental and Resource Economics*, 2002. 122, 123, 124, 125
- [219] Miller R.E and Blair P.D. *Input-Output analysis: foundations and extensions*. Prentice-Hall, Englewood-Cliffs, New Jersey, 1985. 123
- [220] UN Department of Economics and Social Affairs. *Handbook of Input-Output Table Compilation and Analysis*. Studies in Methods – Handbook of National Accounting: Series F. United Nations, NY., 1999. 124
- [221] Panayotou T. Empirical tests and policy analysis of environmental degradation at different stages of economic development. *ILO, Technology and Employment Programme, Geneva*, 1993. 138

## BIBLIOGRAPHY

---

- [222] Pezzey J.C.V. Economic analysis of sustainable growth and sustainable development. *Environment Department working paper 15*, 1989. 140
- [223] Selden T. and Song D. Environmental quality and development: is there a Kuznets Curve for air pollution emissions? *Journal of Environmental Economics and management* 27, 147– 162, 1994. 140, 144
- [224] Baldwin R. *Does sustainability require growth? In: Goldin, I., Winters, L.A. (Eds.). The Economics of Sustainable Development.* Cambridge Univ. Press, Cambridge, UK, pp. 19–47, 1995. 140
- [225] Roca J. Do individual preferences explain Environmental Kuznets Curve? *Ecological Economics* 45 (1), 3– 10, 2003. 140
- [226] Carson R.T., Jeon Y., and McCubbin D.R. The relationship between air pollution emissions and income : US data. *Environment and Development Economics* 2, 433– 450, 1997. 140
- [227] Chaudhuri S. and Pfaff A. Household income, fuel choice, and indoor air quality: micro-foundations of an Environmental Kuznets Curve. *Economics Department, Columbia University. Mimeo*, 1998. 140
- [228] McConnell K.E. Income and the demand for environmental quality. *Environment and Development Economics* 2, 383– 399, 1997. 140
- [229] Shafik N. Economic development and environmental quality: an econometric analysis. *Oxford Economic Papers* 46, 1994. 140
- [230] Birdsall N. and Wheeler D. Trade policy and industrial pollution in Latin America: where are the pollution havens? *Journal of Environment and Development* 2, 137–149, 1993. 141
- [231] Lee H. and Roland-Holst D. The environment and welfare implications of trade and tax policy. *Journal of Development Economics* 52 (1), 65– 82, 1997. 141
- [232] Jones L.E. and Rodolfo E.M. A positive model of growth and pollution controls. *NBER working paper 5205*, 1995. 141, 144

## BIBLIOGRAPHY

---

- [233] Harrison A. Openness and growth: a time-series, crosscountry analysis for developing countries. *Journal of Development Economics* 48, 419– 447, 1996. 142
- [234] Rock M.T. Pollution intensity of GDP and trade policy: can the World Bank be wrong. *World Development* 24, 471– 479, 1996. 142
- [235] Tobey J.A. The effects of domestic environmental policies on patterns of world trade: an empirical test. *Kyklos* 43, 191–209, 1990. 142
- [236] Martin P. and Wheeler D. Price, policies and the international diffusion of clean technology: the case of wood pulp production. In: Low, P. (Ed.). *International Trade and the Environment*. World Bank, Washington, 197–224, 1992. 142
- [237] Reppelin-Hill V. Trade and environment: an empirical analysis of the technology effect in the steel industry. *Journal of Environmental Economics and Management* 38, 283– 301, 1999. 142
- [238] Wheeler D. Racing to the bottom? Foreign investment and air pollution in developing countries. *World Bank Development Research Group working paper no. 2524*, 2006. 143
- [239] Jaffe A., Peterson S., Portney P., and Stavins R. Environmental regulation and the competitiveness of U.S. manufacturing: what does the evidence tell us? *Journal of Economic Literature* 33 (1), 132–163, 1995. 143
- [240] Mani M. and Wheeler D. In search of pollution havens? Dirty industry in the world economy: 1960– 1995. *Journal of Environment and Development* 7 (3), 215– 247, 1998. 143
- [241] Robinson D.H. Industrial pollution abatement: the impact on the balance of trade. *Canadian Journal of Economics* 21, 187– 199, 1988. 143
- [242] Dessus S. and Bussolo M. Is there a trade-off between trade liberalization and pollution abatement? A computable general equilibrium assessment applied to Costa Rica. *Journal of Policy Modeling* 20 (1), 11 – 31, 1998. 143, 144

## BIBLIOGRAPHY

---

- [243] Grether J.M. and Melo J. Globalization and dirty industries: do pollution havens matter? *Department d'économie and Politique, Neuchatel, Switzerland. Mimeo*, 2002. 143
- [244] Andreoni J. and Levinson A. The simple analytics of the Environmental Kuznets Curve. *Journal of Public Economics* 80 (2), 269–286, 2001. 143
- [245] Lopez R. The environment as a factor of production: the effects of economic growth and trade liberalization. *Journal of Environmental Economics and management* 27, 163–184, 1994. 143
- [246] Jaeger W., Patel S., and Pinckney T. Smallholder wood production and population pressure in East Africa: evidence of an Environmental Kuznets Curve? *JLand Economics vol. 71, 1–21*, 1998. 144
- [247] Gawande K., Berrens R.P., and Bohara A.K. A consumptionbased theory of the environmental Kuznets curve. *Ecological economics* 37 (1), 101–112, 2001. 144
- [248] John A. and Pecchenino R. An overlapping generations model of growth and the environment. *Economic Journal* 104, 1393–1410, 1994. 144
- [249] Beltratti A. Models of Economic Growth with Environmental Assets. *Kluwer Academic, London*, 1997. 144
- [250] Stokey N.L. Are there limits to growth? *International Economic Review* 39 (1), 1–31, 1998. 144
- [251] Kadekodi G. and Agarwal S. Why an inverted U-shaped Environmental Kuznets Curve may not exist? *Institute of Economic Growth, Delhi. Mimeo*, 1999. 144
- [252] Bulte E.H. and van Soest D.P. Environmental degradation in developing countries: households and the (reverse) environmental Kuznets curve. *Kluwer Academic, London*, 2001. 144

## BIBLIOGRAPHY

---

- [253] Canas A., Ferrao P., and Conceicao P. A new environmental Kuznets curve? Relationship between direct material input and income per capita: evidence from industrialised countries. *Ecological Economics* 46, 217229, 2003. 145
- [254] Shen J. and Hashimoto Y. Environmental Kuznets curve on country level: evidence from China. <http://www2.econ.osaka-u.ac.jp/library/global/dp/0409.pdf>, 2004. 145
- [255] Cole M.A. Re-examining the pollution–income relationship: a random coefficients approach. *Econ. Bull.* 14 (1), 17, 2005. 145
- [256] Galeotti M., Lanza A., and Pauli F. Reassessing the environmental Kuznets curve for CO<sub>2</sub> emissions: a robustness exercise. *Ecological Economics* 57, 152163, 2006. 145
- [257] Esteve V. and Tamarit C. Threshold cointegration and nonlinear adjustment between CO<sub>2</sub> and income: the environmental Kuznets curve in Spain, 1857-2007. *Energy Economics* , 34 (6) 2148-2156, 2012. 145, 146
- [258] Narayan P.K and Narayan S. Carbon dioxide and economic growth: panel data evidence from developing countries. *Energy Policy* 38, 661-666, 2010. 145
- [259] Soytas U., Sari R., and Ozdemir O. Energy consumption and GDP relation in Turkey: a cointegration and vector error correction analysis. *Economies and Business in Transition: Facilitating Competitiveness and Change in the Global Environment Proceedings. Global Business and Technology Association, Vol. 1, pp. 838-844*, 2001. 146
- [260] Soytas U. and Sari R. Energy consumption and GDP: causality relationship in G-7 countries and emerging markets. *Energy Econ.* 25, 33-37, 2003. 146
- [261] Lee C. Energy consumption and GDP in developing countries: a cointegrated panel analysis. *Energy Econ.* 27, 415-427, 2005. 146
- [262] Lise W. Decomposition of CO<sub>2</sub> emissions over 1980-2003 in Turkey. *Energy Policy* 34, 1841-1852, 2006. 146

- [263] Chontanawat J., Hunt L.C., and Pierse R. Does energy consumption cause economic growth? Evidence from a systematic study of over 100 countries. *J. Policy Model.* 30, 209-220, 2008. 146
- [264] Halicioglu F. An econometric study of CO<sub>2</sub> emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy* 37, 699-702, 2009. 146
- [265] Ozturk I. and Acaravci A. The causal relationship between energy consumption and GDP in Albania, Bulgaria, Hungary and Romania: evidence from ARDL bound testing approach. *Energy* 87, 1938-1943, 2010. 146
- [266] Esteve V. and Tamarit C. Is there and the environmental Kuznets curve for Spain? Fresh evidence from old data. *Economic Modelling* , 29 (6), 2012. 146
- [267] Fosten J., Morley B., and Taylor T. Dynamic misspecification in the environmental Kuznets curve: evidence from CO<sub>2</sub> and SO<sub>2</sub> emissions in the United Kingdom. *Ecological Economics* 76, 25-33, 2012. 146
- [268] Ng S. and Perron P. Lag Length Selection and the Construction of Unit Root Tests with Good Size and Power. *Econometrica* 69, 1519-1554, 2001. 150
- [269] Shin B. A residual-based test of the null of cointegration against the alternative of no cointegration. *Econ. Theory* 10, 91-115, 1994. 151, 152, 153
- [270] Kwiatkowski D., Phillips P.C.P., and P. Schmidt. Testing for Stationarity in the Components Representation of a Time-series. *Cambridge University Press, New York, NY*, 1992. 151
- [271] Newey W.K. and West K.D. A simple positive semi-definite, heteroskedasticity and autocorrelation consistent covariantce matrix. *Econometrica* 55, 703-708, 1987. 153
- [272] Tapio P., Banister D., Luukkanen J., Vehmas J., and Willamo R. Energy and transport in comparison: Immaterialisation, dematerialisation and decarbonisation in the EU15 between 1970 and 2000. *Energy Policy* 35, 433-451, 2007. 162

## BIBLIOGRAPHY

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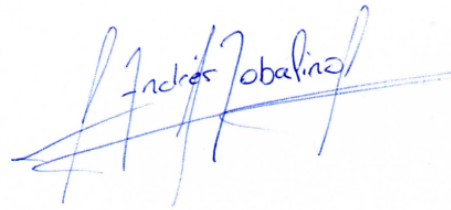
- [273] Goodwin P., Dargay J., and Hanly M. Elasticities of Road Traffic and Fuel Consumption with Respect to Price and Income: A Review. *Transport Reviews* 24 (3), 275-292, 2003. 163

## Declaration

I herewith declare that I have produced this work without the prohibited assistance of third parties and without making use of aids other than those specified; notions taken over directly or indirectly from other sources have been identified as such. This work has not previously been presented in identical or similar form to any examination board.

The dissertation work was conducted from 2010 to 2014 under the supervision of PhD. Angel Mena Nieto and PhD. José Enrique García Ramos at the University of Huelva.

Huelva,

A handwritten signature in blue ink, reading "Andrés Robalino". The signature is stylized with a large initial 'A' and 'R'.

Andrés Robalino López

This dissertation was finished writing in Huelva on Thursday 12<sup>th</sup> June, 2014

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