Universidad de San Andrés

Departamento de Ciencias Sociales

Licenciatura en Ciencia Política

Energy intensity of the Argentine economy and agriculture sector: a decomposition exercise and policy evaluation

Alumno: Ghersa, Felipe

Legajo: 24.262

Mentores: Ferraro, Diego & Moscovich, Lorena

Victoria, mayo 2016

Abstract

Argentina is the seventh largest producer of agricultural products in the world, and as such, its economy is highly dependent upon the relative health of its ecological systems to sustain agricultural production. Understanding energy intensity, the amount of energy used to produce one unit of output, is a key metric in order to gage the sustainability of a system. Considering that all physical systems are constrained by the laws of thermodynamics, the way they use energy to maintain structure and function tells us about their capacity to persist in time, what Ludwig Bolztmann stated as a "fight against entropy". In this thesis, the economic energy intensity of the Argentine economy and agriculture sector between 1960 and 2013 is examined. This research project has two main objectives, the first is to decompose energy intensity and evaluate the weight of two contributing factors, the efficiency of energy use and the sectoral composition of the economy through Logarithmic Mean Divisia Index (LMDI I). The second objective is to provide an energy efficiency policy evaluation scheme under which we suggest certain proposals to future policymakers. Our results show that changes in technical energy efficiency have played a dominant role, relative to economic structure, in the trends of energy intensity. The general economy has an inverted U-shaped curve in its intensity trend, such that between 1960 and 2013 there have been no real improvements in either energy consumption or energy efficiency. At the sectoral level, the economic energy intensity trends have been either inverted U-shaped or strictly increasing, which provides a partial explanation behind the patterns at the aggregate level. The agriculture sector has both increasing intensity, consumption and a high dependence on fossil fuels. Considering that we only take into account the energy used within the economic system (as opposed to all ecosystemic energy flows) our trends only show a partial view of the true situation. Thus, the evidence presented suggests that Argentina is treading down an unsustainable path from a systemic standpoint, in both its general economy and agriculture sector. Feeble energy efficiency oriented public policy and institutions, together with high dependence on fossil fuels, increasing consumption and either stable or increasing energy intensity propose serious difficulties to ensure the longevity of the productive forces behind the Argentine economy and agriculture sector. The incapacity of the productive systems to increase their efficiency could stem from the fact that the degradation of natural capital has exceeded that which technology and higher quality energy can compensate for.

Resumen

Argentina es el séptimo productor agrícola en el mundo. De este modo, su economía depende fuertemente del bienestar de los sistemas ecológicos que funcionan como soporte para la producción agropecuaria. Entender la intensidad energética, la cantidad de energía necesaria por unidad de producto, es una métrica clave para estimar la sustentabilidad del sistema. Considerando que todos los sistemas físicos están constreñidos por las leyes de la termodinámica, la manera en que un sistema utiliza la energía, para mantener su estructura y funcionamiento, nos da indicios de su capacidad de persistir en el tiempo, lo que Ludwing Bolzmann llamó "la lucha contra la entropía”. En esta tesis, se examina la intensidad energética económica de la economía agregada y el sector agrícola argentino entre los años 1960 y 2013. El trabajo tiene dos objetivos principales, el primero es descomponer la intensidad energética económica y evaluar el peso relativo de dos factores contribuyentes, la eficiencia en el uso de la energía y la composición sectorial de la economía. Para esto se utilizara la metodología Logarithmic Mean Divisia Index (LMDI I). El segundo objetivo es proveer un esquema de evaluación de política pública en materia de eficiencia energética y generar propuestas a futuro para los formuladores de políticas. Nuestros resultados muestran que los cambios técnicos en eficiencia energética tuvieron un papel predominante, a comparación con el rol de la estructura económica, en los patrones de cambio de la intensidad energética. El patrón general para la economía muestra una curva en forma de U, tal que entre 1960 y 2013 no hubo disminución en consumo o aumento de la eficiencia energética. En el nivel sectorial, la intensidad energética económica tiene patrones en forma de U invertida o estrictamente crecientes, lo que podría proveer una explicación parcial para el patrón observado a nivel agregado. El sector agrícola tiene un patrón creciente de intensidad energética económica y consumo de energía, y alta dependencia de fuentes fósiles. Cabe destacar que solo tomamos en consideración la energía utilizada dentro del sistema económico (en vez de considerar todos los flujos energéticos del ecosistema). De este modo, nuestros resultados solo muestran una realidad parcial en torno a la situación energética de la economía. La evidencia presentada sugiere que Argentina está yendo por un camino insustentable desde una perspectiva sistémica, tanto en el sector agrícola como en la economía agregada. Políticas públicas e instituciones débiles en materia de eficiencia energética, junto con alta dependencia de fuentes fósiles, consumo creciente e intensidad energética económica estable o creciente, proponen serias dificultades para asegurar la longevidad de las fuerzas productivas detrás de la economía y el sector agrícola argentino. La incapacidad de los sistemas productivos de incrementar su eficiencia energética podría apuntar al hecho de que la degradación del capital natural y los sistemas de soporte está excediendo el potencial de la tecnología para sobrevenir dicha degradación.

Acknowledgements

Countless people have accompanied me through this four-year journey, amongst many to come. I am thankful for their patience and wisdom; they know who they are. However, I cannot fail to mention the few without whom this project would have been impossible. I extend my deepest thanks to:

Universidad of San Andrés, for believing in me and allowing me to complete my degree through their scholarship program.

Lorena and Diego, my mentors, for their guidance, ideas, and for giving me the opportunity to grow as a student and as a person through their teachings.

All my teachers at the Universidad de San Andrés, for zealously investing their time to ensure that I learn about the wonders that surround us.

Roberto Fernández and Analía Menéndez, from the Facultad de Agronomía at Universidad de Buenos Aires, for showing me what it is like to see the world through the eyes of an ecologist.

Charlie Hall, for introducing me to the awesome world of biophysical economics and for inspiring me to learn about the importance of energy in human society.

My friends, for understanding that I spent less time with them because I had to study, and for showing me that an *asado* with good people is just as important as a university degree.

My parents, for their love and support, and for being two solid role models. To my father, Claudio, for transmitting his passion to understand as much as we can about the world and never take anything for granted. To my mother, Alejandra, for being my mentor in life.

My siblings, Marco, Julietta and Josefina, who, even without knowing, make me the best person I can be.

Lucia, my partner, but above all my friend, who keeps me grounded and pushes me to challenge myself every day.

Table of Contents

List of Figures

List of Tables

The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful. If nature were not beautiful, it would not be worth knowing, and if nature were not worth knowing, life would not be worth living.

—Henri Poincaré

At the same pace that mankind masters nature, man seems to become enslaved to other men or to his own infamy. Even the pure light of science seems unable to shine but on the dark background of ignorance. All our invention and progress seem to result in endowing material forces with intellectual life, and in stultifying human life into a material force.

—Karl Marx

Introduction

In this thesis, the economic energy intensities of the Argentine economy and agriculture sector are examined in order to single out the effect of improvements in energy efficiency on the changes in energy intensity. The purpose of this research project is to decompose energy intensity, the amount of energy needed to produce one unit of economic output, and evaluate the weight of two contributing factors, the efficiency of energy use and the sectoral composition of the economy. We will also present an evaluation of public policies that have been implemented in order to increase energy efficiency, decrease energy consumption and contribute to the creation of economic sustainable development structures.

Despite growing interest in most developed countries, there have been very few studies that analyze Argentina's energy intensity, energy efficiency improvements and a temporal follow-up of energy efficiency public policies. From a thermodynamic standpoint, energy is the driver behind the internal and external processes physical systems. Thus, all ecological systems – and therefore economic systems – are thermodynamic systems and are limited by the fluxes of energy. These ideas help us understand the inescapable dependence on energy we have in order to function as a society. Until the late XVII century with the mass usage of industrial coal, and1856, with the initiation of commercial oil trade, human societies were constrained by the material and energy properties of the biosphere. Principally, natural resources and solar energy. However, the discovery of fossil fuels allowed for the attainment of large amounts of surplus energy, which provided the opportunity for unprecedented societal, technological and economic development (Lambert et al. 2014; Hall & Klitgaard 2011; Tainter 1988). This growth was almost entirely explained by the use of a non-renewable energy source that took millions of years to form and accumulate. During the 1970s this bitter reality emerged as a decade long energy crisis.

The principal objective of this thesis is to use theoretical constructs of ecology, economics and thermodynamics in order to analyze the sustainability of Argentina's energy use on an economy-wide level and the agriculture sector. The emphasis on the agricultural sectors stems from the fact that Argentina is the seventh largest producer of agricultural products in the world (Bruinsma 2003). Its economy has been predominantly dependent on agriculture, which in turn has been reliant on resource abundance, suitable climatic conditions and ecosystem services (Ricklefs 1998; Mundlak et al. 1989). Therefore, in order to understand the manner in which Argentina uses its energy sources, it is important to delve into the patterns of energy use of its most territorially predominant economic activity. To do this, we will study the historical developments of efficiency public policy, the composition of the energy matrix and historical trends of energy intensity and consumption for the whole economy and the agriculture sector between 1960 and 2013. Although, the energy crisis began in 1973, studying previous patterns allows us to find clues with respect to the reasons behind the energy trends that Argentina presents.

As a result of the oil crises, academics began to increasingly investigate energy indicators, the link between energy and economic growth and the general dependence of biological systems on energy and energy surplus.

Around this time, one of the fields of analysis that emerged was decomposition exercise in energy and environmental analysis (Ang & Zhang 2000). The principal goal of the methodology is to trace the factors that affect macro level indicators. At the end of the 1970s decomposition analysis was mainly used to understand the impact of changes in industrial product mix on energy consumption. More recently, decomposition analysis has provided a tool to understand economy-wide trends of energy and environmental indicators through the use of sectoral and sub-sectoral data (Ma & Stern 2008). In the case of energy intensity as an economy wide indicator, the recent literature has pointed out that energy efficiency is the principal driver of changes in a countries overall intensity. Notwithstanding, each country has specific intensity patterns and the role of the factors that affect it are not always the same (Shahiduzzaman & Alam 2013).

To our knowledge, no research projects have undertaken the task of decomposing the energy intensity of Argentina as a single case study. However, several studies apply a comparative method to analyze several countries and compare their energy intensity and the driving factors. Park, Dissmann & Nam (1993) evaluate the Kuznets hypothesis of economic material decoupling in developing countries. Their findings show that energy consumption and output in developed countries are decoupling, yet the opposite relationship can be observed for developing countries. The rapid growth in manufacturing energy output and a transformation of energy-intensive industry are the principal factors affecting manufacturing energy consumption in developing countries. A more recent study done by Jiménez & Mercado (Jimenez & Mercado 2014) compare the energy intensities of Latin American countries to another set of countries chosen through the synthetic control method, and the relative effects of the structural mix and improvements in energy efficiency. They conclude that in general, Latin American countries have reduced their intensity by 20% on average, while other low and middle income countries have seen a 50% to 54% decrease. In both cases, the principal driver of the variation has been the changes in energy efficiency. This conclusion is consistent with Mielnik & Goldemberg (2000) who state that developing countries have been reluctant to commit to the Kyoto Protocol on the grounds that decreasing their energy intensity and carbon emissions will constrain their industrialization and growth potential.

Granting that it is not a decomposition exercise, the most recent article on energy intensity in Argentina is (Recalde & Ramos-Martin 2012). They study the energy metabolism of Argentina in order to understand the link between energy consumption and economic growth, in lieu of the burgeoning literature about the energy dependence of developing countries. The principal question they try to answer is: "While energy intensity seems to exhibit a U-Shaped curve from 1990 to 2003 decreasing slightly after that year, total energy consumption increases along the period of analysis. Why does this happen?" Using a Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism they conclude that Argentina has been treading down an unsustainable path, as energy intensity increased. An intensive energy mix and recurrent economic and institutional crises have hindered improvements of energy use, in part.

In conclusion, there have been few studies that undertake serious energy analysis for Argentina. In general, many make comparative statements without delving into the causes behind each case; instead, they group several countries under categories that describe their economic evolution. The few studies on Argentina point to the fact that the country has had an unsustainable pattern of energy use. The main driver behind this has been energy efficiency; nonetheless, no studies have proposed a thorough policy analysis or linked the trends of macro-level energy indicators with national level policy efforts. The answers to the interrogation left open by these studies will be tackled in the rest of this thesis.

The scant literature that exists on Argentina's energy intensity suggests that it has shown an inverted U-shaped curve. That is, there have been no real improvements with regard to how much energy the country uses in order to generate economic wealth and development. We will therefore build on these ideas, explore the patterns on a longer time-scale, and use a decomposition analysis to explore the possible explanations for these patterns. Considering that the Argentine economy has not had great industrialization periods in the last fifty years, and has maintained its sectoral composition relatively stable, we suspect that energy efficiency will have a predominant role in explaining the patterns of energy metabolism. Also, there have been very few consistent energy efficiency policy analyses or evaluations. Governments have taken an incremental role in assuring that countries have energy security. Therefore, public policies and the governmental capacities to implement them play an important role in defining the outcomes of energy efficiency in the economy. It is beyond the scope of this thesis to perform a detailed policy analysis. However, we will perform a policy impact evaluation in order to link the patterns of energy indicators with governmental efforts to ensure sustainable development and energy security.

General objectives

Understand the energy intensity of the Argentine economy as a metric for sustainable growth and development.

Specific objectives

Describe the historical trends of energy intensity in the Argentine economy and the agricultural sector, and single out the effect of technical improvements in energy efficiency. Also, provide an analytical link between energy efficiency and intensity trends and the underlying energy efficiency policy efforts.

Guiding questions

The nature of this study is exploratory and descriptive, since very few other research projects have undertaken the task of understanding the energy intensity of Argentina and its link with policy efforts to increase energy efficiency. Until the final years of the 1970s, Argentina seemed to follow a relatively sustainable path in terms of energy intensity. Economic growth seemed to become independent from energy consumption. However, the 1980s set forth a radically different path increasing the overall energy intensity. Only recently has that trend been able to ameliorate. Therefore, in order to understand the sustainability of Argentina's energy path, and some explanatory propositions, we have set out to study the two decades before and the two decades that follow the sudden growth in energy intensity during the 1980s. Hence, we can gage the changes that took place causing the change in trend, and the posterior policy and governmental actions that helped tip the trend in a more favorable path. The following questions will guide analysis:

1. How and why have the energy intensities of the Argentine economy and agricultural sector fluctuated during the period 1960-2013?
2. Has Argentina followed a similar trend in energy intensity as the rest of the countries in the region during the period 1960-2013?
3. What has been the effect of technical energy efficiency in the trends of energy intensity during the period 1960-2013?
4. What public policies have been implemented in order to increase energy efficiency or mitigate energy consumption during the period 1960-2013?
5. How will energy intensity continue to evolve in the future, and what are possible policy proposals to tackle the sustainability problems it may bring?

The rest of the thesis will be organized as follows: Section 1 shows the link between energy and societal development, presents a conceptual framework and the guiding questions behind the thesis' enquiry. Section 2 will present a historical analysis of the public policies implemented in order to increase energy efficiency. Section 3 will study the Argentine energy panorama looking at consumption, supply and intensity trends on a general and sectoral level. Section 4 will present the data used, where it was obtained and a detailed exposition of the Logarithmic Mean Divisia Index (LMDI) methodology. Section 5 will entail a graphical and statistical demonstration of the results obtained together with an analytical and methodological discussion. Finally, section 6 will present concluding remarks for the whole thesis.

1. Energy, Society and Sustainability

The emergence of man, the shift in his role from minor component of natural systems to predominant and sometimes exclusive occupant of modern industrial cultures, is a story of change in his basis of power support.

– Howard T. Odum

This section presents the conceptual framework and theoretical constructs that will allow analyzing the Argentine economy and agriculture sector in terms of biophysical indicators. It will take on the importance of understanding the link between energy and the development of, not only socioeconomic systems, but also all physical systems within the biosphere.

Human societies have been recently shaped by the abundance of high-energy fossil fuels. Therefore, this section will present the possible consequences of the current energy situation from a systemic perspective.

The section will be organized as follows. The first part will expose the link between energy and the development of society. It shows that under thermodynamic principles, in order to grow, sustain themselves, and develop all societies must rely on a minimum surplus of energy above that which is necessary to cover metabolic needs. The second part is a presentation of the basic concepts that are needed in order to quantify, analyze and understand the biophysical energetic constraints of all biospheric systems.

1.1 Energy and society

In 1798, Thomas R. Malthus made a bold statement in his seminal work, *The First Essay on Population,* regarding the limits posed by the laws of nature on human subsistence,

> I think I may fairly make two postulata. First, that food is necessary to the existence of man. Secondly, that the passion between the sexes is necessary, and will remain nearly in its present state. These two laws ever since we have had any knowledge of mankind, appear to have been

> fixed laws of our nature (…) Assuming then, my postulata as granted, I say that the power of population is indefinitely greater than the power in the earth to produce subsistence for man. Population, when unchecked, increases in a geometric ratio. Subsistence increases only in an arithmetic ratio. A slight acquaintance with numbers will shew the immensity of the first power in comparison of the second. (Malthus 1798)

His work was a rebuttal of the arguments that tended to overestimate mankind's capacity to overcome nature's constraints through the development of ever efficient technology. At the time the panorama seemed clear that population growth would undoubtedly outdo the decreasing marginal returns of agriculture. Notwithstanding, the debate between Cornucopians and Malthusians[1] continued as the industrial revolution gave way to a plethora of innovations that allowed for the slow increment of agricultural productivity towards geometric growth, principally the steam engine and more efficient land use strategies (Hall & Klitgaard 2011; Pimentel & Pimentel 2008; Tilman et al. 2002; Tainter 1988; Odum 1971; White 1943).

The appearance of agriculture, some 10,000 years ago, allowed the human species to overcome the energy restrictions posed by the collector-nomadic way of life. The Sun is the fundamental source of energy in the biosphere, and plants are the only living organisms capable of harnessing it[2]. Their ability to photosynthesize transforms solar energy into chemical energy that can be stored and transferred across trophic levels. However, autotrophs only transform 1% of the solar energy that enters the atmosphere into chemical energy (Chapin III et al. 2012). Before the advent of agriculture, humans had to share the source of energy captured by plants with the rest of the living beings. This meant that human activity, wellbeing and nutrition were highly competitive and energy intensive, leaving little surplus energy in order to allow for cultural evolution and population growth[3]. However, agriculture permitted humans to

[1] For a more detailed review of the debate see: Aligica 2009 and Ehrlich 1971.

[2] There are three other sources of energy used by both humans and natural ecosystems. Gravitational pulls originated by the motions of the planets generate tidal kinetic energy in the Earth's bodies of water. In addition, geological processes, such as tectonic plate movements and volcanic activity, as well as nuclear decay at the Earth's core provide energy to ecosystems.

[3] Recent studies suggest that human development is closely related to the availability of surplus energy sources (Lambert et al. 2014; Hall et al. 2014; Hall et al. 2009; Tainter 1988).

concentrate net primary productivity[4], securing a stable energy source, which allowed civilization, culture and human population to flourish. White suggests that humans culturally evolved in three stages related to the availability of surplus energy, (1) savagery – hunter gathers without agriculture; (2) barbarism – traditional agricultural and pastoral societies; (3) civilization – the integration of engines and fossil fuels into the production of food and necessities (Pimentel & Pimentel 2008; White 1943).

In his analysis, Malthus was unable to include the use of fossil fuels. At the time, they were only beginning to be used in the Industrial Revolution. Their true potential would become clear fifty-eight years later in 1856, when the first commercial oil refinery and well were constructed (Hall & Klitgaard 2011). In turn, his postulates concerning the natural constraints on human development were trumped by the appearance of an unprecedented surplus of energy (i.e. fossil fuels), that was injected into all processes of human society; thus, giving way to civilization in White's scheme of cultural evolution. The bottleneck posed by food scarcity, due to the dependence on solar energy, was averted permitting unseen population growth, affluence and technological progress during the last half of the XIX and all of the XX century. Both technological advancements and the sustenance of human society became dependent upon fossil fuels (Hall & Klitgaard 2011; Odum 1971). It is therefore why Howard T. Odum, in his book *Environment, Power, and Society*, asks himself:

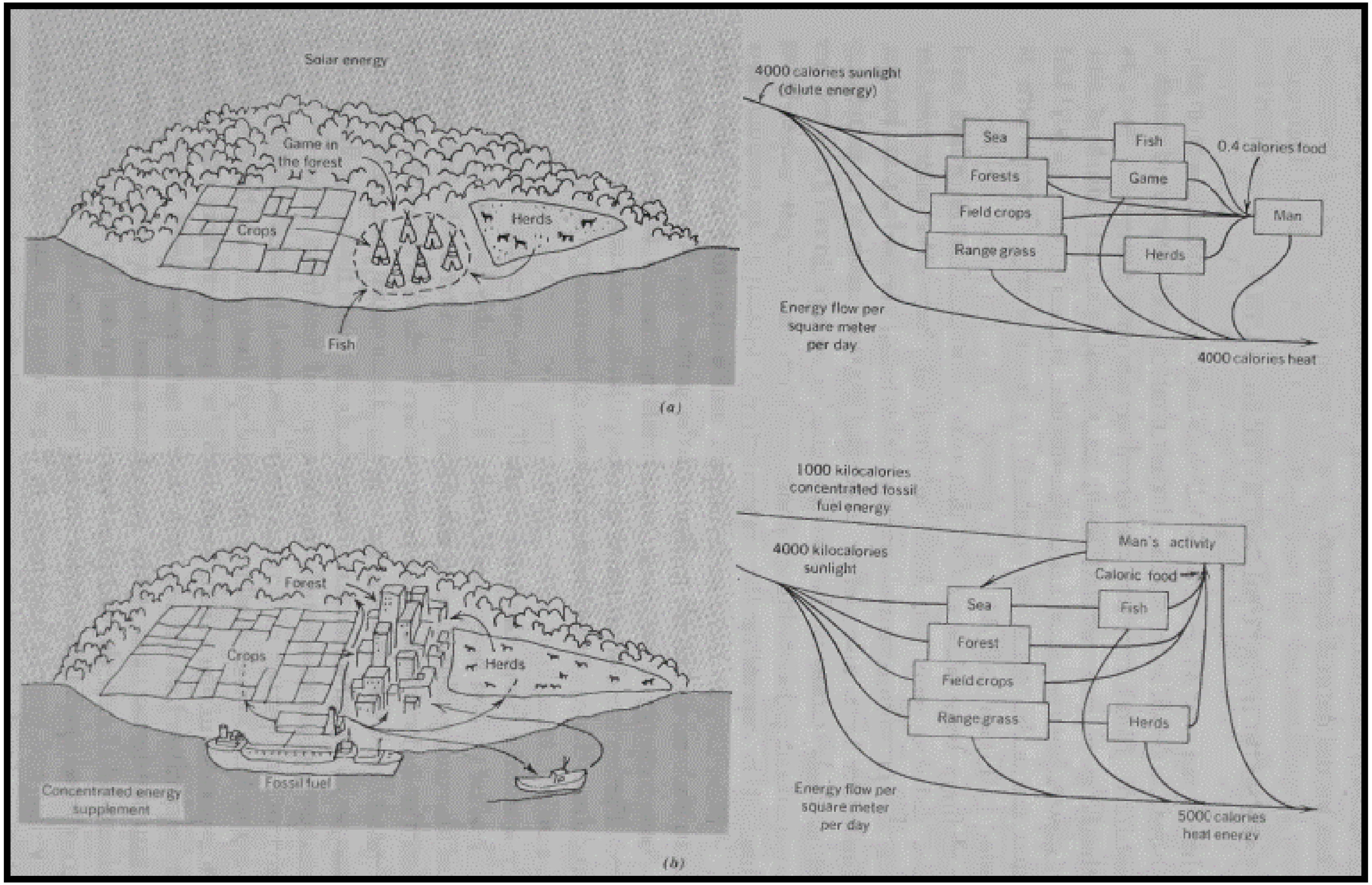
> How many persons know that prosperity of some modern cultures stems from the great flux of oil fuel energies pouring through machinery and not from some necessary and virtuous properties of human dedication and political design? (1971, p.6)

In this, Odum tackles the Malthusian concern from a new angle, the scientific edge of understanding the energy flux in human society. It is not yet clear whether Malthus was right

[4] Net primary productivity (NPP) refers to the rate of biomass accumulation in plants per unit of land area. It is derived from gross primary productivity (GPP) that measures the total rate of photosynthesis per unit of land area. NPP is the stored energy that is left after respiration (R), therefore NPP = GPP – R (Odum & Warret 2004).

or wrong, however the acquired dependence on fossil fuels seemed to change the interaction of humans with the natural ecosystem. Figure 1, shows that the energy flux in a system that incorporates fossil fuels is diametrically different from one that depends solely on solar energy. The industrialized system's processes are less thermodynamically sustainable due to the need of an outside energy source, notwithstanding more complex. On the other hand, the agrarian system presents a scheme that is dependent upon a constant energy flux independent of its components. It is worth noting that in order to compare both systems, the nutrient cycling must be similar in order to gage the effect of different energy fluxes. The purpose of the figure is to show that modern industrialized societies are highly dependent upon a non-renewable energy source that can only be harnessed by advanced technology. In turn, the capacity to produce such technology is dependent upon a large energy surplus – possibly the creation of the steam engine – (Hall & Klitgaard 2011; Homer-Dixon 1999; Odum 1971). As non-renewable resources run out there is increasing evidence that the energy surplus of modern society is decreasing; thus posing a threat to continued human development and the creation of more advanced technology.

Figure 1
A comparison of the energy flux between two socioeconomic systems: (a) agrarian and (b) industrialized.
From: Odum 1971



The XX century provided several periods when vast amounts of the energy surplus from fossil fuels was directed towards technological research and development, World War I, II and the Cold War. Therefore, when belligerence ceased, societies were left with massive amounts of knowledge and technological capital that could be applied in the production of food and satisfaction of necessities. The second half of the XX century saw a new phase in human development. The rate at which these changes took place blurred the lines between human activity and ecosystem functioning, principally nutrient cycling and solar energy flux[5]. Almost all human activity became exclusively dependent on fossil fuels. A clear example of this transition has been the "Green Revolution". Most societies lost the awareness that natural ecosystems were undeniably necessary in order to satisfy their basic necessities.

In part, the energy surplus and technological advancements of the two World Wars gave way to an upsurge of population growth, the "Baby Boom", and the creation of the Welfare State. As a result, this commenced to put enormous pressure on agricultural systems in order to satisfy the growing demands for food and fibers. The "Green Revolution" was an effort to ameliorate the demand for plant and animal products by increasing agro-pecuniary system performance with the use of technology – fertilizers, pesticides, herbicides, agricultural machinery, genetically modified organisms and scientific knowledge, amongst other energy subsidies – (Evenson & Gollin 2003).

However, during the 1970s the dependence of the world economic system on fossil fuels began to show its feebleness and unsustainability, as energy shortages and drops in

[5] Recent efforts have been made by multilateral organisms and academic research fields to bring back the notion that nature is unequivocally needed to sustain human life. The development of the concept of ecosystem services is one of the many efforts. The most relevant definitions are: (1) the conditions and processes through which natural ecosystems, and the living beings that compose them, support and nourish human life (Daily 1997), (2) the specific ecosystem functions that directly or indirectly satisfy human needs (de Groot et al. 2002), (3) all the benefits that human populations obtain from natural ecosystems (Millenium Ecosystem Assessment 2005), (4) natural ecosystem components that are directly consumed, enjoyed, or directly contribute to human wellbeing (Boyd & Banzhaf 2007).

productivity became common (Hall & Klitgaard 2011). Several countries reached their productive oil peaks[6]; the United States being the most important due to its relative weight in the world energy market (Bardi 2009). In addition to this, evidence of decreasing marginal returns on agricultural productivity of industrialized countries began to emerge (Steinhart & Steinhart 1974; Pimentel et al. 1973). Global climate change and the destruction of natural ecosystems due to increased use of fossil fuels, urbanization and the industrialization of economic systems were pivotal in the formation of the environmental movement following the publication of Rachel Carson's book, *Silent Spring* (Nebel & Wright 1999). The belle epoch of the fossil fuel driven economy seemed to be showing its fundamental flaws, unsustainability and disconnection with the rest of the biosphere. It appeared that what Tainter (1988) proposed was beginning to take place; societies collapse because they increase their technological, social and cultural complexity. The initial increase in complexity requires an increase in energy surplus. However, the constant rise in complexity eventually leads to an unsustainable development as energy sources become depleted.

These negative trends in energy use and resource depletion, due to intensive economic activity, challenged the scientific community in order to begin to understand the energy metabolism[7] of socioeconomic systems. The central problem was how to maintain high productivity in the face of environmental constraints. Thus, energy efficiency began to take a preponderant role within the academic circles and the political agenda of most developed nations during the 1970s (Pimentel et al. 1983; Pimentel et al. 1973).

[6] Productive oil peak, or Peak Oil, refers to the point when the maximum level of oil production is reached relative to the amount of reserves. According to Hubbert (1956), the production of non-renewable resources, in time, has a bell-shaped curve. This is because at some point in time, the rate of production becomes higher than the rate of deposit discovery. At this point, the total amount of the resource availability is known and production cannot increase as no new discoveries ultimately leads to terminal depletion.

[7] Energy metabolism is understood as the capacity of a system to transform energy into essential goods and services. That is, the patterns of energy use that drive its productivity (Fischer-Kowalski & Haberl 2007).

1.2 Basic Concepts

In order to delve deeper into the analysis of energy flux and metabolism of socioeconomic systems, it is necessary to define several key concepts: energy, energy intensity, energy efficiency, and energy quality and quantity. This will allow for a more technical basis of analysis, to overcome the controversies that arise due to the difference between economic and biophysical definitions of energy and its indicators (Hall et al. 2001).

1.2.1 Energy

One of the fundamental laws of all physical systems is that of energy conservation; a stable quantity that can be transformed, but not created or destroyed. Energy can have several different forms: gravitational energy, kinetic energy, heat energy, elastic energy, electrical energy, chemical energy, radiant energy, nuclear energy, mass energy. Although, there is no definite knowledge of what energy *is* in physical terms (Feynman et al. 2011), scientists have been able to figure out its behavior and interaction with matter based on two fundamental laws of thermodynamics. Under the assumption that energy is the capacity to do work, or the multiple influences on a body so as to generate movement, the first law of thermodynamics states that as energy is transferred, into or out of a system, by way of work, heat or matter, its internal energy must follow the law of conservation of energy. In other words, the energy in all physical systems behaves as a Euclidean vector of a fixed quantity. The second law of thermodynamics (or law of entropy[8]) states that natural thermodynamic processes tend towards

[8] In physical terms, entropy is a measure of randomness (or order) of molecular structures. In general, systems tend towards high entropy. That is, high levels of molecular randomness. Complex molecular structures such as carbohydrates or hydrocarbons, living organisms, etc. have high levels of organization (low entropy). Conversely, all systems tend to degrade into random molecular distributions with no apparent structure (high entropy). The point of maximum randomness is said to be in equilibrium. Negentropy, that is complex molecular structures, is defined by its unlikeliness, and require lots of energy in order to stop its degradation into randomness. For example, if a new car (low entropy) is left unattended and no energy is input into it, so as to stop it from rusting and degrading, it will eventually turn into inorganic molecules as it falls apart (high entropy) (Feynman et al. 2011).

a maximum entropy equilibrium[9]. That is, due to the law of conservation of energy, any energy transformation process cannot happen spontaneously unless it involves the degradation of energy from an organized (usable) state to a dispersed (unusable) sate (Odum & Warret 2004). The law of entropy makes it impossible for any transfer of energy to happen at an efficiency of 100%, since all natural processes involve the release of heat energy (most dispersed kind of energy); thus, it is a measure of loss of order in thermodynamic systems due to energy transformation.

All ecosystems within the biosphere are thermodynamic systems; that is, they function under the first and second law of thermodynamics. In order to do work (conserve order and complexity – function and structure), they require a high level of thermodynamic order (usable energy), or low entropy. Ecosystems receive highly organized (usable) solar energy and they store it as chemical energy, also thermodynamically organized, through photosynthesis. Thus, following the laws of thermodynamics, organisms and ecosystems are able to perform work and maintain life (unlikely molecular structures) due to their capacity of keeping high levels of internal order (low entropy), while increasing the disorder outside the system (high entropy) as they release heat from energy transfers through respiration (Odum & Warret 2004)[10]. Any system of living organisms, including societies, involves a "fight" against entropy. That is, a

[9] The point at which the maximum entropy is reached. It is an equilibrium because there can be no more transfers of energy due to the absolute randomness of energy (lack of an energy gradient). The third law of thermodynamics states that the entropy of a system approaches zero (maximum disorder) as the temperature of the system reaches absolute zero.

[10]As part of the first studies that began to relate thermodynamics to life on earth physicist Ludwig Boltzmann stated the following: "The general struggle for existence of animate beings is not a struggle for raw materials – these, for organisms, are air, water and soil, all abundantly available – nor for energy which exists in plenty in any body in the form of heat (albeit unfortunately not transformable), but a struggle for entropy, which becomes available through the transition of energy from the hot sun to the cold earth. In order to exploit this transition as much as possible, plants spread their immense surface of leaves and force the sun's energy, before it falls to the earth's temperature, to perform in ways as yet unexplored certain chemical syntheses of which no one in our laboratories has so far the least idea. The products of this chemical kitchen constitute the object of struggle of the animal world." (Boltzmann 1974, p.24)

constant flux of energy to maintain the highly unlikely structures from turning into unstructured molecular randomness.

1.2.2 Energy intensity

Energy intensity is the ratio between energy consumption and total output. In broad terms, it measures the amount of energy needed to produce one unit of output. The following formula provides a general outline to understand energy intensity:

$$EI_i = \frac{I_i}{O_i}$$

where, EI is the energy intensity, I are the inputs and O is the total output of the productive process i. In environmental economics and policymaking, the term has been used as a measure of relative performance of an economy with respect to energy availability and security. The measure for economic energy intensity is the ratio between gross domestic product (GDP) and total energy consumption – or, total primary energy supply (TPES); Recalde & Ramos-Martín (2012) measure energy intensity in terms of TPES since they recognize that primary energy sources are the ones that ultimately have an effect on the environment –. The ensuing equation shows the economic energy intensity:

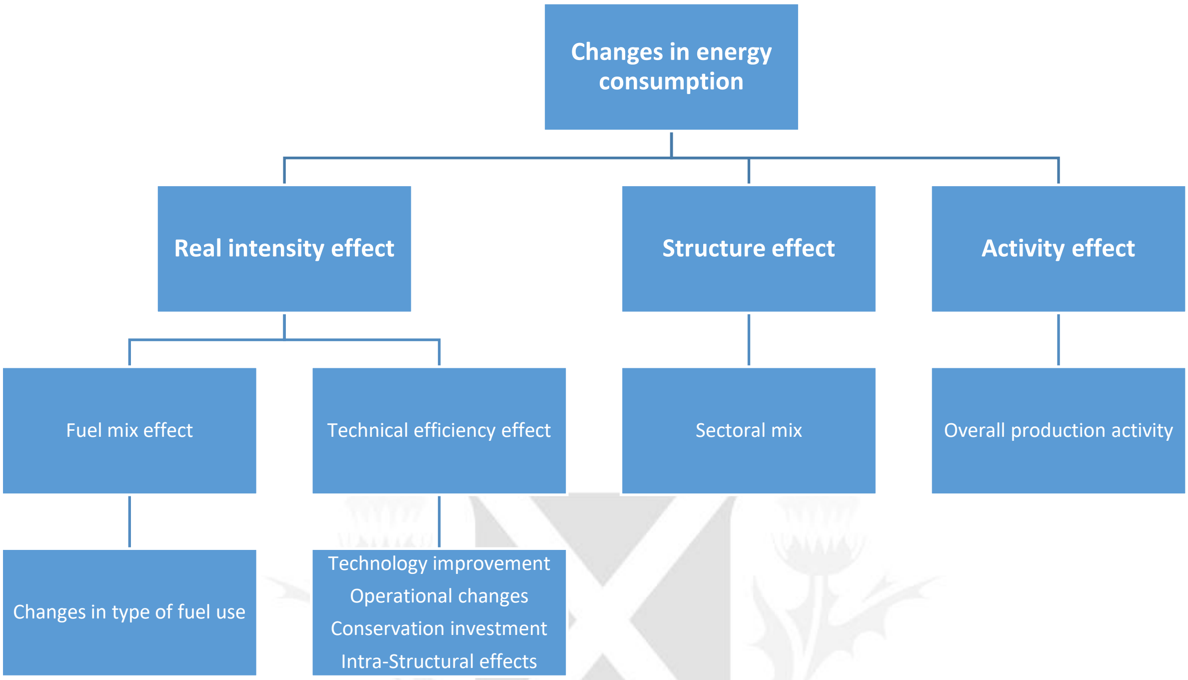
$$Energy\ intensity = \frac{Total\ primary\ energy\ supply\ (TPES)}{Gross\ domestic\ product\ (GDP)}$$

Despite its relatively straightforward utility and simplicity to understand economic energy metabolism, the units in the measurement of economic energy intensity present some controversy. Firstly, GDP can be measured using the exchange-rate method or purchasing power parity method (Callen 2004). Each method has its relative benefits and drawbacks, however the results that they provide are not equal and thus can alter the equation of energy intensity or hinder comparison between productive systems (Reister 1987). Secondly, on its own, the equation does not single out technological advancements in energy efficiency as the cause of variance in energy intensity (Wilson et al. 1994).

Initial studies considering energy intensity, during the 1970s and 1980s, received criticism (Proskuryakova & Kovalev 2015; Patterson 1996) for their inability to contemplate the internal determinants. Therefore, it was viewed as a limited tool for public policy because it only provided a descriptive general view at the national level; no policy recommendations could be extracted from the conclusions. Patterson (1996) adds that when looking at energy intensity on a sectoral level, the results did not linearly correlate to energy intensity at a general level. Thus, it was impossible to perform a comprehensive bottom-up or top-down analysis linking the micro-level activity to macro-level processes.

Notwithstanding, recent methodological advancements have allowed energy intensity to be viewed in much more detail, singling out its fundamental determinants and their coefficients (Ang et al. 2010; Ang 2005; Ang 2004; Ang & Liu 2001; Liu et al. 1992; Wilson et al. 1994). The literature generally recognizes that economic energy intensity changes due to three factors: (1) structure effect, the structural organization of an economy into different sectors (i.e. what sectors compose the economy, recognizing that different sectors require different amounts of energy to produce one unit of output); (2) activity or production effect, the overall amount of activity performed by an economy; and (3) the real intensity or efficiency effect, composed of the fuel mix effect (different fuels render more or less efficiency depending on their quality) and the technical efficiency effect – technological improvements, operational changes, conservation investment and subsectoral mix –. Figure 2 shows the factors that lead to changes in overall energy consumption and ultimately alter the energy intensity equation.

Figure 2
Graphical representation of the factors that lead to changes in energy consumption
Adapted from : Wilson et al. 1994 and Liu et al. 1992



1.2.3 Energy efficiency

The definition of efficiency is directly related to productive processes (Patterson 1996; Hirst & Brown 1990). However, it is commonly mistaken for the term efficacy – to properly "get something done" – (Hall & Klitgaard 2011). In general, energy efficiency refers to the ratio between energy output and energy input, or how much of the input energy is transformed into usable output energy. If one were to think of a productive system as a black box with a certain energy efficiency, the following equation provides a general outline of the relationship between inputs and outputs in the productive process:

$$E_i = \frac{O_i}{I_i}$$

where, *E* is the efficiency, *I* are the inputs used and *O* is the output of the productive process *i*. If we adapt the general equation for energy efficiency into a quantifiable measurement of energy units we can come up with the following equation (Patterson 1996):

$$Energy\ efficiency = \frac{Product\ (usable\ energy)}{Input\ (used\ energy)}$$

Patterson (1996) proposes a scheme to implement the concept of energy efficiency for different disciplinary purposes. He defines energy efficiency in general terms, taking into consideration the relative difficulty of coming up with a precise measure of *what* the output and input should be. Thus, he states that energy efficiency can be defined using: (1) thermodynamic indicators (both input and output are defined in thermodynamic units); (2) physical-thermodynamic indicators (inputs are measured in thermodynamic units and output is measured in physical units – for example, tonnes or kilometers travelled –; (3) economic-thermodynamic indicators (inputs are measured in thermodynamic units and output is measured in economic/monetary units); and (4) economic indicators (inputs and output are measured in economic/monetary units). Due to the available data, economic-thermodynamic indicators will be used in this analysis. Despite the fact that it is impossible to obtain an efficiency of 100, increasing energy efficiency, within a context of limited energy supplies, can provide sustainability of a given process or productive system (van den Bergh 2010; Hanley et al. 2009; Rosen 2009; Hirst 1985).

1.2.4 Energy quantity

Energy quantity is the total amount of available useable energy, measured in constant and uniform units (Lambert et al. 2014). As mentioned above, several studies point out that one of the pillar factors in human development is the availability of energy surplus to cover more than just the essential societal needs.

The relationship between energy efficiency and energy quantity poses problematic situations for society, such as the *Rebound Effect* (Herring 2006; Greening et al. 2000). It happens when an increase in energy efficiency leads to an increase in available energy, given a stable level of output. Despite the fact that energy efficiency increases, the secondary increase in energy quantity leads to a decline in energy prices, which in turn promotes consumption under deregulated market structures. Therefore, in the long run, increases in energy efficiency have to be mediated so as not to create incentives to increase consumption due to a rise in supply and posterior decline in prices.

1.2.5 Energy quality

In layman's terms, energy quality refers to the utility that an energy source has for society. Put differently, the available quantity of real, usable, energy in order to perform work – in socioeconomic terms, the capacity to produce goods and services for individuals. This utility is determined by several attributes such as gravimetric and volumetric density of an energy source, power density, gas emissions, conversion cost and efficiency, financial risk, storage capacity, human health risk and ease of transportation (Cleveland et al. 2004; Cleveland 1992). The diversity of the attributes that determine energy quality make the task of aggregating it in an adequate and encompassing manner extremely complex.

Cleveland, Kaufmann and Stern (2000) identify three types of methods in order to aggregate energy: the basic heat equivalent approach, economic approaches using prices or marginal product for aggregation, eMergy analysis, and thermodynamic approaches such as exergy. It is beyond the scope of this thesis to explain each of these methodologies in detail. However, it is worth clarifying that the utilization of any of the methodologies largely depends on the available data and the units in which it is expressed. In general, the most used method is the basic heat equivalent approach since it respects the physical properties of energy and does not entail any subjective human valuation. It is also important to note that not every heat unit (joule) is the same. That is, for every source of energy, the joules it provides have different utility. Therefore, the aggregation of different fuels must contemplate the caloric difference by way of either *Exergy* (Ayres et al. 1996) or *EMergy Accounting* (Odum 1995; Odum 1988) methodologies. If one were to calculate the basic heat equivalent of a series of energy sources in order to evaluate their utility, the aggregation formula should follow the proceeding logic:

$$E_t^* = \sum_{i=1}^{N} \lambda_{it} E_{it}$$

where, E is the basic heat equivalent of the energy source i (N types) in time t, and λ are the quality factors that vary with type of energy source in time. This equation enables the homogenization of energy fuel units into their heat equivalent in order to aggregate total energy quality.

Energy return on investment (EROI) is another methodology to establish the quality of an energy source by contemplating the net availability of a fuel type (Hall & Klitgaard 2011). In other words, the amount of energy output after discounting the amount of energy that was input in order to acquire energy. Several authors suggest that the EROI provides a basis for the attainment of energy surplus, which correlates strongly with productivity, energy efficiency and human development (Lambert et al. 2014; Hall et al. 2014). The following equation describes the ratio of energy used to obtain energy and energy returned to society:

$$EROI = \frac{energy\ returned\ to\ society}{energy\ used\ to\ get\ that\ energy}$$

1.3 Energy Intensity: Understanding Argentina's recent energy metabolism

Most economic theories have continually ignored the capacity of natural systems to produce negative entropy, thus functioning as human life support systems. This dangerous hoax has occurred due to the seemingly limitless abundance of fossil fuels and the appearance that human capacity can overcome all energy obstacles through sheer wit, intellect and technological advancement (Hall & Klitgaard 2011; Odum 1971). Following this, Recalde & Ramos-Martín (2012) and Recalde (2011) have analyzed the Argentine economy in terms of its energy use. The latter, exhibits that the fluctuations in energy metabolism of Argentina cannot be attributed to energy efficiency, but rather a volatile market structure and abrupt changes in labor productivity. Therefore, although it seems that energy intensity has decreased during the last thirty years, the level of energy consumption has been either steady or increasing. Together with this, Recalde explains that Argentina has not decreased its energy consumption in the last thirty years, and suffers from grave problems of energy supply. In addition, the energy consumption has been unequivocally dependent on fossil fuels, with little to no effort of incorporating renewable energy technology (Villalonga 2013).

This presents a serious panorama for the Argentine society in terms of its capacity to produce food, amongst other basic goods and services. Viglizzo et al. (2011) suggest that during the last fifty years, although Argentina has not ignored the technological advancements of the "Green Revolution", relative to other intensive farming nations "farmers in Argentina developed the capacity to produce under relatively low-input/low-impact schemes". However, this does not mean that energy is not a concern for Argentine agriculture; rather it entails a somewhat positive yet complex outlook. As early as the 1970, scientists have been warning about the feeble link between "Green Revolution" agriculture and energy (Steinhart & Steinhart 1974; Pimentel et al. 1973). The abundance and relative health of Argentine ecosystems should be taken with enormous responsibility in lieu of population growth, the pressures for development and the depletion of worldwide energy and agricultural sources due to intensive farming (Miralles 2013). Energy efficiency and responsible resource use are key factors for the sustainability of both the Argentine and world society. Therefore, energy efficiency should not be ignored even under a context of decreasing or stagnant energy intensity (Recalde & Ramos-Martin 2012). The results of this thesis will contribute to understanding the metabolism of Argentina, and possibly other agriculturally dependent developing nations. In addition, it will provide an outlook of the energy situation and the sustainability of both the economy and the agricultural sectors in the past, and years to come.

It is important to state that our analysis only captures general trends and considers the energy flux that is valued monetarily in the economy. In other words, there are hidden energy subsidies such as soil fertility and nutrient cycling, amongst other material and energy fluxes that provide the economic system with the "free" capital in order produce goods and services. The fact that they are economically unaccounted-for, since they do not require human labor or industrial capital, makes it difficult to include them into our assessment. Notwithstanding, it is clear that ecosystem services (the consumption of natural resources or capital) underlie the trends that we will examine. Thus, their accounting is crucial in order to truly gage, not just the economic energy intensity, but also the energy intensity of Argentina's productive systems. Particularly in agriculture, it seems impossible to imagine an agroecosystem that is capable of providing food and fiber without the support of the surrounding ecosystem (for example, pollinators (Vanbergen & Initiative 2013), primary production, pest control (Gavier-Pizarro et al. 2012) or soil formation (Pimentel et al. 1995)). Therefore, taking these fluxes into consideration can substantially alter the energy trends presented later on, which may hide the true measure of (un)sustainability (Daily 1997).

2. A brief history of energy efficiency: public policy in Argentina

This section presents a detailed historical review of the national public policies that were directly oriented to decrease energy consumption by providing incentives, materials and know-how in order to increase energy efficiency. Therefore, in this section we provide a theoretical outline of the link between state capacity and successful energy efficiency policy. Argentina's weak institutional arrangements and tumultuous sociopolitical and economic history in the second half of the XX century have encumbered the adequate adoption of proficient energy efficiency policy in order to reduce consumption.

The organization of the section is as follows. The first part presents the link between state capacity as understood by Michael Mann and the implementation of adequate energy efficiency policy as a means to reduce energy consumption. The second part briefly reviews the policy efforts that have been done in Argentina. We show the policy successes and suggest reasons to understand the recurrent pitfalls of Argentina's energy efficiency policies. This will allow us to link the trends of energy intensity with governmental efforts in our policy evaluation in order to propose recommendations for policymakers.

2.1 The State and energy efficiency public policy

The attainment of energy efficiency goals is dependent upon variables that are related to end-user behavior and macro variables, such as market structure and governmental regulation. Hirst and Brown (1990) identify two groups of barriers that any country faces when trying to accomplish an efficient use of its energy resources. The first group are behavioral barriers, which they characterize as the problems that have to do with end-users decisions on energy usage. The second group are structural barriers, which are the conditions that cannot be controlled by the end-users. That is, they have to do with market structure and forces, societal variables, governmental fiscal and policy regulations and institutions.

Out of the structural barriers, the governmental fiscal and policy regulations stand out from the rest of the group due to the particular characteristics of the actor that is behind them. Amongst all the actors within the political matrix (Acuña & Chudnovsky 2013), particularly the energy policy community[11], the modern state is the only one with two distinct types of power which allow it to enforce decisions and affect society in ways that no other actors can; these two types of power are despotic and infrastructural (Mann 1984). Mann recognizes that the despotic power of the state is related to the ability to punish; a power over society held by a political elite. On the other hand, infrastructural power for both Mann and Soifer (2008), refers to the "institutional capacity of a central state (…) to penetrate its territories and logistically implement decisions" (Mann 1984, 113). Soifer identifies three approaches that grasp different facets of infrastructural power: (1) national capabilities approach, which looks at the capabilities and resources that a state has to exercise its power through institutions; (2) weight of the state approach, which focuses on the effect that the state has upon the society it controls and the policy outcomes it achieves; and (3) subnational variation approach, which identifies the territorial outreach and control that the state has within its boundaries (2008, 235-236).

The complementarity of both types of power allows the modern state to play a crucial role in the outcomes of energy efficiency development; this is because public policy has become an important instrument to mediate energy consumption trends. These types of policies have sparked heated debates due to the negative externalities that unmediated energy efficiency policy can have. In the late 1850s William S. Jevons identified that an increase in efficiency of

[11] The term policy community is taken from (Miller & Demir 2007). They define it as, "…the extra-formal interactions (i.e., interactions taking place beyond or outside the formal processes of government) that occur in the interstices between and among government agencies, interest groups, corporations, industry associations, elected officials, and other institutions and individuals. It is a grouping of interrelated policy actors pursing a matter of public policy important to them for instrumental reasons (…) a special type of interconnected social formation, wherein communication and influence may flow in non-hierarchal patterns and the resultant policy activism is associated with governmental fragmentation and political particularism." (p. 137).

use of an energy resources does not directly translate into less consumption, but quite the opposite (Alcott 2005). The increase in efficiency makes for higher levels of supply, which generates a drop in the price of energy and ultimately generates incentives for increased consumption. These types of problems spark the need for effective policy control for negative externalities, such as price regulation and consumption quotas. Thus, through despotic and infrastructural power, the state is able to spread information to users, demarcate the legal structure for responsible energy exploitation and consumption, generate market incentives for the advancement of technology, supply centralized resources (unmatched in quantity and quality by any private actor) and coordinate the construction of an energy structure for consumption and distribution (Centro Argentino de Ingenieros 2015; Gomelsky 2003; Benveniste 1985). It can also control prices and ensure a decreasing rate of consumption in case of a large and effective bureaucratic structure.

Until 1973, energy efficiency was seldom, if ever, on any national agenda. The 1970s evidenced the feebleness of the global energy system, and the unsustainability of the global model of production that was fueled by non-renewable energy sources (Hall and Klitgaard 2012). The unsettling oil crisis of 1973 and the global energy crisis of 1979[12], following the Yom Kippur War and the Iranian Revolution, redirected the energy policy and academic research agendas towards the attainment of energy efficiency in most developed countries (Patterson 1996; Pimentel et al. 1983). However, Argentina's tumultuous political context in the second half of the XX century and relative historic availability of high quality energy sources (Gadano 2012) hindered its involvement in the global energy efficiency effort. Despite the fact that during the second part of the 1970s academic research efforts were made through the policy program, Programa Nacional de Investigaciones en Energía No Convencional, it was

[12] For a more detailed background on the 1970s with reference to the oil crises see Martenson 2011, Hall & Klitgaard 2012, and Jacobs 2016.

only after the second oil crisis in 1979 that a national energy management organism, Dirección Nacional de Conservación y Nuevas Fuentes de Energía, was created. It established the very first policy shift towards the implementation of an energy efficiency goal. The constant economic fluxes and crises between 1980 and 2002 greatly encumbered the energy efficiency policy (Centro Argentino de Ingenieros 2015). Therefore, policy design and implementation as well as market coordination for the advancement and incorporation of new technologies were hardly seen in the periods following the 1970s. Energy efficiency policy in Argentina has been characterized by partial efforts and overlapped policies with little continuity.

2.2 Public policy in Argentina

Table 1 shows schematic and chronological review of energy efficiency policies, their objectives, legal frameworks and responsible governmental entity. It is important to understand that several policy proposals. After the creation of the Dirección Nacional de Conservación y Nuevas Fuentes de Energía, Argentina faced an incomparably harsh economic situation. Hyperinflation and energy scarcity were looming over President Alfonsin's administration. The state was in the process of recuperating democracy through a somewhat violent and complicated transition. This, in turn, generated a difficulty to garner financial support in order to increase energy production and investment. The only effective and available way to ameliorate the energy crisis was through the implementation of a program centered on decreasing energy use while maintaining the levels of production (Lapeña 2014). The presidential decree, Decreto Nacional N° 2247/85, set the basic legal framework in order to enforce energy efficiency policy programs. However, the fact that it was a decree exhibited a pattern that would soon follow the national energy efficiency agenda; reactionary policies following crises, rather than a well-planned long term state objectives. The first program was the Programa de Uso Racional de Energía (URE) that began in 1985 and ended with Alfonsin's presidency in 1989. Its main objectives were to improve energy efficiency across all economic sectors, substitute non-abundant and imported resources for renewable and national resources respectively, improve the distribution services to increase territorial reach and diminish transportation costs, and the use of non-conventional fuels instead of fossil fuels. Despite its short lifespan and political complications, the URE allowed for the creation of a research group, Grupo de Estudios sobre Energía (GESE) at the Universidad Técnica Nacional (UTN). Also, agreements were made with both French (AFME) and Spanish (IDEA) energy efficiency agencies in order to develop fuel efficient technologies. Finally, educational programs to teach responsible energy use were carried out at primary and secondary school levels in the City of Buenos Aires and other urban areas in Santa Fé province.

Table 1
Detailed disaggregation of energy efficiency policies in time.
Source: Instituto Argentino de Energía "General Mosconi", Secretaría de Energía, (Bourges 2013)

Year	Policy Program	Objectives	Legal Framework	Responsible Public Entity
1985-1989	Programa de Uso racional de la energía (URE)	- Energy efficiency improvement - Substitution of non-abundant resources and imported resources - Improvement in distribution services - Use of non-conventional fuel resources instead of fossil fuels	Decreto N° 2247/85	Secretaría de Energía
1992	-	- National Electric Energy Law: incentivize the provision, distribution and efficient use of electric energy using appropriate tariff methodologies - National Natural Gas Law: rational use of natural gas with an outlook to protect the environment	Ley N° 24.065 Ley N° 24.076	-
1992-1999	Programa de Uso Racional de la Energía entre la República Argentina y la Unión Europea (URE RA/EU)	- Decision of economic, technical and financial instruments that enable the efficient use of electric energy in prioritized sectors	-	Secretaría de Energía
1998-1999	Programa de Calidad de Artefactos Energéticos (PROCAE)	- Reduce the consumption of electric energy through the use of efficient artifacts and label system	-	Secretaría de Energía/Secretaría de Industria, Comercio y Minería
1999-2005	Programa de Incremento de la Eficiencia Energética y Productiva en la PyME argentina (PIEEP)	- Increase the competitiveness of small enterprises and start-ups in Argentina through the promotion of Energy, Productive and Environmental management	-	Secretaría de Energía/Agencia Alemana de Cooperación Técnica (GTZ)
2003	Programa de Ahorro y Eficiencia Energética en Edificios Públicos (PAyEEP)	- Reduce energy consumption in public administration buildings	-	Secretaría de Energía
2004	Programa de Uso Racional de la Energía Eléctrica (PURE)	- Inform and incentivize the reduction of natural gas and electricity consumption at the residential level relative to 2003 - Increase use of efficient energy in the industrial sector	Resolución N° 415/2004	Secretaría de Energía/ENRE/ ENARGAS
2005 -	Programa de Uso Racional de la Energía Eléctrica (PUREE)	- Inclusion of "Big" users into the Rational Electricity Use program	Resolución SE N° 931/2005	Secretaría de Energía/ENRE
2007 -	Programa Nacional de Uso Racional y Eficiente de la Energía (PRONUREE)	- Improve energy efficiency in all consuming sectors - Improve energy efficiency in public administration buildings	Decreto N° 140/2007	Secretaría de Energía/Jefatura de Gabinete de Ministros
2008	-	- Prohibition of importation and commercialization of incandescent light bulbs	Ley N° 26.473 Decreto N° 2060/2010	-
2009-2015	Proyecto de Eficiencia energética en Argentina (GEF)	- Increase energy efficiency through the growth of the sustainable service sector - Reduce greenhouse gas emissions - Creation of Fondo Argentino de Eficiencia Energética	Decreto N° 1253/2009	Secretaría de Energía

In 1992, two energy laws were passed which included a clear policy objective in line with the responsible use of energy. The legal act, Ley N° 24.065, Régimen de la Energía Eléctica, established the pertinent objectives in order to advance the provision, transport and distribution of electric energy across the country. Amongst these objectives, the provision, transport, distribution and efficient use of electricity, were included, "e) Promote the delivery, transport, distribution and efficiently use electricity by fixing appropriate tariff methods"[13] (LEY Nº 24.065 1992). Following, the legal act, Ley N° 24076, Gas Natural, established a legal framework for the regulation of the development and exploitation of national natural gas. The law included a compromise with energy efficiency and environmental protection, "e) Promote energy efficiency in transport, storage, distribution and use of natural gas; f) Promote the rational use of natural gas, in order to safeguard the environment"[14] (LEY Nº 24.076 1992).

The most notable policy efforts during the 1990s were the policy programs, Programa de Cooperación en el Área del Uso Racional de la Energía entre la República Argentina y la Unión Europea (URE RA/UE), which lasted between 1992 and 1999, and Programa de Calidad de Artefactos de Energía (PROCAE), which began in 1999, was discontinued after the 2001 economic crisis, and reemerged in 2005. The first program was a continuation of Alfonsin's initial policy proposal, with a direct and focused objective to reduce energy consumption in transport, housing and public lighting. It was designed as a cooperative program with the European Union's Instituto Catalan de Energía (ICAEN). It instated the energy management and promotion department, Direción Nacional de Promoción (Uso Racional de Energía y Tecnología Renovable), and was able to successfully reduce energy consumption in the public transport system of Mendoza province and public lighting system in Entre Ríos province. The

[13] Own translation. Origianl text: "e) Incentivar el abastecimiento, transporte, distribución y uso eficiente de la electricidad fijando metodologías tarifarias apropiadas."

[14] Own translation. Original text: "e) Incentivar la eficiencia en el transporte, almacenamiento, distribución y uso del gas natural; f) Incentivar el uso racional del gas natural, velando por la adecuada protección del medio ambiente."

second program targeted end-users, as it provided a label system for household artifact energy consumption and efficiency. There was a third program during the 1990s called the Programa de Incremento de la Eficiencia Energética y Productiva en la PyME argentina (PIEEP). It was highly focalized and consisted on increasing market competitiveness of small enterprises and start-ups through the employment of energy, production and environmental management at industrial plant and service sectors. This program began in 1999 and ended in 2005 because of a policy shift towards an economic model centered on the dependence of big enterprises and government owned companies.

The start of the XXI century was extremely dramatic in economic and social terms as Argentina faced the gravest financial meltdown in its history. The 2001 financial crisis[15] crippled the market, sent 25% of the population into unemployment and forced the resignation of President Fernando de la Rúa. In an attempt to renormalize the energy situation and cut all unnecessary costs, President Nestor Kirchner's administration put the policy program, Programa de Ahorro y Eficiencia Energética en Edificios Públicos (PAyEEP), forward. Its main objective was to reduce energy consumption of all public administration buildings through the application of energy efficient artifacts, and user behavior. Partly funded by other energy policy programs such as PERMER, the program successfully put forth four pilot programs in cities of Neuquén, Buenos Aires, Jujuy and Tucumán.

In 2004 and 2005 two stages of the policy programs, Programa de Uso Racional de la Energía (PURE) & (PUREE), respectively, began. The main focus of these programs was to reduce the electric and natural gas consumption at the residential and commercial levels relative

[15] For a more comprehensive analysis on the financial crisis of 2001 see: Kiguel 2015; Levey et al. 2014; Viegel 2009; Boschi 2005

to 2003. In order to attain such a goal, a tariff and penalty system was applied to those who increased their consumption.

Until 2007, the policy efforts were seldom part of an integral plan to increase energy efficiency. The financing of most projects was scattered across ministerial departments, and the coordination and organization of policies were not centralized. However, the presidential decree, Decreto N° 140/2007, was written and signed in the aftermath of the Kyoto Conference Agreement, which was incorporated into the Argentine law in 2001 by the act, Ley N° 25.438. This decree proposed a national energy efficiency program to improve energy efficiency in all sectors of the economy, public administration buildings and reduce greenhouse gas emissions, in accordance with the stipulations of the Kyoto Protocol and United Nations Framework Convention on Climate Change. The Programa Nacional de Uso Racional y Eficiente de Energía (PRONUREE) incorporated the past policy experiences in order to centralize energy efficiency efforts and make it a top priority topic in the national agenda. The main actions that derived from the program were: application of seasonal daylight savings time change, energy efficiency standards for public administration buildings, coordination with bank, industrial, commercial and financial entities to implement rational and responsible energy usage, application of energy efficiency standards of consumer artifacts through a label system, National Bank credits for users who incorporate energy efficient artifacts and housing construction standards and online information (IRAM 11.900).

Finally, the most recent policy programs have come together through the PRONUREE. First, in 2008 the act, Ley N° 26.473, and in 2010 the presidential decree, Decreto N° 2060/2010, were passed, prohibiting the importation and commercialization of incandescent light bulbs that consumed 60 watts or more. These were to be replaced by low-consumption fluorescent light bulbs, and more recently LED light bulbs. In order to reach the goals stipulated by the legislation, the federal government gave out twenty-five million fluorescent light bulbs across the national territory. This helped inform society about the benefits and existence of an energy efficient technology and provided access to relatively expensive good, which could generate substantial aggregate level energetic and economic benefits. Second, the most recent public policy oriented towards energy efficiency has been the Proyecto de Eficiencia Energética en Argentina – GEF. The project is part of a global effort to implement energy efficient and environmental protection projects through the Global Environmental Facility (GEF). Argentina received a $US 15.155 million donation through the World Bank as the principal administrative agent of GEF funds. The project's main goal is to increase energy efficiency in Argentina through the development of an energy efficiency service market in order to reduce energy costs and provide a sustainable economic future. This is principally done by providing research, consultancy, equipment and implementation, and instructive and promotional programs in three main areas: the development of an Energy Efficiency Fund, an Energy Efficiency program for electricity distribution companies and strengthening of project capacity and management (World Bank 2008).

Energy efficiency public policy has lacked proper national attention, and most efforts until 2007 have been very focalized, short-lived and decentralized. The constant economic and financial fluctuations of the past 30 years have added to the hindrance in the development and implementation of a cohesive and effective energy policy. Also, there has been little oversight and policy analysis to provide a clear panorama of the national energy efficiency situation. The data available through public resources is analytically inconsistent, which complicates the possibility of correctly scrutinizing national energy efficiency trends due to a lack of precise indicators. Not only do official published data hold a "provisional" status, but their aggregation methodology changes periodically.

Few comprehensive energy efficiency policy analyses have been performed. They have been done by multilateral organisms such as: the United Nation Comisión Económica para

América Latina (CEPAL), non-governmental institutions such as the Argentine Comitee for the World Energy Council (Centro Argentino de Ingenieros 2015), Academia Nacional de Ingeniería (Academia Nacional de Ingeniería 2012), Fundación Vida Silvestre Argentina (Bodelon et al. 2012) and academic researchers (Cerioni & Morresi 2012). The CEPAL has published two policy analyses focused on Argentine Legislation (Secretaría de Energía 2014; Abruzzini 2000) as well as several detailed investigations on the energy panorama of Latin America and the Caribbean (International Energy Agency (IEA) 2015; Kreuzer & Wilmeiser 2014; Gomelsky 2003). In general, most reports and policy analyses point to Argentina's difficulty to pursue efficiency, due to the vast energy resources that render it seemingly unnecessary. In addition, the past policy experiences have shown that the volatile economic context, instability (Tommasi 2010), and complex federal political structure (Ardanaz et al. 2013) and instability have greatly problematized the design, implementation and continuity of a national long term energy efficiency policy.

3. Overview of energy trends in Argentina: 1960-2014

In this section, we present the energy trends of the Argentine economy and agriculture sector. That is, the composition of the energy matrix on a time-scale format, the patterns of energy consumption and supply, and the general trends of energy intensity. Looking at these trends will allow us to interpret the sustainability of Argentina's energy consumption paths after disaggregating their contributing factors, namely improvements in energy efficiency and changes in economic sectoral structure. In addition, we will use these trends to gage the relative success or failure of the policy projects presented in Section 2.

The section is organized as follows. The first part includes an exhibition of the energy situation in Argentina. We show the composition of the energy matrix and the level of consumption between 1960 and 2013. In the second part, we present the trends of energy intensity and consumption for the whole economy and a sectoral disaggregation. Finally, in the third part we compare the trends presented in the two previous sections with other countries, at an aggregate economy level and the agriculture sector.

3.1 Argentine energy situation

3.1.1 Energy Matrix

The Argentine energy matrix has evolved with considerable variability in terms of fuel type and intensity of use of each fuel. We define energy matrix as the relative contribution of each type of fuel in the total primary[16] energy used by a country (Propato & Verón 2015). Figure 3 shows the temporal change of the energy matrix by decades between 1960 and 2010. Despite the fact that Argentina incorporated six different fuel types in the time period, the share

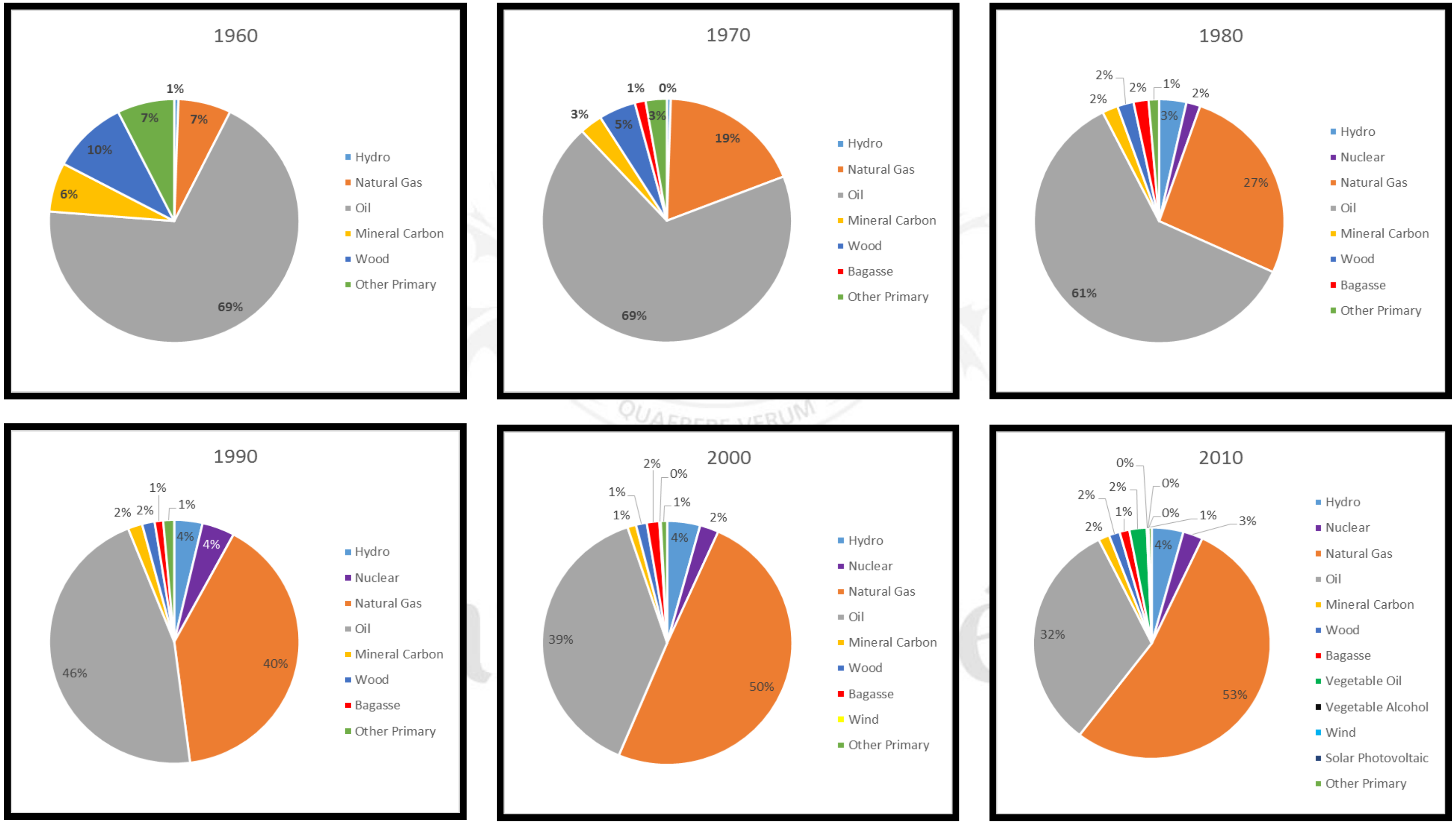
[16] According to the methodology outline provided by the Secretaria de Energía de la Nación for the National Energy Balances, Primary Energy refers to fuels that are directly extracted from nature, through prospection, exploration and exploitation, or by recollection (in the case of biomass). Secondary Energy refers to energy that derives from either primary or secondary sources through different transformation methods.

of energy provided by fossil fuels was relatively stable. In 1960, approximately 82% of the energy supply came from oil, mineral carbon and natural gas; by 2010, the number rose to 87%. It is also noteworthy that, within the pattern of supply of fossil fuels, the share of each fuel changed over time. In the 1960s oil outweighed mineral carbon and natural gas at 69%, 6% and 7% of the total energy supply, respectively. However, by the early 70s and 80s this trend began to show a gradual change towards a bigger share of supply by natural gas. Propato & Verón (2015) and Recalde (2011), recognize that this was principally due to the periodic oil crises of the 1970s – which made oil a very expensive energy source relative to other fossil fuels –, the discovery of new gas deposits, the construction and improvement of gas pipelines that had been started in the 1960s by the state company Gas del Estado, and a national decree, which proposed the gradual substitution of oil by natural gas.

The variation in the share of non-fossil fuels was also considerable. At the start of the period, 18% of the total energy supply came from non-fossil fuels. Wood accounted for 10%, hydroelectricity accounted for 1% and other primary sources for 7%. Only ten years later, Argentina substituted the share of hydroelectricity by incorporating bagasse and increasing the share of natural gas, reducing the role that non-fossil renewable energy played in the energy matrix. Only recently, as of 1994, did renewable energy begin to play a role in the Argentine energy market.

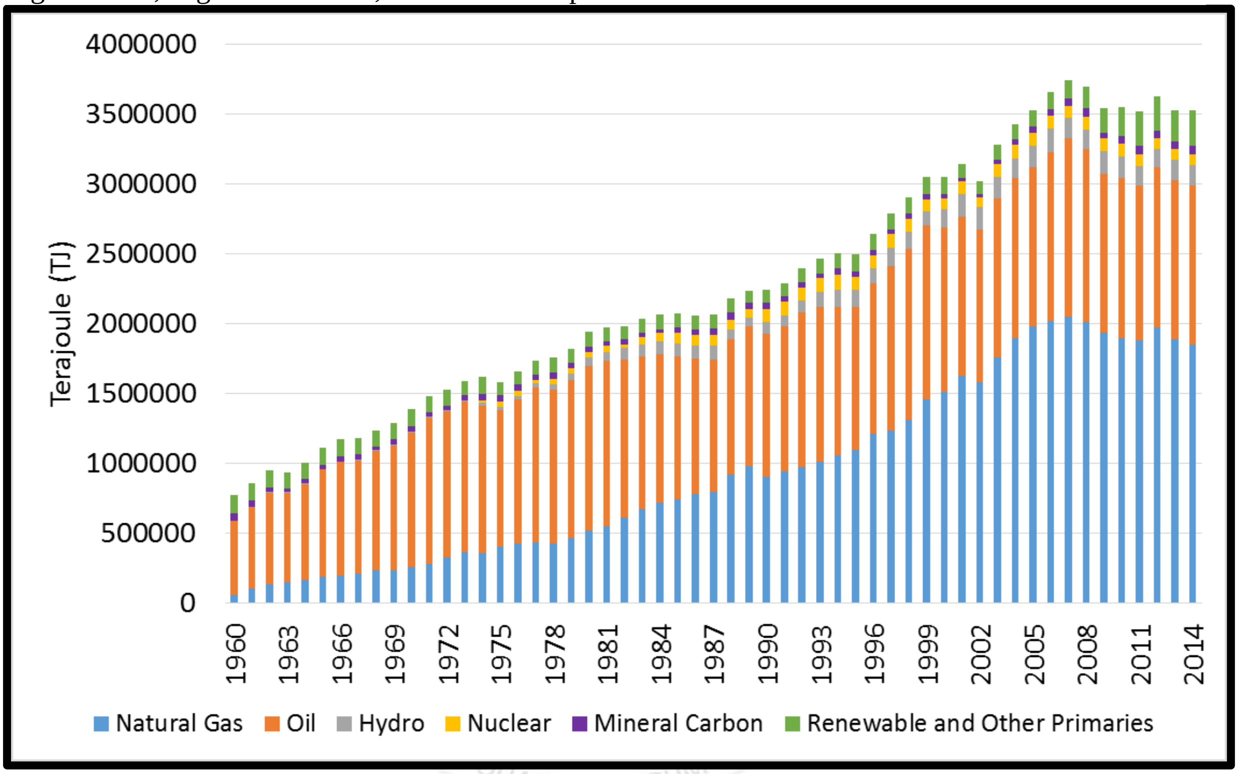
During 1988, 5 years after the consolidation of a democratic government in Argentina, poor governance, fiscal policy and administrative capacities lead to a severe energy crisis. Despite the availability of energy resources, the prices rose far above the purchasing power of most sectors of the economy. As seen on Figure 3, the energy matrix was primordially dependent upon hydrocarbons; thermoelectric power plants produced electricity almost entirely. Recalde (2011) notes that one of the main problems of the Argentine energy sector has been the lack of coordination between electricity generation and hydrocarbon production due to faulty policy proposals. This has led to energy crises such as the 1988 electricity shortage, and more recently the energy crisis of 2004.

Figure 3
Temporal change of the Argentine energy matrix by decades.
Source: Data from the Secretaria de Energía de la Nación (Balance Energético Nacional (BEN)).



In an attempt to prevent further problems with respect to energy provisions, several organizations, institutions and legal frameworks were put in place. Most notably, in 1992, Carlos Menem's government created: the Ente Nacional Regulador de Electricidad (ENRE) an electricity regulation and supervising governmental body; the Mercado Eléctrico Mayorista (MEM) and Mercado Mayorista Sur Patagónica (MEMSP), two institutions that establish a framework for electricity supply and demand from private providers; and the Compañía Administradora del Mercado Eléctrico Mayorista (CAMMESA), the organization responsible for controlling the energy that enters and is distributed within the MEM and MEMSP. In addition, the National Government proposed a plan to deviate the dependence on hydrocarbons towards internally produced sustainable energy sources; thus, reducing the cost of transaction in the supply chain between natural gas and oil production and thermoelectric generation. In 1998, the national law, Ley 25.019 was signed, which promoted renewable energy generation through a tariff incentive system. However, the ensuing financial meltdown in 2001 made it impossible to incorporate renewable energy sources due to lack of economic incentives and resources. Following this, in 2006 the national law Ley 26.190 established that by 2016 8% of all electricity had to be generated by renewable sources. At the time of signing the law, only 1% of electricity came from renewable sources. As shown in Figure 4, the relative contribution of renewable sources has been stable across time. Both laws that intended to promote renewable energy failed due to bad internal and external economic situations, lack of infrastructure, poor policy incentives and as of 2014 a steady drop in the price of oil, which made non-fossil energy sources lose competitiveness (Recalde 2011; Guzowski & Recalde 2008).

Figure 4
Total primary energy supply by fuel type between 1960 and 2014 in Terajoules.
Source: Data from the Secretaria de Energía de la Nación (Balance Energético Nacional (BEN)). Other primary and renewables includes: other primary, as stated by the official database, wood, bagasse, vegetable oil, vegetable alcohol, wind and solar photovoltaic.



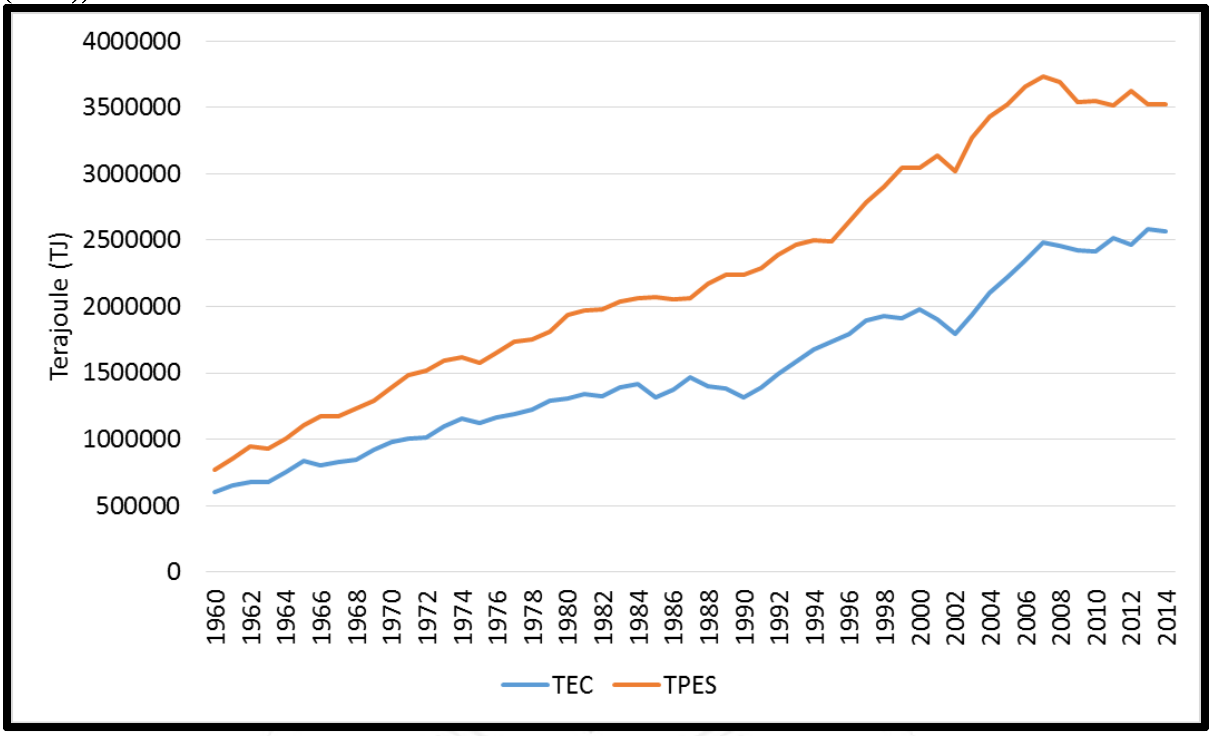
Finally, nuclear fission – incorporated into the grid in 1973 with the creation of Atucha I power plant – and biofuels – incorporated into the grid in 2006 through the act, Ley 26.093, promoting and regulating the sustainable production of biofuels and oils – have contributed a negligible amount of energy. Nuclear energy has contributed a maximum of 4% of total energy and biofuels and oils have not provided more than 1% of total energy during the period in question. Also, although hydroelectricity provided 10% of total energy in 1960, its relative contribution has diminished gradually to only 2% of total energy in 2010.

3.1.2 Energy Consumption & Intensity

In the past forty years, energy consumption and supply have steadily grown. This growth can be attributed to several factors including population growth, sectoral composition of the economy, total output of the economy, energy matrix composition and efficiency of energy use. Figure 5 shows the historical trends of total primary energy supply and total energy consumption between 1960 and 2014. The difference between the two curves arises from the fact that total energy consumption does not account for energy dissipated in conversion process (from primary to secondary), nor the energy used in energy generation. Despite periodical fluctuations, Argentina shows a positive trend in energy consumption, with a slight plateau as of 2009 due to internal and external economic inhibiting factors.

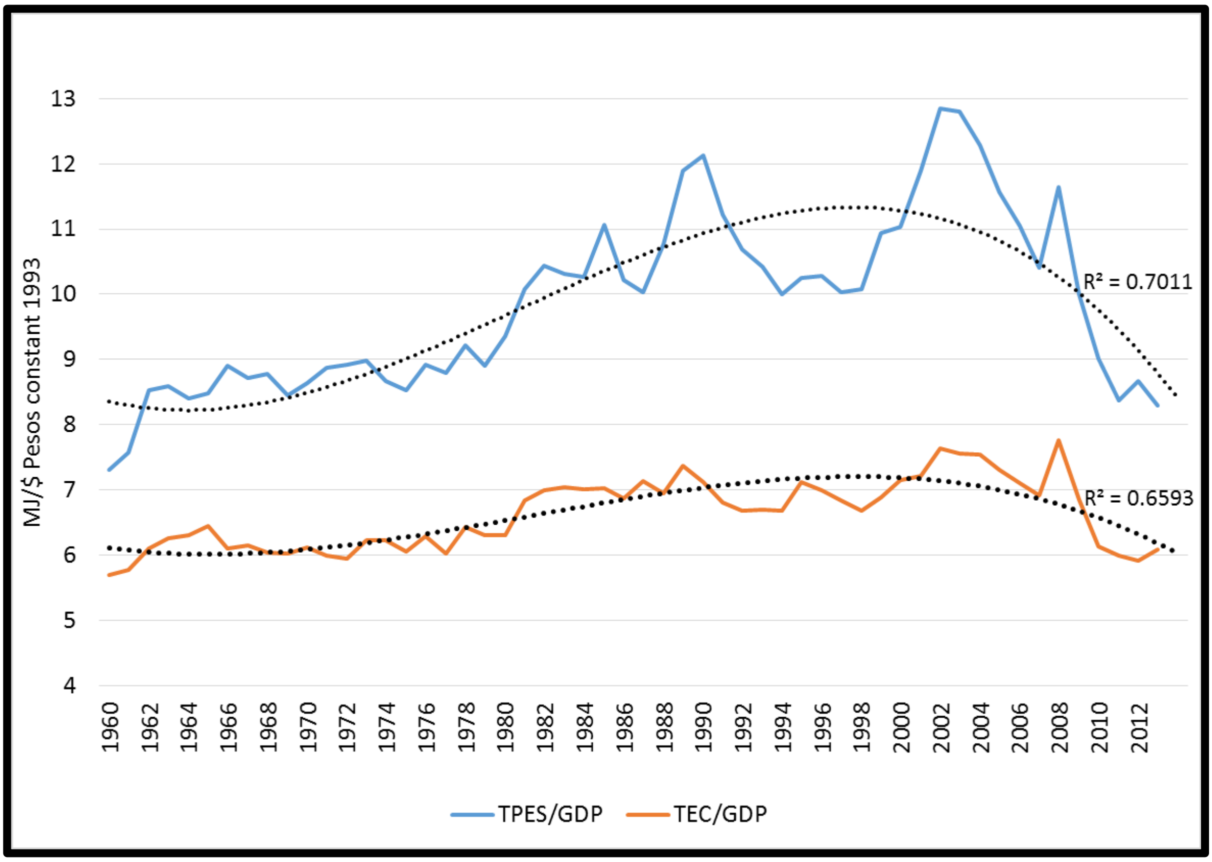
However, energy consumption and supply are limited indicators with respect to the energy situation of a country. We have explored the relatively high dependence on fossil fuels that poses a sustainability threat in the midst of growing energy demands from all sectors. Following, energy intensity provides a useful tool to evaluate the energetic performance of an economy; that is, the amount of energy invested per unit of output. It is important to highlight that the use of GDP and market traded energy are not considering the natural capital or energy subsidies provided by ecosystem services. As such, economic energy intensity is only partially useful in order to understand the adequate measure of the amount of energy needed in order to produce one unit of economic output. Rather, it shows the amount of energy extracted and transformed by humans to move the factors of production and produce one unit of economic output (measured in monetary terms).

Figure 5
Historical trend of Total Primary Energy Supply (TPES) and Total Energy Consumption (TEC) between 1960 and 2014.
Source: Source: Data from the Secretaria de Energía de la Nación (Balance Energético Nacional (BEN)).



Given both the total energy consumption and total primary energy supply curves, it is possible to evaluate the energy intensity. Figure 6 exhibits the evolution of energy intensity between 1960 and 2014. The trend is quite variable, although the starting point and end point show similar values. Considering that energy consumption shows a steady growth in the period, the violent changes in energy intensity may be attributed to the recurrent economic crisis due to political and social fragility. The three most notorious cases are the final years of the last military dictatorship where industrial production plummeted and macroeconomic indicators commenced to fall; the final years of President Alfonsin's government, which were struck with hyperinflation and economic stagnation; and the 2001 economic crisis.

Figure 6
Historical trend of energy intensity for Total Primary Energy Supply (TPES) and Total Energy Consumption (TEC) between 1960 and 2014 in Megajoules/$ Pesos constant 1993.
Source: Energy data from the Secretaria de Energía de la Nación (Balance Energético Nacional (BEN)), and macroeconomic data from Ferreres 2010 and Coremberg et al. 2013.
Note: The dotted lines show third order polynomial trend lines for each curve.



The two other factors that could explain the fluctuations of energy intensity are technical improvements, through technology or fuel mix, and sectoral composition of the economy. It is the goal of this thesis to explore the relative role that technical improvements has on energy intensity in comparison to other factors. Figure 7 shows the percentage of total energy consumption of each sector. This gives us an idea of the material structure of the economy. The agriculture, commercial & public and residential sectors have increased their share of total energy consumption in time. However, the increase has been gradual and the share of each sector has been less than 10% of total consumption (except non-energetic, which spiked above 10% in the 1990s). The residential sector has increased its share of consumption from around 20% to more than 25%, with an initial decrease between 1960 and 1980 and a subsequent increment from 17% to more than 25% between 1980 and 2013. The transport and industrial sector have gradually decreased their share of consumption. Therefore, the largest material composition of the economy has been shared the industrial and transport sectors, and more recently the residential sector.

Figure 8 presents the different trends in energy intensity for the four principal sectors of the economy. The agriculture sector has shown an increasing trend in energy intensity. The economic energy intensity of the commercial & public sector has also grown, although as of the 1990s, it began to show a relative plateau. Oppositely, both the industry and the transport sector present a stable trend in energy intensity in somewhat inverted U-shaped form. The industry sector has decreased its energy intensity since the 1960s, although the present situation is quite similar to that of the 1970s. With respect to transport, there have been no real improvements in energy intensity as the sector presents the smoothest inverted U-shaped curve of all sectors.

The fact that the sectors that increased their energy intensity the most have a relatively small contribution to energy consumption, suggests that the sectoral composition of the economy will not have a substantial effect on the changes in aggregate economic energy intensity.

Figure 7
Percentage of sectoral energy consumption in relation to total energy consumption.
Source: Energy data from the Secretaria de Energía de la Nación (Balance Energético Nacional (BEN)).
Note: Non energetic stands for goods that are derived from primary energy sources but are not directly used as fuels (for example plastics, lubricants, etc.)

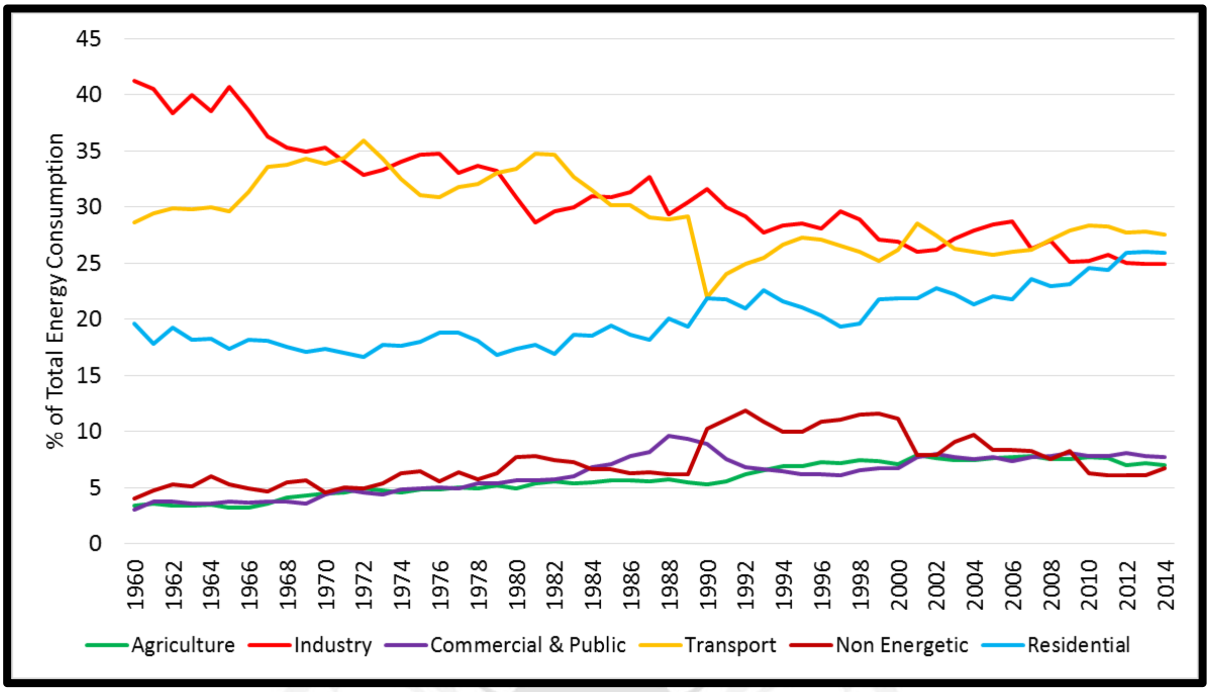
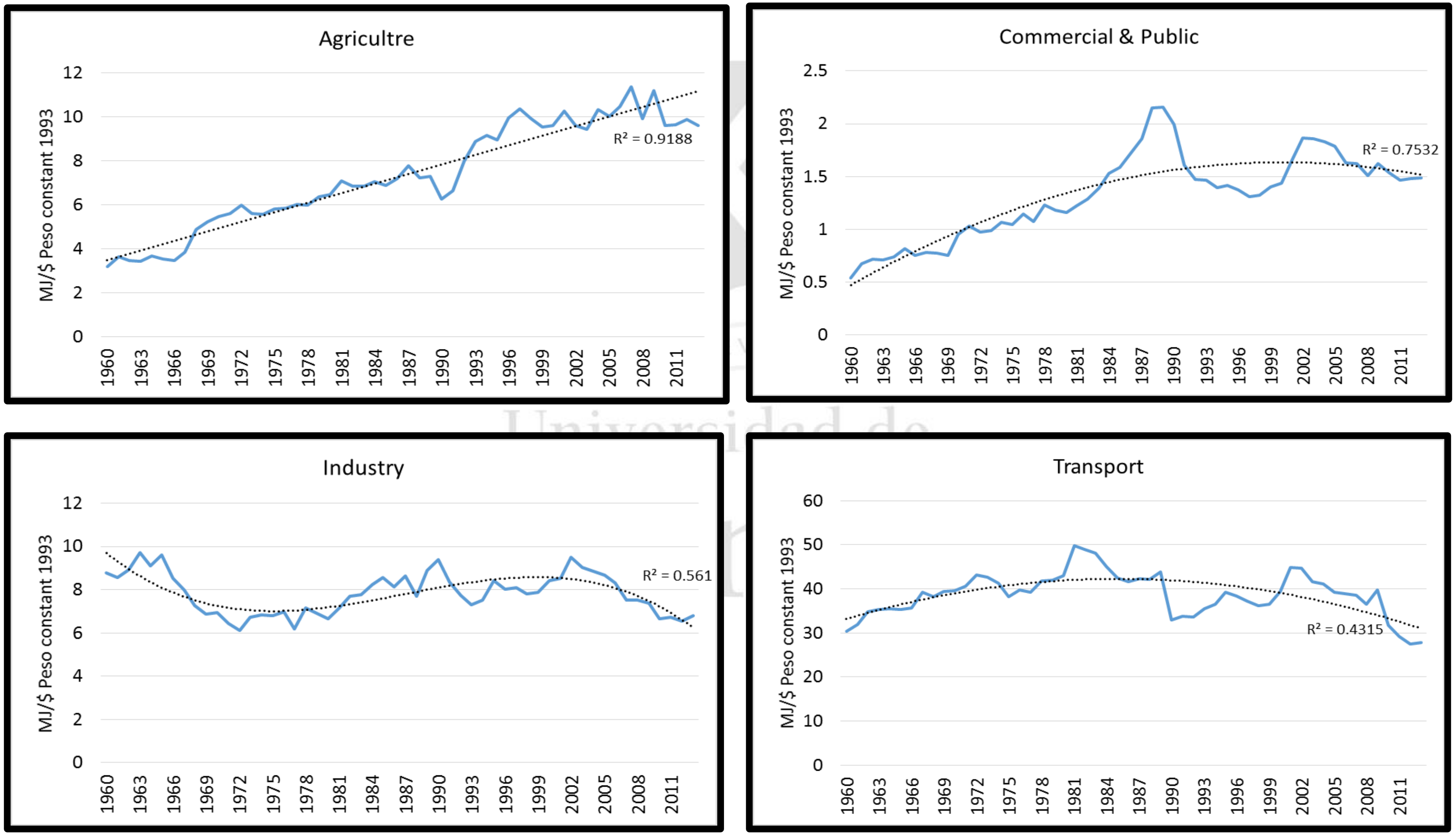


Figure 8

Energy intensity of four main sectors of the economy

Source: Energy data from the Secretaria de Energía de la Nación (Balance Energético Nacional (BEN)), and macroeconomic data from Ferreres 2010 and Coremberg et al. 2013.

Note: The dotted lines show the best-fit curves for each sector. Agriculture shows a linear trend line, commercial & public shows a second order polynomial, industry shows a third order polynomial and transport shows a second order polynomial.



3.2 Agriculture sector

Although Argentina has been historically characterized as an agro-exporting nation, its agricultural sector has continually exhibited a low-input development (Viglizzo et al. 2011). Even in the midst of the "Green Revolution" the application of intensive farming and high energy input production has had a small impact on Argentine agricultural production. Notwithstanding, Figure 10 shows that the energy consumption of the sector has had a somewhat exponential growth except for the period 2008-2014. In part, this breakage of the energy consumption trend has to do with the poor relationship between agricultural producers and the Cristina Fernandez de Kirchner's government as of 2008. A legal conflict sparked because of tax resolution, Resolución 125/2008[17], which increased the export tax for soy, wheat and corn. The fallout of the conflict produced enduring political cleavages that which generated negative production incentives in the agricultural sectors. It is also worth noting that the financial meltdown of 2008 produced severe complications in the commodities market, which can also be adduced to the decrease in production, and thus energy consumption.

However, looking closely at the period 2008-2014 reveals a contradictory trend that posits a dubiousness of the energy data. Figure 9 shows that, except for sunflower, the area planted for the four main agricultural commodities increased during the period. This can be used as a proxy to indicate that the amount of energy used in the agriculture sector actually increased, as opposed to what is presented in Figure 10. Therefore, it is necessary to be cautious with respect to the conclusions that we deduce from the data for this period. We do not hold sufficient evidence to discard the information at hand, but it seems quite clear that our inference should take into account the fact that there are two opposing sets of data for the same period.

[17] For more information on the conflict and legal framework see: Baistrocchi 2011

Figure 9
Planted area for the four main corps produced by Argentine agriculture.
Source: Data from Ministerio de Agroindustria de la Nación.
Note: The line for Total hectares planted corresponds to the right hand axis. It is a summation of the hectares planted for the four main crops.

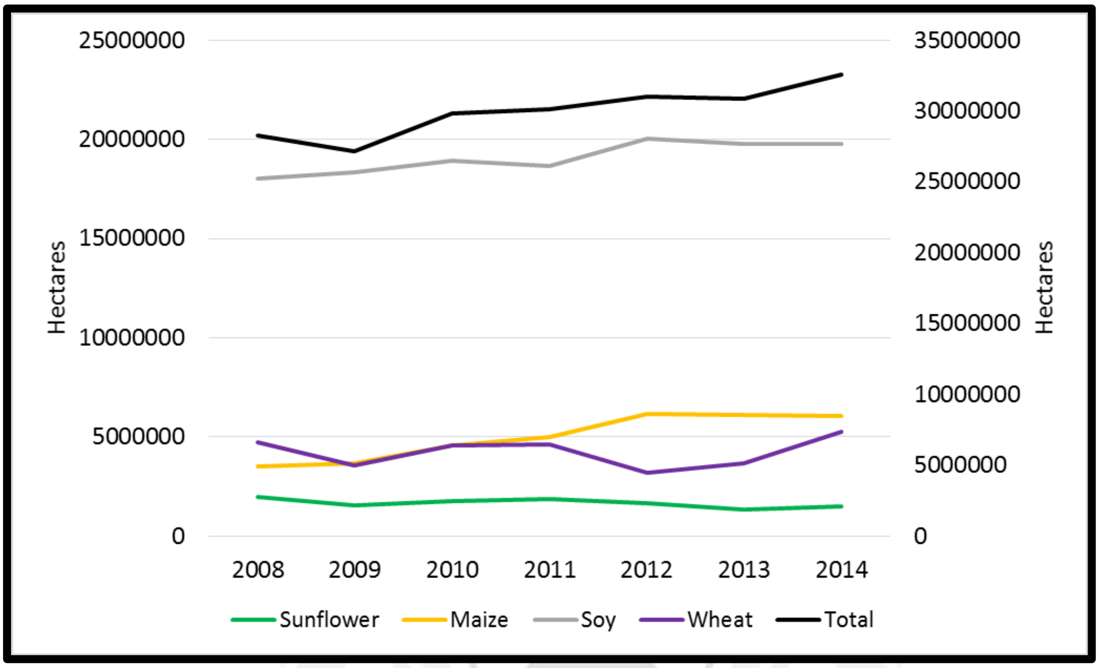
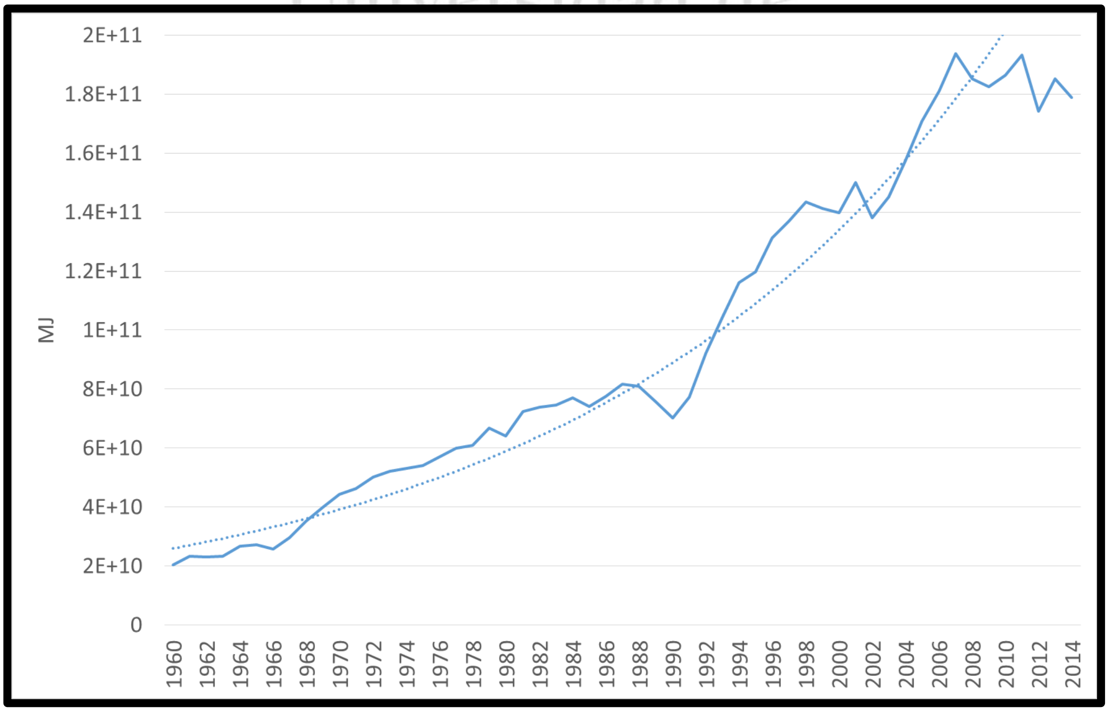
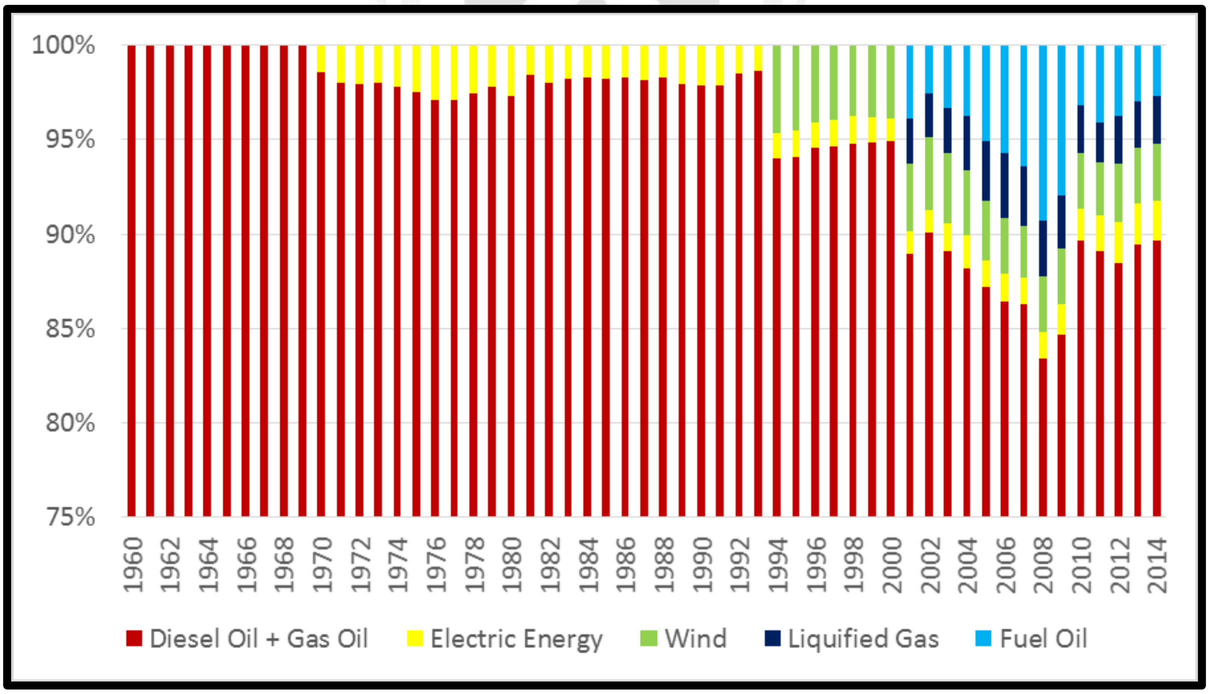


Figure 10
Agricultural energy consumption between 1960 and 2014 in Megajoules.
Source: Data from the Secretaria de Energía de la Nación (Balance Energético Nacional (BEN)). The dotted line shows the trend line for the period.



Despite its apparent sustainability with respect to energy use and environmental impact in comparison to similar agricultural systems, the agricultural energy matrix in Argentina has been grossly predominated by fossil fuels. Between 1960 and 2014, more than 95% of the total energy consumption was provided by petroleum derivatives. Figure 11 shows a clear picture of the evolution of the agricultural energy matrix. Although wind power was incorporated in 1992 as part of the renewable energy efforts post-1988 crisis, the share of energy provided has steadily declined as fossil fuels gained economic and energetic competitiveness (Hall et al. 2014; Guzowski & Recalde 2008).

Figure 11
Composition of agricultural energy matrix between 1960 and 2014.
Source: Data from the Secretaria de Energía de la Nación (Balance Energético Nacional (BEN)).
Note: The vertical axis represents the share of each fuel type in relation to total energy consumed by agricultre.



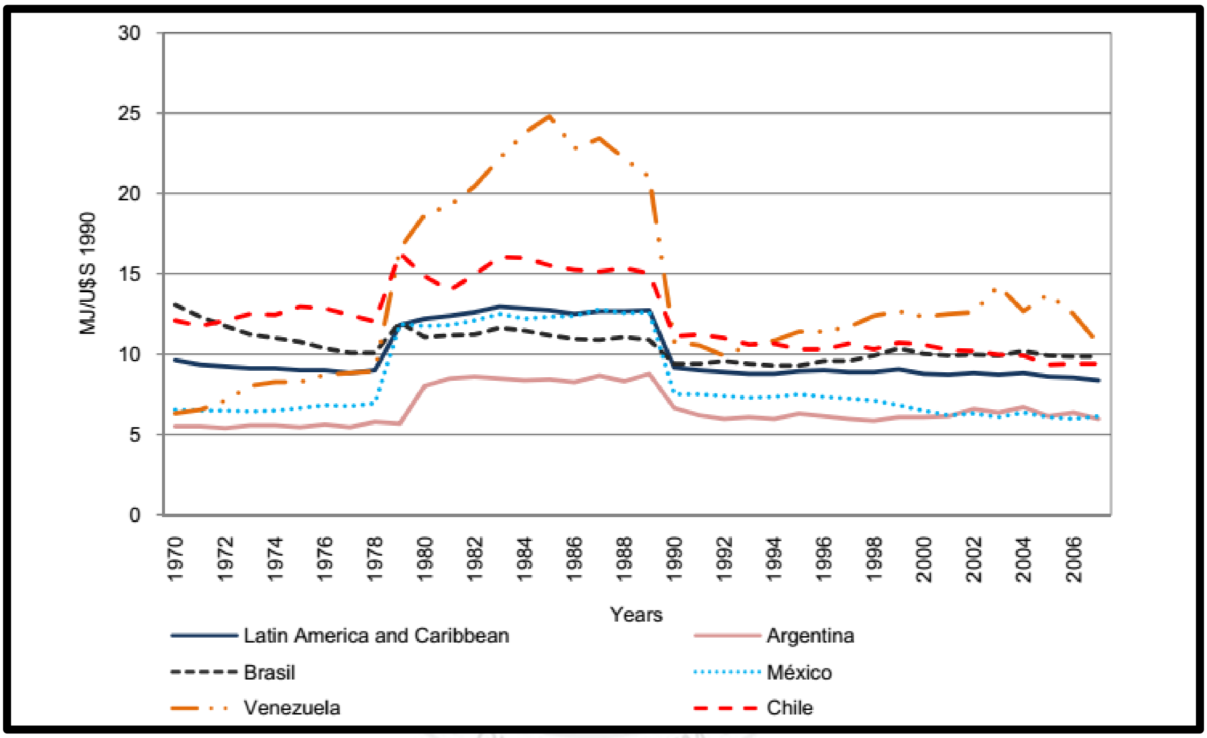
As Figure 8 depicts, energy intensity in agriculture has shown a continual growth since the start of the period, almost quadrupling in fifty years. That is, the amount of energy needed in order to produce one unit of economic output from the agricultural sector has increased almost fourfold. This, in part, has to do with the diminishing returns of agricultural systems and the loss of ecosystems services due to intensification (Barral & Oscar 2012; Tilman et al.

2002; de Wit 1992). Both of these factors generate the need for increasing amounts of energy in order to maintain a stable agricultural production. Thus, improvements in energy efficiency will be crucial asset as food and fiber demands pressure agricultural productive systems. However, these energy efficiency improvements must be corrected to prevent a rebound effect, ultimately increasing the total amount of energy consumption and intensity (van den Bergh 2010; Greening et al. 2000).

3.3 International comparison

Despite the increasing trends of energy intensity and the dependence on fossil fuels, in the whole economy and the agricultural sector, Argentina is both less energy intensive and consumes less fossil fuels in the agricultural sector in comparison to other countries. In Figure 12, it is visible that Argentina has shared an intensity trend between Latin American and Caribbean countries. That is, a somewhat stable intensity trend between 1970 and 1978, followed by a violent increase, a plateau and a final decrease and stabilization after 1990 for most countries. Recalde and Ramos-Martin (2012) point out that the 1978-1989 period, known as the *lost decade*, was caused by a regional financial crises sparked by irresponsible increases in foreign debt. Most countries exceeded their foreign liabilities far above their capacity to generate earning which lead to mass devaluation and a loss of real economic value. Thus, as energy consumption continually grew and GDP decreased, energy intensity saw a substantial growth.

Figure 12
Comparison of final energy intensity of Latin American and Carribbean countries between 1970 and 2007.
Source: from Recalde & Ramos-Martin 2012 based on OLADE/SIEE (Latin American Energy Organization/ Energy Environmental Information System)



Finally, Table 2 shows that in the period 1960-2005, the agricultural system has been a low-input system in relation to other similar agricultural economies. Although initially, Argentina partook in the intensification of agricultural production post-1970, which caused negative impacts on natural habitats and increased greenhouse gas emissions, improved tillage practices, use of less harmful pesticides and ecosystem service conservation have generated a more sustainable productive system in relation to other countries.

Although these facts stack up to a seemingly positive perspective, Argentina has enormous potential to reduce its energy intensity to position itself not only as a policy example, but also as a provider of agricultural products. The abundance and relative health of Argentine ecosystems should be taken with enormous responsibility in lieu of population growth, the pressures for development and the depletion of worldwide energy and agricultural sources due to intensive farming (Miralles 2013). Energy efficiency and responsible resource use are key factors for the sustainability of both the Argentine and world society.

Table 2
Agriculture energy, phosphorous and nitrogen balances for Argentina and other countries.
Source: from Viglizzo et al. 2011

Country	Fossil energy consumption ($GJ\ ha^{-1}\ yr^{-1}$)	Edible energy production ($GJ\ ha^{-1}\ yr^{-1}$)	Nitrogen balance ($kg\ ha^{-1}\ yr^{-1}$)	Phosphorus balance ($kg\ ha^{-1}\ yr^{-1}$)	Soil erosion ($Mg\ ha^{-1}\ yr^{-1}$)	Comments
Argentina[1, 10]	5.0[a]	5.5[a]	+ 12.6[a]	−1.2[a]	8.5[a]	Erosion data from pampas only
	6.6[b]	10.7[b]	+ 9.3[b]	−2.9[b]	11.3[b]	
	9.0[c]	15.9[c]	+ 9.6[c]	−2.1[c]	8.8[c]	
	2.0	21.2				
The Netherlands[2]		62.4	+ 115.0		> 50.0	
UK[3, 4, 5, 9]	26.4[a]	58.6[a]	+ 20.0[c]		0.1–0.4	[a]Wheat
	30.1[b]	83.7[b]				[b]Maize
	21.4[c]	3.9[c]				[c]Beef
China[6, 9, 10]	25.4	62.2	+ 227.0	+ 53.0	220.0–536.0	Inland China
Japan[8, 10]	115.8	47.5	+ 135.0		50.0–250.0	
Scandinavia[8, 9, 10]	15.3	30.3	+ 19.0		0.5–2.5	Sweden and Denmark
France[8]			+ 53.0		50.0–250.0	
Canada[7, 8, 9, 10]	6.0	10.8	+ 13.0		> 50.0	
	6.9	17.4				
USA[6, 8, 9, 10]	12.6	25.6	+ 10.0	−9.0	50.0–250.0	Mid-West states
New Zealand[8, 10]	60.2	37.3	+ 6.0			
Brazil[8, 9, 10]	5.4	25.0	−8.6		> 50.0	Brazilian Cerrado
Nigeria[2, 5, 9, 10]	1.3	12.0	−22.0		10.0–50.0	
Kenya[6, 9]			−52.0	+ 1.0	195.0	

[1]Results from this study: [a]1960, [b]1986–1990 and [c]2001–2005 periods; [2]Giampietro *et al.* (1999); [3]Spedding (1979); [4]Spedding & Walsingham (1975); [5]Stoorvogel & Smaling (1990) and Frissel (1978); [6]Vitousek *et al.* (2009); [7]McRae *et al.* (2000); [8]Organisation for economic co-operation and development (2001); [9]Lal (1994); [10]Estimations from Giampietro *et al.* (1999) and Conforti & Giampietro (1997) for grains only.

4. Data and Methods

4.1 Data

Most of the data used in the analysis was taken from official sources. The rest of the data was taken from previous academic or private compilations. For energy data, the National Energy Balances from the Secretaría Nacional de la Energía were used. These balances provide data for primary and secondary energy supply and consumption in five principal sectors (non-energetic, industry, agriculture, commercial and public, and residential) and the energy used in order to generate energy. There is no sub-sectoral level disaggregation, and it is worth noting that these statistics, although official in nature, are categorized as provisional. There are few indications of the sources from which they were collected or a clear methodology used in order to compile them. Notwithstanding, we could not find any better or more disaggregated and time-series database to perform our analysis.

For macroeconomic indicators we used the recently published statistics compilation by Ferreres (2010). To our knowledge it is the most complete and disaggregated data on national and sectoral indicators. The Gross Domestic Product (GDP) was computed using constant 1993 Argentine Pesos. The time-series in the compilation only covers the period 1810-2009, while our study period extends to 2013. For the missing values we used ARKLEMS+LAND (Coremberg et al. 2013) online database that uses the same methodology to compile GDP values as Ferreres (2010).

The lack of institutional stability during the greater part of the XX century has proved challenging for Argentina's capacity to generate reliable statistics. Thus, energy statistics and macroeconomic indicators are not collected in a cohesive manner, such that it is difficult to relate sectoral level energy statistics with their macroeconomic counterparts. In order to preform our analysis we have decided to reorganize sectoral GDP statistics in order for it to fit our energy data. As mentioned before, the sectoral disaggregation for energy in the National Energy Balances is non-energetic, industry, agriculture, residential, commercial and public. GDP is disaggregated into Agriculture, animal husbandry, hunting and forestry; Fishing; Mineral exploitation; Construction; Manufacturing industry; Electricity, Gas and Water Service; Finance; Communications; Public Administration, Defense and Extraterritorial Organizations; Commerce, Hotels and Restaurants; Real Estate and Renting; Other Services; and Transport and Storage. Therefore, we reorganized our GDP data as follows:

- Agriculture: Agriculture, animal husbandry, hunting and forestry + Fishing
- Industry: Mineral exploitation + Construction + Manufacturing Industry
- Commercial and Public: Electricity, Gas and Water Service + Finance + Communications + Public Administration, Defense and Extraterritorial Organizations + Commerce, Hotels and Restaurants.
- Residential and Other Services: Real Estate and Renting + Other Services
- Transport: Transport and Storage

We can therefore understand the energy intensity of most sectors of the economy and partially explain the historical trends and future projection. We undoubtedly recognize the obvious drawbacks of such a gross reorganization. Nonetheless, given the limited availability of reliable data and the descriptive objectives of this thesis it will not hinder our understanding of the energy panorama of Argentina. An important corollary of our conclusive remarks will expand on the need to produce better, more cohesive, disaggregated and reliable energy and macroeconomic data. It is the only input that will allow us to understand how we use energy, produce wealth and consume resources in a sustainable manner.

We have chosen to analyze the period 1960 to 2013 in order to gage the effects of the oil crises during the 1970s, Argentina's "Green Revolution" and the energy efficiency policies, which began in the middle of the 1980s. The first decade of the period will provide a comparative baseline in order to understand the effect and magnitude of these factors.

4.2 Methods

In broad terms, the disaggregation methodologies to analyze empirical data are closely related to the nature of the available data (Jimenez & Mercado 2014). Hoekstra & van der Berg (2003) compare the two most used techniques to analyze the determinants of the historical changes in economic, energetic, environmental, employment and other socio-economic indicators. That is, structural decomposition analysis (SDA) and index decomposition analysis (IDA). The principal difference between the two techniques is the nature of the data used in order to decompose an indicator; while SDA uses the input-output model developed by Wassily Leontief, IDA uses aggregate data at sector and sub-sector levels. This difference allows users of SDA to differentiate between direct and indirect effects on the indicator. However, although IDA is limited with respect to the capabilities of displaying a detailed account of variable effects, it allows for the use of data on any level of aggregation and time series format (Inglesi-Lotz & Pouris 2012).

Therefore, due to lack of input-output energy data and high levels of aggregation, the models in this thesis are based on the IDA technique. As stated before, this will only allow the observation of direct spillover effects.

Despite its relatively straightforward approach, there are several methods employed within the IDA framework. The choice of method seems to be arbitrary, so there is little consensus with respect to which method is best. In general, most authors justify their choice of method with respect to data availability and relative ease of use. Shahiduzzaman & Alam (2013), Ang (2004) and Ang & Liu (2001) provide a detailed description of the several methodologies within the IDA approach, recognizing their relative benefits and drawbacks. It is beyond the scope of this thesis to offer a literature review on the methodologies used in indicator decomposition. Based on Inglesi-Lotz & Pouris (2012) and Ang & Liu (2001), we will follow the Logarithmic Mean Divisia Index (LMDI I) decomposition methodology as it is preferred over other methods due to: (1) ease of use; (2) theoretical foundation, factor-reversal, time-reversal, proportionality and consistency in aggregation; (3) adaptability, can be used in time-series and cross-country comparisons; (4) ability to handle zero-values; and (5) ease of result interpretation.

Most studies that have used the LMDI I method evaluate energy intensity[18] and CO_2 emissions[19] variation. The first group of studies identify three principal effects as the contributors to the changes in energy consumption and intensity: (1) structural effect, changes of the contribution of each economic sector in total energy consumption; (2) activity effect, changes in overall economic activity; and (3) technical efficiency effect, changes in either fuel mix or improvements in energy efficiency at the sectoral level. In this thesis, due to limited access to reliable data we will analyze the effect of economic structure and technical efficiency improvements. Following Wilson & Swisher (1993) and Bohringer (1998) we have chosen a top-down approach as the economy-wide energy consumption will be considered first, followed by the consideration of energy intensities in each sector.

Specifically for this thesis, the variables proposed in Table 3 are used.

[18] Studies have been done to analyze energy intensity in the following countries using decomposition methods: Australia (Shahiduzzaman & Alam 2013; Wilson et al. 1994), China (Wang et al. 2014; Zhao et al. 2010; Ma & Stern 2008), South Africa (Inglesi-Lotz & Pouris 2012), Slovenia (Al-Mansour 2011), Tunisia (Fodha & Zaghdoud 2015), Latvia (Timma & Blumberga 2014), Lithuania (Baležentis et al. 2011), Europe Cross-Country (Fernández González et al. 2014; Fernandez Gonzalez et al. 2013), Spain (Colinet Carmona & Román Collado 2015; Andrés & Padilla 2015; Ramos-Martin 2001), Brazil (Achão & Schaeffer 2009), Japan (Liu et al. 2011), Turkey (Ediger & Huvaz 2006) and France (Mairet & Decellas 2009).

[19] Studies have been done to analyze CO_2 emissions in the following countries using decomposition methods: China (Zhang et al. 2016; Lin & Zhang 2016; Wang et al. 2005), Australia (Shahiduzzaman et al. 2015), Greece (Papagiannaki & Diakoulaki 2009; Hatzigeorgiou et al. 2008), Denmark (Papagiannaki & Diakoulaki 2009), United States (Vinuya et al. 2010), Spain (Cansino et al. 2015), Ireland (Mahony 2013; Cahill et al. 2010), South Korea (Jung et al. 2012) and Brazil (de Freitas & Kaneko 2011).

Table 3
List of variables considered in the model.

Variable	Definition	Units
E	Total energy consumption	MJ
Q	Total economic output ($=\sum_i Q_i$)	1993 U$D
I	Total energy intensity	MJ/1993 U$D
i	i-th sector of the economy	
E_i	Energy consumption of the i-th sector	MJ
Q_i	Economic output of the i-th sector of the economy	1993 U$D
I_i	Energy intensity of the i-th sector of the economy ($=E_i/Q_i$)	MJ/1993 U$D
S_i	Output share of the i-th sector of the economy ($=Q_i/Q$)	1993 U$D
t	Time period t	Year

If we suppose that an economy is divided into multiple sectors, the total energy consumption of the economy can be written as follows:

$$E = \sum_i E_i = \sum_i \frac{E_i}{Q} \times \frac{Q_i}{Q} \times Q \tag{1}$$

We can divide the total energy consumption by the total activity of the economy in order to obtain the overall energy intensity. Thus, we obtain:

$$I = \sum_i \frac{E_i}{Q_i} \times \frac{Q_i}{Q} \tag{2}$$

Eq. (2) can be simplified by use of symbols as:

$$I = \sum_i I_i \times S_i \tag{3}$$

Thus, the change in total energy consumption between year t and t-1 can be additively decomposed in the following format:

$$\Delta I_{tot} = I^t - I^{t-1} = \Delta I_{eff} + \Delta I_{str} \tag{4}$$

Where ΔI_{tot} is the total change in energy intensity between two time periods, and ΔI_{eff} and ΔI_{str}, are the changes in energy intensity due to real intensity effect (an increase in efficiency) and structural effect, respectively.

In order to decompose the factors of energy intensity, by use of the LMDI I, we must consider the logarithmic average between two variables a and b as proposed by Sato (1976) and Vartia (1976), which can be expressed as:

$$L(a,b) = \frac{a-b}{\ln(a) - \ln(b)} \quad for\ a \neq b \tag{5}$$

and,

$$L(a,b) = a \quad for\ a = b \tag{6}$$

We can therefore write the following logarithmic weighting scheme $L(E_i^t, E_i^{t-1})$ for each factor contributing to the changes of aggregate energy intensity following (Ang 2005):

$$Real\ Intensity\ Effect = \Delta I_{eff} = \sum_{i,m} \frac{I_i^t - I_i^{t-1}}{\ln(I_i^t) - \ln(I_i^{t-1})} \times \ln(\frac{I_i^t}{I_i^{t-1}}) \tag{7}$$

$$Structure\ Effect = \Delta I_{str} = \sum_{i,m} \frac{I_i^t - I_i^{t-1}}{\ln(I_i^t) - \ln(I_i^{t-1})} \times \ln(\frac{S_i^t}{S_i^{t-1}}) \tag{8}$$

Due to the lack of reliable and consistent data, we will look at four of the five sectors that appear in the national energy balances. Although Ang & Liu (2001) recognize that LMDI methodology is best at the smallest possible level of data aggregation, we are limited to doing a sectoral analysis of the energy intensity in the economy. We will thus analyze the real energy intensity and structural effect of the industry, agriculture, commercial and public and transport sectors.

5. Results and Discussion

5.1 Energy intensity decomposition

The decomposition of total energy intensity shows the annual changes in energy intensity between 1960 and 2013. Table 4 presents the changes in decomposed factors in terms of the changes in aggregate intensity. The real intensity effect indicates a change in sector level energy efficiency, while the structure effect indicates a change in the sectoral composition of the economy. Negative values mean that energy intensity decreased, and the converse for positive values. Overall, total energy intensity increased by 0.39 MJ/$ Peso constant 1993. If we look at the two effects, it is quite clear that the structure of the economy has led to a decrease in energy consumption per unit of GDP produced. However, there have been very little improvements in energy efficiency, which has produced an overall effect of increased energy intensity.

Table 4
Decomposition results for changes in aggregate energy intensity: aggregated for different periods
Source: Own elaboration
Notes: Negative numbers represent a positive contribution on energy intensity (decrease). The opposite is true for positive numbers.

Time Period	Real Intensity Effect ΔI_{eff}	Structure Effect ΔI_{str}	Change in Energy intensity
1960-1970	0.45	-0.03	0.42
1970-1980	0.74	-0.55	0.19
1980-1990	0.71	0.11	0.82
1990-2000	0.035	-0.05	0.03
2000-2010	-1.97	0.95	-1.02
2010-2013	-0.11	0.06	-0.05
1960-2013	0.6	-0.21	0.39

During the 1960s, 1970s and 1980s, energy intensity increased at a constant rate with slight fluctuations. However, at the start of the 1990s the increase in energy intensity began to drop and reversed its path in the preceding thirteen years. It has been steadily dropping for the past decade, however it has not yet entered a downward trend. That is, despite the fact that the intensity trend has reversed, Argentina seems to be trapped within what Recalde and Ramos-Martin (2012) identify as attractor points. These points are values for energy intensity in which an economy circles around overtime, without seeing any real improvements. As Figure 14 shows, the real intensity effect has been the predominant force behind the increases in overall energy intensity.

Figure 13 and Figure 14 show the changes in structure effect and real intensity effect, respectively. At the very start of the period studied, the intensity effect did not seem to have a significant effect on overall intensity. However, this trend changed until approximately the start of the XXI century. This means, that we are seeing a change in the energy efficiency of most sectors, which contributes to an overall decrease in the amount of energy needed to produce a unit of economic output. The structure of the economy, on the other hand, has had much less of an effect on the overall intensity. This can be attributed to the fact that the most intensive sectors of the economy (Figure 8) have decreased their share of total energy consumption. In addition, their economic energy intensity has remained relatively constant; that is, despite an inverted U-shaped curve, which exposes an initial increase, the present level is similar to the intensity in 1960. The two sectors that have significantly increased their economic energy intensity are agriculture and commercial & public. However, they have consumed less than 10% of total energy consumption between 1960 and 2013. Therefore, the effect of the increase in energy intensity of these sectors is relatively small. More disaggregated data is needed in order to test the significance of these assertions.

Figure 13
Structure effect on overall energy intensity, 1960-2013
Source: Own elaboration
Notes: Negative numbers represent a positive contribution on energy intensity (decrease). The opposite is true for positive numbers.

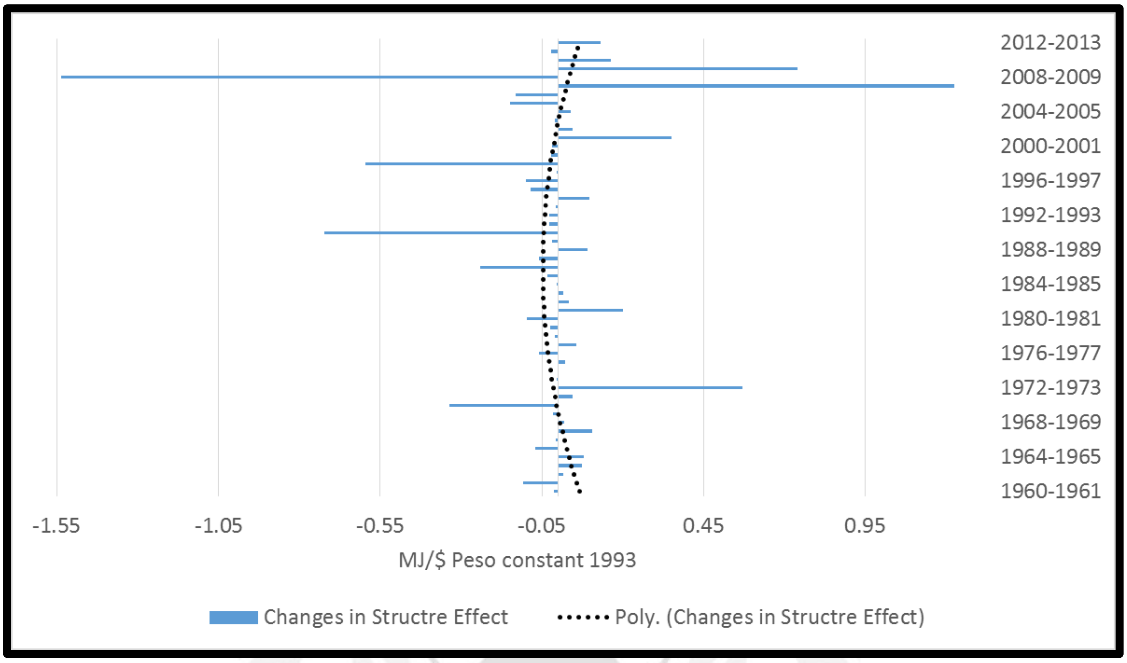
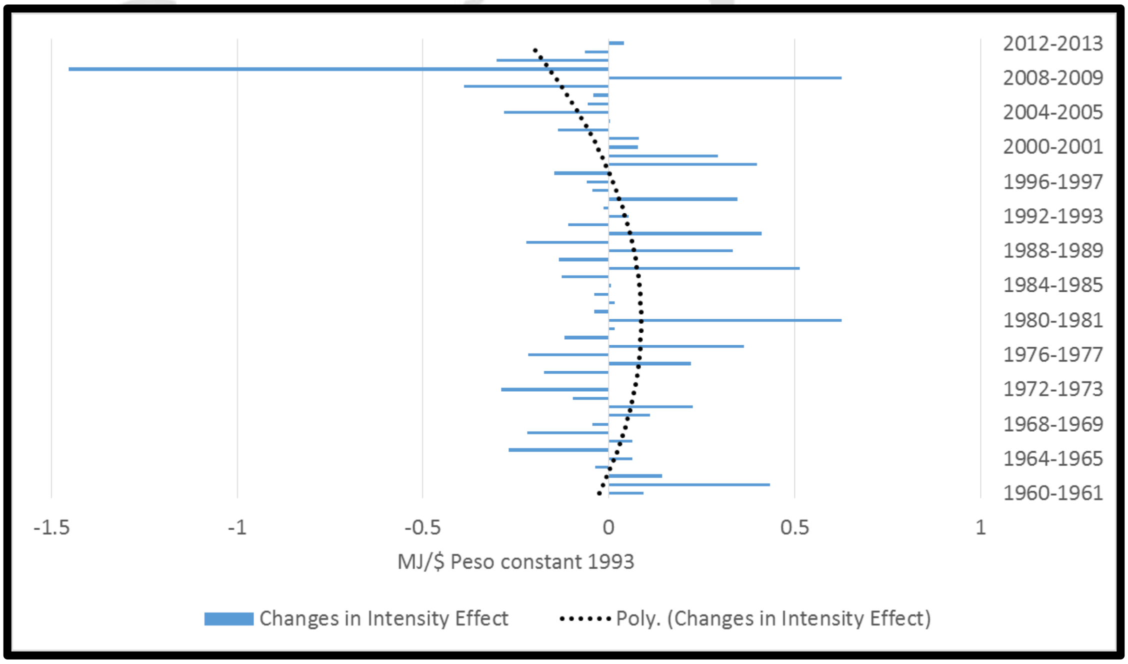


Figure 14
Real intensity effect on overall energy intensity, 1960-2013
Source: Own elaboration
Notes: Negative numbers represent a positive contribution on energy intensity (decrease). The opposite is true for positive numbers.



If we look at our figures on a decade basis, we can see that the country's general trends present serious fluctuations. During the 1960s, energy intensity generally increased, and both sectoral composition and energy intensity contributed positively to the general trend. Argentina began to expand its transport sector (a highly intensive economic activity), crude oil prices were still relatively cheap and the technological advancements of the second post-war era were now available to increase economic performance.

During the 1970s, most fossil fuel dependent economies were slowed down due to the oil and energy crises. More than 90% of Argentina's energy supply came from fossil fuels; oil represented 69% of the energy matrix. Prices surged and energy became relatively scarce, which negatively affected the structural composition of the economy, as many industrial sectors had to halt or slow down their production. Notwithstanding, no efforts were made to improve energy efficiency at the sectoral level. Despite the fact that the structure effect pulled towards a decrease in energy intensity, energy efficiency continued to decrease, increasing intensity by 0.74 MJ per constant 1993 Peso. Although agriculture accounts for a small portion of total energy consumption, the "Green Revolution" was underway during this decade, which caused agricultural energy consumption to begin to rise geometrically for Argentina. This global increase in agricultural inputs and fuel use could help partially explain the increase in energy intensity in Argentina despite the harsh energetic situation. More detailed sub-sectoral data is needed to test the hypothesis and evaluate changes in energy use within the agricultural sector.

The 1980s seem to provide an answer for the reasons behind Argentina's unconventional energy intensity path. The rate of increase between the 1960s and the 1970s was cut down by more than 50% - 0.42 MJ/$ Peso constant 1993 in the 1960s to 0.19 MJ/$ Peso constant 1993 in the 1960s. Many academics refer to the 1980s as the *lost decade*. This denotes a regional financial crisis because of high levels of induced sovereign debt far beyond the earning powers of the economies. The result was a regional default on debt obligations which led many countries to devaluate their currencies on the dollar (Recalde & Ramos-Martin 2012). Although economic activity contracted, the spike in energy intensity could be mostly attributed to the financial problems that governments faced in relation to their foreign liabilities.

The consequences of these crises were widespread, particularly for the energy sector. Argentina saw increasing difficulties to provide energy, which caused power outages during the eighties and a full-blown energy crisis in 1988. This led to the implementation of several efficiency promoting public policies, which can partially explain the substantial reduction of the intensity effect during the 1990s. It must be considered that several financial artifacts were used to balance out the economies monetary problems. Also, the structure effect went down as a result of the economic slowdown due to the liberalization policies implemented by the government. Economic openness was favored and many national productive sectors saw a decrease in activity as competition against foreign products made local production unprofitable.

Finally, as the figures show, energy intensity has been consistently dropping for the past thirteen years – with the exception of the 2008-2009 period, possibly due to the global financial "housing bubble" crisis –. The agricultural sector has been slowly expanding and increasing its intensity. In addition, the growth of the state infrastructure and the consumption in the commercial, residential and transport sectors generate an upsurge of sectoral energy intensity. Thus, as Figure 13 shows the structural effect is beginning to lean towards an increase of overall energy intensity. On the other hand, the real intensity effect is much higher than the structure effect. Therefore, the gains in energy efficiency are canceling out the tendency of the sectoral mix to increase overall intensity.

It is noteworthy that overall energy intensity reached all-time highs in 2001 and 2009 due to internal and external economic crises, respectively. The steady stabilization of economic situation and the increase in the price of agricultural commodities, such as soybean, have provided the possibility of reentering a path of increased efficiency of energy use, or rather, a decrease for energy needed to produce one unit of economic output. Despite this recent trend, Argentina presents about the same levels of energy intensity as it did in the 1960s. The phenomenon has largely been due to the inability to generate sectoral incentives to increase energy efficiency, poor economic and monetary stability, increased fossil energy consumption, a tendency towards increasing the share of high intensity sectors such as transport, commercial, public and residential, as well as the degradation of ecosystem services.

5.2 Energy efficiency policy evaluation

Public policy analysis literature recognizes that the evaluation of a public policy can be done at any stage[20] of the policy process. Thus, we can choose to evaluate a policy anywhere from the stage of thinking about the problem at hand, to the point when the policy has come to a formal end and its results are available. The specific stage we choose to perform our evaluation will necessitate different tools and will entail different objectives (Bardach 2009; Tamayo Sáez 1997). In Section 2, we have laid out a brief history of the energy efficiency policies. In Section 3, we have presented an overview of the energy, energy matrix and energy efficiency context of the Argentine economy and agricultural sector. Following, in this section, we have decomposed the energy intensity trend to single out the effect of improvements in energy efficiency. We will therefore evaluate the policy concerning its impact or efficacy. In

[20] The policy process is a complex web of decisions and actions that do not have a straightforward, homogenous and standardized organization. Rather, policies are structured through feedback processes and do not necessarily start on a clean slate. Policy efforts are often accumulative, which makes it hard for the analyst to methodically analyze policies from start to finish (Hupe & Hill 2006). Harold Laswell (1956) and Paul Sabatier (1999), two American political scientists intended to better understand the policy process, and proposed structured models (or conceptualized maps) of the policy process as if it traversed through different stages, (1) intelligence, (2) promotion, (3) prescription, (4) invocation, (5) application, (6) application, (7) termination, (8) appraisal.

other words, comparing the desired impacts or effects with those observed in reality (Tamayo Sáez 1997). Further analysis is needed in order to understand the internal policy and external contextual factors that explain the divergence or convergence of policy objectives with actual results.

The Jevons' paradox, also known as the *Rebound Effect* (Hanley et al. 2009; Greening et al. 2000), proposes that gains in energy efficiency do not necessarily translate in a more responsible or sustainable energy consumption pattern. Energy efficiency improvements should not be an end in and of themselves, but rather a means to provide sustainable economic development. Therefore, integral energy efficiency policies should be oriented towards a broader goal of reducing or maintaining the level of energy consumption.

In relation to Argentine energy policies that began in the final years of the XX century, efficiency oriented policy is relatively new. As stated above, the first efforts to improve energy efficiency at a national level began with the first set of oil crises during the 1970s; and in Argentina, in 1985 with President Raul Alfonsín. Considering the institutional mess left by the political instability of the XX century in Argentina, it is no surprising the efficiency policies were not very successful until the start of the XXI century. Only as of the 1990s did energy efficiency improvements begin to show an overall decreasing effect on aggregate energy intensity.

The efficiency policies of the 1980s under the program URE provided a somewhat stable level of energy consumption. If we look at Figure 14, we can see that the real intensity effect began to drop around the mid-1980s, as the first efficiency programs were beginning to take place. Notwithstanding, policy efforts were somewhat overshowed by the failing economic legacy inherited from the political turmoil that characterized the second half of Argentina's XX century. Therefore, although the policies implemented managed to change the course of the efficiency trend they were insufficient to provide a drop in aggregate energy intensity.

During the 1990s, several policies followed President Alfonsin's initial efforts. The National Natural Gas Law and National Electric Energy Law that were both passed in 1992 were intended to promote a more responsible use of energy. However, our results do not provide information regarding the effects of the use of different fuels on energy efficiency. A more detailed analysis is needed to gage the consumption of different fuels at a sub-sectoral level and quantify the efficiency improvements generated by altering the composition of the sub-sectoral energy matrix. Figure 8 shows that since the start of the 1990s the energy intensity of transport and industry sectors decreased – we will explore the reasons behind the increase of agriculture intensity later –. It is thus possible to partially conclude, that both the URE and its predecessor URE RA/EU were successful in generating a more efficient use of energy at the sectoral level. We emphasize the use of partial explanation since we need to evaluate the improvements of energy efficiency at the sub-sectoral level to fully grip the true effect in addition to the fact that the commercial and public sector intensity has plateaued since the 1990s. Notwithstanding, a reduction in the amount of energy needed to produce a unit of output at the sectoral level can be used to suppose that energy was being used more efficiently. Finally, lack of price regulations and accompanying consumption regulation policies caused a huge increase in energy consumption (Figure 5). Although efficiency gains were met, the use of energy became unsustainable as the price of energy decreased, which in turn led to higher levels of consumption.

A similar trend can be seen for the first five years of the XXI century. The PURE and PUREE programs failed to meet their objectives of reducing energy consumption. As of 2007, with the introduction of the PRONUREE program, both energy efficiency and energy consumption began to drop. Together with a growth of real GDP, overall energy intensity began to change its course, and in six years dropped to levels comparable with the 1960s. The increase in energy efficiency can also be attributed to the integral energy efficiency program Proyecto de Eficiencia Energética en Argentina – GEF, described in Section 2. It provided economy-wide funds for technological development, research and consultancy allowing industries to implement more rational energy use schemes. It is also important to remember that at the end of 2010 Argentina began to show a slow-down in its economic activity. This could help explain the plateau in energy consumption in the final years of the period studied. However, it is also seemingly clear that despite energy consumption patterns, some policy objectives were met. As stated before, we need better and more disaggregated data in order to fully comprehend the efficiency gains at the sub-sectoral production level.

5.3 Discussion: "Big" picture and future projection

Our research has been exploratory and descriptive, and due to poor data it is necessary to point out that we should be cautious about the strength and depth of our conclusions. The state of energy and output statistics for economic sectors and sub-sectors is very basic and difficult to find. The lack of consistent aggregation and centralization may be one of the factors that explain why Argentine researchers have not tackled economy-wide energy analysis. In addition, for the period 2008-2014 official statistics contradict information provided by other metrics, which makes it difficult to propose reliable conclusions. In order to ensure a sustainable development, it is indisputably necessary to have good and reliable statistics. For this, policymakers should make efforts to provide institutional frameworks that allow transparency, and above all long term continuity in disaggregated energy statistics and sectoral and sub-sectoral output statistics, using economic, physical and thermodynamic indicators. Still, our work is the first to decompose the Argentine energy intensity using the IDA approach. This effort adds to the burgeoning literature on decomposition analysis, which could lead to future comparative analysis and a stronger understanding of the reasons behind different countries' energy intensity

Thus, it seems that there are several trends that we can understand; at least on a superficial level. Despite its volatile pattern, energy intensity in Argentina has remained somewhat constant, or slightly increasing. Our results show that in the last fifty years primary energy intensity – TPES/GDP – has increased 0.99 MJ/$ Peso constant 1993, and total energy intensity – TEC/GDP – has increased 0.39 MJ/$ Peso constant 1993. This is consistent with Recalde & Ramos-Martin (2012) who conclude that energy intensity has been rather stable in the past forty years. They state that in opposition to Kuznets theory of dematerialization, energy consumption has not increased due to improvements in energy efficiency. Rather, highly intensive productive sector composition, high dependence on fossil fuels in the sectoral mix and feeble and volatile economic structures and institutions provide clues as to why Argentina has gone down an undesirable path in terms of energy intensity.

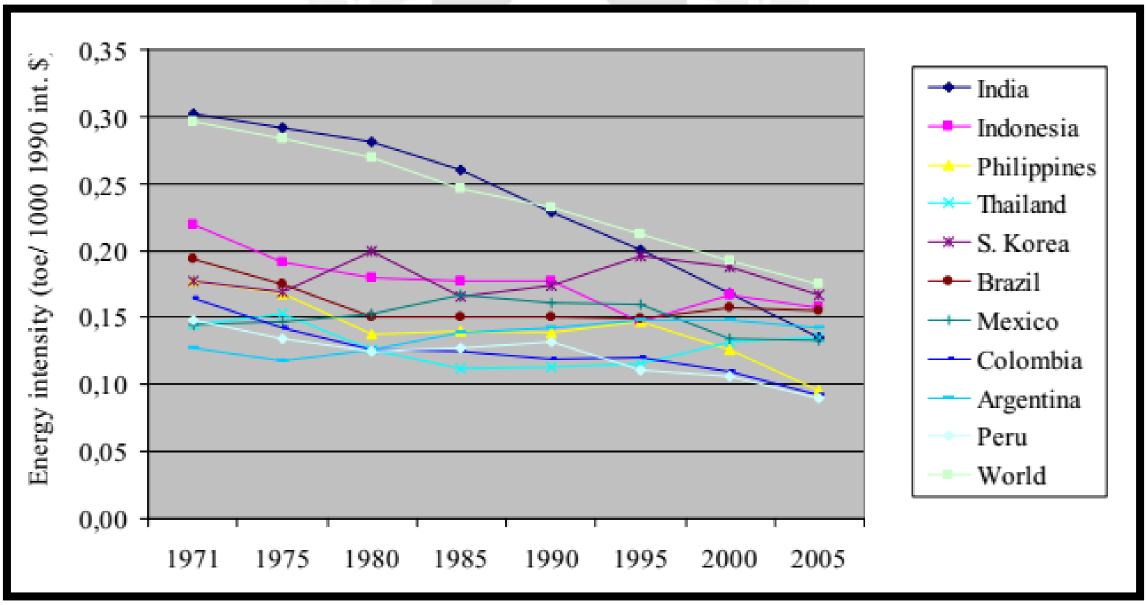
In agriculture, the pattern has not been so stable. Figure 8 shows that it has seen a statistically significant increase in overall energy intensity trend. This result seems counterintuitive if we take into consideration that plot level energy efficiency has increased in the agricultural sector (Ferraro 2012). However, as Viglizzo et al. (2011) point out, the agricultural system has expanded its frontiers west and north of the Pampas in the past fifty years. This has to do with a need for higher agricultural output, and crops that can withstand drier and/or colder climates. This is consistent with general systems ecological theory and the "best first principle". At an aggregate level, societies tend to use the natural resources with the best quality first, which explains the decreasing marginal return of ecosystem services (Cleveland 2008). Also, as thermodynamic systems tend to expand, their efficiency of energy use decreases (Jørgensen et al. 2007).

In the last fifty years, these two processes have taken place; the most fertile land and best climate conditions for commodities agriculture are found in the Pampas region, the “best” natural resource. The expansion of the agricultural frontier meant that ecosystem service quality decreased and more human energy input was needed in order to supplement them (Viglizzo 2010; Izquierdo & Grau 2009; Paruelo et al. 2005). This in turn led to the decrease in thermodynamic efficiency. In addition, the evaluation of increase in energy efficiency at plot level does not take into account the support infrastructure needed for production (for example, construction of transport systems, post-harvest storage, commercialization, etc.). Therefore, it could be hypothesized that the apparent paradox (the fact that energy efficiency increased at plot level while it decreased at the sectoral level) stems from two phenomena. The first is the expansion of the agricultural frontier into zones with lower quality ecosystem services, which increased the need for more energy to maintain the level of production. The second is that the plot level analysis does not take into consideration the support infrastructure for production, which translates into higher levels of energy used per unit of production.

With respect to the effect of energy efficiency improvements on the variation of energy intensity, our results showed that in general, energy efficiency has not improved except for the last ten years in Argentine history. Recalde and Guzowski (2012) point out that the two main boundaries for promoting energy efficiency have been the lack of security in energy supply and frozen energy tariffs that diverge energy prices from its real cost. Our policy evaluation, as well as Recalde (2011), shows that energy policy has lacked centralized organization, temporal consistency and an adequate plan to counter negative spillovers such as the *Rebound Effect*. Only recently have we seen true improvements in reductions of energy intensity related to increased energy efficiency. However, we need more disaggregated data, preferably in thermodynamic indicators, to gage the true gains of energy efficiency at a sectoral and sub-sectoral level.

Relative to other countries, Argentina's economy and agricultural sector are low energy consumers. International comparisons are complex and non-trivial due to the scope and research objectives. Nevertheless, we can use the information provided by previous studies to encompass our results within a comparative framework. That way, our results will have more operational value for future researchers and policymakers. Table 2 shows that Argentina has not increased its agricultural energy consumption relative to other countries when considering the level of production. Also, in Figure 15 we can see that Argentina has a rather low energy intensity, but in agreement with our results, the general tendency seems to be increasing (Figure 6).

Figure 15
Energy intensity for different developing countries, 1971-2005.
Source: From Theodoridis 2012



In general, energy efficiency has played a dominant role in the fluctuations of energy intensity. These results are consistent with previous decomposition literature on both advanced and developed countries (Voigt et al. 2014). Nonetheless, Argentina shows a radically different path than its economic and regional counterparts. As most countries have exhibited increasing levels of energy efficiency and decreased energy intensity, Argentina seems to be in an efficiency trap. It is clear that an unstable economy during the 1980s and declines in real energy prices and conservation efforts during the 1990s set the country in an unsustainable path. However, after the Kyoto Protocol, a strong and cohesive policy strategy was implemented and efforts for more sustainable economic production grew. In contrast, the energy matrix has not shifted its fuel mix towards more efficient fuel types and has relied almost entirely on fossil fuels.

These contradictory trends, together with weak institutional arrangements and poor policy choices will make it extremely difficult to escape the intensity attractor points proposed by Recalde and Ramos-Martin (2012). Argentina's economy and agricultural sector are in an advantageous position relative to most agricultural and industrial countries. Its ecosystem services are more or less in good health, which provides the agricultural sector with enormous sustainability prospects. As we deplete our energy sources, the economies that are able to produce the most with the least amount of energy consumption will provide answers to our ever-growing demand for food, fiber and manufactured goods. We cannot be sure of our energy future, or unequivocally accept Malthus' prognosis. However, with the information at hand regarding the depletion of our main energy sources and a decrease in the provision of the fundamental ecosystem services (Jobbágy 2012), increasing or maintaining our levels of energy intensity seems to be a wrong move against the ticking time-bomb of unsustainable development (Hall 2015; Day et al. 2014; Hall & Klitgaard 2011). In addition to this, as stated above, our analysis did not take into consideration the possibility of accounting the hidden subsidies that are provided by the supporting ecosystem. This entails that, from a systemic perspective, the efficiency trap could be worse than what our data shows, proposing an increasing energy intensity rather than a stable inverted U-shaped trend.

6. Conclusions

In this thesis, we set out to understand the economic energy intensity of the Argentine economy and agricultural sector. We explored the general trend of energy intensity in both the overall economy and the agriculture sector, singling out the relative effect of improvements of energy efficiency and identify the associated national public policies proposed to increase energy efficiency across all sectors.

Our analysis shows that the Argentine economy and agriculture sector have increased their energy intensity despite opposite trends in many developing countries (Theodoridis 2012; Recalde & Ramos-Martin 2012). Energy efficiency improvements have played a much more dominant role than structural composition in decreasing overall energy intensity. However, positive contributions of energy efficiency can only be seen in the final decade of our fifty-year analysis. Industry and transport sectors have an inverted U-shaped curve in the trend of energy efficiency, which follows a similar pattern to that of the general economy. On the other hand, the agriculture sector has a steadily increasing pattern of energy intensity, which could signify a tendency in decreasing its productive efficiency. Together with its almost absolute reliance on fossil fuels and incremental energy consumption, the agriculture sector may be following a very unsustainable trend. If we were to consider the hidden natural energy subsidies behind agriculture, the current trend could present a worse scenario given that more energy would be required to sustain production levels, due to soil erosion, loss of nutrient cycling and deposits amongst other degraded ecosystem services.

Notwithstanding, when comparing it to other countries, Argentina's agriculture and general economy intensity seem to be substantially lower. This proposes a positive present situation but were the negative trends to continue, Argentina could lose its potential as a strong agricultural and industrial producer dependent on a low-input scheme. In the midst of growing energy demands, falling energy supply (Bardi 2009; Hubbert 1956), diminishing ecosystem services (Day et al. 2014; Jordan 2013) and population growth, Argentina's current position provides long term sustainable development possibilities and strong factors for long-term geostrategic economic positioning. An accounting of the energy used, from both the market and ecosystem services, as well as the degradation of Argentina's natural capital are necessary in order to fully comprehend the energy metabolism of the economy and agriculture sector. A continual incapacity to increase energy efficiency could point towards both degraded natural support systems and depleted lower quality energy sources. From a thermodynamic standpoint, Argentine productive systems, and in particular the agricultural system, seem to be losing the "fight against entropy". Considering that technological advancements should increase efficiency, an incapacity to do so points to the fact that the productive capital of the system seems to be degrading beyond that which technology can compensate for.

Well-thought, planned, cohesive and centralized efficiency public policies have not been achieved at the national level. This is one of the central reasons for the failure of Argentina to follow a path of decreasing consumption and energy intensity (Recalde & Guzowski 2012). It must be noted that Argentina is a developing country and thus needs high amounts of energy and resource use in order to materialize its economy and reach economic growth and human development. Nonetheless, it relies on enormously valuable ecosystem services, which could allow for growth and development without the need for an increasing trend in energy consumption and resource use. Further research is needed to understand the economic value and productive usefulness of Argentina's ecosystem services (Costanza et al. 2014; Farber et al. 2002; Costanza et al. 1997). Therefore, one of the principal objectives of energy efficiency policy should be to increase efficiency of energy use and control collateral effects such as the Jevons' Paradox to prevent further consumption of energy.

Taking into account the previous arguments, this thesis has opened the door to several questions that can be used to guide future research at a local and international scale. What are the sub-sectoral patterns of energy intensity and their contributing factors? What is relative contribution of ecosystem services to agricultural and industrial productivity? What effect does the fuel mix of the energy matrix have on overall energy intensity? What is the energy intensity of Argentina's agriculture sector in biophysical terms? Finally, from a policy analysis perspective, how can we identify policy windows of opportunity in order to change in energy efficiency policy? Has energy efficiency policy shown an accumulative pattern? What causes can be drawn from the policy process to explain the historical success and failures in terms of attainment of energy efficiency, less energy consumption and sustainable development? What characteristics of the Argentine state have promoted or inhibited proper policy formulations and implementation? Answering these questions will help understand the mechanisms behind Argentina's energy metabolism and provide substantial information to policymakers in order to formulate adequate policy proposals pushing towards sustainable human and societal development.

Appendix

Table A 1
Time series decomposition of Argentina's energy intensity, 1960-2013, in MJ/$ Peso constant 1993
Source: Own elaboration
Notes: See Section 4: Data & Methods for construction

Time Period	Intensity Effect	Structure Effect	Change in Intensity
1960-1961	0.093783103	-0.012522191	0.081260912
1961-1962	0.434160021	-0.108460465	0.325699557
1962-1963	0.141966553	0.017316548	0.159283101
1963-1964	-0.035894834	0.073662631	0.037767797
1964-1965	0.062982593	0.078824405	0.141806998
1965-1966	-0.26958828	-0.071460513	-0.341048794
1966-1967	0.06405793	-0.007680135	0.056377795
1967-1968	-0.220241244	0.105546176	-0.114695068
1968-1969	-0.043630032	0.019703099	-0.023926933
1969-1970	0.109460569	-0.016260745	0.093199824
1970-1971	0.224725563	-0.3348436	-0.110118037
1971-1972	-0.09774171	0.043892021	-0.053849689
1972-1973	-0.290100683	0.570351273	0.28025059
1973-1974	-0.001508753	-0.001456659	-0.002965412
1974-1975	-0.174115923	0.003092706	-0.171023217
1975-1976	0.22046443	0.022086097	0.242550528
1976-1977	-0.217817254	-0.059292761	-0.277110015
1977-1978	0.364173465	0.05534943	0.419522895
1978-1979	-0.119810129	-0.008585954	-0.128396082
1979-1980	0.015658732	-0.023412412	-0.00775368
1980-1981	0.626978125	-0.097449651	0.529528474
1981-1982	-0.03825909	0.200498327	0.162239236
1982-1983	0.015040714	0.032714779	0.047755492
1983-1984	-0.039294454	0.015417852	-0.023876602
1984-1985	0.006620531	-0.002000593	0.004619938
1985-1986	-0.127353517	-0.031706469	-0.159059986
1986-1987	0.512481015	-0.24165261	0.270828405
1987-1988	-0.135609307	-0.057897051	-0.193506358
1988-1989	0.332753303	0.092324077	0.42507738
1989-1990	-0.223288695	-0.018440694	-0.241729389
1990-1991	0.41092343	-0.721757598	-0.310834169
1991-1992	-0.109842144	-0.026925273	-0.136767417
1992-1993	0.053783151	-0.028095469	0.025687683
1993-1994	-0.01346538	-0.005882913	-0.019348293
1994-1995	0.344841191	0.096455032	0.441296223
1995-1996	-0.045541832	-0.085663731	-0.131205563
1996-1997	-0.060217472	-0.098923468	-0.159140939
1997-1998	-0.146711087	-0.003859219	-0.150570306
1998-1999	0.397201309	-0.595408489	0.19820718
1999-2000	0.293126899	-0.021737396	0.271389503

2000-2001	0.079227445	-0.017741849	0.061485596
2001-2002	0.079443556	0.349865641	0.429309197
2002-2003	-0.136744932	0.046029602	-0.09071533
2003-2004	0.003966463	-0.009772374	-0.005805911
2004-2005	-0.282323412	0.038569793	-0.243753619
2005-2006	-0.057391229	-0.149074634	-0.206465864
2006-2007	-0.043061248	-0.131682648	-0.174743896
2007-2008	-0.389149933	1.224158676	0.835008743
2008-2009	0.627212865	-1.536016353	-0.908803487
2009-2010	-1.452233591	0.741341909	-0.710891682
2010-2011	-0.302892451	0.163848993	-0.139043457
2011-2012	-0.065504406	-0.020952627	-0.086457033
2012-2013	0.040440295	0.131508766	0.171949062

References

Abruzzini, M.P., 2000. *Análisis y propuesta para el proyecto de ley de uso eficiente de la energía en Argentina*, Santiago de Chile.

Academia Nacional de Ingeniería, 2012. *Eficiencia Energética: situación actual y recomendaciones. Un enfoque de política pública*, Buenos Aires.

Achão, C. & Schaeffer, R., 2009. Decomposition analysis of the variations in residential electricity consumption in Brazil for the 1980–2007 period: Measuring the activity, intensity and structure effects. *Energy Policy*, 37(12), pp.5208–5220.

Acuña, C.A. & Chudnovsky, M., 2013. Cómo entender las instituciones y su relación con la política. Lo bueno, lo malo y lo feo de las instituciones y los institucionalismos. In *¿Cuánto importan las instituciones?*. 1: Siglo XXI.

Alcott, B., 2005. Jevons' paradox. *Ecological Economics*, 54(1), pp.9–21. Available at: http://www.sciencedirect.com/science/article/pii/S0921800905001084.

Aligica, P.D., 2009. Julian Simon and the " Limits to Growth " Neo-Malthusianism. *The Electronic Journal of Sustainable Development*, 1(3), pp.73–84.

Al-Mansour, F., 2011. Energy efficiency trends and policy in Slovenia. *Energy*, 36(4), pp.1868–1877.

Andrés, L. & Padilla, E., 2015. Energy intensity in road freight transport of heavy goods vehicles in Spain. *Energy Policy*, 85, pp.309–321.

Ang, B.W., 2004. Decomposition analysis for policymaking in energy: which is the preferred method? *Energy Policy*, 32(9), pp.1131–1139.

Ang, B.W., 2005. The LMDI approach to decomposition analysis: a practical guide. *Energy Policy*, 33(7), pp.867–871.

Ang, B.W. & Liu, F.L., 2001. A new energy decomposition method: Perfect in decomposition and consistent in aggregation. *Energy*, 26(6), pp.537–548.

Ang, B.W., Mu, A.R. & Zhou, P., 2010. Accounting frameworks for tracking energy efficiency trends. *Energy Economics*, 32(5), pp.1209–1219.

Ang, B.W. & Zhang, F.Q., 2000. A survey of index decomposition analysis in energy and environmental studies. *Energy*, 25(12), pp.1149–1176.

Ardanaz, M., Leiras, M. & Tommasi, M., 2013. No The Politics of Federalism in Argentina and its Implications for Governance and Accountability. *World Development*, 53, pp.26–45.

Ayres, R.U., Ayres, L. & Martinas, K., 1996. *Eco-thermodynamics: exergy and life cycle analysis*, Available at: http://flora.insead.edu/fichiersti_wp/inseadwp1996/96-19.pdf.

Baistrocchi, G., 2011. *Campo de Batalla*, Buenos Aires: Ediciones B.

Baležentis, A., Baležentis, T. & Streimikiene, D., 2011. The energy intensity in Lithuania during 1995–2009: A LMDI approach. *Energy Policy*, 39(11), pp.7322–7334.

Bardach, E., 2009. *A practical guide for policy analysis* 4th ed., Los Angeles: Sage.

Bardi, U., 2009. Peak oil: The four stages of a new idea. *Energy*, 34(3), pp.323–326.

Barral, M.P. & Oscar, M.N., 2012. Land-use planning based on ecosystem service assessment: A case study in the Southeast Pampas of Argentina. *Agriculture, Ecosystems & Environment*, 154, pp.34–43.

Benveniste, M., 1985. Efficiency and the role of government in energy policy. *Energy Policy*, 13(1), pp.84–96.

van den Bergh, J.C.J.M., 2010. Energy Conservation More Effective With Rebound Policy. *Environmental and Resource Economics*, 48(1), pp.43–58.

Bodelon, E. et al., 2012. *Escenarios energéticos para la Argentina (2013-2030) con políticas de eficiencia*, Buenos Aires.

Böhringer, C., 1998. The synthesis of bottom-up and top-down in energy policy modeling. *Energy Economics*, 20(3), pp.233–248.

Boltzmann, L., 1974. *Theoretical physics and philosophical problems* B. McGuinness, ed., Boston: D. Reidel Publishing Company.

Boschi, M., 2005. International financial contagion: evidence from the Argentine crisis of 2001–2002. *Applied Financial Economics*, 15(3), pp.153–163.

Bourges, C., 2013. *Política Nacional de Eficiencia Energética: Breve Resumen de las úlitmas tres décadas 1980 - 2010*, Buenos Aires.

Boyd, J. & Banzhaf, S., 2007. What are ecosystem services? The need for standardized environmental accounting units. *Ecological Economics*, 63(2-3), pp.616–626.

Bruinsma, J., 2003. *World agriculture : towards 2015 / 2030. An FAO Perspective*, London.

Cahill, C., Bazilian, M. & Ó Gallachóir, B., 2010. Comparing ODEX with LMDI to measure energy efficiency trends. *Energy Efficiency*, 3(4), pp.317–329.

Callen, T., 2004. PPP Versus the Market: Which Weight Matters? *Finance and Development*, 44(1).

Cansino, J.M., Sánchez-Braza, A. & Rodríguez-Arévalo, M.L., 2015. Driving forces of Spain′s CO2 emissions: A LMDI decomposition approach. *Renewable and Sustainable Energy Reviews*, 48, pp.749–759.

Centro Argentino de Ingenieros, 2015. *Propuestas para el desarrollo de la eficiencia energética en Argentina. Creación de la Agencia Nacional de Eficiencia Energética*, Buenos Aires.

Cerioni, L. & Morresi, S., 2012. Política Energética Argentina: Analisis de la Legislación Vigente Tendiente a Promocionar el Uso de Energías Renovables. *Avances en Energías Renovables y Medio Ambiente*, 12(73-78).

Chapin III, F.S., Matson, P.A. & Mooney, H.A., 2012. *Principles of terrestrial ecosystem ecology* 2nd ed., New York: Springer.

Cleveland, C.J., 1992. Energy quality and energy surplus in the extraction of fossil fuels in the U.S. *Ecological Economics*, 6(2), pp.139–162.

Cleveland, C.J., 2008. Natural Resource Quality. Available at: http://www.eoearth.org/view/article/154798/.

Cleveland, C.J., Kaufmann, R.K. & Stern, D.I., 2000. Aggregation and the role of energy in the economy. *Ecological Economics*, 32(2), pp.301–317.

Cleveland, C.J., Kaufmann, R.K. & Stern, D.I., 2004. Aggregation of Energy. *Encyclopedia of Energy*, 1, pp.17–28.

Colinet Carmona, M.J. & Román Collado, R., 2015. LMDI decomposition analysis of energy consumption in Andalusia (Spain) during 2003–2012: the energy efficiency policy implications. *Energy Efficiency*.

Coremberg, A. et al., 2013. ARKLEMS+LAND. *PIB Argentina 1900-2012: En búsqueda de una tendencia de crecimiento sostenible*. Available at: https://arklems.org/.

Costanza, R. et al., 2014. Changes in the global value of ecosystem services. *Global Environmental Change*, 26, pp.152–158.

Costanza, R. et al., 1997. The value of the world's ecosystem services and natural capital.

Daily, G., 1997. *Nature's Services: Societal Dependence On Natural Ecosystems*, Island Press.

Day, J.W. et al., 2014. Sustainability and place: How emerging mega-trends of the 21st century will affect humans and nature at the landscape level. *Ecological Engineering*, 65, pp.33–48.

Ediger, V.Ş. & Huvaz, O., 2006. Examining the sectoral energy use in Turkish economy (1980–2000) with the help of decomposition analysis. *Energy Conversion and Management*, 47(6), pp.732–745.

Ehrlich, P.R., 1971. *The Population Bomb*, Cutchouge: Bucaneer Books.

Evenson, R.E. & Gollin, D., 2003. Assessing the impact of the green revolution, 1960 to 2000. *Science (New York, N.Y.)*, 300(5620), pp.758–62.

Farber, S.C., Costanza, R. & Wilson, M.A., 2002. Economic and ecological concepts for valuing ecosystem services. *Ecological Economics*, 41(3), pp.375–392.

Fernandez Gonzalez, P., Landajo, M. & Presno, M.J., 2013. Factors influencing changes in aggregate energy consumption. An european cross-country analysis. *Regional and Sectoral Economic Studies*, 13(2), pp.18–30.

Fernández González, P., Landajo, M. & Presno, M.J., 2014. Multilevel LMDI decomposition of changes in aggregate energy consumption. A cross country analysis in the EU-27. *Energy Policy*, 68, pp.576–584.

Ferraro, D.O., 2012. Energy use in cropping systems: A regional long-term exploratory analysis of energy allocation and efficiency in the Inland Pampa (Argentina). *Energy*, 44(1), pp.490–497.

Ferreres, O.J., 2010. *Dos siglos de economía argentina*, Buenos Aires: Norte y Sur.

Feynman, R.P., Leighton, R.B. & Sands, M., 2011. *The Feynman Lectures on Physics, Vol. I: The New Millennium Edition: Mainly Mechanics, Radiation, and Heat*, New York: Basic Books.

Fischer-Kowalski, M. & Haberl, H. eds., 2007. *Socioecological Transitions and Global Change*, Northampton: Edward Elgar Publishing.

Fodha, M. & Zaghdoud, O., 2015. Decomposition Analysis of Aggregate Energy Intensity Changes in Tunisia over the Period 1980–2007. *Environmental Modeling & Assessment*, 20(5), pp.509–520.

de Freitas, L.C. & Kaneko, S., 2011. Decomposing the decoupling of CO2 emissions and economic growth in Brazil. *Ecological Economics*, 70(8), pp.1459–1469.

Gadano, N., 2012. *Historia del petróleo en la Argentina* 2nd ed., Buenos Aires: Edhasa.

Gavier-Pizarro, G.I. et al., 2012. Expansion and intensification of row crop agriculture in the Pampas and Espinal of Argentina can reduce ecosystem service provision by changing avian density. *Agriculture, Ecosystems & Environment*, 154, pp.44–55.

Gomelsky, R., 2003. *Energía y desarrollo sostenible: posibilidades de financiamineto de las tecnologías limpias y eficiencia energética en el Mercosur*, Santiago de Chile.

Greening, L. a., Greene, D.L. & Difiglio, C., 2000. Energy efficiency and consumption - the rebound effect - a survey. *Energy Policy*, 28(6-7), pp.389–401.

de Groot, R.S., Wilson, M.A. & Boumans, R.M.., 2002. A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological Economics*, 41(3), pp.393–408.

Guzowski, C. & Recalde, M., 2008. Renewable energy in Argentina: Energy policy analysis and perspectives. *International Journal of Hydrogen Energy*, 33(13), pp.3592–3595.

Hall, C.A.S., 2015. Energy return on investment (EROI) and its implications for long-term prosperity. In M. Ruth, ed. *Handbook of Research methods and Applications in Environmental Studies*. Northampton: Edward Elgar, pp. 197–224.

Hall, C.A.S. et al., 2001. The Need to Reintegrate the Natural Sciences with Economics. *BioScience*, 51(8), pp.663–673.

Hall, C.A.S., Balogh, S.B. & Murphy, D.J.R., 2009. What is the minimum EROI that a sustainable society must have? *Energies*, 2(1), pp.25–47.

Hall, C.A.S. & Klitgaard, K.A., 2011. *Energy and the Wealth of Nations*, New York: Springer.

Hall, C.A.S., Lambert, J.G. & Balogh, S.B., 2014. EROI of different fuels and the implications for society. *Energy Policy*, 64, pp.141–152.

Hanley, N. et al., 2009. Do increases in energy efficiency improve environmental quality and sustainability? *Ecological Economics*, 68(3), pp.692–709.

Hatzigeorgiou, E., Polatidis, H. & Haralambopoulos, D., 2008. CO2 emissions in Greece for 1990–2002: A decomposition analysis and comparison of results using the Arithmetic Mean Divisia Index and Logarithmic Mean Divisia Index techniques. *Energy*, 33(3), pp.492–499.

Herring, H., 2006. Energy efficiency—a critical view. *Energy*, 31(1), pp.10–20.

Hirst, E., 1985. Is improved energy efficiency still an important policy issue? *Energy Policy*, 13(2), pp.115–116.

Hirst, E. & Brown, M., 1990. Closing the efficiency gap: barriers to the efficient use of energy. *Resources, Conservation and Recycling*, 3(4), pp.267–281.

Hoekstra, R. & van der Bergh, J.J.C.J.M., 2003. Comparing structural and index decomposition analysis. *Energy Economics*, 25(1), pp.39–64.

Homer-Dixon, T.F., 1999. *Environment, Scarcity and Violence*, Princeton: Princeton University Press.

Hubbert, M.K. (Shell D.C.., 1956. *Nuclear Energy and the Fossil Fuel*, New York.

Hupe, P.L. & Hill, M.J., 2006. Three Action Levles of Governance: Re-framing the Policy Process Beyond the Stages Model. In B. G. Peters & J. Pierre, eds. *Handbook of Public Policy*. Thousand Oaks: Sage.

Inglesi-Lotz, R. & Pouris, a., 2012. Energy efficiency in South Africa: A decomposition exercise. *Energy*, 42(1), pp.113–120.

International Energy Agency (IEA), 2015. *Recomendaciones de Políticas de Eficiencia Energética Regionales*, Santiago de Chile.

Izquierdo, A.E. & Grau, H.R., 2009. Agriculture adjustment, land-use transition and protected areas in Northwestern Argentina. *Journal of Environmental Management*, 90(2), pp.858–865.

Jimenez, R. & Mercado, J., 2014. Energy intensity: A decomposition and counterfactual exercise for Latin American countries. *Energy Economics*, 42, pp.161–171.

Jobbágy, E.G., 2012. Ecosystem service evaluation to support land-use policy. *Agriculture, Ecosystems & Environment*, 154, pp.78–84.

Jordan, C.F., 2013. *An Ecosystem Approach to Sustainable Agriculture: Energy Use Efficiency in the American South*, New York: Springer.

Jørgensen, S.E. et al., 2007. *A New Ecology. Systems Perspective*, New York: Elsevier.

Jung, S. et al., 2012. Regional energy-related carbon emission characteristics and potential mitigation in eco-industrial parks in South Korea: Logarithmic mean Divisia index analysis based on the Kaya identity. *Energy*, 46(1), pp.231–241.

Kiguel, M., 2015. *Las Crisis Económicas Argentinas*, Buenos Aires: Sudamericana.

Kreuzer, F.M. & Wilmeiser, G., 2014. *Eficiencia Energética y Movilidad en América Latina y el Caribe: Una Hoja de Ruta para la Sostenibilidad*, Santiago de Chile.

Lambert, J.G. et al., 2014. Energy, EROI and quality of life. *Energy Policy*, 64, pp.153–167.

Lapeña, J., 2014. . *La energía en tiempos de Alfonsín: Innovación, planificación energética, obras y autoabastecimiento* Eudeba., Buenos Aires.

Laswell, H.D., 1956. *The Decision Process: Seven Categories of Functional Analysis*, College Park, Maryland: University of Maryland.

LEY N° 24.065. 1992. "LEY N° 24.065: REGIMEN DE LA ENERGIA ELECTRICA" Información legislativa (INFOLEG). 01 16. Accessed 02 27, 2016. http://infoleg.mecon.gov.ar/infolegInternet/anexos/0-4999/464/norma.htm

LEY N° 24.076. 1992. "LEY N° 24.076: GAS NATURAL" Información legislativa (INFOLEG). 05 20. Accessed 02 27, 2016. http://infoleg.mecon.gov.ar/infolegInternet/anexos/0-4999/475/norma.htm

Levey, C., Ozarow, D. & Wylde, C., 2014. *Argentina Since the 2001 Crisis: Recovering the Past, Reclaiming the Future (Studies of the Americas)*, New York: Palgrave Macmillan.

Lin, B. & Zhang, Z., 2016. Carbon emissions in China′s cement industry: A sector and policy analysis. *Renewable and Sustainable Energy Reviews*, 58, pp.1387–1394.

Liu, H.Q. et al., 2011. Analysis of Energy Consumption Influence Factors in Japan Based on LMDI Model. *Applied Mechanics and Materials*, 71-78, pp.2416–2419.

Liu, X.Q., Ang, B.W. & Ong, H.L., 1992. Interfuel substitution and decomposition of changes in industrial energy consumption. *Energy*, 17(7), pp.689–696.

Ma, C. & Stern, D.I., 2008. China's changing energy intensity trend: A decomposition analysis. *Energy Economics*, 30(3), pp.1037–1053.

Mahony, T.O., 2013. Decomposition of Ireland's carbon emissions from 1990 to 2010: An extended Kaya identity. *Energy Policy*, 59, pp.573–581. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-84879503980&partnerID=tZOtx3y1 [Accessed April 14, 2016].

Mairet, N. & Decellas, F., 2009. Determinants of energy demand in the French service sector: A decomposition analysis. *Energy Policy*, 37(7), pp.2734–2744.

Malthus, T.R., 1798. *First Essay on Population* 3rd ed., London: Palgrave Macmillan.

Mann, M., 1984. The Autonomous Power of the State: Its Originis, Mechanisms and Results. *European Journal of Sociology*, 2, pp.185–213.

Mielnik, O. & Goldemberg, J., 2000. Converging to a common pattern of energy use in developing and industrialized countries. *Energy Policy*, 28(8), pp.503–508.

Millenium Ecosystem Assessment, 2005. *Ecosystems and Human Wellbeing: Synthesis*, Washington D.C.

Miller, H. & Demir, T., 2007. Policy Communities. In F. Fischer, G. Miller, & M. S. Sideny, eds. *Handbook of Public Policy Analysis: Theory, Politics, and Methods*. Boca Ratón: CRC Press, pp. 137–147.

Miralles, D.J., 2013. Estrategias para aumentar la producción de alimentos. *Ciencia Hoy*, 23(134).

Mundlak, Y., Cavallo, D. & Domenech, R., 1989. *Agricultre and Economic Growth in Argentina, 1913-1984*, Washington D.C.

Nebel, B.J. & Wright, R.T., 1999. *Environmental Science: The Way the World Works* 7th ed., Upper Saddle River: Prentice Hall.

Odum, E.P. & Warret, G.W., 2004. *Fundamentals of Ecology* 5th ed., New York: Thompson Learning.

Odum, H.T., 1971. *Environment, Power, and Society*, New York: Wiley-Interscience.

Odum, H.T., 1995. *Environmental Accounting: Emergy and Environmental Decision Making*, New York: Wiley.

Odum, H.T., 1988. Self-Organization, Transformity, and Information. *Science*, 242, pp.1132–1139.

Papagiannaki, K. & Diakoulaki, D., 2009. Decomposition analysis of CO2 emissions from passenger cars: The cases of Greece and Denmark. *Energy Policy*, 37(8), pp.3259–3267.

Park, S.-H., Dissmann, B. & Nam, K.-Y., 1993. A cross-country decomposition analysis of manufacturing energy consumption. *Energy*, 18(8), pp.843–858.

Paruelo, J.M., Guerschman, J.P. & Verón, S.R., 2005. Expansión agrícola y cambios en el uso del suelo. *Ciencia Hoy*, 15(87).

Patterson, M.G., 1996. What is energy efficiency? *Energy Policy*, 24(5), pp.377–390.

Pimentel, D. et al., 1995. Environmental and Economic Costs of Soil Erosion and Conservation Benefits. *Science*, 267(5201), pp.1117–1123.

Pimentel, D. et al., 1973. Food Production and Energy Crisis. *Science*, 182(4111), pp.443–449.

Pimentel, D., Berardi, G. & Fast, S., 1983. Energy efficiency of farming systems: Organic and conventional agriculture. *Agriculture, Ecosystems & Environment*, 9(4), pp.359–372.

Pimentel, D. & Pimentel, M.H., 2008. *Food, energy and society*, Boca Raton: CRC Press.

Propato, T.S. & Verón, S.R., 2015. La matriz energética argentina y su impacto ambiental. *Ciencia Hoy*, 144(24), pp.31–36.

Proskuryakova, L. & Kovalev, A., 2015. Measuring energy efficiency: Is energy intensity a good evidence base? *Applied Energy*, 138, pp.450–459.

Ramos-Martin, J., 2001. Historical Analysis of Energy Intensity of Spain: From a "Conventional View" to an "Integrated Assessment." *Population and Environment: A Journal of Interdisciplinary Studies*, 22(3), pp.281–313.

Recalde, M., 2011. Energy policy and energy market performance: The Argentinean case. *Energy Policy*, 39(6), pp.3860–3868.

Recalde, M. & Guzowski, C., 2012. Boundaries in promoting energy efficiency: Lessons from the Argentinean case. *International Journal of Hydrogen Energy*, 37(19), pp.14725–14729.

Recalde, M. & Ramos-Martin, J., 2012. Going beyond energy intensity to understand the energy metabolism of nations: The case of Argentina. *Energy*, 37(1), pp.122–132.

Reister, D.B., 1987. The link between energy and GDP in developing countries. *Energy*, 12(6), pp.427–433.

Ricklefs, R.E., 1998. *Invitación a la Ecología. La Economía de la Naturaleza* 4th ed., Buenos Aires: Editorial Médica Panamericana.

Rosen, M.A., 2009. Energy Sustainability: A Pragmatic Approach and Illustrations. *Sustainability*, 1(1), pp.55–80.

Sabatier, P.A. ed., 1999. *Theories of the Policy Process*, Boulder: Westview Press.

Sato, K., 1976. The Ideal Log-Change Index Number. *The Review of Economics and Statistics*, 58(2), pp.223–228.

Secretaría de Energía, 2014. *Informe Nacional de Eficiencia energética de la República Argentina*, Santiago de Chile.

Shahiduzzaman, M. & Alam, K., 2013. Changes in energy efficiency in Australia: A decomposition of aggregate energy intensity using logarithmic mean Divisia approach. *Energy Policy*, 56, pp.341–351.

Shahiduzzaman, M., Layton, A. & Alam, K., 2015. Decomposition of energy-related CO2 emissions in Australia: Challenges and policy implications. *Economic Analysis and Policy*, 45, pp.100–111.

Soifer, H., 2008. State Infrastructural Power: Approaches to Conceptualization and Measurement. *Studies in Comparative International Development*, 43, pp.231–251.

Steinhart, J.S. & Steinhart, C.E., 1974. Energy use in the U.S. food system. *Science*, 184(4134), pp.307–316.

Tainter, J.A., 1988. *The Collapse of Complex Societies*, New York: Cambridge University Press.

Tamayo Sáez, M., 1997. El análisis de las póliticas públicas. In R. Bañon & E. Carrillo, eds. *La Nueva Administración Pública*. Madrid: Alianza Universidad.

Theodoridis, D., 2012. *Energy patterns for developing countries- an energy intensity decomposition analysis for economies in Asia and in Latin America*. Lund University.

Tilman, D. et al., 2002. Agricultural sustainability and intensive production practices. *Nature*, 418(6898), pp.671–677.

Timma, L. & Blumberga, D., 2014. Index Decomposition Analysis for Energy Sectors in Latvia. *Energy Procedia*, 61, pp.2180–2183.

Tommasi, M., 2010. Un País Sin Rumbo. Políticas Públicas y Desarrollo en Argentina (Con una breve comparación con el caso chileno). *Desarrollo Económico*, 50(199), pp.392–421.

Vanbergen, A.J. & Initiative, the I.P., 2013. Threats to an ecosystem service: pressures on pollinators. *Frontiers in Ecology and the Environment*, 11(5), pp.251–259.

Vartia, Y.O., 1976. Ideal Log-Change Index Numbers. *Scandinavian Journal of Statistics*, 3(3), pp.121–126.

Viegel, K.F., 2009. *Dictatorship, Democracy, and Globalization: Argentina and the Cost of Paralysis, 1973-2001*, University Park: The Pennsylvania State University Press.

Viglizzo, E.F. et al., 2011. Ecological and environmental footprint of 50 years of agricultural expansion in Argentina. *Global Change Biology*, 17(2), pp.959–973.

Viglizzo, E.F.. ed. . J.E., 2010. *Expansión de la frontera agropecuaria en Argentina y su impacto ecológico-ambiental.*, INTA.

Villalonga, J.C., 2013. *Energías Renovables ¿ Por qué debería ser prioritario cumplir el objetivo del 8% al 2016?*, Buenos Aires.

Vinuya, F., DiFurio, F. & Sandoval, E., 2010. A decomposition analysis of CO 2 emissions in the United States. *Applied Economics Letters*, 17(10), pp.925–931.

Voigt, S. et al., 2014. Energy intensity developments in 40 major economies: Structural change or technology improvement? *Energy Economics*, 41, pp.47–62.

Wang, C., Chen, J. & Zou, J., 2005. Decomposition of energy-related CO2 emission in China: 1957–2000. *Energy*, 30(1), pp.73–83.

Wang, W. et al., 2014. Using a new generalized LMDI (logarithmic mean Divisia index) method to analyze China's energy consumption. *Energy*, 67, pp.617–622.

White, L.A., 1943. Energy and the Evolution of Culture. *American Anthropologist*, 45(3), pp.335–356.

Wilson, B., Trieu, L.H. & Bowen, B., 1994. Energy efficiency trends in Australia. *Energy Policy*, 22(4), pp.287–295.

Wilson, D. & Swisher, J., 1993. Exploring the gap. Top-down versus bottom-up analyses of the cost of mitigating global warming. *Energy Policy*, 21(3), pp.249–263.

de Wit, C.T., 1992. Resource use efficiency in agriculture. *Agricultural Systems*, 40(1-3), pp.125–151.

World Bank, 2008. *Resumen del Documento del Proyecto sobre Una Propuesta de Donación del Fondo Fiduciario del FMAM por Valor de US$ 15,155 millones a la República Argentina para un Proyecto de Eficiencia Energética*, Buenos Aires.

Zhang, W. et al., 2016. Decomposition of intensity of energy-related CO2 emission in Chinese provinces using the LMDI method. *Energy Policy*, 92, pp.369–381.

Zhao, X., Ma, C. & Hong, D., 2010. Why did China's energy intensity increase during 1998-2006: Decomposition and policy analysis. *Energy Policy*, 38(3), pp.1379–1388.