Manchester Metropolitan University

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From the Celtic Tiger to the Celtic Phoenix:

the metabolic profile of Ireland and the main drivers of energy change

Abstract

In this paper, the metabolic profile of Ireland and the main drivers of energy variations are analysed for the period 1998-2014. By considering the years that extend from the Celtic Tiger to the Celtic Phoenix, the socio-economic and energy variables are analysed during periods of economic growth and recession. The main objective is to investigate how demographic and economic trends have influenced the energy used across different levels of analysis. The potential implications of economic growth and population structure are also discussed. The main results show that the standard of living has been the main factor influencing the energy consumption increase. In addition, the reduction of the economic energy intensity, driven by structural changes and implementation of energy efficiency action plans, has contributed to reduce the energy used in relation to gross domestic product and human time. Being characterised by one of the largest financial crashes and one of the quickest economic recovery, together with one of the highest population increase across European Union countries, Ireland represents an interesting case study to investigate the relationships existing between socio-economic and energy variables. The results can support the design of policies oriented to achieve sustainable energy strategies.

Keyword: Energy metabolism; Decomposition analysis; Economic growth and recession; Population; Energy dependency

1. Introduction

During the last few decades, Ireland has experienced extensive changes that largely transformed the socio-economic profile of the country. By adopting a foreign direct investment development model, characterised by low corporate tax and industrialisation by invitation, Ireland has attracted a large number of multinational companies that have driven a dramatic rise in the national income. The so-called and well-documented Celtic Tiger phenomenon, has contributed to change the profile of the country from a traditional agricultural economy to one of the world's main drivers for technological and pharmaceutical innovation (Barry, 2003). In the fifteen years that preceded the global financial crash, Ireland has been able to specialise in high value-added productions enabling the doubling in the size of the economy (Gottheil, 2003). The large number of migrants attracted by favourable working opportunities, contributed to enlarge a fast-growing population that increased by 23% between 1995 and 2007 (Piola, 2015). As a consequence, the energy throughput increased by 84% with an energy import dependency accounting in 2006 for over 91% (NEEAP, 2017).

The global financial crash of 2008 and the related credit-driven housing bubble, drove Ireland into a severe economic recession. Rescued from bankruptcy by a loan of €67.5 billion, Ireland officially exited the bailout in December 2013. Since then, Ireland has experienced some of the highest gross domestic product (GDP) grown rate, and the term "Celtic Phoenix" was coined to describe the quick economic recovery. The significant role played by by multinationals and exports, together with the relocation of intangible assets, largely contributed to boost income generation, employment and growth (Barret et al., 2019; Ruane, 2016).

Despite the economic strengths demonstrated by Ireland, the energy-import dependency and the related impacts on price could however represent a potential threat for the sustainability of the system. To reduce the risks on energy security and competitiveness, Ireland has recently developed a large set of policies oriented to increase energy efficiency and renewable energy production. In addition, the adoption of the Europe 2030 targets and the implementation of energy efficiency action plans are also contributing to improve the energy structure of the Irish society (SEAI, 2018).

The rapid economic and population growth, together with the increased standard of living, could, however, compromise the effectiveness of policies, as demonstrated by the 29% growth of residential energy demand that has taken place during the years of the Celtic Tiger (SEAI, 2018). A clear understanding of the main drivers of energy variation, together with analysis of the relationships existing between socio-economic and energy variables, is then fundamental to support to design of effective policies.

With this in mind, the aim of this paper is to analyse the metabolic structure of the Irish society and to discuss the main drivers of energy changes. The objective is to critically analyse the relationships existing between socio-economic and energy variables and to support the design of sustainable energy strategies.

The paper contributes to the existing literature in the following ways: Firstly, it combines, for the first time, two of the main methodologies used to analyse the energy profile of countries, namely: The Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) and the perfect decomposition technique. By providing integrated descriptions across levels and dimensions, the MuSIASEM approach investigates how society self-organise and evolve based on the interactions of socio-economic and energy variables. The perfect decomposition technique, on the contrary, investigates the main drivers of energy changes and can complement the MuSIASEM approach by investigating the role that socio-economic elements have played in the variation of energy use. Secondly, it considers the case study of Ireland for the time period between 1998 and 2014, this is particularly interesting as: *i)* Ireland has been characterised by one of the largest financial crashes and one of the quickest economic recoveries, together with one of the highest population increases across European countries; *ii)* the analysis extends from the years of the Celtic Tiger to the years of the Celtic Phoenix, and includes periods of economic growth, recessions and recovery. From a theoretical perspective, the 2008 crisis represents an opportunity to investigate the relationships between energy and socio-economic variables not just in a framework of growth, but also in the aftermath of the economic downturn. Finally, from a policy perspective, the paper discusses the achievements of the energy efficiency action plans and identifies some of the main risks and constrains of population growth and structure.

The paper is structured as follow: methods and data are presented in Section 2. In Section 3, the metabolic and the decomposition results are reported and discussed. Section 4 concludes.

2. Methods and data

To investigate the metabolic profile and to identify the main drivers of energy variations two methods have been combined in this paper, namely: MuSIASEM and the perfect decomposition technique. In the following paragraphs the methodological approaches and the data are presented.

2.1 MuSIASEM approach

MuSIASEM technique is developed by the integration of various theoretical concepts, such as the flow-fund model (Gorgescu-Roegen, 1971, 1977), the complex system theory (Maturana and Varela, 1980) and the hierarchy theory (Allen et al., 2009) and it is used to investigate how societies self-organise and evolve based on the use of energy and materials (Giampietro and Mayumi, 1997; Giampietro, 2003). Detailed description of the theoretical framework is provided in Giampietro and Mayumi (2000a, 2000b) and Giampietro et al. (2009). Based on the idea that societies can be described as metabolisms where the input from the natural environment are transformed through capital, technology and labour, the MuSIASEM approach analyses how societies are shaped based on the interaction of socio-economic and energy elements. By considering different descriptive domains and by including different levels of analysis, the MuSIASEM approach has been used to discuss the sustainability trends of countries.

During the last few decades, the MuSIASEM technique has been used as a diagnostic and simulation tool and applications have been oriented to investigate the metabolic profiles of nations (Falconi-Benitez, 2001; Ginard-Bosh and Ramos-Martin, 2016; Andreoni, 2017), productions activities (Silva-Macher, 2016; Parra et al., 2018), regions (Ramos-Martin et al., 2009; Siciliano, 2012; Fierro et al., 2019), cities (Lu et al., 2016; Chifari et al., 2017; Han et al., 2018; Perez-Sanchez et al., 2019) and energy end-uses (Velasco-Fernández at al., 2018). The main accounting framework of the MuSIASEM approach is based on the integration of extensive and inventive variables; where extensive variables are generally used to describe the size of the system and the intensive variables are used to summarize the potential pressures. Following the list of variables reported in Andreoni (2017), the main extensive and intensive variables used in this paper are reported in Tables 1 and 2.

Table 1. MuSIASEM extensive variables

THA	Total human activity: Accounts for the total human time available in one country during one year. It is calculated as population*24hours*365days and it is measured in hours (h) ▪ **HA_{PW}**: Human activity paid work: accounts for the hours allocated to the paid sector o **HA_{PWa}**: Accounts for the hours allocated to the agricultural sector o **HA_{PWi}**: Accounts for the hours allocated to the industrial sector o **HA_{PWc}**: Accounts for the hours allocated to the construction sector o **HA_{PWs}**: Accounts for the hours allocated to the service sector ▪ **HA_{HH}**: Human activity household: accounts for the hours allocated to the household sector
TET	Total energy throughput: Accounts for the total primary energy used in one country during one year. It is measured in megajoule (MJ) ▪ **ET_{PW}**: Energy throughput paid work: Accounts for the energy used in the paid sector o **ET_{PWa}**: Accounts for the energy used by the agricultural sector o **ET_{PWi}**: Accounts for the energy used by the industrial sector o **ET_{PWc}**: Accounts for the energy used by the construction sector o **ET_{PWs}**: Accounts for the energy used by the service sector ▪ **ET_{HH}**: Energy throughput household: Accounts for the energy used in the household sector

GDP	Gross domestic product: Quantifies the value added generated in one country during one year. It is measured in Euro (€) o **GDP_a**: Accounts for the value added generated by the agriculture sector o **GDP_i**: Accounts for the value added generated by the industrial sector o **GDP_c**: Accounts for the value added generated by the construction sector o **GDP_s**: Accounts for the value added generated by the service sector

Source: adapted from Table 2 reported in Andreoni (2017)

Table 2. MuSIASEM intensive variables

EMR	Exosomatic metabolic rate: Quantifies the quantity of energy consumed per hour of human activity. It is calculated as TET/THA (MJ/h) ▪ **EMR_{PW}**: Accounts for the energy consumed per hour in the paid sector. It is calculated as ET_{PW}/HA_{PW} o **EMR_{PWa}**: Accounts for the energy used per hour in the agricultural sector o **EMR_{PWi}**: Accounts for the energy used per hour in the industrial sector o **EMR_{PWc}**: Accounts for the energy used per hour in the construction sector o **EMR_{PWs}**: Accounts for the energy used per hour in the service sector ▪ **EMR_{HH}**: Accounts for the energy consumed per hour in the household sector It is calculated as ET_{HH}/HA_{HH}
EEI	Economic energy intensity: Accounts for the quantity of energy used for the production of one unit of GDP. It is calculated as TET/GDP (MJ/€)
ELP	Economic labour productivity: Accounts for the GDP generated per hour of labour. It is calculated as GDP/HA_{PW} (€/h).
HA_{PW}/THA	Total human time allocated to the paid sector
HA_{HH}/THA	Total human time allocated to the household sector
GDP_a/GDP	Contribution provided by the agricultural sector to the total GDP production
GDP_i/GDP	Contribution provided by the industrial sector to the total GDP production
GDP_c/GDP	Contribution provided by the construction sector to the total GDP production
GDP_s/GDP	Contribution provided by the service sector to the total GDP production

Source: adapted from Table 3 reported in Andreoni (2017)

As previously reported in other studies (Ginard-Bosh and Ramos-Martin, 2016; Andreoni, 2017), the combined use of the intensive and extensive variables is usually performed at different levels of analysis, such as:

- Level N – Refers to the whole society, and includes analysis related to GDP, energy throughput and demographic changes.
- Level N-1 – Splits the previous level into the paid (PW) and the household (HH) sectors and analyses changes in production and consumption.

- Level N-2 – Disaggregates the paid sector into:
    - The agricultural sector, including agriculture, hunting, forestry, fishing, mining and quarrying;
    - The industrial sector, including manufacturing, construction and energy (since Ireland has been affected by one of the most extensive housing bubbles, the data related to the construction sector are presented separately);
    - The service sector, including the commercial and public services.

By performing analysis across different levels, the MuSIASEM approach is able to provide an integrated representation of society, where the considered socio-economic and energy elements are disaggregated across the compartments of activities. By adopting this approach, any change taking place at one specific level forces changes across all the other levels, and the structure of society can be studied both in a diagnostic and in a simulative way (Gerber and Scheidel, 2018). As previously reported by Xiaohui et al. (2015), integrated use of levels and dimensions, make the MuSIASEM approach particularly suitable to investigate the metabolic trends of countries characterised by demographic and economic changes. The large economic crash and the quick economic recovery that took place in Ireland, together with the rapid population increase, represent an interesting case of analysis for the MuSIASEM technique.

2.2 Perfect decomposition technique

The perfect decomposition technique proposed by Sun (1998) is used in this paper to analyse the main factors influencing the variations in the total energy throughput (TET) that have taken place in Ireland during the period 1998-2014. Based on a revised form of the index decomposition (IDA), that aims to analyse the drivers of changes between time 0 and time T, the perfect decomposition technique has been specifically elaborated to eliminate the problem of the residuals arising from decomposition techniques. Based on the approach of "jointly created and equally distributed” (Sun, 1996), the perfect decomposition technique splits the residuals among the variables of analysis and is able to provide more accurate results than the Laspeyres and divisia techniques (Ang and Liu, 2001; Shyamal and Bhattacharya 2004; Chen et al., 2018). The index decomposition and the related perfect decomposition technique have been largely used to investigate the main factors influencing energy and emission changes and have proven to be particularly suitable to analyse the main socio-economic drivers of variations (Ang and Su, 2016; Shahiduzzaman and Layton, 2017; Wang and Zhou, 2018; Andreoni, 2019).

Following SEAI (2018) that identifies the economic energy intensity, the net disposable income and the population increase as three of the main factors influencing the total energy throughput of Ireland, the drivers of variation considered in this paper are:

- The economic energy intensity effect (EI), defined by the ratio of total energy throughput and GDP. It reflects changes in the quantity of energy used in the GDP production;
- The standard of living effect (SL), defined by the GDP per capita. It identifies how changes in the net available income influences the energy throughput;
- The population effect (P), defined by variations in the total human activity. It summarises the aggregate energy throughput generated by population increases.

Following the approach previously used by Sun (1998) and Shyamal and Bhattacharya (2004), in equation [1], the main drivers reported above are combined to express the total energy throughput of a specific year (t) as the product of the economic energy intensity, the standard of living and the population effects

$$TET^t = \frac{TET^t}{GDP^t} \times \frac{GDP^t}{THA^t} \times THA^t = EI^t \times SL^t \times P^t \qquad [1]$$

Where TET is expressed in terajoules (TJ), GDP in millions of Euro and THA in millions of hours and where the drivers of variation (EI, SL and P) are expressed in terajoules (TJ).

The variation of the total energy throughput from a base year 0 to a target year t, can then be calculated in equation [2] as the sum of the economic energy intensity, the standard of living and the population effects

$$\Delta TET = TET^{\,t} - TET^{\,0} = EI + SL + P \qquad [2]$$

The decomposition of the role played by each effect is calculated in equations [3], [4] and [5], where, following the approach adopted by Shyamal and Bhattacharya (2004), the fractional multipliers are used to equally distribute the residuals among the decomposition factors.

Equation [3] calculates the economic energy intensity effect expressed in terajoules (TJ):

$$EI = \Delta EI \times SL^0 \times P^0 + \frac{1}{3}\,\Delta EI \times \Delta SL \times \Delta P + \frac{1}{2}\,\Delta EI\,(\Delta SL \times P^0 + SL^0 \times \Delta P) \qquad [3]$$

Equation [4] calculates the standard of living effect expressed in terajoules (TJ):

$$SL = \Delta SL \times EI^0 \times P^0 + \frac{1}{3}\,\Delta EI \times \Delta SL \times \Delta P + \frac{1}{2}\,\Delta SL\,(\Delta EI \times P^0 + EI^0 \times \Delta P) \qquad [4]$$

Equation [5] calculates the population effect expressed in terajoules (TJ):

$$P = \Delta P \times EI^0 \times SL^0 + \frac{1}{3}\,\Delta EI \times \Delta SL \times \Delta P + \frac{1}{2}\,\Delta P\,(\Delta EI \times SL^0 + EI^0 \times \Delta SL) \qquad [5]$$

The decomposition technique reported above is used in this paper to identify the main drivers of energy changes and to discuss the possible impacts of population structure and growth.

2.3 Data

Eurostat data has been the main source of information for population, GDP and energy use. The EU KLEMS database, that provides information on output, productivity and labour, has been used to calculate the total hours worked per persons engaged. The time period considered starts in 1998, that is the first year for which the EU KMLEMS data are available for Ireland, and ends in 2014. Despite the availability of data, the year 2015 has been excluded from the analysis because characterised by distorted GDP figures. As highlighted by OECD (2016), the

26.3% of GDP growth rate experienced by Ireland in 2015, has mainly been driven by the transfers of ownership of intellectual property products and it does not represent a consistent representation of the value added generated by the country.

Based on the approach previously used by Recalde and Ramos-Martin (2012), the energy balances provided by Eurostat have been used to estimate the total energy throughput, calculated as the total final energy consumption, plus the energy sector own use plus losses. In addition, following the assumption adopted by Ramos-Martin (2001), Ramos-Martin et al. (2007) and in Recalde and Ramos-Martin (2012), the energy consumption of transport has been allocated to the household and to the service sectors in the proportion of 25% and 75%, respectively. This approach assumes that 50% of the mobility is generated by the transport of goods, 25% is related to the service sector as commuting mobility and that the remaining 25% is allocated to the households' sector as non-working mobility. The consumption of the energy sector and the transformation losses have been allocated to the household and paid sectors based on their share in the final energy consumption. The harmonised index of consumer prices (HICP 2015=100) has also been used to harmonise the GDP reported by Eurostat at current prices.

3. Results

In section 3.1, the intensive and the extensive variables presented above are used to discuss the metabolic profile of Ireland for the time period 1998-2014. The decomposition results are reported in Section 3.2 and the main drivers of energy variations are analysed for the entire time period and for four main sub-periods, namely: the period that preceded the credit-driven house price bubble (1998-2003); the period of the credit-driven house price bubble (2003-2008); the period of economic downturn (2008-2012) and the period of economic recovery (2012-2014).

3.1. Metabolic profile of Ireland

According to data reported in Figure 1, the TET and the GDP have increased up to the beginning of the global financial crash. Between 1998 and 2007, the GDP has increased by more than 78.3% and the total energy throughput by around 15%. The largest increases have taken place between 1998 and 2002, these are the years that preceded the beginning of the credit-driven house price bubble of 2003-2007. In the following period, both variables experienced percentage reductions, with the TET decreasing more than 18.8% between 2007 and 2014, and the GDP reducing by around 7.3% both in 2008 and 2009. Over the considered period, however, the percentage GDP increase has been largely higher than the percentage variation of the TET (76.6% and 15.0%, respectively between 1998 and 2014) highlighting an energy efficiency increase of the Irish economy.

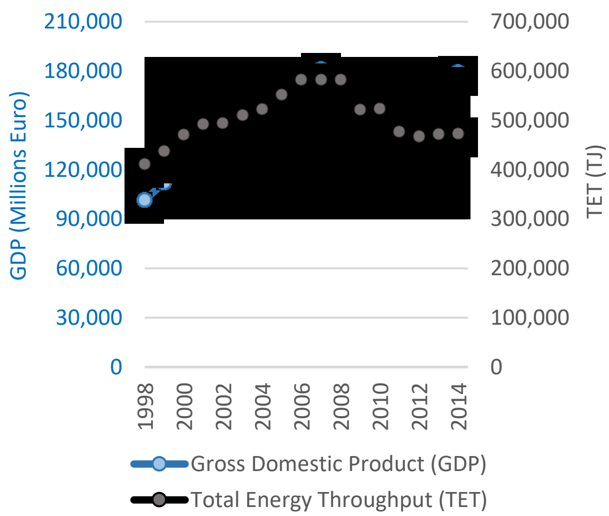

Figure 1. Historical trend of energy use and value added generation (Eurostat - GDP database, 2019; Eurostat – Energy balances, 2019)

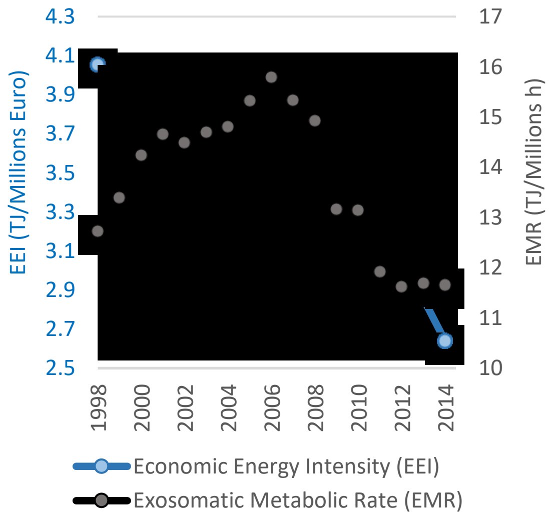

Figure 2. Energy used per unit of value added generated and per hour of human activity (Own elaboration based on Eurostat – Energy balances, 2019)

With this regard, Figure 2 summarises the economic energy intensity (EEI), that accounts for the energy consumed per Euro of value added generated. Between 1998 and 2014, the EEI of Ireland decreased from 4.05 TJ/Millions Euro to 2.64 TJ/Millions Euro, highlighting a reduction in the quantity of energy used per Euro of value added generated. The largest reductions have taken place in the years that preceded the beginning of the credit-driven house price bubble (14.7% between 1998 and 2002) and in the period that followed the global financial crash (11.9% between 2011 and 2014). Similarly to the trend performed by other European countries, such for example Italy and Greece, the energy intensity improvements have however reduced in the year of the crisis due to GDP drop and unused production capacity (Enea 2018; EC, 2015). According to analysis previously reported by SEAI (2018), a number of factors contributed to drive the EEI reductions that have been highlighted by the Eurostat data included in Figure 2, namely:

- The energy efficiency improvements achieved through the implementation of the energy efficiency plan developed in line with the EU 2030 strategy, that supported: *i)* research and investments oriented to reduce the energy requirements of the household and production sectors; *ii)* the large investments in wind turbines, which reduced the primary energy requirement for electricity generation; *iii)* the development of higher efficiency natural gas plants (SEAI, 2018);
- The structural economic changes, that reduced the energy used per unit of GDP generated, but that does not necessarily mean that the actual production process is more energy efficient. As reported above, the period of the Celtic Tiger has been characterised by considerable economic changes, such as for example the replacement of energy intensive industrial activities (e.g. steel and fertilisers) with high value-added productions (e.g. pharmaceutical and electronics).

The economic structural changes that have taken place in the Irish economy can be identified by the contribution that the different economic sectors played to the GDP generation (Figure 3). The agricultural and the industrial sectors, for example, reduced their contribution from 4.4% and 27.8% respectively in 1998 to 1.8% and 24% respectively in 2014. The service sector, on the contrary moved from 61.5% in 1998 to 71.6% in 2014, while the construction sector reached its peak in 2006, contributing to 10.7% of GDP generation and dropped just after the global financial crash, with just 1% of GDP contribution in 2011.

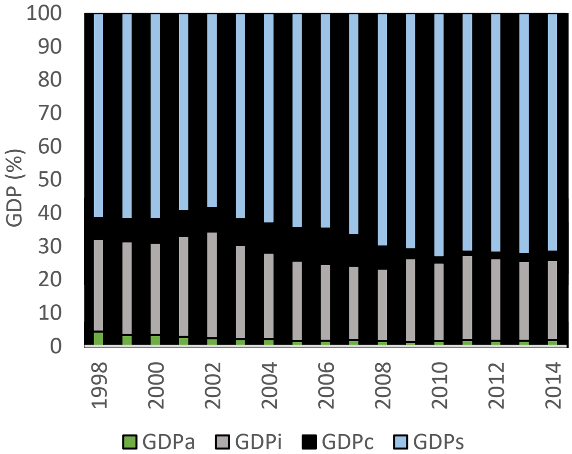

Figure 3. Percentage contribution of economic sectors to GDP generation (Eurostat – NACE A*64 database, 2019)

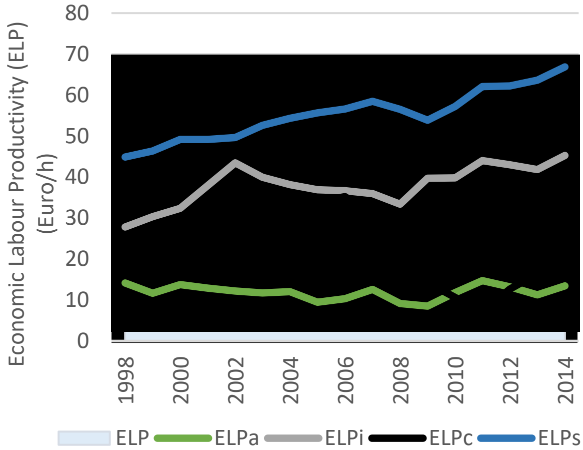

Figure 4. GDP per hour of labour (Eurostat – NACE A*64 database, 2019; EU KLEMS database, 2017)

The labour productivity increase, that accounts for the GDP generated per hour of labour, can also be used to discuss the structural changes of the Irish economy. According to data reported in Figure 4, the economic labour productivity (ELP) has increased from 34.1 Euro/h in 1998 to 53.4 Euro/h in 2014. In line with the structural changes reported above, the largest variations have taken place in the industrial and in the service sectors (62.7% and 48.9%, respectively between 1998 and 2014). The agricultural sector remained almost constant. The productivity of the construction sector largely increased during the house price bubble (22.7 between 1998 and 2007) and largely reduced after the crisis (77% between 2007 and 2011) when, according to analysis previously reported by CSO (2019), the housing market price dropped by around 40% compared to the pre-2008 prices.

In aggregate terms, Ireland has been the country performing the largest labour productivity increase among all the European Countries and Ireland has been ranked by OECD as one of the worlds' most productive countries. According to analysis reported in OECD (2019), the large inflow of companies with significant intellectual property assets and the high concentration of multinationals, which usually drive some of the biggest productivity increases, have been the main factors driving Ireland in having the highest post-crisis labour productivity gain among OECD countries.

The analysis of the exosomatic metabolic rate (EMR) can provide additional information to investigate the drivers behind the energy intensity variations. According to data reported in Figure 2, the exosomatic metabolic rate, that quantifies the energy consumed per hour of human activity, has increased during the period of the Celtic Tiger, moving from 12.7 MJ/h in 1998 to 15.8 MJ/h in 2006. During those years, the percentage variation of the total energy throughput has been higher than the population increase (41.4% and 13.9%, respectively between 1998 and 2006) generating the rise of the EMR. In 2007, the EMR started to reduce. The year 2007 was characterised by one of the highest population growth rates (3.14%), mainly influenced by the large inflow of migrant attracted by the flourishing economic conditions. With the beginning of the global financial crash, the energy throughput declined at a rate higher than the population growth (-18.7% and +1.04%, respectively between 2008 and 2014), generating a reduction of the exosomatic metabolic rate.

The combined analysis of EEI and EMR, highlights that economic structural changes and value added increase have been the main factors influencing the energy intensity reductions of Ireland during the period of the Celtic Tiger. The energy efficiency improvements haven't been able to compensate the increased energy demand that have been required per unit of human time. On the contrary the economic recession that followed 2008, together with the energy price increases and the personal income reduction, have generated a drop in the energy consumed both in TET and EMR terms (18.7% and 21.9% reductions between 2008 and 2014).

This trend is further highlighted by the EMR of the household sector. Based on data reported in Figure 5, the total energy requirement of every hour spent in the household sector (EMR_{HH}) have increased in the period that preceded the global financial crash. Following Pastore et al.

(2000), Gimpietro et al. (2011) and Velasco-Fernandez et al. (2015), the EMR_{HH} can be used as a proxy of the material standard of living and highlights a relationship between income and energy use. According to data provided by SEAI (2017) and SEAI (2018), the large increase in the energy-using appliances together with the average house size (15.9% increase between 1990 and 2015), that have taken place during the years of the Celtic Tiger, has contributed to generate 41% increases in the household energy demand. After the global financial crash, the energy throughput and the exosomatic metabolic rate of the household sector declined (9.8% and 18.9%, respectively between 2008 and 2014). The year 2010 has been the only exception, when the very cold weather increased the energy requirement of the household. According to SEAI (2018), the revision of the building regulations related to fuel and energy conservation (S.I. No. 259/2008), together with the drop of disposable income have contributed to reduce the exosomatic metabolic rate and the energy throughput of the household sector. In addition, the large dependency from energy import (around 85% in 2014) and the related energy price increases, together with the introduction of a carbon tax on liquid based fuels for transport, space and water heating, have driven Ireland to have electricity costs lying above the European average, with consequent impact on energy demand (SEAI, 2018).

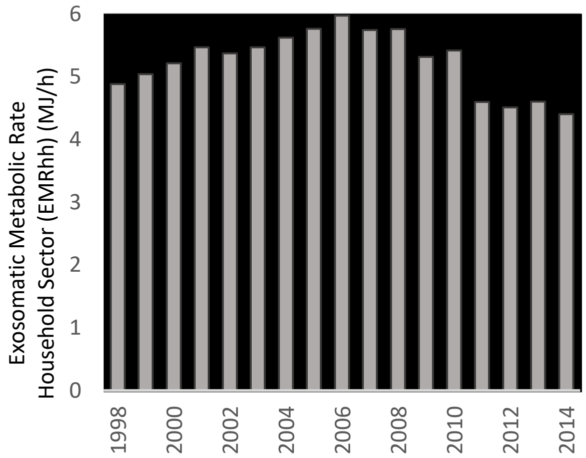

Figure 5. Energy used per hour spent in the household sector (Own elaboration based on Eurostat – Energy balances, 2019; EU KLEMS database, 2017)

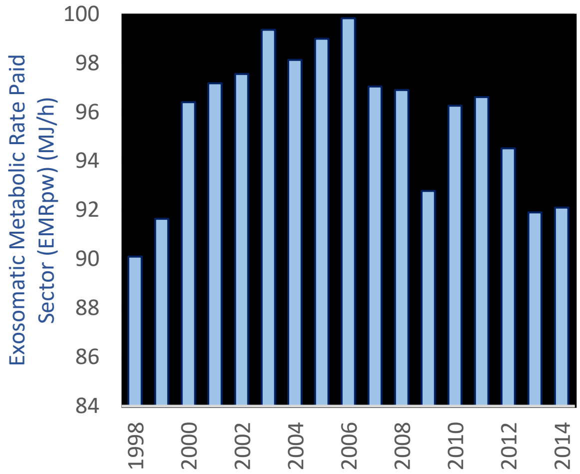

Figure 6. Energy used per hour spent in the paid sector (Own elaboration based on Eurostat – Energy balances, 2019; EU KLEMS database, 2017)

The exosomatic metabolic rate of the paid sector (Figure 6) also highlights how the energy requirements per unit of time spend in the paid activities have not reduced in the period that preceded the global financial crash. In particular, between 1998 and 2006, the EMR_{PW} increased from 90.1 MJ/h to 99.8 MJ/h. On the contrary, after 2007 the EMR_{PW} generally reduced, highlighting that an energy efficiency increase has effectively taken place.

According to data included in Figure 7, that summarises the percentage variations of human time and energy throughput, the energy requirements of production activities have generally increased more than the human time in the period before the crisis. On the contrary, after 2008, the percentage variations of the energy throughput have been lower than the percentage variations of human time, highlighting a decoupling between labour and energy use.

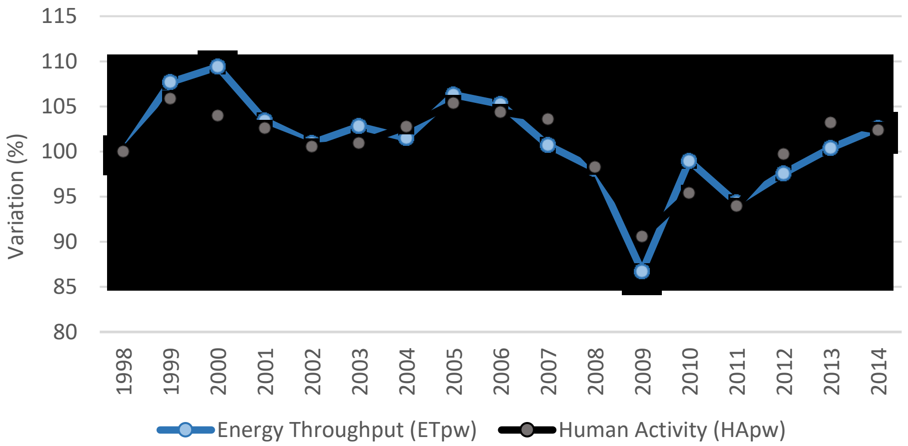

Figure 7. Paid sector – Percentage variations of Energy Throughput (ET_{PW}) and Human Activity (HA_{PW}) (Own elaboration based on Eurostat – Energy balances, 2019; EU KLEMS database, 2017)

As reported by SEAI (2017), changes in fuel mix, such as the reduction in the use of coal and peat and the increase of natural gas and renewable, together with energy prices increase and stricter environmental regulation, oriented to achieve the 2030 EU targets, have been the main factors contributing to reduce the energy used per unit of time. The largest improvements have been achieved in the service sector where a large amount of the energy used is related to space heating, lighting and information and communication technologies. Similarly, to what is reported for the household sector, improvements on energy conservation and building insulation have been the main factor contributing to reduce the EMR_{PWs} (16.2% between 2008 and 2014) (SEAI, 2018). During the years 2008 and 2009, all the economic sectors experienced a large reduction in the quantity of energy used per unit of human time. The economic recession, that affected the production of goods and services generated a reduction in the quantity of energy used (ET_{PW}) that has been higher than the reduction of human time (HA_{PW}) (14.9% and 11,1% between 2007 and 2009). The only exception is the year 2010 that, as reported above, has experienced energy consumption increase due to weather conditions.

When considering population, Ireland has one of the highest nativity rates in EU (1.89 compared to 1.58 of EU average in 2014). Between 1998 and 2014, the Irish population grew by 25.6%, largely above the European average (4.4%). The total increase has been driven by positive variation of the live birth (24.7%), by death reduction (7.3%) and by the large immigration rate experienced in the years of the Celtic Tiger. According to data reported in Figure 8, between 1998 and 2008 more than 867,000 people moved to Ireland and just 387,000 left the country, contributing to generate more than half (62.8%) of the total human activity (THA) increase that have taken place between 1998 and 2008 (20.7%). According to data provided by Piola (2015), the non-restrictive policy on EU citizens' circulation, together with the rapid economic growth, attracted a large number of workers from post-enlargement European countries.

In the years that followed the global financial crash, on the contrary, more people were leaving the country than arriving, and in 2011, when the unemployment rate was at the highest level, one person was leaving the country every six minutes (Piola, 2015). Despite the high emigration rate, however, the rise in the fertility rate experienced between 2008 and 2011 (more than 2.05% yearly average), contributed to increase the Irish population, even in the period that followed the crash (4% between 2008 and 2014).

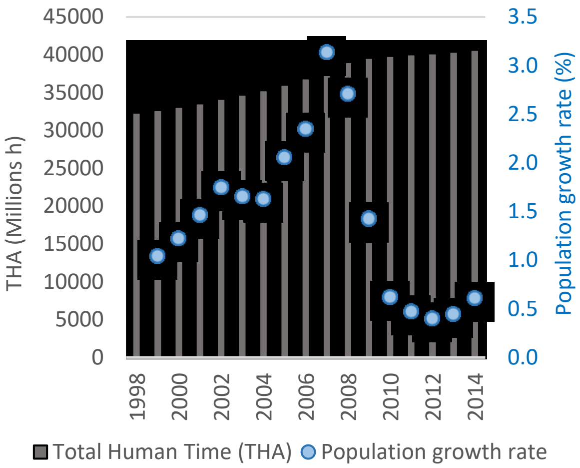

Figure 8. Population trend (Eurostat – Population database, 2019)

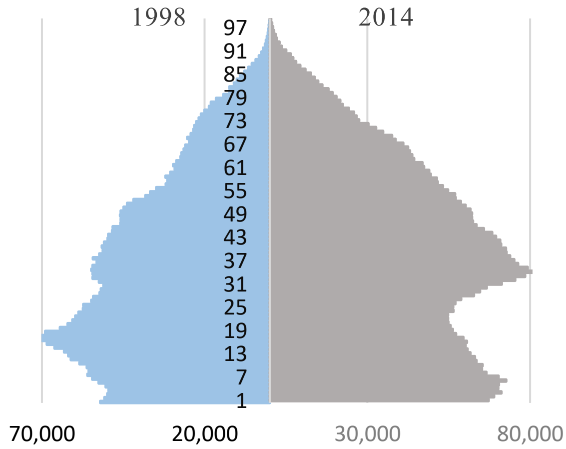

Figure 9. Population pyramid (Eurostat – Population database, 2019)

When considering the population structure, significant changes have taken place between 1998 and 2014. Based on data reported in the Figure 9, the number of children (0-10 years old) has increased by 28.2%, mainly due to the high fertility rate. The working age population (16-64 years old) has also increased (26.6%), mainly as a consequence of the high immigration rate experienced in the years of the Celtic Tiger.

When considering the old dependency ratio, summarising the rate of 65 years old over the working-age population (16-64 years old), Ireland has one of the lowest dependency ratios in EU (19.1 in 2014, compared to 28.2 EU 28 average). During the years that preceded the global financial crash, where the high immigration rate generated a large extension of an already large young adult population, the dependency rate was even lower, reaching 15.6 at the beginning of 2008. Traditionally seen as an indicator of the level of support available to older persons, the dependency ratio is generally used to analyse the socio-economic sustainability of countries. Between 1998 and 2014, the dependency ratio of Ireland has increased by around 11%, remaining however largely below the European average increase (24% between 1998 and 2014). According to data provided by Eurostat, despite the aging population taking place cross high-income countries, Ireland has the youngest population in Europe, with around 25% of the population age 0 to 14 and just 13% of the population age over 65 (15.5% and 18.5%, respectively European average).

The large fertility rates, the dependency ratio increase and the migration trends are also reflected in the distribution of time reported in Figure 10, where the number of hours spent in the household sector raised more than the number of hours spent in the paid sector (26.9% and 12.8%, respectively between 1998 and 2014). Between 2008 and 2011, when the crisis was at its worst, the human time in the paid sector decreased by 18.8%, while the household time increased by 4.9%. On the contrary, when Ireland experienced positive GDP growth rate, such as before 2008 and after 2012, the human time allocated to the production activities increased.

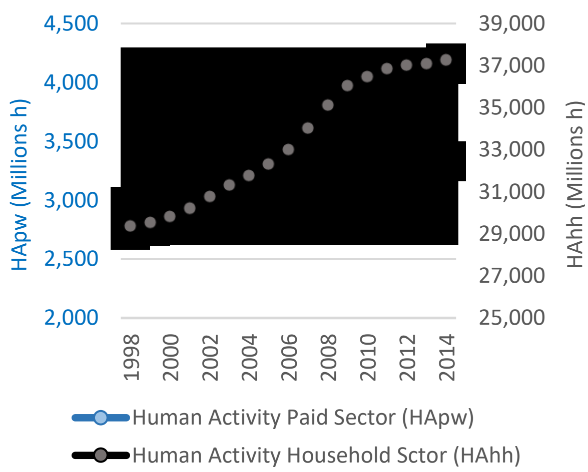

Figure 10. Human time spent in the paid and in the household sectors (EU KLEMS database, 2017)

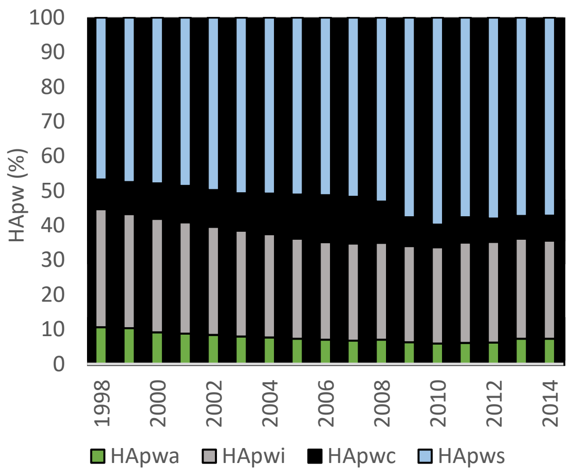

Figure 11. Percentage of working time allocated to economic sectors (EU KLEMS database, 2017)

When considering the contribution provided by production activities (Figure 11), agriculture and industry reduced the percentage contribution provided to the total human time devoted to the paid sector. On the contrary, the human time allocated to the service sector increased from 46.7% in 1998 to 57.2% in 2014. The percentage contribution of the construction sector clearly reflects the implication of the housing bubble and consequent crisis. Between 1998 and 2007 the time devoted to construction increased from 8.6% to 13.5% and decreased by 46.2% in the years that followed the crash.

3.2 Drivers of energy variation

The metabolic discussions reported above provide useful information to analyse the socio-economic and demographic variations that have taken place in the Irish society. To further investigate the impacts generated on energy use, decomposition analysis has been performed based on the methodology reported in Section 2.2. Results are reported in Table 1 and in Figure 12.

The economic energy efficiency effect (EI), summarising the energy used per unit of GDP has reduced during the entire period, with exception for the time period 2003-2008 where the percentage variation of TET and the percentage variation of GDP have been almost the same. During all the other periods, the GDP increase has been higher than the variation in the total energy throughput, generating an economic energy intensity reduction. As discussed above, the structural changes that have taken place during the period of the Celtic Tiger largely influenced the high GDP growth rates. The consequent increase of the per-capita income contributed to raise the standard of living effect (SL), that over the 1998-2014 time period has been the main factor of energy consumption increases.

The economic downturn of 2008-2012, on the contrary, reduced the quantity of energy used in relation to the standard of living effect (SL). The population effect (P), summarising the impact of the total human activity, has increased the energy use during all the four time periods considered in the analysis.

Table 1. Decomposition results

	EI (TJ)	SL (TJ)	P (TJ)	TET Cumulated Change (TJ)
1998-2003	-73,070 (-74%)	138,935 (141%)	32,782 (33%)	98,646 (100%)
2003-2008	623 (1%)	7,735 (11%)	64,032 (88%)	72,390 (100%)
2008-2012	-89,151 (-77%)	-41,437 (-36%)	15,260 (13%)	-115,328 (100%)
2014-2012	-48,280 (-796%)	49,387 (814%)	4,961 (82%)	6,068 (100%)
1998-2014	-196,084 (-317%)	154,525 (250%)	103,335 (167%)	61,776 (100%)

(Own elaboration based on Eurostat – Energy balances, 2019; Eurostat – Population database, 2019; Eurostat – GDP database, 2019)

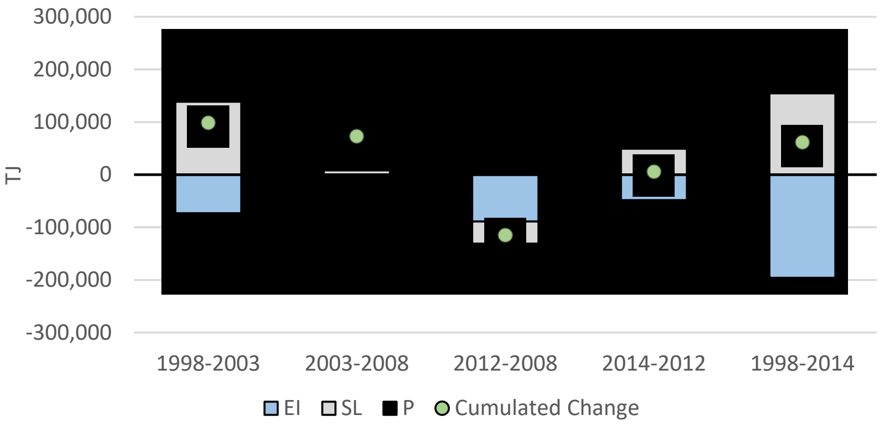

Figure 12. Drivers of energy variation
(Own elaboration based on Eurostat – Energy balances, 2019; Eurostat – Population database, 2019; Eurostat – GDP database, 2019)

4. Conclusion

The MuSIASEM approach and the perfect decomposition technique have been used in this paper to investigate how demographic and economic changes have influenced the energy used in Ireland across different levels of analysis. The time period 1998-2014 has been considered and the following trends have been identified:

- During the years of the Celtic Tiger (1998-2007), the percentage variation of gross domestic product has been higher than the percentage variation of the total energy throughput, highlighting a relative decoupling. The structural changes and the energy efficiency improvements, have been the main factors influencing the energy intensity reduction. However, the high fertility rate, the large migration inflows and the increased per-capita income contributed to rise the overall energy use.
- The deceleration of economic growth that has taken place during the years of the global financial crisis (2008-2011), together with the implementation of energy efficiency action plans, contributed to reduce the energy throughput both in absolute and relative terms.

- During the years of the Celtic Phoenix (2012-2014), energy efficiency continued to improve. However, population growth and standard of living have driven an energy consumption increases. If not accompanied by further energy efficiency improvements, the population and the GDP growth could contribute to worsen the Irish dependency from energy import, with consequent impacts on competitiveness and energy prices. The drastic shrink of the working age population and the related declining age-specific consumption could however reduce the energy use. Up to now, limited analyses have focused on the relationships existing between demographic changes and energy demand, this should be explored further.

To fully investigate the energy requirements of Ireland, the analysis performed with the MuSIASEM and the perfect decomposition technique, would also need to be complemented by data including the energy embedded into imported and exported products. By considering the energy used within a national system, the MuSIASEM approach is unable to disaggregate the energy throughput allocated to internal use or to overseas export. Further analysis investigating the energy footprint of products would then be needed to facilitate the understanding of the per-capita energy demand and the sustainability trends of countries.

Notwithstanding these limitations, the MuSIASEM and the perfect decomposition technique used in this paper, have been functional to investigate the relationships existing between socio-economic variables and energy use. The results can be used to support the design of policies oriented to achieve sustainable energy strategies.

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