Portugal societal exergy accounting - Past and Future

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"Não sou nada.

Nunca serei nada.

Não posso querer ser nada.

À parte isso, tenho em mim todos os sonhos do mundo."

- in ''Tabacaria'', Álvaro de Campos
(aka Fepas ou avô Álvaro)

Abstract

Societal transformations have been reliant on the consumption of energy services such as heat, transport and power, being this evolution enabled by a growing consumption of energy and an increase of its use efficiency. The correct way to evaluate the importance of these energy transfers to society is exergy because this property takes into account their quality, i.e., the maximum amount of work a certain amount of energy may originate (e.g. lift a weight, electrical work, etc.).

The current dissertation is based on societal exergy accounting studies for Portugal in order to provide 1) forecasts of exergy demand up to 2030 and 2) a detailed study on the electricity exergy efficiency series 1913-2014. Forecasts show that due to rebound effect it is not possible to have in the same scenario a rapid economic growth and a decrease in greenhouse gas emissions (decarbonized economy) based solely on efficiency improvements. Investing in renewables is mandatory to achieve that goal. Results regarding the aggregated efficiency of electricity show that rather than a continuous increase of efficiency, electricity final-useful aggregate efficiency has grown until the last quarter of the 20th century, around the 1970s and, after that has been decreasing continuously, reaching in 2014 a value similar to 1913 due to the dilution effect caused by the increasing shares of less efficient end-uses. These results emphasize the importance of the rebound and the dilution effects showing that they can partially offset the gains due to technology evolution.

Keywords: Exergy; Exergy efficiency; Electricity; Useful exergy; Consumption efficiency

Resumo

As transformações da sociedade têm dependido de um crescente consumo e uso mais eficiente dos serviços de energia como calor, transporte e electricidade. A forma correta de avaliar a importância das transferências de energia para a sociedade é através da exergia, uma vez que esta propriedade tem em conta a qualidade da energia, medindo o máximo trabalho que pode ser realizado por uma determinada quantidade de energia (por exemplo, levantar um peso).

A presente dissertação é baseada em estudos de contabilidade exergética feitos para Portugal com os objectivos de realizar: 1) projecções de necessidades exergéticas para 2030 e 2) um estudo detalhado da eficiência exergética da electricidade entre 1913 e 2014. As projecções realizadas mostram que, devido a um efeito de "ricochete" (*rebound effect*), não é possível ter num mesmo cenário um crescimento económico promissor e uma diminuição de emissão de gases com efeito de estufa (descarbonização da economia) exclusivamente com base em melhorias de eficiência. O investimento em fontes de energia renováveis é, também, imperativo. Relativamente aos resultados do estudo da eficiência agregada de electricidade, estes mostram uma evolução diferente dos estudos anteriores. Em vez de um crescimento contínuo, a eficiência da electricidade aumentou até meados do século XX, tendo depois começado a diminuir e atingido, em 2014, valores semelhantes aos de 1913. Isto deve-se ao efeito de diluição causado pelo aumento do uso de aparelhos menos eficientes.

Estes resultados enfatizam a importância dos efeitos de "ricochete" e diluição que podem, em parte, minimizar os ganhos da evolução tecnológica.

Palavras-chave: Exergia; Eficiência exergética; Eletricidade; Exergia útil; Eficiência de consumo

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List of Acronyms

ADENE	Agência para a Energia
AP	Amoníaco Português
APA	Agência Portuguesa do Ambiente: Portuguese Environmental Agency
BCSD	Business Council for Sustainable Development
CNE	Companhia Nacional de Electricidade
COP	Coefficient of Performance
CRGE	Companhias Reunidas de Gás e Electricidade
DGEG	Direção-Geral de Energia e Geologia: Energy and Geology Agency
DGSE	Direção-Geral dos Serviços Eléctricos
EDP	Energias de Portugal
EFTA	European Free Trade Association
ER	Energy Recources method
EU	European Union
EV	Electric vehicles
GDP	Gross Domestic Product
HTH	High Temperature Heat
ICESD	Inquérito ao Consumo de Energia no Sector Doméstico: Domestic sector Consumption survey
IEA	International Energy Agency
IMF	International Monetary Fund
INE	Instituto Nacional de Estatística: National Statistics Institute
IPCC	Intergovernmental Panel on Climate Change
IST	Instituto Superior Técnico

LPG	Liquefied Petroleum Gas
LTH	Low Temperature Heat
MD	Mechanical Drive
MTH	Medium Temperature Heat
MW	Mechanical Work
NG	Natural Gas
NR	Natural Resources method
OCDE	Organisation for Economic Co-operation and Development
OE	Other electrical uses
PCM	Physical Content Method
PNAEE	Plano Nacional de Acção para a Eficiência Energética: National Action Plan for Energy Efficiency
PNBEPH	Plano Nacional de Barragens de Elevado Potencial Hídrico: National Action Plan of High Hidric Potential Dams
PSM	Partial Substitution Method
p.p.	Percentage Points
RCM	Resource Content Method
REN	Rede Eléctrica Nacional
TFP	Total Factor Productivity
toe	Ton of oil equivalent
UFA	União Fabril do Azoto

1. Introduction

The current dissertation focus on societal exergy accounting studies for Portugal, focusing on 1) forecasts of exergy demand up to 2030 and 2) a detailed study on electricity exergy efficiency series 1913-2014.

1.1. Energy

The survival and growth of the humankind as well as of all life is dependent on energy. Consuming energy stored in stocks of biomass which provided food and shelter, has been how animals and humans have survived through times. Furthermore, societal transformations have been reliant on the consumption of other energy services such as heat, transport and power, being this evolution enabled by a growing consumption of energy and an increase of its use efficiency. For that, it is undeniable the relevance of energy for society and economy (Fouquet 2008).

A side-effect of the mentioned transformations, especially after the Industrial Revolution, was the deterioration of the environment, with consequences such as climate change and animals' extinctions. Therefore, Energy, which comes from natural resources, is intrinsically related with the environment too.

Also, the link of Energy with Economy is clear, as Fouquet describes it:

"Human economies – the production, exchange and consumption of goods and services - are driven by refinements in ways of capturing and harnessing energetic resources. The growth of economies has been closely linked with the availability, extraction, distribution and use of energy. Indeed, there is a close relationship between energy consumption and economic development […]." (Fouquet 2009, p.1).

The relation of Energy with all three pillars of Sustainability (Environment, Economy and Society) is, therefore, clear, justifying its relevance for scientific research in finding new paths for a sustainable development.

In the early 20th century, chemist Wilhelm Ostwald already emphasized, the link between energy and society and the relevance of the historical study of energetic consumption. He suggested the possibility of studying and analysing civilizations' history and development from an energy point of view, having civilizations' development as a function of their energy uses (Serrenho 2013).

Aligned with this vision, the EU (European Union) has acknowledged the role energy plays in European society, recognizing that problems such as environment preservation and climate change are intrinsically related with energy. Moreover, EU considers energy efficiency as a pivotal point for climate change adaptation and mitigation measures (Dewulf et al. 2015).

Furthermore, Brockway et al. (2016) point out that energy and resources *availability* is part of at least four of the seven societal challenges, emphasized by the European Commission, that traduce *Europe 2020* strategy policy priorities.

However, the Physical, Chemical and Mathematical Sciences Committee mentions the inconsistencies related with energy efficiency: "*no coherence, no common scale and no agreed metric for energy efficiency"*, finding it problematic. Exergy studies are seen as the solution for such inconsistencies (Dewulf et al. 2015).

Works such as Brockway et al. (2016) and Dewulf et al. (2015) opinion paper, show the growing interest and need in a "gear-shift" towards societal exergy studies (Sousa et al. 2017).

1.2. Exergy

Exergy is the property that allows quantifying energy transfers through heat, work and mass flows taking into account their quality by quantifying the maximum amount of work a certain amount of energy may originate (e.g. lift a weight, electrical work, etc.). In Moran et al. words, "*exergy is the maximum theoretical work obtainable from an* overall *system consisting of a system and the environment as the system comes into equilibrium with the environment*" (2011). For others i.e. Wall (1987) exergy may be seen as a measure for the deviation that a system has from its equilibrium state.

Some authors like Heywood (1988) and Szargut (1988), name this property *availability* rather than exergy, making it clear that it is related to the actual work *available* from a certain quantity of energy.

In a system, there are various types of exergy corresponding to different forms of energy (Figure 1) (Serrenho 2013).

<table>
<tr><th colspan="4">Exergy
B</th></tr>
<tr><td>Potential exergy
B_{pot}</td><td>Kinetic exergy
B_{kin}</td><td>Physical exergy
B_{phy}</td><td rowspan="2">Chemical Exergy
B_{ch}</td></tr>
<tr><td colspan="3">Thermomechanical exergy
$B_{thermomechanical}$</td></tr>
</table>

Figure 1: Subdivisions of total exergy according to Moran and Szargut works (adapted from Serrenho 2013)

Each type of Exergy is explained further:

- B_{kin}, is kinetic exergy which corresponds to the maximum amount of work obtainable from a change in kinetic energy, thus, kinetic exergy is equal to kinetic energy;
- B_{pot}, is potential exergy which has the same reasoning described for kinetic exergy, therefore corresponding to potential energy as well;

- $B_{phy,}$ is physical exergy, associated to the intensive variables pressure and temperature, which means it is the potential to perform work (maximum work) by bringing these systems' properties to a reference state (p_0 and T_0) through a reversible physical process;
- B_{ch}, is chemical exergy which is the ability to perform the maximum work associated to a reversible chemical process in a system into a reference state, being thus related to the chemical potential μ (ibid).

Important aspects of exergy were resumed by Moran et al. (2011):

a) Exergy is an extensive property that is a feature of both the environment and the system;
b) Exergy's maximum work cannot be negative since the minimum work a system can do to move to the dead state is zero (spontaneous processes);
c) Exergy is destroyed by irreversibilities, being the case of a process where the potential to perform work is not used, a case of destruction of systems' total exergy;
d) Exergy may also be seen as the minimum theoretical work necessary to bring a system from dead state to a given state.

Looking closer to c), exergy losses occur mainly due to friction, irreversible heat transfers and/or irreversible diffusion processes (Szargut et al. 1988).

1.2.1. Thermodynamics' first and second law efficiencies

Measuring efficiency can be done using both thermodynamic laws' efficiencies. Both efficiencies are used to account for the losses that happen in systems throughout the energy flow, while undergoing processes where energy carriers are transformed into different forms of energy, on each stage of the flow.

The first law efficiency (η) is computed by the ratio of energy desired output by energy input – equation (1) - (Moran et al. 2011; Ford et al. 1975). It is considered that the higher the first law efficiency the better.

$$\eta = \frac{Energy_{output}}{Energy_{input}} \tag{1}$$

For certain systems, such as heat pumps, energy efficiency can reach values greater than 1, being called a coefficient of performance (COP) rather than efficiency. For these types of systems, the first law does not provide information on how far the system is from the ideal performance because the input and output are different types of energy. This efficiency does not measure the degradation of energy's quality - which can be measured by the exergy of the system, or as mentioned before, the maximum theoretical work that can be performed by it, despite the device (ibid).

The second law or exergy efficiency (ε) deals with these drawbacks and is given by the ratio of exergy desired output by exergy input – equation (2).

$$\varepsilon = \frac{Exergy_{output}}{Exergy_{input}} \tag{2}$$

Ford et al. (1975), using the example of a motors performance, set exergy efficiency as the ratio between the real and the ideal exergy demands that a motor has. In other words, exergy efficiency is the comparison of an ideal performance and the current one – showing how far, e.g. motors are from their ideal thermodynamic performance.

Going back to the heat pump example, for heat exergy is calculated applying Carnot efficiency – which corresponds to the ideal cycle. So, for a heat pump, exergy efficiency would be given by equation (3):

$$\varepsilon = \frac{Q \ \ (1 - \frac{T_0}{T_h})}{W} \tag{3}$$

Where $\frac{Q}{W} = \eta$ and $(1 - \frac{T_0}{T_h})$ is the Carnot efficiency for a heat engine.

As the ideal energy efficiency for a heat pump is given by:

$$\eta_{ideal} = \frac{T_h}{T_h - T_0} \tag{4}$$

One may substitute in equation (3) and obtain equation (5):

$$\varepsilon = \eta \ \ (1 - \frac{T_0}{T_h}) \ \ = \frac{\eta}{\eta_{ideal}} \tag{5}$$

This corresponds to the same ratio used by Ford et al. (1975) for the motors performance example. Therefore, exergy efficiency can be used as a measure of the potential improvement that can be done (Cullen & Allwood 2010).

Exergy efficiency equations per end-use are shown in Chapter 2.

1.2.2. Energy flow stages

Studies focused on the energy flow until the end uses (useful stage) are important not only to understand the energy's use structural changes throughout time but, also, to pinpoint where there is room for efficiency improvement and where technological innovation has occurred (Cullen & Allwood 2010).

When thinking about the energy flow, there are three stages that might be looked at: Primary, Final and Useful.

The OECD Glossary of Statistical Terms defines, like some other authors (e.g. (Boyle 2003)), primary energy as energy that has not undergone any process of conversion or transformation, which means energy at the source (2017). This might be a natural resource and, according to authors such as IEA (International Energy Agency), it might also be the first energy form available to be used (Serrenho 2013), e.g. geothermal heat.

Final energy is second in energy flow. At this stage, the energy is delivered to consumers and accounts for losses happening in the energy sector including transformation, transportation and distribution. Last in energy chain, useful energy is energy in the form used by consumers, accounting for losses associated with the transformation devices' (internal engines, light bulbs, refrigerators, etc.). This stage in energy chain is the best measure of energy needs (Serrenho 2013). These three stages also apply for exergy.

One example of energy flow is given by the process that coal undergoes until its energy is consumed in an end use (Figure 2).

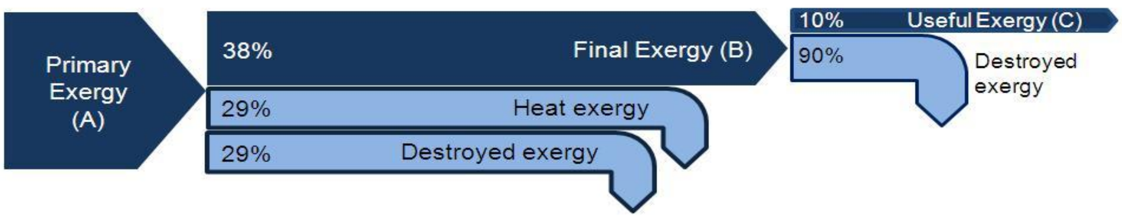

Figure 2: Exergy flow for coal being converted into electricity which is used to provide heat with an electric radiator (Felicio et al. 2017)

Coal, in its natural form (A) is transformed into electricity (B) on a power plant. As a transformation occurs, an efficiency is associated the process from (A) to (B) – electricity production from coal has currently an exergy efficiency of approximately 38% - calculations based on national energy balances (DGEG 2017a; DGEG 2017b). Then, electricity (B) is distributed and used for several ends. Taking as an example a radiator, there is a transformation of electricity into heat (C). Assuming, e.g., a service temperature of 50^{o}C and an environmental temperature of 18ºC its associated exergy efficiency is approximately 10%.

In the described process, there are three efficiencies that can be calculated: primary to final (A to B), final to useful (B to C) and primary to useful (A to C, in this example is approximately 4.6%). And while data on final and primary consumption is made available by entities such as IEA (2016) and DGEG (2017a), useful consumption lacks in available data collected systemically, not only in absolute values but, also, associated efficiencies.

Warr et al. (2008) highlight the difficulties related to this lack of useful exergy data on both the consumption per end-use – and, therefore, allocation of exergy – and conversion efficiency. These bring the necessity to use proxies, thus, contribute to the uncertainty which is unavoidable when computing useful exergy calculations.

1.3. Dissertation context

Studies on societal exergy accounting have been made for the last decades, showing the relevance of exergy. Works like Williams (2008), Serrenho et al. (2014, 2016), Ayres (2003; 2005), Warr (2008; 2010) and Brockway (2014; 2016) use this property to study exergy efficiency, energy transitions, economic growth and forecasting exergy demand (Sousa et al. 2017).

Williams et al. (2008) is an example of a study focusing on exergy efficiency, using it as a proxy to Japan's economy net efficiency. Based on an exergy analysis that allows comparing different uses of energy, sum different energy needs and account for energy demand. The authors suggest that energy consumption/needs (resources consumption), and respective environmental consequences, might be underestimated.

Societal or sectorial exergy analysis might also be relevant in designing public policies. For example, Portuguese policy on Energy Efficiency establishes that a 20% decrease in primary energy consumption is to be achieved by 2020 and this 20% reduction must be based on 2020 consumption projections for a "business-as-usual" scenario, having PNAEE (National Action Plan for Energy Efficiency) website the necessary reductions in toe (PNAEE Executive Commission 2016). However, note that this energy efficiency policy does not establish efficiency goals, but rather consumption goals – which can be achieved with more efficient uses, but also by other means such as different consumption patterns or less energy intensive industries.

In cases like the Energy Efficiency policy, as exergy allows the comparison of different energy uses and the sum of demands in different forms of energy, studies on exergy efficiency become important tools as a basis for new or renewed policies.

Other works focused on exergy efficiency use exergy to compare different countries' energy consumptions on common metrics, such as Serrenho et al. (2014) for 15 European countries, Brockway et al. (2014) for UK & US, and De Sterck (2014) for the World.

Ayres et al. (2003) for USA, Warr et al. (2008) for the UK and Warr et al. (2010) for four countries (UK, Austria, Japan and US) are examples of exergy analysis that use exergy efficiency (primary/final to useful) as a proxy to introduce the technological development in economic analysis. Warr et al. (2008) suggest that useful exergy should be used as a factor of production, which is in accordance with Ayres et al. (2003), because it explains the part of GDP growth that cannot be explained by capital or labour. Ayres also explains how the rebound effect of efficiency improvement could be the driver to economic growth.

More recently, Serrenho and co-authors (2013; 2014; 2016) looked at long-run final and useful exergy consumption series (1856-2009).

In his studies for Portugal, Serrenho (2013) found a proportional relation of useful exergy to GDP (1 MJ per € of GDP). Also, in their work, Santos et al. (2016) show that useful exergy may explain most of the ‘Sollow residual’, which has been throughout time the unexplained part of GDP (attributed to external events) (Figure 3). This is consonant with Ayres et al. (2003) suggestion of this possibility.

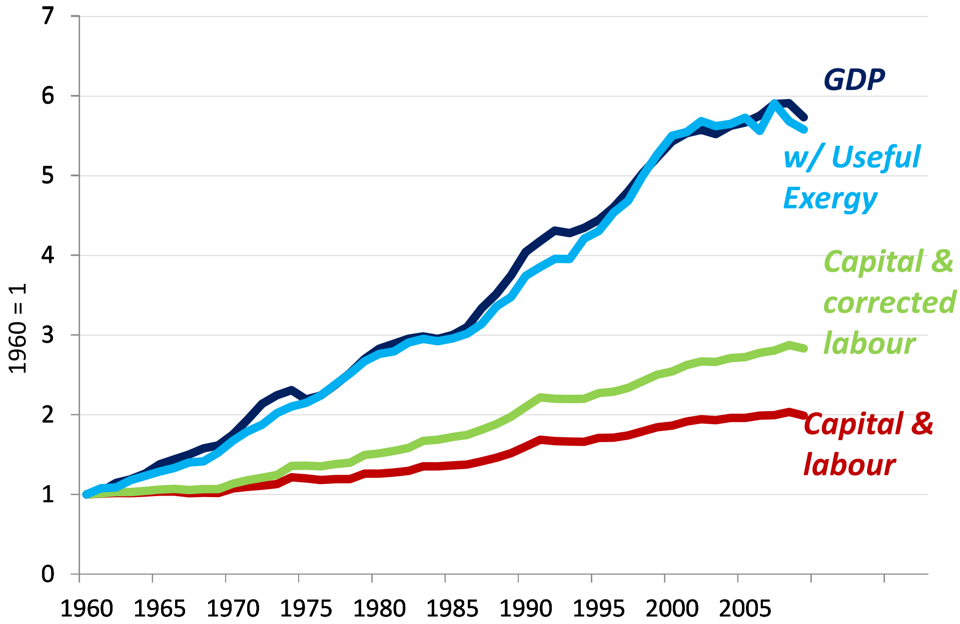

Figure 3: Portugal GDP and functions of capital & labour, capital & corrected labour and GDP as a function of capital labour and useful exergy (Santos et al. 2016)

Based on these findings, a rebound effect for Portugal is calculated, showing that an increase in aggregate final-to-useful efficiency leads to an increase in GDP which might lead to an increase in consumption of final exergy. This effect is also in accordance with Ayres mentioned possibilities and further explained in Chapter 3.

Serrenho et al. (2016) and Santos et al. (2016) findings for Portugal revealed the importance of additional studies on Portugal’s societal exergy accounting. These studies should contribute to (1) decrease the uncertainty of useful calculations by improving details regarding allocation and efficiencies and (2) improve the forecast of energy demand by taking into account the link between useful exergy, exergy efficiency and economic growth – done in this thesis using a new scenario-building methodology.

Also, on a climate perspective, as ratified by EU, in COP21 or the Paris Agreement (UNFCCC 2015) countries agreed to establish measures in order to stop average temperature on the planet from increasing more than 2^{o}C above pre-industrial era values. For this, it was agreed that GHG (greenhouse gas) emissions must be controlled and CO_2 sinks must be developed, reinforcing 2020 goals previously established, and establishing climate-related goals for 2050 as well – such as Carbon neutrality.

As GHG emissions are computed from consumption totals, thus, intrinsically related with energy consumption, the possible paths for a sustainable future within a “decarbonized economy” should be envisioned taking into account the relationships between useful exergy, exergy efficiency and economic growth that were established. MEET2030 project emerges in this context with the focus on near future (2030).

Based on the scientific context presented above and following MEET2030 project goals, two scenarios were developed in order to make 2030 projections of final and useful exergy, GDP and GHG emissions related to fossil fuels’ combustion. These scenarios were developed using a new scenario-building methodology which takes into account, information and know-how on each sector, having the project joined academic, private and public sectors.

Exergy, GHG emission projections and respective results constitute part of the current dissertation that follows the premise to obtain a better understanding of Portugal’s useful exergy consumption.

While trying to have a more profound understanding on Portugal’s exergy consumption, the uncertainty of useful stage calculations was addressed also by focusing on the quality of the data used for historical accounting series. This means, the relevance of detailed data for this type of calculations is explored in this dissertation as a way to fully comprehend setbacks on exergy studies and if exergy-based forecasts may vary much or not - knowing that forecasts are, many times, based on historical trends as in ‘the future follows past patterns’.

In order to look at detailed data and as uncertainty is not only related with useful exergy (end-use) accounting methodologies in general, one opted to choose one energy carrier to develop the second part of this dissertation.

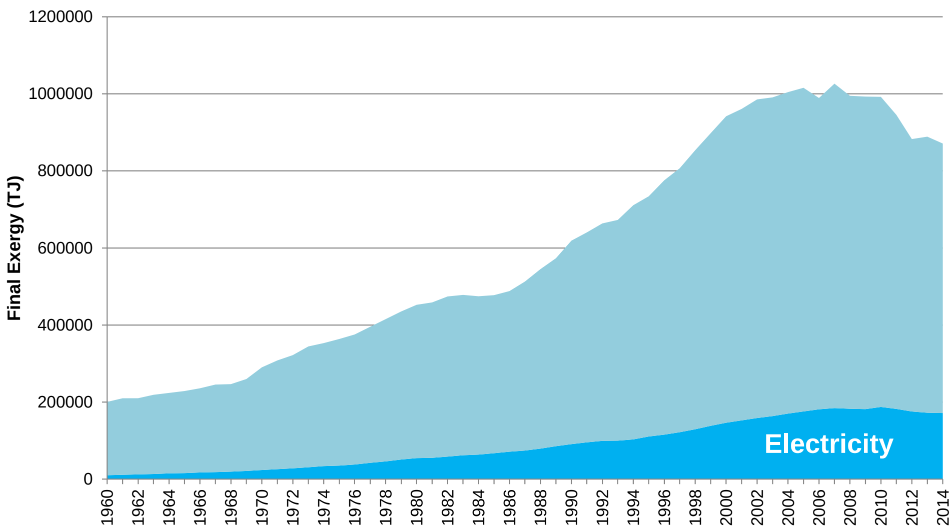

Figure 4: Portugal final exergy consumption highlighting electricity consumption from it 1960-2014 [TJ]

The energy carrier chosen is Electricity because with the technologic evolution, electrification has been increase in the world and appliances tend to be mainly electric. So, the growing importance of this carrier magnifies (1) the difficulties associated with the end-use allocation of this energy carrier and (2) the different methodologies that can be used to calculate primary exergy in electricity production (Sousa et al. 2017), making it relevant to study electricity. Also, while Ayres et al. (2003) highlights the relevance of electric power in past economic growth for the US; in Portugal, during the last 50 years, the share of electricity in total final exergy consumption (Figure 4) has been growing, being currently the second most consumed final energy carrier (about 25% of total consumption) right after Oil products.

Exploring electricity exergy account is also a way to understand the relevance of the use of detailed data in exergy calculations. Using more data and different sources to compute electricity's useful exergy totals is an important part of this, as well as estimating primary exergy with different methodologies.

New useful exergy series built with detailed data for a few benchmark years are compared to Serrenho and co-authors original series (2013, 2016) at the final and useful stages – originally authors did not study primary exergy for Portugal. Nevertheless, in this dissertation, primary stage related to electricity's energy chain is studied as well, being different methodologies tested to calculate primary exergy consumption.

Moving to the primary stage also allows a critical look at possible energy savings or resource savings related to the consumption of electricity.

1.4. Dissertation structure

The current dissertation is structured in five chapters (Figure 5).

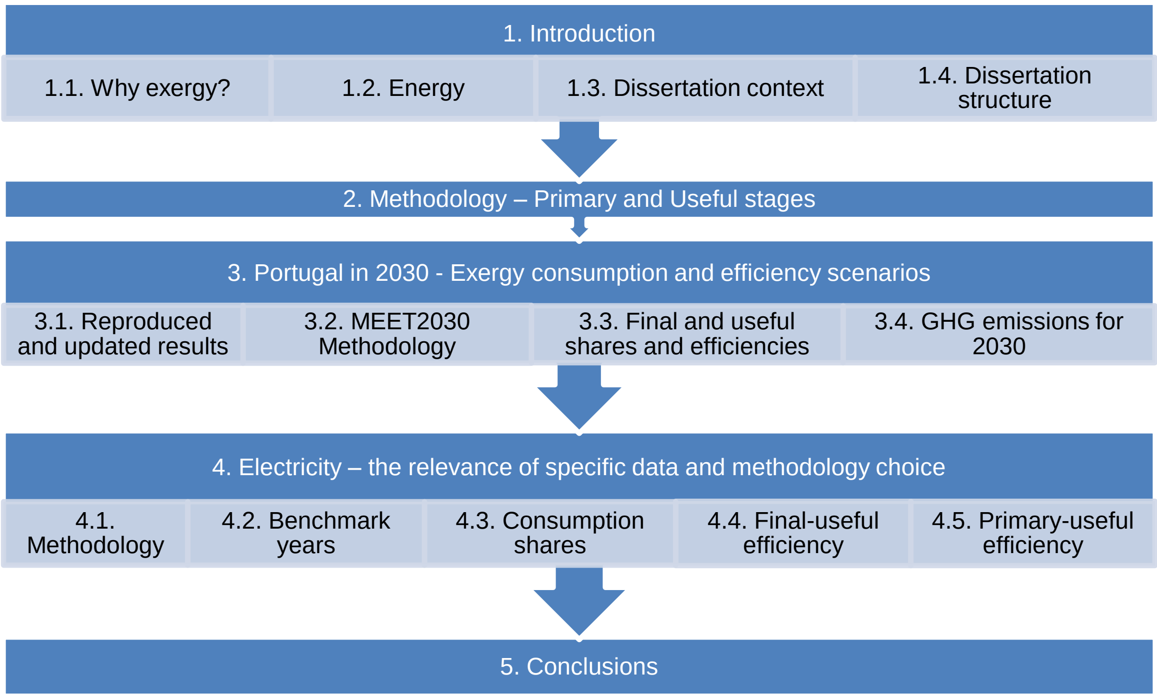

Figure 5: Dissertation structure

The first and current one, “Introduction” sets the context and basic concepts behind the whole document.

The second chapter, “Methodology – Primary and Useful stages”, explains the methods used for the calculations used in the following chapters.

The third chapter, “Portugal in 2030 – Exergy consumption and efficiency scenarios”, is strongly based on previous useful exergy accounting, starting with a brief explanation of Serrenho’s work and results, an update from 2009 to 2014 followed the same assumptions and methods. The chapter, then, continues to 2030 projections for useful exergy shares and aggregate final-useful efficiency, ending with GHG emissions calculations. These projections were made using a new methodology, presented in section 3.3.

The fourth chapter “Electricity – the relevance of specific data and methodology choice” is about one energy carrier: electricity. It starts with the definition of benchmark years for which useful calculations are performed using more detailed data than in previous works. Then, primary exergy is computed using three different methodologies, being all primary-useful efficiencies compared.

Electricity detailed calculations (chapter 4) as well as energy consumption forecasts (chapter 3) are the two approaches that were used in this thesis to improve and explore exergy accounting studies. Part of chapter 4 research was accepted for a communication in the APEEN 2017 conference (Portuguese Association of the Energy Economics), which took place in ISCTE on 15th March, in Lisbon. Also, the whole chapter research as presented in this dissertation was accepted for a communication in the 37th meeting of APHES (Portuguese Association of Economic and Social History) which will take place in Funchal, 17th and 18th November.

Finally, the fifth chapter “Conclusions”, presents conclusions from both chapters 3 and 4, along with general conclusions taken from the whole work. Further work is also suggested by the end of this chapter.

2. Methodology – Primary and Useful Exergy stages

The following chapter describes the methodology used to compute primary and useful exergy calculations. As the useful stage is common to the main chapters of this dissertation - chapters 3 and 4 – methodologies used to compute both energy flow stages are hereby compiled. Specific methodologies followed for each chapter are addressed in subchapters 3.3 and 4.1, respectively.

Many authors have been working on exergy accounting, and their work on national scale accounting follows one of two methodologies. One was applied by Reistad in his exergy analyses (Reistad 1975), the Energy Resources (ER) method (Sousa et al. 2017), and the other follows Wall's work (e.g. 1987; 1977), the Natural Resources (NR) method (Sousa et al. 2017).

Serrenho's work is based on Reistad's methodology, following, therefore, the energy resources method. In this methodology, only flows of energy carriers are considered (Ertesvåg 2001; Sousa et al. 2017).

The NR method, followed by Wall in his works, is based on the notion that all natural resources can be accounted using exergy and, so, it accounts for natural resources such as, e.g. harvested food & fodder and ores & minerals, besides the energy carriers flows (ibid). And, although this method addresses recycling processes in a more consistent way, it does not provide a distinction of the energy end-uses, like ER method, because they are merged and embedded into the materials (Sousa et al. 2017).

A 4-step accounting process is used to calculate useful exergy (right column in *Table 1*) from final energy, since most of the available data on a national scale is at the final stage (consumption of energy). This process is followed by other authors such as Serrenho et al. (2013) and Ayres et al. (2003), while primary exergy is computed with a similar rationale but in 2 steps (left column in *Table 1*).

Table 1: Calculation process of final energy to primary and useful exergy

A - Primary-Final calculations	B - Final-Useful calculations
1 - Apply primary-final efficiencies to final energy to obtain primary energy	1 - Convert final energy into exergy
2 - Convert primary energy into exergy	2 - Allocate final exergy consumption per sector to the different end-uses (e.g. mechanical work, high temperature heat, among others)
	3 - Apply final-useful efficiencies to obtain useful exergy
	4 - Sum the disaggregate results per sector to obtain totals

To convert energy into exergy (steps A-2 and B-1) conversion factors are applied by energy carrier, e.g. coal, oil, combustible renewables, etc. (Table 2). Factors are estimated based on combustion enthalpy[1] and, this, varies depending on the combustible's composition and conditions (e.g. if coal is dry or not). To simplify this issue, many studies such as Chen et al. (2009), Ertesvåg et al. (2000), Wall et al. (1994) and Serrenho (2013) consider an average value (Table 2).

Table 2: Exergy conversion factors per energy carrier *(Serrenho 2013; Chen & Chen 2009; Ertesvåg & Mielnik 2000; Wall et al. 1994)*

Energy carriers	Exergy factors
Coal and Coal products	1.06
Oil and Oil products	1.06
Natural gas	1.04
Combustible Renewables	1.11
Electricity	1
CHP heat	0.6
Food and Feed	1
Other non-conventional	1

Electricity, food & feed and other non-conventional carriers have a factor of 1; therefore, final energy and final exergy are equal. This means one considers that all final energy of these energy carriers can be converted into work.

When computing primary exergy (column A in Table 1), it is simpler to first calculate values for the primary stage (step A-1) and, then, convert energy into exergy (step A-2). Efficiencies that are needed to estimate primary energy (step A-1) are not difficult to obtain because the data available already specifies the electricity produced by each energy carrier. These efficiencies are the production process efficiencies, so the machines' efficiencies, and can be obtained using data from *Direcção-Geral de Energia e Geologia* (DGEG), from national energy balances on primary resources consumption (DGEG 2017a) and electricity produced by each resource (DGEG 2017b).

When estimating useful exergy (column B in Table 1), the conversion into exergy is the first step, as the following steps are all performed using exergy only.

Final exergy is disaggregated (step B-2) into five end-uses/categories that were initially considered by Serrenho (2013): mechanical drive (MD), heat, light, other electrical (OE) uses and muscle work. In Chapter 4, two more categories were considered for electricity uses: cooling, e.g. air-conditioners, and electrochemical uses, e.g. electrolysis processes in industry.

[1] For all combustibles it is considered the Low Heating Value, except for coal gases and natural gas, for which the High Heating Value is considered.

Mechanical drive uses are all the final uses that involve mechanical work except for work from humans and animals, including e.g. the work done by stationary motors, such as electrical motors in a factory or a dish washing machine, and by mobile motors such as vehicles, trains and airplanes.

Heat uses include all end-uses using heat, whether it is a process or an appliance, e.g. furnaces in industry or ovens in a kitchen.

Light includes all lighting end-uses, while OE uses is the category that includes all electrical equipment that is not contemplated in any other category, for example, electronic devices.

Muscle work includes the mechanical drive done by humans and working animals. This category is only addressed in this dissertation when mentioned the reproduction of Serrenho's work. The reason for that is explained in section 3.1.

Cooling includes all uses whose aim is to lower temperatures (i.e. refrigerators and air-conditioning). Electrochemical uses are the industrial processes where electrochemistry is used in production, i.e. electrolysis. Both these categories are further explained in section 4.3.1.

On the allocation topic (still in step B-2), electricity uses are an exception because electricity is used for several ends. While for other energy carriers the pair energy carrier-sector is enough to specify the end-use, e.g. iron and steel industry use coal for heat end-uses, in the electricity's case, allocation is done by applying shares to total final exergy. These shares are estimated separately and, due to this difference in methodology, electricity calculations are computed separately from the other carriers and only summed by the end of the process.

After the allocation process, exergy efficiencies are applied (step B-3 in *Table 1*) according to the pair energy carrier vs end-use. Based on the concept of exergy shown in Chapter 1 as well as the general definition of exergy efficiency, it is possible to formulate equations to be applied depending on the end-use and source (final exergy) (*Table 3*).

Table 3: Exergy efficiency (ε) equations per final and useful uses (Serrenho (2013) based on Ford et al. 1975)

End-Use \ Source		Work	Fuel - Heat of combustion	Heat Q_1 from hot reservoir at T_1
		W_{in}	B	$Q_1 \ (1-\frac{T_0}{T_1})$
Work	W_{out}	$\varepsilon = \eta = \frac{W_{in}}{W_{out}}$	$\varepsilon = \frac{W_{out}}{B} \approx \eta$	$\varepsilon = \frac{W_{out}}{Q_1 \ (1-\frac{T_0}{T_1})} = \frac{\eta}{1-\frac{T_0}{T_1}}$

Source / End-Use		Work	Fuel - Heat of combustion	Heat Q_1 from hot reservoir at T_1
		W_{in}	B	$Q_1 \ (1-\frac{T_0}{T_1})$
Heat Q_2 added to warm reservoir at T_2	$Q_2 \ (1-\frac{T_0}{T_2})$	$\varepsilon = \frac{Q_2}{W_{in}} \ (1-\frac{T_0}{T_2})$ $= \eta \ (1-\frac{T_0}{T_2})$	$\varepsilon = \frac{Q_2}{B} \ (1-\frac{T_0}{T_2})$ $\approx \eta \ (1-\frac{T_0}{T_2})$	$\varepsilon = \frac{Q_2 \ (1-\frac{T_0}{T_2})}{Q_1 \ (1-\frac{T_0}{T_1})}$ $= \eta \frac{1-\frac{T_0}{T_2}}{1-\frac{T_0}{T_2}}$
Heat Q_3 extracted from cool reservoir at T_3	$Q_3 \ (\frac{T_0}{T_3}-1)$	$\varepsilon = \frac{Q_3}{W_{in}} \ (\frac{T_0}{T_3}-1)$ $= \eta \ (\frac{T_0}{T_3}-1)$	$\varepsilon = \frac{Q_3}{B} \ (\frac{T_0}{T_3}-1)$ $\approx \eta \ (\frac{T_0}{T_3}-1)$	$\varepsilon = \frac{Q_3 \ (\frac{T_0}{T_3}-1)}{Q_1 \ (1-\frac{T_0}{T_1})}$ $= \eta \frac{\frac{T_0}{T_3}-1}{1-\frac{T_0}{T_1}}$

Table 3 notes: η = energy efficiency; W = work; Q = heat; B = exergy; T_0 = environment temperature; T1 > T_2 > T_0 > T_3

Based on Ford et al. (1975), Serrenho (2013) has summarized those equations (*Table 3*) where the first row would be applied to mechanical drive uses, while second and third rows to heating and cooling uses, respectively.

Also, columns in *Table 3* can be seen by energy-carrier, in this sense: the first column corresponds to electricity and equations applied to electricity uses; the second corresponds to coal, oil products, natural gas and combustible renewables uses; and, the third, can be linked to co-generation heat uses.

This means that, e.g. to calculate exergy efficiency of electricity mechanical drive uses, one would look at the first square of the table (1^{st} column-1^{st} row), which has the equation for the pair work-work (energy carrier – end-use).

For MD uses, exergy and energy efficiencies are the same, since their exergy corresponds to the maximum potential work that can be done by work itself.

For heat uses, exergy efficiency is calculated applying the Carnot efficiency (η_{Carnot}) as their exergy corresponds to the maximum potential work that could be done by a Carnot power cycle (ideal process). Carnot efficiency is given in *Table 3* by the parcel in brackets in the equation of each heat (Q), e.g. Q1 is given by $\boldsymbol{Q_1} \ (\boldsymbol{1}-\frac{T_0}{T_1})$ in which $\eta_{Carnot} = \ (\boldsymbol{1}-\frac{T_0}{T_1})$.

Heat efficiencies depend on the environment and service temperature (temperature of the system), thus, three subcategories were established considering the service temperature: High Temperature Heat (HTH), for temperatures above 500^{o}C (industrial uses); Medium Temperature Heat (MTH) for temperatures between 500^{o}C and 120^{o}C, and Low Temperature Heat (LTH) for uses bellow 120^{o}C (Ayres & Warr 2010; Serrenho 2013).

The lower the service temperature, the most sensitive is the exergy efficiency to changes, consequently LTH uses are further disaggregated into three sub-subcategories: LTH 1, for uses between 120^{o}C and 90^{o}C; LTH2, for uses between 90^{o}C and 50^{o}C; and, LTH3, for uses bellow 50^{o}C (de Sá 2013; Serrenho et al. 2016).

These changes in exergy efficiency, accordingly with the service temperature are related to the quality of the energy available and the concept of exergy. Heat at higher temperatures has more potential to perform work.

Besides the subcategories established, two environment temperatures were considered: for LTH3, the annual average temperature of winter months and, for all other heating uses, the average air temperature in Lisbon (1856-2007; PORDATA 2017b).

Regarding the lighting and other electrical uses, efficiency is calculated based on equation (5) – Chapter 1 – as the ratio of the real efficiency to the ideal efficiency. Therefore, even though this is the broadly used method in lighting literature, e.g. Fouquet (2009) and Ayres et al. (2005), these category efficiencies are not calculated based on the exergy converted into useful work as an output.

For lighting uses, the efficiency is calculated in lumens per Watt, and the ideal efficiency considered depends on the authors' considerations. Two values are broadly used as the ideal: 400 ln/W or 638 ln/W. This is further explained in Chapter 4, section 4.4.

At the useful stage, all totals are summed (aggregated) in order to analyse useful exergy per energy carrier or even the national total (step B-4).

Information on the national level of aggregation may be used to study the country context, such as EU energy consumption and possible savings, as well as projections in order to understand where current trends may lead the country energy-wise.

3. Portugal in 2030 - Exergy consumption and efficiency scenarios

Having Serrenho and co-authors work (2013; 2016) as a starting point, this chapter focus is on the forecasts of useful exergy, exergy final to useful efficiency and GHG emissions up to 2030.

3.1 Reproduced and updated results

Based on the final-useful methodology shown in Chapter 2, a reproduction of Serrenho's calculations (*Table 4*) was done to: (1) understand the accounting process, its details and difficulties, (2) facilitate the updates on the long-run series and (3) make explicit the assumptions and proxies that were used.

It is important to mention that due to lack of data for such long period (1856-2009) the use of proxies was necessary but turned the reproduction process more difficult.

Table 4: Summary of Serrenho's calculations and assumptions for Portugal useful exergy long-run accounting 1856-2009

Energy Carrier	Period	Data Source	Allocation	Efficiencies	Obs.
Coal	1856-1923	Henriques (2011) & INE (1985-2009)	*MD* corresponds to proxy used to calculate coal consumption on railways (INE data); the remaining final exergy is allocated as 5% to *HTH* and 10% to *MTH*	*MD* as referenced in Serrenho (2013) & Serrenho et al. (2016); *Heat* categories calculated with Carnot equation	-
	1923-1960	Henriques (2011)	Linear proxy of Heat categories shares based on 1960 IEA data	Heat categories calculated with Carnot eq.	
	1960-2009	IEA database	Cited in Serrenho (2013) & Serrenho et al. (2016)	*MD* as referenced in Serrenho (2013) & Serrenho et al. (2016); *Heat* categories calculated with Carnot equation	
Oil	1856-1940	Henriques (2011)	Linear proxy for *Light* being 100% of the final exergy allocated to it in 1900 and 0% in 1940; this happens opposite to the growing share for *Heat* and *MD* categories	*MD* and *Light* efficiencies referenced in Serrenho (2013) & Serrenho et al. (2016); *Heat* categories calculated with Carnot eq.	-

Energy Carrier	Period	Data Source	Allocation	Efficiencies	Obs.
	1940-1960	Henriques (2011) & INE (1985-2009; 1941-1960)	*MD* is calculated taking into account data on the number of vehicles and industry's energy data	*MD* efficiencies as referenced in Serrenho (2013) & Serrenho et al. (2016); *Heat* categories calculated with Carnot equation	-
	1960-2009	IEA database	Cited in Serrenho (2013) & Serrenho et al. (2016)		
Combustible Renewables	1856-1960	Henriques (2011)	Firewood households = *LTH*; Firewood industry = 50% *MTH*/50% *LTH*; Firewood transport = *MD*	*MD* as referenced in Serrenho (2013) & Serrenho et al. (2016); *Heat* categories calculated with Carnot equation	-
	1960-1970		Linear proxy for end-use category exergy shares. Proxy calculated based on Henriques (2011) data for 1951 and IEA data for 1971	Heat categories calculated with Carnot equation	
	1970-1990		Linear proxy based on the shares obtained from IEA data for the Heat categories		
	1990-2009	IEA database	Cited in Serrenho (2013) & Serrenho et al. (2016)	*MD* as referenced in Serrenho (2013) & Serrenho et al. (2016); *Heat* categories calculated with Carnot equation	
Natural Gas	1997-2009	IEA database	Cited in Serrenho (2013) & Serrenho et al. (2016)	*MD* as referenced in Serrenho (2013) & Serrenho et al. (2016); *Heat* categories calculated with Carnot equation	Natural gas only stated being used in Portugal around 1997
Electricity and Heat	1894-1960	Henriques (2011)	Electricity shares in Serrenho et al. (2016) supplementary data, considering Fouquet et al. (2008) *Light* share and making adjustments to the Portuguese reality	*MD and Light* efficiencies referenced in Serrenho (2013) & Serrenho et al. (2016); *LTH2* calculated with Carnot eq.	The first plant (i.e. hydroelectric) to have public distribution started functioning in 1894 only For this specific energy carrier, *LTH2* was calculated considering 80ºC rather than 90ºC
	1960-2009	IEA database			

Energy Carrier	Period	Data Source	Allocation	Efficiencies	Obs.
Non-Conventional	1856-2009	Henriques (2011)	As conversion factor is 1, the allocation is direct to the end-use category *MD*		-
Food & Feed	1856-1960	Henriques (2011)	All final exergy from Food & Feed is allocated to the Muscle Work category	Serrenho (2013) assumptions - gross/metabolized energy ratio; intake/end-use ratio; All working animals from Henriques (2011) data are considered. Animals final/useful efficiency of approx. 10,4%	It was not possible to reproduce total muscle work

Table 4 Acronyms: LTH – Low Temperature Heat (<120ºC); MTH – Medium Temperature Heat (500-120ºC); HTH – High Temperature Heat (>500ºC); MD – Mechanical Drive

It was not possible to reproduce total muscle work series for the whole 1856-2009 period. In fact, only animals' muscle work from 1856 to 1960 was reproduced. Food's final exergy available was also reproduced for the same period with an error of 0.07% but the human muscle work was not, because the details given in Serrenho et al. (2016) regarding final-useful efficiency for human muscle work were not consistent, and so, useful exergy from food could not be calculated. For similar reasons, total muscle work from 1960 to 2009 could not be reproduced, as well.

While this presents a setback in full understanding of Serrenho and co-authors works, total muscle work has no significant contribution to Portugal useful exergy since 1970s (Figure 6), and so this does not compromise future calculations (updates and projections).

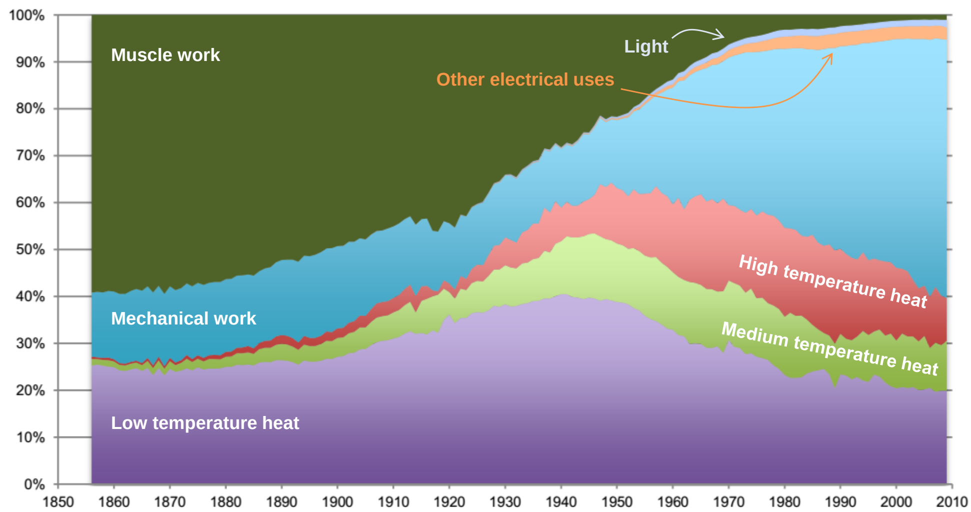

Figure 6: Useful work by end-use category in percentage (Serrenho 2013)

The milestone in calculations is 1960, corresponding to the first year for which IEA (2016) data is available. Most difficulties in the process were associated to the period before 1960, for which many proxies were necessary to compute final and useful exergy.

Serrenho's series were calculated until 2009, inclusive, and since then IEA has made 2010-2014 data available, allowing a series update. These results (Table 5) were calculated using the same methodology and assumptions of Serrenho (2013).

Table 5: Final and useful exergy update 2010-2014 (TJ)

	End-use \ Year	2009	2010	2011	2012	2013	2014
Final exergy	HTH	29333	30928	28424	25878	25308	25504
	MTH	76267	79645	74701	73610	91135	77715
	LTH	254231	237874	231137	208200	207611	201487
	MD	376518	383191	357447	330372	324467	326910
	OE	54639	51627	51645	50655	50423	50619
	Light	20207	21598	19861	18350	17560	17216
	Total	**811194**	**804864**	**763217**	**707064**	**716505**	**699451**
Useful work	Heat	69937	70712	67376	61934	66447	61154
	MD	96762	101841	96794	91454	89700	89519
	OE	4708	4317	4171	3938	3767	3629
	Light	2815	3031	2808	2613	2519	2488
	Total	**174221**	**179901**	**171149**	**159940**	**162434**	**156789**

Table 5 Acronyms: HTH – High Temperature Heat (>500ºC); MTH – Medium Temperature Heat (500-120ºC); LTH – Low Temperature Heat (<120ºC); MD – Mechanical Drive; OE – Other Electrical uses

Food & feed (final exergy) and muscle work (useful) categories are not included in the update because they could not be reproduced. A linear trend based on Serrenho's results until 2009 was applied to final exergy and final to useful efficiency in order to extrapolate the values between 2009 and 2014 (*Table 6*).

Table 6: Food & feed, muscle work and final-useful efficiency trend 2010-2014 [TJ]

	2010	2011	2012	2013	2014
Food & Feed	75700	76411	77125	77803	78411
Muscle Work	1800	1798	1800	1798	1794
Final-to-Useful efficiency	2,4%	2,4%	2,3%	2,3%	2,3%

Despite the values being relatively constant, food & feed increase until 2014 while muscle work tends to decrease. This is because final-useful efficiency is decreasing with time, or in other words, food & feed wastes tend to increase.

Useful and final exergy projections for 2030 were made, based on the updated series. Data series of final energy consumption were taken from IEA (2016) and calculations of final-to-useful exergy efficiencies as well as the allocation per end-use needed for disaggregated share was, also, based mainly on the updated series. Efficiencies are calculated according to the pair energy carrier-end-use, and are further explained in Chapter 2.

3.2 Chapter development context

The following subchapters were developed under the project MEET2030, being the methodology and results integrated in it. The final report of the project is available at http://meet2030.pt/. Due to a matter of timing, results and assumptions presented are preliminary conclusions of the project.

MEET 2030 is a project focused on the recent future, with three main goals: 1) building scenarios for 2030 in the context of a 4th Industrial Revolution (robotisation and mass automation) while complying with European goals for carbon neutrality; 2) identify potential new sectors of economic activity with competitive advantages to enable companies to maintain sustainable growth in the long term; and, 3) to identify added value solutions while contributing to policy action, allowing a strategic definition of priorities in the national and international contexts.

It is a project developed by Instituto Superior Técnico (IST) – mentioned hereby as the research team -, the Business Council for Sustainable Development (BCSD) Portugal, and BCSD associated companies such as, e.g., EDP, GALP, Navigator, Brisa and Tecnoplano.

Interaction between these three groups occurred in workshops, three challenges (questionnaires given for companies to answer after and outside the workshops) and one work session. Besides this, there were meetings with public entities, e.g. Portuguese Environmental Agency (APA) and Environment Ministry, advisory and steering committees.

Workshops were a way to provide information on exergy to BCSD associates, as well as to gather feedback on the development of research and results from them. Challenges were a set of questions sent to companies to give them opportunity to perform research work and provide feedback in between workshops. The 2nd and 3rd challenges were developed, in the context of this thesis, in collaboration with the MEET team; the answers were used as inputs for the forecasts presented in this dissertation (see challenges questions in ANNEX I:).

3.3 Methodology

First, to make 2030 projections within a new scenario-building methodology which includes exergy, two scenarios were built, the worst and best scenarios within the plausible universe.

The worst plausible scenario was named Ostrich, making an analogy with the animal that runs in circles and, according with the myth, buries its head in the sand. Ostrich represents a scenario for 2030 of stagnation, economic instability, social crisis, geopolitical and demographic issues, EU instability and a peripheral development that missed opportunities from the 4th Industrial Revolution (digitalization/mass automation).

With the same rationale, the best plausible scenario was named Iberian Lynx, as a symbol of agility, awareness of surroundings and recovery as its population has been recovering from near extinction in the last decades. Iberian Lynx pictures Portugal in 2030 as a positive surprise in world economy, with a rapid economic growth, achieving sustained growth rates and being an example of a country that took the opportunities created by the 4th Industrial Revolution integrated in a stable geopolitical and demographic EU context.

The scenario-making methodology developed is based on quantitative and qualitative components. Though it is apparently a closed process (*Figure 7*), it has a loop, becoming iterative and open to updates and changes if needed. For this, due to its dynamics, this methodology can test the consistency between both components.

The qualitative part was the start of the narrative, while quantitatively scenarios were drawn after their main guidelines were defined. Besides the work that was done by the research team, in workshops with BCSD associates, options were traced and taken, helping tracing each scenario development, while uncertainties and assumptions were validated as well.

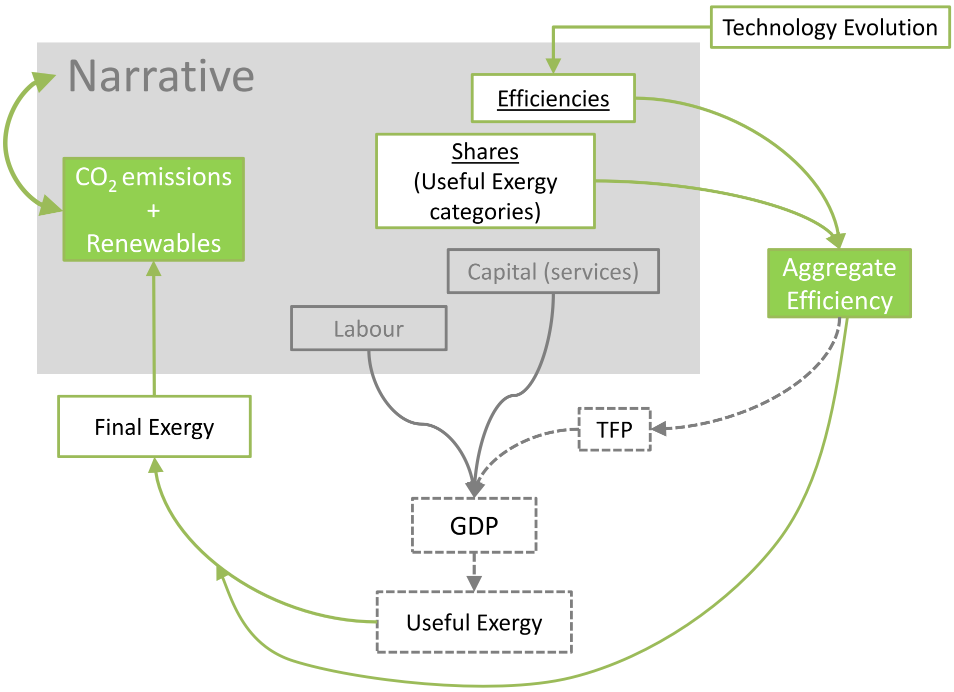

Figure 7: Schematic representation of the scenario-making process (model) quantitative component

Acronyms: TFP - Total Factor Productivity; GDP - Gross Domestic Product

Figure 7 shows a scheme of the quantitative process followed to make the scenarios. Each *narrative* – shaded in grey – is set as the base of each scenario and composed by: 1) a qualitative description of the scenario; 2) a set of uncertainties related with the scenario; 3) series of final and useful exergy *shares*; 4) a series of final-useful *efficiencies*; 5) a series of *capital*; 6) a series of *labour*; 7) a series of fossil fuel CO_2 *emissions* and 8) a series of resources' shares (*renewables* and non-renewables) in electricity production.

Series are for the period 2000-2030, being the last 16 years (2015-2030) projections. Note that forecasts do not "start" in 2017 due to the lack of available data.

As 1) and 2) constitute the qualitative part and were set for each scenario, a research on *technology evolution* was done to project efficiencies in 2015-2030. As an initial step, final exergy shares disaggregated by sector, type of fuel and end-use were estimated based on past tendencies and, then, using respective final-useful *efficiencies,* useful exergy end-use *shares* were calculated as well – following steps B-2 and B-3 from *Table 3* in Chapter 2.

From these first estimates of useful exergy shares, the loop process begins. Based on these initial shares, Portugal's *aggregate final-useful efficiency* series was estimated for 2000-2030. This series was compared to the 2030 aggregate efficiency goals that were set for each scenario. The mismatch was minimized by replacing energy carriers (maintaining the same end-use) and by shifting to more efficient end-uses. To perform these calculations a massive reorganization of the data was needed [2].

The following steps of the process are in dashed lines in *Figure 7* and were developed by Santos & Domingos (2018) in the project.

Based on an empirical relationship obtained for the period 1960-2009, *aggregate efficiency* is used to calculate total factor productivity (*TFP*) – equation (6)

$$TFP_t = \left(\frac{EFF_t}{EFF_0}\right)^{1.87} \tag{6}$$

Where EFF_i, $i = 0, t$ symbolizes aggregate final-to-useful exergy efficiency at the initial moment of the sample (1960), and at any moment of the sample, respectively.

In effect, this relationship implies that, if the Portuguese aggregate final-to-useful exergy efficiency has a 1% annual growth rate between any two years of the sample, the TFP will grow by approximately 1.87% for the same period [3]. Projections on future trends for TFP in the Portuguese economy are based on the evolution of aggregate final-to-useful exergy efficiency over the next decades, assuming that this empirically observed relationship between the two variables is maintained throughout the years.

Then, *TFP* and series on capital and labor (series 5) and 6)) are used to compute Portugal's 2000-2030 gross domestic product (*GDP*) series (empirical method is further described in MEET2030 technical report - as mentioned, the final report is available at http://meet2030.pt/).

A 1% annual growth rate for aggregate final-to-useful exergy efficiency – assuming that both capital and labor inputs to economic production remain constant for the considered period – will also translate to an annual growth of GDP of approximately 1.87%, since GDP is computed by a Cobb-Douglas aggregate production function framework such as equation (7)

$$GDP = TFP \times K^{\alpha} \times L^{\beta} \tag{7}$$

Where α, β symbolize capital (K) and labor's (L) share of payments in total income, respectively.

[2] Data, firstly aggregated by energy carriers and end-use, was grouped in five sectors: Energy (electricity production), Industry, Transportation, Residential/Commercial and Agriculture/Forestry; being the most detailed information organized within the disaggregation chain: by end-use < type of combustible < energy carrier < per sector.
Having the shares disaggregated in a higher level than end-use, all shares within the same end-use category but using different types of fuel, e.g. charcoal and renewable municipal residues are both combustible renewables used for LTH1, were summed within sectors. This was to reach a more aggregate level.

[3] For example, when final-to-useful exergy efficiency grows by 1% between 1987 and 1988 (thus going from 21.7% in 1987 to 21.9% in 1988), TFP grows from 2.25 in 1987 to 2.29 in 1988.

Then, the relationship between useful exergy and GDP, 1 MJ/€ of GDP, found by Serrenho et al. (2016) for the period 1856-2009, is used to generate a series of national useful exergy totals.

Useful exergy consumption *shares* (at the end-use level) were applied to the *useful exergy* total series and, then, all the resulting series were divided by their respective final-useful *efficiencies* to calculate *final exergy* at the most disaggregate level (by end-use per type of fuel/carrier).

A 1% annual growth rate for aggregate final-to-useful exergy efficiency will also translate to an annual growth rate of approximately 1.87% for useful exergy consumed in that period.

Finally, aggregate final-to-useful exergy efficiency (ε) is given by equation (8).

$$\frac{U}{F} = \varepsilon \tag{8}$$

Where F symbolizes final exergy at a given moment of the sample. If aggregate final-to-useful exergy efficiency grows at an annual rate of 1%, while useful exergy grows at an annual rate of approximately 1.87%, then final exergy consumed must grow slower that useful exergy, at an annual rate of approximately 0.86%. Thus, an annual increase in aggregate efficiency of 1% will increase final exergy consumption by 0.86%.

With data disaggregated by energy carrier, it is possible to compute *CO_2 emissions*, 7), that result from national energy consumption. Emission factors were applied to final exergy consumptions per type of combustible except for electricity.

CO_2 emissions from electricity production were calculated separately by computing primary exergy of resources used in production, with values from DGEG on national energy balances and electricity production mix (DGEG 2017b; DGEG 2017a) , 8), and, then, applying emission factors to those values.

Projections for 2030 were then estimated with a linear trend and determining the use of 60% of *renewable* resources by 2030, for both scenarios. Establishing renewables share influenced the consumption of non-renewable resources and was, therefore, determinant to compute *CO_2 emissions*.

Resources consumption for co-generation heat was included in these calculations as well, as it was not possible to separate resources consumed for electricity and for heat in co-generation. However, the co-generation production mix (and emissions) in 2015-2030 was considered constant and equal to the production mix in 2014.

The scenario narratives bound both qualitative (1 and 2) and quantitative (3 to 8) components under the same guidelines and allow the general public to have an overall view of the scenarios. As inputs from companies were obtained and the iterative process (the loop in *Figure 7*) repeated, narratives were also changed to meet those new inputs.

Finally, the loop verified in *Figure 7* is closed with three sources of feedback on some points of the process: the condition that both scenarios must be plausible in the near future (2030), the feedback from BCSD associates and feedback/suggestions from institutions, i.e. APA and ADENE (Portuguese Agency for Energy). Thus, if some results are not consistent with the narratives or associates validation, adjustments were made and the process restarts. This continued until agreement from all involved parts was achieved.

Validation, or feedback, was made for each scenario on: efficiencies, final exergy shares and renewables share on electricity production mix (mainly through the challenges).

This chapter's development and results are about the exergy part of the quantitative component of the process – shown in *Figure 7* in green. It is important to make clear that options taken for both scenarios followed the basic idea that the Iberian Lynx is associated with a high increase in aggregate efficiency while the Ostrich is associated with a low increase.

By the time of this dissertation's conclusion, suggestions from participants were already included being the results shown close to the definitive.

Note that, the calculation process followed from useful exergy to CO_2 emissions can be made in the reverse direction (from CO_2 emissions to useful exergy), in order to include the readjustments mentioned. This shows flexibility in the methodology process that enables testing conditions/assumptions that might be developed and included, afterwards, in the narratives.

3.4 Final and useful shares and efficiencies

The following sections 3.4.1, 3.4.2 and 3.4.3 present quantitative results obtained for both scenarios. The energy carriers considered are: coal, oil products, combustible renewables (such as wood), natural gas, electricity, co-generation heat and solar photovoltaic.

As mentioned, five sectors are considered: Energy, Industry, Transports, Residential/Commercial and Agriculture/Fishing. For the Energy sector solely its own consumption is being analysed.

3.4.1 The Ostrich scenario

This is a conservative scenario in terms of energy options. It is assumed that the evolutions in final-useful efficiencies for pairs energy carrier-end-use, which are controlled by technology evolution and replacement of capital, are negligible. This does not imply that the aggregate overall efficiency, which also depends on the relative importance of each energy carrier-end use, has to be constant (*Figure 8*).

Portugal aggregate final-useful efficiency has been relatively constant in the recent past (since 2000) and so, to develop a conservative scenario, efficiency is considered to maintain the tendency until 2030.

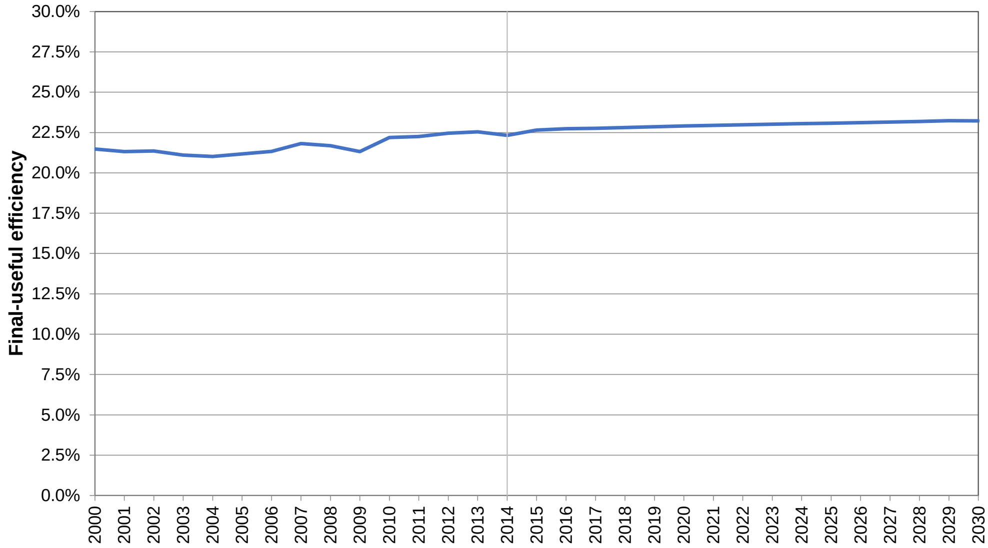

Figure 8: Aggregate final-useful efficiency 2000-2030 (Ostrich scenario)

As following the trend, aggregate efficiency increases about 1.3 p.p. from 2014 to 2030 and about 2.4p.p. from 2000 to 2030, reaching 23.5%. The slight increase is due to assumptions made at the disaggregate level of energy's several end-uses.

Portugal slight increase in final-useful efficiency is intrinsically linked with the increasing uses of electricity in Portuguese society and the increase in efficiency of electrical appliances which in time have been substituting less efficient uses – that do not use electricity. Considering this and the fact the use of electricity has a higher efficiency than the use of any other energy carrier, it is expected that the general efficiency trend would be positive.

The main assumptions made for exergy calculations are presented in *Table 7*.

Table 7: Main variables and configurations for exergy use by category in the Ostrich

	Configurations
Useful exergy shares (exergy by end use category) [(a)]	Unchanged trend except for some heat and for mechanical drive uses from Oil products (i.e., HTH, MTH, LTH3, MW2, MW3 and navigation) and in Electricity shares. For oil products uses, the scenario considers the maintenance of the average observed in the most recent years (2009-2014). For electricity, consumption for stationary MD uses grows up to 60% of industrial electricity consumption.
Electrical vehicles circulating by 2030 (EV and H_2) [(b)]	Slow adoption – approximately 6% of vehicles circulating by 2030

Electric grid ability to integrate electrical vehicles [(b)]	Slow and limited
Final-to-useful exergy efficiencies [(a)]	Technology specific final-to-useful efficiencies are constant [Although, aggregated exergy efficiency has marginal increases]
Energy efficiency in buildings (LTH3) [(c)]	Useful exergy decreases between 0.6 and 1p.p. by 2030 (improved efficiency)
Pace of adoption of energy efficiency technologies and measures and microgeneration [(c)]	Scarce adoption of energy efficiency technologies and measures

Table 7 Acronyms: HTH – High temperature heat; MTH – Medium temperature heat; LTH3 – Low temperature heat 3; MW2 – Gasoline/ LPG engines; MW3 – Diesel engines.
Notes to the table: (a) Defined by the research team in order to link the uncertainties to GDP evolution. (b) Defined by participants (in the 1st Challenge) selected by the research team. (c) Defined and selected by participants in the 1st Challenge and the 2nd Workshop. All configurations were defined and discussed with the workshops' participants.

To the main assumptions explained in Table 7, it is important to add that electricity uses shares and efficiencies considered can be seen in ANNEX II:

Also, in IEA (2016) disaggregate and Serrenho et al (2016) there are no road electric vehicles (EV) considered. To calculate EV totals for each scenario, a direct substitution of diesel and gasoline vehicles per electric ones, was considered.

From numbers on 2016 EV sales and 2017 sales projection (Agência Lusa 2017; Cabrita-Mendes 2017), a number of vehicles was estimated considering a consumption of 0.179 kWh/km and an average travelled distance of 20000 km/year per vehicle. The same distance was considered for diesel and gasoline vehicles, which number was calculated considering consumptions of 0.05 L/km and 0.06 L/km, respectively, and the total was validate using numbers from the Environmental State Report (APA 2017c).

EV projections for 2017-2030 were made considering that each year sales would grow 35% compared to the year before, maintaining 2017 projections. The EV share obtained for 2030 is in accordance with BCSD associates suggestions during the 3rd workshop (suggesting 5% penetration of EV for Ostrich and 15% for the Iberian Lynx).

At disaggregate level, useful exergy shares (*Figure 9*) show the fraction of useful exergy provided by each energy carrier.

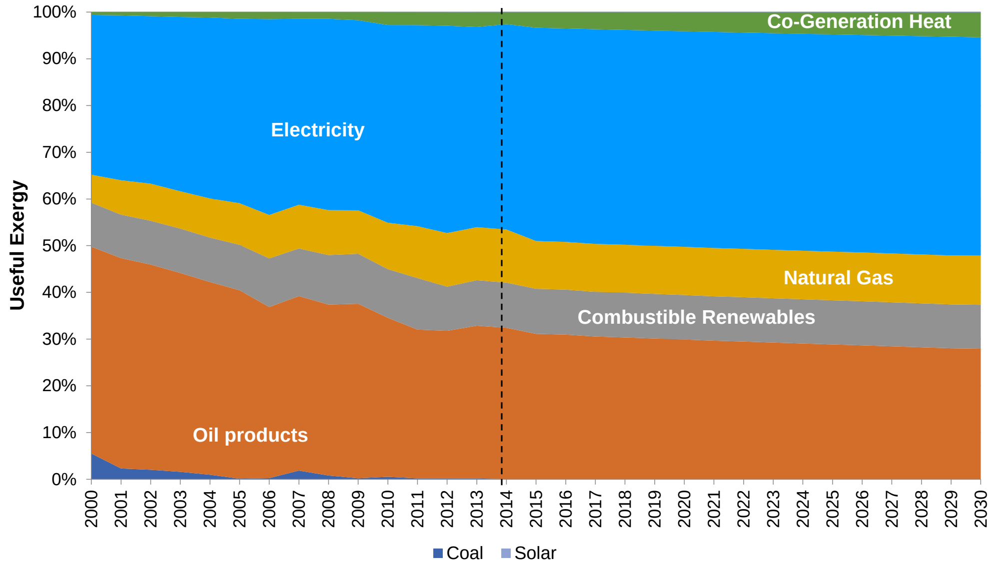

Figure 9: Useful exergy shares per energy carrier 2000-2030 (Ostrich scenario)

Useful and final exergy consumption shares (*Figure 9* and *Figure 10* respectively), are projected to vary mostly in Electricity and Oil products energy carriers (*Table 8*). Energy carriers with lower efficiencies associated grow more in final than in useful exergy shares. The most extreme case is natural gas, whose final exergy share increases while the useful exergy share decreases.

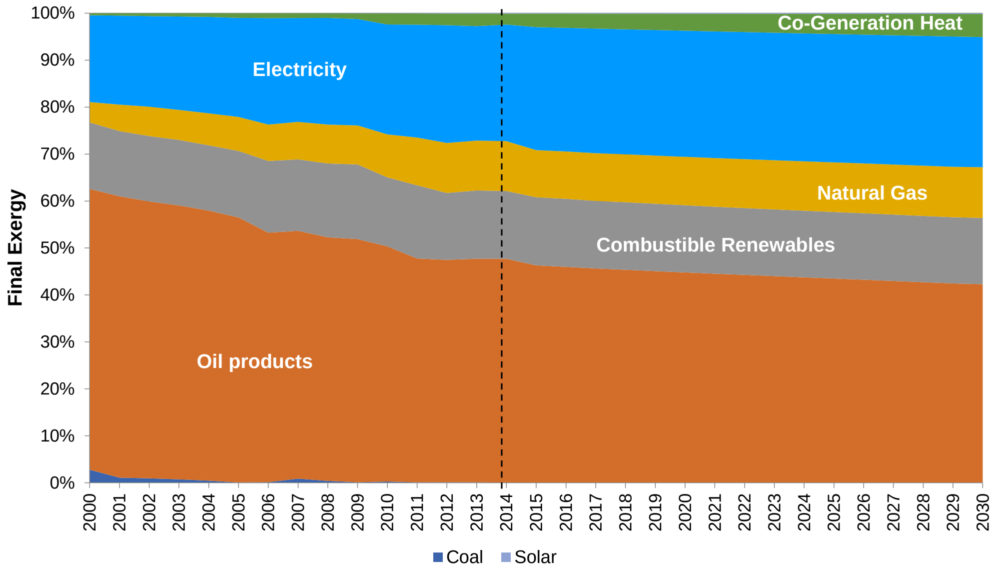

Figure 10: Final exergy shares per energy carrier 2000-2030 (Ostrich scenario)

Table 8: Final and useful exergy shares difference 2014-2030 in percentage points (p.p.) in Ostrich

	Coal	Oil	Combustible Renewables	Natural Gas	Electricity	Heat	Solar
Useful exergy	-0.04 p.p.	-5.47 p.p.	-0.33 p.p.	-0.89 p.p.	3.91 p.p.	2.79 p.p.	0.03 p.p.

	Coal	Oil	Combustible Renewables	Natural Gas	Electricity	Heat	Solar
Final exergy	-0.02 p.p.	-6.61 p.p.	-0.14 p.p.	0.32 p.p.	3.71p.p.	2.67 p.p.	0.07 p.p.

Comparing useful and final exergy distributions per energy carrier, the most noticeable difference is that electricity has the highest share of useful exergy, while oil products is the carrier with the highest share of final exergy. This is explained by the different efficiencies of the conversion devices that use each carrier.

Although the final shares of consumption give an overview of the scenario, absolute values are important to make sure there is no information misleading the reader (*Figure 11*). In fact, what happens in terms of consumption in this scenario is similar to the shares evolution.

In terms of the overall consumption of Portuguese society, it does not change much: 704 PJ (2014) compared to 702 PJ (2030) of final exergy and 156 PJ (2014) compared to 165 PJ (2030) of useful exergy. In this scenario, there is a relatively small increase in total useful exergy consumption, associated to a slow growth in the economy.

GDP calculated for 2015 and 2016 is kept constant, to make a "transition" period (years that already passed and for which there's no exergy and aggregate efficiency data). This is seen in *Figure 11* as consumption values increase suddenly in 2016-2017 and, after, follow past trends until 2030.

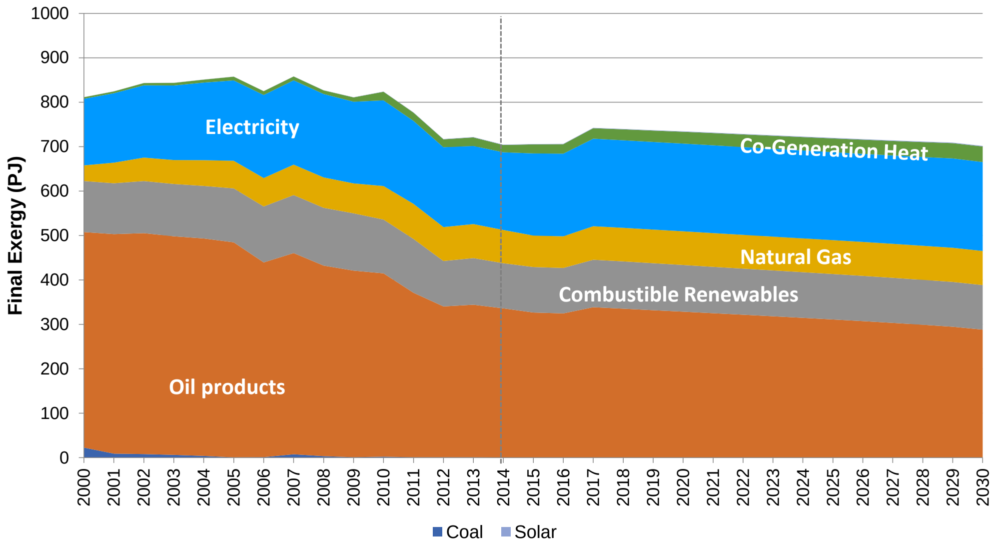

Figure 11: Final exergy consumptions per energy carrier (Ostrich scenario)

For a closer view of the exergy consumption projected for 2030, *Table 9* shows the energy carriers with the highest final consumption per sector in 2030. The table presents consumption shares that are higher that 3% of Portugal's final consumption, except for Agriculture/Fishing in which the highest share is about 2%. These energy carriers are the ones with a potentially higher influence in exergy projections.

Considering Portugal's total consumption the sectors with higher shares of consumption, in general, and that consequently have the most influence on exergy projections are: Residential/Commercial (Services) and Industry. Nevertheless, if Residential and Commercial (Services) sectors were separated, then Transports sector would have the second highest share of consumption.

Table 9: Most significant final energy carriers consumed by sector in 2030

Sectors	Final Energy Carrier	End Use
Energy	Oil products [(a)]	Heat (MTH)
Industry	Combustible Renewables	Heat (LTH1)
	Electricity	Mechanical Drive (Stationary)
Transportation	Oil Products	Mechanical Drive (MW2 & MW3)
Residential/Commercial	Electricity	Mechanical Drive (Stationary), OE
	Combustible Renewables	Heat (LTH3)
	Oil Products	Heat (LTH3)
Agriculture/Fishing	Oil Products	Mechanical Drive (MW3)

Table 9 Acronyms: MTH – Medium temperature heat; LTH1 – Low temperature heat 1; LTH3 – Low temperature heat 3; MW2 – Gasoline/ LPG engines; MW3 – Diesel engines.

(a) This refers to the Energy sector's own uses.

In the Energy sector, final exergy is mostly consumed as fuel oil and LPG in refineries.

Industry's most consumed energy carrier is combustible renewables. In this case, the Paper, Pulp & Print industry is the highest final exergy consumer in this sector, and it is projected to continue to be so in 2030. It uses combustible renewables, e.g. black liquor, for heat processes (LTH1).

Industry's second most consumed energy carrier is electricity, mostly in Paper, Pulp & Print, Food & Tobacco, Chemical & Petrochemical, Iron & Steel and Machinery. Within these industries, the main electricity uses vary from heat (for Iron & Steel; Paper, Pulp & Print and Food), to MD (stationary in general) and OE (electrochemical uses in Chemical).

Even though LTH1 uses with natural gas do not figure in the table, these are the third highest final consumers in Industry, with a projected share close to 2%.

Residential/Commercial sector highest consumption is for other electrical uses due to the growing use of electronic appliances such as computers, smartphones, printers etc. Heat uses are the second highest share from electricity consumption, in appliances such as radiators and air-conditioners.

Transportation and Agriculture/Fishing have their higher final consumptions associated to oil products (diesel and gasoline) for mechanical drive mobile uses (e.g. road vehicles and tractors) as expected.

A summary table with useful and final shares as well as considered efficiencies per sector, energy carrier and end-use is presented in ANNEX II:, Table Annex 3. Note that shares presented in this table are calculated compared to Portugal's total useful exergy consumption and not per sector, while the figures presented below show the calculated useful exergy consumption shares per sector.

It is important to note that a decrease in the share of an energy carrier does not necessarily imply a decrease in absolute value. However, in the case of oil products the decrease of approximately 7% in its final exergy share corresponds effectively to a decrease in consumption of around 47 PJ.

A general overview of the useful exergy evolution disaggregated by end-uses is shown in *Figure 12*, where the followed trends are clear.

For calculations, the five heat categories mentioned previously and eight types of MD uses were considered and, so, for the following set of figures (*Figure 13*, *Figure 14*, *Figure 15*, *Figure 16* and *Figure 17*) presented by sector, all five heat categories are shown, though MD is still aggregated in two. The only exception is for Transport, as all its uses are considered to be for MD and, so, six categories of this type of end-use are shown.

Mechanical drive categories are divided by type of fuel/energy carrier used, as engines' efficiencies vary according to that. Categories are entitled MW meaning mechanical work, with MW1 for aviation, MW2 for gasoline/LPG and MW3 for diesel engines. Other categories are: navigation, electric & hybrid and NG for natural gas vehicles' motors. Also, a separate category is considered for stationary motors and all MD end-uses from electricity are considered stationary MD (except in Transports). Hybrid trains, subways, electric and hybrid vehicles are included in the electric & hybrid category.

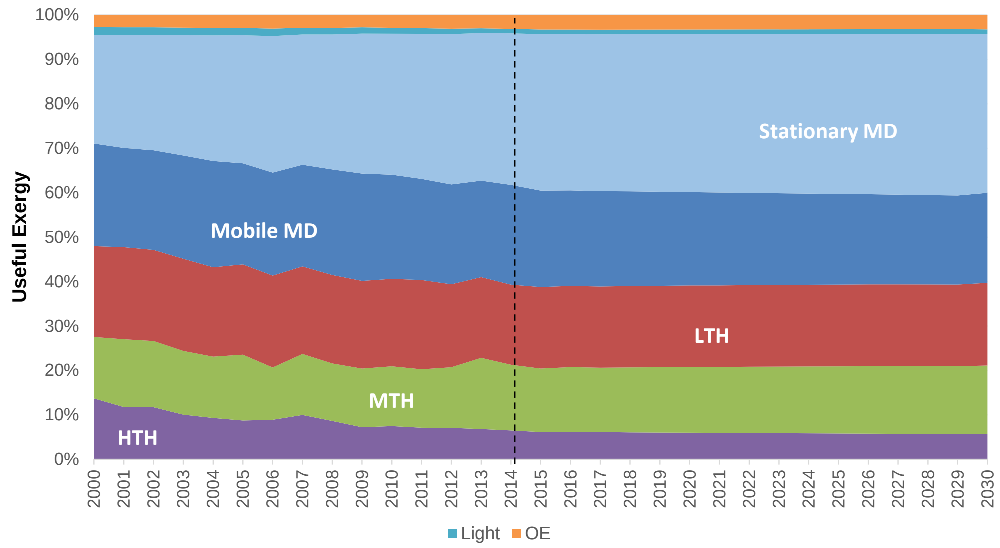

Figure 12: Portugal useful exergy shares per end-use 2000-2030 (Ostrich scenario)

Acronyms: MD – Mechanical Drive; LTH – Low Temperature Heat (<120ºC); MTH – Medium Temperature Heat (500-120ºC); HTH – High Temperature Heat (>500ºC); OE – Other Electrical uses.

The highest shares in the Energy sector (*Figure 13*) are MTH and Stationary MD. In this sector, and to produce Electricity, higher temperatures are used (category HTH); however, when analyzing the sector's own use of energy/consumption, the absolute values represent less than 9% of total final exergy and 10.6% of total useful, which means that the consumption for MTH uses, used mostly for preheating during Electricity production processes, is in fact residual consumption.

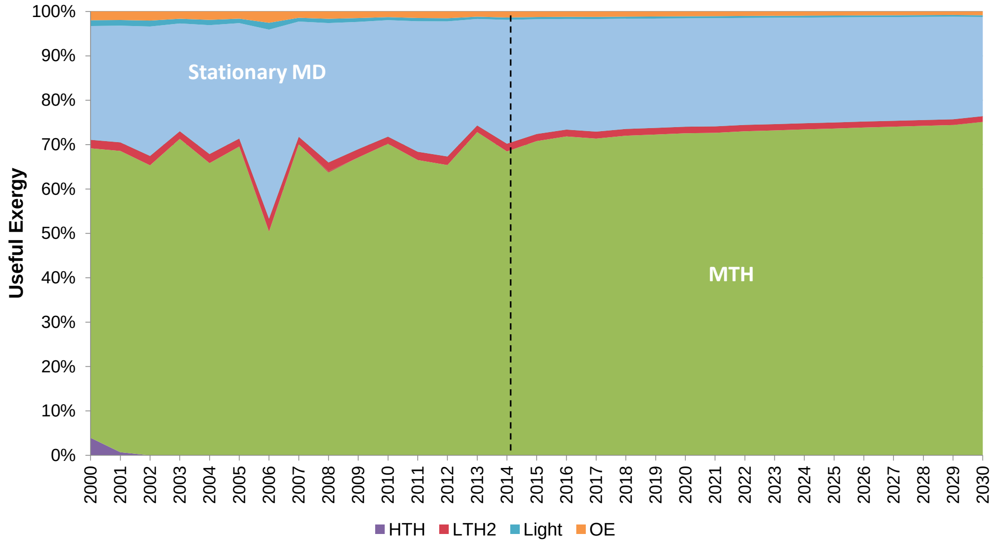

Figure 13: Useful exergy shares in Energy 2000-2030 (Ostrich scenario)

Acronyms: MD – Mechanical Drive; LTH2 – Low Temperature Heat 60-90ºC; MTH – Medium Temperature Heat (500-120ºC); HTH – High Temperature Heat (>500ºC); OE – Other Electrical uses

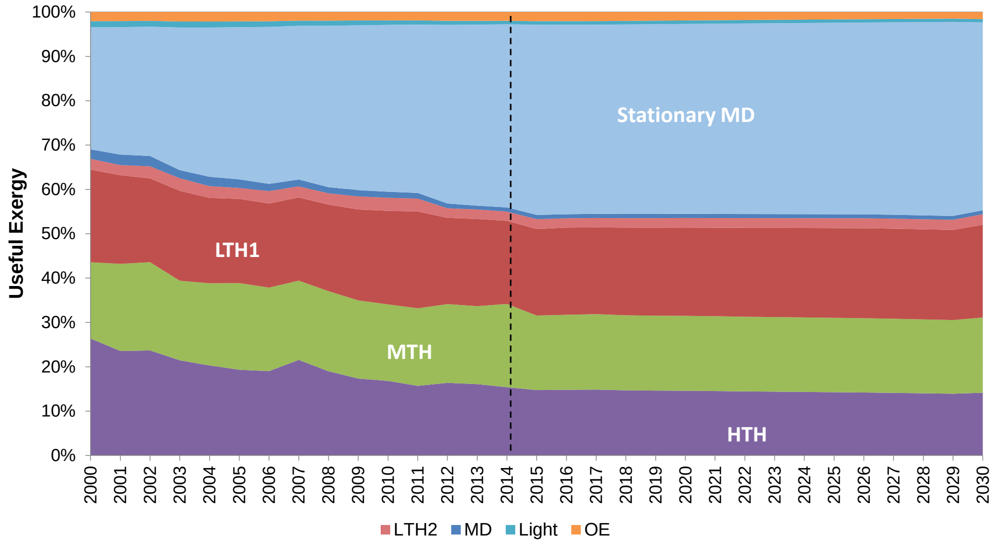

Figure 14: Useful exergy shares in Industry 2000-2030 (Ostrich scenario)

Acronyms: MD – Mechanical Drive (mobile); LTH2 – Low Temperature Heat 60-90ºC; LTH1 – Low Temperature Heat 90-120ºC; MTH – Medium Temperature Heat (500-120ºC); HTH – High Temperature Heat (>500ºC); OE – Other Electrical uses

In Industry, many processes need high temperatures and, for that, HTH, MTH and LTH1 have high shares associated (*Figure 14*), while stationary mechanical drive motors have the highest share, since most industries function in their production lines with stationary motors. For the Ostrich, as mentioned before, projections follow past trends which may be observed in the figure. This shows the conservative mind-set for Ostrich projections' scenario; where trends do not change much from the past years and, therefore, do not lead to a much more energy efficient society.

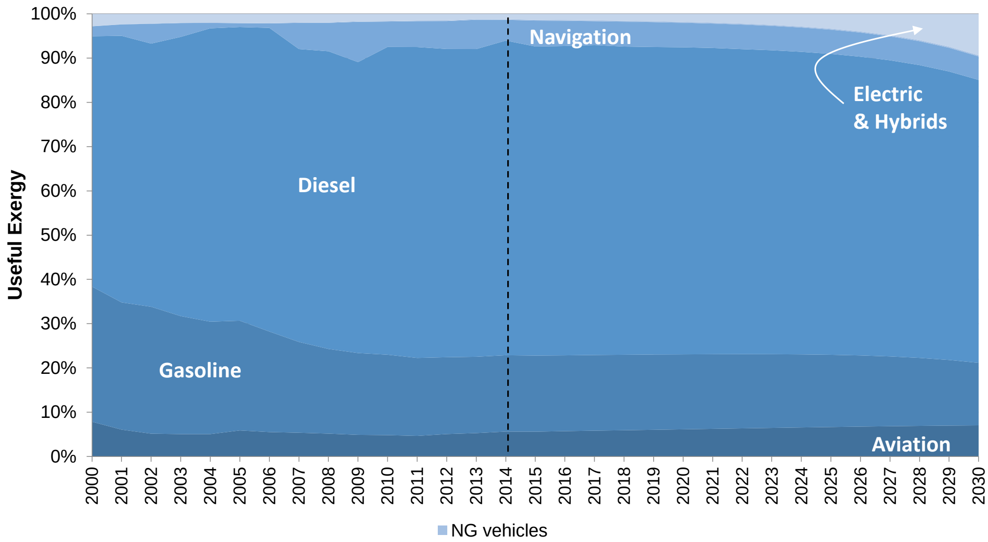

Figure 15: Useful exergy shares in Transports 2000-2030 (Ostrich scenario)

Acronyms: NG – natural gas

As might be expected, in Transports (*Figure 15*), engines fueled by Diesel and Gasoline have the highest shares, followed by Aviation and Navigation. Shares' projections follow the average from recent past years, showing a relative stabilization until 2030. Nevertheless, Electric & Hybrid vehicles have an increase in projections growing to be around 9.4% of Transports useful exergy by 2030.

Stationary MD uses' useful exergy share are highest in the Residential/Commercial sector (*Figure 16*). This is explained by cooling devices included in this category (such as refrigerators and air conditioners) and, also, due to considering a high final-to-useful efficiency for these uses (electric motors). In fact, LTH3 is the category with the highest share of final exergy of this sector. Heat uses LTH2 and LTH3 are mostly associated to Residential and Services sectors, being, these sectors more affected by any changes in this uses' projections. In the case of LTH2 end-uses associated to Electricity, such as radiators, the average temperature considered is 80^{o}C.

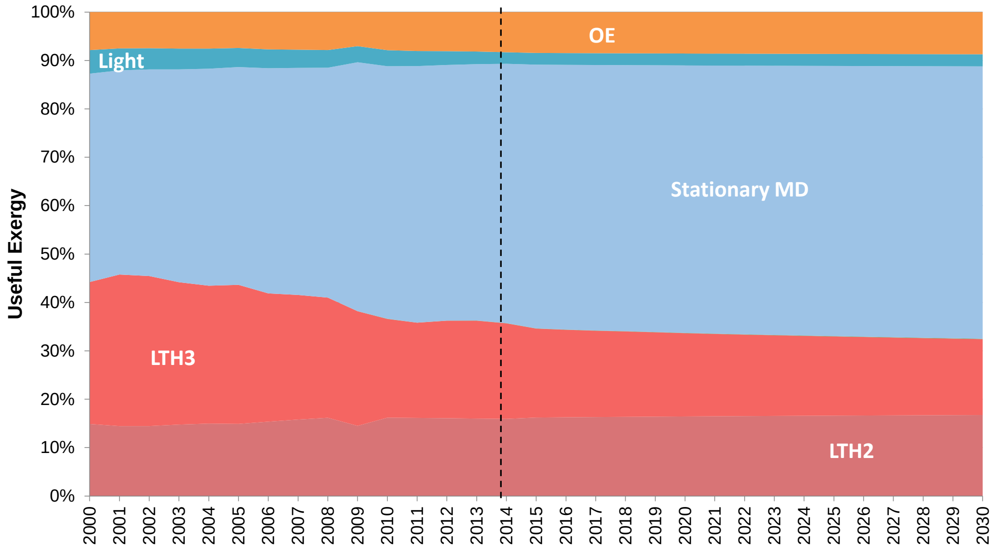

Figure 16: Useful exergy shares in Residential/Commercial 2000-2030 (Ostrich scenario)

Acronyms: MD – Mechanical Drive; LTH3 – Low Temperature Heat <60ºC; LTH2 – Low Temperature Heat 60-90ºC; OE – Other Electrical uses

The Agriculture/Fishing sector (*Figure 17*), which has a relevant role in terms of emissions, has little significance regarding final and useful exergy, corresponding to 2-3 p.p. of total consumptions. Mechanical drive uses have the highest useful shares of the sector, for uses such as tractors (mobile motors – mobile MD) and water pumps (stationary motors – stationary MD).

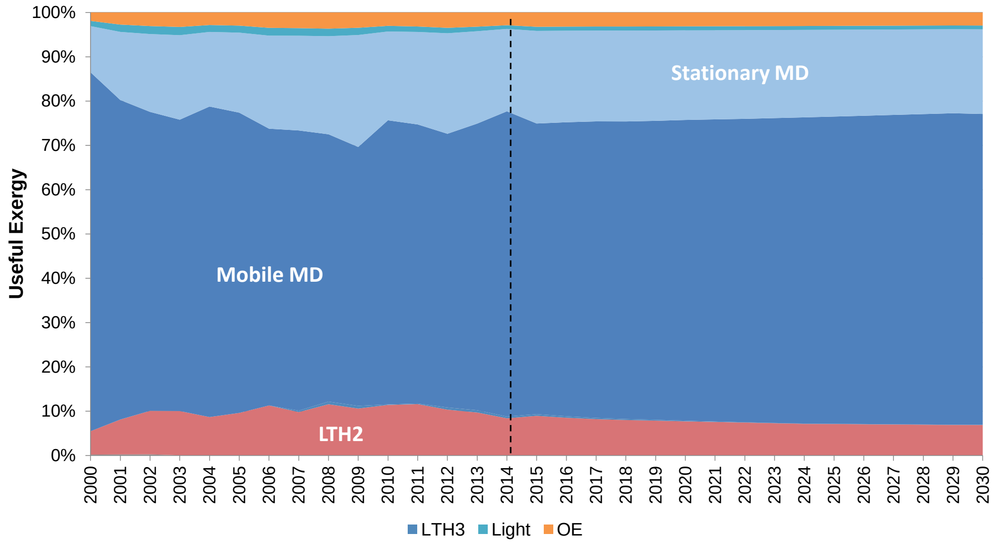

Figure 17: Useful exergy shares in Agriculture/Fishing 2000-2030 (Ostrich scenario)

Acronyms: MD – Mechanical Drive; LTH3 – Low Temperature Heat <60ºC; LTH2 – Low Temperature Heat 60-90ºC; OE – Other Electrical uses

In relation to Light and Other Electrical uses, these are the categories with the lowest shares of consumption (both final and useful). For the Ostrich scenario, there is a trend that shows a relatively constant projection of Light and a small growth of OE uses.

A Sankey diagram was made for each scenario, for an overview of the exergy chain and is included in ANNEX II:.

3.4.2 Iberian Lynx scenario

This scenario represents a situation of fast economic growth and a rapid increase in aggregate efficiency until 2030.

The base scenario assumptions exergy-wise are in *Table 10*.

Table 10: Main variables and configurations for exergy use by category in the Iberian Lynx

	Configurations
Useful exergy shares (exergy by end use category) [a]	Electrification: MW2 share decreases approx. 1.5 p.p. to be approx. 2% of total useful exergy; Diesel uses decrease drastically to almost half of their share from 15.4% (2014) to 9% (2030); Heat needs from electric appliances diminish circa 1.6 p.p. to be 3% of total useful exergy; Consumption for stationary MD uses grows to be 70% of industrial electricity consumption and up until 30% in non-industrial sectors
Electrical vehicles circulating by 2030 (EV and H_2) [b]	Fast adoption - 20% of vehicles circulating by 2030
Electric grid ability to integrate electrical vehicles [b]	Fast and comprehensive
Final-to-useful exergy efficiencies [a]	NG vehicles' efficiency increase 1.4 p.p. by 2030; Lighting efficiency increases 5 p.p. by 2030 (stock replacement)
Energy efficiency in buildings [c]	Exergy for heating decreases 1.4 p.p. by 2030 (improved efficiency)
Pace of adoption of energy efficiency technologies and measures and microgeneration [c]	Energy efficiency is a clear priority. Fast adoption of energy efficiency measures and technologies

Table 10 Acronyms: MD – Mechanical drive; MW2 – Gasoline/ LPG engines; EV – electrical vehicles (including hydrogen vehicles).
Notes to the table: (a) Defined by the research team in order to link the uncertainties to GDP evolution. (b) Defined by participants (in the 1st Challenge) selected by the research team. (c) Defined and selected by participants in the 1st Challenge and the 2nd Workshop. All configurations were defined and discussed with the workshops' participants.

Similarly, to the Ostrich scenario, electricity uses' shares and efficiencies are included in ANNEX III:Table Annex 4 and Table Annex 5.

For this scenario, EV calculations were computed as described before considered, however, that EV sales would grow 50% compared to the previous year, rather than the 35% considered for Ostrich.

This is to achieve a rapid increase of the number of electrics in circulation, following BCSD associates suggestions from the 3r workshop (around 15%, or more, penetration of EVs by 2030, in Iberian Lynx scenario), and in accordance with projections from other authors (The Economist 2017; Cherif et al. 2017).

Within the plausible universe, Iberian Lynx aggregate efficiency projected for 2030 (*Figure 18*) develops quickly, growing approximately 5 p.p. compared to 2014, up to 27.3% in 2030.

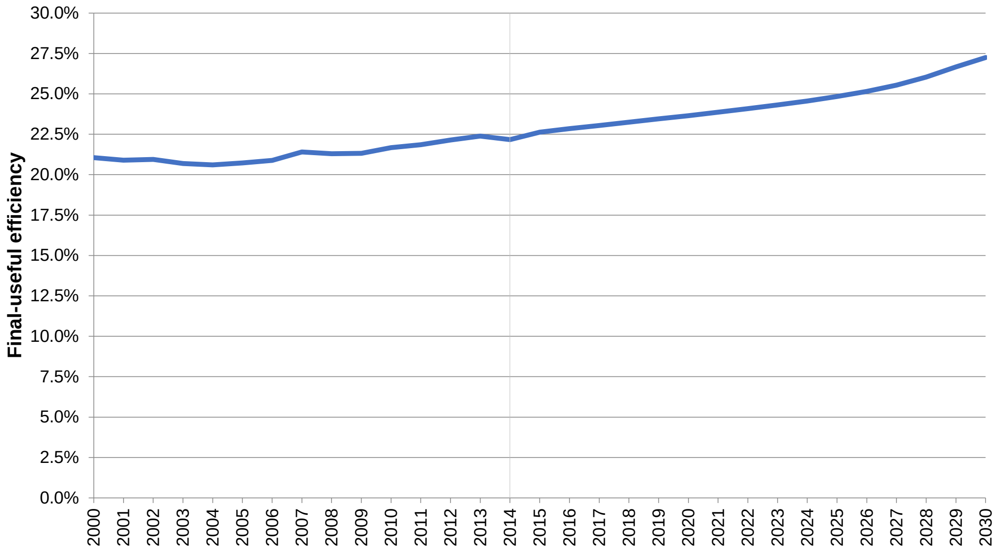

Figure 18: Aggregate final-useful efficiency 2000-2030 (Iberian Lynx scenario)

Once again, the evolution of efficiency is explained at the end-use level, being mainly based on the substitution of energy carriers' and a more accentuated shift in electrification.

The main changes made to past trends in order to make projections are related to oil products and electricity uses (*Table 11*). This because gasoline, diesel and heat have high useful and final exergy shares but low efficiencies (pushing aggregate efficiency to lower values), while electricity has high shares and efficiency, replacing oil products' MD uses by electric uses, e.g., vehicles. This leads to an increase in aggregate efficiency. For that, in the Iberian Lynx, the trends for oil products and electricity uses are steeper than in the Ostrich (*Figure 19* and *Figure 20*).

Table 11: Final and useful exergy shares difference 2014-2030 in percentage points (p.p.) in Iberian Lynx

	Coal	Oil	Combustible Renewables	Natural Gas	Electricity	Heat	Solar
Useful exergy	-0.04 p.p.	-11.34 p.p.	-2.23 p.p.	-0.88 p.p.	12.03 p.p.	2.44 p.p.	0.02 p.p.
Final exergy	-0.02 p.p.	-12.83 p.p.	-0.10 p.p.	1.50 p.p.	8.27 p.p.	3.09 p.p.	0.07 p.p.

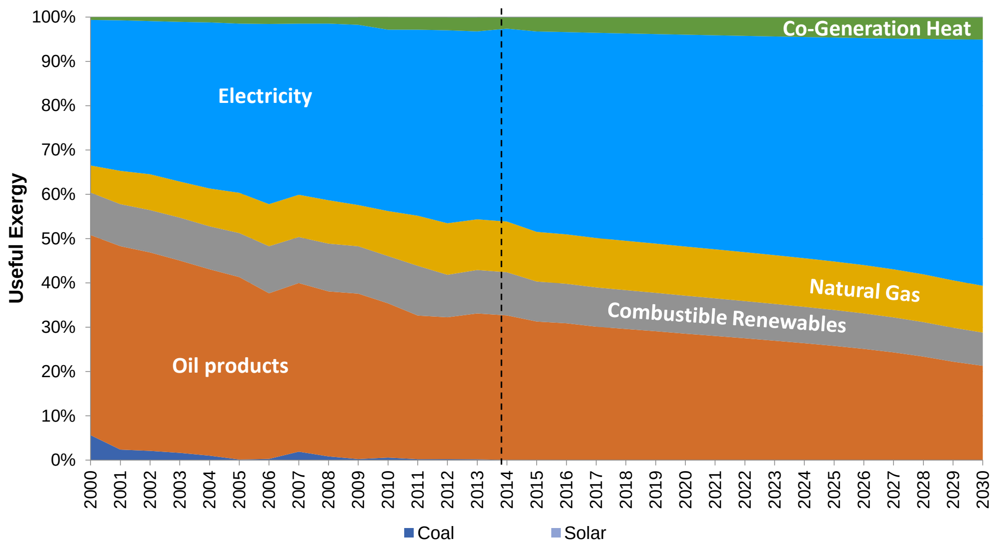

Figure 19: Useful exergy shares per energy carrier 2000-2030 (Iberian Lynx scenario)

Note that oil products' end-uses (mobile and stationary) have aggregate exergy efficiency around 15-16% whereas electricity uses have an efficiency of about 40-43% (these energy carrier aggregate efficiencies are based on end-use efficiencies, used by Serrenho, adapted from Ford et al. (1975) for mechanical drive uses and Ayres et al. (2005) for electric appliances.

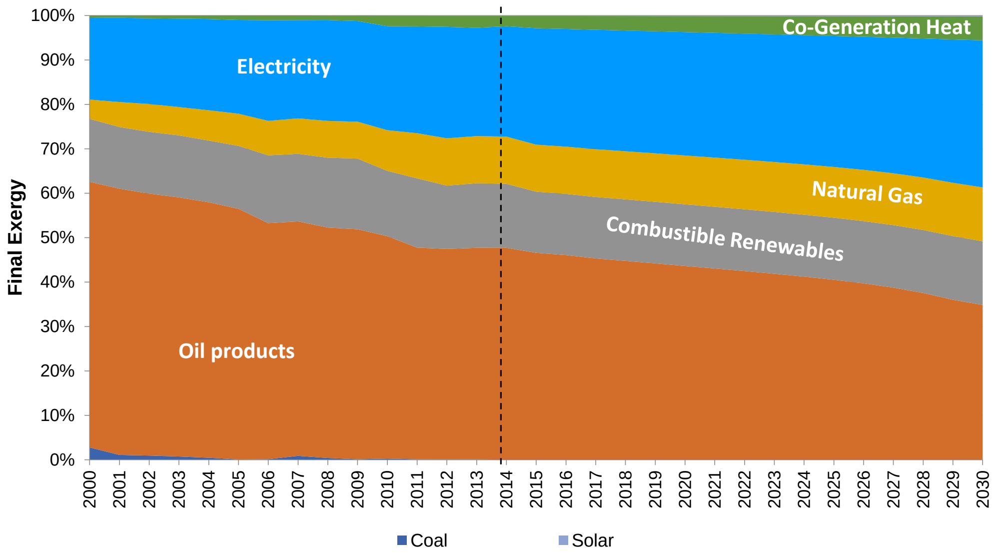

Figure 20: Final exergy shares per energy carrier 2000-2030 (Iberian Lynx scenario)

Figure 21 shows absolute values of consumption. Regarding oil products, although their final exergy share decreases, their absolute consumption remains constant until 2030.

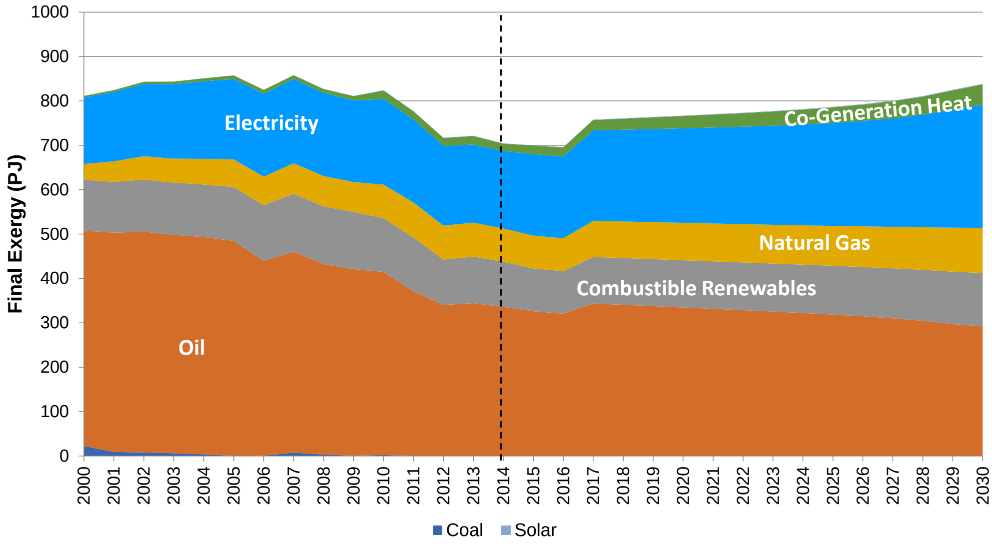

Figure 21: Final exergy consumption per energy carrier (Iberian Lynx scenario)

The rapid economic growth, considered in Iberian Lynx, leads to higher total useful exergy consumptions, in 2030, 229 PJ, than in the Ostrich, 165 PJ. This also happens for final exergy consumption (839 PJ consumed in this scenario). It is expected that an increase in aggregate efficiency would lead to a lower final consumption, however this only happens in Ostrich. In the Iberian Lynx, even though aggregate efficiency increases significantly, final exergy does not diminish because GDP is much higher.

If Iberian Lynx efficiency was the same as the Ostrich (about 23.5%) a useful consumption of 229 PJ would need approximately 974 PJ of final consumption (more 135 PJ than what is projected with the 27.3% Iberian Lynx efficiency).

For a closer view of the exergy consumption projected for 2030, Table 12 shows the energy carriers with the highest (>3%) consumption (final) per sector in 2030, except for Agriculture/Fishing in which the highest share is about 2%.

Considering Portugal's total consumption, the sectors with higher shares of consumption, in general, and that consequently have the most influence on exergy projections are: Residential/Commercial (Services) and Industry.

Table 12: Most significant energy carriers consumed by sector in 2030

Sectors	Energy Carrier	End-Use
Energy	Oil products	Heat (MTH)
Industry	Electricity	Mechanical Drive (stationary)
Transportation	Oil products	Mechanical Drive (MW2 & MW3)
	Combustible Renewables	Mechanical Drive (MW3)

Sectors	Energy Carrier	End-Use
Residential/Commercial	Electricity	Heat (LTH2) & OE
	Combustible Renewables	Heat (LTH3)
	Oil products	Heat (LTH3)
Agriculture/Fishing	Oil products	Mechanical Drive (MW3)

Table 12 Acronyms: MTH - Medium Temperature Heat; LTH3 - Low Temperature Heat 3; MW2 (Gasoline Engines); MW3 (Diesel Engines).

In the scenario Iberian Lynx, for the Industry case, electricity becomes the only carrier with a final share higher than 3%. However, Paper, Pulp & Print industry, which is the greatest consumer of final exergy, continues to consume more final exergy from combustible renewables for LTH1 uses – which cannot be changed due to this industry's processes characteristics. Therefore, LTH1 using combustible renewables still has the second highest share (approximately 2.9%).

Natural gas continues to be, in Industry, the third energy carrier most consumed for LTH1 uses, increasing its share up to circa 2.3%. The highest consumers, in 2030, in Iberian Lynx scenario would be Non-Metallic Minerals (which includes the production of Clay, Cement and Glass), Food & Tobacco, Textile & Leather, Chemical & Petrochemical and Paper, Pulp & Print.

In Transportation, there is a growth of combustible renewable consumptions mainly due to a shift towards the consumption of biofuels – corresponding essentially to biodiesel which is a MW3 use. While in Residential/Commercial sector has an increase in final consumption of approximately 6% of electricity uses, being the highest and second highest shares from stationary MD and OE uses.

A general view of Iberian Lynx useful exergy consumption by end-use is shown below (*Figure 22*).

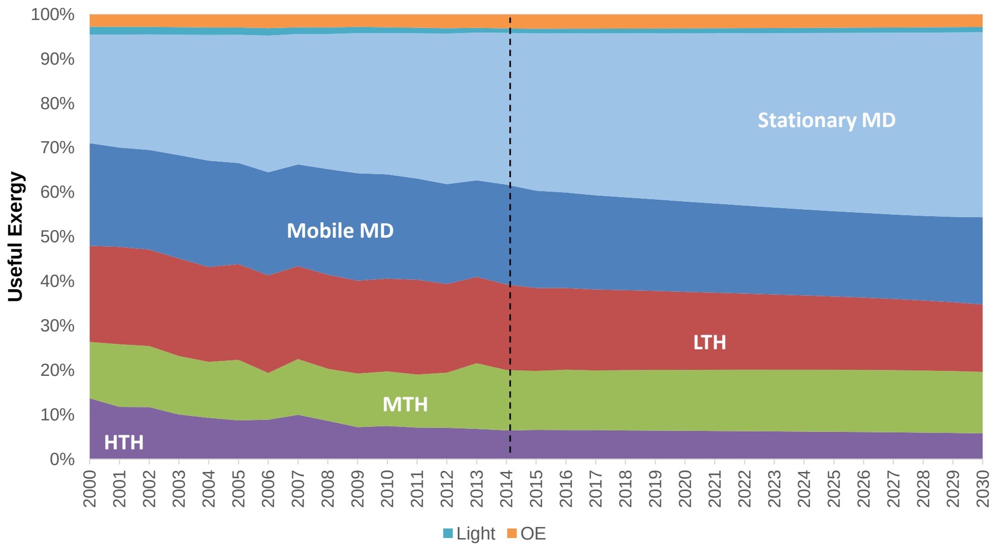

Figure 22: Useful exergy shares 2000-2030 (Iberian Lynx scenario)

Acronyms: MD – Mechanical Drive; LTH – Low Temperature Heat (<120ºC); MTH – Medium Temperature Heat (500-120ºC); HTH – High Temperature Heat (>500ºC); OE – Other Electrical uses

Iberian Lynx follows past trends but accelerates the electrification processes, since it considers a growth in stationary mechanical drive uses up to 70% of electricity's consumption in industry and 30% in Residential/Commercial (services) - mostly electric motors – compared to an increase to be 60% of industrial electricity consumption and 24% of other sectors, in Ostrich.

Efficiency is much higher, mainly due to the change in shares of electric uses. The electricity consumption is projected to be about 56% of Portugal's useful consumption (2030) in this scenario, compared to 29% of useful consumption in the ostrich scenario.

A closer look of this scenario projections, by sector, is also provided for this scenario (Figure 23 to Figure 27), as well as a summary table (in ANNEX III:) that presents efficiencies, useful and final shares. Shares higher than 3% are highlighted as well.

Once again, it is important to keep in mind that at the useful level one is looking to the energy production sector as a consumer, not including the natural resources consumed to produce electricity (which is considered to be at a primary level of the energy chain).

For the Energy sector in this scenario, there is a slight decrease in the LTH2 share (*Figure 23*), though the overall consumption of each end-use does not change much from 2014.

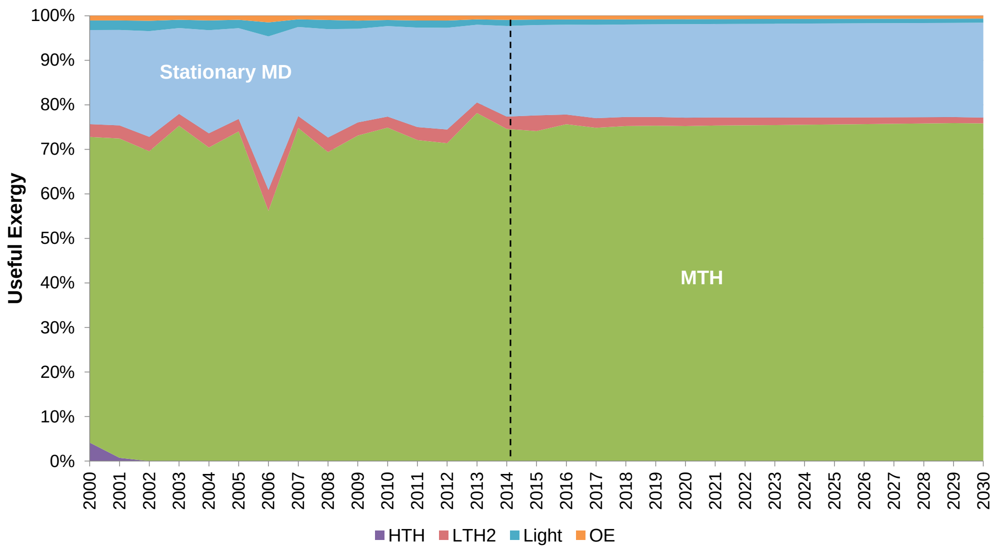

Figure 23: Useful exergy shares in the Energy sector 2000-2030 (Iberian Lynx scenario)

Acronyms: MD – Mechanical Drive; LTH2 – Low Temperature Heat 60-90ºC; MTH – Medium Temperature Heat (500-120ºC); HTH – High Temperature Heat (>500ºC); OE – Other Electrical uses

For the Industrial sector, end-use categories with higher shares in Iberian Lynx (*Figure 24*) are the same as in the Ostrich.

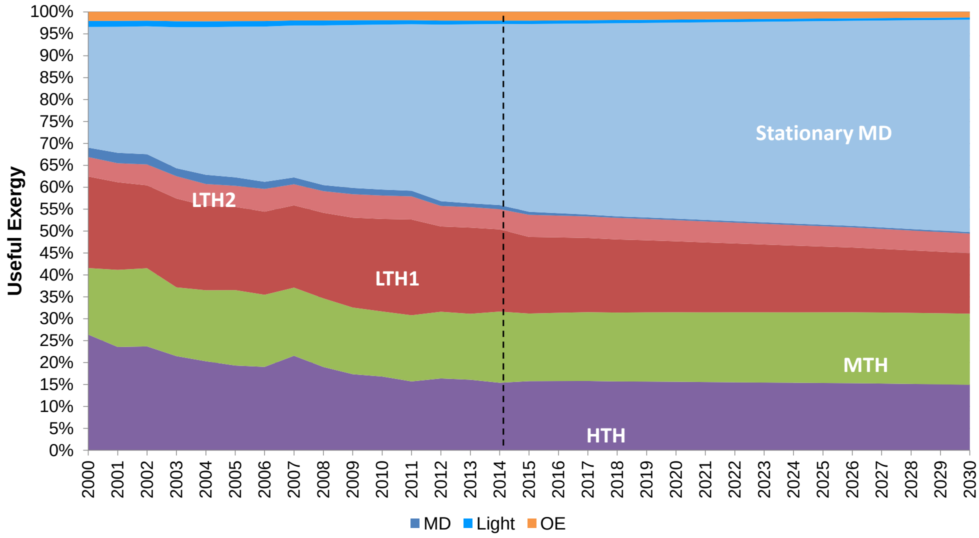

Figure 24: Useful exergy shares in Industry 2000-2030 (Iberian Lynx scenario)

Acronyms: MD – Mechanical Drive (mobile); LTH2 – Low Temperature Heat 60-90ºC; LTH1 – Low Temperature Heat 90-120ºC; MTH – Medium Temperature Heat (500-120ºC); HTH – High Temperature Heat (>500ºC) ; OE – Other Electrical uses

For the Iberian Lynx, projections show a growing share of stationary MD uses as the main change from the Ostrich. This increase mirrors the introduction of new technologies, such as replacing traditional heat uses by electricity (e.g. furnaces) and a strong increase in automation in processes.

Stationary MD is done mostly by electric motors already since 2000 and, thus, the increased share in Iberian Lynx is related to continuous automation and robotisation of Industry. This shift towards a higher share of stationary MD was done between 2000-2014 with the decrease of consumption of higher temperature processes (HTH and MTH). However, in the Iberian Lynx, the continuous automation of Industry is done by reducing low temperature processes (LTH1 and LTH2), replacing their share with much more efficient uses and stabilizing high temperature categories shares – which leads to an increase in aggregate efficiency. It can, also, be done using dissipated heat from other processes as a source (e.g. co-generation heat), rather than using other energy carriers.

This shift in shares is based on the notion that, as electricity is the carrier with the highest final-to-useful efficiency, one way to move into a considerably more efficient society is to substitute other energy carriers by electricity uses.

An increase of stationary MD uses contemplates the possibility for new industrial sectors in the Portuguese Economy as well as new forms of production, which should be the focus of technological efforts if trying to make this re-distribution of consumption shares in Industry.

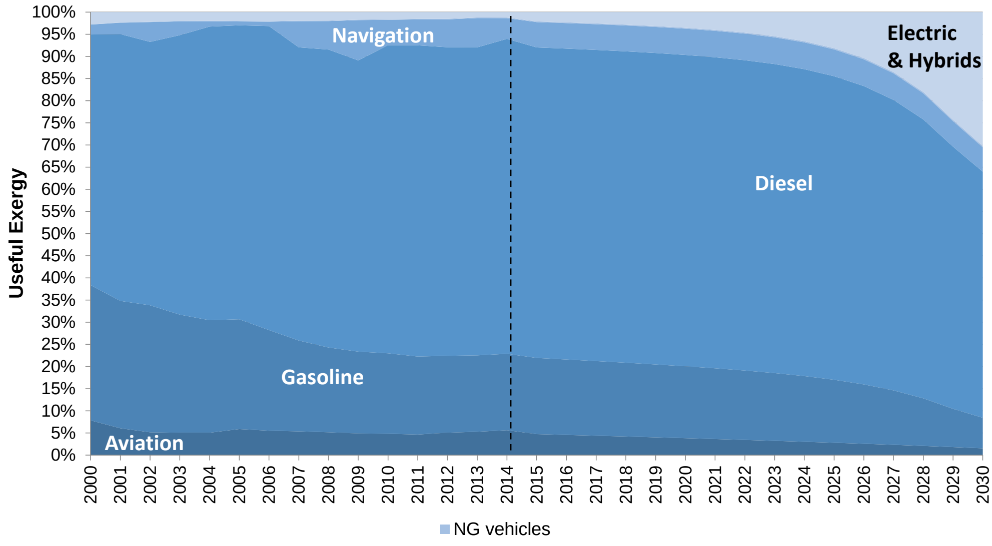

Figure 25: Useful exergy shares in Transportation 2000-2030 (Iberian Lynx scenario)

Acronyms: NG – natural gas

In Transports' Iberian Lynx shares (*Figure 25*), gasoline useful shares have a projection similar to the evolution in Ostrich, while diesel useful shares grow. However, if considering Portugal's total useful consumption (all five sectors), diesel and gasoline uses shares are projected to decrease from 2014 to 2030.

Both diesel and gasoline shares include biofuels. Therefore, a growth in one of these categories does not necessarily mean an increase in GHG emissions, as that is influenced by the weight of biofuels in the mixtures consumed (which is one of various factors that influence emissions).

Electric & Hybrid vehicles are the end use that considerably changes between scenarios, growing its share to represent around 30% of the transport sector useful exergy in this scenario. The growth is due to an increase in final consumption share – representing electric cars, in 2030, about 20% of the circulating vehicles.

The projections for Electric & Hybrid vehicles were made considering massive implementation of alternative business models such as car-sharing and Uber. These services also influence the number of circulating cars, which for Iberian Lynx in 2030, are considered to be about 80% of the 2014 circulating vehicles total.

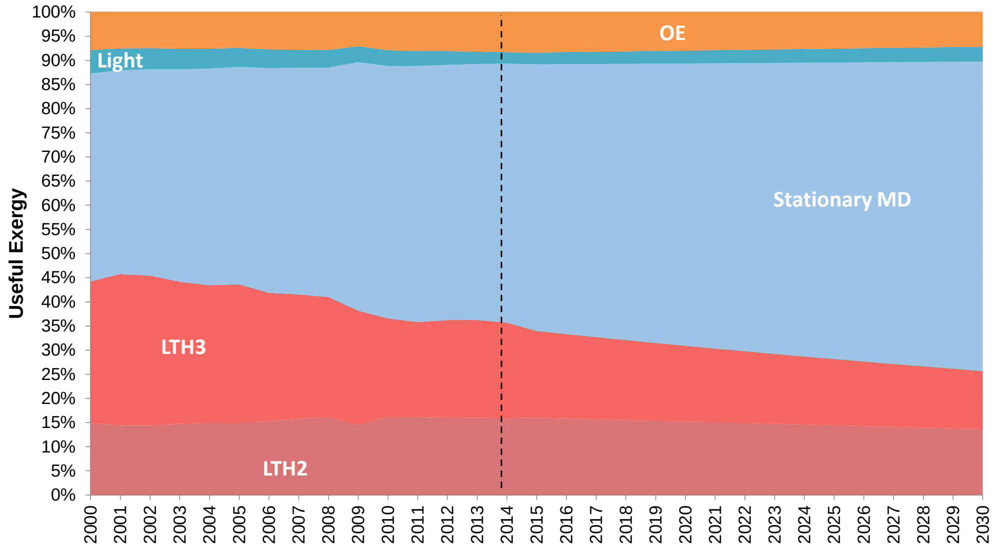

Figure 26: Useful exergy shares in the Residential/Commercial sector 2000-2030 (Iberian Lynx scenario)

Acronyms: MD – Mechanical Drive; LTH3 – Low Temperature Heat <60ºC; LTH2 – Low Temperature Heat 60-90ºC; OE – Other Electrical uses

Projections for the Residential/Commercial sector (*Figure 26*) show LTH3 and stationary MD as being the end use categories where the main changes occur. The LTH3 is a category related to buildings' heating needs, so a decrease in its share is associated to an effort to diminish these needs and increase the use of more efficient electricity-based heat pumps (in accordance to current national policies on building energetic efficiency), increasing stationary MD. In this sector, stationary MD corresponds to cooling devices, such as refrigerators and air conditioners and machines, e.g. washing and dishing.

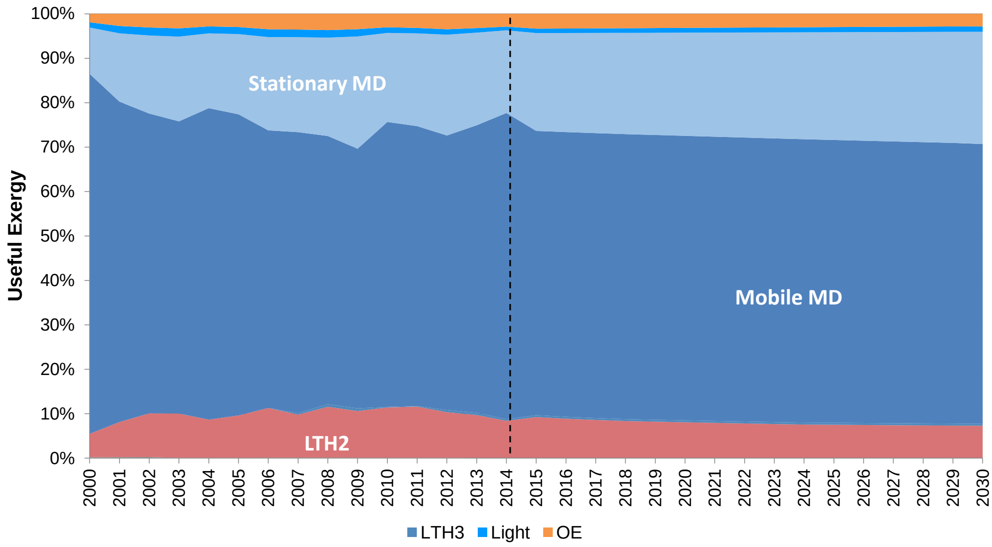

Figure 27: Useful exergy shares in Agriculture/Fishing 2000-2030 (Iberian Lynx scenario)

Acronyms: MD – Mechanical Drive; LTH3 – Low Temperature Heat <60ºC; LTH2 – Low Temperature Heat 60-90ºC; OE – Other Electrical uses

Regarding Agriculture/Fishing, in *Figure 27* it is visible that projections in this scenario lead to developments in mobile MD and stationary MD uses opposite to the Ostrich's projection. This means a decrease in mobile MD useful share while stationary MD has an increasing share, which follows the Electrification trend.

For the Iberian Lynx in general, a particular change that is worth highlighting is in MD uses, because there is an increase of about 6 p.p. in final exergy consumption by electric motors. This change is associated with the rapid implementation of technology advances in the continued process of automation in industries and in other sectors (e.g. delivery and mailing services, domestic robots, etc.).

Finally, For the Iberian Lynx scenario, Light technology and substitution of standing stock might allow an increase of 5% in final-to-useful efficiency, by 2030, but this has no significant effect in Light's[4] final share. Meanwhile, for OE uses, due to a very low final-to-useful efficiency, these uses share decreases slightly (approx. 0.3 p.p. in useful share) in the period 2014-2030.

A Sankey diagram was made for this scenario as well and is included in ANNEX III:.

3.4.3 General Considerations

In the Ostrich scenario, there is a slow growth in aggregate efficiency and economic growth from 2014 to 2030. In contrast, in the Iberian Lynx it is expected a rapid growth in the transition from 2014 to 2030, associated to a growth in consumption as well as in aggregate efficiency.

The differences in aggregate efficiencies between scenarios are explained by differences among individual efficiencies and end-uses' shares due to different patterns of technology evolution and adoption and behaviour/habit changes in society as well. Another important factor is the replacement of energy carriers by carriers with higher efficiencies for the same or different end-uses (e.g. a growth of electric motors share which efficiency is around 85%).

3.5 Fossil fuel GHG Emissions for 2030

Results from GHG emissions' calculations by sector are portrayed in the current section, showing projections for both scenarios. These calculations were computed using IPCC (2006) emission factors as followed by APA (Agência Portuguesa do Ambiente) and in the NIR (National Inventory Report on GHG emissions) (APA 2017a).

The context of MEET2030 fits in IPCC's Energy category, which means that studied GHG emissions are all related to fossil fuels combustion but do not consider emissions from other sources (namely the majority of CH_4 and N_2O emissions). This means that the results presented correspond to circa 70% of

[4] Light includes not only street lighting but all light uses (e.g., offices, houses and industry).

Portugal total GHG emissions and that IPPC's Energy category comprises the energy consumptions of all five sectors mentioned in this dissertation. It is important to remind that the "Energy sector" of the current dissertation is referring to electroproduction and refineries sector and not IPCC's Energy category.

The GHG emission totals obtained are result of all the assumptions taken for each scenario, related to useful and final exergy consumption, as well as choices taken on resources consumption (primary exergy level) for electricity production. This means that if solely assumptions related to consumers or assumptions related to production were changed the differences of GHG emission results between scenarios, presented hereby, would not be achieved.

An overview of total GHG emissions for the five sectors studied is shown in *Figure 28*. This section (3.5) results consider that the mix of resources consumed to produce electricity is the same for both scenarios: 60% from renewable resources (Biomass, Hydro, Wind, Geothermal and Solar) and 40% from non-renewable (Thermo-electricity production excluding the use of Biomass). This is in order to make a plausible comparison between both scenarios.

Interestingly, the Iberian Lynx is the scenario with the most GHG emissions associated, approximately 55 Mt $CO_{2\ eq}$ compared to the 46.2 Mt $CO_{2\ eq}$ projected for Ostrich in 2030. This is explained by the economic growth of the Iberian Lynx scenario.

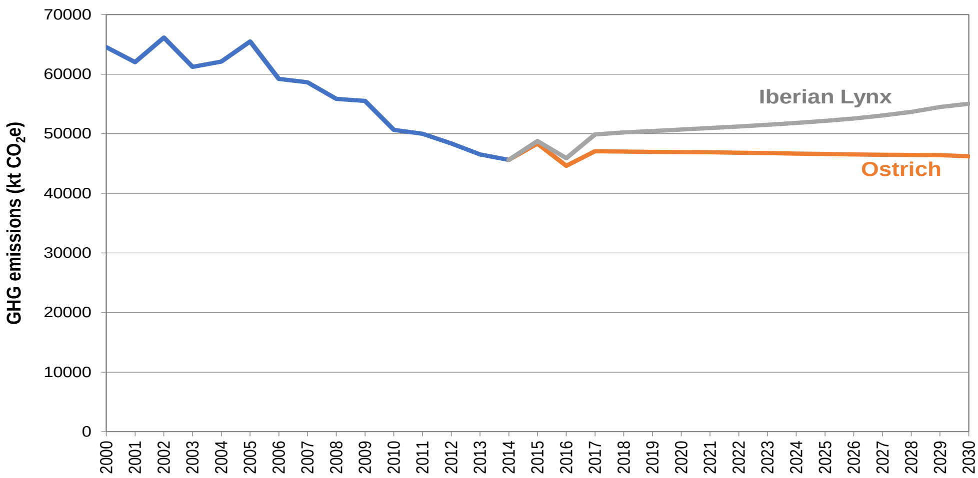

Figure 28: Portugal's GHG total emissions for both scenarios in 2000-2030 (kt $CO_{2\ eq}$)

With the computed values for GHG total emissions, both scenarios comply only with the less stringent scenario of the National Low-Carbon Roadmap (APA & Comité Executivo da Comissão para as Alterações Climáticas 2012), which is not in track to achieve EU goals for GHG emissions – less 80% compared to 1990 totals.

3.5.1 Energy sector

The Energy sector is the one with the highest GHG emissions associated (*Figure 29*), being the sector where GHG emissions from electricity production and co-generation heat are included.

Considering, throughout time, the same share of renewable resources in the mix consumed for electricity production implies that, as consumption is higher in the Iberian Lynx, production from renewable resources has to be higher in 2030 compared to any other previous year. This also means that, increasing the renewables share in the mix requires an even bigger effort from the Energy production sector and the use of renewable resources in that scenario.

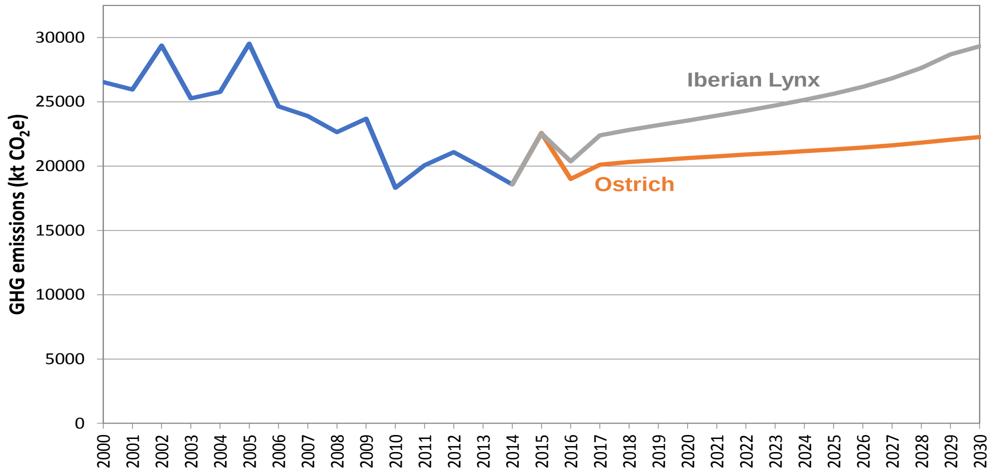

Figure 29: Energy sector GHG emissions for both scenarios 2000-2030 (kt $CO_{2\ eq}$)

GHG emissions, in 2030, in the Ostrich are lower (circa 22.3 Mt $CO_{2\ eq}$) than for the Iberian Lynx (approximately 29.3 Mt $CO_{2\ eq}$), because there is a huge increase in electricity in the Iberian Lynx.

3.5.2 Industrial sector

What is noticeable in *Figure 30*, besides the clear difference of behaviour between scenarios, is that GHG emissions for Ostrich are relatively similar to 2014 values (6 Mt $CO_{2\ eq}$), while Iberian Lynx GHG emissions reach values closer to the 2008 (around 8.4 Mt $CO_{2\ eq}$).

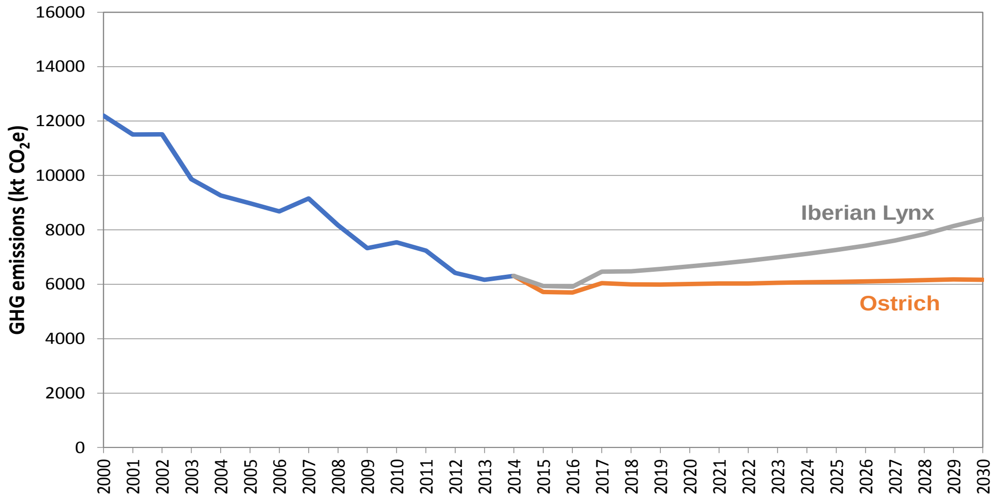

Figure 30: Industry GHG emissions for both scenarios 2000-2030 (kt $CO_{2\ eq}$)

The increase in emissions for Iberian Lynx is understandable as this scenario has a rapid economic growth and consequent increase in consumption. Furthermore, this is one of the sectors with higher energy consumption in the Portuguese society as well as a wider range (than other sectors) of types of resources used. This means that some resources with high emission factors are consumed leading, expectedly, to higher emission levels.

3.5.3 Transport sector

The Transport sector is the one with the second highest total GHG emissions after the Energy sector (*Figure 31*).

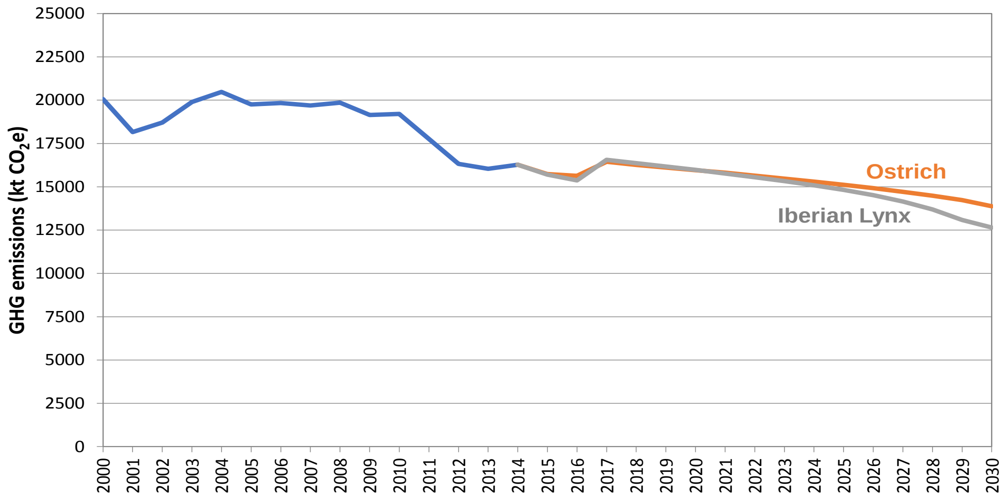

Figure 31: Transportation GHG emissions for both scenarios 2000-2030 (kt $CO_{2\ eq}$)

For this sector, Iberian Lynx projection has approximately less 1.3 Mt $CO_{2\ eq}$ than the Ostrich projection, decreasing to a total of 12.6 Mt CO_{2e}. These results are directly linked with the adoption of electric vehicles, 6% of 2030 circulating vehicles in the Ostrich compared to 20% in Iberian Lynx, as well as the number of circulating vehicles – 86% of 2014 total in Ostrich compared to only 80% in the Iberian Lynx.

3.5.4 Residential / Commercial (Services) sector

In *Figure 32* it is possible to observe GHG emissions for the Residential/Commercial sector. Iberian Lynx scenario GHG emissions are about 500 kt $CO_{2\ eq}$ higher than Ostrich emissions, mainly due to the increase in consumption in the Iberian Lynx, despite the strong electrification which removes GHG emissions from this sector (and transfers to the energy sector).

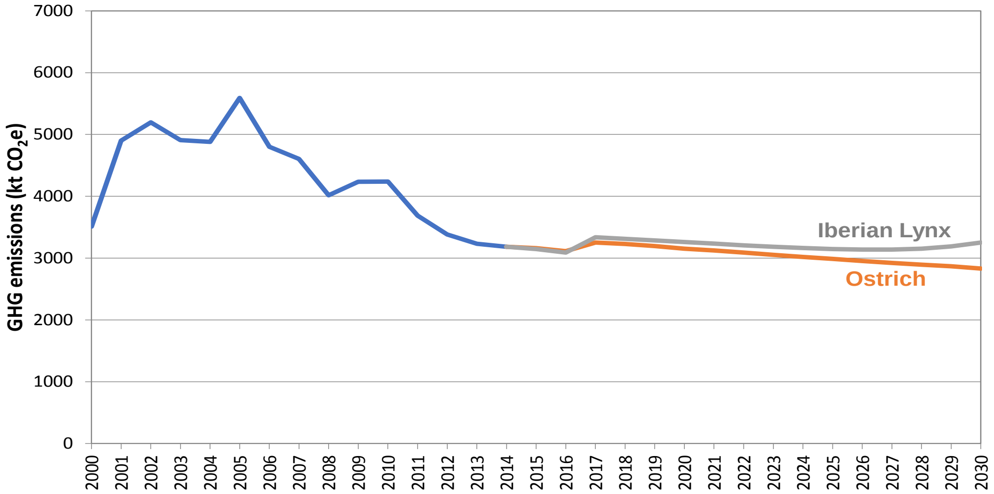

Figure 32: Residential/Commercial GHG emissions for both scenarios 2000-2030 (kt $CO_{2\ eq}$)

3.5.5 Agriculture/Fishing sector

The Agriculture/Fishing sector is, in this analysis (*Figure 33*), the sector with the lowest GHG emissions associated because the energy consumption is, also, the lowest. Nevertheless, it is probably the sector whose total GHG emissions are much larger than the ones included in the IPCC's Energy category, implying that this analysis focused on energy does not completely represent this sector's reality. GHG emission scenarios are close to each other.

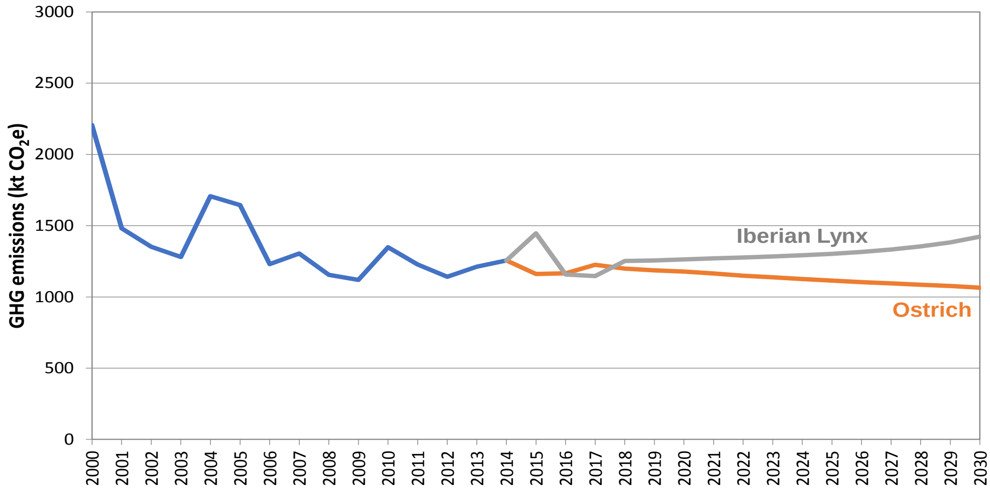

Figure 33: Agriculture/Fishing GHG emissions for both scenarios 2000-2030 (kt $CO_{2\ eq}$)

Iberian Lynx GHG emissions increase, contrarily to Ostrich emissions, reaching 1.4 Mt $CO_{2\ eq}$. This difference in the curves development is due to the increase in consumption in the Iberian Lynx scenario.

Overall, looking to the GHG emissions analyses it is clear that higher efficiency does not necessarily mean decarbonisation. This is shown by the Iberian Lynx results on GHG emissions, being higher than Ostrich projections, due to the rebound effect that happens in consumption when aggregate efficiency increases.

Iberian Lynx results showed that it is not possible to have a rapid economic growth without increase GHG emissions. So, the challenge revealed by these results is how to reduce the GHG emissions, being this the central theme of the 4th workshop. An adjusted version of the Iberian Lynx is being built focused on the Carbon neutrality issue – which is central to the project. For this, two main variables are considered: electricity production mix of resources and carbon sequestration through processes that enhance ecosystem services.

Changes made to the Iberian Lynx are set to achieve totals of GHG emissions that are equal to the GHG emission total of the most stringent scenarios in the National Low-Carbon Roadmap(APA & Comité Executivo da Comissão para as Alterações Climáticas 2012). The most stringent scenarios are on track to achieve European goals set for 2050.

4. Electricity – the relevance of specific data and methodology choice

In this chapter primary to useful efficiency of electricity use in Portugal is calculated over the period 1913-2014 by benchmarks. It is challenging to calculate the exergy efficiency of electricity over a long period due to 1) the allocation of final electricity to end-uses and respective final-useful efficiency, and 2) methodological accounting options in the primary stage of energy chain (Sousa et al. 2017). This chapter addresses both uncertainties. Allocation difficulties are studied by using new and different data to allocate electricity to its different end-uses. Methodological options are addressed by testing the impact of the different primary exergy accounting methods on electricity efficiency.

4.1. Methodology

The point of departure is Serrenho work on final to useful exergy accounting calculations for Portugal over the period 1856-2006: Serrenho (2013) and Serrenho et. al (2016). Palma (2014) has performed some tests on Serrenho's useful exergy accounting work for Portugal. These tests were made exclusively for the period after 1960. Some of these tests made by Palma, i.e. introducing the cooling end-use category (which showed improvements to the original series), are incorporated in this work.

This chapter extends and improves Serrenho and Palma work in three ways. First, a new electricity end-use is considered and disaggregated: electrochemical uses. Second, end use shares are detailed by sectors (Agriculture & Fishing, Residential/Commercial and Transports). Third, primary exergy associated to electricity was calculated using three different possible methods which were described by Sousa et al. (2017).

In order to perform detailed calculations one started by defining benchmark years for which data was available, to minimize the use of proxies as much as possible. These results can then be used to correct the original continuous long-run series.

Then, the four-step methodology used by Ayres et al. (2003) and other authors to calculate useful exergy was followed (see Chapter 2), knowing that for electricity the method applied has its specificities, namely the fact that allocation is done by applying end-use shares to total final exergy. It was in the allocation step that the new end-use category (electrochemical uses) was introduced.

After benchmarks and electricity end-use shares were defined and applied, total useful exergy for each benchmark was calculated. From this, primary exergy was calculated by using three different methods: Resource Content method (RCM), Physical Content method (PCM) and Partial Substitution method (PSM). These are further explained in subchapter 4.5.

4.2. Benchmark years

Benchmark years were chosen accordingly with their energy historical importance as well as the availability of specific data that could be found, being those years: 1913, 1950, 1973, 1986, 2005 and

2014. These years are characterized by changes in the evolution of energy consumption in Portugal, either to a different growth rate or into a period of decreasing or stable consumption (e.g. as seen in Henriques (2011) work). The main periods of consideration were the following:

1890 - 1913: The 'beginning' of domestic consumption

Before1890 , electricity was only used in Portugal for communication (telegraphs and telephones), medical applications and lighting (lighthouses and private space illumination, e.g. theatres and factories) (Henriques 2009). At this point, small coal-power plants, selling electricity to the public, were already working, such as the plant in Passos Manuel street (Porto) since 1888 and the Avenida da Liberdade (Lisbon) plant, the first in the country to distribute electricity for street lighting, in 1889 (Matos 2004). The first hydroelectric plant with public distribution started working in 1894 (Nogueira 2008).

At the beginning of the 20th century, CRGE (Companhias Reunidas de Gás e Electricidade) was responsible for public distribution of electricity, in Lisbon, whose cables were spreading quickly along the principal avenues of the city, having grown from 250 km in 1910 to 338.7km in 1914, following the start of production of the new power plant (Central Tejo) (Matos 2004; Fundação EDP 2017).

Until 1910, the electricity consumption, in Lisbon, increases mainly for mechanical drive uses. This is shown in CRGE reports (CRGE, 1891-1974), where 9% of Lisbon sales are stated as electric motors in 1906/07 and, then, in 1908/09 this number is almost the triple (26%). The number of electricity consumers grows similarly to the gas city consumers. In Porto, public and private lighting grown significantly only after the inauguration of Central do Ouro (1908), this trend accentuated in 1912 (Matos 2004).

The year of 1913 was then chosen in order to understand Portuguese energy consumption levels at the beginning of the 20th century. Note that, as electricity was not widely spread in Portugal before 1913, it would not be possible to draw general consumption patterns conclusions for the whole country for 1890, so this year is not considered for this study.

1913 – 1950: Instability and hydro-power

The 1950 benchmark represents the changes over the period 1913 to 1950. Relative to other European countries, Portugal had a slow development of its electricity sector with very low levels of per capita consumption of electricity in 1950s This period occurs in a context of instability, as Portugal political system had recently changed from a Monarchy to a Republic, and this *First Republic* (1910-1926) was a troubled period, marked by rebellions, coups and financial instability. After 1926, when Salazar dictatorship came into power Portugal had chronical lacks of capital.

In terms of natural resources consumption for electricity production, this period is marked by coal as the main energy carrier. While many coal-poor countries shifted to domestic hydro-power in this period, lack of capital and industrial demand halted the investment in Portuguese abundant but difficult hydro-resources (Henriques & Sharp 2017). Thermoelectricity production by several small plants was dominant (Henriques 2009), representing 73% of total production in 1913 and 54% in 1950.

The year 1950 is a turning-point moment. In 1951, the Castelo do Bode dam was inaugurated shifting Portuguese electricity production to hydro-power over a period of 20 years.

For all of this, the year of 1950 was chosen, allowing a look at the middle of the century as well as to the "aftermath" of both World Wars regarding electricity consumption.

This benchmark is the richest in sources with available data for useful exergy calculations. Data from electrical installations' statistics (Estatísticas das Instalações Eléctricas, DGSE) and industrial statistics (Estatística Industrial, INE) cover national electricity consumption, while providing important information for end-use shares.

1950 - 1973: Shift in resources

The 1950s and 1960s are considered to be "the golden years of hydro-power" (Henriques 2009, p.91) showing already a strong presence of renewable sources in Portugal's electricity production mix.

After a period of strong incentives to consume electricity, as a result of economic changes in 1960 – Portugal joined EFTA (European Free Trade Association) and was admitted into the World Bank and IMF (International Monetary Fund) – there was a change in the cost of electricity. A 10% increase in electricity cost for public distribution companies, i.e. CNE (Companhia Nacional de Electricidade), as well as a denied request from private companies for a price compensation, translated then into an increase in price, changing the electricity panorama present up until then (Bussola & Madureira 2005).

Despite national policies focused on the development of hydroelectric production, by 1970-71, the Portuguese economy had shifted towards the use of oil derivatives that were cheaper at the time, authorizing the building of a terminal and refinery works in Sines as well as other investment in shipyards. However, these efforts and investments were stopped by a crisis in international maritime trade and the 1973-74 crisis that lead to an increase in oil prices and decline in petroleum business (ibid).

The year of 1973 is, therefore, very interesting to study because of all that was mentioned above, and also considering its historic context. This is because Portugal was under authoritarian regimes for about fifty years (1926-1932 military dictatorship; 1932-1974 *Estado Novo* regime), and in 1974 a military coup (the Carnation Revolution) ended Estado Novo regime.

1973- 1986: European Union

While the beginning of the 1970s is marked by a peak in gas consumption (LPG and city gas), Electricity consumption increases up until 1986. By this time, in 1987, around 97% of households had electricity and used big electric appliances such as refrigerators (approximately 86%) and washing machines (circa 44%) (Teives & Bussola 2005). Thus, it is possible to consider that electrification of households was nearly complete by 1986.

This 1986 benchmark is the year when Portugal joined the European Union (EU) being, therefore, an important benchmark in Portuguese economy (EU (European Union) 2017). It also represents a period of instability in strategy for the electricity sector due to the oil crisis of 1973, but also lack of funds for nuclear or hydro power. In 1985, the Sines power plant that uses coal started functioning, which makes 1986 a turning point in Portugal's electricity production strategy (REN 2012b).

Furthermore, available data from electric installations' statistics is from a period that is rather close to the benchmark (last year of the series is 1984).

2005 and 2014: Consumption Peak and Current times

Finally, both 2005 and 2014 are benchmarks to understand more recent consumption patterns.

2005 is year that marks a consumption peak and consequent change in the Portuguese energy consumption development (APA 2017c). This was also an extreme drought year, which influenced the electricity production mix as hydroelectric production represents about 30-40% of production and it was less than 15% in the dry period (Instituto Meteorologia 2006).

From 2005 to 2014 there was a new investment in renewable power, with a shift to wind-power. 2014 is also the most recent year for which one has available data from IEA (2016) and the update of Serrenho's total useful exergy series was made (see section 3.1).

4.3. Consumption Shares

To calculate each sector's share from the total electricity consumed in the country, energy consumption data from DGSE (1927-1984) and IEA (1960-2014) was used, considering the following sectors: 1) Industrial, 2) Domestic/Services and 3) Transports. Agriculture and Fishing were aggregated to the Industrial sector as there wasn't specific data on their electricity shares, despite the possibility to calculate the total electricity consumed in this sector.

For the 1913 benchmark, due to the lack of available information, calculations were mainly done with extrapolations based on the following benchmark years' consumption data. And, although the objective of the work is to have better estimates based on years rich on information, this benchmark is relevant to have a glimpse of the beginning of electricity consumption in Portugal.

Also, for recent years, despite the IEA data available from 1960 to 2014, it was necessary to assure the consistency of data from different sources, which imposed the necessity to use some proxies.

Serrenho's allocation of electricity end uses (*Table 13*) aggregates all sectors. However, in supplementary data from Serrenho et al. (2016) electricity and co-generation heat consumptions were summed and end-use shares are made for that combined total. The disaggregation of these shares for each energy carrier separately was, also, made while reproducing original useful exergy series (see section 3.1.

Table 13 - Electricity's final exergy allocation (shares) by Serrenho et al. (2013, 2016)

	1913	1950	1973	1986	2005	2014
Mechanical Drive	44.28%	42.00%	40.22%	39.26%	36.76%	36.25%
Light	38.43%	37.03%	25.43%	17.13%	10.18%	10.03%
Heat	9.08%	8.47%	14.19%	18.97%	24.11%	24.21%
Other Electrical	8.21%	12.50%	20.16%	24.64%	28.95%	29.50%

New end-use shares considered for this work are shown aggregated accordingly with the original allocation (*Table 14*) for comparison purposes, despite the estimations made per sector. Thus, cooling and electrochemical uses are not separate from their original end use categories, MD and OE respectively.

Table 14: Electricity's final exergy new allocation

	1913	1950	1973	1986	2005	2014
Mechanical Drive	46,22%	55,52%	54,61%	48,90%	42,41%	38,19%
Light	44,94%	21,40%	10,62%	8,64%	9,86%	9,42%
Heat	5,34%	12,32%	17,79%	25,05%	24,71%	26,76%
Other Electrical	3,49%	10,76%	16,99%	17,42%	23,02%	25,63%

Comparing *Table 13* with *Table 14* some differences between allocations may be noted but there is no change in the main end-uses, i.e. mechanical drive end-uses have the highest share in both cases. Yet, this category has a higher share in the new allocation.

Regarding light, it has a higher share in 1913 due to end-use allocation in the Residential/Services sector being considered 100% rather than 38%. However, for all other benchmarks it has a lower share than Serrenho's allocation, which is a result of considering that light share (for the new allocation) is different in Industry and Residential/Services sectors. For this, also, MD and Heat shares, in the new allocation, are higher in Industry and, consequently, in Portugal totals.

OE shares evolution is similar for both allocations, a steady increase; however it is lower in the new allocation as different data sources were used – not only for OE uses but also to computed electrochemical uses which are included in OE in *Table 14*.

In order to understand the new allocation, it is important to explain how shares were calculated for new end-use categories and by sectors.

4.3.1. End-use categories update

Electrochemical uses

Uses in which electricity is used to perform chemical reactions are included in electrochemical uses category, i.e. electrolytic processes in industry. Several industries such as Chemical, Non-Ferrous and Paper, Pulp & Print have this type of uses to manufacture some products, respectively, e.g. sodium, aluminum and hydrogen peroxide (for bleaching) (Ayres et al. 2005).

This end-use has higher exergy efficiency than the aggregated efficiency considered for the OE uses (Ayres et al. 2005; Serrenho et al. 2016) and, so, UW calculations from this new end-use may improve the results obtained originally and lead to an increase in aggregate final-to-useful efficiency.

IEA data (2016) on Industry's electricity consumption was used for the benchmarks from 1960 to 2014 and the electrochemical uses were separated based on DGSE data (DGSE, 1927-1984). This was done by applying available electrochemical uses shares to IEA data.

Note that, DGSE available data on electrochemical consumption is for the period 1927- 1984 and, so, only the 1950 and 1973 benchmarks are contemplated in the series (*Figure 34*). Electrochemical shares for other benchmarks were estimated based on the DGSE series, following a tendency of consumption observed. For years previous to 1960, electrochemical shares were applied to the electrical installations' statistics consumption totals as there is no IEA data available.

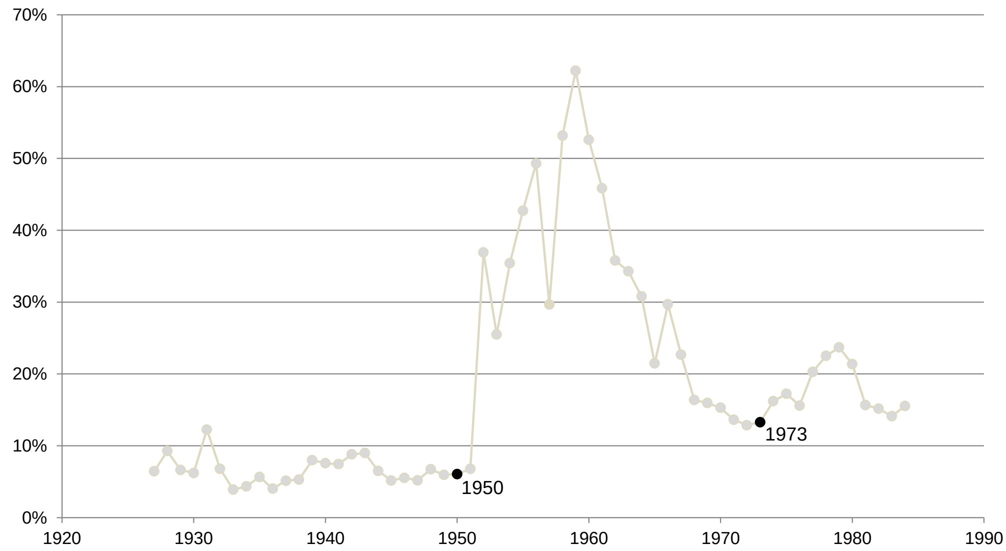

Figure 34: Share of electrochemical uses in industrial electricity consumption totals - (DGSE 1927-1984)

Data from national statistics institute, INE, (INE 1969; INE 1950) was also used in order to achieve better estimations, being those based on consumption tendencies.

It is estimated that electrochemical uses in Portugal represent, nowadays (2014), around 13.7% of the total electricity consumed in the Industrial sector, which is approximately 5% of the total electricity consumed in the whole country.

As *Figure 34* shows, the share of electrochemical uses in industry before the 1950s was limited (about 29 GWh consumed for this uses in 1950). The change began in 1944 when a national law would establish mechanisms and incentives to attract heavy industries to establish in the country, such as the electrochemical (cyanimide, ammonium sulfate). These mechanisms were made to restructure Portugal's electricity production from thermal to hydro power, beginning with the inauguration of Castelo de Bode dam in 1951 (Henriques 2011). As hydro power plants produced more electricity than demanded from consumers, these heavy industries would consume the "exceeding" electricity at very low prices (ibid). The share of electrochemical uses in industrial electricity total final consumption increases after 1950 to reach a maximum of 62% in 1959 (*Figure 34*). This is explained due the establishment of big electrochemical industries such as the *Amoníaco Português* (AP), for ammonia production, and the *União Fabril de Azoto* (UFA), for nitrogen production, back in 1952 (Bussola & Madureira 2005). In the late 1960s, with the increasing of other industrial uses and the shift to thermo-power, electrochemical industries would decrease to 15% of industrial electricity consumption (by 1973 the consumption for electrochemical uses was approximately 620 GWh).

When comparing original OE shares and the new allocation for these uses (*Figure 35*), it is clear that even without the disaggregation into two categories, the new shares are lower, with the largest difference occurring in 1986.

Also, the highest shares are in 1973 and 1986. This could be due to two effects. The first is related directly to the values, as these are the benchmarks immediately after the installation of the electrochemical industry in Portugal. So, it is the time electrochemical shares are higher after these industries' peak (see *Figure 34*). The second effect is that the OE uses category, as well as other explored further bellow, increase its share in more recent benchmarks, leading to the decrease of other end-use categories shares such as electrochemical – OE shares are further explained per sector in section 4.3.2.

It is important to mention that electrochemical uses share remains constant within the industrial sector after 1973. This happens despite the decreasing share within Portugal's total final exergy, which is consequence of Industry's decreasing electricity consumption share compared to Residential/Commercial services. Consumption, in absolute values, increases steadily until 2005 (*Figure 36*).

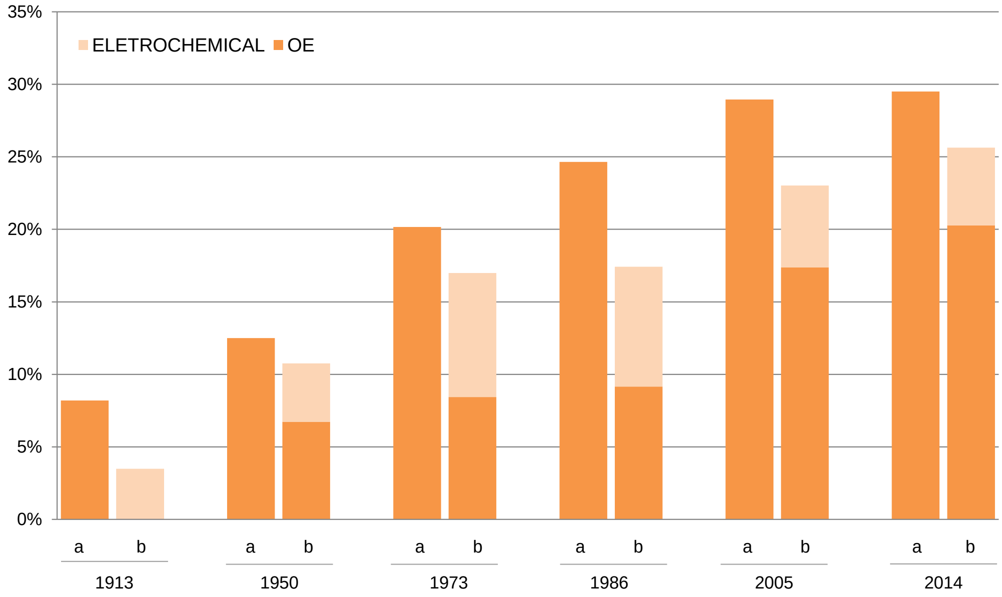

Figure 35: Other electrical and electrochemical uses shares from total final exergy (series a: Serrenho allocation, series b: new allocation) – OE (other electrical)

Figure 36: Electrochemical uses final exergy consumption 1913-2014 (TJ)

Cooling uses

Palma and co-authors (2014; 2016), have already introduced Cooling as a new end-use category to be considered. Their work shows how relevant it is a further disaggregation of the end-use categories of this energy carrier for data between 1960 and 2009. They show a decrease of 3.4% in overall aggregate efficiency for 2009 data (ibid). However, the lack of data for the period before 1960 makes it difficult to proceed to a very detailed disaggregation.

For the current dissertation, the cooling category was considered accordingly with Palma's assumptions. This means that the Cooling uses are disaggregated from stationary mechanical drive (stationary) category, as mentioned, and include air-conditioners and refrigerators.

The electricity shares used in Palma's work were applied directly. In other words, the cooling shares presented in Palma's work for final exergy were subtracted from each sector's mechanical drive uses. The exception was the Transport sector, as all exergy was allocated to mobile MD uses, considering that cooling shares in vehicles are low enough to be negligible (ibid).

For the Domestic/Services sector, we only consider the cooling category for benchmarks after 1960. This is based on the fact that consumptions were not significant for this category before this date. For example, in 1950, Porto was the city where the consumption of electricity was higher but the refrigerators were rare, with only 3.4% of the families with access to electricity having this type of appliances (Teives & Bussola 2005).

For the Industrial sector, the share allocated for cooling in 1950 was based on the tendency of the values from the following benchmarks for which data was available.

The consumption values of air-conditioning uses (cooling and heating) were calculated based on ICESD survey (Domestic Sector Consumption survey) (INE & DGEG 2010). It was considered that all the cooling that was not for refrigeration was performed by air-conditioning equipment. However, as it may be found in ICESD survey for 2010, most of the air cooling was performed by fans (69.5 of households) and here lies a problem. It was not possible to find data on allocation within the cooling uses (separate refrigerators and electrical fans consumption) for the Residential/Commercial services sector.
Also, fans bring out a problem as to which efficiency should be used, as they do not produce cold but rather their mechanical work cools the environment of, e.g., a room. Heun et al. (2017) (authors' ongoing work) have recently made a study in which they calculate electrical fans exergy efficiency for the period 1971-2013, for Ghana. According to authors, electrical fans efficiencies range from 10.2%, in 1971, to 12.6% in 2013, which are similar to efficiencies considered by Palma (2014) – and used in the new allocation - for all cooling uses in both Industry and Residential/Commercial services sectors.

When comparing allocations for mechanical drive uses, with and without cooling end-use (*Figure 37*), what is clear is an accentuated variation in MD uses evolution. This means that, for the first two benchmarks, despite considering the cooling uses in 1950, new allocation presents higher shares for MD. However, in 1950 the difference between shares is partially the cooling category and, for the following more recent benchmarks, MD uses have lower shares in the new allocation if excluding the cooling category.

What this may lead to is, in fact, a decrease in overall final-to-useful efficiency, as the cooling category has an efficiency lower than the one considered for other MD uses. And this effect is not perceptible when comparing shares of both allocations aggregated only into the end-use categories originally considered (*Table 13* and *Table 14*), because the aggregated efficiencies of MD uses are different for each allocation.

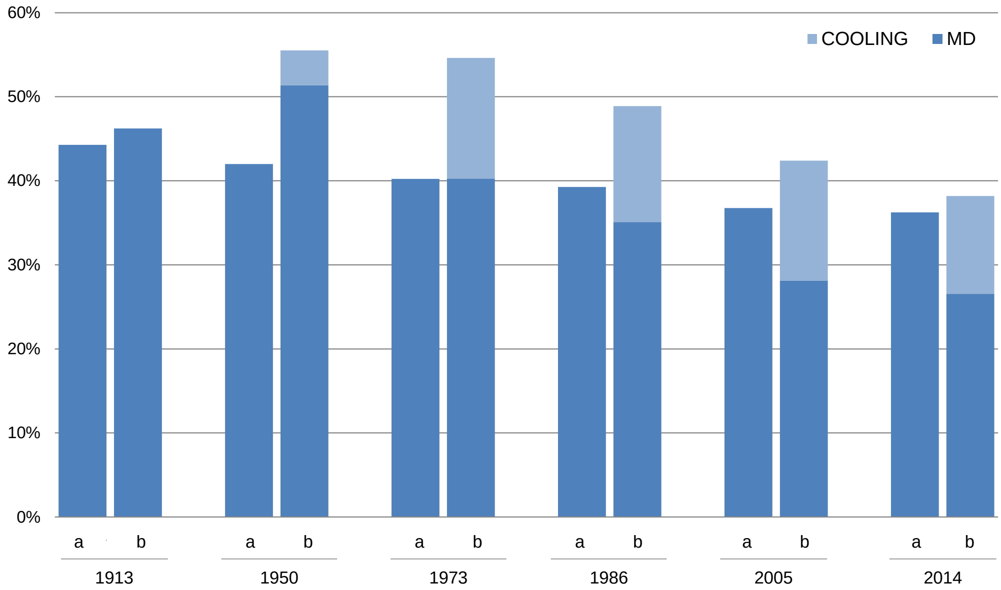

Figure 37: Mechanical drive uses shares from total final exergy (series a: Serrenho allocation, series b: new allocation) – MD (Mechanical Drive)

Similarly, to electrochemical uses consumption evolution, cooling uses final consumption (*Figure 38*) has been growing throughout time up until 2005, suffering then a decline of about 5000 TJ until 2014. What happens in fact is a peak of electricity consumption for cooling uses in 2005, and this is explained by the very high temperatures that occurred in the summer months of this year (Instituto Meteorologia 2006) – which was an extreme drought year, as mentioned previously. The identical consumption behavior for both types of uses is actually explained by fact that 2005 had an historical energy consumption peak, never met in the previous or following years.

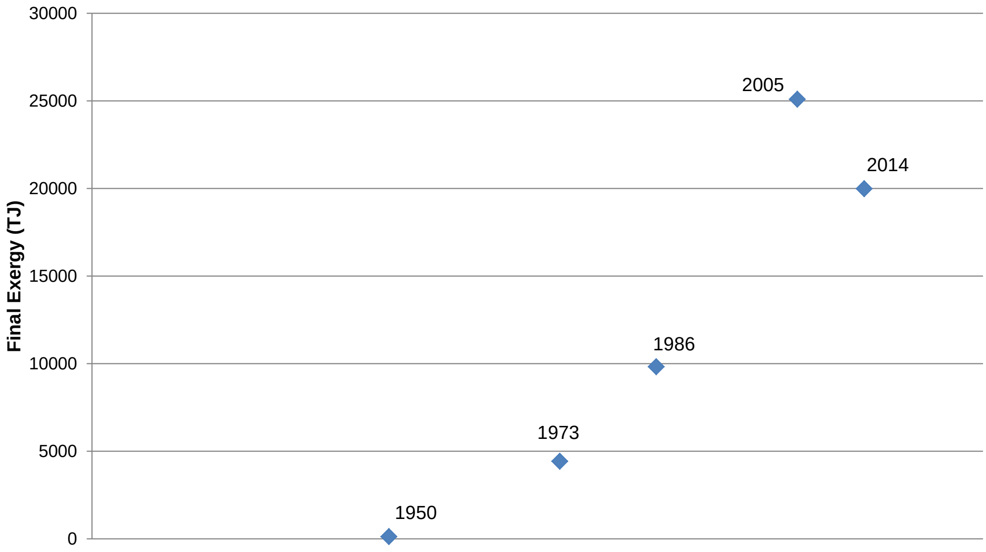

Figure 38: Cooling uses final exergy consumption 1913-2014 (TJ)

Going further than disaggregating end-use categories, shares were calculated by sector. This may allow a better understanding of Portugal's final exergy consumption throughout time, showing the influence each sector had.

4.3.2. Final exergy consumption shares by sector

A closer look to each sector individually allows a clearer picture of electricity's real uses. In other words, knowing the sector where, e.g., heat is used makes it possible to realize if the end use could be an electric furnace (industry) or a radiator (residential/commercial sector).

The evolution of sectors' final exergy shares (*Table 15*) shows a change in Portugal's electricity consumption structure. While the residential/commercial sector has been increasing its share, becoming the highest consumer between 1986 and 2005, the industrial sector has been decreasing its share.

Table 15 - Electricity shares per sector

	1913	1950	1973	1986	2005	2014
Industry	**44%**	**60%**	**65%**	**57%**	**42%**	**39%**
Electrochemical	8%	7%	13%	14%	13%	14%
Mechanical Drive	72%	69%	57%	55%	57%	57%
Cooling	0%	7%	8%	7%	8%	8%
Light	8%	8%	7%	6%	6%	6%
Heat	12%	9%	15%	16%	14%	15%
Other Electrical	0%	0%	0%	1%	1%	1%
Domestic/services	**41%**	**32%**	**33%**	**42%**	**57%**	**60%**
Mechanical Drive	0%	6%	2%	5%	5%	6%
Cooling	0%	0%	29%	23%	19%	14%
Light	100%	68%	19%	12%	13%	12%
Heat	0%	22%	25%	39%	33%	35%
Other Electrical	0%	4%	25%	21%	30%	33%
Transports	**14%**	**8%**	**2%**	**1%**	**1%**	**1%**
Mechanical Drive	100%	100%	100%	100%	100%	100%

Note that, if the Domestic and Services sectors were not aggregated, the Industry would be the highest electricity consumer (final exergy) for almost all benchmarks.

Domestic/services

Allocation in the domestic/services' sector has a high level of uncertainty because some of the equipment used in this sector could be allocated to several end-use categories (*Figure 39*), e.g. washing machines perform both MD and heat uses. Yet, the lack of data on the shares of each use requires the use of proxies, especially before the 1970's.

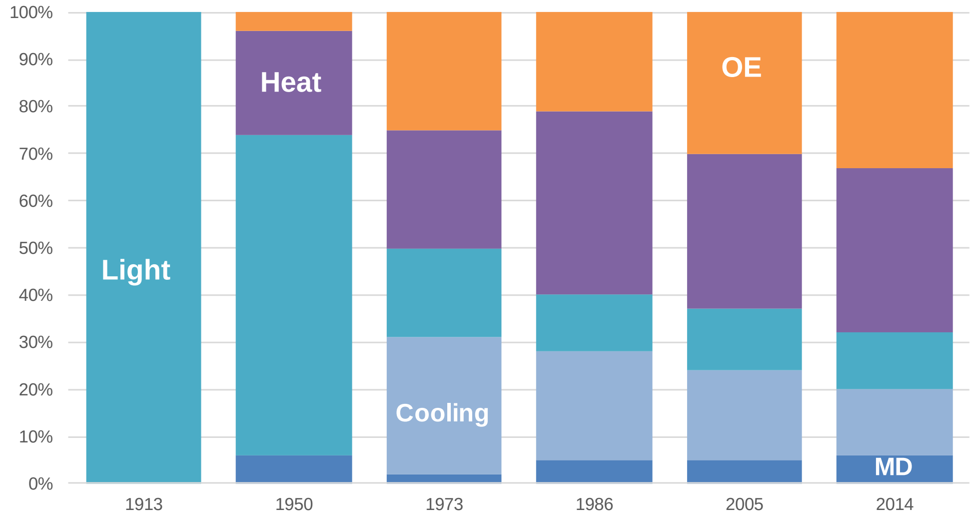

Figure 39: Final exergy shares for domestic/services sector 1913-2014

Acronyms: OE - other electrical uses; MD - Mechanical Drive

For this work, electricity shares were calculated based on Portuguese data from DGSE (1927-1984), INE/DGEG (1989; 2010) and a study from DGE (1980). From these sources not all available data could be directly allocated to the considered end-use categories (heat, MD, light, cooling and OE), because data was mainly aggregated as *lighting*, *kitchen uses*, *electrical equipment (miscellaneous)*, and *water/space heating*. Therefore, a rearrangement in domestic uses allocation had to be made to match data and end-use categories defined (*Table 16*).

Table 16 - Electricity shares allocation in the Domestic/Services sector

Sources allocation	Equivalent end-use categories
%Kitchen uses + water/space heating	Heat
Lighting	Light
%Kitchen uses	Mechanical Drive (a % was allocated to cooling)
Electrical equipment (miscellaneous)	Other Electrical uses

Exergy used for *lighting, electrical equipment (miscellaneous)* and *water/space heating* could be directly allocated to light, OE and heat categories, respectively. However, the *kitchen uses* group includes the big household appliances, i.e. refrigerators, washing machines and dishwashers, as well as other appliances, such as the electric stove/hob and the microwave.

Exergy consumed by kitchen appliances was allocated to heat and MD uses. Defining these end-use shares was done in three steps. First, available data on the appliances' consumption, which was obtained from DGE (1980), EDP (2017) and the website Loja da Luz (2017). The years for which data was available did not correspond directly to all the benchmarks and, so, a linear proxy was made to fill the data gaps. Then, refrigerator and kitchen extractor hood consumptions were allocated to MD uses while the electric stove/hob and microwave consumptions were allocated to heat. And, finally, consumptions attributed to machines (washing and dishwasher) were 20% allocated to MD and 80% to heat.

In the last step it was assumed that 80% of the machines' consumption is to heat the water and the rest is used for mechanical work (EDP 2017) for all the benchmark years, implying that, though their efficiencies have improved, the machines' mechanisms haven't change much throughout the decades.

At last, after allocating all the *kitchen uses*, a share from MD was allocated to the cooling based, as mentioned, on Palma's work (2014).

Industry

Data used for Industrial sector end-use allocation was taken from DGSE (1927-1984), INE (1950), and Ayres (2005), and final exergy was allocated to: heat, MD, light, cooling, electrochemical and OE uses (*Figure 40*).

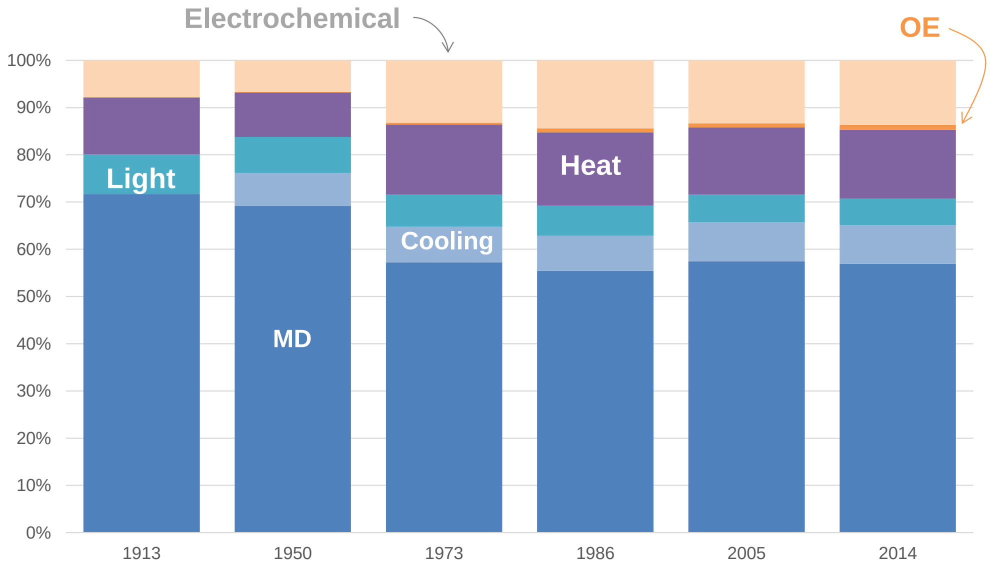

Figure 40: Final exergy shares for industrial sector 1913-2014

Acronyms: OE - other electrical uses; MD - Mechanical Drive

The shares considered for light and OE uses are from Ayres (2005) data for industry. Although there is an attempt to use solely Portuguese data in this work, the lack of it could only be solved by applying other country's shares. Taking into account that United States and EU developments might be similar to Portugal, this does not present an inconsistency, because the uses within the industrial sector and within each industry specifically, do not differ much from country to country. Therefore, even though Portugal and US have different exergy consumptions in absolute values, for the industrial sector specifically, it is acceptable to consider similar shares for light and OE.

Mechanical drive shares were based on INE (1943 1950). Available data from Industrial statistics (INE 1950) could not be used directly due to a representativeness issue in the study (Portugal industrial reality was not represented in the study by the few industries that participated). Thus, Electric installations statistics (DGSE 1927-1984), which do not present this issue, were used to correct values. However, this correction could only be done for 1950 and 1943 and, so, proxies for all other benchmarks were done based on corrected values.

Industrial statistics' data is divided into two categories: *força motriz* (mechanical drive) and *outros fins* (other uses). However, MD shares obtained directly from data were too high and had to be adjusted using other sources, i.e. Henriques (2009): light, electrochemical, cooling and OE uses were subtracted to MD shares obtained directly, considering that the "other uses" share included heat only. This problem emerges due to the representativeness issue mentioned above.

Transportation

All final exergy consumption was allocated to mechanical drive end-uses. Electricity consumed in this sector is used in rail transports such as trains, trams and subways, being more recently used in hybrid and electric road vehicles as well. Nonetheless, IEA (2016) does not allocate electricity for road vehicles in Portuguese data, yet.

4.4. Final-to-Useful efficiency

In Serrenho's work some of the shares used for Portugal are based on other countries' data (United Kingdom, Fouquet et al. (2006) and Unites States, Ayres et al. (2005)). As other data sources could not be found, final-to-useful efficiencies used are, in majority, the ones used by Serrenho.

In the efficiencies case, this does not represent an inconsistency with the argument of using Portuguese sources and more detailed data, because machinery is usually imported and exported worldwide and, thus, has similar efficiencies in several countries. This, of course, as long as singular characteristics of the region have small or no influence at all in the calculations, e.g. heat pumps are influenced by the temperature of the local where they are used. Also, being Portugal a European country, it is acceptable that final-to-useful efficiencies are the same within Europe and US, knowing these efficiencies refer to the technologies which are similar in developed countries.

Palma et al. (2016) showed that if considering a 10 year delay in technological level of Portugal, based on average life of stationary MD uses at home (e.g. washing machines), aggregate efficiency shows no significant difference (maximum difference of 0.2 percent).

Final-to-useful efficiencies are presents in *Table 17*.

Table 17 - Final-to-Useful Efficiencies

	1913	1950	1973	1986	2005	2014
Industry	**57.29%**	**63.84%**	**61.75%**	**62,62%**	**67.10%**	**68.39%**
Mechanical Drive	76.60%	76.99%	79.82%	82.53%	85.32%	86.24%
Cooling (refrigeration)	-	11.65%	11,26%	11,55%	12.13%	12.23%
Light	0.40%	0.70%	2.70%	2.65%	3.36%	3.86%
Heat	20.25%	33.35%	42.27%	45.12%	46.81%	46.80%
Other Electrical	0.00%	0.00%	0.04%	0.20%	1.27%	1.91%
Electrochemical	17.20%	27.39%	33.16%	36.43%	41.51%	43.64%
Domestic/services	**0.40%**	**6.35%**	**9.72%**	**10.54%**	**11.58%**	**12.59%**
Mechanical Drive	-	74.57%	76.59%	78.22%	79.98%	80.99%
Cooling (air-conditioning)	-	-	-	4.17%	5.50%	2.49%
Cooling (refrigeration)	-	15.10%	14.64%	14.98%	15.67%	15.78%
Light	0.40%	0.70%	2.70%	2.65%	3.36%	3.86%
Heat (air-conditioning)	-	-	-	8.23%	7.54%	6.84%
Heat (other)	-	10.73%	13.66%	14.54%	14.97%	16.09%
Other Electrical	-	-	0.04%	0.20%	1.56%	1.94%
Transports	**66.03%**	**77.73%**	**81.00%**	**82.90%**	**85.68%**	**87.01%**
Mechanical Drive	66.03%	77.73%	81.00%	82.90%	85.68%	87.01%

Mechanical drive efficiencies for Industry and Domestic/Services sectors were taken from Ayres et al. (2005), while the ones for Transportation are the efficiencies used by Serrenho et al. (2016), which are based on Ford et al. (1975) works.

Concerning exergy efficiencies of electrochemical and other electrical uses, both are from Ayres et al. (2005), as well as light efficiency for industry.

Light efficiency for Domestic/Services was taken from Warr et al. (2010). Although Serrenho (2013) used for Portugal's long-run series light efficiencies from Ayres (2005A), useful exergy series done more recently in his work for EU-15 countries (Serrenho et al. 2014) use Warr's efficiencies..

The difference in light efficiencies between the mentioned works is due to the use of different reference values. Light exergy efficiency is calculated by the ratio of lumens/watt generated by a real light source (e.g. in a fluorescent bulb) and a reference value of maximum lumens/watt generated by an ideal light source (Guevara et al. 2016). While Ayres (2005) and Serrenho (2013) consider 400 ln/W as the maximum reference, Warr et al. (2010) and Serrenho et al. (2014) consider 683 ln/W (considering a wavelength to which the human eye is most sensible – 555 nm) (Guevara et al. 2016). Light efficiencies with 400 ln/W as a reference are around 10% higher than the ones calculated for 683 ln/W reference.

Exergy efficiencies of cooling by refrigerators and air-conditioning (AC), as well as heating by AC, are calculated separately using the COP (coefficient of performance) and Carnot equation (*Figure 41*).

Exergy efficiency: $\epsilon = \frac{COP_{real}}{COP_{ideal}}$

Space cooling efficiency:

$$COP_{cool,ideal} = \frac{T_c}{T_0 - T_c}$$

$$\epsilon_{cool} = COP_{cool,real}\left(\frac{T_0 - T_c}{T_c}\right)$$

Space heating efficiency:

$$COP_{heat,ideal} = \frac{T_h}{T_h - T_0}$$

$$\epsilon_{heat} = COP_{heat,real}\left(\frac{T_h - T_0}{T_h}\right)$$

Figure 41: Exergy efficiencies for space cooling and heating (from Palma, 2014)

Regarding refrigerators, the average real COP considered was 2.7 (Taib et al. 2010), while to calculate the ideal COP it was considered that one third of the load was consumed by the freezer, -18^{o}C, and two thirds by the cooler box, 5 ^{o}C, for service temperature, following the works of Palma (2014) and Reistad (1975); the environmental temperature was considered to be the average temperature of the year.

For air-conditioners the real COP considered for both cooling and heating was 3.4 (Michel et al. 2015), while to calculate the ideal COP, the average maximum temperature of the hottest month was considered as environmental temperature (PORDATA 2017a) and 25^{o}C as the service, for cooling uses, whereas for heating, the average annual minimum temperature was used as the environmental temperature (PORDATA 2017c) and 20^{o}C was considered the service temperature.

Having all the end-use shares and final-to-useful efficiencies, it is possible to obtain the aggregate final-to-useful efficiency for Portugal (*Figure 42*). In order to estimate the impact on results of the new categories considered (electrochemical and cooling), aggregate efficiency calculations were computed considering, first, only one of these categories and then the new allocation complete.

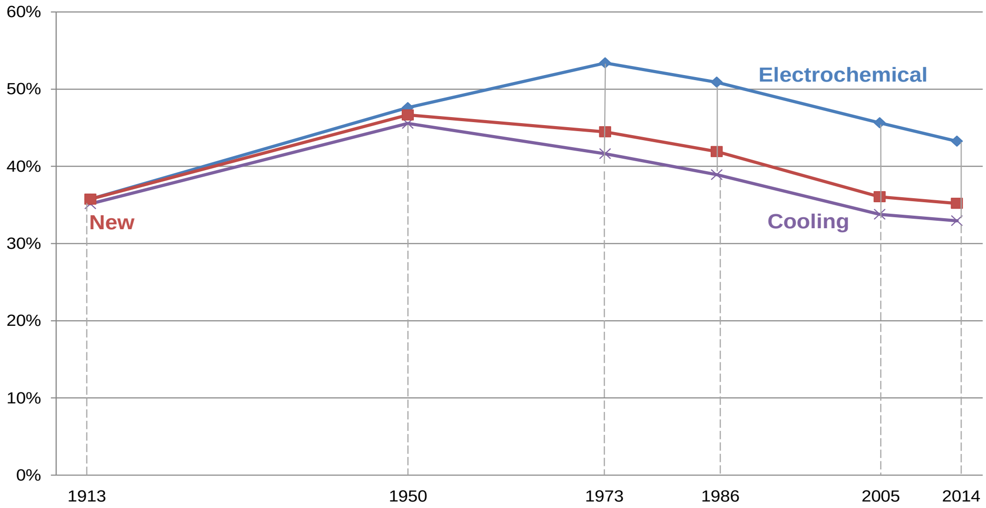

Figure 42: Electricity aggregate final-to-useful efficiency 1913-2014 (Electrochemical: new allocation without cooling uses; Cooling: new allocation without electrochemical uses; New: new series with all new categories)

First, it is clear that electrochemical uses increase the aggregate efficiency, while cooling has the opposite effect. This is because electrochemical uses have higher exergy efficiencies than OE, which was the category they were aggregated with. Using the same reasoning, cooling uses have a lower efficiency than MD, leading than to a decrease in aggregate efficiency.

When combining both ("New" series in *Figure 42*), the effect of cooling appears to outweigh electrochemical influence, resulting in a decrease of efficiency since 1950. The explanation is twofold: (1) on one hand electrochemical uses are only part of the industry consumption and, throughout time, this sector's share decreases (see *Table 15*), (2) on the other hand, cooling uses are present in both industry and domestic/services sectors. Besides that, not only cooling shares are around 20% of domestic/services final consumption – which is the double of its share in industry – but, also, the overall domestic/services consumption grows faster than the industrial, which leads to a growing share of the first and, consequently, a growing influence of cooling uses efficiency.

Now, when comparing the new series with the series from Serrenho's results (*Figure 43*), one observes that the aggregated efficiencies have different evolutions, starting both around 36% in 1913 but leading to values with a difference of about 4 p.p., being the new efficiency lower (around 36%). While Serrenho's aggregated efficiency has a growing tendency such that in 2014 efficiency is approximately 4 p.p. higher than in 1913, in the new series efficiency grows circa 9 p.p. in between the first and second benchmarks and, then, proceeds to decrease until it reaches approximately the same value in 2014 as in 1913.

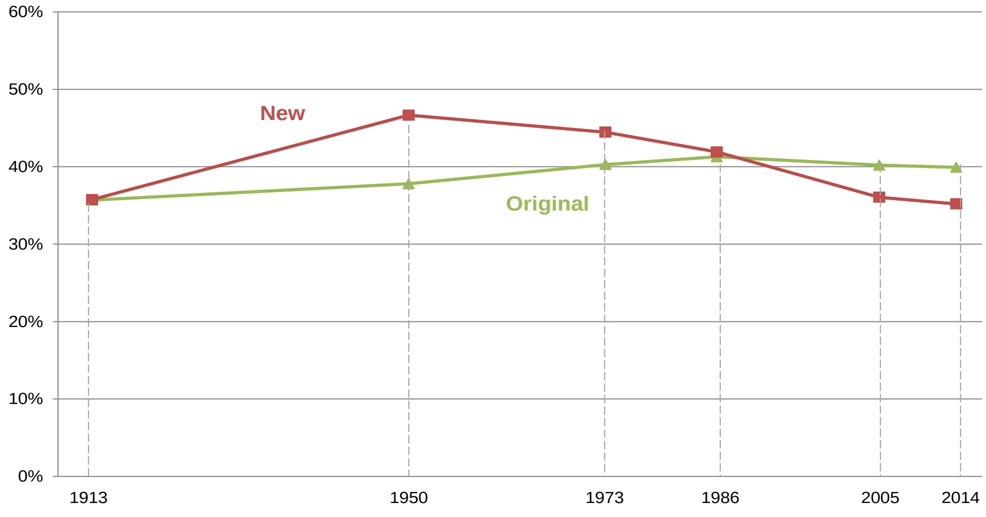

Figure 43: Electricity aggregate final-to-useful efficiency 1913-2014 (New: new series with all new categories; Original: Serrenho series and allocation)

The evolution in the electricity aggregate final to useful efficiency is explained by the "dilution" effect, where even though technologies have been increasing their individual efficiencies, the growth in consumption is towards less efficient uses, e.g. other electrical uses, leads overall final-useful efficiency to reach similar values of the beginning of the 20th century.

Interestingly this move towards less efficiency uses, and consequent dilution effect, is also verified by Ayres et al. (2005) for the United States in 1900-2000 at the final-useful level.

Finally, taking into account the new allocation and efficiencies used, new totals for final and useful exergy were obtained (Table 18 and Table 19).

For the new calculations, the totals obtained for final exergy differ from the original results only for the benchmarks previous to 1960. This happens due to the use of different sets of data for that period while after 1960, both the original and the new calculations for used IEA data for final exergy values. Nevertheless, for useful exergy, the results are different for all years, as expected.

4.5. Primary-to-Useful efficiency

The calculation of primary exergy for the Portuguese case study is new. Works done by Serrenho, Palma and co-authors were focused only on the final and useful stages. A primary-to-useful look brings a different notion of the energy flow and reveals the complete process associated to electricity consumption in all its stages and with all its transformations.

To calculate primary exergy data, primary-to-final efficiencies were used, tracing back values from final energy – gross electricity produced (*Figure 44*). Final energy data used to compute calculations was taken from Henriques (2009; 2011) and national energy balances – 2005 and 2014 (DGEG 2017a).

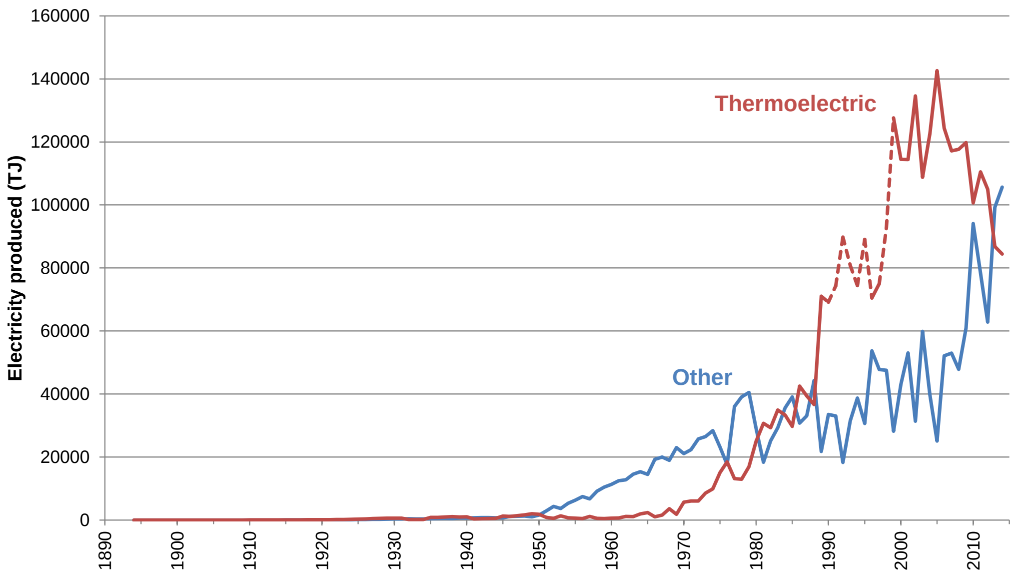

Figure 44: Electricity produced by source 1894 – 2014 [TJ] (Thermo: includes production from coal, oil, natural gas, biomass and other non-renewables; Other: includes production from hydro, wind, geothermal and solar photovoltaic)

Table 18: Final Exergy from electricity, original and new results (TJ)

	1913		1950		1973		1986		2005		2014	
	Original	New	Original	New	Original	New	Original	New	Original	New	Original	New
Mechanical Drive	7.3	7.5	1241.3	1566.1	12396.4	12408.1	27961.9	25010.3	64596.8	49420.1	62200.8	45542.5
Cooling	-	0	-	126.6	-	4422.5	-	9817.8	-	25095.3	-	19984.6
Light	6.3	7.3	1094.5	652.4	7837.4	3271.3	12201.0	6150.9	17887.6	17328.4	17215.7	16154.6
Heat	1.5	0.9	250.2	375.5	4372.4	5481.1	13513.1	17844.7	42355.7	43413.3	41546.5	45917.3
Other Electrical	1.3	0.001	369.5	205.3	6211.8	2598.5	17552.0	6522.1	50871.5	30539.6	50618.7	34777.9
Electrochemical	-	0.6	-	122.6	-	2636.4	-	5882.3	-	9914.9	-	9204.8
Total final exergy	**16.4**	**16.1**	**2955.5**	**3048.6**	**30817.9**	**30817.9**	**71228.0**	**71228.0**	**175711.6**	**175711.6**	**171581.7**	**171581.7**

Table 19: Useful exergy from electricity, original and new results (TJ)

	1913		1950		1973		1986		2005		2014	
	Original	New	Original	New	Original	New	Original	New	Original	New	Original	New
Mechanical Drive	5.1	5.5	920.3	1290.2	9700.2	10544.9	22788.9	21631.3	55714.8	44689.4	55047.7	41896.3
Cooling	-	0	-	14.8	-	596.7	-	1367.0	-	3690.5	-	2921.3
Light	0.2	0.03	84.4	4.6	789.1	88.3	1412.4	162.9	2417.1	581.7	2487.6	623
Heat	0.3	0.2	44.8	79.2	785	1596.3	2414.5	4532.6	7496.0	9791.4	7341.1	10252.7
Other Electrical	0.2	0	67.6	0.0001	1140.7	1.04	2789.9	13.04	5019.2	474.1	3628.6	675.4
Electrochemical	-	0.1	-	33.6	-	874.2	-	2142.9	-	4115.3	-	4017.3
Total useful exergy	**5.8**	**5.8**	**1117.1**	**1422.3**	**12414.9**	**13701.4**	**29405.8**	**29849.7**	**70647.1**	**63342.5**	**68505.1**	**60385.9**

The share of electricity obtained from thermoelectric production was higher than the share of primary electricity between 1990 and 2010. In *Figure 44*, the dashed line from 1990 to 2000 corresponds to a period for which only data on aggregate thermoelectric production totals were available and it was not possible to calculate production from each separate resource that constitutes it.

Also, as thermoelectric production as presented includes biomass consumption, *Figure 44* does not represent a comparison between renewable and non-renewable sources in the electricity mix.

If one looks separately for each resource used in electricity production (*Figure 45* and *Figure 46*), it is noticeable that hydro power was the first significant resource of electricity, and has been since 1894 one of the main sources used to produce electricity. Hydro production has had a similar range of values of thermoelectric production using non-renewable sources, i.e. coal, oil and, more recently, natural gas, separately.

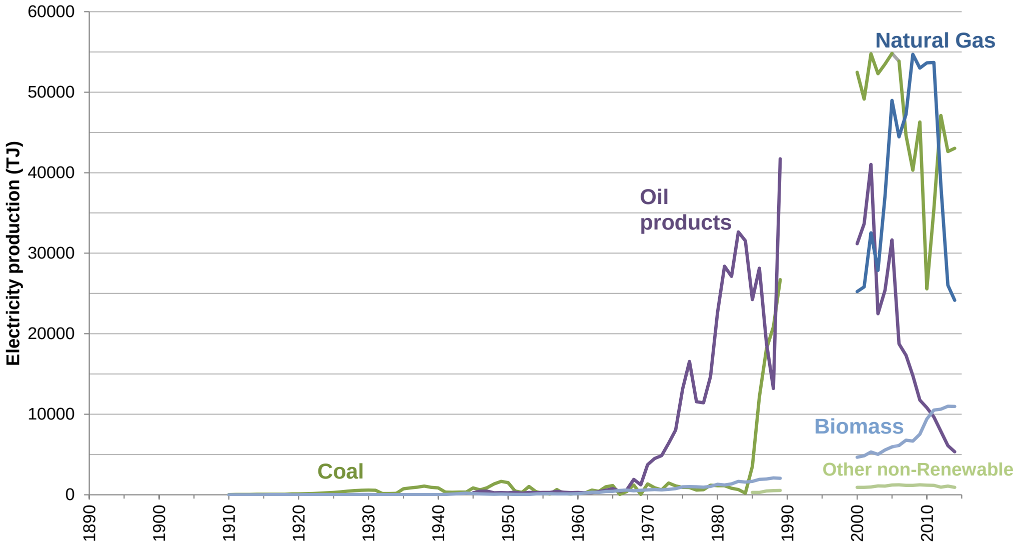

Figure 45: Thermoelectric production 1910 – 2014 [TJ]

Figure 45 presents series interrupted in the period of 1990 – 2000 due to the same reason pointed for the dashed line of thermoelectric production – only aggregate data was available.

While coal has been the main fuel up until 1940s – used in Tejo and Santos power plants – hydro power gains relevance since the 1950s with the start of production in several dams, specially Castelo de Bode (1951), Cabril (1954) and later, in 1964, Alto Rabagão dam (Madureira & Baptista 2002; REN 2012a).

By the beginning of the 1970s, three power plants – Carregado (1968), Tunes (1973) and Setúbal (1979) - using oil derivatives (fuel oil and diesel) started production, hence the increase in Oil products consumption by that time (REN 2012b).

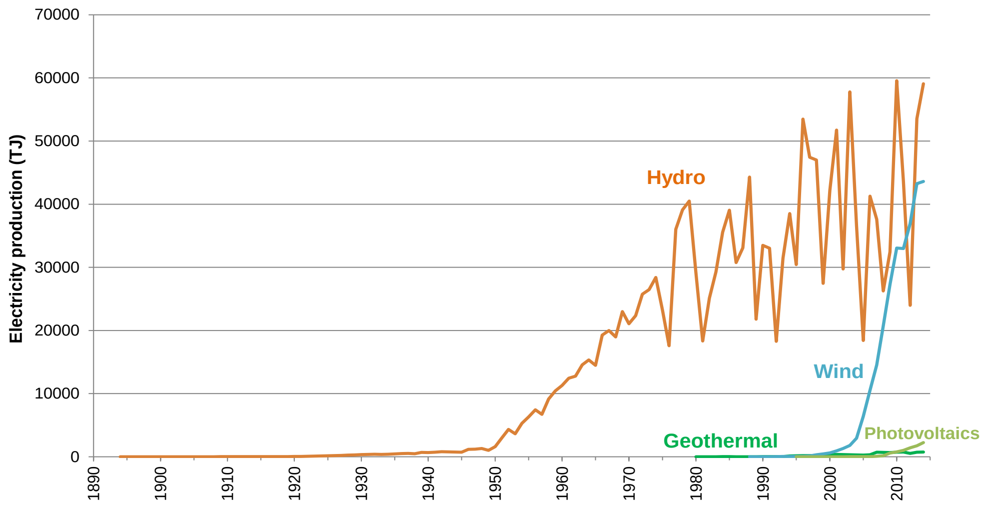

Figure 46: Electricity production with renewable sources 1884 – 2014 [TJ]

More recently, hydro power has grown firstly with the construction of Alqueva dam, that started production in 2003, as well as motivated by Government policies, i.e. the PNBEPH (Plano Nacional de Barragens de Elevado Potencial Hídrico) which is a plan that promotes the construction of dam to use around 20% more of Portugal's hydric power potential until 2020 (APA 2017b).

Also, due to Government incentives, wind power has been gaining relevance in the Portuguese electricity mix, reaching in 2014 a production equivalent to more than half of hydro's production (DGEG 2017b).

There are three different methods pointed by Sousa et al. (2017) to compute primary energy associated with electricity produced directly from renewable sources (hydro, wind, geothermal, solar, etc.): the Resource Content method (RCM), the Physical Content method (PCM) and the Partial Substitution method (PSM). All have been used in the last decades, although the RCM is the most common and has been used in works such Brockway et al. (2015), Warr et al. (2008), Rosen et al. (1992) and Wall et al. (1987).

The RCM is a method in which it is considered that primary energy is the energy of the resources. For this, the technologies' efficiencies used to produce electricity from renewable sources, are taken into account, e.g. the kinetic energy that pull the blades of wind turbines or the kinetic and potential energy of water in a dam (Sousa et al. 2017).

In Henriques (2009), the efficiencies considered to calculate final energy (and, so, the same used to trace back primary energy totals) were: 75% until 1960 and, from then on, 85% for hydro power; 40% for wind power; and, 15% for geothermal and photovoltaic.

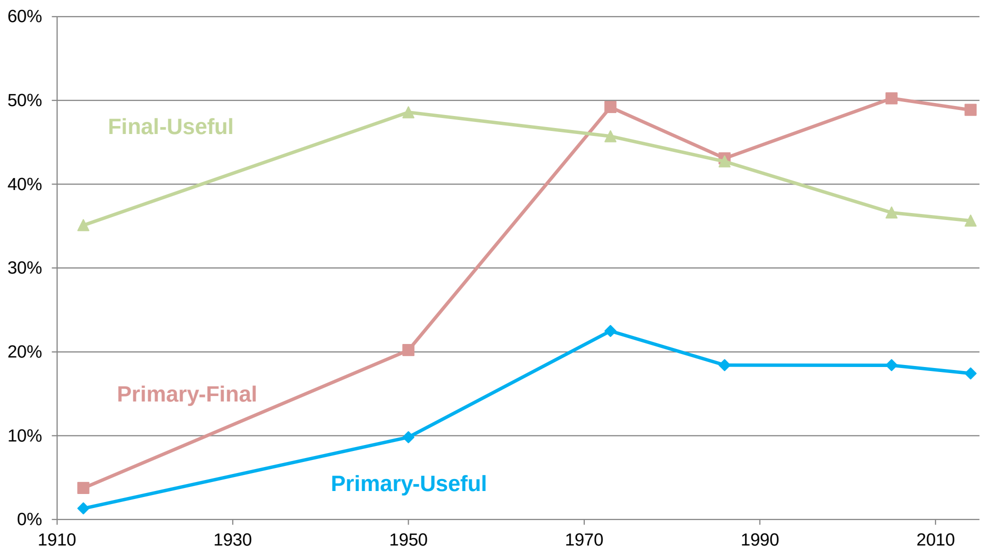

Figure 47: Electricity exergy efficiencies 1913 - 2014 (Resource Content method)

So, using RCM primary-final efficiency is about 3.7% in 1913 and evolves to approximately 48.9% in 2014, while primary-useful is around 1.3% and 14.7% in 1913 and 2014, respectively (*Figure 47*).

In the primary-final efficiency it is noticeable that 1973 is a benchmark where there's a peak of efficiency, deviating from the trend followed by other benchmarks. This might be explained if one looks at the resources being used for electricity production, as in 1973 is when hydropower is growing, being the main energy provider, and hydro efficiency (primary-final) considered in this work is higher than thermoelectric efficiency (about 2.4 times higher). With an opposite effect, in 1986, efficiency drops as the main resource for electricity production are Oil products (fuel-oil and diesel).

Combining previous efficiencies, one obtains the primary-useful for all benchmarks, which grows until 1973, proceeding to a drop in 1986 and, since then, a slight continuous decrease.

From another perspective, the PCM is based on the notion that the primary form of energy is the first form of energy available to be commercialized or, in other words, the gross electricity production is the primary energy considered (Sousa et al. 2017) for all renewable except for geothermal. In this case, heat is the first form of energy that can be commercialized. Works such Nakićenović et al. (1996) for the OCDE countries and for the world, as well as Schaeffer & Wirtshafter (1992) for Brazil, use this accounting method for electricity.

In the context of this dissertation it was considered that, to apply this method, the gross electricity produced from hydro, wind and solar photovoltaic is the primary energy correspondent to these resources, being considered for geothermal that only 10% of primary energy (heat) is gross electricity produced – so an efficiency of 10%.

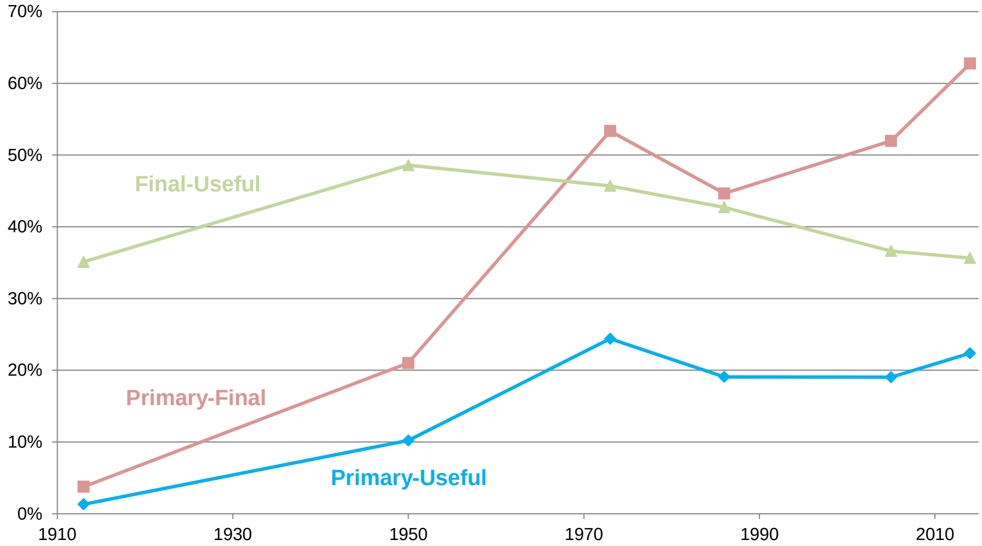

Figure 48: Electricity exergy efficiencies 1913 - 2014 (Physical Content method)

With the PCM, primary-final efficiency is around 3.7% in 1913, reaching about 62.8% in 2014 (*Figure 48*). After the peak in 1973 and subsequent drop in 1986, primary to final electricity efficiency tends to continuously grow at a fast rate, contrarily to what happened with RCM. This is due to a change in the electricity mix in the recent years, especially after 2000, with electricity production from renewables growing its share. This change is particularly highlighted using PCM because, while a primary-final efficiency is applied to thermoelectric production, to other sources it is considered that electricity is the primary stage, resulting in“100% primary-final efficiency” for those. The geothermal exception to this is, in fact, not relevant in Portugal case as its share is significantly lower than any other resource used, thus, with no significant effect in the results.

As for primary-useful efficiency, the development follows the same trend of primary-final but at lower values, being circa 1.3%, in 1913, and growing to 22.4% in 2014.

Finally, the PSM is a method that quantifies primary energy as the quantity of coal necessary in a conventional thermoelectric power plant to produce the same electricity produced by the renewable resources, so, the equivalent coal, ignoring the structure of the energy sector (Sousa et al. 2017).

For this work, unfortunately, it was not possible to find all fuel-specific efficiencies of thermoelectric production for all benchmarks (1986 is missing). Therefore, the efficiency used when applying this method was the aggregate thermoelectric production efficiency, since it was the only data available for all years and, which means that, here, we do not consider the equivalent coal, but rather the equivalent mix of fuels used for thermoelectric production in each year.

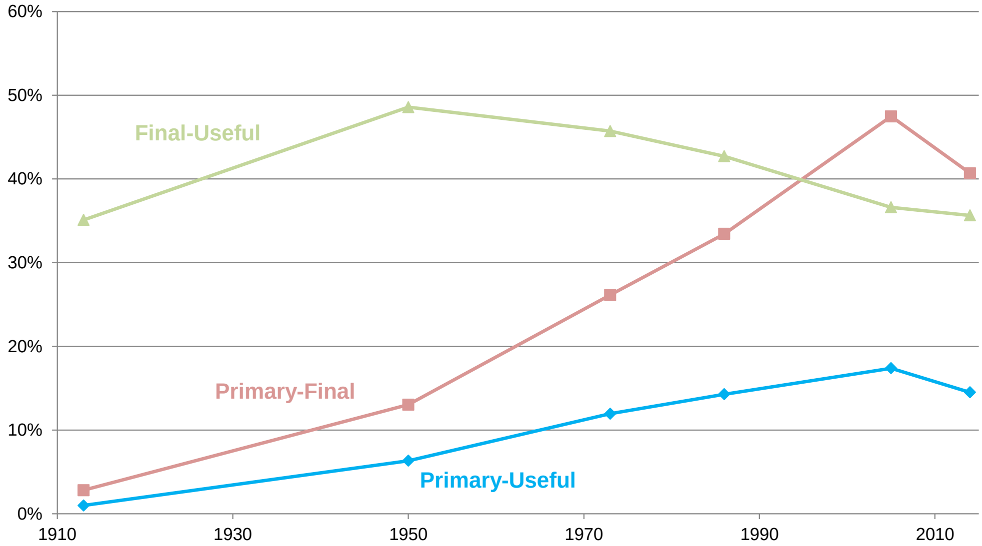

Figure 49: Electricity exergy efficiencies 1913 - 2014 (Partial Substitution method)

Using the PSM, primary-final efficiency grows from 2.8% to 40.7% in 1913 and 2014, respectively (*Figure 49*).

As expected, there is no peak in 1973 because, to this method, all resources have the same efficiencies and, so, a change in the mix of production is not perceptible in results. In 2005, there is a peak in efficiency which is motivated by a growth in consumption of coal for thermoelectric production as well as it is the first benchmark that considers the use of natural gas (in Portugal since 1997) for the same purpose. This motivates a peak because these two combustibles have the highest process efficiencies of all combustibles used to produce electricity. Note that, in Portugal, natural gas power plants with combined cycles have efficiencies much higher than coal power plants.

Comparing efficiencies calculated for all methods (*Table 20*), the Physical Content method presents the highest efficiencies because renewable resources have had an important role in the country's electricity production mix throughout time and this method highlights the use of those resources.

Table 20: Exergy efficiencies obtained using RCM, PCM and PSM in 1913 - 2014

	Primary - Final efficiency			Primary - Useful efficiency		
	RCM	PCM	PSM	RCM	PCM	PSM
1913	3.74%	3.76%	2.81%	1.31%	1.32%	0.99%
1950	20.19%	21.00%	13.02%	9.81%	10.20%	6.33%
1973	49.19%	53.35%	26.13%	22.49%	24.39%	11.95%
1986	43.08%	44.64%	33.43%	18.40%	19.07%	14.28%
2005	50.25%	51.97%	47.47%	18.40%	19.03%	17.38%
2014	48.85%	62.76%	40.67%	17.42%	22.37%	14.50%

Table 20 acronyms: RCM (Resource Content Method); PCM (Physical Content Method); PSM (Partial Substitution Method)

Also, as mentioned, average efficiency considered for thermoelectric production is lower (less than half) of hydro efficiency – the main renewable resource used – and, for that, PSM is the method presenting the lowest efficiencies. It points out the efficiency that would exist if only thermoelectric production was used.

Primary-final show an evolution similar to primary-useful (*Figure 50* and *Figure 51*), appearing all methods to converge to closer values in 2005. This can be explained by that year' weather conditions.

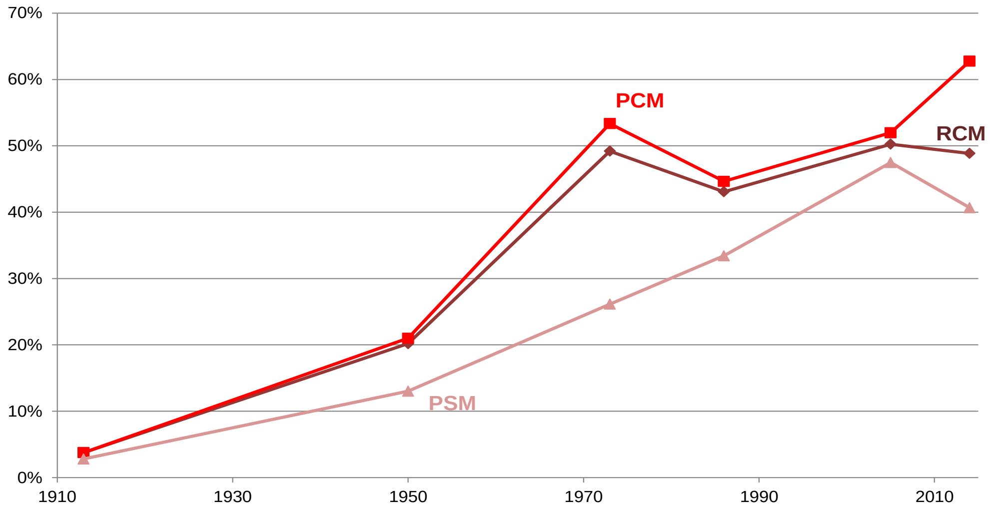

Figure 50: Primary-Final exergy efficiencies using RCM, PCM and PSM 1913 – 2014

Acronyms: RCM (Resource Content Method); PCM (Physical Content Method); PSM (Partial Substitution Method)

In 2005, Portugal endured an extreme draught (Instituto Meteorologia 2006), which led to a drop in hydric production and, consequently, an electricity mix with approximately 85% of electricity from thermal power plants. This fact brings RCM and PCM calculation results closer to the ones obtained with PSM, since the highest the share of thermoelectric production the closer it is to the assumption behind PSM – 100% thermoelectric production.

The relation of higher shares of renewables with higher efficiencies at the primary-final stage is also noticed by Williams et al. (2008) in a study for Japan, for the 20th century. The authors mention how a dilution effect, previously seen for Portugal in final-useful calculations, happens also at the primary-final stage in electricity generation for that country.

In Portugal's case, primary-final and primary-useful efficiencies series show that there is no dilution effect when going back to primary stage. This is because the share of renewables has increased in the 2000s once again. Contrarily to this, in Japan, hydro power decreased its share throughout time, as fossil fuel and nuclear plants were used to meet the growing electricity demand.

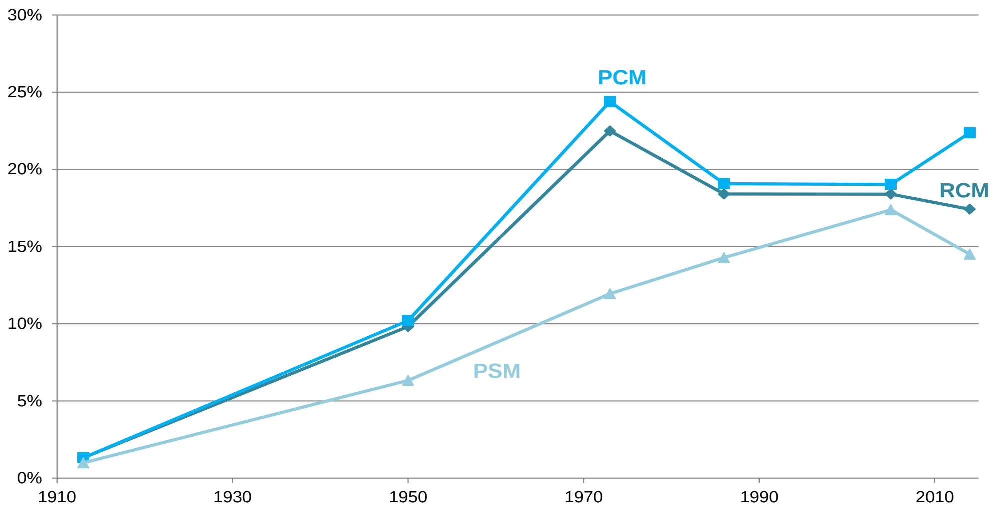

Figure 51: Primary-Useful exergy efficiencies using RCM, PCM and PSM 1913 – 2014

Acronyms: RCM (Resource Content Method); PCM (Physical Content Method); PSM (Partial Substitution Method)

However, the inverted U shape of final-useful efficiencies influences the primary-useful efficiency because it does not grow (using any of the methods) as much as primary-final efficiency does. In fact, for PCM and RCM methods, efficiency in 1986-2005 is practically constant. This is due to the decrease in final-useful efficiency observed.

As mentioned by Sousa et al. (2017) the choice of method should depend on the purpose for which calculations are being computed. However, as it is seen for Portugal, it is important to keep in mind that for cases where renewable resources have high shares in electricity production mix, efficiencies may differ significantly from one method to the other, e.g. around 10 p.p. difference in primary-useful 1973 RCM and PSM efficiencies, and primary-final efficiency approximately 20 p.p. lower in 2014 PSM than in PCM.

5. Conclusions

Within the core subject of useful exergy accounting, this dissertation explored: forecasts of useful exergy and exergy efficiency, as well as the use of detailed data for electricity to improve exergy accounting. The main goals were: 1) to calculate/simulate Portugal exergy consumption up to 2030, taking into account the effect of aggregate exergy efficiency in the economy and, 2) to study the impact of the use of detailed and specific data and the choice of methodology for primary electricity on exergy accounting.

Exergy forecasts for 2030 were estimated for two scenarios: the worst plausible scenario, the Ostrich, and the best plausible scenario, the Iberian Lynx.

The Ostrich scenario had an efficiency that grew about 1.3 p.p. by 2030, reaching an aggregate efficiency of approximately 23.5%. To this corresponds a decrease of 0.3 p.p. or 2 PJ in final exergy consumption 2014-2030 (702 PJ in 2030) and a slight increase of 9 PJ in useful exergy (165 PJ in 2030), for the same period.

A growth of almost 5 p.p. in aggregate efficiency up to 27.3% was observed in the Iberian Lynx scenario. With this aggregated efficiency, there is an associated consumption of 839 PJ of final exergy (more 135 PJ by 2030 compared to 2014) and 229 PJ of useful exergy, in 2030 (increase of 73 PJ).

These results show a rebound effect in both scenarios. In the Ostrich scenario, the decrease in final exergy (0.3 p.p.) is lower than the increase in efficiency (1.3 p.p.) between 2014 and 2030 while in the Lynx scenario the final exergy increases by 19 p.p. instead of decreasing. The explanation is that the increase in aggregated efficiency causes an economic growth (an increase in GDP); however, as higher GDP is directly liked to useful exergy (1 MJ /€ of GDP) there is always an increase in the consumption of useful exergy. The final exergy is then obtained by the ratio between the useful exergy and the aggregated efficiency.

The aggregate efficiency increases more in the Lynx scenario because the substitution: (1) of energy carriers by more efficient ones for the same uses (e.g. electricity replacing diesel in transport) and (2) of uses by more efficient ones (stationary mechanical drive replacing low temperature heat uses) occur faster for the Lynx scenario. This means that the Lynx corresponds to a move towards a society more reliant on electric transport and an industry more robotised and less dependent on heat.

Regarding GHG emissions, the main conclusion that can be taken is that a gain in aggregate exergy efficiency does not necessarily mean a decrease in emissions. What was observed in this case was a consequence of the mentioned rebound effect in consumption, as a significant increase in aggregate efficiency (Iberian Lynx scenario) leads to more consumption and, consequently, GHG emissions.

For that, the obtained results show that it is important to have policies that address possible rebound effects associated with higher exergy efficiency. For example, a continuous promotion of energysaving patterns of consumption in the society, at the consumers' level, should be accompanied by investment in renewable resources, allowing an increase in electricity consumption without an increase in the GHG emissions. Results show that policies must be directed to both energy consumption and production (electricity).

Jacobson (2017) with his roadmaps for countries' transition into 100% clean, renewable energy in 2050 (with 80% by 2030) corroborates this, highlighting the need for a rapid transition in order to tackle global warming and related issues such as health problems. For these roadmaps, it is considered the complete electrification of the countries – requiring the exclusive use of electrical appliances such as heat pumps, air conditioners, LED light bulbs, electric cars, cooktop stoves, induction furnaces and arc furnaces - and a 100% renewable electricity production from wind, water and solar power. So, the roadmaps consider and present the necessity for changes in all energy chain stages: primary, final and useful.

Focusing now on the fourth chapter of this dissertation, one looks at the use of detailed data. Benchmarks were chosen and new sources were explored to determine more accurately and reliably final exergy shares and efficiencies for electricity.

The inclusion of a new end-use category, i.e. electrochemical uses, as well as other changes such as the introduction of cooling uses (already done in by Palma (2014)), showed significant differences in electricity aggregate final-useful efficiency when compared to the series obtained by Serrenho (2013). In 2014, the Electricity aggregate efficiency obtained is 36%, in 2014, which is 4 p.p. lower than the aggregated efficiency obtained by Serrenho et al. (2016). The new results show that rather than a continuous increase of efficiency, suggested by Serrenho's results, electricity final-useful aggregate efficiency has grown until the last quarter of the 20th century, around the 1970s. After that, efficiency has been decreasing continuously, reaching in 2014 a value similar to 1913.

This efficiency decrease is due to the "dilution effect", also mentioned by Ayres et al. (2005) for the US (1900-2000). The explanation for this effect is the following. While individual thermodynamic efficiencies of appliances increase due to technological evolution, the aggregate efficiency, which is a weighted average of all efficiencies, decreases because the end-uses that are less efficient become more important. One example is the new technologies for wireless charging of appliances such as smartphones. Although it's a new technology, it shifts consumption towards a less efficient use.

This effect may occur at the primary-final level as well when societies move towards less efficient resources such as moving from hydropower to fossil fuels, as shown by Williams et al. (2008) for Japan.

The differences between results show the importance of using as much detailed data as possible to estimated final to useful exergy efficiency.

Results obtained in chapter 4, make us question the increase of almost 5 p.p. in aggregated efficiency between 2014 and 2030, assumed for the Lynx scenario (in Chapter 3). Replacing the new electricity series on Portugal's aggregate final-useful series and making a linear projection to 2014-2030 reveals a difference of approximately 2 p.p. with the linear trend forecast based on Serrenho's values. Applying that difference to both scenarios would show the Ostrich with no increase, and even a decrease, in aggregate efficiency 2014-2030, and an increase around 3 p.p. for the Iberian Lynx, in the same period.

This means that, to assure an increase in aggregate efficiency at a national level, besides increasing thermodynamic efficiencies with technologic development, it is important to take into account consumers habits and behaviour, and how this "part of the equation" may influence the calculations.

Based on previous studies such as Williams et al. (2008), it is clear that the higher the share of renewable sources in the production mix of a country is, the bigger are the differences between methodologies. The results obtained, corroborate this for Portugal, showing that the choice of methodology to calculate primary exergy has a significant influence in results obtained – as the Portuguese production mix has a high share of renewables, i.e. about 60% for 2014.

For cases such as the Portuguese, efficiencies may differ significantly between methods, e.g. in 1973 there is a 10 p.p. difference in the primary-useful aggregate efficiency between the Physical Content method and the Partial Substitution Method, while in 2014, primary-final efficiency is approximately 15 p.p. lower in Resources Content method than in Physical Content method.

Primary-useful efficiencies show an evolution that is similar to primary-final. However, the dilution effect influences the primary-useful efficiency as it does not grow (using any of the methods) as much as primary-final efficiency does. In fact, for PCM and RCM methods, primary-useful efficiency in 1986-2005 is practically constant.

In other words, throughout time, by observing all efficiencies calculated one understands that savings of natural resources increase along with primary efficiency increase and the use of alternatives to fossil fuels. Yet, the technological evolution leads to a growth in electricity consumption due to the dilution effect at the useful stage. So, it is as if two different forces lead the evolution of electricity production-consumption chain. At the primary stage, towards the consumption of less resources, and at the useful stage towards the opposite way.

Finally, with an overall view of this work, it is interesting to highlight a couple more notes:

- When researching for new data, past efficiencies were very difficult to obtain. For example, to try to improve the energy efficiency for heat uses an historic series of boiler efficiencies was used. However, due to the uncertainties in the efficiency values that varied within a range of ≈20% the dataset could not be used;

- Working in MEET2030 project has revealed the communication difficulties inherent to the use of concepts that are not widely known, such as exergy, and the need to fully understand the scientific background of a theme to be able to simplify it to a "non-scientific language" in order to achieve a broader public besides the scientific community.

Based on the work developed in this dissertation, some topics that are worth developing in the future have emerged, such as: (1) upgrades in Serrenho's useful exergy series for Portugal by improving coal related calculations (vapour locomotives consumption calculations) and including city gas as an energy carrier, (2) detailed analysis of the impact that rebound and "dilution" effects have had in the past for energy consumption and efficiencies evolutions in Portugal.

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ANNEXES

ANNEX I: 2nd and 3rd Challenges' Questions

- **2nd Challenge -** In some questions participants should answer filling in tables as presented here.

Q1 – Specify all the outputs (with economic value) of your company?

Q2 - Which is (are) the final societal service(s) that your company is contributing to? How?

Societal Services	How?

Q3 – For each technology used in your company, identify the energy carrier and the end-use? (a list of energy carriers and end-uses is provided in the Supporting Material)

Energy Carrier	Technology	Energy End-Use

Q4 - Identify 2 or 3 technologies that would allow your company to: 1) use energy & material wastes; and/or 2) decrease energy consumption; and/or 3) use more renewable energy; and/or 4) decrease CO_2 emissions in its own production process.

Current technology	New technology	Description

Q5 – Identify 1 (or more) technology (ies) or products or services that would allow your company to decrease the materials & energy consumption outside its production process with an impact in society (a list of technologies will be provided for inspiration).

Technology/Product/Service	Description

Q6 – In the past, what were the technologies that have deeply transformed your sector? How?

Past	Present	Changes

Q7 - In the future, what are the technologies that might transform your sector (the more disruptive, the better)? How? (a list of technologies will be provided for inspiration).

Present	Future	Changes

- **3rd Challenge -** To complete this challenge each company received information about shares and efficiencies considered for its own sector.

Q1 – Do you agree with the evolution of exergy consumption shares and efficiencies presented for your sector? Do you think there should be changes? Please comment on the results presented in graphs.

Q2 – Imagine your company in the Iberian Lynx scenario.

Q2.1 – Would new Technologies be needed in your company/sector in order to achieve suggested changes in efficiencies and/or end-use shares? Which technologies and for what type of end-uses? (Please consider your answers to questions Q3, Q4 and Q5 in the 2nd Challenge).

Q2.2 – In order to lead your company in the Iberian Lynx goals' direction, what would be the new business models needed for your company to access new technologies and/or overcome policy possible policy constraints?

Q2.3 – Which public policies could help your company in the transition for the Iberian Lynx scenario direction?

ANNEX II: Ostrich scenario data

- **Electricity uses final exergy shares and final-useful efficiencies, per end-use 2000-2030**

Table Annex 1: Electricity uses final exergy shares for industrial sector and others 2000-2014 (Ostrich scenario)

	Industry				Non-Industry			
	Mechanical drive	Heat	Other Electrical uses	Light	Mechanical drive	Heat	Other Electrical uses	Light
2000	46%	11%	27%	15%	21%	35%	29%	15%
2001	47%	11%	27%	15%	21%	35%	29%	15%
2002	48%	11%	27%	14%	21%	35%	30%	14%
2003	48%	11%	27%	13%	22%	35%	30%	13%
2004	49%	11%	27%	13%	22%	35%	31%	13%
2005	50%	11%	27%	12%	22%	35%	31%	12%
2006	50%	11%	27%	11%	22%	35%	32%	11%
2007	51%	11%	27%	11%	22%	35%	33%	11%
2008	52%	11%	27%	10%	21%	35%	34%	10%
2009	52%	11%	27%	9%	24%	33%	33%	9%
2010	53%	11%	27%	9%	23%	34%	34%	9%
2011	54%	11%	27%	8%	23%	34%	35%	8%
2012	54%	11%	27%	7%	23%	34%	35%	7%
2013	55%	11%	27%	7%	24%	34%	36%	7%
2014	56%	11%	27%	6%	24%	34%	36%	6%
2015	56%	11%	27%	6%	24%	34%	36%	6%
2016	56%	11%	27%	6%	24%	34%	36%	6%
2017	56%	11%	27%	6%	24%	34%	36%	6%
2018	56%	11%	26%	6%	24%	34%	36%	6%
2019	57%	11%	26%	6%	24%	34%	36%	6%
2020	57%	11%	25%	6%	24%	34%	36%	6%
2021	58%	11%	25%	6%	24%	34%	36%	6%
2022	58%	11%	24%	6%	24%	34%	36%	6%
2023	59%	11%	24%	6%	24%	34%	36%	6%
2024	59%	11%	23%	6%	24%	34%	36%	6%
2025	60%	11%	23%	6%	24%	34%	36%	6%
2026	60%	11%	22%	6%	24%	34%	36%	6%
2027	61%	11%	22%	6%	24%	34%	36%	6%
2028	61%	11%	21%	6%	24%	34%	36%	6%
2029	62%	11%	21%	6%	24%	34%	36%	6%
2030	60%	11%	23%	6%	24%	34%	36%	6%

Table Annex 2: Final-useful efficiencies for electricity uses 2000-2030 (Ostrich scenario)

	Mechanical drive	Heat (industry)	Heat (non-industrial)	Other electrical uses	Light
2000	85,0%	26,4%	17,7%	11,3%	13,1%
2001	85,0%	26,4%	17,8%	11,0%	13,2%
2002	85,0%	26,4%	17,7%	10,7%	13,3%
2003	85,0%	26,3%	17,6%	10,4%	13,3%
2004	85,0%	26,4%	17,7%	10,1%	13,4%
2005	85,0%	26,4%	17,7%	9,9%	13,5%
2006	85,0%	26,3%	17,6%	9,6%	13,6%
2007	85,0%	26,4%	17,8%	9,3%	13,6%
2008	85,0%	26,4%	17,8%	8,9%	13,8%
2009	85,0%	26,3%	17,5%	8,6%	14,2%
2010	85,0%	26,3%	17,6%	8,6%	14,0%
2011	85,0%	26,2%	17,5%	8,6%	14,2%
2012	85,0%	26,4%	17,7%	8,6%	14,3%
2013	85,0%	26,4%	17,8%	8,6%	14,4%
2014	85,0%	26,3%	17,7%	8,6%	14,5%
2015	85,0%	26,3%	17,7%	8,6%	14,5%
2016	85,0%	26,3%	17,7%	8,6%	14,5%
2017	85,0%	26,3%	17,7%	8,6%	14,5%
2018	85,0%	26,3%	17,7%	8,6%	14,5%
2019	85,0%	26,3%	17,7%	8,6%	14,5%
2020	85,0%	26,3%	17,7%	8,6%	14,5%
2021	85,0%	26,3%	17,7%	8,6%	14,5%
2022	85,0%	26,3%	17,7%	8,6%	14,5%
2023	85,0%	26,3%	17,7%	8,6%	14,5%
2024	85,0%	26,3%	17,7%	8,6%	14,5%
2025	85,0%	26,3%	17,7%	8,6%	14,5%
2026	85,0%	26,3%	17,7%	8,6%	14,5%
2027	85,0%	26,3%	17,7%	8,6%	14,5%
2028	85,0%	26,3%	17,7%	8,6%	14,5%
2029	85,0%	26,3%	17,7%	8,6%	14,5%
2030	85,0%	26,3%	17,7%	8,6%	14,5%

- **Shares for useful and final exergy per sector, energy carrier and end-use, for 2000, 2014 and 2030, as well as final-useful efficiencies for the same years**

Table Annex 3: Final-Useful efficiencies, useful & final exergy shares in 2000, 2014 and 2030 (Ostrich scenario)

Sector	Energy Carrier	Type of End-use	Useful Share			Final Share			Efficiency		
			2000	2014	2030	2000	2014	2030	2000	2014	2030
Energy sector	**Coal**	HTH	0,29%	0,00%	0,00%	0,13%	0,00%	0,00%	46,81%	46,80%	46,80%
		LTH1	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	19,55%	19,53%	19,53%
	Oil	MW3 smd	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	12,56%	12,61%	12,61%
		MTH	**4,85%**	**4,63%**	**4,38%**	**3,96%**	**3,90%**	**3,90%**	26,36%	26,34%	26,34%
	Natural Gas	MW3 smd	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	38,40%	39,58%	39,58%
		HTH	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	46,81%	46,80%	46,80%
		MTH	0,00%	1,04%	1,82%	0,00%	0,88%	1,62%	26,36%	26,34%	26,34%
	Electricity	Industry	1,92%	**3,09%**	2,83%	1,04%	1,28%	1,17%	47,54%	53,54%	56,80%
	Heat	MTH	0,00%	1,04%	2,37%	0,00%	0,87%	2,11%	26,36%	26,34%	26,34%
Industry	**Coal**	HTH	**4,88%**	0,02%	0,00%	2,27%	0,01%	0,00%	46,81%	46,80%	46,80%
		MTH	0,25%	0,01%	0,00%	0,15%	0,01%	0,00%	26,36%	26,34%	26,34%
	Oil	HTH	**5,18%**	2,22%	1,76%	2,99%	1,34%	1,13%	46,81%	46,80%	46,80%
		MTH	**4,75%**	2,20%	1,75%	2,79%	1,34%	1,12%	26,36%	26,34%	26,34%
		LTH1	**3,53%**	0,31%	0,25%	**3,87%**	0,35%	0,29%	19,55%	19,53%	19,53%
		LTH2	0,78%	0,24%	0,07%	1,11%	0,35%	0,12%	14,97%	14,95%	14,95%
		MW2	0,03%	0,03%	0,02%	0,07%	0,06%	0,05%	10,12%	10,37%	10,37%
		MW3 d	1,03%	0,36%	0,31%	1,77%	0,63%	0,58%	12,56%	12,61%	12,61%
		MW3 smd	0,37%	0,21%	0,03%	0,64%	0,37%	0,05%	12,56%	12,61%	12,61%
	Combustible Renewables	HTH	0,00%	0,01%	0,03%	0,00%	0,01%	0,02%	46,81%	46,80%	46,80%
		MTH	0,00%	0,74%	1,27%	0,00%	0,62%	1,13%	26,36%	26,34%	26,34%
		LTH1	**6,31%**	**5,59%**	**4,94%**	**6,93%**	**6,35%**	**5,94%**	19,55%	19,53%	19,53%
		LTH2	0,34%	0,11%	0,01%	0,49%	0,16%	0,01%	14,97%	14,95%	14,95%
		MW3 d	0,00%	0,01%	0,02%	0,00%	0,01%	0,03%	12,65%	12,96%	12,96%
		MW3 smd	0,00%	0,07%	0,19%	0,00%	0,04%	0,12%	38,40%	39,58%	39,58%
	Natural Gas	HTH	2,71%	**3,96%**	2,97%	1,56%	2,32%	1,79%	46,81%	46,80%	46,80%
		MTH	2,46%	**3,33%**	2,14%	1,44%	2,02%	1,37%	26,36%	26,34%	26,34%
		LTH1	0,43%	1,35%	1,74%	0,47%	1,53%	2,09%	19,55%	19,53%	19,53%
		LTH2	0,10%	0,53%	0,87%	0,15%	0,78%	1,37%	14,97%	14,95%	14,95%
	Electricity	Industry	**13,46%**	**19,36%**	**18,57%**	**7,25%**	**8,02%**	**7,68%**	47,54%	53,54%	56,80%
	Heat	HTH	0,37%	0,28%	0,88%	0,17%	0,13%	0,44%	46,81%	46,80%	46,80%
		MTH	0,11%	0,57%	0,65%	0,09%	0,48%	0,58%	26,36%	26,34%	26,34%
		LTH1	0,13%	0,65%	1,42%	0,15%	0,74%	1,71%	19,55%	19,53%	19,53%
Transports	**Oil**	MW1	1,53%	1,16%	1,31%	1,25%	0,83%	1,00%	26,16%	30,94%	30,94%
		MW2	**5,94%**	**3,55%**	2,63%	**12,62%**	**7,59%**	**5,95%**	10,12%	10,37%	10,37%
		MW3 d	**11,01%**	**13,63%**	**11,03%**	**18,84%**	**23,97%**	**20,53%**	12,56%	12,61%	12,61%

Sector	Energy Carrier	Type of End-use	Useful Share			Final Share			Efficiency		
			2000	2014	2030	2000	2014	2030	2000	2014	2030
		Navigation	0,44%	0,96%	0,99%	0,25%	0,54%	0,59%	38,40%	39,58%	39,58%
		Electric & Hybrid	0,36%	0,07%	0,06%	0,32%	0,07%	0,06%	24,33%	25,35%	25,35%
	Combustible Renewables	MW2	0,00%	0,01%	0,01%	0,00%	0,01%	0,02%	10,12%	10,37%	10,37%
		MW3 d	0,00%	1,01%	0,90%	0,00%	1,73%	1,63%	12,65%	12,96%	12,96%
	Natural Gas	NG vehicles	0,00%	0,03%	0,05%	0,01%	0,08%	0,14%	8,00%	8,00%	8,00%
	Electricity	Electric & Hybrid	0,19%	0,18%	1,69%	0,16%	0,16%	0,72%			
Residential / Commercial (Services)	**Coal**	LTH3	0,10%	0,00%	0,00%	0,23%	0,00%	0,00%	8,80%	8,80%	8,80%
	Oil	LTH3	2,32%	1,58%	1,38%	**5,68%**	**3,97%**	**3,67%**	8,80%	8,80%	8,80%
		MW2	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	10,12%	10,37%	10,37%
	Combustible Renewables	LTH3	2,76%	2,16%	1,99%	**6,74%**	**5,44%**	**5,30%**	8,80%	8,80%	8,80%
		MW3 d	0,00%	0,01%	0,02%	0,00%	0,01%	0,04%	12,65%	12,96%	12,96%
	Natural Gas	LTH3	0,29%	1,18%	0,95%	0,72%	2,98%	2,53%	8,80%	8,80%	8,80%
	Electricity	Other	**18,01%**	**20,32%**	**23,86%**	**9,70%**	**14,93%**	**18,57%**	29,30%	30,16%	30,16%
	Heat	LTH3	0,01%	0,04%	0,06%	0,02%	0,10%	0,15%	8,80%	8,80%	8,80%
	Solar thermal	LTH3	0,01%	0,05%	0,07%	0,02%	0,12%	0,19%	8,80%	8,80%	8,80%
Agriculture / Fishing	**Oil**	LTH2	0,04%	0,04%	0,00%	0,06%	0,06%	0,01%	14,97%	14,95%	14,95%
		LTH3	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	8,80%	8,80%	8,80%
		MW1	0,00%	0,20%	0,17%	0,00%	0,15%	0,13%	26,16%	30,94%	30,94%
		MW2	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	10,12%	10,37%	10,37%
		MW3 d	2,10%	1,23%	1,01%	**3,58%**	2,17%	1,88%	12,56%	12,61%	12,61%
	Combustible Renewables	LTH3	0,00%	0,01%	0,00%	0,00%	0,02%	0,00%	8,80%	8,80%	8,80%
		MW3 d	0,00%	0,01%	0,04%	0,00%	0,02%	0,07%	12,65%	12,96%	12,96%
	Natural Gas	LTH2	0,00%	0,02%	0,02%	0,00%	0,03%	0,03%	14,97%	14,95%	14,95%
		LTH3	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	8,80%	8,80%	8,80%
	Electricity	Other	0,60%	0,59%	0,50%	0,32%	0,43%	0,39%	29,30%	30,16%	30,16%
	Heat	LTH1	0,01%	0,00%	0,00%	0,01%	0,00%	0,00%	19,55%	19,53%	19,53%

- **Sankey Diagram –** Only for electricity and co-generation was primary-final efficiency considered. For other energy carriers, the only losses are from transport, with exception of oil products, but are not significant. For oil products, refinery efficiency is higher than 90%. For this, exergy destruction showed in the final stage is related solely to electricity and co-generation heat production. Within the exergy destruction is considered the dissipated heat.

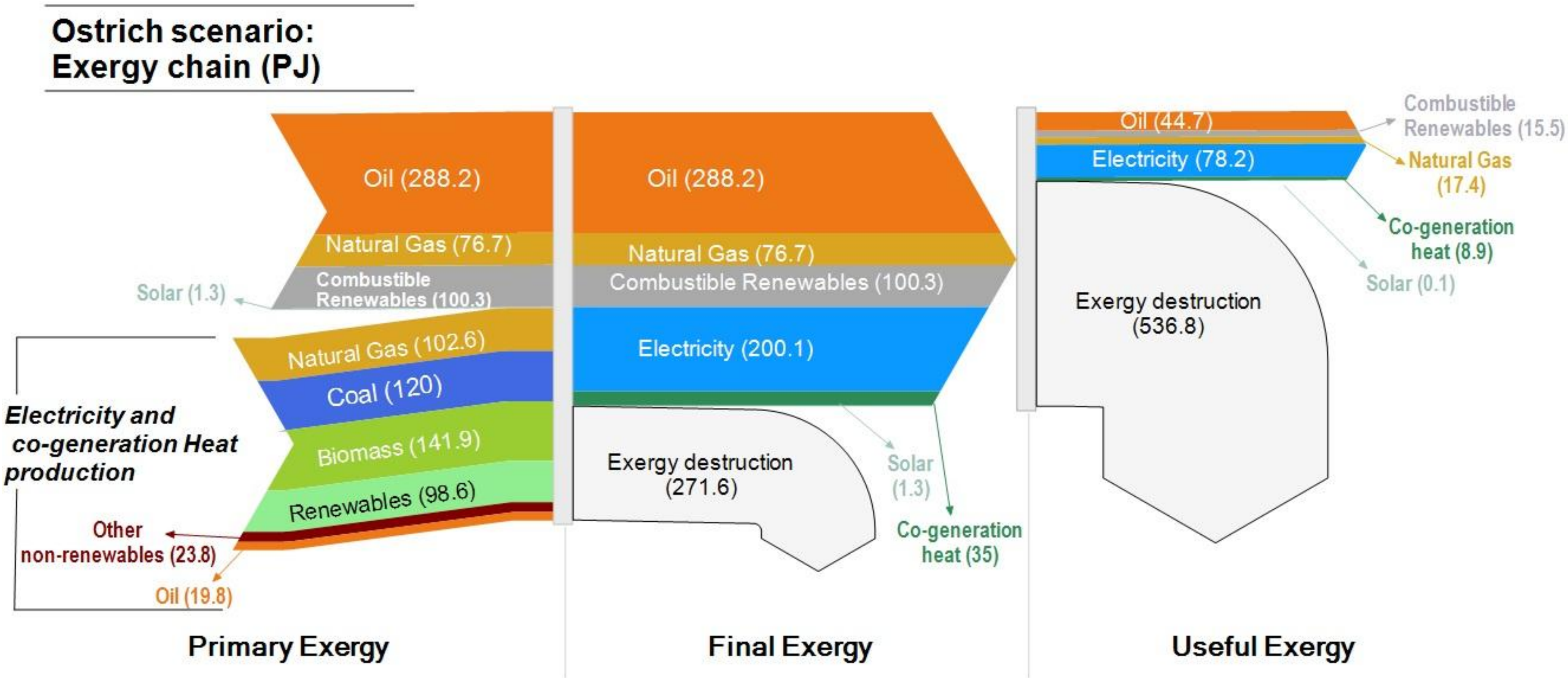

Figure Annex 1: Sankey Diagram for 2030 (Ostrich scenario)

ANNEX III: Iberian Lynx scenario data

- **Electricity uses final exergy shares and final-useful efficiencies, per end-use 2000-2030**

Table Annex 4: Electricity uses final exergy shares for industrial sector and others 2000-2014 (Iberian Lynx scenario)

	Industry				Non-Industry			
	Mechanical drive	Heat	Other Electrical uses	Light	Mechanical drive	Heat	Other Electrical uses	Light
2000	46%	11%	27%	15%	21%	35%	29%	15%
2001	47%	11%	27%	15%	21%	35%	29%	15%
2002	48%	11%	27%	14%	21%	35%	30%	14%
2003	48%	11%	27%	13%	22%	35%	30%	13%
2004	49%	11%	27%	13%	22%	35%	31%	13%
2005	50%	11%	27%	12%	22%	35%	31%	12%
2006	50%	11%	27%	11%	22%	35%	32%	11%
2007	51%	11%	27%	11%	22%	35%	33%	11%
2008	52%	11%	27%	10%	21%	35%	34%	10%
2009	52%	11%	27%	9%	24%	33%	33%	9%
2010	53%	11%	27%	9%	23%	34%	34%	9%
2011	54%	11%	27%	8%	23%	34%	35%	8%
2012	54%	11%	27%	7%	23%	34%	35%	7%
2013	55%	11%	27%	7%	24%	34%	36%	7%
2014	56%	11%	27%	6%	24%	34%	36%	6%
2015	57%	11%	26%	6%	24%	34%	36%	6%
2016	58%	11%	26%	6%	24%	34%	36%	6%
2017	58%	11%	25%	6%	25%	33%	36%	6%
2018	59%	11%	25%	5%	25%	33%	35%	6%
2019	60%	10%	24%	5%	26%	33%	35%	6%
2020	61%	10%	24%	5%	26%	33%	35%	6%
2021	62%	10%	23%	5%	26%	33%	35%	6%
2022	63%	10%	23%	5%	27%	32%	35%	6%
2023	64%	10%	22%	4%	27%	32%	34%	6%
2024	65%	9%	22%	4%	28%	32%	34%	6%
2025	66%	9%	21%	4%	28%	32%	34%	6%
2026	66%	9%	21%	4%	28%	32%	34%	6%
2027	67%	9%	20%	4%	29%	31%	34%	6%
2028	68%	9%	20%	3%	29%	31%	33%	6%
2029	69%	9%	19%	3%	30%	31%	33%	6%
2030	70%	8%	19%	3%	30%	31%	33%	6%

Table Annex 5: Final-useful efficiencies for electricity uses 2000-2030 (Iberian Lynx scenario)

	Mechanical drive	Heat (industry)	Heat (non-industrial)	Other electrical uses	Light
2000	85,0%	26,4%	17,7%	11,3%	13,1%
2001	85,0%	26,4%	17,8%	11,0%	13,2%
2002	85,0%	26,4%	17,7%	10,7%	13,3%
2003	85,0%	26,3%	17,6%	10,4%	13,3%
2004	85,0%	26,4%	17,7%	10,1%	13,4%
2005	85,0%	26,4%	17,7%	9,9%	13,5%
2006	85,0%	26,3%	17,6%	9,6%	13,6%
2007	85,0%	26,4%	17,8%	9,3%	13,6%
2008	85,0%	26,4%	17,8%	8,9%	13,8%
2009	85,0%	26,3%	17,5%	8,6%	14,2%
2010	85,0%	26,3%	17,6%	8,6%	14,0%
2011	85,0%	26,2%	17,5%	8,6%	14,2%
2012	85,0%	26,4%	17,7%	8,6%	14,3%
2013	85,0%	26,4%	17,8%	8,6%	14,4%
2014	85,0%	26,3%	17,7%	8,6%	14,5%
2015	85,0%	26,3%	17,7%	8,6%	14,9%
2016	85,0%	26,3%	17,7%	8,6%	15,2%
2017	85,0%	26,3%	17,7%	8,6%	15,6%
2018	85,0%	26,3%	17,7%	8,6%	15,9%
2019	85,0%	26,3%	17,7%	8,6%	16,2%
2020	85,0%	26,3%	17,7%	8,6%	16,6%
2021	85,0%	26,3%	17,7%	8,6%	16,9%
2022	85,0%	26,3%	17,7%	8,6%	17,3%
2023	85,0%	26,3%	17,7%	8,6%	17,6%
2024	85,0%	26,3%	17,7%	8,6%	18,0%
2025	85,0%	26,3%	17,7%	8,6%	18,3%
2026	85,0%	26,3%	17,7%	8,6%	18,6%
2027	85,0%	26,3%	17,7%	8,6%	19,0%
2028	85,0%	26,3%	17,7%	8,6%	19,3%
2029	85,0%	26,3%	17,7%	8,6%	19,7%
2030	85,0%	26,3%	17,7%	8,6%	20,0%

- **Shares for useful and final exergy per sector, energy carrier and end-use, for 2000, 2014 and 2030, as well as final-useful efficiencies for the same years**

Table Annex 6: Final-Useful efficiencies, useful & final exergy shares in 2000, 2014 and 2030 (Iberian Lynx scenario)

Sector	Energy Carrier	Type of End-use	Useful Share			Final Share			Efficiency		
			2000	2014	2030	2000	2014	2030	2000	2014	2030
Energy sector	Coal	HTH	0,29%	0,00%	0,00%	0,13%	0,00%	0,00%	46,81%	46,80%	46,80%
		LTH1	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	19,55%	19,53%	19,53%
	Oil	MW3 smd	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	12,56%	12,61%	12,61%
		MTH	**4,85%**	**4,63%**	**4,21%**	**3,96%**	**3,90%**	**4,36%**	26,36%	26,34%	26,34%
	Natural Gas	MW3 smd	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	38,40%	39,58%	39,58%
		HTH	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	46,81%	46,80%	46,80%
		MTH	0,00%	1,04%	1,52%	0,00%	0,88%	1,58%	26,36%	26,34%	26,34%
	Electricity	Industry	1,92%	**3,09%**	**3,06%**	1,04%	1,28%	1,30%	47,54%	53,54%	63,92%
	Heat	MTH	0,00%	1,04%	1,79%	0,00%	0,87%	1,85%	26,36%	26,34%	26,34%
Industry	Coal	HTH	**4,88%**	0,02%	0,00%	2,27%	0,01%	0,00%	46,81%	46,80%	46,80%
		MTH	0,25%	0,01%	0,00%	0,15%	0,01%	0,00%	26,36%	26,34%	26,34%
	Oil	HTH	**5,18%**	2,22%	1,69%	2,99%	1,34%	1,26%	46,81%	46,80%	46,80%
		MTH	**4,75%**	2,20%	1,68%	2,79%	1,34%	1,25%	26,36%	26,34%	26,34%
		LTH1	**3,53%**	0,31%	0,24%	**3,87%**	0,35%	0,33%	19,55%	19,53%	19,53%
		LTH2	0,78%	0,24%	0,22%	1,11%	0,35%	0,41%	14,97%	14,95%	14,95%
		MW2	0,03%	0,03%	0,03%	0,07%	0,06%	0,07%	10,12%	10,37%	10,37%
		MW3	1,03%	0,36%	0,08%	1,77%	0,63%	0,17%	12,56%	12,61%	12,61%
		MW3 smd	0,37%	0,21%	0,03%	0,64%	0,37%	0,06%	12,56%	12,61%	12,61%
	Combustible Renewables	HTH	0,00%	0,01%	0,03%	0,00%	0,01%	0,02%	46,81%	46,80%	46,80%
		MTH	0,00%	0,74%	1,22%	0,00%	0,62%	1,26%	26,36%	26,34%	26,34%
		LTH1	**6,31%**	**5,59%**	2,10%	**6,93%**	**6,35%**	2,93%	19,55%	19,53%	19,53%
		LTH2	0,34%	0,11%	0,00%	0,49%	0,16%	0,01%	14,97%	14,95%	14,95%
		MW3	0,00%	0,01%	0,02%	0,00%	0,01%	0,04%	12,65%	12,96%	12,96%
		MW3 smd	0,00%	0,07%	0,15%	0,00%	0,04%	0,10%	38,40%	39,58%	39,58%
	Natural Gas	HTH	2,71%	**3,96%**	**3,24%**	1,56%	2,32%	2,28%	46,81%	46,80%	46,80%
		MTH	2,46%	**3,33%**	2,44%	1,44%	2,02%	1,82%	26,36%	26,34%	26,34%
		LTH1	0,43%	1,35%	1,67%	0,47%	1,53%	2,33%	19,55%	19,53%	19,53%
		LTH2	0,10%	0,53%	0,82%	0,15%	0,78%	1,50%	14,97%	14,95%	14,95%
	Electricity	Industry	**13,46%**	**19,36%**	**20,05%**	**7,25%**	**8,02%**	**8,55%**	47,54%	53,54%	63,92%
	Heat	HTH	0,37%	0,28%	0,84%	0,17%	0,13%	0,49%	46,81%	46,80%	46,80%
		MTH	0,11%	0,57%	0,97%	0,09%	0,48%	1,00%	26,36%	26,34%	26,34%
		LTH1	0,13%	0,65%	1,36%	0,15%	0,74%	1,90%	19,55%	19,53%	19,53%
Transports	Oil	MW1	1,53%	1,16%	0,28%	1,25%	0,83%	0,24%	26,16%	30,94%	30,94%
		MW2	**5,94%**	**3,55%**	1,24%	**12,62%**	**7,59%**	**3,25%**	10,12%	10,37%	10,37%

		MW3 d	**11,01%**	**13,63%**	**7,67%**	**18,84%**	**23,97%**	**16,59%**	12,56%	12,61%	12,61%
		Navigation	0,44%	0,96%	0,99%	0,25%	0,54%	0,68%	38,40%	39,58%	39,58%
		Electric & Hybrid	0,36%	0,07%	0,36%	0,32%	0,07%	0,33%	24,33%	25,35%	30,00%
	Combustible Renewables	MW2	0,00%	0,01%	0,01%	0,00%	0,01%	0,02%	10,12%	10,37%	10,37%
		MW3 d	0,00%	1,01%	2,33%	0,00%	1,73%	**4,90%**	12,65%	12,96%	12,96%
	Natural Gas	NG vehicles	0,00%	0,03%	0,05%	0,01%	0,08%	0,16%	8,00%	8,00%	9,40%
	Electricity	Electric & Hybrid	0,19%	0,18%	**5,09%**	0,16%	0,16%	1,94%	24,33%	25,35%	30,00%
Residential / Commercial (Services)	**Coal**	LTH3	0,10%	0,00%	0,00%	0,23%	0,00%	0,00%	8,80%	8,80%	8,80%
	Oil	LTH3	2,32%	1,58%	1,15%	**5,68%**	**3,97%**	**3,58%**	8,80%	8,80%	8,80%
		MW2	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	10,12%	10,37%	10,37%
	Combustible Renewables	LTH3	2,76%	2,16%	1,58%	**6,74%**	**5,44%**	**4,90%**	8,80%	8,80%	8,80%
		MW3	0,00%	0,01%	0,02%	0,00%	0,01%	0,04%	12,65%	12,96%	12,96%
	Natural Gas	LTH3	0,29%	1,18%	0,77%	0,72%	2,98%	2,39%	8,80%	8,80%	8,80%
	Electricity	Other	**18,01%**	**20,32%**	**26,57%**	**9,70%**	**14,93%**	**20,67%**	29,30%	30,16%	35,02%
	Heat	LTH3	0,01%	0,04%	0,05%	0,02%	0,10%	0,17%	8,80%	8,80%	8,80%
	Solar Thermal	LTH3	0,01%	0,05%	0,07%	0,02%	0,12%	0,21%	8,80%	8,80%	8,80%
Agriculture / Fishing	**Oil**	LTH2	0,04%	0,04%	0,00%	0,06%	0,06%	0,01%	14,97%	14,95%	14,95%
		LTH3	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	8,80%	8,80%	8,80%
		MW1	0,00%	0,20%	0,61%	0,00%	0,15%	0,54%	26,16%	30,94%	30,94%
		MW2	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	10,12%	10,37%	10,37%
		MW3	2,10%	1,23%	0,80%	**3,58%**	2,17%	1,74%	12,56%	12,61%	12,61%
	Combustible Renewables	LTH3	0,00%	0,01%	0,01%	0,00%	0,02%	0,03%	8,80%	8,80%	8,80%
		MW3	0,00%	0,01%	0,04%	0,00%	0,02%	0,09%	12,65%	12,96%	12,96%
	Natural Gas	LTH2	0,00%	0,02%	0,04%	0,00%	0,03%	0,07%	14,97%	14,95%	14,95%
		LTH3	0,00%	0,00%	0,00%	0,00%	0,00%	0,00%	8,80%	8,80%	8,80%
	Electricity	Other	0,60%	0,59%	0,80%	0,32%	0,43%	0,62%	29,30%	30,16%	35,02%
	Heat	LTH1	0,01%	0,00%	0,00%	0,01%	0,00%	0,00%	19,55%	19,53%	19,53%

- **Sankey Diagram -** Note that only for electricity and co-generation was primary-final efficiency considered. For other energy carriers, the only losses are from transport, with exception of oil products, but are not significant. For oil products, refinery efficiency is higher than 90%. For this, exergy destruction showed in the final stage is related solely to electricity and co-generation heat production. Within the exergy destruction is considered the dissipated heat.

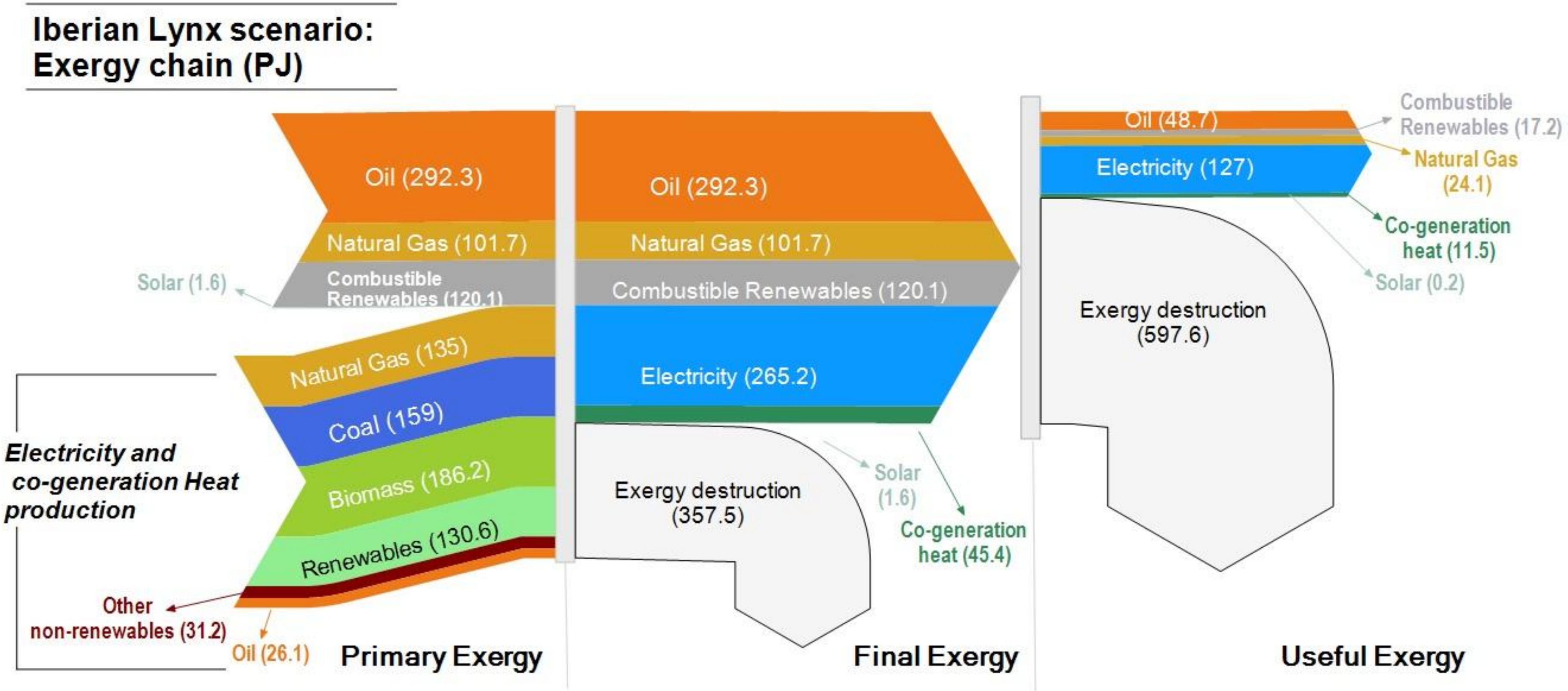

Figure Annex 2: Sankey Diagram for 2030 (Iberian Lynx scenario)