Development of a flexible model for the industrial sector, adaptable for different scales (local, regional, national)

Gonçalo Bastos Oliveira

Master Dissertation

FEUP Supervisor: Prof. Zenaida Sobral Mourão

FEUP Co-Supervisor: Prof. Isabel Maria Gonçalves Azevedo

U.PORTO
FEUP FACULDADE DE ENGENHARIA
UNIVERSIDADE DO PORTO

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Resumo

A presente Tese de Mestrado em Engenharia Mecânica na área de Fluidos e Energia desenvolve um modelo energético para o setor da indústria em que é feita uma caracterização detalhada do setor, dada a necessidade de implementar soluções adaptadas aos diferentes processos industriais no contexto de um novo paradigma energético onde é explícito de que apenas com o contributo de todos é possível ultrapassar o desafio das alterações climáticas e travar o aquecimento global do planeta a apenas 2ºC acima dos níveis pré industriais.

Como os atuais sistemas energéticos são extremamente insustentáveis, o desenvolvimento sustentável tornou-se um objetivo social e deve ser a força motriz por detrás do planeamento energético. Em 2016, Portugal assumiu o objetivo de atingir a Neutralidade Carbónica até 2050, contribuindo para os objetivos mais ambiciosos no quadro do acordo de Paris. Estes objetivos estipulam metas graduais como as de redução de emissões face a 2005 de 18 a 23% em 2020, que foram cumpridas, 45 a 55% em 2030 e 85 a 90% em 2050.

Esta dissertação pretende contribuir para esta problemática através da extensão de um modelo OSeMOSYS *open source* já existente, que inclui a modelação do sistema energético nacional entre 2015 e 2050 e considera os fluxos de energia desde as fontes de energia primária até ao consumo de energia final por setor, de forma a integrar os serviços energéticos do setor da indústria ao nível dos usos finais no mesmo período.

Foram gerados 3 cenários onde 2 deles têm limites anuais de emissões GHG de acordo com o RNC2050 e o FitFor55 e outro cenário (BAU) sem limite de emissões de forma a analisar o comportamento do modelo a cada um deles.

Através da análise de resultados conclui-se que para atingir os objectivos do RNC e do FitFor55 tem que se implementar várias soluções de descarbonização que passam pela implementação de novas tecnologias e processos mais eficientes e com baixa pegada ecológica, pela independência dos fosseis na produção de eletricidade e pela redução do uso de energia.

Abstract

This MSc thesis in Mechanical Engineering in the field of Fluids and Energy develops an energy model for the industry sector in which a detailed sector characterization is made, given the need to implement solutions adapted to the different industrial processes in the context of a new energy paradigm where it is explicit that only with everyone's contribution is it possible to overcome the challenge of climate change and limit global warming to 2ºC above pre-industrial levels.

As current energy systems are extremely unsustainable, sustainable development has become a social goal and must be the driving force behind energy planning. In 2016, Portugal committed to becoming carbon neutral by 2050, contributing to the more ambitious objectives of the Paris agreement. These objectives stipulate gradual targets such as emission reductions compared to 2005 of 18 to 23% in 2020, which have been met, 45 to 55% in 2030 and 85 to 90% in 2050.

This dissertation aims to contribute to this problem by extending an existing open source OSeMOSYS model, which models the national energy system between 2015 and 2050 and considers energy flows from primary energy sources to final energy consumption by sector, to integrate the energy services of the industry sector at the end-use level during the same time period.

Three scenarios were generated where 2 of them have annual limits of GHG emissions according to the RNC2050 and FitFor55 and another scenario (BAU) without emissions limit in order to analyse the model behaviour to each of them.

Through the analysis of results it is concluded that to achieve the objectives of the RNC and FitFor55 several decarbonisation solutions have to be implemented which include the implementation of new technologies and more efficient processes with low ecological footprint, by the independence of fossil fuels in electricity production and by the reduction of energy use.

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Abbreviations

BM	Biomass
CHP	Combined Heat and Power
DGEG	Direção Geral de Energia e Geologia
DIE	Diesel
EL	Electricity
EU	European Union
EV	Electric Vehicle
FO	Fuel Oil
GDP	Gross Domestic Product
GHG	Greenhouse Gas
HTH	High Temperature Heat
HVAC	Heating, Ventilation and Air Conditioning
IEA	International Energy Agency
INE	Instituto Nacional de Estatística
IPCC	Intergovernmental Panel po Climate Change
LB	Light bulbs
LPG	Liquefied Petroleum Gas
NG	Natural gas
NPC	Net Present Cost
PA	Paris Agreement
PNEC2030	National Energy Climate Plan
PT	Portugal
REF	Reference
RNC2050	Roadmap for Carbon Neutrality 2050
TES	Total Energy Supply
TFC	Total Final Consumption
Toe	Tonnes of Oil Equivalent
UED	Usable Energy Database
UK	United Kingdom
UNFCC	United Nations Framework Convention on Climate Change

Chapter 1 - Introduction

1.1 - Background and motivation

Current energy systems are mostly fuelled by the burning of fossil fuels which has a variety of detrimental environmental, social and economic effects, with greenhouse gas (GHG) emissions regarded as the primary driver of climate change (IPCC, 2022). Thus, sustainable development has become one of the primary policy and societal goals, and the driving force behind energy planning. According to the IPCC AR6 report (IPCC, 2022), to limit global warming to well below 2°C, global emissions will have to decrease by 97.4% of relative to 2010, with 60% of the reduction already secured by 2030. The United States, European Union (28), Russia, and Japan, contribute for 32% of global emissions, with China, India, and the rest of the world accounting for 68% of global emissions in absolute terms (Belbute & Pereira, 2019). Figure 1 presents the evolution of global GHG emissions from 1990 to 2019 showing that GHG emissions have grown consistently over the past 30 years.

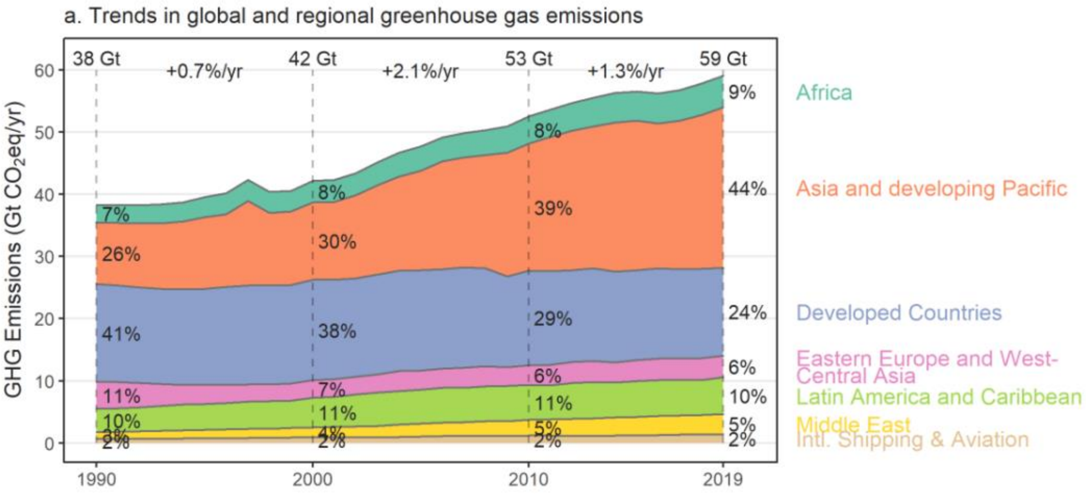

Figure 1 - Evolution of global GHG emissions (IPCC, 2022).

The lack of progress in the reduction of GHG emissions, combined with the high dependence of many countries on imported fossil (e.g., 76% of primary energy supply in Portugal in 2017) show the dimension of the challenge that the world faces in achieving even the most conservative scenarios of the minimum emissions reductions needed to mitigate climate change, which requires that the already substantial GHG emissions reductions are reached in 2030 - the EU has been set the target at 55% from 1990 levels.

Emissions from the energy system represent the major contributor to GHG emissions in the EU, and in Portugal. Thus, most roadmaps to 2030 and 2050 include a plethora of measures to decarbonize energy supply while increasing energy efficiency of end use sectors leading to an overall rapid reduction in primary energy use. EU countries rely on the National Energy and Climate Plan (NECP) to set a roadmap to reaching the EU targets for overall GHG emissions for the 2021-2030 period. For example, the PT NECP 2030 supports Portugal's commitment to decarbonize its economy and pursue an energy transition, also considering the trajectories towards carbon neutrality in 2050 outlined in the Roadmap for Carbon Neutrality 2050 (RNC2050), which established goals to reduce total emissions by at least 85-90% by 2050 compared to 2005 levels, and to use carbon sequestration to offset the remaining emissions.

Given the challenge of the major changes that will have to occur over the next 10 to 30 years in our society, that imply changes to the way we move, work, eat, produce and consume goods, and enjoy our free time, it is absolutely essential to involve a wider range of stakeholder in the decision-making pertaining to our energy system. In addition to the public at large, policy makers and students in training could also hugely benefit from having access to extensive data, open and easily accessible models to test the effects of different changes in supply and demand to the sustainability of our future systems and to identify pathways of change that would allow for a more consistent and accelerated change.

Energy modelling may be helpful for several aspects of society, as these can provide insights into the dynamics between energy access, making use of resources, and achieving sustainable development (Howells et al., 2011). Open-source and transparent energy modelling and the availability of open energy system data have emerged in recent years as major needs to support efforts to allow a wider pool of stakeholders and society in general to take a more active role in deciding the roadmap for future changes.

There is currently no open-sourced energy optimization model that allows different end users to generate potential energy system futures for the Portuguese energy system. Additionally, there is in general a lack of energy system models that map the full chain if energy transformation from primary resources to final energy services. The work presented here is meant as the first step towards building a detailed energy system model for Portugal that does just that.

1.2 - Objectives

The main goal of this theses is thus to expand the existing national energy model, that maps energy use only to the level of final energy, to cover the whole energy chain from primary to useful energy. Specifically, this work focusses on the industrial sector, and aims to develop a detailed industrial energy model covering the Portuguese industrial energy use.

To complete the disaggregation of the industrial energy system, it is necessary to model all subsectors and their final uses. The optimal strategy for industry sector disaggregation is to be able to model all conversion technologies at the level of useful energy. Due to the heterogeneity of the sector, it is necessary to collect substantial amounts of data on different technologies, uses, techno-economic information from sources that are also inconsistent.

This dissertation project was developed with the following specific objectives:

- To develop a detailed energy model for the industrial sector with disaggregation at the level of end uses and technologies,
- To implement the industrial model in the existing OSeMOSYS model for Portugal, extending the mapping of the energy transformation chain to the level of useful energy
- To apply the model to the national setting between 2015 and 2050, considering the evolution scenarios outlined in the Roadmap for Carbon Neutrality (RNC 2050) and FitFor55.

1.3 - Thesis structure

This thesis is structured into 7 chapters. The first chapter provides an overview of the problem of climate change caused by greenhouse gas emissions, as well as an introduction to energy modelling and the need to develop an energy model for the industrial sector and the objective of the dissertation. Chapter 2 presents current energy use and GHG emissions across all sectors in Portugal. In addiction addresses the planning of energy policies for future energy systems and the energy use in the industrial sector. Chapter 3 presents a state-of-the-art analysis of the energy modelling of the industrial sector starting with an introduction of energy modelling with a focus on the OSeMOSYS model and the strategy for modelling the sector. Chapter 4 describes the methodology used to develop the model and extend the existing OSeMOSYS model for Portugal. The results are presented and discussed in Chapter 5. In chapter 6, the project's conclusions are drawn. In chapter 7, perspectives on future work that can offer this project continuity are presented.

Chapter 2 – National Energy System and Policies

This chapter addresses energy consumption and the evolution of GHG emissions across all sectors in Portugal, as well as the planning of energy policies for future energy systems, energy consumption in the industrial sector, and GHG emissions inherent to the sector.

2.1 - Current energy use and GHG emissions in Portugal

Portugal, like many of the EU Member States, is highly dependent on imported fossil fuel sources to meet its energy demand. According to national energy statistics (DGEG, 2019), 76% of Portugal's total energy supply (TES) was derived from fossil fuels in 2019, with crude oil, natural gas, and coal sourced entirely from imports. Most notably, even though there have been significant advances in implementation of energy efficiency measures and increased integration of renewable energy into the national energy system, the fossil fuel share of the TES has been stable at approximately 75% since 2014 with an increase in natural gas supplies balancing out decreases in oil and coal supplies.

Energy end use sectors like industry and transports have a high share of their energy needs met by fossil final energy vectors, with use of oil products accounting for 56% of TES (36% in the transport sector). Natural gas is the second-largest source of energy, accounting for 17% of TES, and is mostly utilized for the generation of electricity (60%) and industrial operations (24%) – as per figure 2. Even though direct consumption of natural gas in buildings accounts for only 10% of total natural gas consumption in IEA nations, as buildings are the largest consumer of electricity, overall buildings are the second largest (indirect) user of natural gas (IEA, 2021).

National endogenous resources accounted for only 24% of TES, with bioenergy (biomass and other renewables) and waste accounting for 14% of TES (used mainly in buildings (75%), industry (18%) and power supply (7%)), and primary renewable electricity (from hydro, wind, and PV) making up the remaining 10% of TES. With the phase out of coal thermal generation, coal has progressively accounted for a decreasing share of TES, accounting for 5% of TES in 2019 (99% for electricity generation, and less than 1% used in industry). As the last coal power plants were phased out in 2021, the use of coal in the national energy system represents a negligible share of the TES.

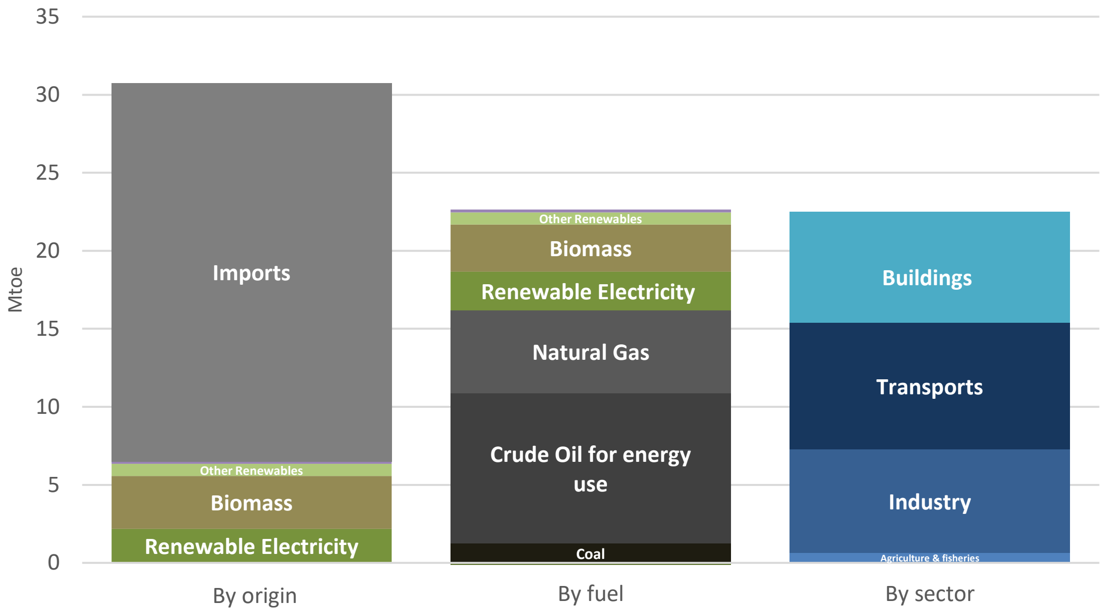

Figure 2 – Total energy supply (TES) for Portugal by origin, energy source, and sector in 2019 Source: DGEG,2019

In the last 10 years total final energy consumption (TFC) has been consistent at around 16 Mtoe, with demand in the transport, services and residential sectors growing slightly, agriculture and fishing demand remaining stable, and industrial demand consistently decreasing. In 2019, the transportation sector accounted for 36% of TFC, followed by the industrial sector (29%), the residential sector (17%), services (14%) and agriculture and fisheries (3%). In the same year, oil products (46%) and electricity (25%) accounted for the highest shares of consumption, followed by renewables and waste (12%) and natural gas (11%), with direct use of heat accounting for just 7% of TFC.

Most of the oil consumption is due to road transportation, but there is also substantial oil demand for agriculture and fisheries in Portugal (Figure 3). Electricity accounted for one-fourth of total demand in 2019, representing the largest share of demand in both service (60%) and residential (39%) buildings. Natural gas was introduced in the national energy system largely in 1997, and despite its quick acceptance across all sectors except transportation, it accounted for only 11% of TFC in 2019 – in the same year natural gas accounted for 21% of TFC among IEA member countries. Most of the heat demand is met by industrial cogeneration plants, with a negligible share met by district heating (IEA, 2021).

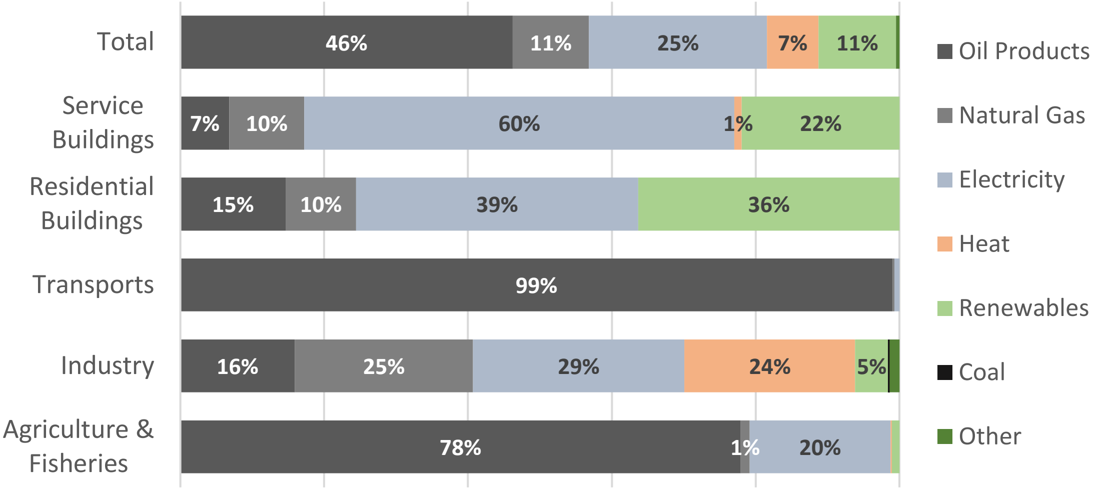

Figure 3 – Total final energy consumption by sector and vector in Portugal in 2019. Source: DGEG, 2019

The national Greenhouse Gas Emissions (GHG) have overall decreased since 2000, largely due to the progressive changes towards less carbon intensive economic activities and due to the changes in the energy system (decreasing consumption of coal and oil products, partially offset by increased use of natural gas) – Figure 4. In 2019, the total national GHG emissions were 69,2 $MtCO_2eq$, with the largest share coming from transports (25%) followed by electricity and heat generation (23%), aviation and shipping (11%), agriculture (10%), manufacturing and construction (8%), and industry (7%).

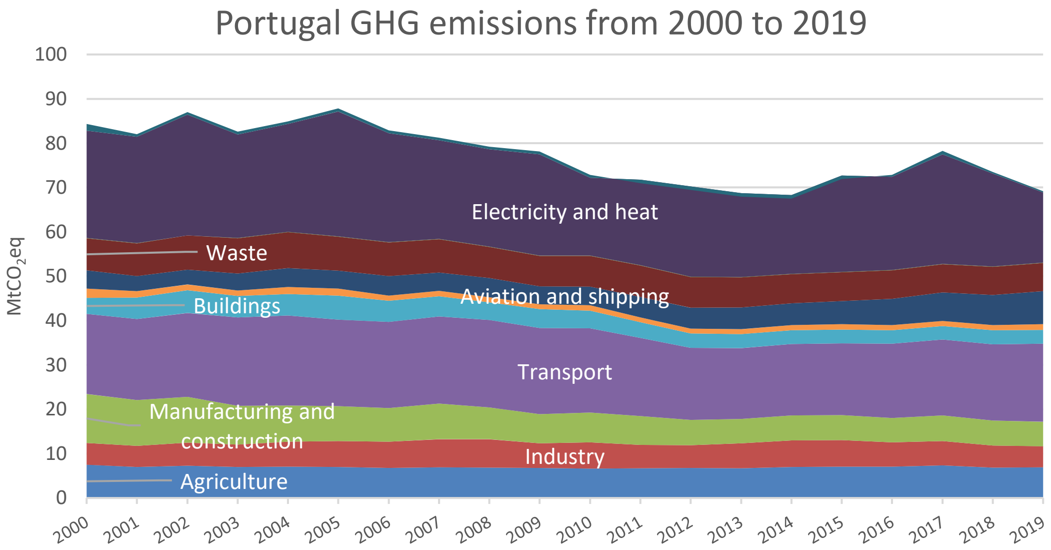

Figure 4 – Emissions by sector from 2000 to 2019. Source: (Ritchie et al., 2020)

2.2 - Future energy systems and Energy policies

The Paris Agreement (PA) of 2015 established long-term targets to limit the average global temperature increase to no more than 2°C above pre-industrial levels, with commitments from the international community to work towards reducing GHG emissions levels in line with limiting global temperature increase to 1.5°C. This is the maximum increased that research has shown to limit climate change effects to levels that can still be managed (PNEC, 2019). In addition to this, the PA outlined objectives to increase the capacity to adapt to climate change and to provide financial support for the implementation of the low-emission pathways and resilient development in line with these targets.

At the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) in 2016, Portugal committed to the goal of becoming carbon neutral by the year 2050. Three years later in 2019, the Portuguese Government released the national Roadmap for Carbon Neutrality (Roteiro para a Neutralidade Carbónica – RCN 2050), in line with the implementation of the PA. The RNC2050 outlines the national vision, trajectories, and guidelines for the policies and measures that are to be implemented within this time frame to guarantee that carbon neutrality is reached by 2050.

In line with the findings of the IPCC Special Report on 1.5°C, RCN 2050 stated that increased efforts were required to reduce greenhouse gas emissions during the decade 2021-2030. This reduction was deemed essential for aligning the national economy with a trajectory that produces leads to carbon neutrality in 2050. The RCN 2050 objectives for the horizon of 2030 were used as the starting point for the development of ambitious targets for the period up to 2030.

The goals up to 2030 are defined in the National Energy and Climate Plan (NECP), which is the key national climate and energy policy document for the years 2021-2030. The NECP included goals to improve energy efficiency – reduction in primary energy demand to 21.5 million tonnes of oil equivalent (Mtoe), from 22.1 Mtoe in 2019, and in final energy demand to less than 14.9 Mtoe, from 17.1 Mtoe in 2019); and increased share of renewable energy in the national energy system (which is responsible for 47 % of final energy demand, 80 percent of electricity generation) are all targets that are outlined in Portugal's National Energy and Climate Plan (NECP). Both reductions are compared to the 2005 levels of emissions.(PNEC, 2019)

To reach carbon neutrality by 2050 and promote sustainable energy transitions in challenging-to-decarbonize sectors and end uses, Portugal sees a central role for hydrogen produced with renewable energy. By 2030, according to the National Hydrogen Strategy (EN-H2), hydrogen should meet 1-2% of national energy demand, 5% of the energy needs of the industrial sector, 3% of the needs of domestic maritime shipping, 1% of the needs of road transportation, and 10% of the volume of gas delivered via the natural gas network. To accomplish this goal, necessary laws, rules, and standards must be put in place, and it is predicted that 2-2.5 GW of electrolysis capacity using renewable electricity must be deployed by 2030. Long-term, the EN-H2 suggests using renewable hydrogen directly for power generation and energy storage (Cascão & Sousa, 2020).

2.3 - Energy use in the industrial sector

Industry is a key sector of activity in the Portuguese economy with manufacturing industries accounting for 21.9% of gross value added and 21.0% of gross operating surplus of non-financial companies[1] (INE, 2019). In 2019, manufacturing industries accounted for 5.2% of active, non-financial sector firms in Portugal, employed 22.9% of the active population, accounted for 21.9% of the Gross Value Added and 21.0% of the Gross Operating Surplus, of non-financial companies.

Portugal's industrial energy demand was strongly impacted by the 2008 crisis, with demand decreasing by 16% till 2012. Even though industrial activity began to grow again in 2012; industrial energy demand continued to decline through 2018 because of improved efficiency and a shift to less carbon and energy-intensive activities. (IEA, 2021). This shift is also noted in the changes in final energy use from 2009 to 2019, with industrial demand increasing by 36% for natural gas, 9% for electricity and 5% for heat, while demand decreased for coal (-50%), oil products (-48%) and renewables (e.g., biomass, -64%).

In 2019, four industrial sectors – paper and pulp; cement and lime; chemicals, and food and beverages – accounted for 65% of Portugal's industrial energy demand. The pulp and paper industry accounts for 31% of the industry's consumption in 2019, followed by non-metallic sectors (cement, ceramics, and glass) with 24%. Chemicals (including petrochemicals), plastics, and rubber industries accounted for 12% of consumption, while steel, metallurgical, and metal-electromechanical sectors accounted for 10%. During the period 2014-2019, the cement industry energy demand decreasing by 18% while the remaining industries, on average, had an increase of 8%.

Worldwide, the use of energy in the industrial sector is mainly providing for the thermal energy use in processes (Figure 5), with 74% of total energy use in the sector dedicated for the generation of low, medium, and high temperature heat. This shows some of the challenges that the strategy to electrify end use sectors may face in the

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[1] Non-financial companies are those whose object is the production and/or commercialisation of non-financial goods and/or services (Economias, n.d.).

industrial sector. On the other hand, it also highlights that about half of the heat needs are for process temperatures below 400°C, for which there is a wider spectrum of low carbon choices. The specific structure of the industrial sector also explains at least partially the focus on decarbonization of heat in this sector – namely through the increase of renewable gas use in the industrial sector – including green hydrogen.

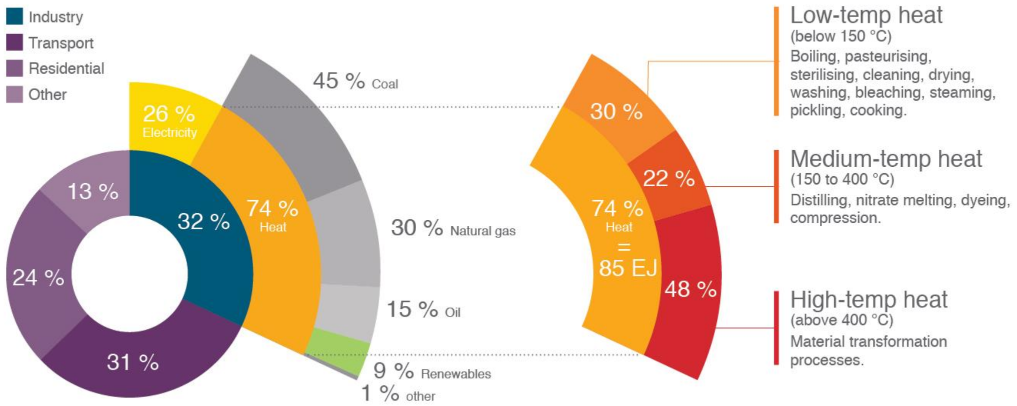


Figure 5 - Worldwide energy use in the industrial sector for process heat. (IRENA, 2017)

The diversity of energy end uses, technologies, fragmentation of some of the industrial sectors and the long lifetime of some of the technologies condition the options for decarbonization in the industrial sector, also requiring a high level of detail about the energy use in its subsectors to produce effective energy policies, especially in light of the ambitious GHG mitigation goals set out in the NECP (PNEC2030) and RNC2050, supported at the EU level by the European Green deal and the recent FitFor55 legislative package, that sets out a goal for a 55% GHG emissions reduction already in 2030 (from 1990 levels) at EU level. This supports the need to develop industrial energy system models that are open, built on solid and consistent data resources and that can be used by wide variety of end users.

Chapter 3 – Energy modelling

This chapter introduces an approach to energy models and their structure, with particular emphasis on the model used in this project (Osemosys) and how the industrial sector is defined.

3.1 - Energy system models

Often when making decisions about which measures to implement to ensure a clean and just transition of the energy system, a complex chain of energy transformations and connections along the whole energy system from primary energy resources to end uses and factors needs to be considered in the process. Energy system models are especially helpful in this situation as these can translate the connections and effects from different energy system interventions (e.g., at the level of decarbonizing final energy vector, or improving building insulation) into mathematical formulations, which facilitate the quantification of impacts of policies and measures. Typically, this process includes scenario and sensitivity assessments run over specific future changes and narratives applied to the modelled energy system (Dementjeva, 2009) to deal with uncertainty of looking over large time horizons.

An important example of the application of energy system models is related to the development of energy policies, delineating decarbonization strategies, and implementing transitions towards renewable energy sources, especially within the time horizon to 2050. Currently, many of the national energy plans to decarbonize the economy in 2050 and the NECPs for 2030, are supported by energy system models based on the TIMES Model (Loulou R et al., 2005) including the former JRC-TIMES model used by the EC (Simões et al., 2013), which is typically implemented, supported, and updated by one or a group of few public research institutions in each country (e.g., in Portugal this role is taken up by the modelling team at LNEG).

The TIMES Model is part of a group of energy system models that model the future based on optimum pathways with the minimum cost, and typically maximizing other benefits – e.g., reduction of GHG emissions. In this case the model “chooses” optimal deployment of new technologies and the speed of decarbonization of different energy vectors. Models in this category include OSeMOSYS s (Howells et al., 2011; Gardumi et al., 2018a), and PRIMES (E3MLab, 2018), among many others. Other groups of models look at the future in terms of simulating different outcomes (e.g., simulation models), or carrying out an accounting of costs and emissions based on different narratives of the future that imply certain transition pathways (accounting methods) (Chang et al., 2021). For the purposes of this work, only optimization models will be considered as the main aim is to be able to model the future pathways for industry with the minimum cost, for a target reduction in GHG emissions.

Energy system models can also be divided into top-down – where projection of economic indicators like energy prices serve as the basis to model energy demand and supply -, and bottom-up – where the physical system is described in detail and technology costs, efficiencies and impacts on environment drive the model choices. The analysis time-horizons can focus on short to long term modelling horizons (Howells & Rogner, 2017). Lastly, the technological detail and the way that demand and supply are modelled can also differ substantially between models. There is often criticism of related to the use of these models as many are not transparent in the assumptions made, data sources used, and do not provide the detailed algorithms – often used as a sort of black box (Süsser et al., 2022). This also makes widespread use of these models difficult and their interpretation complicated.

Long-term energy system models for larger systems usually have to compromise on the temporal and spatial resolution in order to be able to model complex and technology rich systems, to make the optimization problem solvable. Typically, this means that in terms of the temporal resolution, instead of hourly or greater resolution, the year is divided in time slices – e.g., typically different times of day (day and night), days of the week, and seasons - to account for the different availability of renewable resources or profiles of demand throughout the year (Welsch et al., 2012b; Taliotis et al., 2018).

3.2 - Structure of the Energy System

In this work, the methodology followed calls for a bottom-up, technology rich model that specifies each stage of the energy chain, from primary energy to final energy service demand (process heat, machine drive, etc.), from a technological and cost point of view (Bouckaert et al., 2011). The final energy demand is defined as the amount of energy necessary to supply the goods and services, and often refers to final energy vectors (Santos Silva & Margarido, 2020). Technologies are defined as the processes that allow the transformation of one form of energy into another (e.g., allowing extraction of fossil fuels, imports, processing of primary energy in final energy). Energy carriers (primary, energy, and useful energy), energy services, and emissions are typically considered examples of commodities (or fuels in the OSeMOSYS model). Figure 6 represents the approach followed in this work to represent the energy system in terms of energy flows, energy conversion technologies and processes, and energy flows between these.

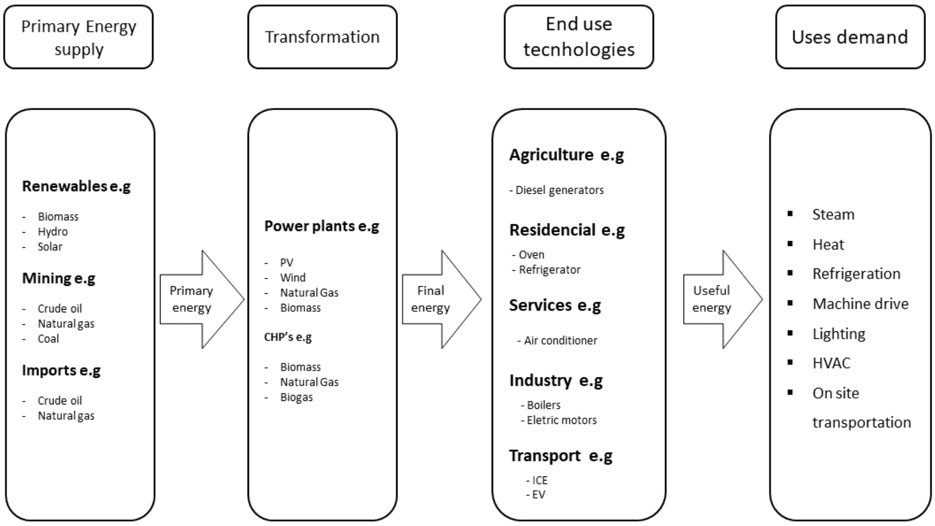


Figure 6 - Diagram that represents activities, technologies, and energy flows from primary energy supply to useful energy use and end uses.

The breakdown of basic energy into useful energy is crucial since energy is constantly wasted during conversion (Figure 7). In this context, useful energy is the energy that is utilised by users. It refers to the proportion of final energy that is available after conversion at end-use technologies. What electricity becomes, for example, depends on the technological conversion (heat, machine drive, etc) (Ritchie, 2022).

Detailed descriptions of the stock of technologies, the stock of passive systems and their technical characteristics, and the energy services provided, allowing for detailed modelling of effects of policies and measures that target demand rather than supply. This is especially relevant since there is a very significant untapped potential for demand reduction at the end use level, considering both active (e.g., at the level of technologies) and well as passive (e.g., at the level of vehicles, buildings, etc.) measures. In the industrial sector, for example, it has been estimated that more than 60% savings in energy demand by acting at the level of final energy conversion related to systems supplying high temperature heat, steam production and machine drive (Cullen et al., 2011).

The approach taken in this work is to model the industrial energy demand to the level of useful energy, i.e., by disaggregating demand to the level of final end uses related with the different energy uses in industry and by considering the different technologies that convert final energy into useful energy supporting these services.

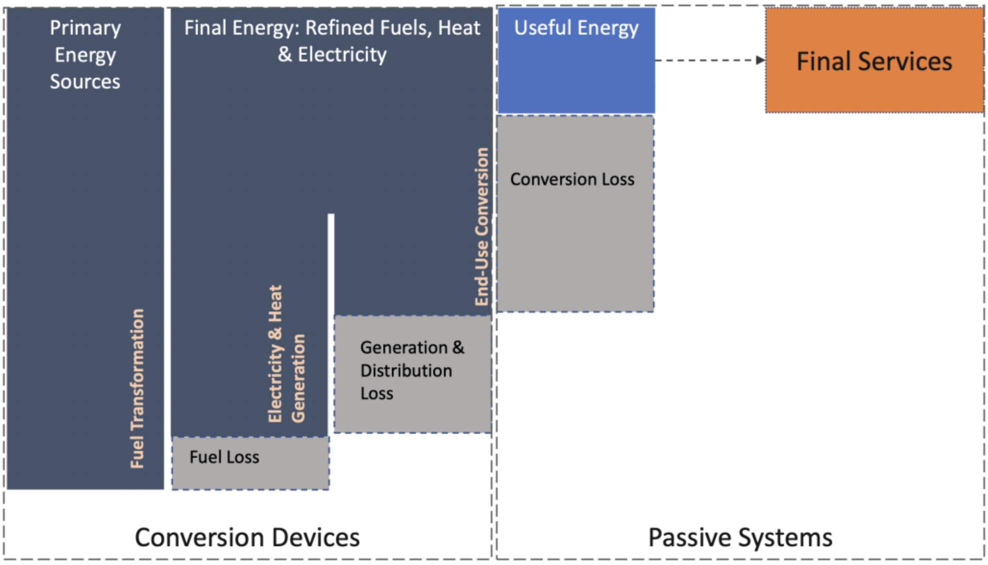


Figure 7 - Conversion of primary energy resources into end use services, based on (Cullen et al., 2011)

3.3 - Osemosys energy system model

OSeMOSYS (the Open-Source energy MOdelling SYStem) is an open-source bottom-up modelling framework for the long-term optimization of the energy system and energy mix that can be developed to model systems at different spatial scales (Howells et al., 2011; Gardumi et al., 2018a). OSeMOSYS does not use proprietary software or commercial programming languages and solvers, which makes this a perfect fit for a wide variety of stakeholders, notably for training purposes, for communities of students, but also for business analysts, government, and energy researchers in emerging nations. Since the model is freely available, this allows graduate students to iteratively construct and develop formal energy models, thus training the next generation of energy system experts that may take up positions in various areas, contributing to the implementation of the climate neutrality plans to 2050. Given these characteristics of the model, OSeMOSYS was selected to be used in this thesis, as the basis for the modelling of the PT energy system, and the industrial model.

In general, OSeMOSYS calculates the energy supply mix in terms of generating capacity and energy delivery that delivers the specified demand at final, useful of energy service level for each year within the modelled time horizon, while minimizing the total costs of the energy system (dESA, 2018b). The energy system modelled within OSeMOSYS can cover the full value chain and the energy demands may be supplied by a variety of technologies with specific efficiencies and associated capital, operational and variable specified by specific parameters (Table 1). In addition, users can add limits related to deployment of technologies, energy resources, investments, capacity deployments and environmental targets – e.g., reduction of GHG emissions (Gardumi et al., 2018a).

The first version of the OSeMOSYS code was released in 2008, which originally included the following seven blocks of functionality (Gardumi et al., 2018b): the objective function, which calculates the lowest Net Present Cost (NPC) of the energy system to satisfy exogenously specified energy demands; (ii) Costs, determined by a equations considering capital and O&M technology costs; (iii) Storage, defining energy balances and restrictions; (iv) Capacity adequacy, which ensures enough capacity for the energy demand in time slice; (v) Energy balance, which assures the yearly balance of production and consumption of energy vectors along the whole energy chain; (vi) Emissions, for the modelled time period, considering the restrictions added by the user and/or costs of carbon; and, any other (vii) Constraints, which restrict the overall installed capacity, use of resources or production of technologies. More recently, new functionalities have been added related to modelling smart grids and demand side flexibility, improved modelling of storage, and costs of cyclic operation of fossil fuel plants (Welsch et al., 2015; Gardumi et al., 2015; Welsch et al., 2012a).

To build energy system models in OSeMOSYS users need to define sets, parameters, and variables. Sets comprise the physical structure of a model providing the time horizon for the modelling, the number of regions, the time split, the technologies and the energy vectors (dESA, 2018a). In this work, the sets Technology and Fuel were used to construct the reference energy model, including the disaggregation of the industrial sector as per the description of Chapter 4. The set "Technology" includes all components of the energy system that convert a commodity from one form to another, utilises it, or provides it. Fuel comprises any energy vector, energy service, or other that flows through a technology (inputs and outputs).

To fully define the characteristics of the energy system model under study, users need to define global parameters related to demand, performance, technology costs, storage, capacity constraints, activity constraints, reserve margin, generation target and emissions. Table 1 shows the parameters used to fully describe the industrial sector according to the level of disaggregation used in this work. Using these parameters, it is possible, for instance, to determine the efficiency of a technology, which is necessary for calculating the useful energy consumption.

Table 1-Parameters used to define the sets used to complete de industrial sector.

Parameter		Description
Demand	Specified Annual Demand	Total specified demand for the year, linked to a specific 'time of use' during the year.
	Specified Demand Profile	Annual fraction of energy-service or commodity demand that is required in each time slice. For each year, all the defined Specified Demand Profile input values should sum up to 1.
Performance	Capacity To Activity Unit	Conversion factor relating the energy that would be produced when one unit of capacity is fully used in one year.
	Capacity Factor	Capacity available per each Time Slice expressed as a fraction of the total installed capacity, with values ranging from 0 to 1. It gives the possibility to account for forced outages.
	Operational Life	Useful lifetime of a technology, expressed in years.
	Input Activity Ratio	Rate of use of a commodity by a technology, as a ratio of the rate of activity.
	Output Activity Ratio	Rate of commodity output from a technology, as a ratio of the rate of activity.
Technology costs	Capital Cost	Capital investment cost of a technology, per unit of capacity.
	Variable Cost	Cost of a technology for a given mode of operation (Variable O&M cost), per unit of activity.
	Fixed Cost	Fixed O&M cost of a technology, per unit of capacity.
Emissions	Emission Activity Ratio	Emission factor of a technology per unit of activity, per mode of operation.

Developing an energy system model inside a framework such as OSeMOSYS is not a simple task. It necessitates the mapping of primary resources and their conversion chains to their end uses. Therefore, for the tool to be completely accessible, its interface must be open-source, user-friendly, but thorough and informative. OSeMOSYS has three types of user interfaces available, according to the expertise level of the user (dESA, 2018a):

- clicSAND (Simple And Nearly Done), which is an Excel based tool that allows modelling of systems with up to 200 technologies, 50 commodities, and five different categories of emissions,

- MoManI (Model Management Infrastructure) which is a browser-based interface for Windows OS, aimed at middle level users,
- Otoole which is Python module that allows users to build the energy system model through a set of Excel files, then process these into input files for the OSeMOSYS runs, and to process the output files.

3.4- Modelling Industrial Energy Use

To model the PT industrial sector and its evolution to 2050, two models/sets of data were used to disaggregate the final energy from official national energy statistics (DGEG) and to provide a consistent set of cost and technology specification data – the JRC-EU TIMES model (Ruiz et al., 2019) and the Usable Energy Database (UED, (Griffin et al., 2013)). After an initial literature search, these sources were able to provide full information to allow the disaggregation of the energy consumption of the industrial sector and subsectors (mainly based on the UED model). This combination of models/datasets is also able to provide the necessary technoeconomic data (e.g., costs, technical characteristics – efficiencies, lifetime) for the characterization of the sector in the base year and that can then be used as the starting structure for the energy modelling to 2050.

The JRC-EU-TIMES model includes the residential, industrial, transportation, and agricultural sectors of European countries. Within this model, the industrial sector is separated into energy-intensive and other industries. Iron and steel, non-ferrous metals (aluminium and copper), chemicals (ammonia and chlorine), non-metallic minerals (cement, lime, glass), and pulp, paper, and printing are categorized as energy-intensive industries, and the model provides a comprehensive description of the production processes for each of these industries.

The other industries include other non ferreous metal, other chemical and petrochemical, other non-metallic minerals, food, beverages and tobacco, textile and leather, transport equipment, machinery, mining and quarrying and other non-energy-intensive industries. The production processes for each of these individual subsectors are not specified within the JRC-EU-TIMES model, rather energy for other industries is considered as a whole and disaggregated by different end uses including steam production, heat, motive power, electrochemical, and other processes. Although the JRC model has a very detailed description of the processes it does define, for some sectors the level of disaggregation is more limited, which does not allow the mapping of the full energy conversion chain till useful energy.

The UED model in turn fills in some of the gaps from the JRC TIMES model. The UED model describes the energy consumption, emissions, and technologies of the manufacturing sectors with the potential to reduce emissions. The following sectors are explicitly modelled: iron and steel, chemicals, food and beverages, paper, and cement. For each subsector, the state of the sector, energy consumption, and the related processes and technologies are characterised. Additionally, several technologies with the potential to minimise emissions in each area are reviewed. Despite focusing on the UK industry, the UED model was used in this work to carry out the classification of the sub-sectors of the PT industrial sector, particularly those not considered sufficient detail in the JRC model.

The literature search also confirmed that although there are many models like the ones stated above, few offer the data needed, and the ones that do are particular to a certain nation or to all of Europe. Often also, in models that share data openly do not provide sufficient details to study the system at the level of useful energy or the models consider a different disaggregation of the industry sectors represented in the DGEG's energy balances. Nonetheless, the JRC-EU-TIMES model provides a substantial amount of data for Portugal, which allowed the detailed characterization of the energy model for the Portuguese industrial sector. The literature search also confirmed that there are currently no industrial energy models for Portugal fully based on open and consistent data that have been implemented in an open energy system model, which further validates the main aim of this thesis.

As shown in chapter 2, Portugal's industrial sector is diverse and comprised of a variety of manufacturing and extractive industries. Each industry is a subsector for which DGEG performs an annual energy balance. The sub sectors considered in this work are:

- Food and beverages
- Textile
- Pulp and paper
- Chemical and plastics
- Ceramics
- Glass
- Cement and lime
- Metallurgical
- Steelworks
- Clothing
- Wood
- Rubber
- Metal-electro-mechanical
- Other Industries

The sectors have been reorganised according to the methodology presented in Chapter 4 to fit the available data. Due to the vast diversity of sectors, the way energy is utilised within each sector can vary considerably. Each subsector is comprised of a variety of industrial processes, technologies and energy uses. It is thus not trivial to quantify the energy consumption of each subsector due to the difficulty of classifying all industrial companies, and even more so the energy consumption of small and medium-sized companies. Nevertheless, there are studies that provide reasonable approximations of the final uses of the various industrial subsectors (Norman, 2013), e.g., process heat, drying and separation, motors, compressed air, lighting, refrigeration, space heating and cooling, others. The end uses considered in this work are based on (Norman, 2013) with the adaptations and assumptions described in Chapter 4.

In addition to the UED and the JRC models and datasets, some of the allocations of final energy use to the end uses in the defined subsectors, the UK BEIS energy consumption model (BEIS, 2021) for the industrial sector was also considered to allocate the final energy consumption for some of the subsectors (as described in Chapter 4).

Chapter 4 – Methodology

This chapter describes the model used as a starting point, the development of the energy model for the industrial sector, and the baseline for each industrial sector considered in the model. Future implementation scenarios, demand evolution in the model, and future technologies are also addressed.

4.1 Reference Energy Model

The detailed industrial energy model for Portugal was built from a previously develop national energy model which mapped out the energy flows from primary energy to final energy demand for the end use sectors – i.e., agriculture and fisheries, residential buildings, services buildings, transport, and industry sectors. This model had already been previously implemented as an OSeMOSYS model. In OSeMOSYS this model is called Reference Energy System (REF) and is shown in Figure 8. The reference year for the national model is 2015, and this reference energy system has been previously used to generate future scenarios for the Portuguese energy system in accordance with the RNC 2050 scenarios. The model was implemented from national energy statistics for the reference year (2015), and the IEA technology and costs database was used as the main source for the costs and technical performance of future energy technologies. The model was developed and populated from using the MoManI interface.

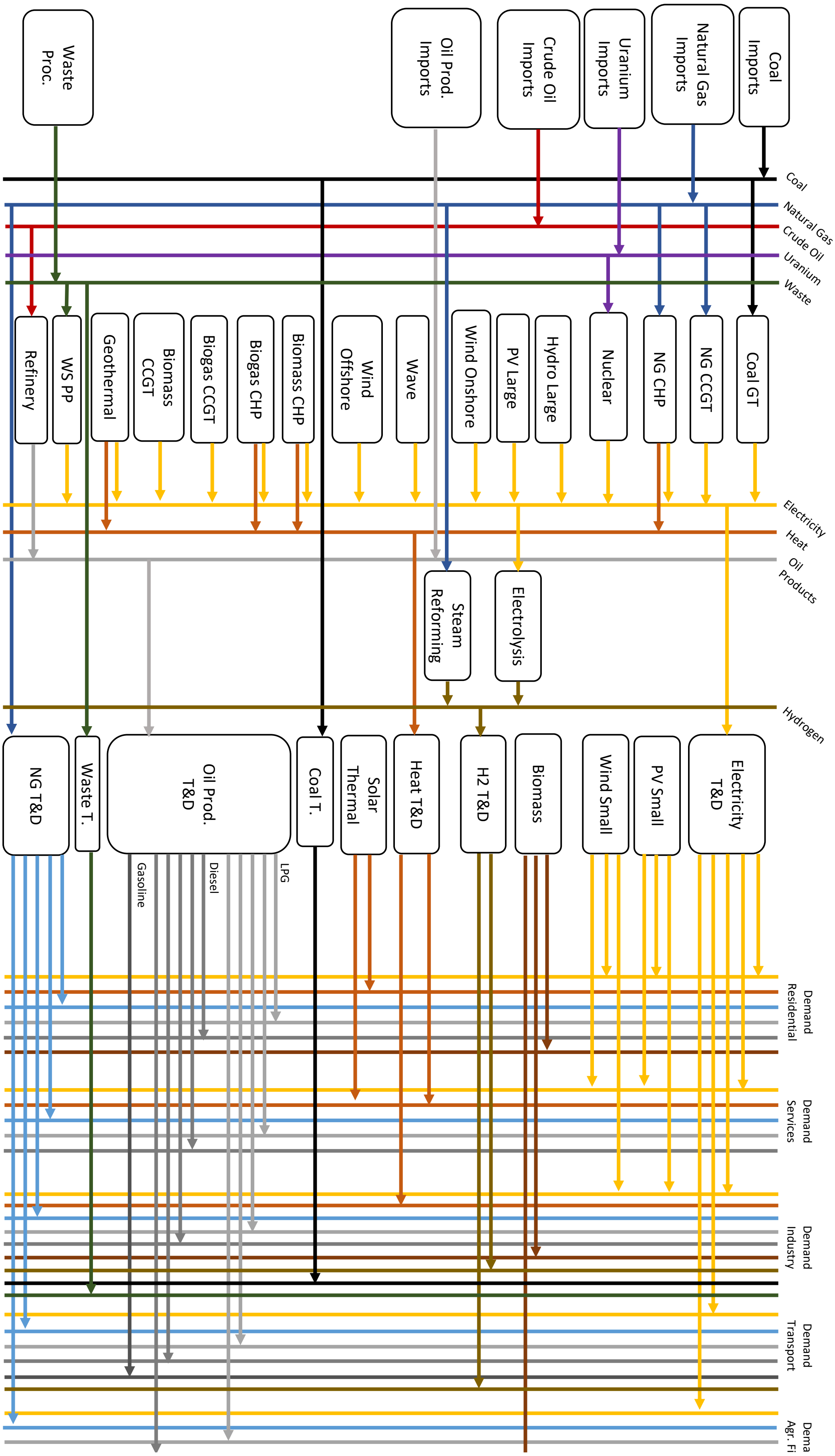


Figure 8 - Reference Energy System (REF) for the Portuguese energy system, used as the starting model.

4.2 Development of the detailed industrial model

Until now, the structure of the REF model stopped at the final energy demand of all end use sectors, i.e., the demand of the different energy carriers was seen as a whole. As explained before, to properly model the energy transition, energy system models should allow for a detailed characterization of the end use sectors. The overarching goal is to work from this initial simplified demand model to eventually build up a detailed model with a disaggregated demand for all end use sectors. For this thesis, since the goal is to develop a detailed model for the industrial sector, further disaggregating the final energy flows of the existing model is needed to map out the different uses and technologies of the industrial subsectors.

To construct the detailed industrial model, the general methodology starts it with the categorization of the industry into sub-sectors, followed by the identification of the end-uses of each sub-sector, and finally, by the identification the technologies employed to serve those end-uses. Several technical and economic data are required for each technology (e.g., CAPEX and OPEX costs of technologies, efficiencies). In addition, the demand for each end use must be specified. Once the structure of the industrial sector has been created and these data have been defined, the OSeMOSYS model is able to simulate the behaviour of the industry sector from 2015 to 2050 and select the most cost-effective strategies to respond to the various GHG emissions scenarios imposed.

The industrial sector was divided into eight sectors: (1) iron and steel, (2) food and drinks, (3) chemicals, (4) cement and lime, (5) ceramics and glass, (6) non-ferrous metal, (7) paper and pulp, and (8) other sectors. As described previously, this category was based on the JRC model because it is one of the few sources with sufficient data to characterise the technologies. Following this choice of industrial segmentation, the end-uses of each subsector were specified. The end-uses considered were based on existing research on the end-uses that cut across the various sub-sectors, as described previously. The following end uses were considered for all industrial subsectors:

- Heat
- Steam
- Refrigeration
- Machine drive
- Lighting
- HVAC
- On site transportation
- Other uses

It should be noted that for each subsector, additional end uses, such as the manufacture of materials, can be considered. On the other hand, there are end uses that, according to the type of industry, are not addressed, such as the use of refrigeration or steam.

A representative example of this position in the creation of the model is shown in Figure 9.

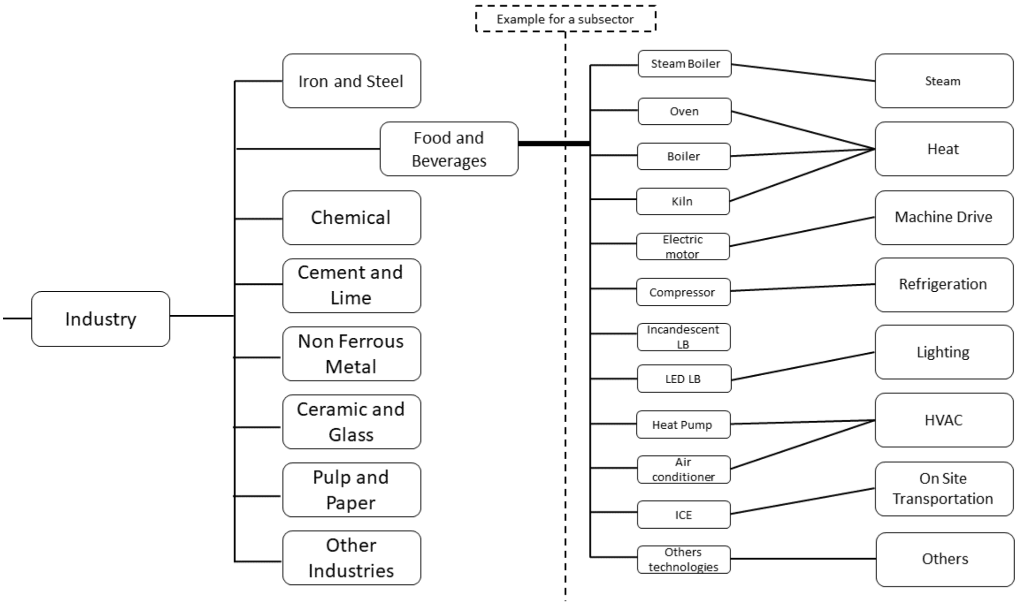


Figure 9 - Diagram illustrating the process of industry breakdown

After conducting an extensive review on the technologies employed in each end-use of each subsector, a document containing all the technologies and their corresponding technical and economic data was compiled and is available in ANNEX A. As previously stated, the JRC model that identifies many processes and technologies for each industry subsector was the primary source for the data used. However, additional sources were used (as identified in Annex A) to properly characterise the technologies incorporated into each subsector of the detailed industrial model.

Once all the necessary data had been collected, the basic structure for the model was created and populated using the MoManl user interface. The process begins by defining the model's structure, i.e., by adding the "fuels" that are the inputs and outputs of each technology (corresponding to energy sources and carriers) and the technologies. In this instance, only the fuels corresponding to the outputs were included, as the inputs were already part of the base model. Due to constraints imposed by the interface, the names for each fuel and technology cannot contain spaces; therefore, codes are typically used to define these elements, as shown in Figure 10. The interface also allows for the creation of a description and insertion into a group.

Data entry for set TECHNOLOGY

Name	Description	Group	Color	Remove
INDCH_BL_NG	Natural Gas Boiler Chemical Industry	Chemical Industry	🟥	−
INDFB_Oven_Ele	Eletric Oven Food Beverages Industry	Food Beverages Industry	🟦	−

Data entry for set FUEL

Name	Description	Group	Color	Remove
Heat_IND_CH	Heat produced in the chemical industry sector	Output Chemical Industry	🟦	−
Heat_IND_FB	Heat produced in the Food Beverages Industry	Output Food Beverages Industry	🟥	−
HVAC_IND_CMLM	HVAC use in Cemente and Lime Industry	Output Cement and Lime industry	■	−

Figure 10– Definition of technologies and fuels for the industrial model in MoManI.

As illustrated in Figure 10, a code is produced for each fuel or technology that typically consists of two to four letters to designate the fuel, followed by _IND to denote "industry" and the code for each sub-sector. For technologies, the format is nearly identical and may be easily comprehended by examining the example presented in figure 10. A full list and description of all the technologies and fuels that are part of the model is provided in Annex A and B.

The next step in implementing the model, after completing the construction of the basic structure (i.e., identifying the technologies and end uses), consists in specifying the parameters for each technology and fuel. Table 2 depicts an example of the characterization of a technological requiring the definition of the input and output (fuel) for the technology, CAPEX (capital cost), OPEX (fixed cost), operational lifetime, and variable cost parameters.

Table 2 - Example of process followed to define a technology in OSeMOSYS using the MoManI interface.

Parameter	Technology	Fuel	2015	2016	...	2049	2050	Value
CapacityToActivityUnit	INDCH_BL_NG							1
CapitalCost	INDCH_BL_NG		208.14	208.14	...	208.14	208.14	
FixedCost	INDCH_BL_NG		11.94	11.94	...	11.94	11.94	
InputActivityRatio	INDCH_BL_NG	NG_Ind	1	1	...	1	1	
OperationalLife	INDCH_BL_NG				...			30
OutputActivityRatio	INDCH_BL_NG	Heat_IND_CH	0.8	0.8	...	0.8	0.8	
VariableCost	INDCH_BL_NG		0.0001	0.0001	...	0.0001	0.0001	

The definition of fuels occurs through the definition of different parameters to those used in the definition of the technologies. For each fuel (i.e., in this case for the industrial model, the end uses), the annual demand from 2015 to 2050 must be stated, along with the annual consumption profile. The defined demand profile is the proportion of annual energy demand necessary at each time interval (i.e., time slice). The year was divided into 4 seasons: winter, spring, summer, and autumn. For each of the seasons all days are the same and two distinct consumption periods were considered - day and night, resulting in eight time slices: autumn day (AD), autumn night (AN), spring day (SpD), spring night (SpN), summer day (SuD), summer night (SuN), winter day (WD), and winter night (WN). These time slices are of equal duration. Thus, each of these time slices will represent one-eighth of a year. Table 3 shows an example of the parameters used to characterize a fuel (end-use) for the chemical industry.

Table 3 - Example of the process followed to define a fuel in OSeMOSYS through the MoManI interface.

Parameter	TIMESLICE	Fuel	2015	2016	…	2049	2050
SpecifiedAnnualDemand		AM_IND_CH	0.228076	0.228076	…	0.228076	0.228076
SpecifiedDemandProfile	AD	AM_IND_CH	0.2	0.2	…	0.2	0.2
SpecifiedDemandProfile	NA	AM_IND_CH	0.05	0.05	…	0.05	0.05
SpecifiedDemandProfile	SpD	AM_IND_CH	0.2	0.2	…	0.2	0.2
SpecifiedDemandProfile	SpN	AM_IND_CH	0.05	0.05	…	0.05	0.05
SpecifiedDemandProfile	SuD	AM_IND_CH	0.2	0.2	…	0.2	0.2
SpecifiedDemandProfile	SuN	AM_IND_CH	0.05	0.05	…	0.05	0.05
SpecifiedDemandProfile	WD	AM_IND_CH	0.2	0.2	…	0.2	0.2
SpecifiedDemandProfile	WN	AM_IND_CH	0.05	0.05	…	0.05	0.05

The structure of each subsector considered in the detailed industrial model are presented in Annex F.

4.3 Characterization of the energy use for the industrial sector in the base year (2015)

This section describes the characterization of the detailed industrial energy system for the base year (2015). To complete the process of fully defining the model, in addition to the techno-economic data described in the previous section, the demand for the different end uses was added to the model for all the different “fuels” considered in the model structure. The demand data was calculated using the national energy statistics (DGEG, energy balance for 2015), the JRC model data and additional sources for specific uses/technologies. The process for the calculations and assumptions for each subsector is described below. The information on the sources of data can be found in Annex J and the representation of the disaggregation of each subsector in terms of energy vector and end uses can be found in Annex F.

By examining the DGEG's 2015 national energy balance presented in annex D, we know the exact quantity of final energy consumed by each industry and each energy vector. To calculate the energy demand by each end use several steps need to be taken. Firstly, for each subsector the final energy consumption from the national energy statistics is allocated to each technology and its corresponding end use; in this manner, we obtain the useful energy, which is the final energy consumed by the technology multiplied by its efficiency.

There are end uses where it is clear how much energy is used, such as the manufacturing of ammonia, where data of both the annual output and the technology's energy usage is available. However, there are other end uses where we do not have enough data to unambiguously allocate the energy to the end uses, e.g., in many of the process heat uses, because there are multiple technologies for the same use that are not defined in terms of their energy flows. Consequently, assumptions were made to assign the energy consumption to the end uses of each subsector and to split these shares by the feeding technologies.

The JRC model defines the reference used for the energy consumed in the production of the materials considered in each subsector while the shares of final energy consumption allocated to the end-uses in each industry end-uses were primarily adapted from the BEIS UK consumption model, which lists the energy consumed by energy carrier in each end-use and industry, and this was then converted to shares of final energy per vector and per end-use. This procedure included various assumptions, which are detailed separately for each subsector.

4.3.1 Iron and Steel Industry

To match the disaggregation considered in the JRC model to the subsectors in the national energy statistics, the iron and steel subsector in the detailed industrial model includes two subsectors: the steel and metal-eletro-mechanic industries. The data for the iron and steel sector was primarily taken from the JRC model, which categorises this sector as an energy intensive sector and thus has a detailed description of the production processes and materials produced within the subsector: in this case, steel and crude steel. Specific technologies were assigned to each of these produced materials as well as to the end uses, such as heat, machine drive, lighting, HVAC, on-site transportation, and others.

Since the demand for the base year is derived from a combination of the aggregated national energy data and the disaggregated JRC data, before getting to the transversal end uses in this sector, the energy used in the manufacture of the material (steel and crude steel) is deducted to the overall final energy demand per vector from the national statistics. The procedure described is depicted in Table 4.

Table 4 – Energy consumed in the iron and steel sector.

	Final Energy [PJ]			
DGEG 2015	Foundries	Metal-electro-mechanics	Iron and Steel Industry	Without crude and iron and steel production
Coal	0.36827	0.00507	0.37334	0.16430
Oil Products	0.07201	1.06943	1.14145	0.94471
Natural gas	1.48468	2.27414	3.75883	1.65616
Electricity	4.95420	5.37317	10.32737	5.44574
Heat	0.00000	0.02788	0.02788	0.02788
Non Renewables	0.00000	0.00000	0.00000	0.00000
Solar Thermal	0.00000	0.00000	0.00000	0.00000
Biomass	0.00000	0.00251	0.00251	0.00251
Urban Solid Waste	0.00000	0.00000	0.00000	0.00000
Sulphite Liquors	0.00000	0.00000	0.00000	0.00000
Other Renewables	0.00000	0.00000	0.00000	0.00000
Biogas	0.00000	0.00000	0.00000	0.00000
Biofuels	0.00000	0.00000	0.00000	0.00000

The following assumptions were made in the iron and steel sector:

1. Since there was no consideration for steam use in these industries, it was assumed that steam was part of the process heat. As a result, 89% of natural gas, biomass, and fuel oil were allocated equally for process heat for each technology utilised for that purpose.

2. For the machine drive use, 12% of the electricity was allocated; however, there were more uses that were not accounted for in this model but were included in this use, so we combined the percentages of these additional uses and assigned 70% of the electricity to the machine drive use.

3. Since the diesel combustion engine is the sole technology that fits this application, on-site transportation accounted for 80% of the sector's fuel consumption.

Table 5 shows all end uses, technologies, final energy allocated to each technology, and the efficiency that permits calculating the useful energy expended by each, and thus the demand for each end use that were used to specify the parameters associated with the steel and iron subsector in the extended OSeMOSYS model.

Table 5 -End uses, technologies and energy use distribution in iron and steel industry for 2015.

Final Uses Demand	**Useful Energy Demand (or tonnes produced)**	**Technologies**	**Efficiency**	**Final energy Vectors**	**Final Energy**
Crude Steel Prod [Mt]	1.66	Eletric arc furnace		Electricity	3.565926
				NG	0.836148
Iron and Steel Prod [Mt]	1.66	Iron and steel production techs		Coal	0.209037
				Electricity	1.315704
				NG	1.266519
				FO	0.135259
				LPG	0.061481
Heat	0.0009502	High efficiency boilers	0.85	BM	0.001118
	0.6264420		0.85	NG	0.736991
	0.0058595		0.85	OilP	0.006894
	0.0010061	Very High efficiency boilers	0.9	BM	0.001118
	0.6632915		0.9	NG	0.736991
	0.0062042		0.9	FO	0.006894
Machine Drive	3.4308166	Electrical Motor	0.9	Electricity	3.812018
Lighting	0.0074879	LED LB	0.55	Electricity	0.013614
	0.0012253	Halogen LB	0.09	Electricity	0.013614
	0.0006807	Incandencent LB	0.05	Electricity	0.013614
	0.0027229	Fluorecent LB	0.2	Electricity	0.013614
HVAC	0.0397478	Boilers	0.8	NG	0.049685
	0.0172419		0.8	LPG	0.021552
	0.0003718		0.8	Oil Products	0.000465
	0.9148844	Heat Pump	4.8	Electricity	0.190601
	0.5718028	AC	3	Electricity	0.190601
On site Transportation	0.0811737	Diesel ICE	0.25	Diesel	0.324695
Others	0.584208	Others		Oil Products	0.584208
	0.132493			Natural gas	0.132493
	1.211677			Electricity	1.211677

4.3.2 Food and beverages

In the food and beverage sector, the data was derived from a combination of the JRC model, which classifies this industry as "other industries," and techno-economic data extracted from technologies that aligned with the end uses considered by the UED model, which include direct heating, steam systems, refrigeration, motors, and others. The end-uses for this subsector include heat, steam, refrigeration, machine drive, lighting, HVAC, on site transportation and others.

The final energy consumption from the national energy statistics for 2015 for the food and beverage industry is presented in Table 6. The values shown in this table are then distributed by each technology and end use according to assumptions presented below.

Table 6 - Energy consumed in the Food and Beverages sector.

	Final Energy [PJ]
DGEG 2015	Food and beverages
Coal	0.00000
Oil Products	3.23832
Natural gas	6.09385
Electricity	6.80803
Heat	1.98844
Non Renewables	0.00000
Solar Thermal	0.00000
Biomass	1.09987
Urban Solid Waste	0.00000
Sulphite Liquors	0.00000
Other Renewables	0.00000
Biogas	0.05267
Biofuels	0.00000

In the food and beverages sector the following assumptions were made:

1. This industrial subsector is characterised using information from the UED model and data from the UK BEIS energy consumption database. The UED model indicates that steam is used in this sector, and our model includes steam boilers. The BEIS database in turn, indicates that 75% of natural gas, biomass, and oil products are utilised for process heat. Combining this with data from the UED model, each energy vector was allocated in the shares of 73% and 27% to the use of steam and heat respectively.
2. For end uses that are served by many technologies that utilise the same energy carrier, the energy carrier is distributed equally among all

technologies. For instance, heat is produced in ovens and boilers, and the natural gas required by these technologies is distributed equally through these technologies.

Table 7 shows all end uses, technologies, final energy used by each technology, and the efficiency that was used to calculate the useful energy associated to each end use. There were used as to specify the parameters associated with the end uses of the Food and Beverages subsector in 2015 in the extended OSeMOSYS model.

Table 7 - End uses, technologies and energy use distribution in food and beverages industry for 2015.

Final Uses Demand [PJ]	Useful Energy Demand (PJ or tonnes produced)	Technologies	Efficiency	Final energy Vectors	Final Energy
Heat	0.32907	Ovens	0.8	NG	0.41133
	0.21417		0.8	Diesel	0.26771
	0.21997		0.8	Biomass	0.27497
	1.90625		0.8	Electricity	2.38281
	0.06294		0.8	FO	0.07867
	0.02003	Efficiency Boiler	0.85	BM	0.02357
	0.34963		0.85	NG	0.41133
	0.06687		0.85	F0	0.07867
	0.24747	High efficiency boiler	0.9	BM	0.27497
	0.37020		0.9	NG	0.41133
	0.07080		0.9	F0	0.07867
Steam	0.51048	Steam Boiler	0.8	F0	0.63810
	0.57905		0.8	Diesel	0.72381
	2.66910		0.8	NG	3.33638
Refrigeration	1.65435	Compressor	0.9	Electricity	1.83817
Machine Drive	1.83817	Electrical Motor	0.9	Electricity	2.04241
Lighting	0.00936	LED LB	0.55	Electricity	0.01702
	0.00153	Halogen LB	0.09	Electricity	0.01702
	0.00085	Incandencent LB	0.05	Electricity	0.01702
	0.00340	Fluorecent LB	0.2	Electricity	0.01702
HVAC	0.34126	Boilers	0.8	NG	0.42657
	0.04161		0.8	LPG	0.05201
	0.06527		0.8	F0	0.08158
	0.98036	Heat Pumps	4.8	Electricity	0.20424
	0.61272	AC	3	Electricity	0.20424
On site Transportation	0.08263	Diesel ICE	0.25	Diesel	0.33051

Others	0.90859	Others		OilP	0.90859
	1.09689			NG	1.09689
	0.08510			Electricity	0.08510
	0.52637			Biomass	0.52637

4.3.3 Chemicals

In the chemicals industry, data were derived primarily from the JRC model that categorises this industry as energy intensive, as well as from other references, to better characterise several technologies used in this subsector. Ammonia and chlorine are the materials produced by this industry. Specific technologies were assigned to each of these produced materials, as well as the end-uses listed, which include heat, steam, refrigeration, machine drive, lighting, HVAC, on-site transportation, and others. Before proceeding to the transversal end uses in this industry, one must deduct the energy used in the already-defined material production (ammonia and chlorine). The described procedure is depicted in Table 8.

Table 8 - Energy consumed in the chemical sector.

	Final Energy [PJ]			
DGEG 2015	Chemical and Plastics	Rubber	Chemical Industry	Without ammonia and chlorine production
Coal	0.000	0.000	0.000	0.000
Oil Products	0.351	0.011	0.361	0.361
Natural gas	5.737	0.153	5.890	1.670
Electricity	8.230	0.755	8.986	8.272
Heat	3.246	0.440	3.687	3.687
Non Renewables	0.002	0.000	0.002	0.002
Solar Thermal	0.000	0.000	0.000	0.000
Biomass	0.093	0.015	0.108	0.108
Urban Solid Waste	0.000	0.000	0.000	0.000
Sulphite Liquors	0.000	0.000	0.000	0.000
Other Renewables	0.000	0.000	0.000	0.000
Biogas	0.000	0.000	0.000	0.000
Biofuels	0.022	0.000	0.022	0.022

The following assumptions were made in the chemical industry:

1. 14% of natural gas is used to produce steam; however, natural gas steam production technologies were not evaluated in this industry, therefore these 14% were allocated to end use “others”.

Table 9 lists all end uses, technologies, final energy used by each technology, and the efficiency used in the calculation of the useful energy associated with each end use.

Table 9 - End uses, technologies and energy use distribution in chemicals industry.

Final Uses Demand	**Useful Energy Demand (PJ or tonnes produced)**	**Technologies**	**Efficiency**	**Final energy Vectors**	**Final Energy**
NH3 Prod [Mt]	0.228000	Plasma Arc decomposition		NG	4.220000
				Electricity	0.114000
Cl2 Prod [Mt]	0.038000	Advanced membrane production		Electricity	0.301141
	0.038000	Advanced membrane production improvement		Electricity	0.271191
Heat	0.187076	Boilers	0.8	NG	0.233846
	0.051881		0.8	LPG	0.064851
	0.018803		0.8	Biomass	0.023504
	0.027592		0.8	Oil Products	0.034489
	0.019978	High efficiency boilers	0.85	BM	0.023504
	0.198769		0.85	NG	0.233846
	0.029316		0.85	OilP	0.034489
	0.021154	Very High efficiency boilers	0.9	BM	0.023504
	0.210461		0.9	NG	0.233846
	0.031041		0.9	OilP	0.034489
Steam	0.017828	Steam Boilers	0.8	Oil Products	0.022285
	0.011174		0.8	LPG	0.013968
	3.612953		0.98	Waste Heat	3.686687
Refrigeration	0.000000	Compressor		Electricity	1.161919
Machine Drive	4.855161	Electrical Motor	0.9	Electricity	5.394623
Lighting	0.011412	LED LB	0.55	Electricity	0.020749
	0.001867	Halogen LB	0.09	Electricity	0.020749
	0.001037	Incandencent LB	0.05	Electricity	0.020749
	0.004150	Fluorecent LB	0.2	Electricity	0.020749
HVAC	0.053450	Boilers	0.8	NG	0.066813
	0.003991		0.8	LPG	0.004989
	0.006367		0.8	Oil Products	0.007959
	1.195116	Heat Pumps	4.8	Electricity	0.248983
	0.746948	AC	3	Electricity	0.248983
Onsite Transportation	0.020473	Diesel ICE	0.25	Diesel	0.081894
Others	0.901976	Others		NG	0.901976
	1.154999			Electricity	1.154999
	0.037968			Biomass	0.037968

4.3.4 Cement and lime

In the cement and lime subsector, data were gathered primarily from the JRC model that categorises this industry as an energy-intensive industry, as well as from other references, to better characterise some of the technologies used in this industry. Cement, clinker, and lime are the primary products considered. Specific technologies that have been assigned to each of these manufactured materials, as well as their end uses, which include heat, machine drive, lighting, HVAC, on-site transportation, and others are shown in Table 11.

Before proceeding to the allocation of the final energy consumption to the transversal end uses in this industry, one must deduct the energy used in the production of cement, clinker, and lime. The final energy consumption in the Cement and Lime industry is presented in Table 10. The remaining energy per vector is then allocated to the other end uses according to the values presented in Table 11.

Table 10 - Energy consumed in the cement and lime sector.

	Final Energy [PJ]	
DGEG 2015	Cement and Lime	Without cement, lime and clinker production
Coal	0.00000	0.00000
Oil Products	15.01479	13.91404
Natural gas	1.39316	1.39316
Electricity	2.97493	1.03513
Heat	0.04254	0.00000
Non Renewables	2.30316	2.30316
Solar Thermal	0.00000	0.00000
Biomass	0.30961	0.30961
Urban Solid Waste	0.00000	0.00000
Sulphite Liquors	0.00000	0.00000
Other Renewables	1.61724	1.61724
Biogas	0.00000	0.00000
Biofuels	0.00000	0.00000

The following assumptions were made in the cement and lime industry:

1. The clinker manufacturing process requires 22.5 PJ of heat. Since all the heat is produced centrally in the REF model, this amount of heat is considered as sourced from the centralized production of heat in the model (through CHP).

Table 11 lists all the end uses, technologies, the final energy consumed by each technology, and the efficiency used in the calculation of the useful energy per each end use, and hence the demand for each end use considered in the extended OSeMOSYS model.

Table 11 - End uses, technologies and energy use distribution in cement and lime industry.

Final Uses	**Useful Energy Demand (PJ or tonnes produced)**	**Technologies**	**Efficiency**	**Final energy Vectors**	**Final Energy**
Clinker prod [Mt]	8.04300000	Dry Process equipment		Electricity	0.8686926
				Heat	
Cement prod [Mt]	8.04300000	Finished Cement production equipment		Electricity	1.8831798
				OilP	1.1007489
Lime Prod [Mt]	0.22500000	Quick Lime Production		Electricity	0.0566250
				Heat	0.0566250
Heat	0.31578241	Kiln	0.8	NG	0.3947280
	2.74937187		0.8	HFO	3.4367148
	0.11184801	High efficiency boilers	0.85	BM	0.1315859
	0.33551881		0.85	NG	0.3947280
	1.46060381		0.85	OilP	1.7183574
	0.11842730	Very High efficiency boilers	0.9	BM	0.1315859
	0.35525521		0.9	NG	0.3947280
	1.54652168		0.9	OilP	1.7183574
Machine Drive	0.37264535	Electrical Motor	0.9	Electricity	0.4140504
Lighting	0.00142330	LED LB	0.55	Electricity	0.0025878
	0.00023290	Halogen LB	0.09	Electricity	0.0025878
	0.00012939	Incandencent LB	0.05	Electricity	0.0025878
	0.00051756	Fluorecent LB	0.2	Electricity	0.0025878
HVAC	0.02229052	Boilers	0.8	NG	0.0278632
	0.00041801		0.8	LPG	0.0005225
	0.00007838		0.8	Oil Products	0.0000980
	0.09937209	Heat Pumps	4.8	Electricity	0.0207025
	0.06210756	AC	3	Electricity	0.0207025
Onsite Transportation	0.16819213	Diesel ICE	0.25	Diesel	0.6727685
Others	6.3672183	Others		OilP	6.3672183
	0.1811105			NG	0.1811105
	0.5719071			Electricity	0.5719071
	0.0464421			BM	0.0464421

4.3.5 Ceramics and Glass

The data for the ceramics and glass industries were primarily taken from the JRC model, which categorises this sector as an energy-intensive one, as well as from other references to characterise more accurately some of the technologies that are employed. Flat glass and hollow glass were the two products manufactured in this industry. For each of these materials, particular technologies have been assigned, as well as for the other end uses, which include heat, machine drive, lighting, HVAC, on-site transportation, and others presented in Table 13

The final energy use by vector for this subsector results from the combination of the energy statistics for the ceramic and glass sectors, which have been combined to represent the final energy consumption of the Ceramic and Glass industry sector. Before allocating the final energy to the transversal end uses in this sector, one must deduct the energy required in the manufacturing of flat and hollow glass. The procedure described is represented in Table 12.

Table 12 - Energy consumed in the ceramic and glass sector.

	Final Energy [PJ]			
DGEG 2015	Ceramics	Glass and glassware	Ceramic and glass industry	Without Flat and Hollow Glass Prod
Coal	0.000	0.000	0.000	0.000
Oil Products	0.758	0.053	0.811	0.185
Natural gas	8.054	8.700	16.754	10.396
Electricity	1.490	1.873	3.363	2.313
Heat	0.656	0.000	0.656	0.656
Non Renewables	0.000	0.000	0.000	0.000
Solar Thermal	0.000	0.000	0.000	0.000
Biomass	0.749	0.000	0.749	0.749
Urban Solid Waste	0.000	0.000	0.000	0.000
Sulphite Liquors	0.000	0.000	0.000	0.000
Other Renewables	0.000	0.000	0.000	0.000
Biogas	0.000	0.000	0.000	0.000
Biofuels	0.000	0.000	0.000	0.000

The following assumptions were made in the ceramic and glass industry:

1. After deducting the energy consumed in the manufacturing of the materials given in Table 12, there was no final energy from oil products

for other uses; therefore, approximately 20% of oil products were added to the industry to satisfy the requirements of other uses.

2. In the UK BEIS energy consumption model, there is an indication of the percentage use of natural gas, electricity, biomass and oil products for process heat and steam in the ceramics and glass industry. In our model, this industry does not utilise steam, thus the proportion of steam produced by natural gas, electricity, and biomass is added to the percentage of heat.
3. The percentage of steam generated from technologies using oil products referred to in the first point was distributed 18% to heat uses, 2% to HVAC use and 5% to other uses.

Table 13 lists all the end uses, technologies, the final energy consumed by each technology, and the efficiency used to calculate the useful energy associated with each end use, and hence the demand for each end use.

Table 13 - End uses, technologies and energy use distribution in ceramic and glass industry.

Final Uses Demand	**Useful Energy Demand (PJ or tonnes produced)**	**Technologies**	**Efficiency**	**Final energy Vectors**	**Final Energy**
Flat glass prod [Mt]	0.0567	Flat Production Equipment		Electricity	0.0638
				NG	0.0407
	0.1053	Flat Production Equipment w/ heat recovery		Electricity	0.0892
				NG	0.0569
Glass Hollow prod [Mt]	0.368368	Glass Hollow equipment		Electricity	0.3481
				NG	2.3349
				Oil	0.3655
	0.684112	Glass Hollow equipment w/ heat recovery		Electricity	0.4858
				NG	3.2586
				Oil	0.5100
	0.050232	Glass recycling equipment		Electricity	0.0262
				NG	0.2746
				Oil	0.0496
	0.093288	Glass recycling equipment w/ improved melting		Electricity	0.0373
				NG	0.3918
				Oil	0.0708

Heat	0.169749061	Kiln	0.8	BM	0.2122
	2.356447064		0.8	NG	2.9456
	0.999270103		0.8	Electricity	1.249
	0.180358377	High efficiency boilers	0.85	BM	0.212186326
	2.503725005		0.85	NG	2.94555883
	0.058963623		0.85	OilP	0.069368968
	0.190967694	Very High efficiency boilers	0.9	BM	0.212186326
	2.651002947		0.9	NG	2.94555883
	0.062432072		0.9	OilP	0.069368968
Machine Drive	0.832725086	Electrical Motor	0.9	Electricity	0.925250096
Lighting	0.003180547	LED LB	0.55	Electricity	0.005782813
	0.000520453	Halogen LB	0.09	Electricity	0.0057828
	0.000289141	Incandencent LB	0.05	Electricity	0.0057828
	0.001156563	Fluorecent LB	0.2	Electricity	0.0057828
HVAC	0.16633744	Boilers	0.8	NG	0.2079218
	0.001479871		0.8	LPG	0.001849839
	0.001479871		0.8	Oil Products	0.001849839
	0.222060023	Heat Pumps	4.8	Electricity	0.046262505
	0.138787514	AC	3	Electricity	0.046262505
Onsite Transportation	0.008324276	Diesel ICE	0.25	Diesel	0.033297105
Others	1.35	Others		NG	1.35
	0.21			Electricity	0.21
	0.11			BM	0.11
	0.66			Heat	0.66

4.3.6 Non Ferrous Metals

The data for the non-ferrous metals sector are primarily derived from the JRC model, which categorises this subsector as energy intensive. Aluminium and aluminium crude are the two types of materials produced by this industry. Specific technologies have been designated for each of these materials, as well as for the end uses, which include heat, steam, machine drive, lighting, HVAC, on site transportation, and others, as shown in Table 15

Before allocating the final energy consumption for this subsector to the transverse end uses in this sector, one must subtract the energy required in the already-defined manufacturing of aluminium and aluminium crude. The final energy consumption of the Non-Ferrous Metals industry is provided in Table 14. Through this table, the distribution of each energy vector that enters this industry by each technology that uses it, excluding the energy consumed in the manufacture of materials, is determined.

Table 14 - Energy consumed in the Non Ferrous Metal sector.

	Final Energy [PJ]	
DGEG 2015	Non Ferrous Metal	Without aluminum and aluminum crude prod
Coal	0.13173	0.13173
Oil Products	0.14458	0.14398
Natural gas	0.83565	0.72435
Electricity	0.84871	0.61111
Heat	0.00000	0.00000
Non Renewables	0.00000	0.00000
Solar Thermal	0.00000	0.00000
Biomass	0.00008	0.00008
Urban Solid Waste	0.00000	0.00000
Sulphite Liquors	0.00000	0.00000
Other Renewables	0.00000	0.00000
Biogas	0.00000	0.00000
Biofuels	0.00000	0.00000

The following assumptions were made in the Non-Ferrous Metal industry:

1. In the UK BEIS energy consumption model, 45% of the oil products are allocated to steam and another 45% for heat uses. However, this energy vector is also required for other applications, such as on-site mobility. Consequently, the steam and heat use were decreased by 5% to increase transportation use by 10%.

Table 15, lists all the end uses, technologies, the final energy consumed by each technology, and the efficiency used to calculate the useful energy associated with each end use, and hence the demand for each end use.

Table 15 - End uses, technologies and energy use distribution in non-ferrous metal industry in 2015.

Final Uses	Useful Energy Demand (PJ or tonnes produced)	Technologies	Efficiency	Final energy Vectors	Final Energy
Al prod [Mt]	0.018	Finished Aluminium Prod Equip		Eletricity	0.18
				NG	0.0897
				OilP	0.0006
Al crude [Mt]	0.018	Inert Anodes		Eletricity	0.0576
				NG	0.0216
Heat	0.171913139	Boilers	0.8	NG	0.214891423
	0.032328795		0.8	LPG	0.040410994
	0.04215268		0.8	Coal	0.05269085
	1.98686E-05		0.8	Biomass	2.48357E-05
	0.015357603		0.8	Oil Products	0.019197004
	2.11104E-05	High efficiency boilers	0.85	BM	2.48357E-05
	0.18265771		0.85	NG	0.214891423
	0.016317454		0.85	OilP	0.019197004
	2.23522E-05	Very High efficiency boilers	0.9	BM	2.48357E-05
	0.193402281		0.9	NG	0.214891423
	0.017277304		0.9	OilP	0.019197004
Steam	0.263454252	Steam Boiler	0.8	Coal	0.329317815
	0.04607281		0.8	Oil Products	0.057591013
	0.032328795		0.8	LPG	0.040410994
Machine Drive	0.066000183	Electrical Motor	0.9	Electricity	0.073333537
Lighting	0.00084028	LED LB	0.55	Electricity	0.001527782
	0.0001375	Halogen LB	0.09	Electricity	0.001527782
	7.63891E-05	Incandencent LB	0.05	Electricity	0.001527782
	0.000305556	Fluorecent LB	0.2	Electricity	0.001527782
HVAC	0.017384475	Boilers	0.8	NG	0.021730593
	0.00161644		0.8	LPG	0.00202055
	0.002303641		0.8	Oil Products	0.002879551
	0.102666952	Heat Pumps	4.8	Electricity	0.021388948
	0.064166845	AC	3	Electricity	0.021388948
On site Transportation	0.020205497	Diesel ICE	0.25	Diesel	0.080821987
Others	0.13	Others		Coal	0.13
	0.06			NG	0.06
	0.49			Electricity	0.49

4.3.7 Pulp and Paper

In the Pulp and Paper industry, the data were derived primarily from the JRC model, which categorises this industry as an energy-intensive industry, as well as from other references used to characterise some of the employed technologies. Low-quality paper, high-quality paper, and paper pulp are the materials considered in this industry. Specific technologies were assigned to produce each of these materials, as well as for their end uses, which include heat, machine drive, lighting, HVAC, on-site transportation, and others, as shown in Table 17.

Before allocating the final energy consumption for this subsector to the transversal end uses, one must subtract the energy required for the manufacturing of high and low quality paper and pulp. The final energy consumption of the Pulp and Paper industry is provided in Table 16. The values allocated to each energy vector that is used in technologies within this industry are calculated from the total final energy consumption for the sector excluding the energy consumed to produce the identified materials.

Table 16 - Energy consumed in the pulp and paper sector.

	Final Energy [PJ]	
DGEG 2015	Pulp and Paper Industry	Without Pulp and Paper production
Coal	0.00000	0.00000
Oil Products	1.45098	1.45098
Natural gas	3.46269	0.82354
Electricity	10.66943	-2.74892
Heat	39.18686	-2.18625
Non Renewables	0.00000	0.00000
Solar Thermal	0.00000	0.00000
Biomass	0.83443	0.83443
Urban Solid Waste	0.00000	0.00000
Sulphite Liquors	0.00000	0.00000
Other Renewables	0.01905	0.01905
Biogas	0.28328	0.28328
Biofuels	0.00000	0.00000

The following assumptions were made in the Pulp and Paper industry:

1. The direct heat consumption and electricity used in the materials production were assumed to be produced by the cogeneration CHP units, that are

allocated to the centralised heat and electricity production in the extended OSeMOSYS model.

2. Given the need for heat in this industry and the fact that the use of steam was not considered, all the heat related uses are accumulated in the high temperature heat (HTH) end use.

Table 17 lists all the end uses, technologies, the final energy consumed by each technology, and the efficiency used to calculate the useful energy associated with each end use, and hence the demand for each end use for this subsector.

Table 17 - End uses, technologies and energy use distribution in pulp and paper industry in 2015.

Final Uses	Useful Energy Demand (or tonnes produced)	Technologies	Efficiency	Final energy Vectors	Final Energy
Low Quality paper prod	0.83925	Low Quality Paper Equipment		Electricity	2.8454024
				Heat	10.841271
	1.02575	Low Quality Paper Equip w/ adv drives		Electricity	3.1615582
				Heat	12.045856
High Quality paper prod	0.0522	High Quality Paper Equipment		Electricity	0.1874939
				Heat	0.7776735
	0.0638	High Quality Paper Equip w/ adv drives		Electricity	0.2083265
				Heat	0.8640816
Pulp Prod	0.103961747	Mechanical Pulp Prod		Electricity	1.2370138
				NG	1.1226558
	0.177015948	Mechanical Pulp Prod w/ adv drives		Electricity	1.6709715
				NG	1.5164956
	0.842933087	Chemical Pulp Production		Electricity	3.295585
				Heat	13.685267
	0.280977696	Recycling Pulp Production		Electricity	0.8120019
				Heat	0.5198087
HTHeat	0.133508678	Kiln	0.8	BM	0.1668858
	0.131766637		0.8	NG	0.1647083
	0.186570507		0.8	Oil Products	0.2332131
	0.131766637	Boilers	0.8	NG	0.1647083
	0.133508678		0.8	Biomass	0.1668858

	0.046642627		0.8	Oil Products	0.0583033
	0.141852971	High efficiency boilers	0.85	BM	0.1668858
	0.140002052		0.85	NG	0.1647083
	0.049557791		0.85	OilP	0.0583033
	0.150197263	Very High efficiency boilers	0.9	BM	0.1668858
	0.148237467		0.9	NG	0.1647083
	0.052472955		0.9	OilP	0.0583033
Machine Drive	6.529692249	Electrical Motor	0.9	Electricity	7.2552136
Lighting	0.014670469	LED LB	0.55	Electricity	0.0266736
	0.002400622	Halogen LB	0.09	Electricity	0.0266736
	0.001333679	Incandencent LB	0.05	Electricity	0.0266736
	0.005334716	Fluorecent LB	0.2	Electricity	0.0266736
HVAC	0.052706655	Boilers	0.8	NG	0.0658833
	0.00538054		0.8	LPG	0.0067257
	0.074628203		0.8	Oil Products	0.0932853
	1.024265451	Heat Pumps	4.8	Electricity	0.2133886
	0.640165907	AC	3	Electricity	0.2133886
Onsite Transportation	0.040109544	Diesel ICE	0.25	Diesel	0.1604382
Others		Others		Oil Products	0.79
				NG	0.10
				BM	0.33
				Other renewables	0.0190499
				Biogas	0.2832789

4.3.8 Other Industries

For the other industries subsector, the main source of data was the JRC model, more specifically the "other industries" sector. This sector of industry is grouped together due to a lack of data to characterise some existing sectors or because their size is relatively small in terms of total energy use. Heat, steam, refrigeration, machine drive, lighting, HVAC, and on-site transportation are the end-uses considered for this subsector. In this industry subsector, no material manufacturing technology was considered; therefore, in order to allocate the final energy consumption in this industry to different end uses, the final energy consumption of each of industries included in this subsector, as shown in Table 18 were first combined into a single overall energy consumption for each vector.

Table 18 - Energy consumed in the other industries sector.

	Final Energy [PJ]				
DGEG 2015	Textiles	Clothing, shoes and leather	Wood and wood products	Other Industries	Other Industries
Coal	0.000	0.000	0.000	0.062	0.062
Oil Products	0.278	0.355	0.385	1.259	2.277
Natural gas	4.848	0.557	0.328	0.201	5.933
Electricity	3.191	1.176	3.132	1.958	9.457
Heat	1.672	0.102	0.517	0.071	2.361
Non Renewables	0.000	0.000	0.000	0.000	0.000
Solar Thermal	0.000	0.000	0.000	0.000	0.000
Biomass	0.110	0.102	0.991	0.055	1.258
Urban Solid Waste	0.000	0.000	0.000	0.000	0.000
Sulphite Liquors	0.000	0.000	0.000	0.000	0.000
Other Renewables	0.000	0.000	0.000	0.000	0.000
Biogas	0.000	0.000	0.000	0.000	0.000
Biofuels	0.000	0.000	0.000	0.000	0.000

No additional assumptions were made in this subsector. Table 19 lists all end uses, technologies, final energy used by each technology, and the efficiency used to calculate the useful energy per end use, thus the demand for each end use.

Table 19 - End uses, technologies and energy use distribution in other industries in 2015.

Final Uses	**Useful Energy Demand (or tonnes produced)**	**Technologies**	**Efficiency**	**Final energy Vectors**	**Final Energy**
Heat	0.743658969	Boilers	0.8	NG	0.9295737
	0.079743468		0.8	LPG	0.0996793
	0.078835155		0.8	Biomass	0.0985439
	0.015994246		0.8	Oil Products	0.0199928
	0.083762352	High efficiency boilers	0.85	BM	0.0985439
	0.790137655		0.85	NG	0.9295737
	0.016993886		0.85	OilP	0.0199928
	0.08868955	Very High efficiency boilers	0.9	BM	0.0985439
	0.836616341		0.9	NG	0.9295737
	0.017993527		0.9	OilP	0.0199928
Steam	0.047982738	Steam Boiler	0.8	Oil Products	0.0599784
	0.079743468		0.8	LPG	0.0996793
	1.605636125		0.8	Waste Heat	2.007
Machine Drive	6.553452507	Electrical Motor	0.9	Electricity	7.2816139

Lighting	0.013002882	LED LB	0.55	Electricity	0.0236416
	0.002127744	Halogen LB	0.09	Electricity	0.0236416
	0.00118208	Incandencent LB	0.05	Electricity	0.0236416
	0.004728321	Fluorecent LB	0.2	Electricity	0.0236416
HVAC	0.569611126	Boilers	0.8	NG	0.7120139
	0.056484956		0.8	LPG	0.0706062
	0.033987773		0.8	Oil Products	0.0424847
	0.907837577	Heat Pumps	4.8	Electricity	0.1891328
	0.567398485	AC	3	Electricity	0.1891328
Onsite Transportation	0.322316611	Diesel ICE	0.25	Diesel	1.2892664
Others	0.062	Others		Coal	0.062
	0.555			OilP	0.56
	2.433			NG	2.43
	1.726			Electricity	1.73
	2.361			Heat	2.361
	0.962			BM	0.96

4.4 Future Scenarios

Future scenarios allow us to estimate the behaviour of the modelled system in future situations, i.e., considering changes in consumption, emissions targets, and production, among other things. For the time horizon of 2050, both the NECP for 2030 as well as the national Roadmap for carbon neutrality have defined targets that require, amongst other changes, a substantial reduction in the production of electricity from fossil fuels. It is possible to use the OSeMOSYS extended model to analyse the changes in the energy system from the reference year (2015) through alternative future scenarios generated by imposing limits on certain parameters of the modelled system, which allows for the study of the effect of these constraints.

The future scenarios analysed in this study consist of 1 with no GHG emissions restrictions (Business-as-Usual, BAU2050) and 2 alternative scenarios with emission limits that are imposed on the system according to the RNC2050 and the more accelerated GHG emissions reductions schedule of the Fit For 55 agenda (55% reduction by 2030).

To analyse the impacts of these scenarios on the energy system and the future configurations of the industrial sector, the evolution of several outputs of the OSeMOSYS model - such as emissions, final energy consumption, end-use demand, evolution of the energy mix, associated technologies, etc. - were studied in more detail and are presented in Chapter 5 and in the Annexes.

All scenarios share some of the restrictions, as these represent policies that are already implemented and will have impacts on the pathways of the future energy system (e.g., phase out of coal, increased share of renewables in the electricity mix). These constraints limit certain possibilities of the model, such as the import of electricity from Spain, the use of coal to generate electricity, and certain technologies that rely on fossil fuels, which the model tends to favour due to their low cost but which are due to be phased out (e.g., the ban on diesel vehicles from 2035 will inevitably result in lower oil products consumption across scenarios).

The BAU2050 scenario represents the evolution of the system without any additional policies, e.g., it does not consider that the targets of the NECP 2030 and the RNC 2050 need to be met. The second scenario is the RNC2050 which is based on the emissions limit of the carbon neutrality roadmap based on an emissions reduction trajectory of -45% to -55% in 2030, -65% to -75% in 2040 and -85% to -90% in 2050, compared to 2005 levels. The third scenario is the FitFor55 which in addition to meeting carbon neutrality by 2050, added an intermediate step with a reduction of at least 55% in 2030. GHG Emissions limits in the RNC2050 and the FitFor55 scenarios. shows the emission limits of each scenario in 5-year intervals from 2015 to 2050.

Table 20 - GHG Emissions limits in the RNC2050 and the FitFor55 scenarios.

Emission limit [$MtCO_2eq$]	2015	2020	2025	2030	2035	2040	2045	2050
RNC2050	67.75	57.6	52.43	47.25	38.66	30.07	23.2	8
FitFor55	67.75	45.35	34.33	23.30	16.77	10.23	10.23	8

4.4.1 Evolution of demand up to 2050 for each sector

In this study, the evolution of demand was adopted from the JRC model, which estimates future energy demand for different sectors according to economic growth drivers of the GEM-E3 general equilibrium model (Simoes et al., 2013). The model includes exogenous assumptions on macroeconomic development, such as population growth, world energy costs, technological advancement, energy intensity, labour productivity developments, and GDP growth targets.

The evolution of the demand for energy services is connected to the forecasts of demand drivers via elasticities. These elasticities are intended to represent shifting patterns in energy service demand in connection to economic growth, such as saturation in certain energy end-use demand, growing urbanisation, or changes in consumption patterns when fundamental necessities are met.

The JRC model depicts the evolution of demand by country for each material manufactured by the industries under consideration. To perform the evolution of demand for the industries considered in our model, we applied the same evolution in production of materials that was considered in the JRC model. The behaviour of the "other industries" sector from the JRC model was considered for the rest.

Table 21 provides the evolution of the demand applied to all end-uses for each industry sub-sector from 2015 to 2050, with variations every five years, with 2015 serving as the reference year; for example, in the Iron and Steel sector, the demand of end-uses in 2030 is 4.6% higher than in 2015.

Table 21 - Evolution of demand for each industrial sector with year 2015 as reference.

	Demand							
Industry	2015	2020	2025	2030	2035	2040	2045	2050
Iron and Steel	-	3.13%	3.33%	4.60%	5.01%	5.46%	5.96%	6.20%
Food and beverages	-	6.56%	13.51%	18.28%	22.89%	26.73%	29.81%	32.11%
Chemical	-	0.92%	2.82%	3.86%	5.07%	6.34%	7.60%	8.62%
Cement and Lime	-	-0.32%	3.61%	7.15%	8.76%	10.34%	11.43%	10.34%
Ceramic and Glass	-	7.19%	8.19%	5.37%	0.33%	-6.88%	-13.80%	-23.01%
Non Ferrous Metal	-	-0.62%	22.70%	31.60%	31.43%	40.46%	43.44%	44.97%
Pulp and Paper	-	8.31%	17.07%	21.73%	20.78%	17.54%	16.36%	17.10%
Ohter Industries	-	6.56%	13.51%	18.28%	22.89%	26.73%	29.81%	32.11%

4.5 Future Technologies

Every year, new innovations lead to advances in low carbon technologies. Despite the challenges associated with incorporating future technologies into the model due to a lack of technical and economic data, our model includes technologies whose main objective is to decarbonize some of the currently available technologies.

Both biogas and natural gas are primarily made up of methane ($CH4$), so technologies that use natural gas could be replaced by biogas, a renewable energy source that results from the decomposition of organic materials. Additionally, other higher efficiency and lower carbon technologies have also been incorporated into the model that could eventually replace completely the current technologies that use natural gas, helping to move society closer to carbon neutrality.

The Extended OSeMOSYS model also includes hydrogen, which is anticipated to become one of the leading green energy sources for the industrial sector in the future. Additionally, hydrogen holds great promise for fuel cell-based sustainable transportation in the future so this technology has been added as an option to the model.

Lastly, electric vehicles (EV) will likely become more commonplace in the near future due to their high market penetration, so this technology was added for use in on-site transportation across all industries.

Chapter 5 – Results and Discussion

This chapter presents and discusses the results obtained in the different modelled scenarios.

5.1 Annual GHG Emissions

Figure 11 depicts the annual evolution of emissions for each scenario. As a result of the limitations of the various situations, it is possible to observe the behaviour of the model. The BAU (business-as-usual) scenario, which does not limit emissions, serves as a contrast to the other scenarios, whose evolution diverges significantly after 2030. In 2050, the BAU model emits 18.9 $MtCO_2eq$ while the other models achieve the reduction goal of -85% to -95% by emitting 8 $MtCO_2eq$. The FitFor55 model provides a sharper reduction due to the ambitious reduction goal of 55% by 2030, which may indicate an increase in expenses due to the necessity to integrate new technologies sooner and the fact that the cost of technology has not yet stabilised. In the RNC model, the reduction of emissions is slower, but after 2045, it follows the same trajectory. The FitFor55 model released 30.8 $MtCO_2eq$ less (-12%) than the RNC model between 2030 and 2045. During the entire period (2015 to 2050), the BAU model reduced emissions by 17% compared to the RNC and by 23% compared to FitFor55.

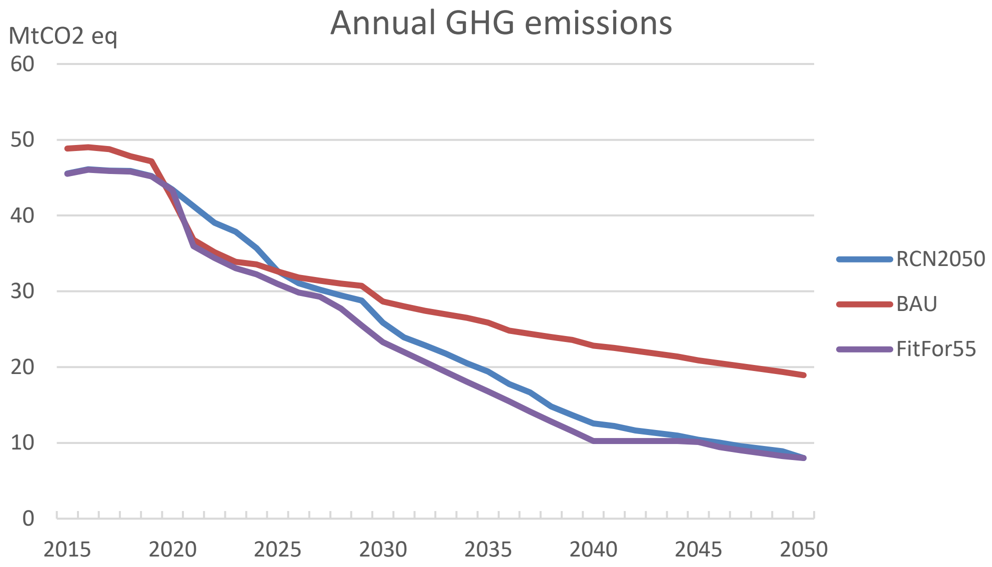


Figure 11- Annual GHG emissions produced in each scenario.

5.2 Energy use

Figure 12 demonstrates that, according to the BAU model, overall energy use in the agriculture, residential, services, industry, and transportation sectors drops steadily from 2015 to 2050. During the period modelled, the transport sector contributes for an average of 39% of final energy consumption, followed by industry with 24%, residential and services with 17%, and agricultural with the remaining 4%. The evolution of consumption in the transportation sector from 2015 to 2050 has decreased dramatically (-77%), whilst demand in the industry sector has climbed by 13%, constituting 19% of TFC in 2019 and 28% in 2050.

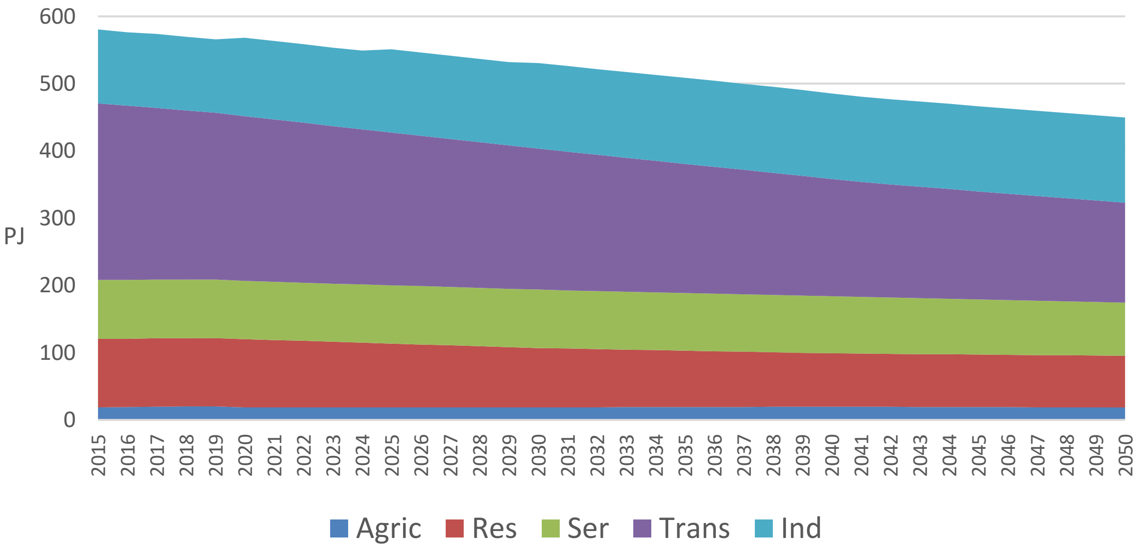


Figure 12 – Evolution of the energy consumed in all sectors in BAU scenario.

Energy consumption in the RNC and FitFor55 models is nearly equal, since the trends and values are nearly identical. Figure 13 demonstrates the RNC model's representation of the progression of energy consumption for both systems. Similar to the BAU model, the total energy consumption of the agriculture, residential, services, industry, and transportation sectors falls, but not until 2025. The RNC model has a lower total energy consumption than the BAU model, with a difference of -8% in 2015 and -14% in 2050, proving that the emissions cap has led to a reduction in energy consumption. In the RNC model, over the modelling period, the transport sector accounts for an average of 33% of total consumption, followed by the industry sector with 27%, the residential sector with 19%, the services sector with 17%, and the agriculture sector with 4%.

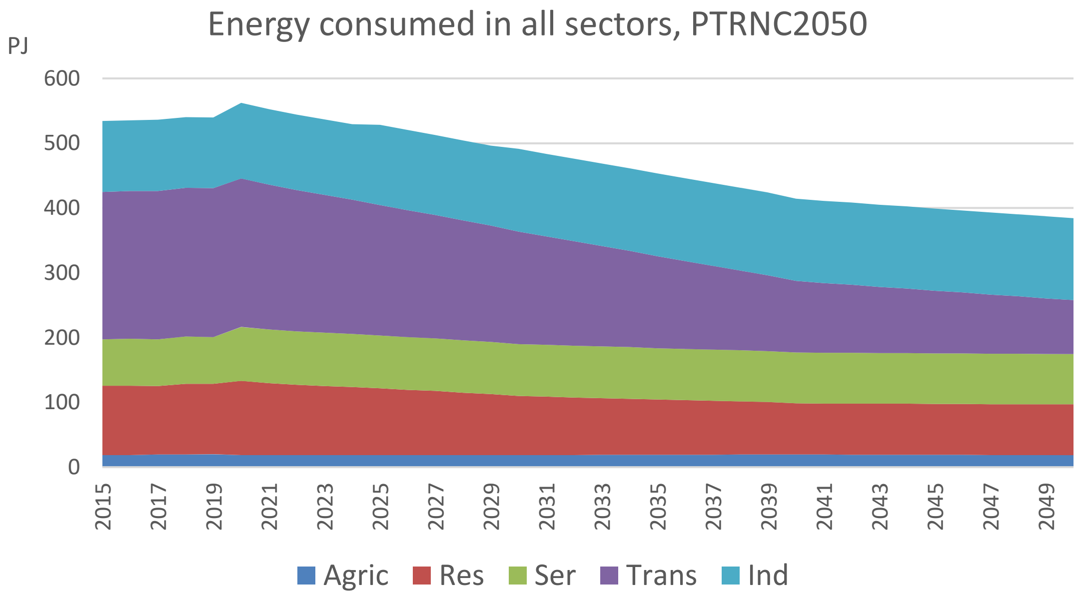


Figure 13- Evolution of the energy consumed in all sectors in RNC scenario.

5.3 Energy use by vector

The total energy consumption in the BAU model in the agriculture, residential, services, industry and transport sectors divided by energy vector is presented in Figure 14. With an average consumption percentage of 38%, electricity is the most utilised energy vector over the modelled period, followed by diesel with 30%, heat with 13%, natural gas with 7%, and the remaining vectors with percentages below 5%. Diesel consumption in 2050 remains high (22%) due to the agriculture and transportation sectors, as well as other fossil fuels such as natural gas and coal, which continue to be used in industry throughout the modelled period, and which in 2015 represent 6.6%

and 1.1% of consumption and by 2050 suffer little reduction, exhibiting 5.8% and 0.7%, respectively. Until 2050, the residential sector's demand for biomass will decrease significantly, resulting in a considerable drop in biomass use. In 2050, electricity will account for 44% of total energy use, up from 34% in 2015. This is principally due to the substitution of electric vehicles for diesel vehicles in the transportation sector.

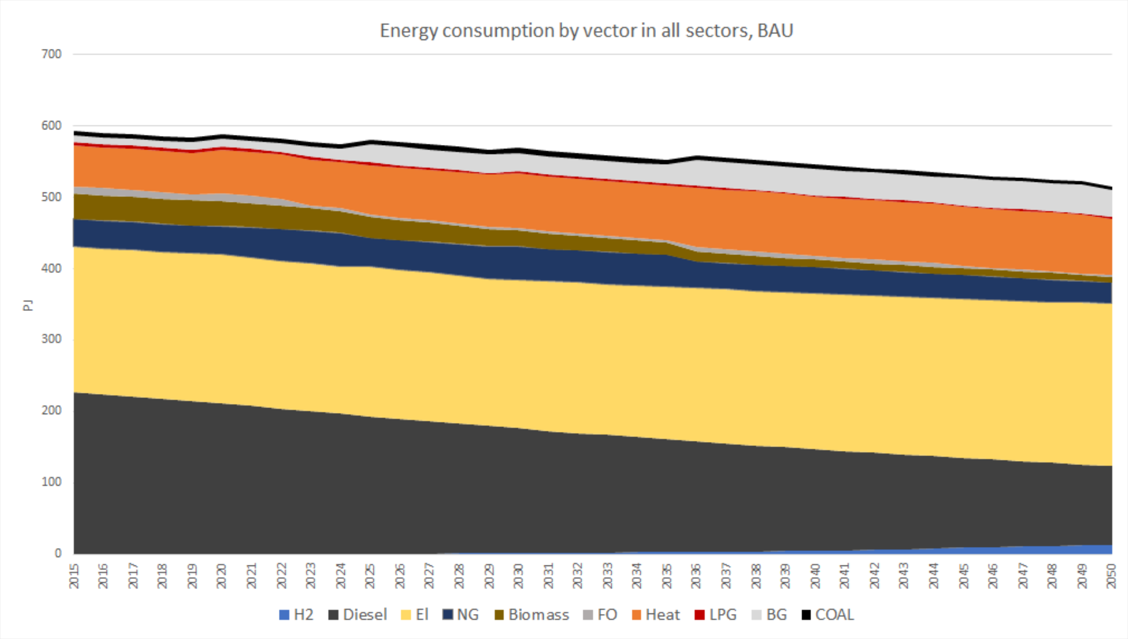


Figure 14 – Evolution of energy consumption by vector in all sectors in BAU scenario.

Energy consumption in the RNC and FitFor55 models is nearly equal, since the trends and numbers are nearly identical. Having said so, the RNC model depicts the evolution of energy consumption per vector for both systems in Figure 15. Compared to the previously analysed BAU model, this model has a reduced overall energy usage, and its behaviour is obviously influenced by the emissions cap. In 2050, diesel represents only 4% of fossil fuel usage, there is no coal consumption, natural gas consumption is 2%, and fuel oil consumption is relatively low. The replacement of fossil fuels by electricity, which increases by about 40% between 2015 and 2050, is largely due to the electrification of mobility or the replacement of technologies used in the heat process that currently rely on fossil fuels such as natural gas but will be electrified or replaced by biofuels. It is also possible to see the subtle entry of hydrogen as a result of future demand in the transportation sector, although due to the expense of technologies and their efficiency, this will account for just 3% of total consumption in 2050.

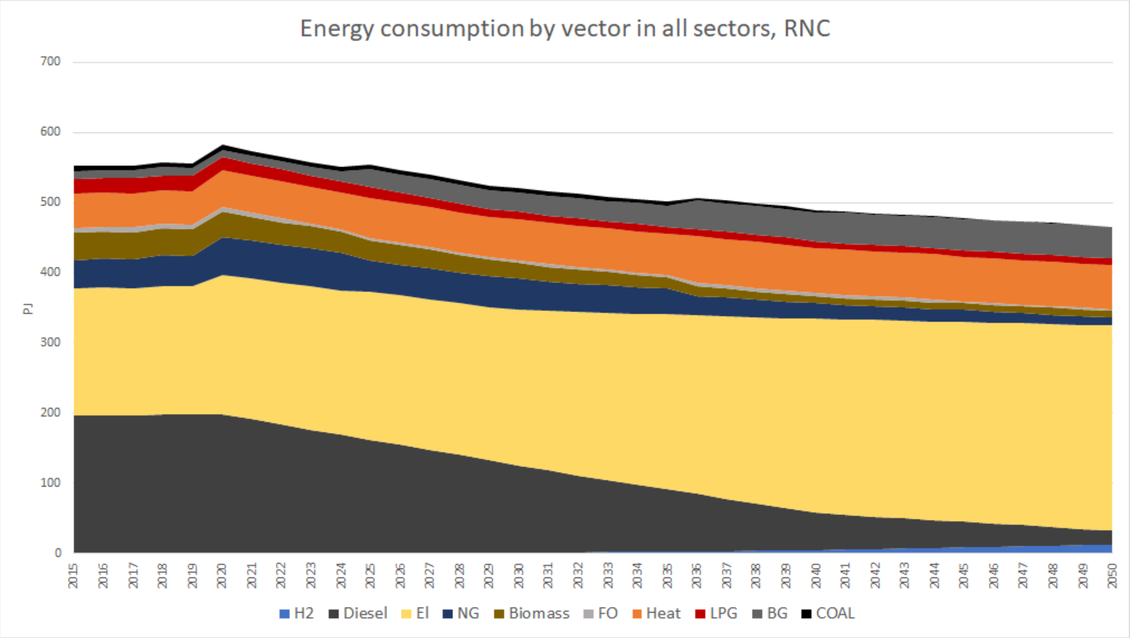


Figure 15 - Evolution of energy consumption by vector in all sectors in RNC scenario.

5.4 Installed Capacity

Regarding installed capacity for electricity production, the BAU scenario begins with around 30 GW in 2015 and concludes with approximately 45 GW. Due to the absence of an emissions restriction in this model, the installed capacity during the modelled time is determined by the cost of implementation. This model, despite not being "required" to invest in renewable energy productions, increases capacity in 2020 and 2030 by investing in wind and photovoltaic capacity due to their cost. In 2050, there will be no installed capacity for coal-based power generation, and natural gas cogeneration capacity will be minimal.

The installed capacity varies between the RNC2050 and the FitFor55 scenarios. The FitFor55 model induces higher investment in renewable capacity than the RNC model since decarbonization must be accomplished sooner. Until 2030, we have increased investment in renewable capacity, and FitFor55 demonstrates that this is due to the need to decarbonize sooner than the RNC model predicts.

All graphs referring to the installed capacity discussed above can be found in Annex H.

5.5 Electricity and heat production

The amount of electricity generated by the models is proportional to their installed production capacity, despite the models' ability to import electricity (Figure 16). The next figures illustrate the closure of coal-fired power plants in Portugal across all models and the rising development of production through renewable energy, primarily wind and photovoltaic. The heat produced in the models is essentially through solar thermal and cogeneration (Figure 17). The cogeneration in question is made through the use of biomass, natural gas and biogas. In all scenarios, with the exception of FitFor55, which terminates earlier, natural gas generation ceases in 2030 and is replaced by biogas generation. The evolution of heat production is highly dependent on the evolution of the industry sector, particularly the paper subsector, which uses a lot of heat in its manufacturing methods and generates the majority of this heat through cogeneration inside the industry.

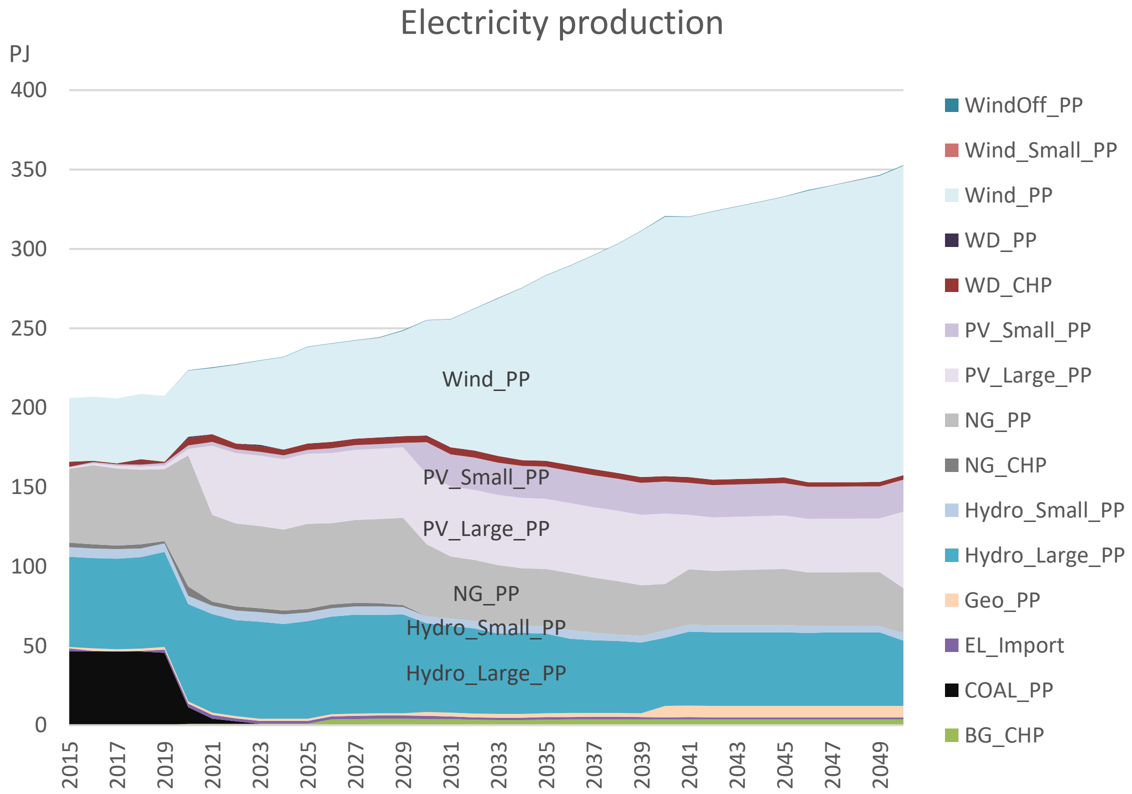


Figure 16 - Evolution of the electricity production according to RNC scenario.

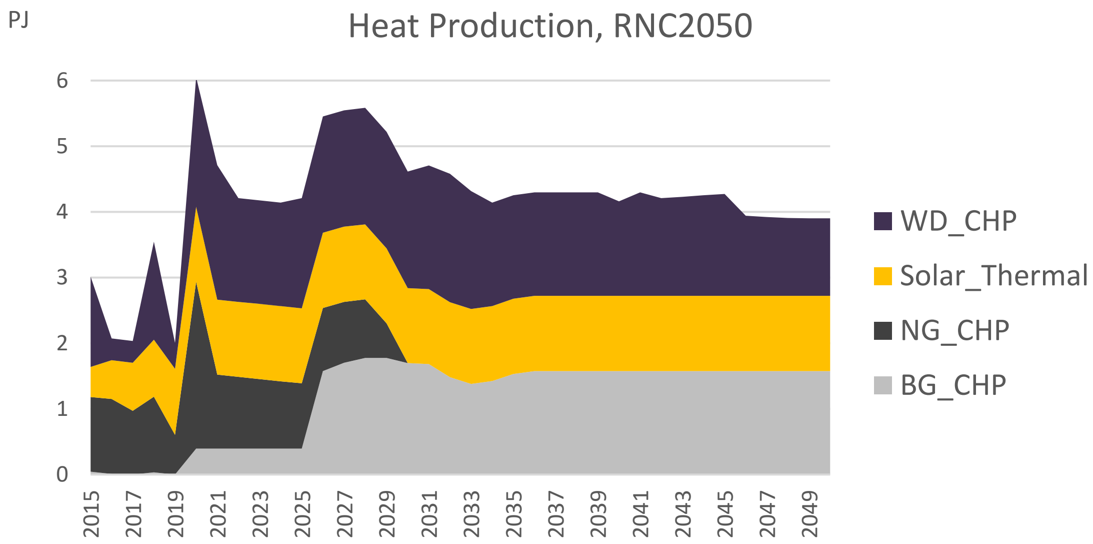


Figure 17 - Evolution of the heat production according to RNC scenario.

5.6 Evolution of the use of final energy in industry

In all scenarios, the total final energy consumption in industry evolves in the same way since the energy demand in industry does not vary. However, the manner in which it is dispersed among energy carriers varies slightly. In the BAU scenario, the usage of coal, albeit minimal, continues until 2050 due to its application in selected technologies. In the FitFor55 scenario, coal use in 2030 has decreased relative to the RNC scenario. In 2050, the FitFor55 and RNC scenarios exhibit a distribution of energy carriers that is virtually comparable. Annex I presents the energy mix of the industry sector under the various scenarios.

5.7 End use Analysis

Since the demand established for each end-use of each industry does not vary, the end-uses and their demand are same in all scenarios. Nevertheless, the manner in which each scenario responds to demand, i.e. the technologies chosen over the modelled period, may vary depending on the scenario. Below is an analysis of how each scenario responds to end-use demand. It is important to note that in technologies involving the manufacturing of materials, whose demand is stated in Mt, the energy represented in the end uses corresponds to the final energy, as opposed to the useful energy represented by all other cross-sector uses. Cross-uses include heat, steam, refrigeration, machine drive, lighting, HVAC and on-site transportation. Annex F presents the technologies chosen in 2030 and 2050 for each industrial sector and respective end use.

5.7.1 Industrial sector as a whole

When analysing the end uses of the whole industry aggregating all the production uses of each sector it can be seen that the most energy consuming use is heat use with 38.6% of the average consumption in the modelled interval (Figure 18). Production uses account for 36.6% of the total energy consumed, followed by machine drive at 14.3%, steam at 5.6%, HVAC at 3.4%, refrigeration at 1%, on-site transportation at 0.4%, and lighting at 0.1%.. The development of the demand for end uses is increasing because it is related to the variation in demand for the production of materials in the various sectors, which, according to the JRC model, upon which the demand for the remaining uses is based, is rising in the majority of sectors.

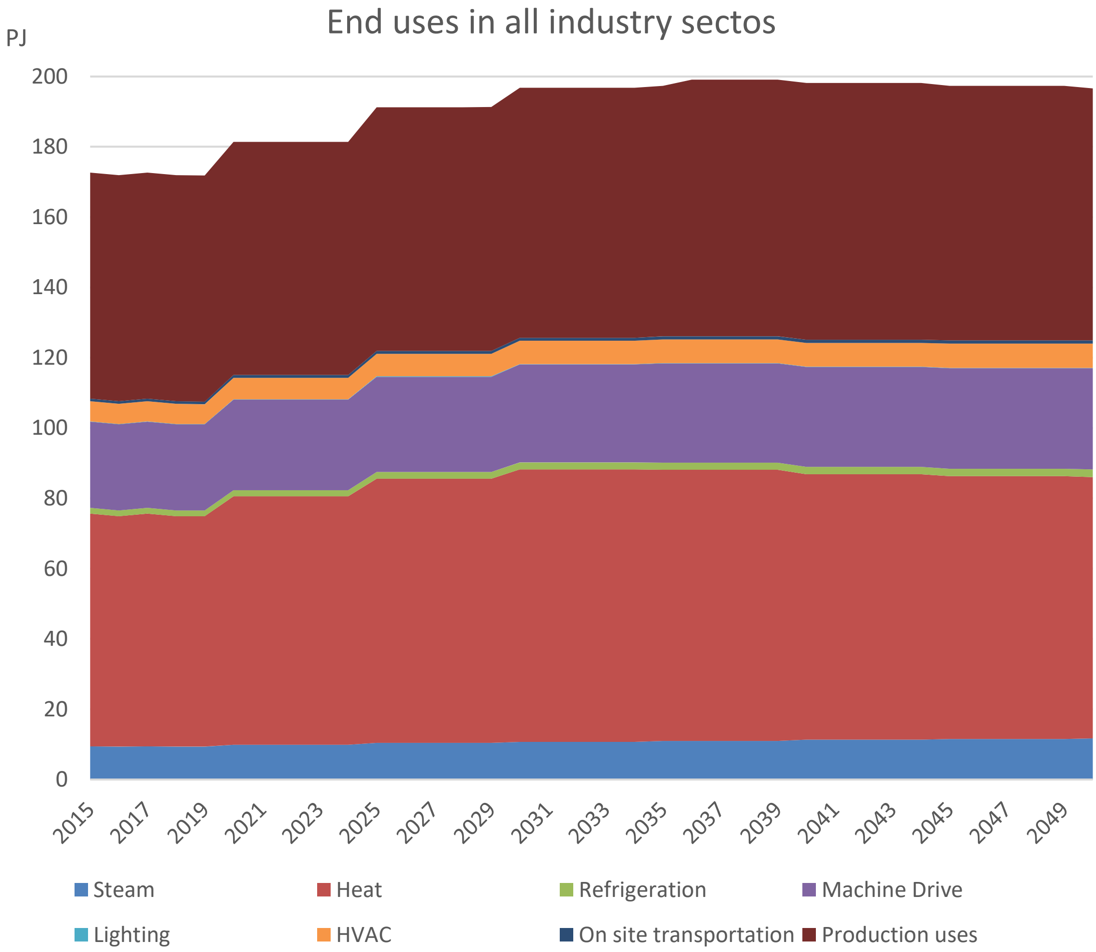


Figure 18 - Energy consumption in end uses in all sectors.

5.7.2 Iron and Steel

Figure 19 depicts the demand end uses for the iron and steel sector. In order to respond to the production of steel and crude steel, all models begin with the same technologies, which in this case are INDIS_EAF and INDIS_ISPT, which use electricity and natural gas. These technologies are later replaced by INDIS_EAF_BG and INDIS_ISPT_BG, which use biogas instead of natural gas, as shown in the figure below. The crude steel production use is the most resource-intensive production use. In this industry, the transverse end use that consumes the most energy is machine drive usage, followed by heat use.

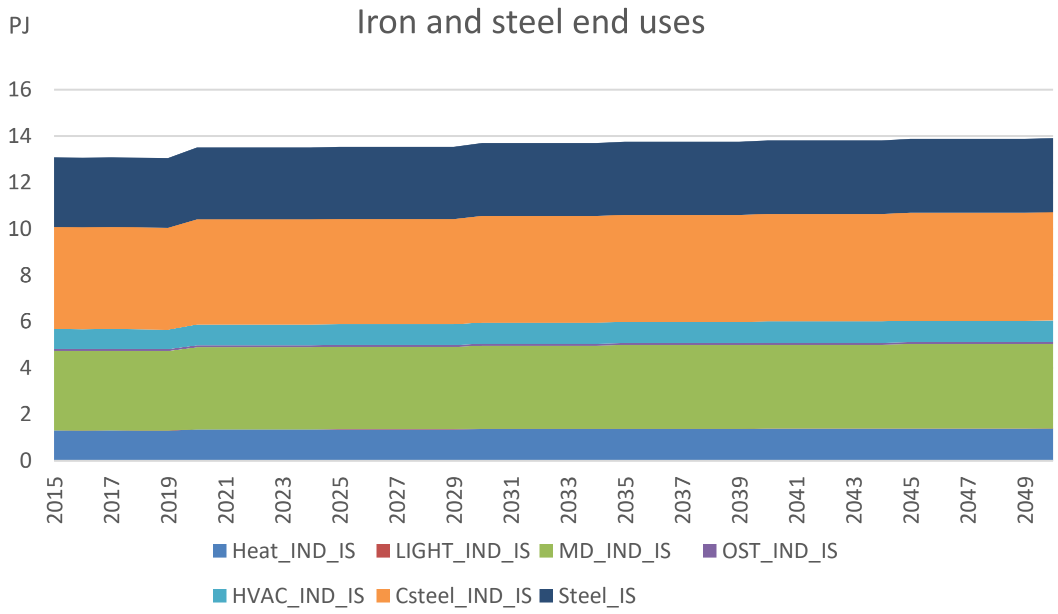


Figure 19 - Energy consumption by the end uses in iron and steel industry.

For process heat in the early years, all scenarios rely on high-efficiency natural gas, fuel oil, biomass, and biogas boilers; however, as the modelling period progresses, biogas boilers will replace all others as the sole source of process heat in 2050.

There is no variation in the technology utilised for machine drive in whatever scenario, as only one technology, the electric motor, is available for this use.

Since the LED lamp technology is utilised to fulfil all the modelling periods in the different scenarios, the technologies that satisfy the lighting use do not alter in any scenario.

In the initial years, all models employ air conditioning, heat pumps, and boilers powered by fossil fuels such as fuel oil and LPG. Due to the decarbonisation process and the great efficiency of heat pumps, towards the end of the modelled time, only heat pumps will be employed to satisfy HVAC demands.

Initially, all models used diesel vehicles for on-site transportation, but these are being replaced by electric vehicles, not just because diesel is a fossil fuel but also because the electric vehicle is more efficient.

5.7.3 Food and Beverages

Figure 20 depicts the demand of the end users for the food and beverage industry. There are no material production uses in this business. Heat and steam are the most energy-intensive cross-cutting uses, using around 30% of the sector's energy throughout the modelled time frame. Another significant usage is refrigeration, which is unique to this industry and accounts for approximately 13% of the industry's energy consumption over the modelled time period, followed by machine drive utilisation with 15%.

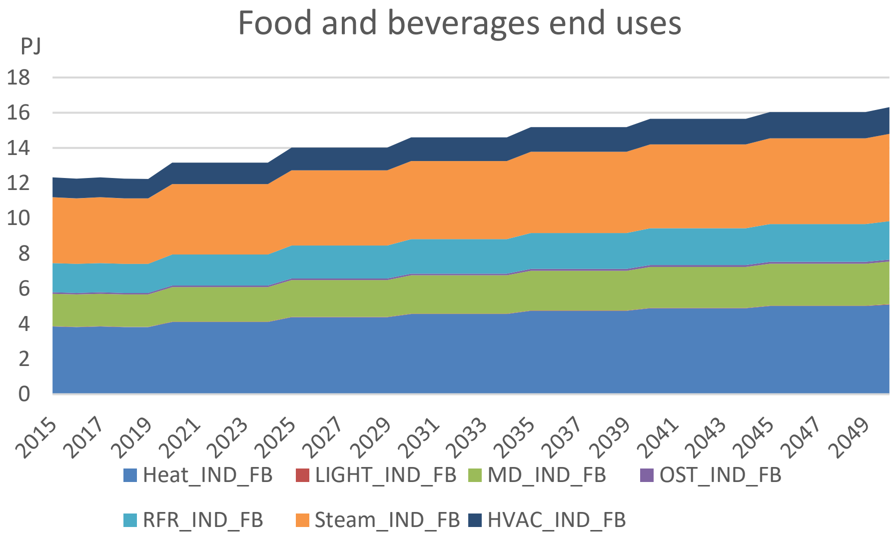


Figure 20 - Energy consumption by the end uses in food and beverages industry.

At the start of the modelling period, the usage of steam in all scenarios is matched with steam boilers fuelled by biogas, diesel, natural gas, or fuel oil. As the scenario unfolds, steam boilers fuelled by biogas will replace those first utilised, and by 2050, they will supply all steam demand.

In 2015, all scenarios use boilers and furnaces fuelled by natural gas, biomass, fuel oil, biogas, and electricity to generate process heat. However, as the modelling period progresses, high-efficiency biogas boilers will replace all other technologies to generate process heat in 2050.

Due to there being no alternative contemplated in the model for this use, the refrigeration use is always fulfilled with the same technology.

There is no variation in the technology utilised for machine drive in whatever scenario, as only one technology, the electric motor, can meet this use.

The technologies that fulfil the lighting use do not change in any scenario, as the incandescent bulb technology is employed to satisfy the lighting use for the duration of the modelling period in all scenarios. In this sector, incandescent lamps were selected by the models due to an inaccuracy in the efficiency of the technology in the input data, regardless of the fact that led bulbs are typically utilised for lighting and are more efficient.

HVAC usage faces some adjustments across all scenarios. Initially, all versions utilise air conditioning, heat pumps, LPG and fuel oil boilers, with the exception of the BAU model, which also utilises natural gas boilers. Over the span of the model, both the FitFor55 and RNC scenarios end up fulfilling the HVAC use with biogas boilers, which is odd because heat pumps are not only more efficient, but they can also provide both heat and cold, unlike boilers. In the BAU scenario, air conditioning was chosen as the technology to address HVAC demands.

Initially, all models for on-site transportation use diesel vehicles, which are being replaced by electric vehicles not only because diesel is a fossil fuel but also because the electric vehicle is more efficient.

5.7.4 Chemical

Figure 21 shows the demand for the chemical industry's final uses. In ammonia and chlorine production all models initially use the INDCH_AMP and INDCH_AMPI technologies which is an evolution of the previous technology for production for the ammonia production use and the INDCH_PAC and INDCH_PAC_BG which is the previous technology but with substitution of natural gas by biogas for the chlorine production use. At the end of the modelled period, the ammonia production technology is INDCH_AMPI due to its superior efficiency, and the chlorine production technology is INDCH_PAC_BG, which substitutes the usage of natural gas with biogas, thus complying to the model's decarbonization process. Within ammonia and chlorine production, chlorine production is the most energy-intensive, with an average final energy consumption eight times that of ammonia production during the modelled period. In the cross-cutting end uses, machine drive consumes the greatest energy, followed by steam use.

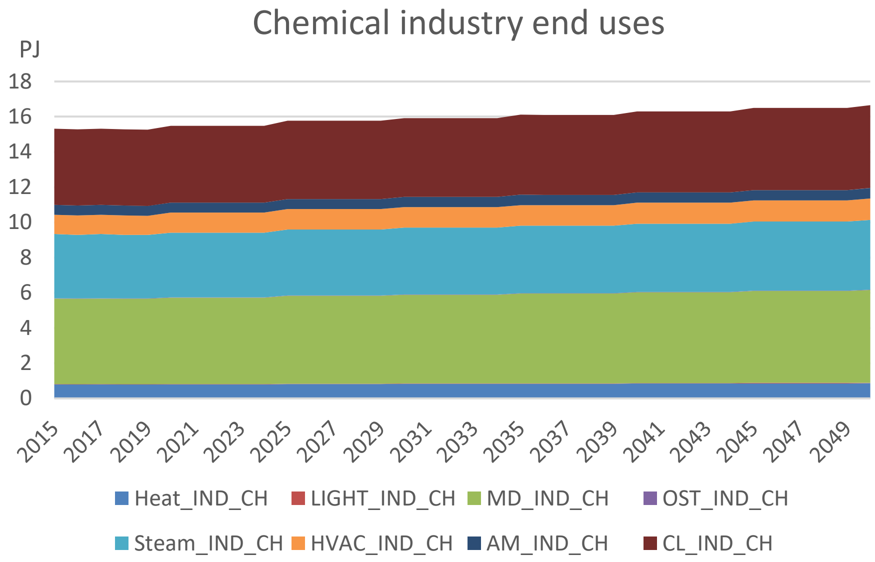


Figure 21 - Energy consumption by the end uses in chemical industry.

The use of steam in each situation is initially matched with a steam boiler that burns fuel oil, LPG, or heat. The heat in question may come from the reuse of high temperature processes or cogeneration. As the scenario develops, recovered heat steam boilers take over and displace the previous technologies, supplying all steam demand by 2050.

For process heat in early years, all scenarios use boilers with different efficiencies and different types of energy carriers, such as natural gas, biomass, fuel oil, and biogas. High efficiency biogas boilers will eventually replace all the other technologies, providing all the process heat needed in 2050, as the modelling period progresses.

Since the electric motor is the only technology that may be utilised for machine drive, there is no change in the technology used in any given scenario.

Since LED lamp technology is employed to fulfil all modelling periods in the various situations due to its efficiency combined with its low cost, the technologies that satisfy lighting consumption also do not alter in any scenario.

All scenarios experience some modifications in HVAC use. All models, with the exception of the BAU model, which also employs natural gas boilers, initially use air conditioning, heat pumps, LPG, and fuel oil boilers. Over the modelled time period, both the FitFor55 and RNC scenarios end up supplying HVAC needs with natural gas boilers, which is illogical due to the availability of more ecological and efficient alternatives, such as biogas boilers and heat pumps, which, in addition to being more efficient, are also capable of providing both heat and cold, unlike natural gas or biogas boilers. In the BAU scenario, air conditioning was chosen as the HVAC technology because, despite being less efficient than heat pumps, it required a lower initial investment.

Initially, for the use of on-site transportation, all models use diesel vehicles that are being replaced by electric vehicles due not only to diesel being a fossil fuel, but also because the efficiency of the electric vehicle is higher.

5.7.5 Cement and lime

Figure 22 depicts the demand of end uses for the cement and lime sector. In clinker manufacturing, INDCMLM_DPE is utilised, while INDCMLM_FCPE and INDCMLM_QLP are utilised for cement and lime, respectively. Due to the fact that only these technologies were considered for the manufacturing of these materials, all scenarios employ the same technologies throughout the modelled interval. Within the clinker, cement, and lime manufacturing, the one with the largest consumption is the clinker production, which consumes substantially more than cement and lime production. The use of heat consumes the greatest energy among cross end uses, followed by the use of machine drive.

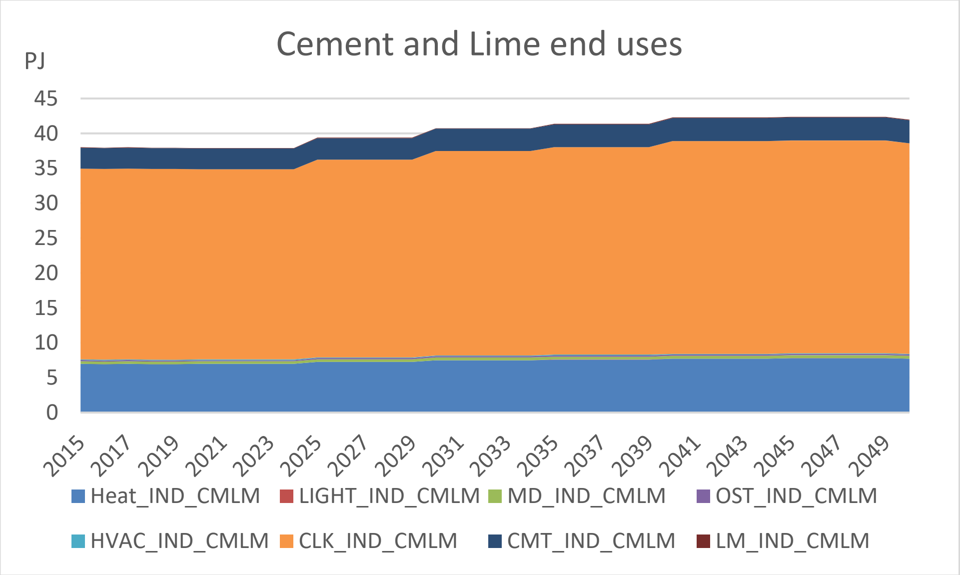


Figure 22 - Energy consumption by the end uses in cement and lime industry.

All scenarios initially rely on various technologies such as boilers and furnaces that use different forms of energy carriers such as natural gas, biomass, fuel oil, and coal for process heat. However, when the scenarios evolve, not all of them behave in the same manner. As the modelling period progresses, the BAU scenario limits the spectrum of technologies initially used to utilise biogas and coal boilers. The low investment cost of these technologies influenced this decision. The heat process is met exclusively by biogas boilers in the FitFor55 and RNC scenarios due to their low cost and use of a biofuel, whereas the other possibilities were natural gas or coal (fossil fuels).

There is no change in the technology utilised in all circumstances for machine drive because there is only one technology to suit this use, which is the electric motor.

The technologies utilised to fulfil lighting needs do not alter in any scenario since LED lamp technology is employed to satisfy all of the modelling periods in the various scenarios due to its efficiency and low cost.

All scenarios experience some modifications in HVAC use. Initially, all variants are equipped with air conditioning, heat pumps, and LPG, fuel oil, and natural gas boilers. Due to their great efficiency, both the FitFor55 and the RNC scenarios end up fulfilling the HVAC demand with heat pumps over the projection timeframe. In the BAU scenario, the HVAC usage was satisfied by air-conditioning, which, while not as effective as heat pump, required a lower investment.

Initially, all models used diesel vehicles for on-site transportation, but they are being phased out in favour of electric vehicles, not just because diesel is a fossil fuel, but also because electric vehicles are more efficient.

5.7.6 Ceramics and glass

Figure 23 depicts the end-use demand for the ceramic and glass industries. To produce flat glass, all scenarios employ the technologies INDCRGL_FPE, INDCRGL_FPEHR, which is the progression of the former technology, and INDCRGL_FPEHR_BG, which is the same technology but uses biogas instead of natural gas. In all circumstances, the technologies INDCRGL_GHEHR, INDCRGL_GHEHR_BG, which is identical to INDCRGL_GHEHR but uses biogas instead of natural gas, and INDCRGL_GLREIM, which is a recycled glass technology, are employed for hollow glass production. At the conclusion of the modelled time, all flat glass production scenarios will employ the INDCRGL_FPEHR_BG technology due to its superior efficiency and substitution of natural gas with biogas. In the manufacturing of hollow glass, all scenarios use the most efficient technology, INDCMLM_GHEHR_BG, which substitutes the usage of natural gas with biogas. Within the production of flat glass and hollow glass, hollow glass production is the most resource intensive. The transverse end use that consumes the most energy is process heat, followed by machine drive, but at a far lower rate.

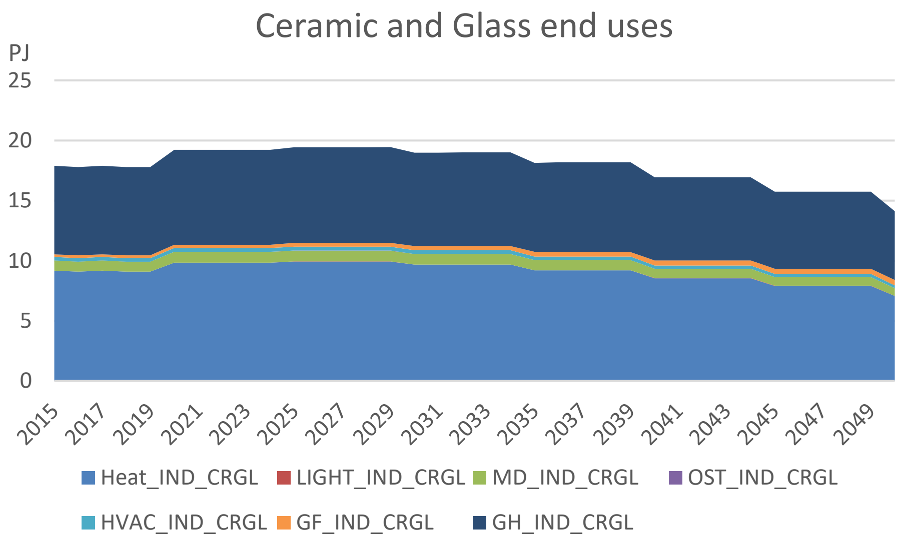


Figure 23 - Energy consumption by the end uses in ceramics and glass industry.

Initially, all scenarios use a variety of technologies for process heat, including biomass, natural gas, fuel oil, and biogas boilers, as well as biomass, electric, and natural gas furnaces. As the modelling period progresses, high efficiency biogas boilers replace all others, supplying all process heat in the end.

There is no change in the technology utilised in all circumstances for machine drive because there is only one technology to suit this use, which is the electric motor.

Because LED lamp technology is employed to meet the entire modelling period in the varied scenarios due to its efficiency combined with low cost, the technologies that satisfy the lighting need do not alter in any model.

Initially, in all scenarios, air conditioning, heat pumps, and natural gas boilers are the technologies used to fulfil the HVAC use demand. Due to their great efficiency, both the FitFor55 and the RNC scenarios end up satisfying the HVAC use with heat pumps over the modelling period. In the BAU scenario, the HVAC usage was satisfied by air conditioning, which, while not as efficient as heat pumps, requires a lower investment.

In terms of onsite transportation, all scenarios employ electric vehicle technology for the duration of the modelled time.

5.7.7 Non Ferrous Metals

Figure 24 depicts the demand of end applications for the Non-Ferrous Metals industry. In the production of aluminium and aluminium crude, all scenarios initially employ the INDNFM_FAP and INDNFM_FAP_BG technologies for aluminium production and the INDNFM_IA technology for aluminium crude production. At the end of the modelled time, in all scenarios, the technology used in aluminium production is INDNFM_FAP_BG, which substitutes the use of natural gas with biogas, and the same technology is used from the beginning to the end of the model to produce aluminium crude. Within aluminium production and aluminium crude production, aluminium crude production consumes twice as much aluminium production as aluminium production. In the cross-cutting end uses, heat consumption accounts for 33% of energy consumption over the modelled period, followed by steam consumption at 17%.

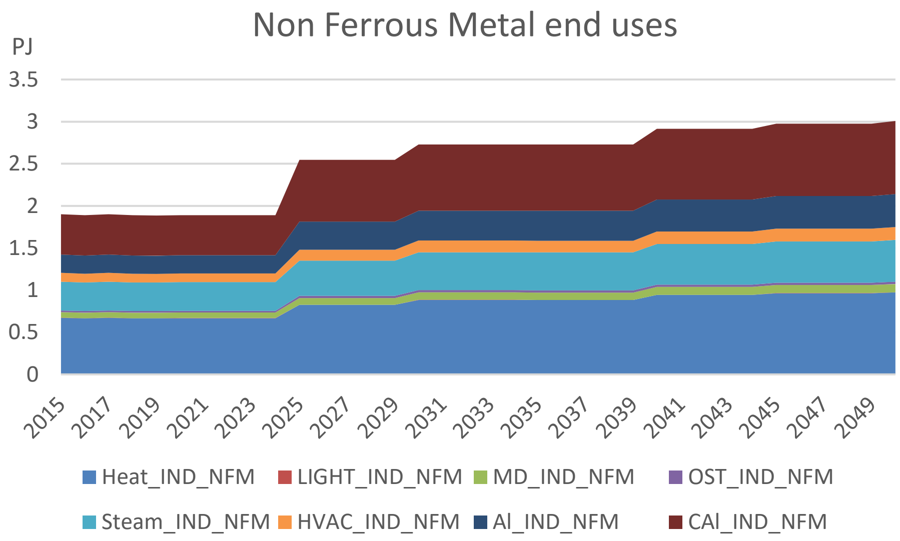


Figure 24 - Energy consumption by the end uses in non-ferrous metals industry.

At the start of the modelling period, the use of steam in all scenarios is matched with steam boilers employing different energy carriers, including heat and LPG. The heat in question can be generated through cogeneration or the reutilization of high-temperature processes. As the situation unfolds, steam boilers utilising recovered heat predominate, supplanting those first utilised, and supplying all steam demand by 2050.

Except for the BAU scenario, which also employs fuel oil boilers, all scenarios initially employ diverse technologies, such as biomass boilers, natural gas, and LPG, to provide process heat. As the modelling period progresses, high-efficiency biogas boilers replace all the others to provide all the required heat demand by the period's conclusion.

There is no variation in the technology utilised for machine drive in whatever circumstance, as only one technology, the electric motor, can meet this use.

Due to its efficiency and low cost, the LED bulb technology is employed throughout the entire modelling period in all the varied scenarios, therefore the lighting technologies do not vary in any scenario.

In the beginning, all scenarios use air conditioning, heat pumps, and LPG boilers, with the exception of the BAU scenario, which also uses natural gas boilers. Over the course of the modelled time, both the FitFor55 and RNC scenarios end up supplying HVAC demand using biogas powered boilers, which does not correlate to a real-world scenario in which more efficient and electrified technologies, such as heat pumps, are available. In the BAU scenario HVAC use was satisfied by air conditioning, which, despite being a preferable alternative to biogas boilers, is not justified by the higher cost of air conditioning.

All the scenarios utilise diesel and electric vehicles for on-site transportation initially. However, as the scenario progresses, electric vehicles assume control of all on-site transportation.

5.7.8 Pulp and Paper

Figure 25 illustrates the demand of the pulp and paper industry's end uses. During the whole simulated time period, the same production technologies are utilised by all scenarios. Pulp production uses the INDPP_CPP technology, high quality paper manufacture uses INDPP_HQPE and INDPP_HQPEAD, which is an evolution of the previous technology with more efficiency, and low quality paper production uses INDPP_LQPEAD. Unexpectedly, as the scenarios progress, all the models choose for the identical early technologies, INDPP_HQPE and INDPP_LQPE for high and low quality paper manufacture, with the catch being the less efficient variant. These selections are made because these technologies require less capital costs. In pulp production the same technology is used in all scenarios from the beginning to the end. The transversal end-use that consumes the most energy is the use of heat, which accounts for 66% of energy consumption, followed by machine drive with 11%.

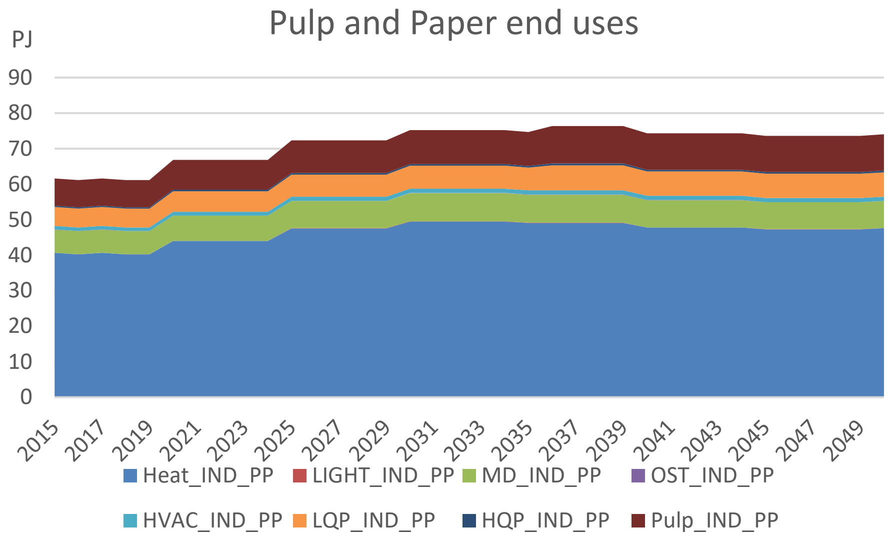


Figure 25 - Energy consumption by the end uses in pulp and paper industry.

Except for the BAU model, which relies solely on natural gas boilers from the beginning to the conclusion of the scenario to supply heat demand, all other scenarios use both natural gas boilers and CHPs to generate process heat. As the modelling time progresses, the FitFor55 and RNC scenarios select the same technologies, the CHP and the natural gas boiler, to provide all heat demand. The difference between the beginning and end periods of these two scenarios is that the gas boiler provides the majority of heat at the beginning, whilst the cogeneration system provides the majority of heat at the conclusion. Due to the fuel being a by product of the sector, the paper industry depends on internal cogeneration.

There is no variation in the technology utilised for machine drive in whatever scenario, as only one technology, the electric motor, can satisfy this use.

Since LED lamp technology is used during the entire modelling period in the many scenarios due to its efficiency and low cost, the technologies that fulfil lighting consumption likewise do not vary in any scenario.

Initially, air conditioning and boilers fuelled by natural gas, LPG, and fuel oil are utilised for HVAC use in the BAU scenario, however in the other scenarios, just boilers are used without air conditioning. Over the modelled timeframe, both the FitFor55 and RNC scenarios end up fulfilling the HVAC use with natural gas boilers, which was unexpected due to the availability of the biogas boiler, which has the same costs but does not utilise a fossil fuel. In the BAU scenario, air conditioning was selected as the HVAC technology, which, despite being a superior option over natural gas boilers, is not justified by the higher cost of air conditioning.

All variants utilise diesel and electric vehicles for on-site transportation initially. As the scenario unfolds, however, electric vehicles are responsible for meeting the entire demand for this use.

5.7.9 Other Industries

Figure 26 depicts the demand from end uses for different industries. There are no material production uses in this sector. Among the cross-uses, the one with the biggest demand is the usage of machine drive, which accounts for 52 and 22% of the sector's total energy consumption, respectively.

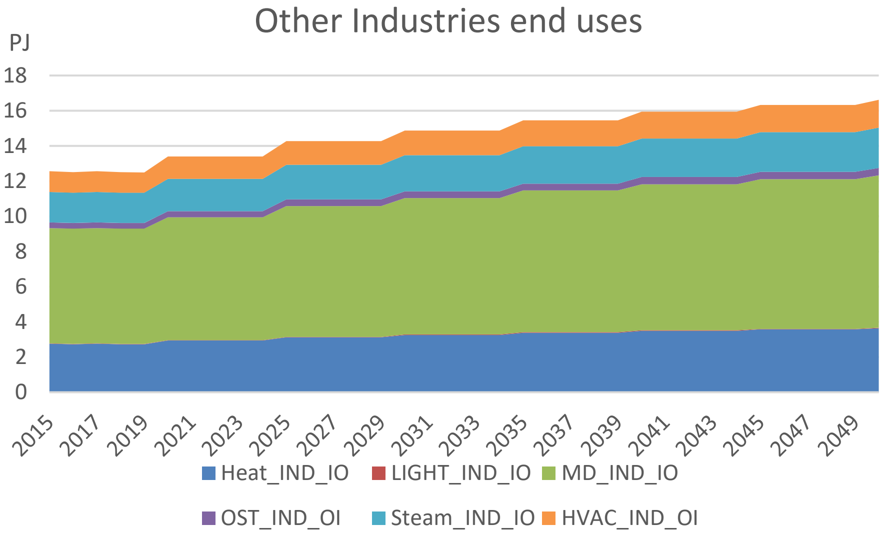


Figure 26 - Energy consumption by the end uses in other industries.

At the start of the modelling period, the use of steam in all scenarios is matched with steam boilers employing various energy carriers, including heat, LPG, and fuel oil. The heat in question can be generated through cogeneration or the energy recovery of high-temperature processes. As the situation unfolds, steam boilers utilising recovered heat predominate, supplanting those first utilised, and supplying all steam demand by 2050.

Initially, all scenarios use boilers with varying efficiency and energy carriers such as natural gas, biomass, and fuel oil for process heat. As the modelling period progresses, the technologies chosen to provide all process heat in 2050 are biomass and natural gas boilers with great efficiency. Since biogas boilers have the same technical and economic qualities as natural gas boilers, but utilise a biofuel instead of a fossil fuel, the option of natural gas boilers is unjustified.

There is no variation in the technology utilised for machine drive in whatever circumstance, as only one technology, the electric motor, can meet this use.

The lighting technologies are consistent across all of the different scenarios since LED bulb technology is used during the whole modelling period due to its effectiveness and inexpensive cost.

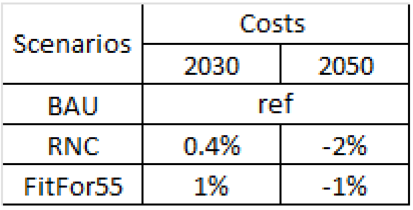
HVAC usage faces some adjustments across all models. In the beginning, all models are equipped with air conditioning, heat pumps, and LPG, fuel oil, and natural gas boilers. Over the modelled time period, both the FitFor55 and RNC scenarios satisfy HVAC needs with heat pumps, however the BAU scenario opts for air conditioning since it is less expensive and disregards heat pump efficiency.

All the scenarios utilise diesel and electric vehicles for on-site transportation initially. However, as the scenario continues, electric vehicles are responsible for meeting all this need.

5.8 Cost Analysis

Due to the poor calibration of the model, no costs are displayed, since the model makes investments in the first year that are unnecessary at the outset, as they are the ones that begin in 2015, i.e. we know that the initial capacity inserted is sufficient. Despite this, it can be noted that the BAU scenario has a greater overall cost than the FitFor55 and RNC scenarios, and this may be due to the carbon emitted expenses that the BAU scenario must pay due to its continued usage of fossil fuels. The FitFor55 and RNC scenarios have nearly equivalent costs at the end of the modelled period, however due to the faster decarbonisation in the FitFor55 scenario, the cost is slightly higher by 2030 compared to the RNC scenario (Table 20), which makes the investments later.

Table 20 - Percentage difference in investment costs of the BAU and RNC scenarios compared to BAU.



Scenarios	Costs	
	2030	2050
BAU	ref	
RNC	0.4%	-2%
FitFor55	1%	-1%

Chapter 6 – Conclusions

This chapter presents the work's conclusions along with any model shortcomings.

6.1 Conclusions from the results

The objectives of this dissertation were to build a model of the energy system of the industry in Portugal using the OseMOSYS software, which allows the model to be open source, and then, after the implementation of the model in the OseMOSYS system, to create future scenarios that somehow reproduce the objectives regarding the limits of GHG emissions from the RNC and FitFor55 in order to analyse the evolution of the behaviour of each scenario having BAU as the reference scenario.

It was possible to obtain a model supported by a database containing technical and economic data on the technologies used in the various sectors, as well as a list of end uses, to give meaning to the characterization of the industry sector and to completely disaggregate the energy usage in this sector.

According to the analysis of GHG emissions of the 3 scenarios it is concluded that if emissions limits and more drastic restrictions are not imposed in relation to the use of technologies powered by fossil fuels as shown by the BAU scenario we will not achieve the objectives described in the carbon neutrality roadmap by 2050 as well as in FitFor55 where the decarbonisation plan is anticipated.

Although in all scenarios the total energy consumed by all sectors drops, the study of the RNC and FitFor55 scenarios reveals that a more extreme change is required, with the evolution of energy consumption consisting of a drastic reduction of energy derived from fossil fuels and a replacement with energy generated from renewable sources.

In terms of installed capacity, the RNC and FitFor55 scenarios make it abundantly evident that investments in wind and photovoltaic electricity generation capacity are required to produce electricity with a small ecological impact.

In all scenarios, the industry's final energy consumption increases; nevertheless, the goal is to reduce energy consumption by increasing the energy efficiency of the circular economy technologies and strategies described in chapter 3. Despite this, it is once again reasonable to conclude from the analysis of the three scenarios that the road to be followed involves independence from the use of fossil fuels in industry and an electrification of the respective end-use technologies.

From the discussion of the demand of end-uses in industry and the technologies chosen by each model according to the point of scenario evolution where the technologies used by each scenario in all industrial sectors and respective end-uses were analysed it was concluded that the choices made by the BAU, RNC and FitFor55 scenarios are initially based mostly on the cost/efficiency ratio given that the GHG emissions limit are high or non-existent in the case of BAU causing the model in most cases not to choose the technologies according to the ecological footprint in the system. The BAU scenario continues to select technologies based solely on cost/efficiency without interpreting the type of energy carrier used, whereas the FitFor55 and RNC scenarios must comply with the set emission restrictions, making their technology selections more decarbonisation aware. However, there are choices made by the model in the scenarios that are illogical because there are more efficient alternatives. This is likely due to an error in the calibration of some model parameters.

6.2 Model shortcomings

Energy models are a very helpful instrument with numerous benefits, but they also have limitations. The lack of input data sources forces the use of assumptions, which impacts the accuracy of the model's output. Each industry sector has its own peculiarities, such as the conversion technologies they employ or certain internal processes that are not quantified in the statistics, such as heat reproduction for low-temperature processes, particularly in medium and small businesses where the accounting of energy consumption is not very refined. Future unpredictability generated by situations we are currently experiencing, such as pandemics and war, makes it extremely difficult to project future scenarios. To maintain the economic sustainability of the country or region under study, energy policies are sometimes put on hold, jeopardising future objectives.

All these factors result in difficult-to-mitigate model flaws, and possibly the best method to counteract them is to update the data with the most reliable sources of information available in order to preserve the energy model's data reliability.

Chapter 7 – Future Work

Some ideas for future research have emerged during the course of this work. They are mentioned briefly here:

- Not every subsector considered by DGEG was analysed in detail, particularly those aggregated in the sector we deemed "other industries." It would be a valuable contribution to the study to analyse these subsectors in depth.
- Add data or compare existing data with energy audits conducted in several companies across various subsectors to refine the energy consumption data, end use demand, etc. incorporated into the energy model.
- Local case studies could also be an integral part of this study, and they could be used to compare opportunities with other efficiency improvements.
- A variety of methods with potential for development, such as waste heat recovery to meet low temperature heat demand, could be the subject of further targeted research.
- Complement this model with the remaining sectors (Agriculture, Residential, Services and Transport) in order to model the whole energy system in Portugal.

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Annex A – List with description and assumptions of the technologies introduced in the model

Annex A contains the list of technologies that were introduced in the model to characterise the industry sector.

#		Description	Assumptions
1	H2_ALK	Production of Hydrogen via electrolysis (Alkaline)	
2	H2_PEM	Production of Hydrogen via PEM electrolysis	
3	H2_STREFF	Production of Hydrogen via steam reforming	
4	INDCH_AC	Air conditioner to HVAC use in Chemical Industry	Technology taken from the JRC model, in the service sector, used for HVAC . Since HVAC in industry is mostly installed in offices, it was considered a suitable approximation.
5	INDCH_AMP	Advanced Membrane Production Chemical Industry	Technology used in ammonia standard production process that JRC considers
6	INDCH_AMPI	Advanced Membrane Production Improvement in Chemical Industry	

7	INDCH_BL_BM	Biomass Boiler Chemical Industry	The technology used in the heat process is a boiler
8	INDCH_BL_COA	Coal Boiler Chemical Industry	
9	INDCH_BL_LPG_SH	LPG Boiler for space heating in Chemical Industry	Technology taken from the JRC model, in the service sector, used for HVAC . Since HVAC in industry is mostly installed in offices, it was considered a suitable approximation.
10	INDCH_BL_BG_SH	BG Boiler for space heating in Chemical Industry	
11	INDCH_BL_NG_SH	NG Boiler for space heating in Chemical Industry	
12	INDCH_BL_OilP_SH	OilP Boiler for space heating in Chemical Industry	
13	INDCH_BL_LPG	LPG Boiler Chemical Industry	
14	INDCH_BL_BG	Biogas Boiler Chemical Industry	
15	INDCH_BL_NG	Natural Gas Boiler Chemical Industry	
16	INDCH_BL_H2	Hydrogen Boiler in Chemical Industry	Future technology implemented in this industry with study-based data
17	INDCH_BL_Oil	Oil Boiler Chemical Industry	
18	INDCH_CE_Diesel	Diesel internal combustion engine for onsite transportation use in Chemical Industry	On site transportation is mostly done by diesel vehicles. The technology refers to a diesel combustion engine. Data refer to other machine drive end use with oil products as input vector.
19	INDCH_EV	Electric vehicle to on site transportation use	Future technology implemented in this industry with study-based data
20	INDCH_FC	Hydrogen vehicle to on site transportation use	Future technology implemented in this industry with study-based data
21	INDCH_CMP_Ele	Compressor for refrigeration use in Chemical Industry	
22	INDCH_FLRT	Fluorescent light bulb for lighting use in chemical industry	
23	INDCH_HEBL_BM	High Efficiency Biomass Boiler in Chemical Industry	High efficiency boiler presented in the PP

24	INDCH_HEBL_BG	High Efficiency BG Boiler in Chemical Industry	industry in the JRC model which is suitable for all industries
25	INDCH_HEBL_NG	High Efficiency NG Boiler in Chemical Industry	
26	INDCH_HEBL_OilP	High Efficiency OilP Boiler in Chemical Industry	
27	INDCH_HLG	Halogen light bulb for lighting use in chemical industry	
28	INDCH_HP	Heat Pump for HVAC use in Chemical Industry	Technology from the service sector since HVAC is mostly used in offices of the industries.
29	INDCH_INCT	Incandescent light bulb for lighting use in chemical industry	
30	INDCH_LED	LED light bulb for lighting use in Chemical Industry	
31	INDCH_MTR	Motors for machine drive use in Chemical Industry	An electric motor is the technology considered to produce machine drive since all the machine drive comes from electricity
32	INDCH_PAC	Plasma Arc Decomposition-Chemical Industry	The technology used in the steam process is a steam boiler
33	INDCH_PAC_BG	Plasma Arc Decomposition with biogas instead of NG	
34	INDCH_SBL_COA	Coal Steam Boiler Chemical Industry	
35	INDCH_SBL_HEAT	Heat Steam Boiler Chemical Industry	
36	INDCH_SBL_LPG	LPG Steam Boiler Chemical Industry	
37	INDCH_SBL_Oil	Oil Steam Boiler Chemical Industry	
38	INDCH_VHEBL_BM	Very High Efficiency Biomass Boiler in Chemical Industry	Very high efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
39	INDCH_VHEBL_BG	Very High Efficiency BG Boiler in Chemical Industry	
40	INDCH_VHEBL_NG	Very High Efficiency NG Boiler in Chemical Industry	
41	INDCH_VHEBL_OilP	Very High Efficiency OilP Boiler in Chemical Industry	

42	INDCMLM_AC	Air conditioner to HVAC use in Cemente and Lime Industry	Technology taken from the JRC model, in the service sector, used for HVAC . Since HVAC in industry is mostly installed in offices, it was considered a suitable approximation.
43	INDCMLM_BL_LPG_SH	LPG Boiler for space heating in Cement and Lime In	Technology taken from the JRC model, in the service sector, used for HVAC . Since HVAC in industry is mostly installed in offices, it was considered a suitable approximation.
44	INDCMLM_BL_BG_SH	BG Boiler for space heating in Cement and Lime Ind	
45	INDCMLM_BL_NG_SH	NG Boiler for space heating in Cement and Lime Ind	
46	INDCMLM_BL_OilP_SH	OilP Boiler for space heating in Cement and Lime In	
47	INDCMLM_BL_H2	Hydrogen Boiler in Cement and Lime Industry	Future technology implemented in this industry with study-based data
48	INDCMLM_CE_Diesel	Diesel combustion engine in Cement and Lime Industry	On site transportation is mostly done by diesel vehicles. The technology refers to a diesel combustion engine. Data refer to other machine drive end use with oil products as input vector.
49	INDCMLM_EV	Electric vehicle to on site transportation use	Future technology implemented in this industry with study-based data
50	INDCMLM_FC	Hydrogen vehicle to on site transportation use	Future technology implemented in this industry with study-based data
51	INDCMLM_CMP_Ele	Compressor for refrigeration Cement and Lime	
52	INDCMLM_DPE	Dry Process Equipment (Cement)	
53	INDCMLM_FCPE	Finished Cement Production Equipment	
54	INDCMLM_FLRT	Fluorescent lighting in Cement and Lime Industry	
55	INDCMLM_HEBL_BM	High Efficiency Biomass Boiler in Cement and Lime	High efficiency boiler presented in the PP industry in the JRC model which is suitable for
56	INDCMLM_HEBL_BG	High Efficiency BG Boiler in Cement and Lime	

57	INDCMLM_HEBL_NG	High Efficiency NG Boiler in Cement and Lime	all industries
58	INDCMLM_HEBL_OilP	High Efficiency OilP Boiler in Cement and Lime	
59	INDCMLM_HLG	Halogen lighting in Cement and Lime Industry	
60	INDCMLM_HP	Heat Pump for HVAC use in Cement and Lime Industry	Technology from the service sector since HVAC is mostly used in offices of the industries.
61	INDCMLM_INCT	Incandescent lighting in Cement and Lime Industry	
62	INDCMLM_KLNCM_COA	Coal Kiln Cement Industry	
63	INDCMLM_KLNCM_NG	NG KilDry Process Equipment (Cement)n Cement In	
64	INDCMLM_KLNCM_BG	BG KilDry Process Equipment (Cement)n Cement In	
65	INDCMLM_KLNLM_Oil	NG KilDry Process Equipment (Cement)n Cement In	
66	INDCMLM_LED	LED light bulb for lighting use in Cement and Lime	
67	INDCMLM_MTR	Motors for machine drive use in Cement and Lime Industry	
68	INDCMLM_QLP	Quick Lime Production Equipment	
69	INDCMLM_VHEBL_BM	Very High Efficiency Biomass Boiler in Cement and Lime Ind	Very high efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
70	INDCMLM_VHEBL_BG	Very High Efficiency BG Boiler in Cement and Lime Ind	
71	INDCMLM_VHEBL_NG	Very High Efficiency NG Boiler in Cement and Lime Ind	
72	INDCMLM_VHEBL_OilP	Very High Efficiency OilP Boiler in Cement and Lime Ind	
73	INDCRGL_AC	Air conditioner to HVAC use in Ceramic and Glass industry	
74	INDCRGL_BL_LPG_SH	LPG Boiler for space heating in Ceramic and Glass ind	Technology taken from the JRC model, in the service sector, used for HVAC . Since HVAC in industry is mostly installed in offices, it was considered a suitable approximation.
75	INDCRGL_BL_BG_SH	BG Boiler for space heating in Ceramic and Glass ind	
76	INDCRGL_BL_NG_SH	NG Boiler for space heating in Ceramic and Glass ind	
77	INDCRGL_BL_OilP_SH	OilP Boiler for space heating in Ceramic and Glass ind	

78	INDCRGL_BL_H2	Hydrogen Boiler in Ceramic and Glass Industry	Future technology implemented in this industry with study-based data
79	INDCRGL_CE_Diesel	Diesel combustion engine in Ceramic and Glass ind	On site transportation is mostly done by diesel vehicles. The technology refers to a diesel combustion engine. Data refer to other machine drive end use with oil products as input vector.
80	INDCRGL_EV	Eletric vehicle to on site transportation use	Future technology implemented in this industry with study-based data
81	INDCRGL_FC	Hydrogen vehicle to on site transportation use	Future technology implemented in this industry with study-based data
82	INDCRGL_CMP_Ele	Compressor for refrigeration Ceramic and Glass Industry	
83	INDCRGL_FLRT	Fluorescent lighting in Ceramic and Glass industry	
84	INDCRGL_FPE	Flat Glass production equipment in Ceramic and Glass industry	
85	INDCRGL_FPE_BG	Flat Glass production equipment with BG instead BG	
86	INDCRGL_FPEHR	Glass flat production equipment with heat recovery	
87	INDCRGL_FPEHR_BG	Glass flat production eq. with heat recovery with BG instead BG	
88	INDCRGL_GHE	Hollow Glass production equipment in Ceramic and	
89	INDCRGL_GHE_BG	Hollow Glass production equipment with BG instead NG	
90	INDCRGL_GHEHR	Glass Hollow equipment heat recovery	
91	INDCRGL_GHEHR_BG	Glass Hollow equipment heat recovery with BG instead NG	
92	INDCRGL_GLRE	Recycling glass production equipment in Ceramic an	
93	INDCRGL_GLRE_BG	Recycling glass production equipment with BG instead NG	
94	INDCRGL_GLREIM	Glass Recycling equipment improved melting	
95	INDCRGL_GLREIM_BG	Glass Recycling equipment improved melting with BG instead NG	
96	INDCRGL_HEBL_BM	High Efficiency Biomass Boiler in Ceramic and Glass Industry	High efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
97	INDCRGL_HEBL_BG	High Efficiency BG Boiler in Ceramic and Glass Industry	
98	INDCRGL_HEBL_NG	High Efficiency NG Boiler in Ceramic and Glass Industry	

99	INDCRGL_HEBL_OilP	High Efficiency OilP Boiler in Ceramic and Glass Industry	
100	INDCRGL_HLG	Halogen lighting in Ceramic and Glass industry	
101	INDCRGL_HP	Heat Pump for HVAC use in Ceramic and Glass Industry	Technology from the service sector since HVAC is mostly used in offices of the industries.
102	INDCRGL_INCT	Incandescent lighting in Ceramic and Glass industry	
103	INDCRGL_KLN_BM	Biomass Kiln for CRGL industry	
104	INDCRGL_KLN_Ele	Eletric Kiln for CRGL Industry	
105	INDCRGL_KLN_BG	BG Kiln for CRGL Industry	
106	INDCRGL_KLN_NG	NG Kiln for CRGL Industry	
107	INDCRGL_LED	LED for lighting use in Ceramic and Glass Industry	
108	INDCRGL_MTR	Motors Ceramic and Glass industry	An electric motor is the technology considered to produce machine drive since all the machine drive comes from electricity
109	INDCRGL_VHEBL_BM	Very High Efficiency Biomass Boiler in Ceramic and Glass	Very high efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
110	INDCRGL_VHEBL_BG	Very High Efficiency BG Boiler in Ceramic and Glass	
111	INDCRGL_VHEBL_NG	Very High Efficiency NG Boiler in Ceramic and Glass	
112	INDCRGL_VHEBL_OilP	Very High Efficiency OilP Boiler in Cement and Lime Industry	
113	INDFB_AC	Air conditioner to HVAC use in Food and Beverages industry	
114	INDFB_BL_Diesel	Diesel Boiler Food Beverages Industry	
115	INDFB_BL_H2	Hydrogen Boiler in Food and Beverages Industry	Future technology implemented in this industry with study-based data
116	INDFB_BL_BG	Biogas Boiler Food Beverages Industry	
117	INDFB_BL_NG	Natural Gas Boiler Food Beverages Industry	
118	INDFB_BL_OilP	OilP Boiler Food Beverages Industry	
119	INDFB_BL_LPG_SH	LPG Boiler for space heating in Food Beverages Ind	Technology taken from the JRC model, in the service sector, used for HVAC . Since HVAC in
120	INDFB_BL_BG_SH	BG Boiler for space heating in Food Beverages Indu	

121	INDFB_BL_NG_SH	NG Boiler for space heating in Food Beverages Industry	industry is mostly installed in offices, it was considered a suitable approximation.
122	INDFB_BL_OilP_SH	OilP Boiler for space heating in Food Beverages Ind	
123	INDFB_CE_Diesel	Diesel combustion engine in Food Beverages Industry	On site transportation is mostly done by diesel vehicles. The technology refers to a diesel combustion engine. Data refer to other machine drive end use with oil products as input vector.
124	INDFB_EV	Electric vehicle to on site transportation use	Future technology implemented in this industry with study-based data
125	INDFB_FC	Hydrogen vehicle to on site transportation use	Future technology implemented in this industry with study-based data
126	INDFB_CMP_Ele	Compressor for refrigeration Food Beverages Industry	Technology used for cooling that corresponds to the compression refrigeration technology of the Mapping and analyses of the current and future heating / cooling fuel deployment model
127	INDFB_FLRT	Fluorescent lighting in Food Beverages Industry	
128	INDFB_HEBL_BM	High Efficiency Biomass Boiler in Food and Beverages Industry	High efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
129	INDFB_HEBL_BG	High Efficiency BG Boiler in Food Beverages Industry	
130	INDFB_HEBL_NG	High Efficiency NG Boiler in Food Beverages Industry	
131	INDFB_HEBL_OilP	High Efficiency OilP Boiler in Food Beverages Industry	
132	INDFB_HLG	Halogen lighting in Food Beverages Industry	
133	INDFB_HP	Heat Pump for HVAC use in Food and Beverages Industry	Technology from the service sector since HVAC is mostly used in offices of the industries.
134	INDFB_INCT	Incandescent lighting in Food Beverages Industry	
135	INDFB_LED	LED for lighting use in Food Beverages	

136	INDFB_MTR	Motors Pulp and Paper Industry	An electric motor is the technology considered to produce machine drive since all the machine drive comes from electricity
137	INDFB_Oven_BM	Biomass Oven Food Beverages Industry	Technologies taken from the UED model with techno-economic data adapted from the JRC model.
138	INDFB_Oven_Coal	Coal Oven Food Beverages Industry	
139	INDFB_Oven_Diesel	Diesel Oven Food Beverages Industry	
140	INDFB_Oven_Ele	Eletric Oven Food Beverages Industry	
141	INDFB_Oven_BG	Natural Gas Oven Food Beverages Industry	
142	INDFB_Oven_NG	Natural Gas Oven Food Beverages Industry	
143	INDFB_Oven_OilP	OilP Oven Food Beverages Industry	
144	INDFB_SBL_Diesel	Diesel Steam Boiler Food and Beverages Industry	
145	INDFB_SBL_BG	BG Steam Boiler Food and Beverages Industry	
146	INDFB_SBL_NG	NG Steam Boiler Food and Beverages Industry	
147	INDFB_SBL_OilP	OilP Steam Boiler Food and Beverages Industry	
148	INDFB_VHEBL_BM	Very High Efficiency Biomass Boiler in Food Beverages	Very high efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
149	INDFB_VHEBL_BG	Very High Efficiency BG Boiler in in Food Beverages Industry	
150	INDFB_VHEBL_NG	Very High Efficiency NG Boiler in in Food Beverages Industry	
151	INDFB_VHEBL_OilP	Very High Efficiency OilP Boiler in in Food Beverages Industry	
152	INDIS_AC	Air conditioner to HVAC use in Iron and Steel industry	
153	INDIS_BL_LPG_SH	LPG Boiler for space heating in Iron and Steel Indus	Technology taken from the JRC model, in the service sector, used for HVAC . Since HVAC in industry is mostly installed in offices, it was considered a suitable approximation.
154	INDIS_BL_BG_SH	BG Boiler for space heating in Iron and Steel Industry	
155	INDIS_BL_NG_SH	NG Boiler for space heating in Iron and Steel Industry	
156	INDIS_BL_OilP_SH	OilP Boiler for space heating in Iron and Steel Industry	
157	INDIS_BL_H2	Hydrogen Boiler in Iron and Steel Industry	Future technology implemented in this industry with study-based data
158	INDIS_CE_Diesel	Diesel combustion engine in Iron and Steel Industry	

159	INDIS_EV	Electric vehicle to on site transportation use	Future technology implemented in this industry with study-based data
160	INDIS_FC	Hydrogen vehicle to on site transportation use	Future technology implemented in this industry with study-based data
161	INDIS_CMP_Ele	Compressor for refrigeration use in Iron and Steel Industry	
162	INDIS_EAF	Electric Arc Furnace in Iron and Steel Industry	
163	INDIS_EAF_BG	Electric Arc Furnace with BG instead NG	
164	INDIS_FLRT	Fluorescent lighting in Iron and Steel Industry	
165	INDIS_HEBL_BM	High Efficiency Biomass Boiler in Iron and Steel Ind	High efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
166	INDIS_HEBL_BG	High Efficiency BG Boiler in Iron and Steel Industry	
167	INDIS_HEBL_NG	High Efficiency NG Boiler in Iron and Steel Industry	
168	INDIS_HEBL_OilP	High Efficiency OilP Boiler in Iron and Steel Industry	
169	INDIS_HLG	Halogen lighting in Iron and Steel Industry	
170	INDIS_HP	Heat Pump for HVAC use in Iron and Steel Industry	Technology from the service sector since HVAC is mostly used in offices of the industries.
171	INDIS_INCT	Incandescent lighting in Iron and Steel Industry	
172	INDIS_ISPT	Iron and Steel production techs	
173	INDIS_ISPT_BG	Iron and Steel production techs with BG instead NG	
174	INDIS_LED	LED for lighting use in Iron and Steel Industry	
175	INDIS_MTR	Motors for machine drive use in Iron and Steel Industry	An electric motor is the technology considered to produce machine drive since all the machine drive comes from electricity
176	INDIS_VHEBL_BM	Very High Efficiency Biomass Boiler in Iron and Steel Industry	Very high efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
177	INDIS_VHEBL_BG	Very High Efficiency BG Boiler in Iron and Steel Industry	
178	INDIS_VHEBL_NG	Very High Efficiency NG Boiler in Iron and Steel Industry	
179	INDIS_VHEBL_OilP	Very High Efficiency OilP Boiler in Iron and Steel Industry	
180	INDNFM_AC	Air conditioner to HVAC use in Non Ferrous Metal industry	

181	INDNFM_BL_BM	Biomass Boiler Non Ferreous Metal Industry	
182	INDNFM_BL_LPG	LPG Boiler Non Ferreous Metal Industry	
183	INDNFM_BL_BG	BG Boiler Non Ferreous Metal Industry	
184	INDNFM_BL_NG	NG Boiler Non Ferreous Metal Industry	
185	INDNFM_BL_OilP	OilP Boiler Non Ferreous Metal Industry	
186	INDNFM_BL_COAL	Coal Boiler Non Ferreous Metal Industry	
187	INDNFM_BL_H2	Hydrogen Boiler in Non and Ferrous Metal Industry	Future technology implemented in this industry with study-based data
188	INDNFM_BL_OilP_SH	OilP Boiler for space heating in Non Ferreous Metal Indust	Technology taken from the JRC model, in the service sector, used for HVAC . Since HVAC in industry is mostly installed in offices, it was considered a suitable approximation.
189	INDNFM_BL_LPG_SH	LPG Boiler for space heating in Non Ferreous Metal Indus	
190	INDNFM_BL_BG_SH	BG Boiler for space heating in Non Ferreous Metal Industr	
191	INDNFM_BL_NG_SH	NG Boiler for space heating in Non Ferreous Metal Industr	
192	INDNFM_CE_Diesel	Diesel combustion engine in Non Ferreous Metal Ind	
193	INDNFM_EV	Electric vehicle to on site transportation use	Future technology implemented in this industry with study-based data
194	INDNFM_FC	Hydrogen vehicle to on site transportation use	Future technology implemented in this industry with study-based data
195	INDNFM_CMP_Ele	Compressor for refrigeration use in Non Ferrous Metal Industry	
196	INDNFM_FAP	Finished Aluminium Production Equipment	
197	INDNFM_FAP_BG	Finished Aluminium Production Equipment with BG instead NG	
198	INDNFM_IA	Inert Anodes to produce Al Crude	
199	INDNFM_IA_BG	Inert Anodes to produce Al Crude with BG instead NG	
200	INDNFM_FLRT	Fluorescent lighting in Non Ferreous Metal Industry	
201	INDNFM_HEBL_BM	High Efficiency Biomass Boiler in Non Ferreous Metal Ind	High efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
202	INDNFM_HEBL_BG	High Efficiency BG Boiler in Non Ferreous Metal Industry	
203	INDNFM_HEBL_NG	High Efficiency NG Boiler in Non Ferreous Metal Industry	

204	INDNFM_HEBL_OilP	High Efficiency OilP Boiler in Non Ferreous Metal Industry	
205	INDNFM_HLG	Halogen lighting in Non Ferreous Metal Industry	
206	INDNFM_HP	Heat Pump for HVAC use in Iron and Steel Industry	Technology from the service sector since HVAC is mostly used in offices of the industries.
207	INDNFM_INCT	Incandescent lighting in Non Ferreous Metal Industry	
208	INDNFM_LED	LED for lighting in Non Ferreous Metal Industry	
209	INDNFM_MTR	Motors Non Ferreous Metal Industry	An electric motor is the technology considered to produce machine drive since all the machine drive comes from electricity
210	INDNFM_SBL_HEAT	Waste Heat Steam Boiler Non Ferreous Metal Indus	
211	INDNFM_SBL_LPG	Coal Steam Boiler Non Ferreous Metal Industry	
212	INDNFM_SBL_Coal	LPG Steam Boiler Non Ferreous Metal Industry	
213	INDNFM_SBL_BG	BG Steam Boiler Non Ferreous Metal Industry	
214	INDNFM_SBL_NG	NG Steam Boiler Non Ferreous Metal Industry	
215	INDNFM_SBL_OilP	Oil Products Steam Boiler Non Ferreous Metal Indus	
216	INDNFM_VHEBL_BM	Very High Efficiency Biomass Boiler In Other Industries	Very high efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
217	INDNFM_VHEBL_BG	Very High Efficiency BG Boiler in Non Ferrous Metal Industries	
218	INDNFM_VHEBL_NG	Very High Efficiency NG Boiler in Non Ferrous Metal Industries	
219	INDNFM_VHEBL_OilP	Very High Efficiency OilP Boiler in Non Ferrous Metal Industries	
220	INDOI_AC	Air conditioner to HVAC use in Other Industries	
221	INDOI_BL_BM	Biomass Boiler Other Industries	
222	INDOI_BL_LPG	LPG Boiler Other Industries	
223	INDOI_BL_BG	BG Boiler Other Industries	
224	INDOI_BL_NG	NG Boiler Other Industries	
225	INDOI_BL_OilP	Oil Products Boiler Other Industries	
226	INDOI_BL_H2	Hydrogen Boiler in Other Industries	Future technology implemented in this industry with study-based data

227	INDOI_CE_Diesel	Diesel combustion engine in Other Industries	
228	INDOI_EV	Electric vehicle to on site transportation use	Future technology implemented in this industry with study-based data
229	INDOI_FC	Hydrogen vehicle to on site transportation use	Future technology implemented in this industry with study-based data
230	INDOI_CMP_Ele	Compressor for refrigeration use in Other Industries	
231	INDOI_HEBL_BM	High Efficiency Biomass Boiler in Other Industries	High efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
232	INDOI_HEBL_BG	High Efficiency BG Boiler in Other Industries	
233	INDOI_HEBL_NG	High Efficiency NG Boiler in Other Industries	
234	INDOI_HEBL_OilP	High Efficiency OilP Boiler in Other Industries	
235	INDOI_HP	Heat Pump for HVAC use in Other Industries	Technology from the service sector since HVAC is mostly used in offices of the industries.
236	INDOI_LED	LED for lighting use in Other Industries	
237	INDOI_SBL_HEAT	Waste Heat Steam Boiler Other Industries	
238	INDOI_SBL_LPG	LPG Steam Boiler Other Industries	
239	INDOI_SBL_BG	BG Steam Boiler Other Industries	
240	INDOI_SBL_NG	NG Steam Boiler Other Industries	
241	INDOI_SBL_OilP	Oil Products Steam Boiler Other Industries	
242	INDOI_VHEBL_BM	Very High Efficiency Biomass Boiler In Other Industries	Very high efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
243	INDOI_VHEBL_BG	Very High Efficiency BG Boiler in Other Industries	
244	INDOI_VHEBL_NG	Very High Efficiency NG Boiler in Other Industries	
245	INDOI_VHEBL_OilP	Very High Efficiency OilP Boiler In Other Industries	
246	INDOI_BL_LPG_SH	LPG Boiler for space heating in Other Industries	Technology taken from the JRC model, in the service sector, used for HVAC . Since HVAC in industry is mostly installed in offices, it was considered a suitable approximation.
247	INDOI_BL_BG_SH	BG Boiler for space heating in Other Industries	

248	INDOI_BL_NG_SH	NG Boiler for space heating in Other Industries	
249	INDOI_BL_OilP_SH	OilP Boiler for space heating in Other Industries	
250	INDOI_FLRT	Fluorescent lighting in Other Industries	
251	INDOI_HLG	Halogen lighting in Other Industries	
252	INDOI_INCT	Incandescent lighting in Other Industries	
253	INDOI_MTR	Motors Other Industries	An electric motor is the technology considered to produce machine drive since all the machine drive comes from electricity
254	INDPP_AC	Air conditioner to HVAC use in Paper and Pulp industry	
255	INDPP_BL_BM	LPG Boiler Chemical Industry	
256	INDPP_BL_BG	Biogas Boiler in Pulp and Paper Industry	
257	INDPP_BL_NG	Natural Gas Boiler in Pulp and Paper Industry	
258	INDPP_BL_OilP	Oil Boiler in Pulp and Paper Industry	
259	INDPP_BL_H2	Hydrogen Boiler in Pulp and Paper Industry	Future technology implemented in this industry with study-based data
260	INDPP_BL_OilP_SH	OilP Boiler for space heating in Pulp and Paper Industry	Technology taken from the JRC model, in the service sector, used for HVAC . Since HVAC in industry is mostly installed in offices, it was considered a suitable approximation.
261	INDPP_BL_BG_SH	BG Boiler for space heating in Pulp and Paper Industry	
262	INDPP_BL_NG_SH	NG Boiler for space heating in Pulp and Paper Industry	
263	INDPP_BL_LPG_SH	LPG Boiler for space heating in Pulp and Paper Industry	
264	INDPP_CE_Diesel	Diesel combustion engine in Pulp and Paper Industry	
265	INDPP_EV	Electric vehicle to on site transportation use	Future technology implemented in this industry with study-based data
266	INDPP_FC	Hydrogen vehicle to on site transportation use	Future technology implemented in this industry with study-based data
267	INDPP_CMP_Ele	Compressor for refrigeration use in Pulp and Paper Industry	

268	INDPP_CPP	Chemical Pulp Production	
269	INDPP_FLRT	Fluorescent lighting in Pulp and Paper Industry	
270	INDPP_HeatCHP		
271	INDPP_HEBL_BM	High Efficiency Biomass Boiler In Pulp and Paper Industry	High efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
272	INDPP_HEBL_BG	High Efficiency BG Boiler In Pulp and Paper Industry	
273	INDPP_HEBL_NG	High Efficiency NG Boiler In Pulp and Paper Industry	
274	INDPP_HEBL_OilP	High Efficiency OilP Boiler In Pulp and Paper Industry	
275	INDPP_HLG	Halogen lighting in Pulp and Paper Industry	
276	INDPP_HP	Heat Pump for HVAC use in Pulp and Paper industry	Technology from the service sector since HVAC is mostly used in offices of the industries.
277	INDPP_HQPE	High Quality Paper Equipment	
278	INDPP_HQPEAD	High Quality Paper Prod Equp with Advanced Drives	
279	INDPP_INCT	Incandescent lighting in Pulp and Paper Industry	
280	INDPP_KLN_BM	Biomass Kiln Pulp and Paper Industry	
281	INDPP_KLN_BG	Biogas Kiln Pulp and Paper Industry	
282	INDPP_KLN_NG	Natural Gas Kiln Pulp and Paper Industry	
283	INDPP_KLN_Oil	Oil Kiln Pulp and Paper Industry	
284	INDPP_LED	LED for lighting use in Pulp and Paper industry	
285	INDPP_LQPE	Low Quality Paper Equipment	
286	INDPP_LQPEAD	Low Quality Paper Prod Equp with Advanced Drives	
287	INDPP_MPP	Mechanical Pulp Production	
288	INDPP_MPP_BG	Mechanical Pulp Production	
289	INDPP_MPPAD	Mechanical Pulp Prod Airless drying in PP industry	
290	INDPP_MPPAD_BG	Mechanical Pulp Prod Airless drying with BG instead NG	

291	INDPP_MTR	Motors Pulp and Paper Industry	An electric motor is the technology considered to produce machine drive since all the machine drive comes from electricity
292	INDPP_RPP	Recycling Pulp Production	
293	INDPP_VHEBL_BM	Very High Efficiency Biomass Boiler In Pulp and Paper	Very high efficiency boiler presented in the PP industry in the JRC model which is suitable for all industries
294	INDPP_VHEBL_BG	Very High Efficiency BG Boiler In Pulp and Paper	
295	INDPP_VHEBL_NG	Very High Efficiency NG Boiler In Pulp and Paper	
296	INDPP_VHEBL_OilP	Very High Efficiency OilP Boiler In Pulp and Paper	

Annex B – List of fuels used in the model

Annex B contains the list of fuels that were introduced in the model to characterize the industry sector.

#	Fuel code	Description
1	Al_IND_NFM	Aluminum produced in the Non Ferrous Metal
2	AM_IND_CH	Ammonia produced in the chemical industry
3	CAl_IND_NFM	Aluminum crude produced in the Non Ferrous Metal
4	CHL_IND_CH	Chlorine produced in the chemical industry
5	CLK_IND_CMLM	Clinker produced in the cement and lime industry se
6	CMT_IND_CMLM	Cement produced in the cement and lime industry s
7	CSteel_IND_IS	Crude Steel produced in the Iron and Steel Industry
8	GF_IND_CRGL	Glass flat produced
9	GH_IND_CRGL	Glass hollow produced
10	Heat_IND_CH	Heat produced in the chemical industry sector
11	Heat_IND_CMLM	Heat produced in the cement and lime industry sect
12	Heat_IND_CRGL	
13	Heat_IND_FB	Heat produced in the Food Beverages Industry
14	Heat_IND_OI	Heat produced in the Other Industries
15	Heat_IND_IS	
16	Heat_IND_NFM	Heat produced in Non Ferreous Metal Industry
17	Heat_IND_PP	Heat produced in the Pulp and paper industry sector
18	HVAC_IND_CH	HVAC use in Chemical Industry
19	HVAC_IND_CM	HVAC use in Cement and Lime Industry
20	HVAC_IND_CR	HVAC use in Ceramic and Glass industry
21	HVAC_IND_FB	HVAC use in Food Beverages Industry
22	HVAC_IND_IS	HVAC use in Iron and Steel Industry
23	HVAC_IND_NF	HVAC use in Non Ferreous Metal Industry
24	HVAC_IND_OI	HVAC use in Other Industries
25	HVAC_IND_PP	HVAC use in Pulp and Paper industry
26	HQP_IND_PP	High Quality Paper produced in the Pulp and Paper industry
27	LIGHT_IND_CH	Light produced in the chemical industry sector
28	LIGHT_IND_CMLM	Light produced in the Heat produced in space heating
29	LIGHT_IND_CRGL	Light produced in the Heat produced in space heating
30	LIGHT_IND_FB	Light produced in the Heat produced in space heating

31	LIGHT_IND_OI	Light produced in the Heat produced in space heating
32	LIGHT_IND_IS	Light produced in the Heat produced in space heating
33	LIGHT_IND_NFM	Light produced in Non Ferreous Metal Industry
34	LIGHT_IND_PP	Light produced in the Heat produced in space heating
35	LM_IND_CMLM	Lime produced in the cement and lime industry sector
36	LQP_IND_PP	Low Quality Paper produced in the Pulp and Paper industry
37	MD_IND_CH	Machine Drive produced in the chemical industry se
38	MD_IND_CMLM	Machine Drive produced in the Heat produced in spa
39	MD_IND_CRGL	Machine Drive produced in the Ceramic and Glass in
40	MD_IND_FB	Machine Drive produced in the Food Beverages Indu
41	MD_IND_OI	Machine Drive produced in the Other Industries
42	MD_IND_IS	Machine Drive produced in the Iron and Steel Indust
43	MD_IND_NFM	Machine Drive produced in Non Ferreous Metal Indu
44	MD_IND_PP	Machine Drive produced in the Paper and Pulp indu
45	OST_IND_CH	On Site Transportation in Chemical Industry
46	OST_IND_CMLM	On Site Transportation in Cement and Lime industry
47	OST_IND_CRGL	On Site Transportation in Ceramic and Glass industr
48	OST_IND_FB	On Site Transportation in Food Beverages Industry
49	OST_IND_IS	On Site Transportation in Iron and Steel Industry
50	OST_IND_NFM	On Site Transportation in Non Ferreous Metal Indust
51	OST_IND_OI	On Site Transportation in Other Industries
52	OST_IND_PP	On Site Transportation in Paper and Pulp industry
53	OU__IND_NFM	Other uses in Non Ferreous Metal Industry
54	OU_IND_CMLM	Other uses in Cement and Lime industry
55	OU_IND_CRGL	Other uses in Ceramic and Glass industry
56	OU_IND_FB	Other uses in Food Beverages Industry
57	OU_IND_IS	Other uses in Iron and Steel Industry
58	OU_IND_OI	Other uses in Other Industries
59	OU_IND_PP	Other uses in Paper and Pulp industry
60	OU_IND_CH	Other uses in Chemical Industry
61	PULP_IND_PP	Pulp produced in the Paper and Pulp industry
62	RFR_IND_CH	Refrigeration in Chemical Industry
63	RFR_IND_CMLM	Refrigeration in Cement and Lime industry
64	RFR_IND_CRGL	Refrigeration in Ceramic and Glass industry
65	RFR_IND_FB	Refrigeration in Food Beverages
66	RFR_IND_IS	Refrigeration in Iron and Steel Industry
67	RFR_IND_NFM	Refrigeration in Non Ferreous Metal Industry
68	RFR_IND_OI	Refrigeration in Other Industries
69	RFR_IND_PP	Refrigeration in Paper and Pulp industry
70	Steam_IND_CH	Steam produced in the chemical industry sector
71	Steam_IND_FB	Steam produced in the Food Beverages Industry
72	Steam_IND_OI	Steam produced in the Other Industries
73	Steam_IND_NFM	Steel produced in Non Ferreous Metal Industry
74	Steel_IND_IS	Steel produced in the Iron and Steel Industry

Annex C – Technical and economic data of the technologies

Annex C contains a list with the technical and economic data of the technologies included in the model.

Technology	**Capital Cost [€/kW]**	**Fixed Cost [€/kW]**	**Input**	**Output**	**Operational Life Time (years)**
H2_ALK	625.9	41.54	EL	H2	30
H2_PEM	1200	36	EL	H2	30
H2_STREFF	201	98	EL, NG	H2	30
INDCH_AC	481	24.05	EL	HVAC_IND_CH	10
INDCH_AMP	1100	86.36	EL	CHL_IND_CH	30
INDCH_AMPI	1312.55	86.36	EL	CHL_IND_CH	30
INDCH_BL_BM	728.48	53.93	BM	Heat_IND_CH	30
INDCH_BL_COA	517.19	18.92	COAL	Heat_IND_CH	30
INDCH_BL_LPG	315.36	15.77	LPG	Heat_IND_CH	30
INDCH_BL_LPG_SH	182.05	9.1	LPG	HVAC_IND_CH	20
INDCH_BL_BG	208.14	11.94	BG	Heat_IND_CH	30

INDCH_BL_NG	208.14	11.94	NG	Heat_IND_CH	30
INDCH_BL_H2	90	5	H2	Heat_IND_CH	30
INDCH_BL_BG_SH	179.39	12.56	BG	HVAC_IND_CH	20
INDCH_BL_NG_SH	179.39	12.56	NG	HVAC_IND_CH	20
INDCH_BL_Oil	378.43	31.536	FO	Heat_IND_CH	30
INDCH_BL_OilP_SH	77.34	3.87	FO	HVAC_IND_CH	20
INDCH_CE_Diesel	208.14	11.98	DIE	OST_IND_CH	30
INDCH_EV	249.8	5	El	OST_IND_CH	30
INDCH_FC	291.3	15.6	H2	OST_IND_CH	30
INDCH_CMP_Ele	382	0.01	EL	RFR_IND_CH	30
INDCH_FLRT	2	3.37	EL	LIGHT_IND_CH	1
INDCH_HEBL_BM	150	10	BM	Heat_IND_CH	30
INDCH_HEBL_BG	75	5	BG	Heat_IND_CH	30
INDCH_HEBL_NG	75	5	NG	Heat_IND_CH	30
INDCH_HEBL_OilP	75	5	FO	Heat_IND_CH	30
INDCH_HLG	0.0001	0	EL	LIGHT_IND_CH	5
INDCH_HP	1351.02	67.55	EL	HVAC_IND_CH	15
INDCH_INCT	1	14.45	EL	LIGHT_IND_CH	0.15
INDCH_LED	8	2.64	EL	LIGHT_IND_CH	5
INDCH_MTR	0.024	0.01	EL	MD_IND_CH	30
INDCH_PAC	285	8.5	EL , NG	AM_IND_CH	25
INDCH_PAC_BG	285	8.5	EL , BG	AM_IND_CH	25
INDCH_SBL_COA	239.67	12.61	COAL	Steam_IND_CH	30
INDCH_SBL_HEAT	80	10	Heat	Steam_IND_CH	30
INDCH_SBL_LPG	197.25	12.61	LPG	Steam_IND_CH	30
INDCH_SBL_Oil	197.25	12.61	FO	Steam_IND_CH	30
INDCH_VHEBL_BM	150	10	BM	Heat_IND_CH	30

INDCH_VHEBL_BG	75	5	BG	Heat_IND_CH	30
INDCH_VHEBL_NG	75	5	NG	Heat_IND_CH	30
INDCH_VHEBL_OilP	75	5	FO	Heat_IND_CH	30
INDCMLM_AC	481	24.05	EL	HVAC_IND_CMLM	10
INDCMLM_BL_LPG_SH	182.05	9.1	LPG	HVAC_IND_CMLM	20
INDCMLM_BL_BG_SH	179.39	12.56	BG	HVAC_IND_CMLM	20
INDCMLM_BL_NG_SH	179.39	12.56	NG	HVAC_IND_CMLM	20
INDCMLM_BL_OilP_SH	77.34	3.87	FO	HVAC_IND_CMLM	20
INDCMLM_BL_H2	90	5	H2	Heat_IND_CMLM	30
INDCMLM_CE_Diesel	208.14	11.98	DIE	OST_IND_CMLM	30
INDCMLM_EV	249.8	5	El	OST_IND_CMLM	30
INDCMLM_FC	291.3	15.6	H2	OST_IND_CMLM	30
INDCMLM_CMP_Ele	382	0.01	EL	RFR_IND_CMLM	30
INDCMLM_DPE	125	5	EL , Heat	CLK_IND_CMLM	30
INDCMLM_FCPE	10	3	EL, FO IND	CMT_IND_CMLM	25
INDCMLM_FLRT	0.0001	0	EL	LIGHT_IND_CMLM	8
INDCMLM_HEBL_BM	150	10	BM	Heat_IND_CMLM	30
INDCMLM_HEBL_BG	75	5	BG	Heat_IND_CMLM	30
INDCMLM_HEBL_NG	75	5	NG	Heat_IND_CMLM	30
INDCMLM_HEBL_OilP	75	5	FO	Heat_IND_CMLM	30
INDCMLM_HLG	0.0001	0	EL	LIGHT_IND_CMLM	5
INDCMLM_HP	1351.02	67.55	EL	HVAC_IND_CMLM	15
INDCMLM_INCT	1	14.45	EL	LIGHT_IND_CMLM	0.15
INDCMLM_KLNCM_COA	50	0	COAL	Heat_IND_CMLM	30
INDCMLM_KLNCM_BG	50	0	BG	Heat_IND_CMLM	30
INDCMLM_KLNCM_NG	50	0	NG	Heat_IND_CMLM	30
INDCMLM_KLNLM_Oil	50	0	FO	Heat_IND_CMLM	30

INDCMLM_LED	8	2.64	EL	LIGHT_IND_CMLM	5
INDCMLM_MTR	0.024	0.01	EL	MD_IND_CMLM	30
INDCMLM_QLP	300	10	EL,Heat	LM_IND_CMLM	25
INDCMLM_VHEBL_BM	150	10	BM	Heat_IND_CMLM	30
INDCMLM_VHEBL_BG	75	5	BG	Heat_IND_CMLM	30
INDCMLM_VHEBL_NG	75	5	NG	Heat_IND_CMLM	30
INDCMLM_VHEBL_OilP	75	5	FO	Heat_IND_CMLM	30
INDCRGL_AC	481	24.05	EL	HVAC_IND_CRGL	10
INDCRGL_BL_LPG_SH	182.05	9.1	LPG	HVAC_IND_CRGL	20
INDCRGL_BL_BG_SH	179.39	12.56	BG	HVAC_IND_CRGL	20
INDCRGL_BL_NG_SH	179.39	12.56	NG	HVAC_IND_CRGL	20
INDCRGL_BL_OilP_SH	77.34	3.87	FO	HVAC_IND_CRGL	20
INDCRGL_BL_H2	90	5	H2	Heat_IND_CRGL	30
INDCRGL_CE_Diesel	208.14	11.98	DIE	OST_IND_CRGL	30
INDCRGL_EV	249.8	5	El	OST_IND_CRGL	30
INDCRGL_FC	291.3	15.6	H2	OST_IND_CRGL	30
INDCRGL_CMP_Ele	382	0.01	EL	RFR_IND_CRGL	30
INDCRGL_FLRT	2	3.37	EL	LIGHT_IND_CRGL	1
INDCRGL_FPE	200	15	EL,NG	GF_IND_CRGL	25
INDCRGL_FPE_BG	200	15	EL, BG	GF_IND_CRGL	25
INDCRGL_FPEHR	190	12	EL,NG	GF_IND_CRGL	30
INDCRGL_FPEHR_BG	190	12	EL, BG	GF_IND_CRGL	30
INDCRGL_GHE	250	20	EL, FO, NG	GH_IND_CRGL	30
INDCRGL_GHE_BG	250	20	EL, FO, BG	GH_IND_CRGL	30
INDCRGL_GHEHR	290	22	EL, FO, NG	GH_IND_CRGL	30
INDCRGL_GHEHR_BG	290	22	EL, FO, BG	GH_IND_CRGL	30
INDCRGL_GLRE	200	15	EL, FO, NG	GH_IND_CRGL	25

INDCRGL_GLRE_BG	200	15	EL, FO, BG	GH_IND_CRGL	25
INDCRGL_GLREIM	280	17	EL, FO, NG	GH_IND_CRGL	30
INDCRGL_GLREIM_BG	280	17	EL, FO, BG	GH_IND_CRGL	30
INDCRGL_HEBL_BM	150	10	BM	Heat_IND_CRGL	30
INDCRGL_HEBL_BG	75	5	BG	Heat_IND_CRGL	30
INDCRGL_HEBL_NG	75	5	NG	Heat_IND_CRGL	30
INDCRGL_HEBL_OilP	75	5	FO	Heat_IND_CRGL	30
INDCRGL_HLG	0.0001	0	EL	LIGHT_IND_CRGL	5
INDCRGL_HP	1351.02	67.55	EL	HVAC_IND_CRGL	15
INDCRGL_INCT	1	14.45	EL	LIGHT_IND_CRGL	0.15
INDCRGL_KLN_BM	728.5	53.92	BM	Heat_IND_CRGL	30
INDCRGL_KLN_Ele	473	15.77	EL	Heat_IND_CRGL	30
INDCRGL_KLN_BG	208.1	11.98	BG	Heat_IND_CRGL	30
INDCRGL_KLN_NG	208.1	11.98	NG	Heat_IND_CRGL	30
INDCRGL_LED	8	2.64	EL	LIGHT_IND_CRGL	5
INDCRGL_MTR	0.024	0.01	EL	MD_IND_CRGL	30
INDCRGL_VHEBL_BM	150	10	BM	Heat_IND_CRGL	30
INDCRGL_VHEBL_BG	75	5	BG	Heat_IND_CRGL	30
INDCRGL_VHEBL_NG	75	5	NG	Heat_IND_CRGL	30
INDCRGL_VHEBL_OilP	75	5	FO	Heat_IND_CRGL	30
INDFB_AC	481	24.05	EL	HVAC_IND_FB	10
INDFB_BL_Diesel	315.36	15.768	DIE	Steam_IND_FB	30
INDFB_BL_LPG_SH	182.05	9.1	LPG	HVAC_IND_FB	20
INDFB_BL_BG	208.14	11.98	BG	Steam_IND_FB	30
INDFB_BL_NG	208.14	11.98	NG	Steam_IND_FB	30
INDFB_BL_H2	90	5	H2	Heat_IND_FB	30
INDFB_BL_BG_SH	179.39	12.56	BG	HVAC_IND_FB	20

INDFB_BL_NG_SH	179.39	12.56	NG	HVAC_IND_FB	20
INDFB_BL_OilP	378.43	31.54	FO	Steam_IND_FB	30
INDFB_BL_OilP_SH	77.34	3.87	FO	HVAC_IND_FB	20
INDFB_CE_Diesel	208.14	11.98	DIE	OST_IND_FB	30
INDFB_EV	249.8	5	El	OST_IND_FB	30
INDFB_FC	291.3	15.6	H2	OST_IND_FB	30
INDFB_CMP_Ele	382	0.01	EL	RFR_IND_FB	30
INDFB_FLRT	2	3.37	EL	LIGHT_IND_FB	1
INDFB_HEBL_BM	150	10	BM	Heat_IND_FB	30
INDFB_HEBL_BG	75	5	BG	Heat_IND_FB	30
INDFB_HEBL_NG	75	5	NG	Heat_IND_FB	30
INDFB_HEBL_OilP	75	5	FO	Heat_IND_FB	30
INDFB_HLG	0.0001	0	EL	LIGHT_IND_FB	5
INDFB_HP	1351.02	67.55	EL	HVAC_IND_FB	15
INDFB_INCT	0.01	0	EL	LIGHT_IND_FB	2
INDFB_LED	8	2.64	EL	LIGHT_IND_FB	5
INDFB_MTR	0.024	0.01	EL	MD_IND_FB	30
INDFB_Oven_BM	728.48	53.92	BM	Heat_IND_FB	30
INDFB_Oven_Coal	517.19	18.92	COAL	Heat_IND_FB	30
INDFB_Oven_Diesel	378.48	31.64	DIE	Heat_IND_FB	30
INDFB_Oven_Ele	473.04	15.768	EL	Heat_IND_FB	30
INDFB_Oven_BG	208.14	11.98	BG	Heat_IND_FB	30
INDFB_Oven_NG	208.14	11.98	NG	Heat_IND_FB	30
INDFB_Oven_OilP	315.36	15.768	FO	Heat_IND_FB	30
INDFB_SBL_Diesel	315.36	15.768	DIE	Steam_IND_FB	30
INDFB_SBL_BG	208.14	11.98	NG	Steam_IND_FB	30
INDFB_SBL_NG	208.14	11.98	NG	Steam_IND_FB	30

INDFB_SBL_OilP	378.43	31.54	FO	Steam_IND_FB	30
INDFB_VHEBL_BM	150	10	BM	Heat_IND_FB	30
INDFB_VHEBL_BG	75	5	BG	Heat_IND_FB	30
INDFB_VHEBL_NG	75	5	NG	Heat_IND_FB	30
INDFB_VHEBL_OilP	75	5	FO	Heat_IND_FB	30
INDIS_AC	481	24.05	EL	HVAC_IND_IS	10
INDIS_BL_LPG_SH	182.05	9.1	LPG	HVAC_IND_IS	20
INDIS_BL_BG_SH	179.39	12.56	BG	HVAC_IND_IS	20
INDIS_BL_NG_SH	179.39	12.56	NG	HVAC_IND_IS	20
INDIS_BL_OilP_SH	77.34	3.87	FO	HVAC_IND_IS	20
INDIS_BL_H2	90	5	H2	Heat_IND_IS	30
INDIS_CE_Diesel	208.14	11.98	DIE	OST_IND_IS	30
INDIS_EV	249.8	5	El	OST_IND_IS	30
INDIS_FC	291.3	15.6	H2	OST_IND_IS	30
INDIS_CMP_Ele	382	0.01	EL	RFR_IND_IS	30
INDIS_EAF	168.88	13.51	EL,NG	Steel_IND_IS	30
INDIS_EAF_BG	168.88	13.51	EL,BG	Steel_IND_IS	30
INDIS_FLRT	2	3.37	EL	LIGHT_IND_IS	1
INDIS_HEBL_BM	150	10	BM	Heat_IND_IS	30
INDIS_HEBL_BG	75	5	BG	Heat_IND_IS	30
INDIS_HEBL_NG	75	5	NG	Heat_IND_IS	30
INDIS_HEBL_OilP	75	5	FO	Heat_IND_IS	30
INDIS_HLG	0.0001	0	EL	LIGHT_IND_IS	5
INDIS_HP	1351.02	67.55	EL	HVAC_IND_IS	15
INDIS_INCT	1	14.45	EL	LIGHT_IND_IS	0.15
INDIS_ISPT	200	50	COAL,EL, FO, LPG, NG	CSteel_IND_IS	100

INDIS_ISPT_BG	200	50	COAL,EL, FO, LPG, BG	CSteel_IND_IS	100
INDIS_LED	8	2.64	EL	LIGHT_IND_IS	5
INDIS_MTR	0.024	0.01	EL	MD_IND_IS	30
INDIS_VHEBL_BM	150	10	BM	Heat_IND_IS	30
INDIS_VHEBL_BG	75	5	BG	Heat_IND_IS	30
INDIS_VHEBL_NG	75	5	NG	Heat_IND_IS	30
INDIS_VHEBL_OilP	75	5	FO	Heat_IND_IS	30
INDNFM_AC	481	24.05	EL	HVAC_IND_NFM	10
INDNFM_BL_BM	728.48	53.93	BM	Heat_IND_NFM	30
INDNFM_BL_LPG	315.36	15.768	LPG	Heat_IND_NFM	30
INDNFM_BL_LPG_SH	182.05	0	LPG	HVAC_IND_NFM	1
INDNFM_BL_BG	208.14	11.98	BG	Heat_IND_NFM	30
INDNFM_BL_NG	208.14	11.98	NG	Heat_IND_NFM	30
INDNFM_BL_COAL	517.19	18.92	Coal	Heat_IND_NFM	30
INDNFM_BL_H2	90	5	H2	Heat_IND_NFM	30
INDNFM_BL_BG_SH	179.39	0	BG	HVAC_IND_NFM	1
INDNFM_BL_NG_SH	179.39	0	NG	HVAC_IND_NFM	1
INDNFM_BL_OilP	315.36	15.77	FO	Heat_IND_NFM	30
INDNFM_BL_OilP_SH	77.34	0	FO	HVAC_IND_NFM	1
INDNFM_CE_Diesel	208.14	11.98	DIE	OST_IND_NFM	30
INDNFM_EV	249.8	5	El	OST_IND_NFM	30
INDNFM_FC	291.3	15.6	H2	OST_IND_NFM	30
INDNFM_FAP	500	25	EL, NG, LFO	Al_IND_NFM	30
INDNFM_FAP_BG	500	25	EL, BG, LFO	Al_IND_NFM	30
INDNFM_IA	4100	145.45	EL, NG	CAl_IND_NFM	30
INDNFM_IA_BG	4100	145.45	EL, BG	CAl_IND_NFM	30

INDNFM_CMP_Ele	382	0.01	EL	RFR_IND_NFM	30
INDNFM_FLRT	2	3.37	EL	LIGHT_IND_NFM	1
INDNFM_HEBL_BM	150	10	BM	Heat_IND_NFM	30
INDNFM_HEBL_BG	75	5	BG	Heat_IND_NFM	30
INDNFM_HEBL_NG	75	5	NG	Heat_IND_NFM	30
INDNFM_HEBL_OilP	75	5	FO	Heat_IND_NFM	30
INDNFM_HLG	0.0001	0	EL	LIGHT_IND_NFM	5
INDNFM_HP	1351.02	67.55	EL	HVAC_IND_NFM	15
INDNFM_INCT	1	14.45	EL	LIGHT_IND_NFM	2
INDNFM_LED	8	2.64	EL	LIGHT_IND_NFM	1
INDNFM_MTR	0.024	0.01	EL	MD_IND_NFM	30
INDNFM_SBL_HEAT	80	10	Heat	Steam_IND_NFM	30
INDNFM_SBL_Coal	293.67	12.61	Coal	Steam_IND_NFM	30
INDNFM_SBL_LPG	197.25	12.61	LPG	Steam_IND_NFM	30
INDNFM_SBL_BG	133.94	12.61	BG	Steam_IND_NFM	30
INDNFM_SBL_NG	133.94	12.61	NG	Steam_IND_NFM	30
INDNFM_SBL_OilP	197.25	12.61	FO	Steam_IND_NFM	30
INDNFM_VHEBL_BM	150	10	BM	Heat_IND_NFM	30
INDNFM_VHEBL_BG	75	5	BG	Heat_IND_NFM	30
INDNFM_VHEBL_NG	75	5	NG	Heat_IND_NFM	30
INDNFM_VHEBL_OilP	75	5	FO	Heat_IND_NFM	30
INDOI_AC	481	24.05	EL	HVAC_IND_OI	10
INDOI_BL_BM	728.48	53.93	BM	Heat_IND_IO	30
INDOI_BL_LPG	315.36	15.768	LPG	Heat_IND_IO	30
INDOI_BL_BG	208.14	11.98	BG	Heat_IND_IO	30
INDOI_BL_NG	208.14	11.98	NG	Heat_IND_IO	30
INDOI_BL_OilP	315.36	15.77	FO	Heat_IND_IO	30

INDOI_BL_H2	90	5	H2	Heat_IND_IO	30
INDOI_CE_Diesel	208.14	11.98	DIE	OST_IND_OI	30
INDOI_EV	249.8	5	El	OST_IND_OI	30
INDOI_FC	291.3	15.6	H2	OST_IND_OI	30
INDOI_CMP_Ele	382	0.01	EL	RFR_IND_OI	30
INDOI_HEBL_BM	150	10	BM	Heat_IND_IO	30
INDOI_HEBL_BG	75	5	BG	Heat_IND_IO	30
INDOI_HEBL_NG	75	5	NG	Heat_IND_IO	30
INDOI_HEBL_OilP	75	5	FO	Heat_IND_IO	30
INDOI_HP	1351.02	67.55	EL	HVAC_IND_OI	15
INDOI_LED	8	2.64	EL	LIGHT_IND_IO	1
INDOI_SBL_HEAT	80	10	Heat	Steam_IND_IO	30
INDOI_SBL_LPG	197.25	12.61	LPG	Steam_IND_IO	30
INDOI_SBL_BG	133.94	12.61	BG	Steam_IND_IO	30
INDOI_SBL_NG	133.94	12.61	NG	Steam_IND_IO	30
INDOI_SBL_OilP	197.25	12.61	FO	Steam_IND_IO	30
INDOI_VHEBL_BM	150	10	BM	Heat_IND_IO	30
INDOI_VHEBL_BG	75	5	BG	Heat_IND_IO	30
INDOI_VHEBL_NG	75	5	NG	Heat_IND_IO	30
INDOI_VHEBL_OilP	75	5	FO	Heat_IND_IO	30
INDOI_BL_LPG_SH	182.05	9.1	LPG	HVAC_IND_OI	20
INDOI_BL_BG_SH	179.39	12.56	BG	HVAC_IND_OI	20
INDOI_BL_NG_SH	179.39	12.56	NG	HVAC_IND_OI	20
INDOI_BL_OilP_SH	77.34	3.87	FO	HVAC_IND_OI	20
INDOI_FLRT	2	3.37	EL	LIGHT_IND_IO	1
INDOI_HLG	0.0001	0	EL	LIGHT_IND_IO	5
INDOI_INCT	1	14.45	EL	LIGHT_IND_IO	0.15

INDOI_MTR	0.024	0.01	EL	MD_IND_IO	30
INDPP_AC	481	24.05	EL	HVAC_IND_PP	10
INDPP_BL_BM	150	10	BM	Heat_IND_PP	30
INDPP_BL_LPG_SH	182.05	9.1	LPG	HVAC_IND_PP	20
INDPP_BL_NG	75	5	NG	Heat_IND_PP	30
INDPP_BL_BG	75	5	BG	Heat_IND_PP	30
INDPP_BL_NG_SH	179.39	12.56	NG	HVAC_IND_PP	20
INDPP_BL_BG_SH	179.39	12.56	BG	HVAC_IND_PP	20
INDPP_BL_OilP	75	5	FO	Heat_IND_PP	30
INDPP_BL_OilP_SH	77.34	3.87	FO	HVAC_IND_PP	20
INDPP_BL_H2	90	5	H2	Heat_IND_PP	30
INDPP_CE_Diesel	208.14	11.98	DIE	OST_IND_PP	30
INDPP_EV	249.8	5	El	OST_IND_PP	30
INDPP_FC	291.3	15.6	H2	OST_IND_PP	30
INDPP_CMP_Ele	382	0.01	EL	RFR_IND_PP	30
INDPP_CPP	1355	40	EL, Heat, BM	PULP_IND_PP	25
INDPP_FLRT	2	3.37	EL	LIGHT_IND_PP	1
INDPP_HeatCHP	0.0001	0	EL_Distribution	Heat_IND_PP	30
INDPP_HEBL_BM	150	10	BM	Heat_IND_PP	30
INDPP_HEBL_NG	75	5	NG	Heat_IND_PP	30
INDPP_HEBL_BG	75	5	BG	Heat_IND_PP	30
INDPP_HEBL_OilP	75	5	FO	Heat_IND_PP	30
INDPP_HLG	0.0001	0	EL	LIGHT_IND_PP	5
INDPP_HP	1351.02	67.55	EL	HVAC_IND_PP	15
INDPP_HQPE	2500	125	EL, Heat	HQP_IND_PP	30
INDPP_HQPEAD	3414.57	162.5	EL, Heat	HQP_IND_PP	25
INDPP_INCT	1	14.45	EL	LIGHT_IND_PP	0.15

INDPP_KLN_BM	728.48	53.93	BM	Heat_IND_PP	30
INDPP_KLN_NG	208.14	11.94	NG	Heat_IND_PP	30
INDPP_KLN_BG	208.14	11.94	BG	Heat_IND_PP	30
INDPP_KLN_Oil	378.43	31.54	FO	Heat_IND_PP	30
INDPP_LED	8	2.64	EL	LIGHT_IND_PP	5
INDPP_LQPE	1100	53	EL, Heat	LQP_IND_PP	30
INDPP_LQPEAD	1550.33	68.9	EL, Heat	LQP_IND_PP	20
INDPP_MPP	300	15	EL, NG	PULP_IND_PP	25
INDPP_MPP_BG	300	15	EL, BG	PULP_IND_PP	25
INDPP_MPPAD	704.7	52	EL, NG	PULP_IND_PP	25
INDPP_MPPAD_BG	704.7	52	EL, BG	PULP_IND_PP	25
INDPP_MTR	0.024	0.01	EL	MD_IND_PP	30
INDPP_RPP	642	30	EL, Heat	PULP_IND_PP	30
INDPP_VHEBL_BM	150	10	BM	Heat_IND_PP	30
INDPP_VHEBL_BG	75	5	BG	Heat_IND_PP	30
INDPP_VHEBL_NG	75	5	NG	Heat_IND_PP	30
INDPP_VHEBL_OilP	75	5	FO	Heat_IND_PP	30

Anexo D – National Energy Balance - DGEG 2015

BALANÇO ENERGÉTICO 2015 tep	**Carvão**	**Petróleo**	**Gás Natural**	**Eletricidade**	**Calor**	Resíduos não Renováveis	**Solar Térmico**	**Biomassa**	**Resíduos Sólidos Urbanos**	**Licores Sulfítivos**	**Outros Renováveis**	**Biogás**	**Biocombustíveis**	**TOTAL GERAL**
INDÚSTRIAS TRANSFORMADORAS	**13 543**	**583 727**	**1 053 834**	**1 276 261**	**1 145 264**	**55 064**	**0**	**104 182**	**0**	**0**	**39 082**	**8 024**	**527**	**4 279 508**
Alimentação, bebidas e tabaco	*0*	*77 346*	*145 549*	*162 607*	*47 493*	*0*	*0*	*26 270*	*0*	*0*	*0*	*1 258*	*0*	*460 523*
Têxteis	*0*	*6 636*	*115 797*	*76 213*	*39 927*	*0*	*0*	*2 633*	*0*	*0*	*0*	*0*	*0*	*241 206*
Papel e Artigos de Papel	*0*	*34 656*	*82 705*	*254 835*	*935 962*	*0*	*0*	*19 930*	*0*	*0*	*455*	*6 766*	*0*	*1 335 309*
Químicas e Plásticos	*0*	*8 379*	*137 026*	*196 582*	*77 534*	*54*	*0*	*2 226*	*0*	*0*	*0*	*0*	*527*	*422 328*
Cerâmicas	*0*	*18 097*	*192 361*	*35 597*	*15 675*	*0*	*0*	*17 887*	*0*	*0*	*0*	*0*	*0*	*279 617*
Vidro e Artigos de Vidro	*0*	*1 273*	*207 796*	*44 737*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*253 806*
Cimento e Cal	*0*	*358 622*	*33 275*	*71 055*	*1 016*	*55 010*	*0*	*7 395*	*0*	*0*	*38 627*	*0*	*0*	*565 000*
Metalúrgicas	*3 147*	*3 454*	*19 964*	*20 276*	*0*	*0*	*0*	*2*	*0*	*0*	*0*	*0*	*0*	*46 843*
Siderurgia	*8 796*	*1 720*	*35 461*	*118 329*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*164 306*
Vestuário, Calçado e Curtumes	*0*	*8 476*	*13 294*	*28 080*	*2 429*	*0*	*0*	*2 434*	*0*	*0*	*0*	*0*	*0*	*54 713*
Madeira e Artigos de Madeira	*0*	*9 197*	*7 834*	*74 815*	*12 340*	*0*	*0*	*23 662*	*0*	*0*	*0*	*0*	*0*	*127 848*
Borracha	*0*	*253*	*3 662*	*18 039*	*10 521*	*0*	*0*	*365*	*0*	*0*	*0*	*0*	*0*	*32 840*
Metálo-eletro-mecânicas	*121*	*25 543*	*54 317*	*128 336*	*666*	*0*	*0*	*60*	*0*	*0*	*0*	*0*	*0*	*209 043*
Outras Indústrias Transformadoras	*1 479*	*30 075*	*4 793*	*46 760*	*1 701*	*0*	*0*	*1 318*	*0*	*0*	*0*	*0*	*0*	*86 126*

Annex E – Technologies used in 2030 and 2050 in all industry sectors

Iron and steel sector			
Final Use	Scenario	Tecnhology used	
		2030	2050
Crude Steel Prod	BAU	INDIS_ISPT	INDIS_ISPT_BG
	FitFor55	INDIS_ISPT	INDIS_ISPT_BG
	RNC	INDIS_ISPT	INDIS_ISPT_BG
Iron and Steel Prod	BAU	INDIS_EAF, INDIS_EAF_BG	INDIS_EAF, INDIS_EAF_BG
	FitFor55	INDIS_EAF, INDIS_EAF_BG	INDIS_EAF, INDIS_EAF_BG
	RNC	INDIS_EAF, INDIS_EAF_BG	INDIS_EAF, INDIS_EAF_BG
Heat	BAU	INDIS_HEBL_BM/OilP, INDIS_VHEBL_BG/BM/NG/OilP	INDIS_VHEBL_BG
	FitFor55	INDIS_HEBL_BM/OilP, INDIS_VHEBL_BG/BM/NG/OilP	INDIS_VHEBL_BG
	RNC	INDIS_HEBL_BM/OilP, INDIS_VHEBL_BG/BM/NG/OilP	INDIS_VHEBL_BG
Machine Drive	BAU	INDIS_MTR	INDIS_MTR
	FitFor55	INDIS_MTR	INDIS_MTR
	RNC	INDIS_MTR	INDIS_MTR
Lighting	BAU	INDIS_LED	INDIS_LED
	FitFor55	INDIS_LED	INDIS_LED
	RNC	INDIS_LED	INDIS_LED
HVAC	BAU	INDIS_AC,INDIS_HP	INDIS_AC
	FitFor55	INDIS_AC,INDIS_HP	INDIS_HP
	RNC	INDIS_AC,INDIS_HP	INDIS_HP
On site Transportation	BAU	INDIS_CE_Diesel, INDIS_EV	INDIS_EV
	FitFor55	INDIS_CE_Diesel, INDIS_EV	INDIS_EV
	RNC	INDIS_CE_Diesel, INDIS_EV	INDIS_EV

Food and Beverages sector			
Final Use	Scenario	Tecnhology used	
		2030	2050
Steam	BAU	INDFB_SBL_BG/DIE/NG/OilP	INDFB_SBL_BG
	FitFor55	INDFB_SBL_BG/DIE/NG/OilP	INDFB_SBL_BG
	RNC	INDFB_SBL_BG/DIE/NG/OilP	INDFB_SBL_BG
Heat	BAU	INDFB_Oven_BM/DIE/EL/NG/OilP, INDFB_HEBL_BM/NG/OilP, INDFB_VHEBL_BG/BM/NG/OilP	INDFB_VHEBL_BG
	FitFor55	INDFB_Oven_BM/DIE/EL/NG/OilP, INDFB_HEBL_BM/NG/OilP, INDFB_VHEBL_BG/BM/NG/OilP	INDFB_VHEBL_BG
	RNC	INDFB_Oven_BM/DIE/EL/NG/OilP, INDFB_HEBL_BM/NG/OilP, INDFB_VHEBL_BG/BM/NG/OilP	INDFB_VHEBL_BG
Refrigeration	BAU	INDFB_CMP_Ele	INDFB_CMP_Ele
	FitFor55	INDFB_CMP_Ele	INDFB_CMP_Ele
	RNC	INDFB_CMP_Ele	INDFB_CMP_Ele
Machine Drive	BAU	INDFB_MTR	INDFB_MTR
	FitFor55	INDFB_MTR	INDFB_MTR
	RNC	INDFB_MTR	INDFB_MTR
Lighting	BAU	INDFB_INCT	INDFB_INCT
	FitFor55	INDFB_INCT	INDFB_INCT
	RNC	INDFB_INCT	INDFB_INCT
HVAC	BAU	INDFB_AC,INDFB_HP, INDFB_BL_NG_SH	INDFB_AC
	FitFor55	INDFB_AC,INDFB_HP, INDFB_BL_NG_SH	INDFB_BL_BG_SH
	RNC	INDFB_AC,INDFB_HP, INDFB_BL_NG_SH	INDFB_BL_BG_SH
On site Transportation	BAU	INDFB_CE_Diesel, INDFB_EV	INDFB_EV
	FitFor55	INDFB_CE_Diesel, INDFB_EV	INDFB_EV
	RNC	INDFB_CE_Diesel, INDFB_EV	INDFB_EV

Chemical sector			
Final Use	Scenario	Tecnhology used	
		2030	2050
Amonia Prod	BAU	INDCH_PAC,INDCH_PAC_BG	INDCH_PAC_BG
	FitFor55	INDCH_PAC,INDCH_PAC_BG	INDCH_PAC_BG
	RNC	INDCH_PAC,INDCH_PAC_BG	INDCH_PAC_BG
Chlorine Prod	BAU	INDCH_AMP,INDCH_AMPI	INDCH_AMPI
	FitFor55	INDCH_AMP,INDCH_AMPI	INDCH_AMPI
	RNC	INDCH_AMP,INDCH_AMPI	INDCH_AMPI
Steam	BAU	INDCH_SBL_HEAT	INDCH_SBL_HEAT
	FitFor55	INDCH_SBL_HEAT	INDCH_SBL_HEAT
	RNC	INDCH_SBL_HEAT	INDCH_SBL_HEAT
Heat	BAU	INDCH_BL_BM/LPG/OilP, INDFB_HEBL_BM/OilP, INDFB_VHEBL_BG/BM/NG/OilP	INDCH_VHEBL_BG
	FitFor55	INDCH_BL_BM/LPG/OilP, INDFB_HEBL_BM/OilP, INDFB_VHEBL_BG/BM/NG/OilP	INDCH_VHEBL_BG
	RNC	INDCH_BL_BM/LPG/OilP, INDFB_HEBL_BM/OilP, INDFB_VHEBL_BG/BM/NG/OilP	INDCH_VHEBL_BG
Machine Drive	BAU	INDCH_MTR	INDCH_MTR
	FitFor55	INDCH_MTR	INDCH_MTR
	RNC	INDCH_MTR	INDCH_MTR
Lighting	BAU	INDCH_LED	INDCH_LED
	FitFor55	INDCH_LED	INDCH_LED
	RNC	INDCH_LED	INDCH_LED
HVAC	BAU	INDCH_AC,INDFB_HP	INDCH_AC
	FitFor55	INDCH_AC,INDCH_HP	INDCH_BL_NG_SH
	RNC	INDCH_AC,INDCH_HP	INDCH_BL_NG_SH
On site Transportation	BAU	INDCH_CE_Diesel, INDCH_EV	INDCH_EV
	FitFor55	INDCH_CE_Diesel, INDCH_EV	INDCH_EV
	RNC	INDCH_CE_Diesel, INDCH_EV	INDCH_EV

Cemente and lime sector			
Final Use	Scenario	Tecnhology used	
		2030	2050
Clinker Prod	BAU	INDCMLM_DPE	INDCMLM_DPE
	FitFor55	INDCMLM_DPE	INDCMLM_DPE
	RNC	INDCMLM_DPE	INDCMLM_DPE
Cement Prod	BAU	INDCMLM_FCPE	INDCMLM_FCPE
	FitFor55	INDCMLM_FCPE	INDCMLM_FCPE
	RNC	INDCMLM_FCPE	INDCMLM_FCPE
Lime Prod	BAU	INDCMLM_QLP	INDCMLM_QLP
	FitFor55	INDCMLM_QLP	INDCMLM_QLP
	RNC	INDCMLM_QLP	INDCMLM_QLP
Heat	BAU	INDCMLM_KLNCM_COA/NG, INDCMLM_HEBL_BM/OilP/NG, INDCMLM_VHEBL_BM/NG/OilP	INDCMLM_KLN_BG/COA
	FitFor55	INDCMLM_KLNCM_BG/COA/NG, INDCMLM_HEBL_BM/OilP/NG, INDCMLM_VHEBL_BM/NG/OilP	INDCMLM_KLN_BG
	RNC	INDCMLM_KLNCM_BG/COA/NG, INDCMLM_HEBL_BM/OilP/NG, INDCMLM_VHEBL_BM/NG/OilP	INDCMLM_KLN_BG
Machine Drive	BAU	INDCMLM_MTR	INDCMLM_MTR
	FitFor55	INDCMLM_MTR	INDCMLM_MTR
	RNC	INDCMLM_MTR	INDCMLM_MTR
Lighting	BAU	INDCMLM_LED	INDCMLM_LED
	FitFor55	INDCMLM_LED	INDCMLM_LED
	RNC	INDCMLM_LED	INDCMLM_LED
HVAC	BAU	INDCMLM_AC,INDCMLM_HP, INDCMLM_BL_LPG/NG/OilP_SH	INDCMLM_AC
	FitFor55	INDCMLM_AC,INDCMLM_HP, INDCMLM_BL_LPG/NG/OilP_SH	INDCMLM_HP
	RNC	INDCMLM_AC,INDCMLM_HP, INDCMLM_BL_LPG/NG/OilP_SH	INDCMLM_HP
On site Transportation	BAU	INDCMLM_CE_Diesel, INDCMLM_EV	INDCMLM_EV
	FitFor55	INDCMLM_CE_Diesel, INDCMLM_EV	INDCMLM_EV
	RNC	INDCMLM_CE_Diesel, INDCMLM_EV	INDCMLM_EV

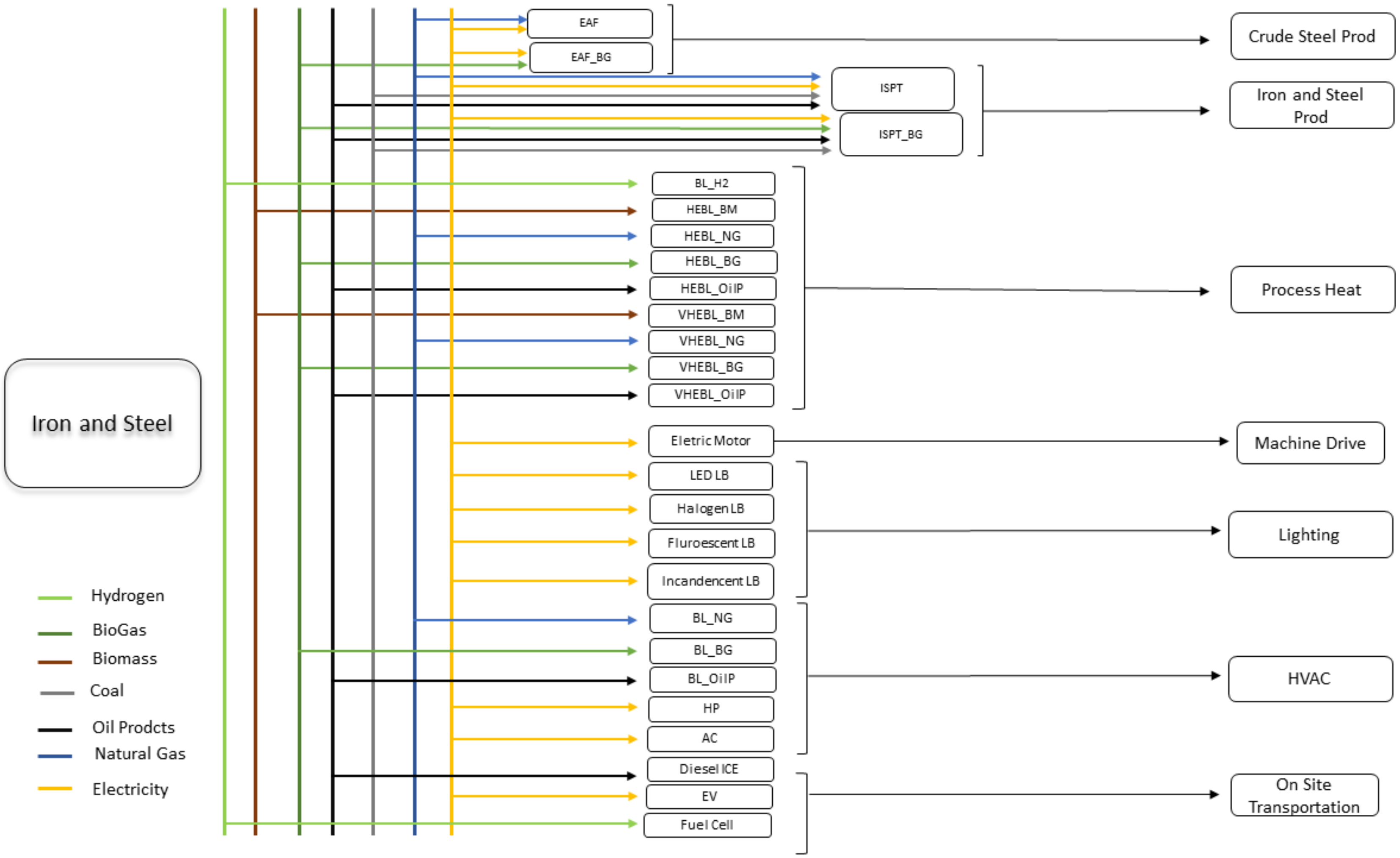
Ceramic and glass sector			
Final Use	Scenario	Tecnhology used	
		2030	2050
Flat glass prod	BAU	INDCRGL_FPE,INDCRGL_FPEHR,INDCRGL_FPEHR_BG	INDCRGL_FPEHR_BG
	FitFor55	INDCRGL_FPE,INDCRGL_FPEHR,INDCRGL_FPEHR_BG	INDCRGL_FPEHR_BG
	RNC	INDCRGL_FPE,INDCRGL_FPEHR,INDCRGL_FPEHR_BG	INDCRGL_FPEHR_BG
Hollow glass Prod	BAU	INDCRGL_GHEHR,INDCRGL_GHEHR_BG,INDCRGL_GLREIM	INDCRGL_GHEHR_BG
	FitFor55	INDCRGL_GHEHR,INDCRGL_GHEHR_BG,INDCRGL_GLREIM	INDCRGL_GHEHR_BG
	RNC	INDCRGL_GHEHR,INDCRGL_GHEHR_BG,INDCRGL_GLREIM	INDCRGL_GHEHR_BG
Heat	BAU	INDCRGL_KLN_BM/EL, INDCRGL_HEBL_BM/NG, INDCRGL_VHEBL_BG/BM/NG/OilP	INDCRGL_VHEBL_BG
	FitFor55	INDCRGL_KLN_BM/EL, INDCRGL_HEBL_BM, INDCRGL_VHEBL_BG/BM/NG/OilP	INDCRGL_VHEBL_BG
	RNC	INDCRGL_KLN_BM/EL, INDCRGL_HEBL_BM, INDCRGL_VHEBL_BG/BM/NG/OilP	INDCRGL_VHEBL_BG
Machine Drive	BAU	INDCRGL_MTR	INDCRGL_MTR
	FitFor55	INDCRGL_MTR	INDCRGL_MTR
	RNC	INDCRGL_MTR	INDCRGL_MTR
Lighting	BAU	INDCRGL_LED	INDCRGL_LED
	FitFor55	INDCRGL_LED	INDCRGL_LED
	RNC	INDCRGL_LED	INDCRGL_LED
HVAC	BAU	INDCRGL_AC,INDCRGL_HP, INDCRGL_BL_NG_SH	INDCH_AC
	FitFor55	INDCRGL_AC,INDCRGL_HP, INDCRGL_BL_NG_SH	INDCRGL_HP
	RNC	INDCRGL_AC,INDCRGL_HP, INDCRGL_BL_NG_SH	INDCRGL_HP
On site Transportation	BAU	INDCRGL_EV	INDCRGL_EV
	FitFor55	INDCRGL_EV	INDCRGL_EV
	RNC	INDCRGL_EV	INDCRGL_EV

Non Ferrous Metal sector			
Final Use	Scenario	Tecnhology used	
		2030	2050
Aluminium Prod	BAU	INDNFM_FAP, INDNFM_FAP_BG	INDNFM_FAP_BG
	FitFor55	INDNFM_FAP, INDNFM_FAP_BG	INDNFM_FAP_BG
	RNC	INDNFM_FAP, INDNFM_FAP_BG	INDNFM_FAP_BG
Crude aluminium Prod	BAU	INDNFM_IA	INDNFM_IA
	FitFor55	INDNFM_IA	INDNFM_IA
	RNC	INDNFM_IA	INDNFM_IA
Steam	BAU	INDNFM_SBL_HEAT/LPG	INDNFM_SBL_HEAT
	FitFor55	INDNFM_SBL_HEAT/LPG	INDNFM_SBL_HEAT
	RNC	INDNFM_SBL_HEAT/LPG	INDNFM_SBL_HEAT
Heat	BAU	INDNFM_BL_BM/LPG, INDNFM_HEBL_BM/NG, INDNFM_VHEBL_BG/BM/NG/OilP	INDNFM_VHEBL_BG
	FitFor55	INDNFM_BL_BM/LPG, INDNFM_HEBL_BM, INDNFM_VHEBL_BG/BM/NG	INDCH_VHEBL_BG
	RNC	INDNFM_BL_BM/LPG, INDNFM_HEBL_BM, INDNFM_VHEBL_BG/BM/NG	INDCH_VHEBL_BG
Machine Drive	BAU	INDNFM_MTR	INDNFM_MTR
	FitFor55	INDNFM_MTR	INDNFM_MTR
	RNC	INDNFM_MTR	INDNFM_MTR
Lighting	BAU	INDNFM_LED	INDNFM_LED
	FitFor55	INDNFM_LED	INDNFM_LED
	RNC	INDNFM_LED	INDNFM_LED
HVAC	BAU	INDNFM_AC,INDNFM_HP, INDNFM_BL_NG_SH	INDNFM_AC
	FitFor55	INDNFM_AC,INDNFM_HP, INDNFM_BL_NG_SH	INDNFM_BL_BG_SH
	RNC	INDNFM_AC,INDNFM_HP, INDNFM_BL_NG_SH	INDNFM_BL_BG_SH
On site Transportation	BAU	INDNFM_CE_Diesel, INDNFM_EV	INDNFM_EV
	FitFor55	INDNFM_CE_Diesel, INDNFM_EV	INDNFM_EV
	RNC	INDNFM_CE_Diesel, INDNFM_EV	INDNFM_EV

Pulp and paper sector			
Final Use	Scenario	Tecnhology used	
		2030	2050
High Quality Paper prod	BAU	INDPP_HQPE, INDPP_HQPEAD	INDPP_HQPE
	FitFor55	INDPP_HQPE, INDPP_HQPEAD	INDPP_HQPE
	RNC	INDPP_HQPE, INDPP_HQPEAD	INDPP_HQPE
Low Quality Paper prod	BAU	INDPP_LQPEAD	INDPP_LQPE
	FitFor55	INDPP_LQPEAD	INDPP_LQPE
	RNC	INDPP_LQPEAD	INDPP_LQPE
Pulp prod	BAU	INDPP_CPP, INDPP_RPP	INDPP_CPP
	FitFor55	INDPP_CPP, INDPP_RPP	INDPP_CPP
	RNC	INDPP_CPP, INDPP_RPP	INDPP_CPP
Heat	BAU	INDPP_BL_BM/NG/OilP, INDPP_HEBL_BM/OilP, INDPP_VHEBL_BM/OilP, INDPP_KLN_BM/Oil, INDPP_HeatCHP	INDPP_BL_NG
	FitFor55	INDPP_BL_BM/NG(OilP, INDPP_HEBL_BM/OilP, INDPP_VHEBL_BM/OilP, INDPP_KLN_BM/OilP, INDPP_HeatCHP	INDCRGL_VHEBL_BG
	RNC	INDPP_BL_BM/NG(OilP, INDPP_HEBL_BM/OilP, INDPP_VHEBL_BM/OilP, INDPP_KLN_BM/OilP, INDPP_HeatCHP	INDCRGL_VHEBL_BG
Machine Drive	BAU	INDPP_MTR	INDPP_MTR
	FitFor55	INDPP_MTR	INDPP_MTR
	RNC	INDPP_MTR	INDPP_MTR
Lighting	BAU	INDPP_LED	INDPP_LED
	FitFor55	INDPP_LED	INDPP_LED
	RNC	INDPP_LED	INDPP_LED
HVAC	BAU	INDPP_AC, INDCRGL_BL_NG/LPG/OilP_SH	INDPP_AC
	FitFor55	INDPP_HP, INDCRGL_BL_NG/LPG/OilP_SH	INDCRGL_BL_NG_SH
	RNC	INDPP_HP, INDCRGL_BL_NG/LPG/OilP_SH	INDCRGL_BL_NG_SH
On site Transportation	BAU	INDPP_CE_DIESEL, INDPP_EV	INDPP_EV
	FitFor55	INDPP_CE_DIESEL, INDPP_EV	INDPP_EV
	RNC	INDPP_CE_DIESEL, INDPP_EV	INDPP_EV

Other industries sector			
Final Use	Scenario	Tecnhology used	
		2030	2050
Steam	BAU	INDFB_SBL_Heat/LPG/OilP	INDOI_SBL_BG
	FitFor55	INDFB_SBL_Heat/LPG/OilP	INDOI_SBL_BG
	RNC	INDFB_SBL_Heat/LPG/OilP	INDOI_SBL_BG
Heat	BAU	INDOI_BL_BM/NG/OilP/LPG, INDOI_HEBL_BM/NG/OilP, INDOI_VHEBL_BM/NG/OilP	INDOI_VHEBL_BM/NG
	FitFor55	INDOI_BL_BM/NG/OilP/LPG, INDOI_HEBL_BM/NG/OilP, INDOI_VHEBL_BM/NG/OilP	INDOI_VHEBL_BM/NG
	RNC	INDOI_BL_BM/NG/OilP/LPG, INDOI_HEBL_BM/NG/OilP, INDOI_VHEBL_BM/NG/OilP	INDOI_VHEBL_BM/NG
Machine Drive	BAU	INDOI_MTR	INDOI_MTR
	FitFor55	INDOI_MTR	INDOI_MTR
	RNC	INDOI_MTR	INDOI_MTR
Lighting	BAU	INDOI_LED	INDOI_LED
	FitFor55	INDOI_LED	INDOI_LED
	RNC	INDOI_LED	INDOI_LED
HVAC	BAU	INDOI_AC,INDOI_HP, INDOI_BL_NG_SH	INDOI_AC
	FitFor55	INDFB_AC,INDFB_HP, INDFB_BL_NG_SH	INDOI_HP
	RNC	INDFB_AC,INDFB_HP, INDFB_BL_NG_SH	INDOI_HP
On site Transportation	BAU	INDOI_CE_Diesel, INDOI_EV	INDOI_EV
	FitFor55	INDOI_CE_Diesel, INDOI_EV	INDOI_EV
	RNC	INDOI_CE_Diesel, INDOI_EV	INDOI_EV

Annex F – Industry sectors representation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HEBL_NG
HEBL_BG
HEBL_OilP
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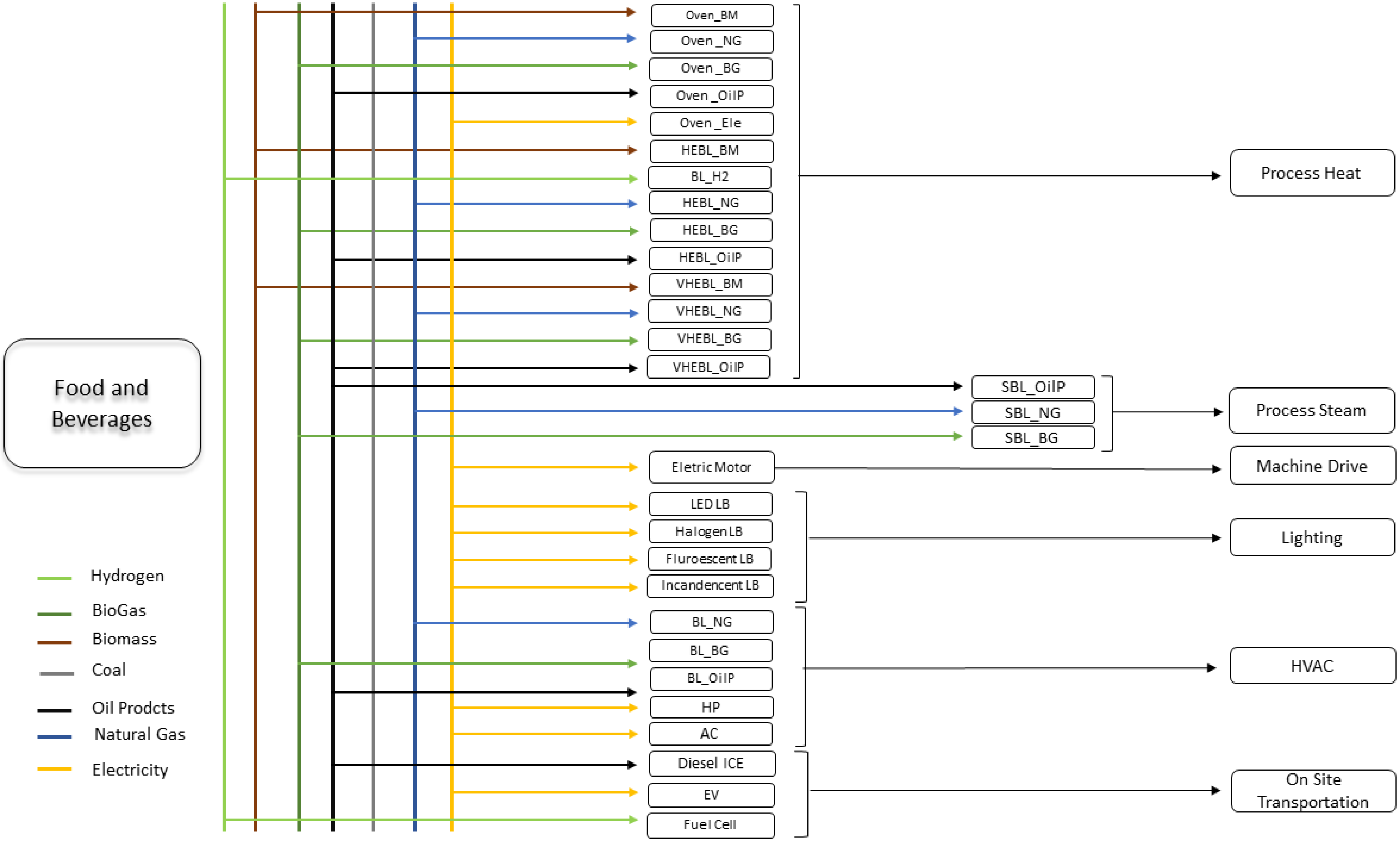
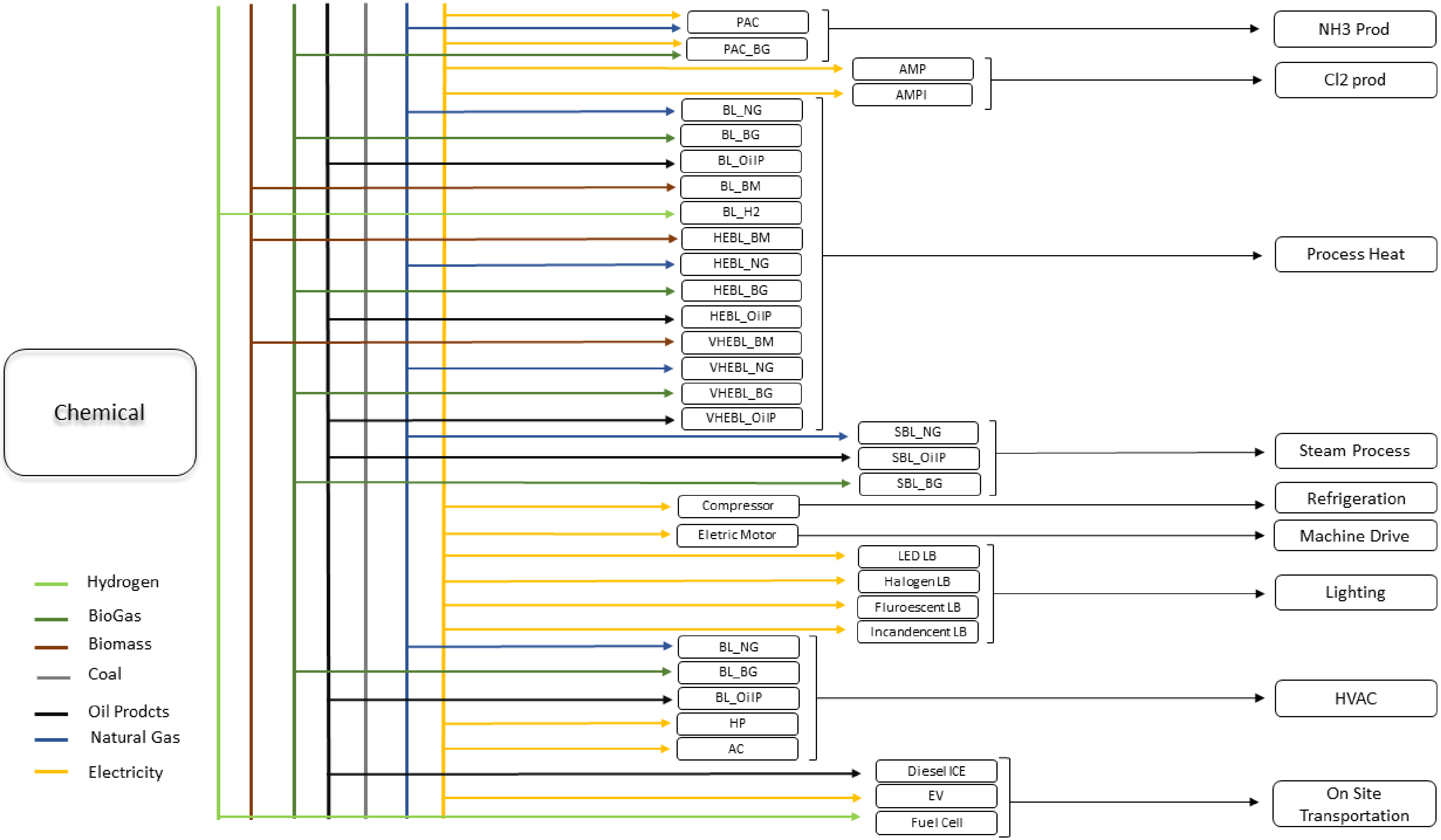
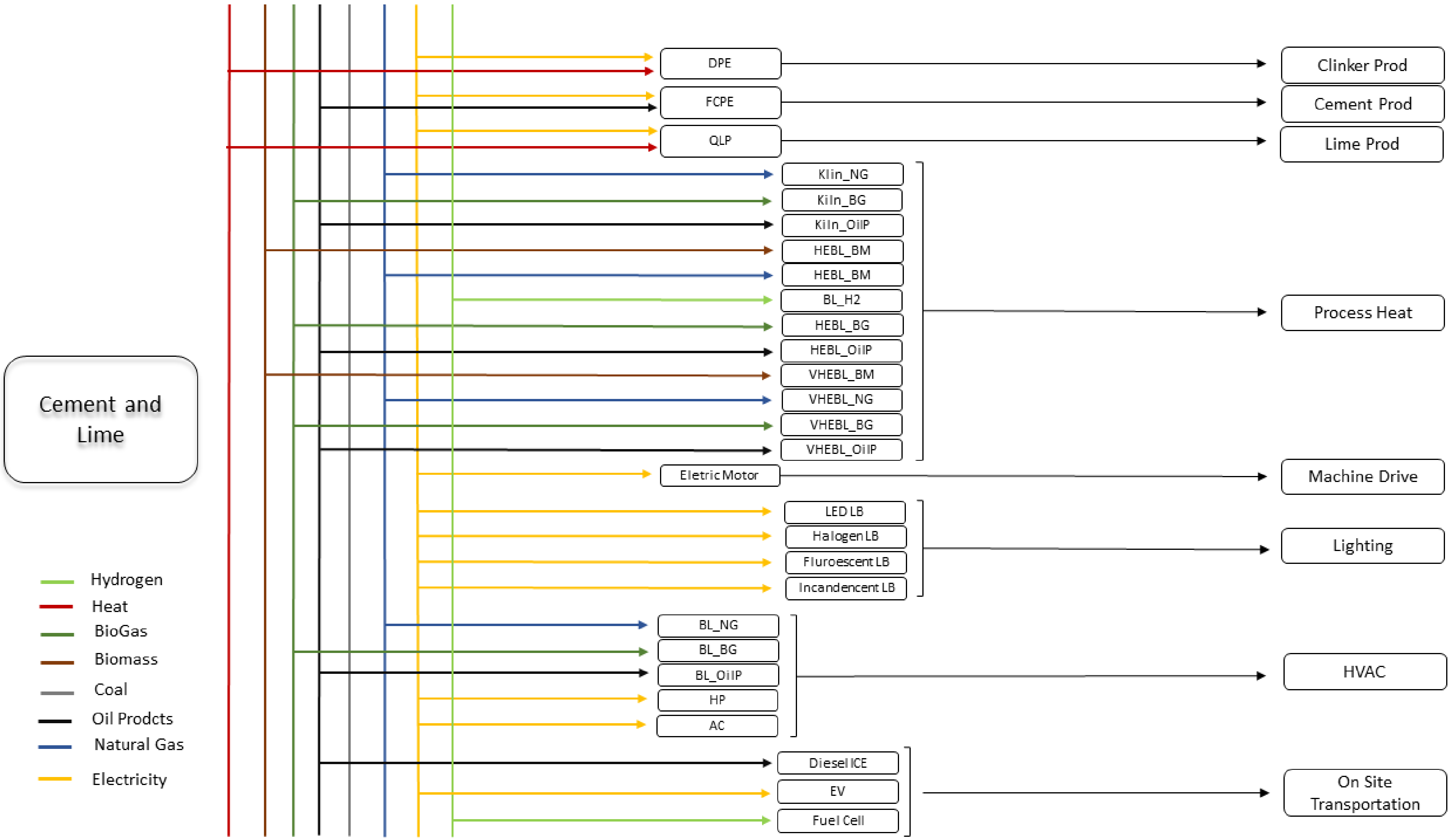
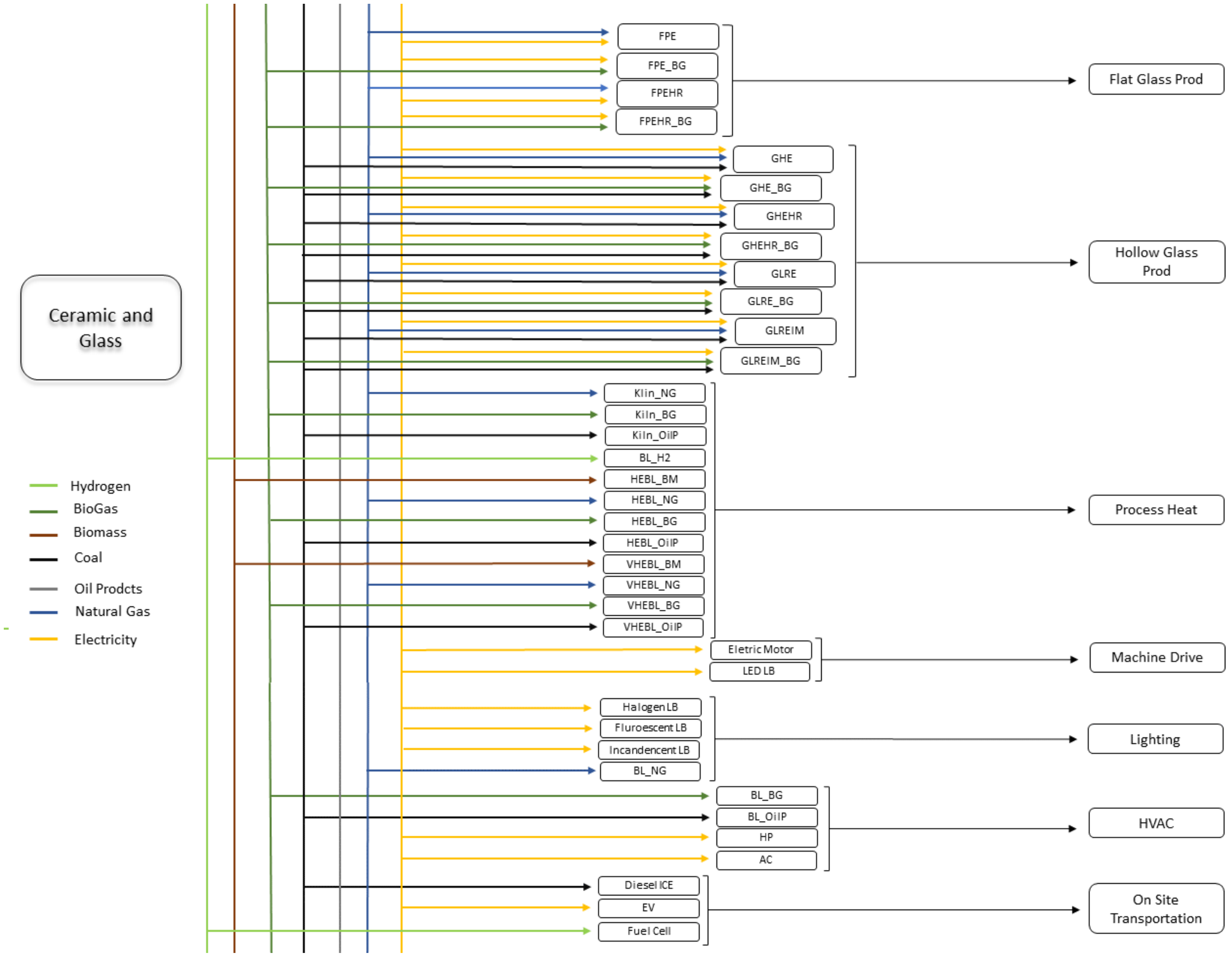
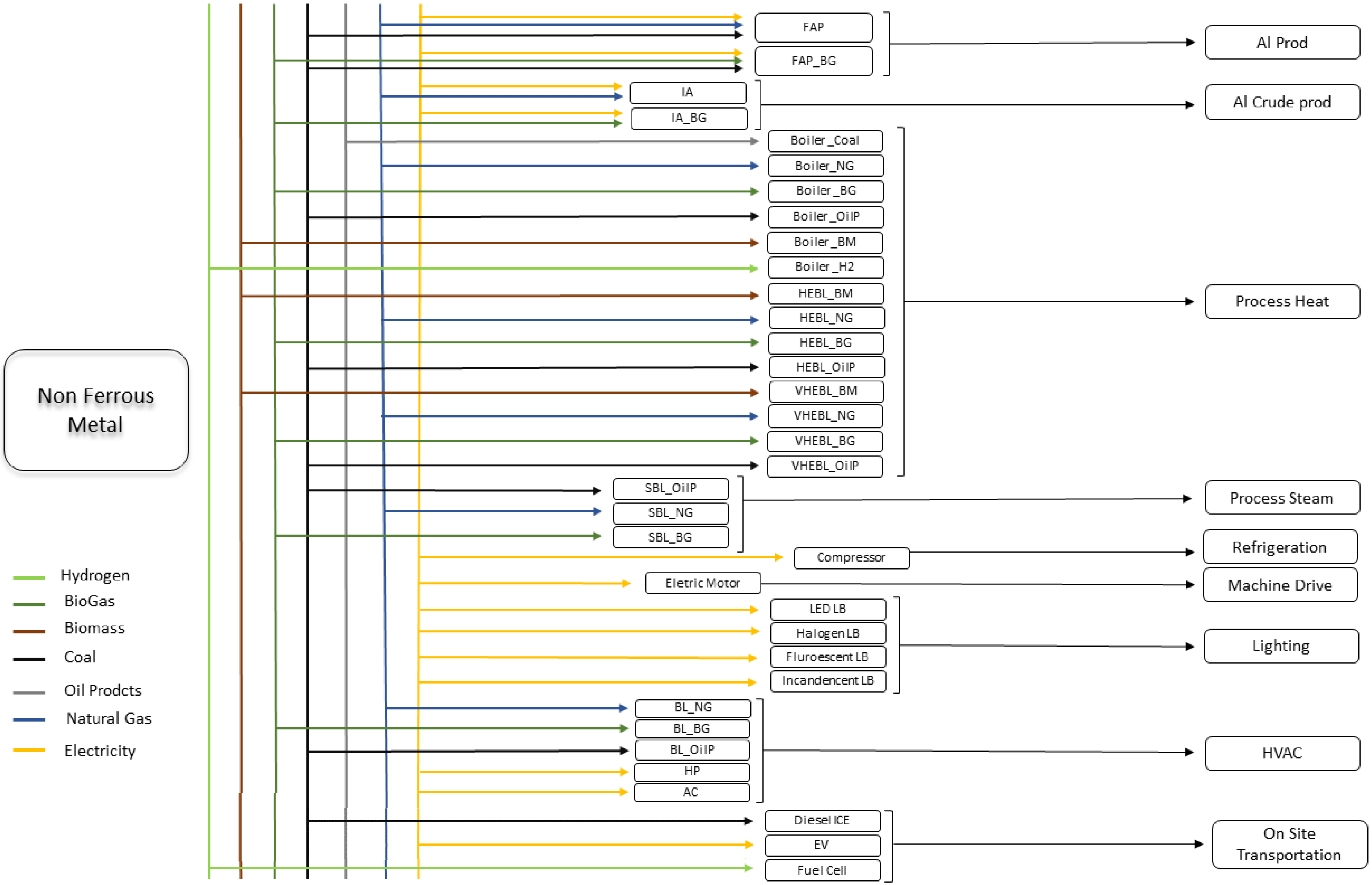
VHEBL_NG
VHEBL_BG
VHEBL_OilP
Eletric Motor
LED LB
Halogen LB
Fluroescent LB
Incandencent LB
BL_NG
BL_BG
BL_OilP
HP
AC
Diesel ICE
EV
Fuel Cell
Crude Steel Prod
Iron and Steel Prod
Process Heat
Machine Drive
Lighting
HVAC
On Site Transportation
Hydrogen
BioGas
Biomass
Coal
Oil Prodcts
Natural Gas
Electricity

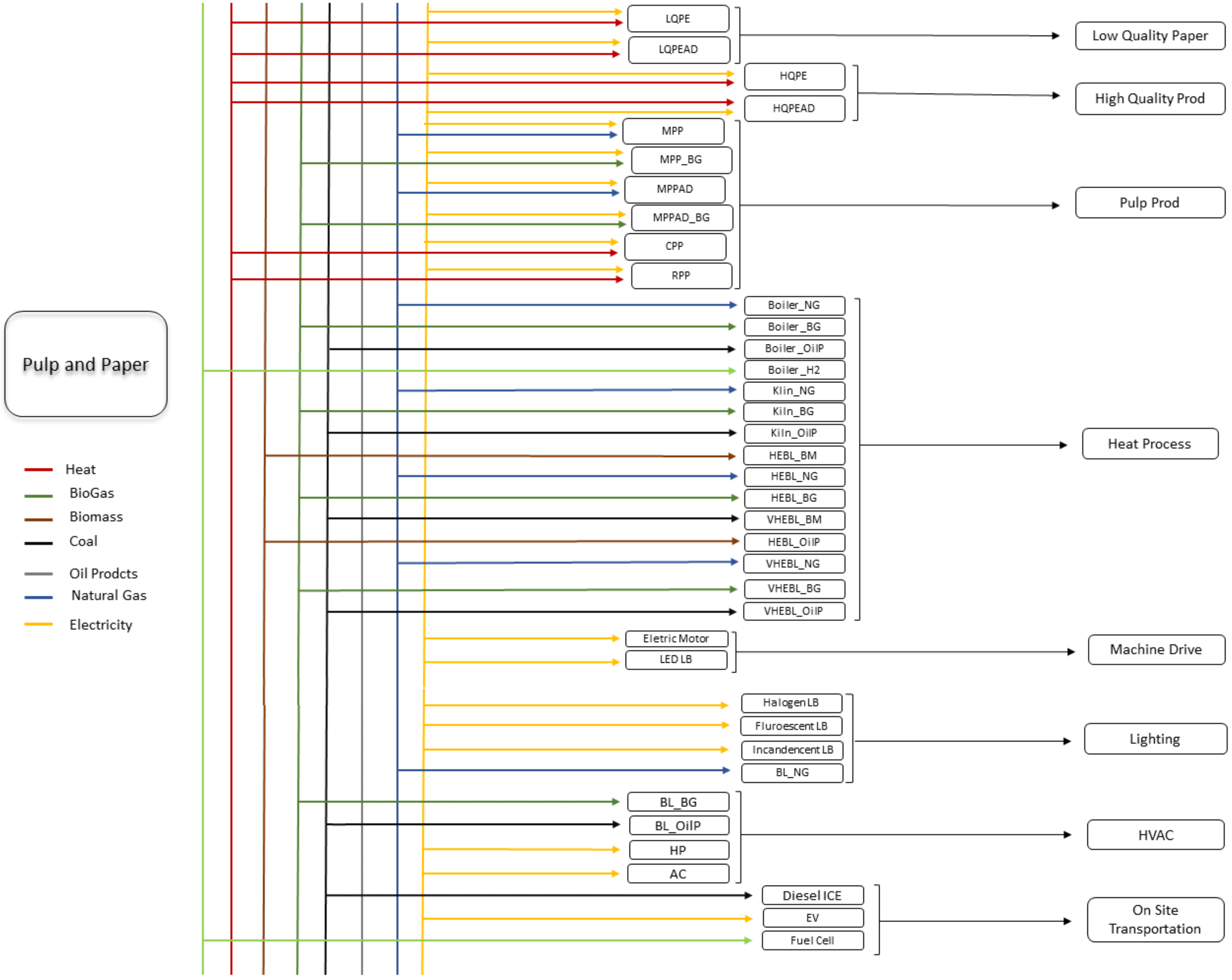

Food and Beverages
Hydrogen
BioGas
Biomass
Coal
Oil Prodcts
Natural Gas
Electricity
Oven_BM
Oven _NG
Oven _BG
Oven _OilP
Oven _Ele
HEBL_BM
BL_H2
HEBL_NG
HEBL_BG
HEBL_OilP
VHEBL_BM
VHEBL_NG
VHEBL_BG
VHEBL_OilP
Process Heat
SBL_OilP
SBL_NG
SBL_BG
Process Steam
Eletric Motor
Machine Drive
LED LB
Halogen LB
Fluroescent LB
Incandencent LB
Lighting
BL_NG
BL_BG
BL_OilP
HP
AC
HVAC
Diesel ICE
EV
Fuel Cell
On Site Transportation

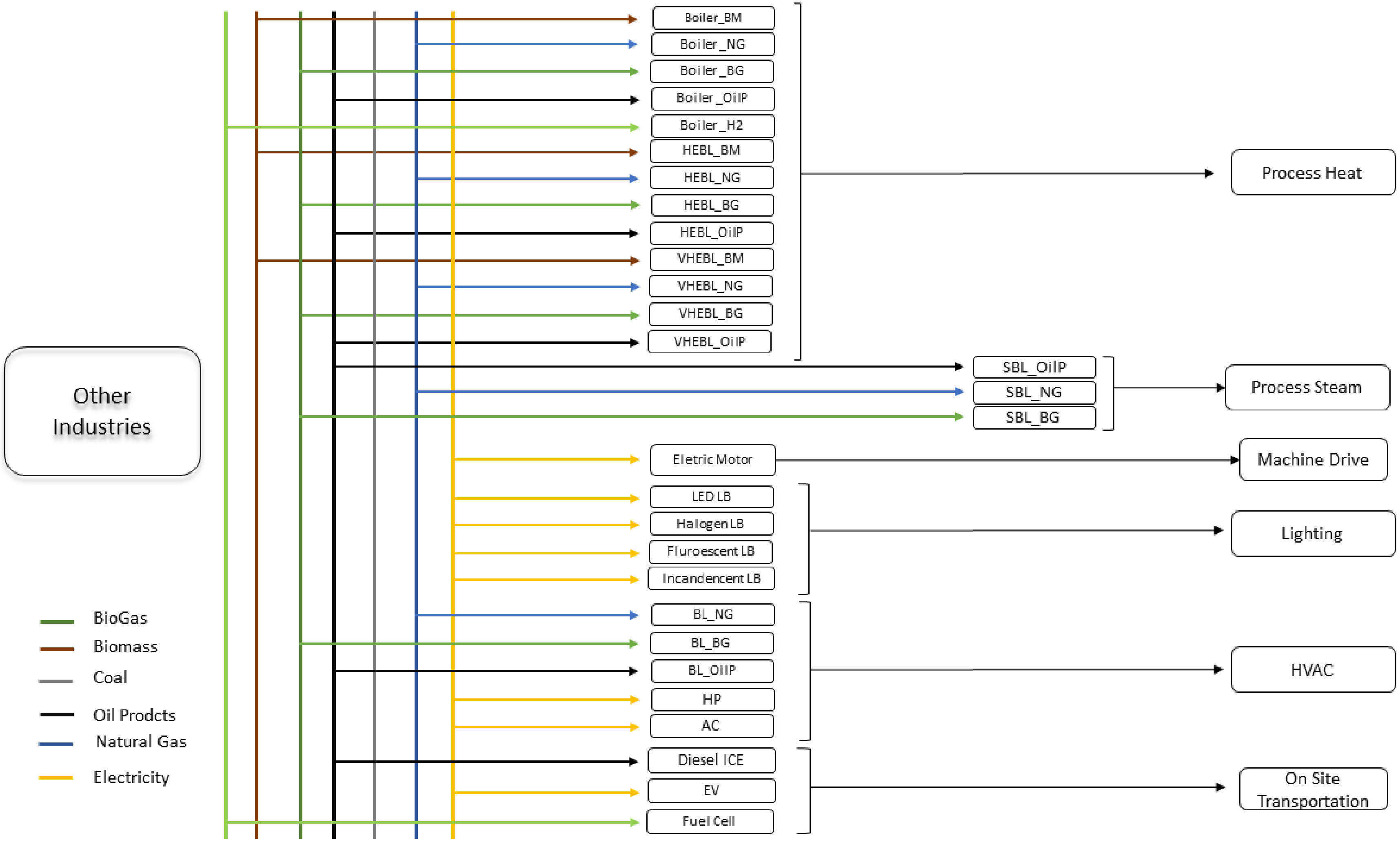

Chemical
PAC
PAC_BG
NH3 Prod
AMP
AMPI
Cl2 prod
BL_NG
BL_BG
BL_OilP
BL_BM
BL_H2
HEBL_BM
HEBL_NG
HEBL_BG
HEBL_OilP
VHEBL_BM
VHEBL_NG
VHEBL_BG
VHEBL_OilP
Process Heat
SBL_NG
SBL_OilP
SBL_BG
Steam Process
Compressor
Refrigeration
Eletric Motor
Machine Drive
LED LB
Halogen LB
Fluroescent LB
Incandencent LB
Lighting
BL_NG
BL_BG
BL_OilP
HP
AC
HVAC
Diesel ICE
EV
Fuel Cell
On Site Transportation
Hydrogen
BioGas
Biomass
Coal
Oil Prodcts
Natural Gas
Electricity


Cement and Lime
DPE
FCPE
QLP
Clinker Prod
Cement Prod
Lime Prod
Klin_NG
Kiln_BG
Kiln_OilP
HEBL_BM
HEBL_BM
BL_H2
HEBL_BG
HEBL_OilP
VHEBL_BM
VHEBL_NG
VHEBL_BG
VHEBL_OilP
Process Heat
Eletric Motor
Machine Drive
LED LB
Halogen LB
Fluroescent LB
Incandencent LB
Lighting
BL_NG
BL_BG
BL_OilP
HP
AC
HVAC
Diesel ICE
EV
Fuel Cell
On Site Transportation
Hydrogen
Heat
BioGas
Biomass
Coal
Oil Prodcts
Natural Gas
Electricity

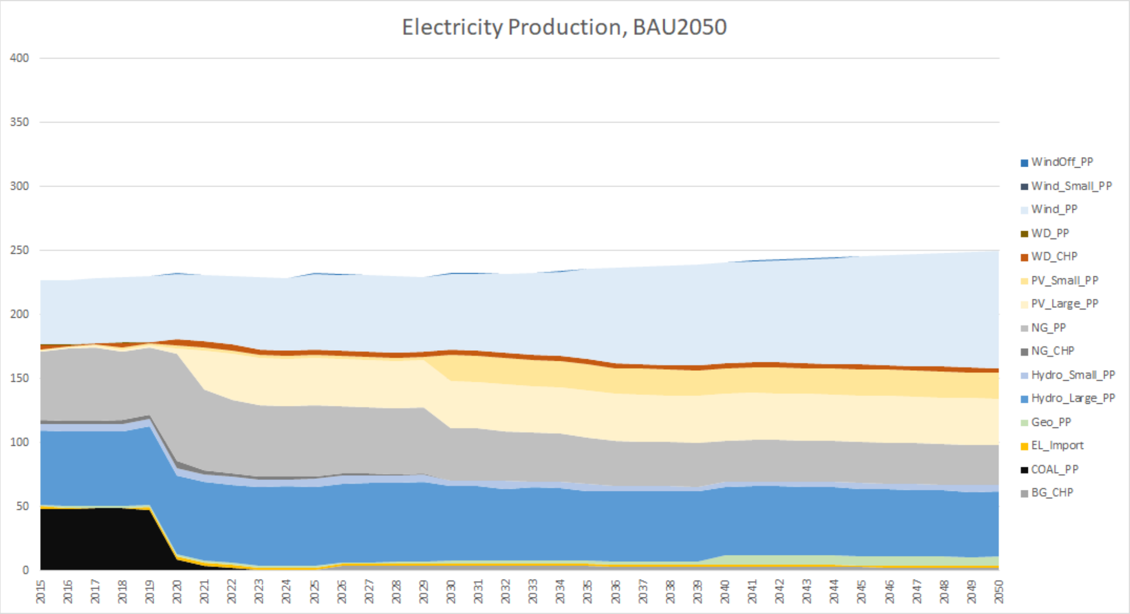

Ceramic and Glass
Hydrogen
BioGas
Biomass
Coal
Oil Prodcts
Natural Gas
Electricity
FPE
FPE_BG
FPEHR
FPEHR_BG
GHE
GHE_BG
GHEHR
GHEHR_BG
GLRE
GLRE_BG
GLREIM
GLREIM_BG
Klin_NG
Kiln_BG
Kiln_OilP
BL_H2
HEBL_BM
HEBL_NG
HEBL_BG
HEBL_OilP
VHEBL_BM
VHEBL_NG
VHEBL_BG
VHEBL_OilP
Eletric Motor
LED LB
Halogen LB
Fluroescent LB
Incandencent LB
BL_NG
BL_BG
BL_OilP
HP
AC
Diesel ICE
EV
Fuel Cell
Flat Glass Prod
Hollow Glass Prod
Process Heat
Machine Drive
Lighting
HVAC
On Site Transportation

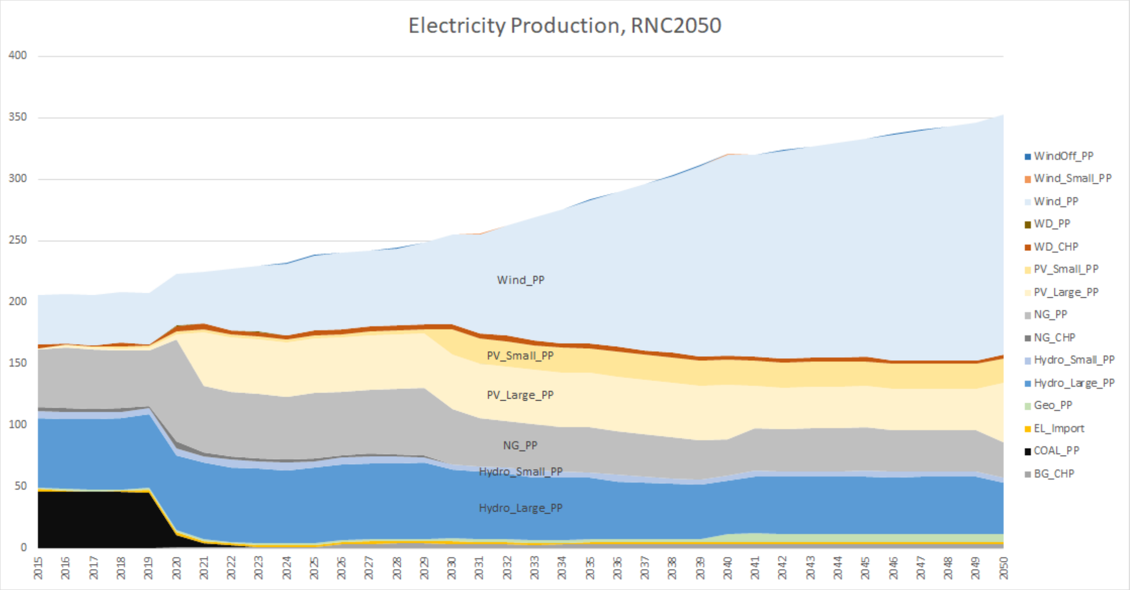

Non Ferrous Metal
Hydrogen
BioGas
Biomass
Coal
Oil Prodcts
Natural Gas
Electricity
FAP
FAP_BG
IA
IA_BG
Boiler_Coal
Boiler_NG
Boiler_BG
Boiler_OilP
Boiler_BM
Boiler_H2
HEBL_BM
HEBL_NG
HEBL_BG
HEBL_OilP
VHEBL_BM
VHEBL_NG
VHEBL_BG
VHEBL_OilP
SBL_OilP
SBL_NG
SBL_BG
Compressor
Eletric Motor
LED LB
Halogen LB
Fluroescent LB
Incandendent LB
BL_NG
BL_BG
BL_OilP
HP
AC
Diesel ICE
EV
Fuel Cell
Al Prod
Al Crude prod
Process Heat
Process Steam
Refrigeration
Machine Drive
Lighting
HVAC
On Site Transportation

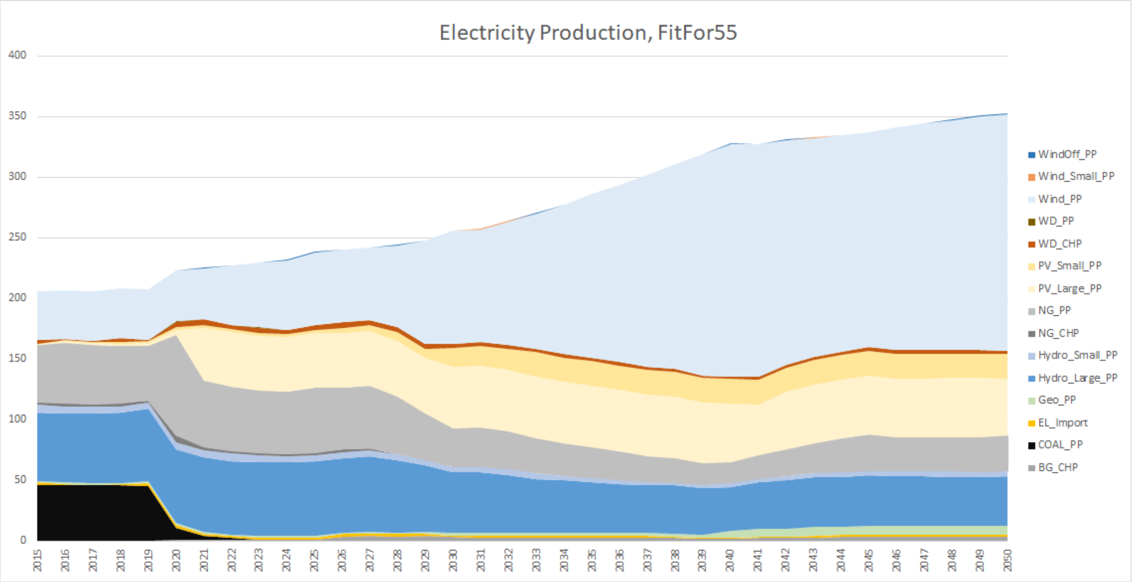

Pulp and Paper
Heat
BioGas
Biomass
Coal
Oil Prodcts
Natural Gas
Electricity
LQPE
LQPEAD
HQPE
HQPEAD
MPP
MPP_BG
MPPAD
MPPAD_BG
CPP
RPP
Boiler_NG
Boiler _BG
Boiler _OilP
Boiler _H2
Klin_NG
Kiln_BG
Kiln_OilP
HEBL_BM
HEBL_NG
HEBL_BG
VHEBL_BM
HEBL_OilP
VHEBL_NG
VHEBL_BG
VHEBL_OilP
Eletric Motor
LED LB
Halogen LB
Fluroescent LB
Incandencent LB
BL_NG
BL_BG
BL_OilP
HP
AC
Diesel ICE
EV
Fuel Cell
Low Quality Paper
High Quality Prod
Pulp Prod
Heat Process
Machine Drive
Lighting
HVAC
On Site Transportation


Other Industries
Boiler_BM
Boiler_NG
Boiler_BG
Boiler_OilP
Boiler_H2
HEBL_BM
HEBL_NG
HEBL_BG
HEBL_OilP
VHEBL_BM
VHEBL_NG
VHEBL_BG
VHEBL_OilP
Process Heat
SBL_OilP
SBL_NG
SBL_BG
Process Steam
Eletric Motor
Machine Drive
LED LB
Halogen LB
Fluroescent LB
Incandencent LB
Lighting
BL_NG
BL_BG
BL_OilP
HP
AC
HVAC
Diesel ICE
EV
Fuel Cell
On Site Transportation
BioGas
Biomass
Coal
Oil Prodcts
Natural Gas
Electricity

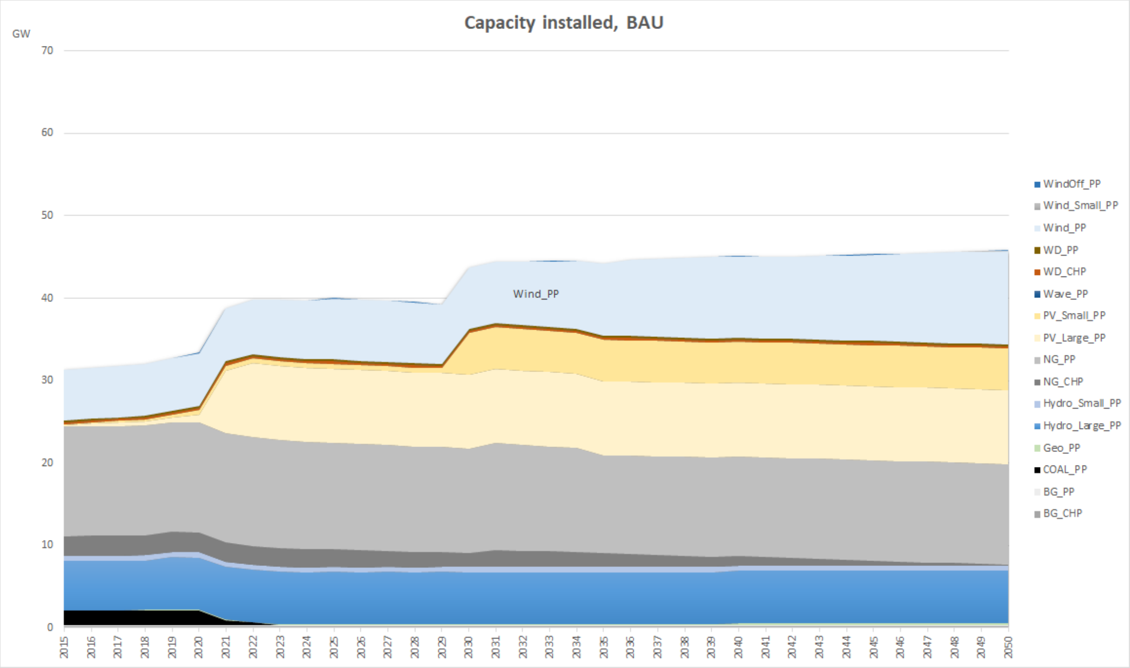
Annex G – Electricity mix

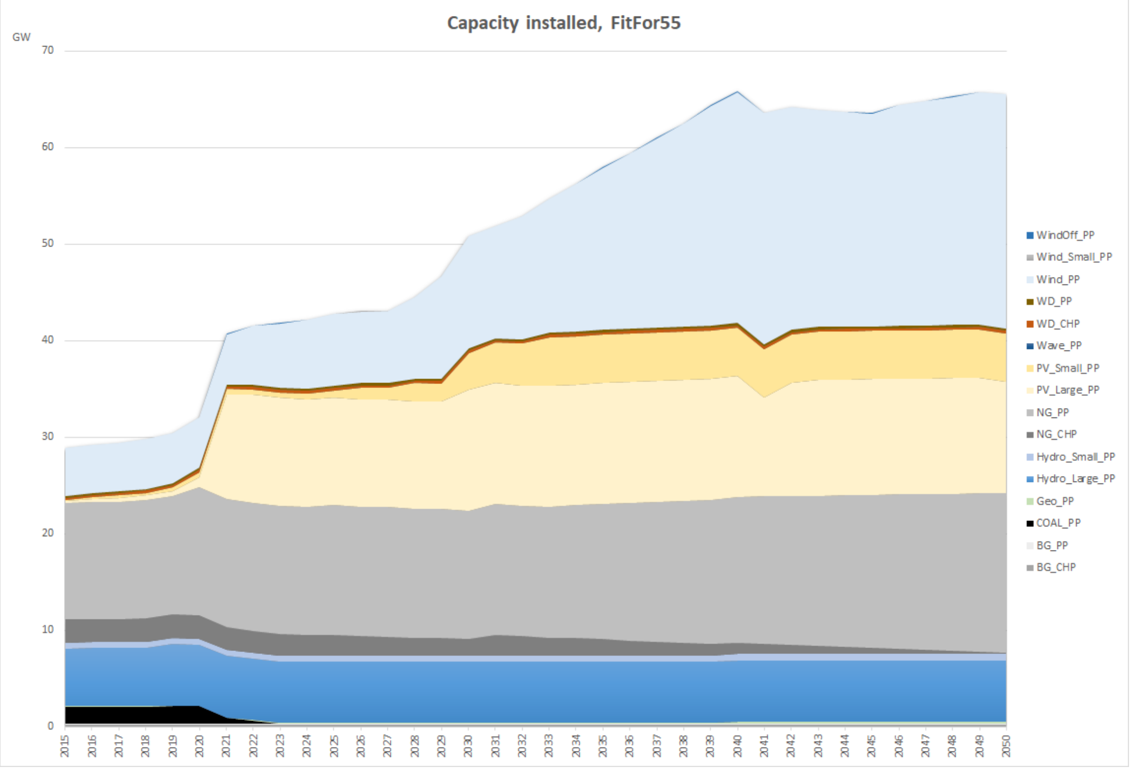


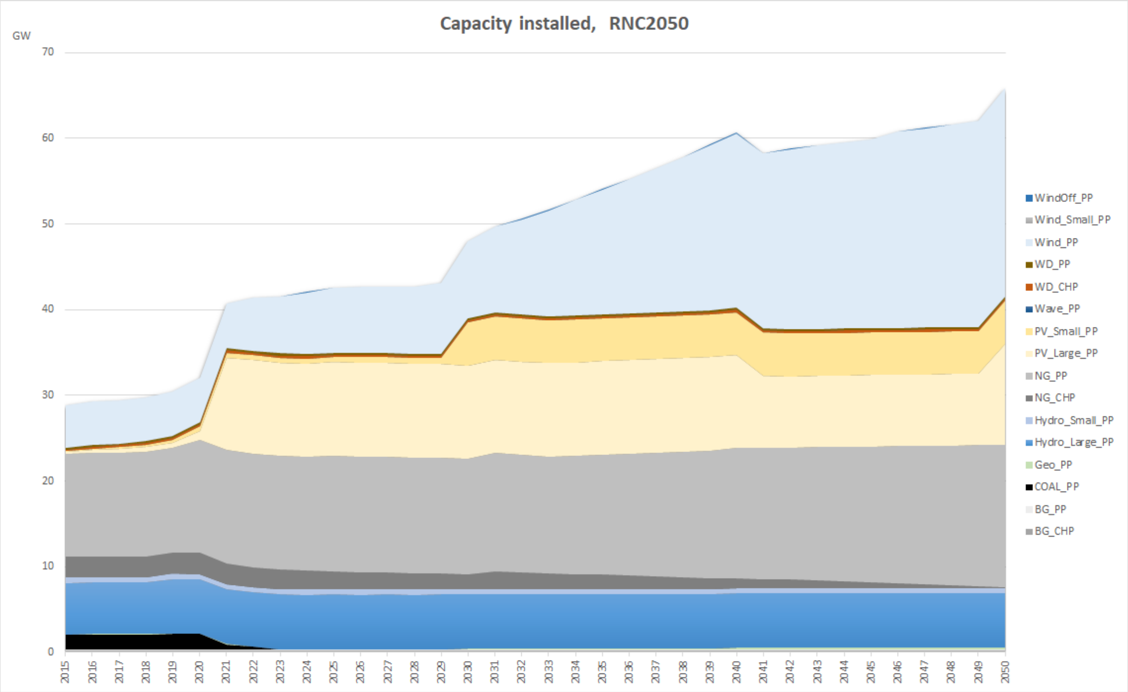



Electricity Production, FitFor55
400
350
300
250
200
150
100
50
0
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
WindOff_PP
Wind_Small_PP
Wind_PP
WD_PP
WD_CHP
PV_Small_PP
PV_Large_PP
NG_PP
NG_CHP
Hydro_Small_PP
Hydro_Large_PP
Geo_PP
EL_Import
COAL_PP
BG_CHP

Annex H – Capacity installed in the scenarios






Capacity installed, RNC2050
GW
70
60
50
40
30
20
10
0
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
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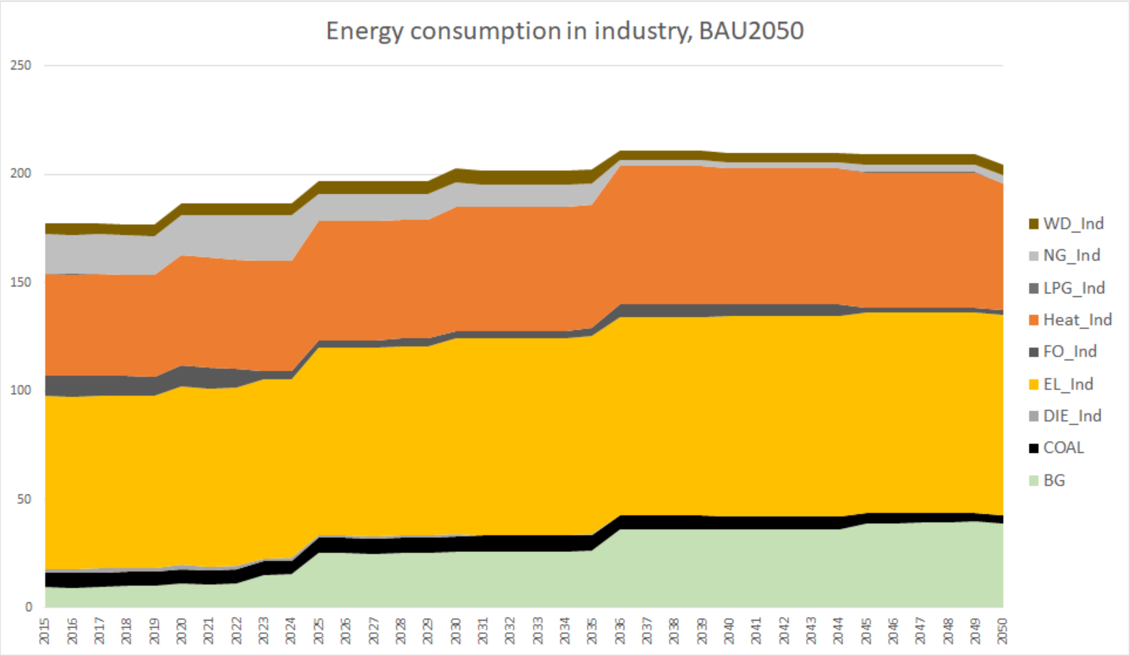
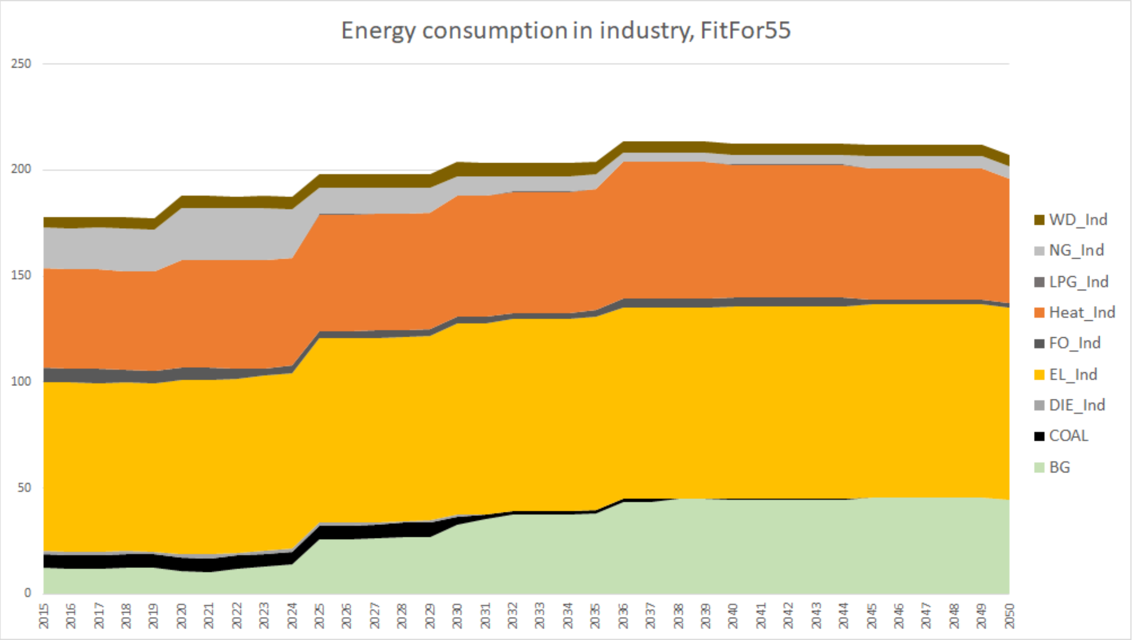
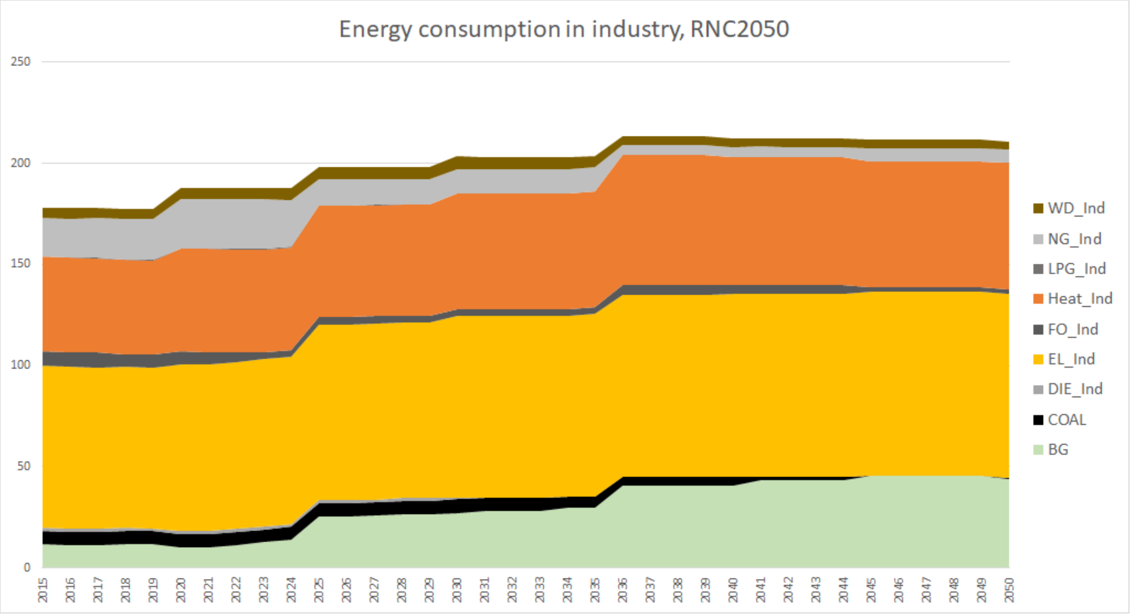
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
WindOff_PP
Wind_Small_PP
Wind_PP
WD_PP
WD_CHP
Wave_PP
PV_Small_PP
PV_Large_PP
NG_PP
NG_CHP
Hydro_Small_PP
Hydro_Large_PP
Geo_PP
COAL_PP
BG_PP
BG_CHP

Annex I – Evolution of energy consumption in industry by vector






Energy consumption in industry, RNC2050
250
200
150
100
50
0
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
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2038
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2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
WD_Ind
NG_Ind
LPG_Ind
Heat_Ind
FO_Ind
EL_Ind
DIE_Ind
COAL
BG

Annex J – Data references for the industrial subsectors

Iron and Steel Industry

End Uses	**Technologies**	**Final energy Vectors**	**Reference**
Crude Steel Prod [Mt]	Eletric arc furnace	Electricity NG	JRC database
Iron and Steel Prod [Mt]	Iron and steel production techs	Coal Electricity NG FO LPG	JRC database
HTHeat [PJ]	High efficiency boilers	BM NG OilP	JRC database
	Very High efficiency boilers	BM NG FO	JRC database
Machine Drive [PJ]	Electrical Motor	Electricity	JRC database
Lighting [PJ]	LED LB	Electricity	JRC database and (Kim & Brown, 2019)
	Halogen LB	Electricity	
	Incandencent LB	Electricity	
	Fluorecent LB	Electricity	
HVAC [PJ]	Boilers	NG LPG Oil Products	JRC database, (Rita et al., 2012)
	Heat Pump	Electricity	
	AC	Electricity	
On site Transportation [PJ]	Diesel ICE	Diesel	JRC database, (Rita et al., 2012)
Others [PJ]	Others	Oil Products Natural gas Electricity	

Food and beverages Industry

End Uses	Technologies	Final energy vectors	Reference
HTHeat	Ovens	NG Diesel Biomass Electricity Oil Products	UED and JRC database
	Efficiency Boiler	BM NG OilP	JRC database
	High efficiency boiler	BM NG OilP	JRC database
Steam	Steam Boiler	Oil Products Diesel NG	UED and JRC database
Refrigeration	Compressor	Electricity	(European Commission, 2016)
Machine Drive	Electrical Motor	Electricity	JRC database
Lighting	LED LB	Electricity	JRC database and (Kim & Brown, 2019)
	Halogen LB	Electricity	
	Incandencent LB	Electricity	
	Fluorecent LB	Electricity	
HVAC	Boilers	NG LPG Oil Products	JRC database, (Rita et al., 2012)
	Heat Pumps	Electricity	
	AC	Electricity	
Onsite Transportation	Diesel ICE	Diesel	UED and JRC database
Others	Others	Others	

Chemical Industry

End Uses	Technologies	Final energy Vectors	Reference
NH3 Prod [Mt]	Plasma Arc decomposition	NG Electricity	JRC database, (Ghavam et al., 2021)
Cl2 Prod [Mt]	Advanced membrane production	Electricity	JRC database
	Advanced membrane production improvement	Electricity	JRC database
HTHeat	Boilers	NG LPG Biomass Oil Products	JRC database
	High efficiency boilers	BM NG OilP	JRC database
	Very High efficiency boilers	BM NG OilP	JRC database
Steam	Steam Boilers	Oil Products LPG Waste Heat	JRC database
Refrigeration	Compressor	Electricity	(European Commission, 2016)
Machine Drive	Electrical Motor	Electricity	JRC database
Lighting	LED LB	Electricity	JRC database and (Kim & Brown, 2019)
	Halogen LB	Electricity	
	Incandenent LB	Electricity	
	Fluorecent LB	Electricity	
HVAC	Boilers	NG LPG Oil Products	JRC database
	Heat Pumps	Electricity	
	AC	Electricity	
Onsite Transportation	Diesel ICE	Diesel	JRC database, (Rita et al., 2012)
Others	Others	NG Electricity Biomass	

Cement and Lime Industry

Final Uses Demand	Technologies	Final energy Vectors	Reference
Clinker prod	Dry Process equipment	Electricity Heat	JRC database, (Vallero, 2008)
Cement prod	Finished Cement production equipment	Electricity OilP	JRC database, (Vallero, 2008)
Lime Prod	Quick Lime Production	Electricity Heat	JRC database
HTHeat	Kiln	NG HFO	
	High efficiency boilers	BM NG OilP	
	Very High efficiency boilers	BM NG OilP	
Machine Drive	Electrical Motor	Electricity	
Lighting	LED LB	Electricity	JRC database and (Kim & Brown, 2019)
	Halogen LB	Electricity	
	Incandencent LB	Electricity	
	Fluorecent LB	Electricity	
HVAC	Boilers	NG LPG Oil Products	JRC database
	Heat Pumps	Electricity	
	AC	Electricity	
Onsite Transportation	Diesel ICE	Diesel	JRC database, (Rita et al., 2012)
Others	Others	OilP NG Electricity BM	

Ceramics and Glass Industry

Final Uses	Technologies	Final energy Vectors	Reference
Flat glass prod	Flat Production Equipment	Electricity NG	JRC database
	Flat Production Equipment w/ heat recovery	Electricity NG	
Glass Hollow prod	Glass Hollow equipment	Electricity NG Oil	JRC database, (*Glass | Industrial Efficiency Technology & Measures*, n.d.)
	Glass Hollow equipment w/ heat recovery	Electricity NG Oil	
	Glass recycling equipment	Electricity NG Oil	
	Glass recycling equipment w/ improved melting	Electricity NG Oil	
HTHeat	Kiln	BM NG Electricity	JRC database
	High efficiency boilers	BM NG OilP	
	Very High efficiency boilers	BM NG OilP	
Refrigeration	Compressor	Electricity	(European Commission, 2016)
Machine Drive	Electrical Motor	Electricity	JRC database
Lighting	LED LB Halogen LB Incandencent LB Fluorecent LB	Electricity Electricity Electricity Electricity	JRC database and (Kim & Brown, 2019)
HVAC	Boilers	NG LPG Oil Products	JRC database
	Heat Pumps	Electricity	
	AC	Electricity	
Onsite Transportation	Diesel ICE	Diesel	JRC database, (Rita et al., 2012)
Others	Others	NG	

	Electricity BM

Non-Ferrous Metals Industry

End Uses	Technologies	Final energy Vectors	Reference
Al prod	Finished Aluminium Prod Equip	Eletricity NG OilP	JRC database, (Rehfeldt et al., 2018)
Al crude	Inert Anodes	Eletricity NG	
HTHeat	Boilers	NG LPG Coal Biomass Oil Products	JRC database
	High efficiency boilers	BM NG OilP	
	Very High efficiency boilers	BM NG OilP	
Steam	Steam Boiler	Coal Oil Products LPG	
Machine Drive	Electrical Motor	Electricity	
Lighting	LED LB	Electricity	JRC database and (Kim & Brown, 2019)
	Halogen LB	Electricity	
	Incandencent LB	Electricity	
	Fluorecent LB	Electricity	
HVAC	Boilers	NG LPG Oil Products	JRC database
	Heat Pumps	Electricity	
	AC	Electricity	
On site Transportation	Diesel ICE	Diesel	JRC database, (Rita et al., 2012)
Others	Others	Coal NG Electricity	

Pulp and Paper Industry

Final Uses	Technologies	Final energy Vectors	Reference
Low Quality paper prod	Low Quality Paper Equipment	Electricity	JRC database
		Heat	
	Low Quality Paper Equip w/ adv drives	Electricity	
		Heat	
High Quality paper prod	High Quality Paper Equipment	Electricity	
		Heat	
	High Quality Paper Equip w/ adv drives	Electricity	
		Heat	
Pulp Prod	Mechanical Pulp Prod	Electricity	JRC database, (*Pulp and Paper | Industrial Efficiency Technology & Measures*, n.d.)
		NG	
	Mechanical Pulp Prod w/ adv drives	Electricity	
		NG	
	Chemical Pulp Production	Electricity	
		Heat	
	Recycling Pulp Production	Electricity	
		Heat	
HTHeat	Kiln	BM	JRC database
		NG	
		Oil Products	
	Boilers	NG	
		Biomass	
		Oil Products	
	High efficiency boilers	BM	
		NG	
		OilP	
	Very High efficiency boilers	BM	
		NG	
		OilP	
Machine Drive	Electrical Motor	Electricity	
Lighting	LED LB	Electricity	JRC database and (Kim & Brown, 2019)
	Halogen LB	Electricity	
	Incandencent LB	Electricity	
	Fluorecent LB	Electricity	
HVAC	Boilers	NG	JRC database
		LPG	
		Oil Products	

	Heat Pumps	Electricity	
	AC	Electricity	
Onsite Transportation	Diesel ICE	Diesel	JRC database, (Rita et al., 2012)
Others	Others	Oil Products	
		NG	
		BM	
		Other renewables	
		Biogas	

Other Industries

End Uses	**Technologies**	**Final energy Vectors**	**Reference**
HTHeat	Boilers	NG	JRC database
		LPG	
		Biomass	
		Oil Products	
	High efficiency boilers	BM	
		NG	
		OilP	
	Very High efficiency boilers	BM	
		NG	
		OilP	
Steam	Steam Boiler	Oil Products	
		LPG	
		Waste Heat	
Machine Drive	Electrical Motor	Electricity	
Lighting	LED LB	Electricity	JRC database and (Kim & Brown, 2019)
	Halogen LB	Electricity	
	Incandencent LB	Electricity	
	Fluorecent LB	Electricity	
HVAC	Boilers	NG	JRC database
		LPG	
		Oil Products	
	Heat Pumps	Electricity	
	AC	Electricity	
Onsite Transportation	Diesel ICE	Diesel	JRC database, (Rita et al., 2012)
Others	Others	Coal	
		OilP	
		NG	
		Electricity	
		Heat	
		BM	