Trajectories of Energy Conversion and GHG Emission Factors for Portugal

Direção-Geral de Energia e Geologia

REPÚBLICA PORTUGUESA
AMBIENTE E ENERGIA

Direção-Geral de Energia e Geologia

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Executive Summary

This document reports a study for Portugal by its Directorate-General for Energy and Geology, on the current and future values of factors used to analyse energy processes and systems, namely the lower calorific value, the conversion factor from final to primary energy, and the intensity of greenhouse gas emissions relative to final energy use.

A wide range of energy carriers are covered: electricity produced with various technologies, fossil fuels, and renewable fuels – the later of both biological and non-biological origin (i.e. based on renewable hydrogen). There are also energy carriers with a mixed composition: grid electricity, grid gas, fuels for land, sea and air travel, whose composition and renewable fraction are evolving rapidly.

The use of these factors is emphasised in the context of European Directives 2023/1791 and 2024/1275, known as EED and EPBD, respectively on energy efficiency and energy performance of buildings, whose most recent versions are currently being transposed into the Portuguese legislation. National circumstances may justify the use of specific national or regional values rather than default values. The study shows that this is indeed the case in Portugal, given its decarbonisation strategy and more advanced stage in the energy transition than the EU as a whole. The use of the proposed factors is compatible with the requirements of the Directives, since the study it presents the required characteristics: clarity in the sources of basic data and calculation methodologies, compatibility with national strategic plans such as the NECP and subsequent plans, and standardised reporting according to EN 17423:2020.

In general, the results seem to express a tension between decarbonisation objectives and the 'efficiency first' principle. In particular, decarbonising high-temperature industrial processes, grid gas, or marine and aviation fuels, through renewable hydrogen and derived synthetic fuels, benefits from very low emissions, but implies large primary energy factors. However, what this really means is that it would be preferable to use electricity directly instead of fuels – which is indeed in line with 'efficiency first' – were it not for technical, economic and security of supply aspects that also need to be weighed up.

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Sumário Executivo

Este documento reporta um estudo para Portugal, da Direção-Geral de Energia e Geologia, sobre os valores atuais e futuros de fatores utilizados na análise de processos e sistemas energéticos, designadamente o poder calorífico inferior, o factor de conversão de energia final a primária, e a intensidade de emissão de gases com efeito de estufa relativamente ao uso de energia final.

Estão abrangidos um largo conjunto de vetores energéticos: eletricidade produzida com diversas tecnologias, combustíveis fósseis, e combustíveis renováveis – estes tanto de origem biológica como não biológica (i.e. baseados em hidrogénio renovável). Também, vetores energéticos de composição mista: electricidade da rede, gás de rede, combustíveis rodoviários, marítimos e aéreos, cuja composição e fração renovável evoluem rapidamente.

Realça-se a utilização destes fatores no contexto das Diretivas Europeias 2023/1791 e 2024/1275, conhecidas como EED e EPBD, respetivamente sobre eficiência energética e desempenho energético dos edifícios, cujas versões mais recentes estão atualmente a ser transpostas para a legislação nacional. Circunstâncias nacionais podem justificar a utilização de valores nacionais ou regionais específicos, em vez de valores por defeito. O estudo demonstra que isto é o caso de Portugal, dada a sua estratégia de descarbonização e fase na transição energética, mais avançada que na EU como um todo. A utilização dos fatores propostos é compatível com as exigências das Diretivas: clareza nas origens de dados de base e nas metodologias de cálculo, compatibilidade com os planos estratégicos nacionais como o PNEC e subsequentes, e reporte padronizado segundo a EN 17423:2020.

De um modo geral, os resultados aparentam exprimir uma tensão entre os objectivos de descarbonização e o princípio da "eficiência primeiro". Em particular, descarbonizar processos industriais de alta temperatura, gás de rede, ou combustíveis marítimos e aéreos, através de hidrogénio renovável e de combustíveis sintéticos derivados, beneficia de frações renováveis altas e reduz fortmente emissões, mas implica aumentos em termos de energia primária. No entanto, o que isto realmente significa é que seria preferível utilizar diretamente eletricidade em vez de combustíveis – o que está de facto de acordo com o princípio da "eficiência primeiro" – não fossem existir aspetos técnicos, económicos, e de segurança de abastecimento, também a ser ponderados.

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1. Introduction

1.1. Objectives

This work was prompted by the processes of transposition to the national legislation of the European Directives 2023/1791 and 2024/1275, respectively about energy efficiency and energy performance of buildings, commonly known as EED (2024) and EPBD (2024).

The EED states that, when EU Member States compute energy savings, they must use certain default net calorific values (or low calorific values, LHV). In case the energy data consists of final energy values, but the Member State opts to express the savings in terms of primary energy, then primary energy factors (PEF) will be used. Here again there are default values, particularly 1.9 for grid electricity.

However, national circumstances can justify using other values for LHV and PEF conversion factors. This is what happens in Portugal, where the national decarbonization strategic approach has some distinctive features, and the energy transition is in a more advanced stage than in the EU as a whole. For instance, currently the primary energy factor of grid electricity for Portugal stands around 1.4, much lower than the default 1.9.

As for the EPBD, it specifies that the energy performance of buildings is to be evaluated (among other indicators) by a primary energy indicator. This also requires specification of primary energy factors. A greenhouse gas (GHG) emissions indicator is optional, but in practice GHG emissions factors must be available for purposes related to energy performance certificates, building renovation passports, and the national building renovation plans.

For both Directives, the issue of future values of these coefficients is relevant, as the grid electricity mix and the composition of fuel blends like grid gas, road gasoline and gasoil, sustainable aviation fuel (SAF), and marine diesel, changes significantly as the energy transition advances.

This study is intended to assist the transposition of EED and EPBD to Portuguese legislation by providing calculations of the said factors using clear data origins and methodologies, whilst keeping coherence with the national strategic approach for reaching carbon neutrality by 2050.

1.2. General framework for energy

The most common broad framework for processes related to energy use in modern societies is to consider a chain leading from energy resources to energy supply, then transmission (transport and distribution) of that energy, then ending up satisfying the energy demand at the various economic sectors. Setting aside for the moment physical and legal rigorous definitions, at each stage of the resource / supply / transmission / demand chain, the energy is labelled primary / secondary / final / useful, respectively E_P, E_S, E_F, E_U.

In this context the concept of energy vector, or energy carrier, is useful. This is the support by which the energy can flow across the energy chain. The most important energy vectors are fuels (solid, liquid or gaseous, apt for combustion), electricity, and heated or cooled fluids (heated air, water; or oil, cooled air or water)[1].

[1] Other vectors exist, but are of less or no importance in this context, like compressed air, laser beams or sound waves

Factors can be defined to account for losses in transitioning from one step to the next, like gas leaks, electric resistance, or conversion efficiency of devices. The primary energy factor PEF, labelled f_P in EN 17423:2020, stands as the ratio of primary to final energy,

$$f_P = E_P/E_F \text{ [adimensional].} \quad (1)$$

In addition, consider that the origin of energy can be renewable – from inexhaustible sources[2] such as solar radiation, wind, hydro flows, ocean waves, biomass, etc. – or non-renewable – from exhaustible sources such as fossil fuels, this including non-renewable wastes[3]. The primary energy factor can then be further presented as the sum of a partial renewable primary energy factor

$$f_{P,REN} = E_{P,REN}/E_F \text{ [adimensional],} \quad (1a)$$

and a partial non-renewable primary energy factor

$$f_{P,nREN} = E_{P,nREN}/E_F \text{ [adimensional].} \quad (1b)$$

However, the apparently simple picture presented about energy flows is soon found to be hiding a very high complexity. Most of all, there are scope issues about what processes are to be included at each step. For instance, is primary energy to be considered as the fundamental electromagnetic, chemical, mechanical, etc. energy available in Nature, or already as the physical energy content of fuels or electricity? Where does energy used for extracting, producing and transporting fuels go? How to handle simultaneous co-generation of electricity and heat? And imports and exports? What about non-energy uses of fuels?

The conceptual scheme that provides guidance for most energy analysis and practical applications is illustrated in Figure 1. Primary energy is considered as the physical energy contained in the first energy form that can enter the chain of energy transformation. Thus, if raw energy sources ("0" in Figure 1) consist already of directly combustible products (e.g. coal, crude oil, natural gas, wood), these are considered primary energy ("1", that can either be fossil "2", or renewable "3"). For non-directly combustible products, there are two alternatives. In case the raw energy sources provide heat (e.g. solar radiation, geothermal fluids, nuclear reactions), then heat is classified as the primary energy form. In the remaining cases – typically mechanical or potential energy sources – the primary energy form is the electricity obtained from their conversion (e.g. solar photovoltaic, wind, hydro, wave energy).

The energy used in building infrastructures and devices (e.g. pumps, wind turbines) can be discounted ("4" and "5") if a detailed Life Cycle Analysis (LCA) is done. This is often not done: not just because of the difficulty of LCA exercises, but also because these energy flows can be assigned to processes occurring outside the assessment boundary (e.g. fossil fuel extraction and transportation from foreign countries) or outside the energy sector (e.g. energy used to build hydroelectric dams or power plants can be associated only with the construction sector, thus avoiding eventual double counting).

Energy losses ("6" and "7") occur during transformations of primary to secondary energy carriers (e.g. gasoil refined from crude oil, hydrogen from water electrolysis, electricity produced in thermoelectric power plants), during transmission – meaning transport and distribution – (e.g. electric losses in power cables, inverters; leaks from pipelines) and as a result of storage processes (e.g. input/output efficiency of reverse hydro systems or batteries).

[2] At human time scale
[3] The classification of nuclear energy is not a concern here, as no such power plants exist or are foreseen for Portugal

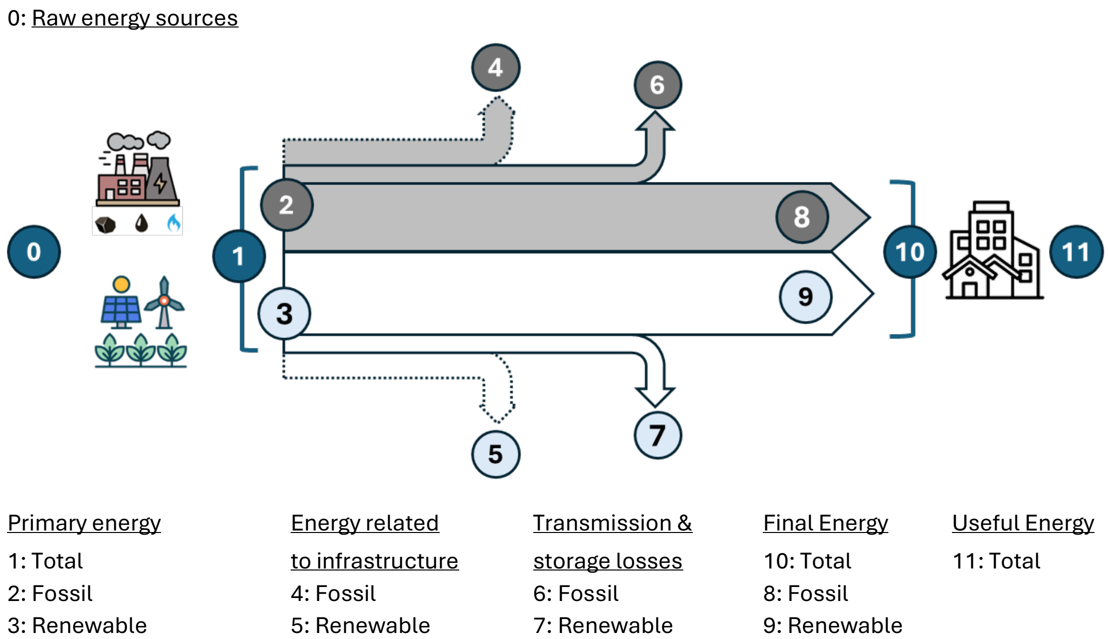


Figure 1. Basic conceptual scheme of energy flows.

The remaining energy delivered to the final users, is termed final energy (“10”). This can be seen as being composed of a fossil part “8” and a renewable part “9”, although it must be stressed that is often a virtual classification, as the energy carrier can be the same (e.g. electricity). In a final step, the users convert the final energy “10” into useful energy “11” with devices having a certain conversion efficiency (e.g. motors, boilers).

Symbolically, the total primary energy factor is the ratio of fluxes “10”/”1”; the fossil primary energy factor is the ratio of fluxes “8”/”1”; and the renewable primary energy factor is the ratio of fluxes “9”/”1”.

1.3. General framework for emissions

As for GHG emissions, they can occur at every step of the chain in Figure 1. The almost universally used framework for GHG is the one provided by the Intergovernmental Panel for Climate Change (IPCC). As regards energy, the set of GHG generally considered includes CO_2, CH_4 and N_2O.

The GHG emission intensity factor K_{CO2}, or simply GHG factor, stands for the ratio of overall GHG emissions to final energy,

$$K_{CO2} = \mathrm{GHG}/E_F \text{ [kg } CO_2\text{eq/MWh]}. \quad (2)$$

Note that in the IPCC framework, carbon dioxide emissions from biomass burning (biogenic CO_2) are not accounted for in the Energy sector as causing global warming, because they are already accounted for in the Land Use, Land Use Changes and Forestry (LULUCF) sector. Nevertheless, it is remarked that there is relevance in calculating biogenic CO_2 anyway, for handling processes such as biogas methanation, production of RFNBO, or carbon capture and storage (CCS). As for methane and nitrous oxide, their emissions should be computed for all fuel combustion processes, including biomass-based ones.

A GHG factor for final energy is defined as the ratio of the accumulated GHG emissions (viz. at all stages) to the final energy “10” (similar ratios could be defined e.g. for primary or useful energy, but this is not common).

1.4. Additional considerations

Biomass-based fuels and renewable fuels of non-biological origin (RFNBO) display added complexity, as different pathways of producing (and transporting) the fuels will result in different numerical values for the factors, as some examples will show. Densified biomass products – such as pellets and briquettes – require additional energy compared with simple wood logs or even wood chips. Bioliquids such as used vegetable oils must be filtered, purified, and chemically transformed to become components of gasoline or gasoil, like FAME and HVO. In the case of HVO, hydrogen can be of fossil origin (natural gas / steam reforming) or of renewable origin (e.g. electrolysis with renewable electricity), these alternatives resulting in very different primary energy factors. Biogas production yields and energy requirements are different according to the feedstocks used and even the ambient temperature. Biomethane can be obtained from simple biogas cleaning, but also from methanation of the CO_2 fraction of biogas, again using hydrogen of various sources. These few examples suggest that for practical applications, simplifications like averaging or using default values may be acceptable, to avoid having to produce and deal with long lists of feedstock-specific and process-specific primary energy factors.

Especially for buildings, the issue of calculation boundaries is important. While most of the energy carriers are delivered to a building from distant sources, in some cases the final energy can be produced on-site, like electricity from a rooftop solar photovoltaic system (PV), or from nearby sources, like PV electricity from another building, cogeneration heat from a close industry, or more generally from an energy community. Therefore, primary energy and GHG emission factors can be, and generally are, very different according to the assessment boundary.

Other issues also relevant, such as geographical scope, time scope (e.g. hourly to annual), time horizon (accounting for changing characteristics of the energy system), and handling of exports of excess energy production.

It is not the purpose of this document to dwell deep into these issues, but only to consider them to the extent that they are relevant for the calculation of LHV, PEF and GHG emission factors to be used under Portuguese public policies.

2. Literature review

2.1. Relevant EED dispositions

It must be highlighted that primary energy factors would only be absolutely required if Portugal decides to express EED energy efficiency obligations in terms of primary energy instead of final energy. Nevertheless, it is important to know the factors to make an informed decision; plus anyway, this is indispensable for EPBD purposes, see the next section.

The EED sets a 1.9 default value for the primary energy factor for electricity but allows a Member State to set up its own value in a justified manner, always taking into account the energy mix of the last version of the NECP. This mention of the NECP – that sets energy efficiency and decarbonization targets for 2030 but also the respective trajectories up to 2040 at least – also means that the EED implicitly indicates that a forward-looking approach should be adopted when computing primary energy factors. It is significant to realize that even the default value 1.9 was in fact computed with a forward-looking approach.

Hereafter the most relevant dispositions for primary energy factors in the EED Directive are reproduced.

Article 9, Energy efficiency obligation schemes

(…)

8. Member States shall express the amount of energy savings required of each obligated party in terms of either primary energy consumption or final energy consumption. The method chosen to express the amount of energy savings required shall also be used to calculate the savings claimed by obligated parties. When converting the amount of energy savings, the net calorific values set out in Annex VI of Commission Implementing Regulation (EU) 2018/2066(41) and the primary energy factor pursuant to Article 31 shall apply unless the use of other conversion factors can be justified.

Article 31, Conversion factors and primary energy factors

1. For the purpose of comparison of energy savings and conversion to a comparable unit, the net calorific values in Annex VI of Regulation (EU) 2018/2066 and the primary energy factors set out in paragraph 2 of this Article shall apply unless the use of other values or factors can be justified.

2. A primary energy factor shall be applicable when energy savings are calculated in primary energy terms using a bottom-up approach based on final energy consumption.

3. For savings in kWh electricity, Member States shall apply a coefficient in order to accurately calculate the resulting primary energy consumption savings. Member States shall apply a default coefficient of 1,9 unless they use their discretion to define a different coefficient based upon justified national circumstances.

4. For savings in kWh of other energy carriers, Member States shall apply a coefficient in order to accurately calculate the resulting primary energy consumption savings.

5. Where Member States establish their own coefficient to a default value provided pursuant to this Directive, Member States shall establish that coefficient through a transparent methodology on the basis of *national, regional or local circumstances affecting primary energy consumption. The circumstances shall be substantiated, verifiable and based on objective and non-discriminatory criteria.*

6. Where establishing an own coefficient, Member States shall take into account the energy mix included in the update of their integrated national energy and climate plans submitted pursuant to Article 14(2) of Regulation (EU) 2018/1999 and their subsequent integrated national energy and climate plans (NECP) notified to the Commission pursuant to Article 3 and Articles 7 to 12 of that Regulation. If they deviate from the default value, Member States shall notify the coefficient that they use to the Commission along with the calculation methodology and underlying data in those updates and subsequent plans.

Additional methodological indications can be taken from §146 of the EED prologue, regarding how default values were calculated by the Commission: *"Reflecting technological progress and the growing share of renewable energy sources in the electricity generation sector, the default coefficient for savings in kWh electricity should be reviewed in order to reflect changes in the primary energy factor for electricity and other energy carriers. The calculation methodology is in accordance with the Eurostat energy balances and definitions, except for the allocation method of fuel input for heat and electricity in combined heat and power plants, for which the efficiency of the reference system, required for the allocation of fuel consumption, was aligned with Eurostat data for 2015 and 2020. Calculations reflecting the energy mix of the primary energy factor for electricity are based on annual average values. The 'physical energy content' accounting method is used for nuclear electricity and heat generation and the 'technical conversion efficiency' method is used for electricity and heat generation from fossil fuels and biomass. For non-combustible renewable energy, the method is the direct equivalent based on the 'total primary energy' approach. To calculate the primary energy share for electricity in cogeneration, the method set out in this Directive is applied. An average rather than a marginal market position is used. Conversion efficiencies are assumed to be 100 % for non-combustible renewables, 10 % for geothermal power stations and 33 % for nuclear power stations. The calculation of total efficiency for cogeneration is based on the most recent data from Eurostat. The conversion, transmission and distribution losses are taken into account. Distribution losses for energy carriers other than electricity are not considered in the calculations, due to the lack of reliable data and the complexity of the calculation. As for system boundaries, the primary energy factor is 1 for all energy sources. The selected coefficient for the primary energy factor for electricity is the average of 2024 and 2025 values, since a forward-looking primary energy factor will provide a more appropriate indicator than a historical one."*

2.2. Relevant EPBD dispositions

The variety of energy conversion factors required for the operational implementation of the EPBD is larger than for the EED not just because of this, but also because of the following two other issues.

First, the EPBD explicitly requires consideration of three spatial scopes (or boundaries of calculation) for energy vectors: on-site, nearby, and distant.

Second, forward-looking primary energy factors are required, not just historical values. The national building renovation plan shall include definition of decarbonization trajectories of building stocks, and the EPBD mentions the specific dates 2030, 2040 and 2050. Also, it is explicitly said that the calculation of primary energy shall be based on regularly updated and forward-looking primary energy factors, distinguishing non-renewable, renewable and total, and – like for the EED – taking into account the NECP.

The instances where primary energy and GHG emissions are referred directly or indirectly in the EPBD are just too numerous to be reproduced here, but a selection of the most relevant ones is provided hereafter.

Article 2, Definitions

(…)

(2) 'zero-emission building' means a building with a very high energy performance, as determined in accordance with Annex I, requiring zero or a very low amount of energy, producing zero on-site carbon emissions from fossil fuels and producing zero or a very low amount of operational greenhouse gas emissions, in accordance with Article 11;

(…)

(11) 'non-renewable primary energy factor' means an indicator that is calculated by dividing the primary energy from non-renewable sources for a given energy carrier, including the delivered energy and the calculated energy overheads of delivery to the points of use, by the delivered energy;

(12) 'renewable primary energy factor' means an indicator that is calculated by dividing the primary energy from renewable sources from an on-site, nearby or distant energy source that is delivered via a given energy carrier, including the delivered energy and the calculated energy overheads of delivery to the points of use, by the delivered energy;

(13) 'total primary energy factor' means the sum of renewable and non-renewable primary energy factors for a given energy carrier;

(14) 'energy from renewable sources' means energy from renewable non-fossil sources, namely wind, solar (solar thermal and solar photovoltaic) and geothermal energy, osmotic energy, ambient energy, tide, wave and other ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas, and biogas;

(…)

(23) 'operational greenhouse gas emissions' means greenhouse gas emissions associated with the energy consumption of the technical building systems during the use and operation of the building;

(…)

(55) 'energy from renewable sources produced nearby' means energy from renewable sources, produced within a local or district-level perimeter of a particular building, which fulfils all of the following conditions:

(a) it can be distributed and used only within that local and district-level perimeter through a dedicated distribution network;

(b) it allows for the calculation of a specific primary energy factor valid only for the energy from renewable sources produced within that local or district-level perimeter; and

(c) it can be used on-site through a dedicated connection to the energy production source, where that dedicated connection requires specific equipment for the safe supply and metering of energy for self-use of the building

(…)

(62) 'delivered energy' means energy, expressed per energy carrier, supplied to the technical building systems through the assessment boundary, to satisfy the uses taken into account or to produce the exported energy;

(63) 'exported energy' means the proportion of the renewable energy, expressed per energy carrier and per primary energy factor, that is exported to the energy grid instead of being used on-site for self-use or for other on-site uses;

Article 3, National building renovation plan

2. Each national building renovation plan shall include:

(b) a roadmap with nationally established targets and measurable progress indicators, including the reduction of the number of people affected by energy poverty, with a view to achieving the 2050 climate neutrality goal, in order to ensure a highly energy-efficient and decarbonised national building stock and the transformation of existing buildings into zero-emission buildings by 2050;

(…)

(e) the thresholds for the operational greenhouse gas emissions and annual primary energy demand of a new or renovated zero-emission building pursuant to Article 11;

(f) minimum energy performance standards for non-residential buildings on the basis of maximum energy performance thresholds pursuant to Article 9(1);

(g) national trajectory for the renovation of the residential building stock, including the 2030 and 2035 milestones for average primary energy use in kWh/(m2.y) pursuant to Article 9(2);

(…)

The roadmap referred to in point (b) of this paragraph shall include national targets for 2030, 2040 and 2050 as regards the annual energy renovation rate, the primary and final energy consumption of the national building stock and its operational greenhouse gas emission reductions; specific timelines for non-residential buildings to comply with lower maximum energy performance thresholds pursuant to Article 9(1), by 2040 and 2050, in line with the pathway for transforming the national building stock into zero-emission buildings;

Article 9, Minimum energy performance standards for non-residential buildings and trajectories for progressive renovation of the residential building stock

1. Member States shall establish minimum energy performance standards for non-residential buildings which ensure that those buildings do not exceed the specified maximum energy performance threshold, as referred to in the third subparagraph, expressed by a numeric indicator of primary or final energy use in kWh/(m^2.y), by the dates specified in the fifth subparagraph.

(…)

3. In addition to primary energy use referred to in paragraphs 1 and 2 of this Article, Member States may establish additional indicators of non-renewable and renewable primary energy use, and of operational greenhouse gas emissions produced in kgCO2eq/(m^2.y) (…)

(…)

ANNEX I, Common general framework for the calculation of the energy performance of buildings

1. (…) The energy performance of a building shall be expressed by a numeric indicator of primary energy use per unit of reference floor area per year, in kWh/(m².y) for the purposes of both energy performance certification and compliance with minimum energy performance requirements. The methodology applied for the determination of the energy performance of a building shall be transparent and open to innovation.

2. (…) The calculation of primary energy shall be based on regularly updated and forward-looking primary energy factors (distinguishing non-renewable, renewable and total) or weighting factors per energy carrier, which have to be recognized by the national authorities and taking into account the expected energy mix on the basis of its national energy and climate plan. Those primary energy factors or weighting factors may be based on national, regional or local information. Primary energy factors or weighting factors may be set on an annual, seasonal, monthly, daily or hourly basis or on more specific information made available for individual district systems.

Primary energy factors or weighting factors shall be defined by Member States. The choices made and data sources shall be reported according to EN 17423 or any superseding document. Member States may opt for an average Union primary energy factor for electricity established pursuant to Directive (EU) 2023/1791 instead of a primary energy factor reflecting the electricity mix in the country.

3. For the purpose of expressing the energy performance of a building, Member States shall define additional numeric indicators of total, non-renewable and renewable primary energy use, and of operational greenhouse gas emissions produced in kgCO2eq/(m².y).

ANNEX II, Template for the national building renovation plans (referred to in Article 3)

(a) Overview of the national building stock

Mandatory indicators

Primary energy factors: per energy carrier, non-renewable primary energy factor; renewable primary energy factor; total primary energy factor

Primary and final annual energy consumption (ktoe): per building type, per end use

Average primary energy use in kWh/(m².y) for residential buildings

Annual operational greenhouse gas emissions (kgCO2eq/(m².y), per building type

Annual operational greenhouse gas emission reduction (kgCO2eq/(m².y), per building type

Targets for expected operational greenhouse gas emissions (kgCO2eq/(m².y), per building type

Targets for expected operational greenhouse gas emission reduction (%): per building type

(e) Thresholds of new and renovated zero-emission buildings, referred to in Article 11:

operational greenhouse gas emissions thresholds of new zero-emission buildings;

operational greenhouse gas emissions thresholds of renovated zero-emission buildings;

annual primary energy use thresholds of new zero-emission buildings;

annual primary energy use thresholds of renovated zero-emission buildings

ANNEX V, Template for energy performance certificates (referred to in Article 19)

1. On its front page, the energy performance certificate shall display at least the following elements:

(…)

(b) the calculated annual primary energy use in kWh/(m².y);

(c) the calculated annual final energy use in kWh/(m².y);

(e) operational greenhouse gas emissions (kgCO2/(m².y))

2.3. EUROSTAT methodologies

At European level, the methodologies of EUROSTAT regarding primary emission factors are of course a major consideration. They are repeated in many documents; a good reference is the Eurostat Energy Balance Guide (Eurostat, 2019). Relevant contents are quoted hereafter.

(…) The general principle of Eurostat's approach is that the primary energy form should be the first energy form in the production process for which various energy uses are in reality practiced.

Eurostat's methodology is based on the physical energy content method. For directly combustible energy products (for example coal, crude oil, natural gas, biofuels, waste) it is their actual energy content measured by their gross and net calorific values. For products that are not directly combustible, the application of this principle leads to the choice of heat as the primary energy form for nuclear, geothermal and solar thermal; and to the choice of electricity as the primary energy form for solar photovoltaic, wind, hydro, tide, wave, ocean. The measurement of the primary energy form for the not directly combustible fuels is done as gross electricity production for those where electricity is the primary energy form and as gross heat production for those where heat is the primary energy form.

According to obligations in Regulation (EC) No. 1099/2008 on energy statistics the reporting cover geothermal and solar thermal inputs needed for electricity and/or heat production from these sources. If countries do not have information on energy inputs available, but only the amount of electricity and/or heat produced is known, the reporting countries are advised to use the following efficiencies to estimate inputs:

For electricity from geothermal sources: 10 %

For electricity from concentrating solar: 33 %

For derived heat from geothermal sources: 50 %

For derived heat from solar thermal energy: 100 %

2.4. Academic studies

Numerous documents can be consulted in the international literature that develop the notions of energy chains, primary energy and GHG emission factors. For the current document, the report "Support to Primary Energy Factors Review (PEF)" (COM, 2023) and the study of the evolution of PEF for electricity in EU countries done by Balaras et al. (2023), were especially relevant concerning methodological guidelines and computational examples. For addressing the complex cases of biomass-based fuels and RFNBO, the most relevant studies consulted were those of Garraín et al. (2010) and Vivadinar and Purwanto (2020) on HVO, JRC (2014) on well-to-wheels analysis of road fuels, and JRC (2017) on solid and gaseous bioenergy pathways. For Portugal, PEFs for the public electricity network were studied by Gonçalves (2019) and GHG emission factors for the national public network are regularly published by APA (2025).

2.5. *Comparison of published primary energy factors*

Given that for many energy carriers there will not be enough detailed Portuguese data to enable computation of primary energy factors, it is relevant to scan some published lists of these factors.

PEFs for electricity are the most studied, but these are so country-specific that they are of no interest here. Table 1 depicts six interesting PEF lists. The norm ISO 52000-1 (ISO, 2017) gives default values that may be used in the absence of better information. However, it proposes some apparently odd values for energy carriers that should have different PEFs, such as biogas and biomethane, or wood logs and wood pellets. The Sustainable Energy Authority of Ireland (SEAI, 2024) proposes an even more radical approach by assigning 1.1 to the PEF of *all* energy carriers. In Austria, the Austrian Standard ÖNORM EN 15316-4-5, quoted in COM (2023), provides values aligned with ISO 52000-1, except for heating oil (higher) and solid biomass (lower). The Ministry of Industry, Energy and Tourism of Spain (RITE, 2014) and the Department for Energy Security & Net Zero of the United Kingdom (DESNZ, 2023) carried out detailed assessments that provided PEFs values consistent with an *a priori* expected pattern. The Concerted Action on the EPBD, produced some years ago an assessment of the range of PEFs in the EU Member States as declared in the mandatory cost-optimal studies on performance requirements (CA-EPBD, 2017). This analysis has shown that some countries just attributed a PEF of 1 for all cases, but in general, the upper end of the range has the same well-behaved pattern of the UK and Spanish studies.

Table 1. Primary energy factors proposed by different sources.

	ISO 52000-1	Ireland	Austria	UK	Spain	CA EPBD
Gas (public grid)	1.1	1.1	1.10	1.120	1.195	1.00 - 1.26
LPG	1.1	1.1	1.10	1.104	1.204	1.00 - 1.20
Biogas	1.4	1.1	1.40	1.442	--	1.00 - 1.10
Biomethane	1.4	1.1	1.40	--	--	1.00 - 1.10
Heating oil	1.1	1.1	1.20	1.136	1.182	1.00 - 1.14
HVO	1.5	1.1	--	1.010	--	1.00 - 1.10
FAME	1.5	1.1	1.50	1.152	--	1.00 - 1.10
Bioethanol	1.5	1.1	1.50	1.384	--	1.00 - 1.10
Wood logs	1.2	1.1	1.13	1.065	1.037	1.00 - 1.20
Wood chips	1.2	1.1	1.13	1.069	1.037	1.00 - 1.20
Wood pellets	1.2	1.1	1.13	1.306	1.113	1.00 - 1.26

3. Data

3.1. *Historic statistics*

The National Energy Balances published annually by DGEG (2025) are the main information source for the current study. Annexed to the matrix «energy carrier vs. processes» that constitutes the energy balance itself, there is a list of LHV for the energy carriers represented, along with a brief explanation of the methodology used in each case. The National Energy Balances are assembled with the best available data provided by energy suppliers (import/export, transformation, storage, distribution) and energy users (e.g. industry). Especially for the demand side, in some cases, estimations must be made based on sources like surveys (e.g. to the residential sector), or equipment providers (heat pumps). Additional historic data may be required especially from the electricity and gas utilities and for Madeira and Azores.

These historic data are communicated to DGEG with some uncertainty, which can be large for some energy vectors and processes. In addition, although the energy landscape is always evolving, the National Energy Balance format is not being constantly updated. This is because it is considered a priority to maintain a consistent time series of these tables, so that the evolution of the energy sector and the impact of policies and measures can be traced without perturbations from data breaks. This means that there although the statistical data and the LHV list are communicated to EUROSTAT by DGEG according to the latest guidelines, this is not reflected on some categories of energy vectors and processes. Specific cases important for calculations of primary energy and GHG factors will now be discussed.

Geothermal primary energy is assigned as heat in the EUROSTAT framework. However, in the Portuguese National Energy Balances, the geothermal primary energy data is provided as electricity. For this study the heat is considered the actual primary energy. For the related computations, EUROSTAT proposes a 10.0% default conversion efficiency to electricity; in the case of Portugal, the value used by DGEG is 9.44%, on the basis of reports from «Electricidade dos Açores».

Densified biomass primary energy data is reported in the Portuguese National Energy Balances in the same column «Wood and Vegetable Wastes» of non-densified biomass. It is probable that the energy spent in densifying biomass is included in the energy demand of the «Wood and Wood Products» industrial subsector, but there is no way to confirm this, much less to extract this detail from the data.

The column of the Portuguese National Energy Balances where biofuels are reported, does refer to final energy products, i.e. to components of fuels blends such as road gasoline and diesel. It was confirmed that the energy required to process bioliquids into biofuels is not included in the refinery activity. Therefore, it probably appears in the energy demand of the «Other industries» industrial subsector. Again, there is no way to confirm this, or to extract detail from the data provided.

There is of course a whole class of biofuels and RFNBO that are not reported in the Portuguese National Energy Balances simply because they are not yet produced, or they are, but just at a pilot scale. These include biomethane, bio jet fuel, renewable hydrogen and derived RFNBO such as synthetic methane, methanol, ammonia, marine fuel, and aviation fuel.

3.2. Scenarios

For forward-looking computations, the revised NECP (PNEC, 2024) and the Carbon Neutrality Roadmap 2050 (RNC, 2019) are the main strategic documents to consider, in particular the *With Additional Measures* («WAM») scenario of the NECP.

There were some limitations on the available information, namely when performing computations regarding grid electricity and fuel blends. For grid electricity the NECP and RNC provide national perspectives, however for the Madeira and Azores regions the speed and characteristics of the decarbonization pathways are expected to be different from those at the mainland, so specific regional perspectives are needed. For fuel blends, the NECP available information at the time of writing reaches only up to 2040; and it could not be completed up to 2050 with RNC perspectives, because in these respects these are outdated by now – in fact, the RNC is currently being revised. Also not available: the composition of municipal solid wastes (MSW), marine diesel, and grid gas after 2030; shares of physical incorporation of fossil and renewable fuels imports in the fuel blends (i.e. excepting compliance of policy targets with certificates); shares of GHG emissions from the refinery to be allocated to the production of each type of secondary fossil fuel; and energy losses during the distribution of fuels.

To address regional issues, official strategic documents for the archipelagos were consulted, namely the *Estratégia Açoriana para a Energia 2030*, EAE (2022), the *Plano de Ação para a Energia Sustentável e Clima da Região Autónoma da Madeira* 2022-2050, PAESC (2022), and the *Roteiro para a Neutralidade Carbónica dos Açores*, RNCA (2024). For allocating refinery GHG emissions to fossil fuels, typical data from Valdenaire et al. (2022) was used. For addressing the remaining items, the *Carbon Neutrality Scenario for the Energy Sector by 2050* (DGEG, 2025), referred hereafter as «CN50», was used.

4. Methodologies

4.1. Energy chain scope

It is undeniable that LCA can provide guidance for the best pathways and choices for achieving an efficient, secure and sustainable energy system. However, a full LCA analysis will not be performed for the numerous energy carriers that are addressed in this document. Energy used in building infrastructures and energy conversion devices will also be place out of scope. Three main reasons for this are the following. First, although in principle a LCA could be performed for computing historic values of the factors, for forward-looking values such estimates would be loaded with high uncertainty, as they relate to a period when energy systems undergo fast transitions. Second, as the purpose here is to compute specific national factors, the energy consumed in other countries for extracting, processing and exporting primary and secondary energy carriers to Portugal, should be reflected in the factors of those other countries, to avoid double counting energy flows in the complete international system. Third, last but not the least, it would be an endeavour much too complex to be carried out in the time allocated to produce this document.

Nevertheless, imports of energy into Portugal will be considered, as they are very significant, and so must be reflected somehow in the primary energy demand and thus in the primary energy factors.

With adaptations, the above choices and arguments also apply to LHV and GHG factors.

4.2. Time scope and time horizons

Annual values of the factors are deemed adequate. Historic values are herewith computed for 2023, the most recent year with a National Energy Balance available.

Future values are estimated with basis on scenarios for the years 2030, 2040, and 2050. It is adequate to perform interpolations between these years, as the LHV and PEF evolution slows down much after 2030.

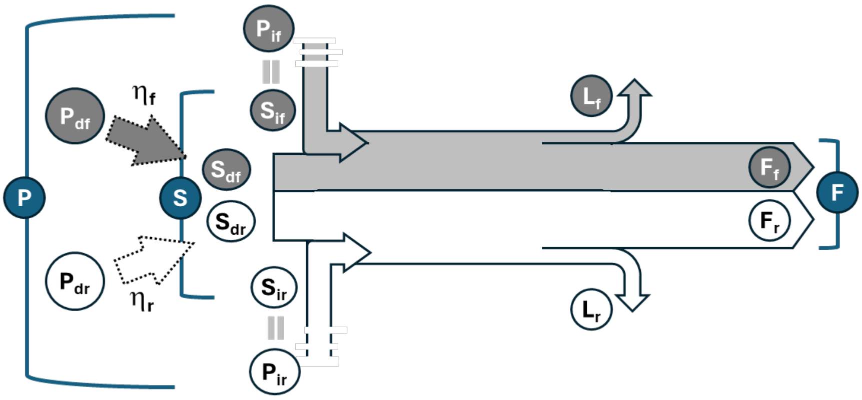
4.3. Geographical scope

The NUTS I level is adopted, i.e. mainland Portugal, Autonomous Region of Azores (archipelago with nine islands, to be simply mentioned as «Azores» in the following) and Autonomous Region of Madeira (archipelago with two inhabited islands, to be simply mentioned as «Madeira»).

Note that up to the level of NUTS III, Madeira and Azores are not broken down into component islands. To do so for the current purposes, while still maintain consistency with a similar spatial resolution at mainland, would imply to define primary energy and emission factors for hundreds of municipalities – which seems excessive and anyway very often not even meaningful.

4.4. Calculation of primary energy factors

Under the methodological choices set in section 4.1, the general scheme of energy flows presented in Figure 1, transforms to the specific scheme presented in Figure 2.



Primary energy	Secondary Energy	Transmission Losses	Final Energy
P: Total	S: Total		F: Total
P_{df}: Domestic, fossil	S_{df}: Domestic, fossil	L_f: fossil origin	F_f: fossil
P_{ir}: Imported (net), fossil	S_{df}: Imported (net), fossil	L_f: renewable origin	F_r: renewable
P_{dr}: Domestic, renewable	S_{dr}: Domestic, renewable		
P_{ir}: Imported (net), renewable	S_{ir}: Imported (net), renewable		

Figure 2. Scheme of energy flows adopted for this study.

In this scheme, primary energy is converted to secondary energy carriers at national level, with conversion efficiencies η_f or η_r according to energy being of fossil or renewable origin. However, imported energy is handled as if such efficiencies were set to 1, or in other words, imported secondary energy is equal to imported primary energy. GHG emissions associated with these external transformations of primary to secondary fuels are considered out of scope.

This is adopted mainly because in the National Energy Balances, such is the actual situation for many energy carriers. For instance, biofuels, and not bioliquids, are presented as primary energy; the same for imported fossil fuels such as LPG, gasoline, etc. As explained before, this is for statistical as well as historical reasons.

The formula for computing primary energy factors f_P are therefore the following:

$$f_P = P/F \qquad [1]$$

$$P = P_{df} + P_{if} + P_{dr} + P_{ir} \qquad [2]$$

$$f_P = f_{P;nREN} + f_{P;REN} = (P_{df} + P_{if}) / F + (P_{dr} + P_{ir}) / F \qquad [3]$$

However, while f_P can be calculated directly from the historic or scenario P and F data, the estimation of the partial factors $f_{P;nREN}$ and $f_{P;REN}$ is more difficult, because what is available in practice are merged values of renewable plus fossil primary domestic energy and primary imported energy. Considering this, and in the interest of coherence, historic as well as future factors are all computed with the same methodological approach, commonly known as 'technical efficiencies'. For the case of historic values, this is further referred to as simulated historic'.

For performing the breakdowns into renewable and fossil components, useful ancillary data consists of renewable fractions of final energy ρ, and shares of imports of renewable energy ϕ_r and of fossil energy ϕ_f. While the former can in principle be computed from National Energy Balances, the latter must be estimated from other references and/or from scenarios. Another useful strategy is to assume the same percentual transmission losses λ for fossil and for renewable secondary energy flows. The final pieces of ancillary data are the technical efficiencies η_r and η_f. With these various coefficients available, it is possible to mount a computation scheme for the final energy starting from primary energy data, and compute the desired primary energy factors, even in case of aggregated data. The coefficients η and λ adopted are listed in Table 2; the coefficients ρ and ϕ, viz. trajectories of decarbonization and imports, were obtained from the CN50 scenario.

Table 2. Adopted values of efficiency and losses

Secondary energy production	Efficiency η	Obs.
Processing of crude oil	94%	w/ non-energy products
Processing of bioliquids	90%	FAME, bioethanol, HVO, etc.
Biogas from wastes	80%	waste handling & digestor heating
Renewable H_2	75%	CN50 water electrolysis etc.
CH_4 by simple biogas cleaning	94%	CN50 scenario
CH_4 by methanation of CO_2 from biogas	84%	CN50 in-situ methanation
CH_4 by methanation of captured CO_2	60%	CN50 CCU pathway
NH_3 from H_2	82%	Haber-Bosch pathway
Other RFNBO from H_2	36%	Methanol, marine or jet fuel, etc.
Gas power plants	53%	NGCC type, see APA (2025)
Fueloil power plants	41%	see APA (2025)
Gasoil power plants	37%	see APA (2025)
Large fuel cells	60%	H_2 input
Waste burning power plants	20%	see APA (2025)
Wind, Wave, Hydro, PV power systems	100%	by convention
Geothermal power plants	9.44%	Info from DSPEE/DGEG
Solar thermal and geothermal heat	100%	by convention
Densification of solid biomass	94%	pellets and briquettes
Cogeneration (for electricity)	51%	CN50 average
Transmission processes	**Losses λ**	**Obs.**
Transportation of fuels	2%	by road and sea
Sea transportation of fuels	1%	from mainland
Natural gas regasification	1%	from shipped CNG
National gas network leaks, regasification, etc.	1%	mainland public system
H_2 networks leaks etc.	1%	dedicated grids
Electricity transportation	2%	VHV/HV mainland grid
Electricity storage	3%	23% weighted w/actual utilization
Electricity distribution	7%	LV mainland grids
Electricity transmission within islands	5% 3%	Madeira Is. Azores Is.
Electricity for RFNBO production	1%	dedicated connections
Electricity short range transmission	--	on-site and nearby systems
Fuel blending	--	all types

For secondary energy carriers that are produced from other secondary energy carriers, the primary energy factors are compounded. For instance, the PEFs for renewable methane produced from renewable hydrogen and carbon dioxide, compounds the PEFs for the electrolysis process (H_2 production) and for the methanation process (CH_4 production).

4.5. Calculation of LHV factors

As mentioned before, LHV are calculated by DGEG and listed along each annual National Energy Balance, but only for the energy carriers represented there, thus more information is provided hereafter.

Electricity and heat have a LHV of 1 MJ/MJ. For «pure» chemical substances (such as hydrogen, methane, methanol, etc.), the energy content is also fixed; Table 3 provides a list of the values adopted.

Table 3. Lower calorific value of basic chemical energy carriers

Substance	LHV	Units
Hydrogen (H_2)	12 010	kJ/kg
Ammonia (NH_3)	18 800	kJ/kg
Methane (CH_4)	50 000	kJ/kg
Methanol (CH_3OH)	21 000	kJ/kg

For many energy products of 100% fossil origin, like gasoil or jet fuel, approximately constant values through time can be considered as well. In these cases, the default value used by EUROSTAT (and often by the International Energy Agency as well) is adopted, as presented in Table 4. For natural gas and coal products, the LHV updated each year in the National Energy Balance are to be used; for forward-looking LHV, the 2023 values reported by the commercial operators are proposed, also depicted in Table 4.

Table 4. Lower calorific value of fossil fuels

Energy carrier	LHV	Units	Obs.
Natural gas	37 966	kJ/Nm^3	Reported by REN Gasodutos, 2023
Hard coal	24 664	kJ/kg	Reported by operators, 2023
Anthracite	30 359	kJ/kg	Reported by operators, 2023
Coal coke	30 811	kJ/kg	Reported by operators, 2023
Crude oil	43 040	kJ/kg	EUROSTAT
Butane, Propane and Auto Gas (LPG)	46 000	kJ/kg	EUROSTAT
Gasoline (fossil)	44 000	kJ/kg	EUROSTAT
Gasoil (fossil)	43 000	kJ/kg	EUROSTAT
Jet fuel	43 000	kJ/kg	EUROSTAT
Petrol	43 806	kJ/kg	EUROSTAT
Fuel oil	40 000	kJ/kg	EUROSTAT
Naphtha	44 000	kJ/kg	EUROSTAT
Petroleum coke	32 000	kJ/kg	EUROSTAT
Asphalts	39 000	kJ/kg	EUROSTAT
Paraffins	40 000	kJ/kg	EUROSTAT
Solvents	43 600	kJ/kg	EUROSTAT
Propylene	49 820	kJ/kg	EUROSTAT

Regarding renewable fuels, their origin and production pathways are diverse and often not known in detail. For historic values, again the LHV updated each year in the National Energy Balance are to be used. For forward-looking LHV, the 2023 values reported by the commercial operators are proposed, as depicted in Table 5. In addition, Table 5 also includes default values for Hydrotreated Vegetable Oil (HVO) and Fatty Acid Methyl Ester (FAME), although the latter is somewhat sensitive to the feedstock used.

Table 5. Lower calorific value of renewable fuels

Energy carrier	LHV	Units	Obs.
Bioethanol	27 000	kJ/kg	Reported by operators, 2023
Bio-ETBE	36 000	kJ/kg	Reported by operators, 2023
Vegetable coal	29 517	kJ/kg	Reported by operators, 2023
Non-renewable wastes	23 534	kJ/kg	Reported by operators, 2023
Wood	10 467	kJ/kg	Reported by operators, 2023
Vegetable and forest wastes	7 866	kJ/kg	Reported by operators, 2023
Briquettes / Pellets	18 841	kJ/kg	Reported by operators, 2023
Municipal solid wastes	7 955	kJ/kg	Reported by operators, 2023
Sulphurous liquors	11 603	kJ/kg	Reported by operators, 2023
Biogas	22 468	kJ/Nm^3	Reported by operators, 2023
Other renewable	20 097	kJ/kg	Reported by operators, 2023
HVO	43 000	kJ/kg	EN 15940:2016
FAME	37 000	kJ/kg	EN 14214:2012

The remaining cases respect fuel blends, with a composition that changes through time. For forward-looking LHV, they are computed as a weighted average of the LHV for each component, according to their share in the blend. These are communicated in section 5 along with PEF and GHG factors.

4.6. Calculation of GHG intensity factors

For computation of GHG emissions, those from the combustion of fuels are largely dominant over those related to their production and transport.

For fuel combustion the emission factors were extracted from the IPCC Sixth Assessment Report (IPCC, 2021). In brief, the Global Warming Potentials for the combustion of the three main gases, at the 100-year time horizon, were $CO_2 = 1$, $CH_4 = 27$, $N_2O = 273$. In addition, for natural gas and other methane leaks, the value $CH_4 = 29.8$ was adopted.

For coherence with the energy chain scope, emissions related to the production of imported fuels were not considered. The emissions related to the domestic production of biofuels (e.g. densified biomass, biogas) will be disregarded as well. However, those related to the domestic production of fossil fuels will be considered, i.e. processing at the Sines refinery of crude oil and refinery feedstocks into secondary fossil fuels such as (pure fossil) gasoil, gasoline, marine fuel, etc. The coefficients required for estimating refinery emissions attributable to various fuels were obtained from a CONCAWE report (Valdenaire et al., 2022).

For the transportation stage, emissions will be disregarded due to their low relative importance, as well as the high uncertainty in their estimation. However, as mentioned before, leaks during handling and pipeline transmission were counted for grid gas blend and grid hydrogen.

Table 6 depicts the final set of GHG emission intensity factors proposed.

Table 6. GHG emission factors (kgCO_2eq./MWh)

Energy carrier	GHG emissions at production and processing	GHG emissions at final use (combustion)	Total GHG emissions
Wood	--	34	34
Vegetable coal	--	20	20
Biofuels	--	2	2
LPG	28	228	255
Gasoline	21	241	262
Jet fuel	21	229	250
Gasoil	23	268	291
Heating oil	16	268	284
Marine diesel	16	268	284
Marine fueloil	2	280	281
Other fossil products	6	268	273
Natural gas	--	203	203

The emissions for blended fuels were computed according to percentage and emission factors of the various components (renewable and fossil), and taking into account also the shares of imported and domestically produced fuels.

4.7. Gas leaks and other losses

The National Energy Balances data shows transmission leaks in the public gas network of about 0.2% only. It is noted that additional energy is likely consumed in regasification, pumping and storing gas. It is also relevant to point out that the uncertainty in the reported gas data (unmatched demand vs. supply data) is around 0.7%. In conclusion, an estimate of 1% consumption is compatible with the statistical data for mainland Portugal. This would translate directly to a historic PEF of 1.01.

However, the gas composition in the national gas network is foreseen to change, by blending with natural gas increasing shares of renewable hydrogen, biomethane, and RFNBO methane. Therefore, forward-looking PEFs for network gas must compound the 1% losses with the PEFs of the blend components.

For Madeira, no natural gas leaks are declared in the Regional Energy Balance. However, it must be noted that natural gas is transported to Madeira, first by truck from the Sines refinery to the Lisbon harbour, then shipped to Madeira, distanced around 1000 km. Again, an estimate of at least 1% energy consumption for handling natural gas seems reasonable.

4.8. Electricity transmission and storage losses

Although historic PEFs for public network electricity can be computed directly from the ratio between the sum of primary domestic production plus net imports, to the final energy demand, for forward-looking PEFs it is required an estimate of losses. An examination of the latest National Energy Balances points to around 11% losses in electricity transmission, plus 2% losses in hydroelectric storage (reversible hydro systems) and another 2% related to self-consumption of power plants, thus 15% at the whole. For Madeira and Azores, the electricity is transmitted over distances much shorter than in mainland Portugal, so the transmission losses are smaller, around 5% for Madeira and 3% for Azores.

It is likely that these percentage losses persist, because although self-consumption of power plants and distribution losses tend to reduce, storage losses should increase with more storage capacity added to the electric system, and more intense use of such storage.

It is possible to consider more complex estimates. For instance, residential electricity clients connect to lower voltage distribution network, while large industrial clients may connect directly to transport network at high or very high voltage, thus avoiding about 7% distribution losses. Detailed data about this situation is provided by ERSE (2023). Therefore, it would be possible to specify different PEFs for different types of electricity clients. At this stage, only two classes of clients were considered, those directly connected to the transport lines (VHV/VH clients), typically industrial facilities, and the remaining, connected to the distribution grids (MV/LV clients). For dedicated power supply to facilities, e.g. for electrolysis, it is suggested to adopt the VHV/VH client type.

4.9. Fuel transportation

Distribution of fuels by road involves energy consumption that was conservatively estimated as 2% of the energy content of the transported fuel, for mainland. For the islands, distribution distances are much smaller, but maritime transportation is required, so, again a 2% value was adopted.

4.10. Exported electricity

An aspect with important consequences for the case of buildings, relates to electricity exported by small self-consumption systems (e.g. rooftop PV) and by energy communities. In case the systems export to nearby buildings, transmission losses can be disregarded. In case the systems export excess electricity production to the public electricity distribution network, then distribution losses should be assigned. In any case, the PEF of imported electricity will be different (larger) than the PEF of exported electricity.

4.11. Sensitivity analyses

Numerous sensitivity analyses were carried out, regarding the impact on the computed PEFs of changes in the various parameters of the calculation scheme. The impacts of variations of efficiencies and losses were restricted to the range 0.01 to 0.03. However, for cases related to the future pathway of renewable energy shares, there were larger impacts, reflecting in the first decimal place.

This prompted further explorations. As the scenarios of NECP or RNC rely on the success of the policies and measures therein, the sensitivity to their effectiveness was explored. Scenario variations were explored reducing the expected impact of the public policy measures for renewable electricity, hydrogen, and fuel blends, in a range of 75% to 95%. This was reflected only in the second decimal place of the PEFs up to 2030 and had no significant impacts after that. This is because by 2030 it is foreseen that the Portuguese energy system will already be highly decarbonized, and afterwards the future trajectories can't spread much if carbon neutrality is to be reached by 2050. However, for 2030, indeed the rounding of computed values with and without full policy effectiveness can reflect in the first decimal place (±0.1). As this was judged small, full effectiveness of policies was used, to avoid introducing ad-hoc assumptions.

5. Energy Conversion and GHG factors

Linear interpolation between the coefficients reported for dates 2023 / 2030 / 2040 / 2050 is seen as adequate.

5.1. *Lower calorific values of fuel blends*

For fuel blends, Table 7 depicts the LHV calculated by DGEG for 2023, and those resulting from consideration of the energy scenarios for later dates.

Table 7. Lower calorific values of fuel blends

Energy carrier	LHV				Units
	2023	2030	2040	2050	
Grid gas	37 966	37 034	35 943	34 535	kJ/Nm³
Road gasoil	42 677	42 350	41 806	40 718	kJ/kg
Road gasoline	43 494	42 370	40 496	36 749	kJ/kg
Marine diesel	42 566	42 370	40 496	36 749	kJ/kg
Jet fuel	43 000	43 018	42 563	41 700	kJ/kg
MSW	7 955	7 955	7 955	7 955	kJ/kg

5.2. *Primary energy and GHG emission factors*

The primary energy factors and the GHG emission factors computed for Portugal are hereafter provided according to the forms recommended by EN 17423:2020.

It is remarked that the CN50 scenario foresees the end of crude oil refining in Portugal some years after 2040 (refineries may continue to refine biofuels and produce RFNBO), which justifies some sharp changes of trajectories of oil-based fuels near this date.

In view of uncertainties in the scenarios, and even in the historic data, it seems adequate to express primary energy factors and GHG emission factors to the first decimal place only. This is also aligned with the practice of ISO 52000-1 and of the EED itself, and also simplifies calculations under the EPBD.

5.3. Heat

Reference document				
Trajectories of Primary Energy Factors and GHG Emission Factors for Portugal, DGEG, 2025.				
Energy carrier: heat	$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Ambient energy (aero, hydro, geo)	0,0	1,0	1,0	0
Solar heat	0,0	1,0	1,0	0
Geothermal waters	0,0	1,0	1,0	0

Choices related to the perimeter of the assessment										
Geographical area:	Portugal									
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic		Simulated historic		Forward looking	X	Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion	X	Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)		Technical efficiencies		Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot	X	Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

Notes:
Ambient energy is the energy transferred from the environment by heat pumps.
Regarding solar heat, be aware that solar thermal systems always require storage and an auxiliary system.
Geothermal refers to naturally occuring hot water springs; pumping etc. energy consumption is not accounted for.

5.4. Electricity

Reference document				
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.				
Energy carrier: electricity	$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
(Imported from abroad)	0,2	0,8	1,0	0
Renewable - H2 fuel cells	0,0	1,8	1,8	0
Renewable - Wind, Hydro, PV, Oceanic	0,0	1,0	1,0	0
Renewable - Concentrated Solar Thermal	0,0	1,0	1,0	0
Renewable - Geothermal (Azores)	0,0	10,6	10,6	0
Renewable - Biomass	0,0	3,6	3,6	122
Renewable - Wastes	0,0	5,0	5,0	171
Non-renewable - Wastes	5,0	0,0	5,0	550
Fossil - Natural gas	0,0	1,9	1,9	382
Fossil - Fueloil (Madeira)	2,4	0,0	2,4	710
Fossil - Fueloil (Azores)	2,4	0,0	2,4	710
Fossil - Gasoil (Azores)	2,7	0,0	2,7	738

Choices related to the perimeter of the assessment										
Geographical area:	Portugal									
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies		Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

5.5. Grid electricity

Reference document					
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.					
Energy carrier: electricity		$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Public network - MV/LV clients	2023	0,6	0,8	1,4	138
	2030	0,2	1,0	1,2	55
	2040	0,0	1,1	1,1	9
	2050	0,0	1,1	1,1	5
Public network - VHV/HV clients	2023	0,5	0,8	1,3	129
	2030	0,2	1,0	1,2	52
	2040	0,0	1,1	1,1	8
	2050	0,0	1,1	1,1	5
Renewable - Exported by prosumers		0,0	1,1	1,1	0

Choices related to the perimeter of the assessment										
Geographical area:	Mainland Portugal									
Geographical perimeter		European		National	X	Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies		Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

Notes: Electricity delivered to VHV/VH clients does not suffer diistribution losses; electricity exported by prosumers does not suffer transport and storage losses.

Reference document					
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.					
Energy carrier: electricity		$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Public network	2023	1,0	0,7	1,7	256
	2030	0,9	0,8	1,7	215
	2040	0,5	0,9	1,3	117
	2050	0,1	1,0	1,1	25
Renewable - Exported by prosumers		0,0	1,0	1,0	0

Choices related to the perimeter of the assessment										
Geographical area:	Azores									
Geographical perimeter		European		National	X	Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies		Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

Reference document				
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.				
Energy carrier: electricity	$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Public network 2023	1,7	0,3	2,0	429
Public network 2030	1,1	0,6	1,7	287
Public network 2040	0,7	0,7	1,4	9
Public network 2050	0,3	0,9	1,2	5
Renewable - Exported by prosumers	0,0	1,1	1,1	0

Choices related to the perimeter of the assessment										
Geographical area:	Madeira									
Geographical perimeter		European		National	X	Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies		Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

5.6. Solid fuels

Reference document				
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.				
Energy carrier	$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Wood and forest wastes	0,0	1,0	1,0	33
Pellets and briquettes	0,0	1,1	1,1	33
Vegetable coal	0,0	1,1	1,1	19
Biowastes	0,0	1,0	1,0	33
Non-renewable wastes	1,0	0,0	1,0	436

Choices related to the perimeter of the assessment										
Geographical area:	Portugal									
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies		Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

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5.7. Municipal solid wastes

Reference document					
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.					
Energy carrier		$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Municipal solid wastes	2023	0,5	0,5	1,0	235
	2030	0,6	0,4	1,0	275
	2040	0,7	0,3	1,0	315
	2050	0,8	0,2	1,0	356

Choices related to the perimeter of the assessment										
Geographical area:	Portugal									
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies	X	Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

Note: As domestic biowaste recycling increases, the remaining unseparated waste becomes more non-renewable.

5.8. Imported liquid fuels

Reference document				
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.				
Energy carrier: *imported*	$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Gasoil	1,0	0,0	1,0	291
Gasoline	1,0	0,0	1,0	262
Heating oil	1,0	0,0	1,0	284
Jets	1,0	0,0	1,0	250
Marine diesel	1,0	0,0	1,0	284
Marine fueloil	1,0	0,0	1,0	281
Other oil-based fuels	1,0	0,0	1,0	273
Biofuels	0,0	1,0	1,0	2
Synthetic fuels (RFNBO)	0,0	1,4	1,4	2

Choices related to the perimeter of the assessment										
Geographical area:	Portugal									
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren}$ = 0)		Direct equivalent ($f_{P;nren}$ = 1)	X	Technical efficiencies		Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

Note: Portugal simultaneously imports and exports several types of refined fuels, thus the need for this table.

5.9. Domestically produced liquid fuels

Reference document				
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.				
Energy carrier: *domestic production*	$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Gasoil	1,1	0,0	1,1	291
Gasoline	1,1	0,0	1,1	262
Heating oil	1,1	0,0	1,1	284
Jets	1,1	0,0	1,1	250
Marine diesel	1,1	0,0	1,1	284
Marine fueloil	1,1	0,0	1,1	281
Other oil-based fuels	1,1	0,0	1,1	273
Biofuels	0,0	1,1	1,1	2
Synthetic fuels (RFNBO)	0,0	3,9	3,9	2

Choices related to the perimeter of the assessment										
Geographical area:	Portugal									
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies		Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

5.10. Road gasoil (blended fuel)

Reference document					
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.					
Energy carrier		$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Road gasoil	2023	0,9	0,1	1,1	253
	2030	0,9	0,2	1,1	248
	2040	0,6	0,4	1,1	175
	2050	0,1	1,0	1,1	31

Choices related to the perimeter of the assessment									
Geographical area:	Portugal								
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren}$ = 0)		Direct equivalent ($f_{P;nren}$ = 1)	X	Technical efficiencies	X	Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

Note: Renewable share targets can be achieved partially through certificates, however the table was constructed considering actual physical incorporation amounts (same note for the remaing fuel blends).

5.11. Road gasoline (blended fuel)

Reference document					
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.					
Energy carrier		$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Road gasoline	2023	1,0	0,1	1,1	244
	2030	0,9	0,2	1,1	223
	2040	0,6	0,4	1,1	158
	2050	0,1	1,0	1,1	28

Choices related to the perimeter of the assessment									
Geographical area:	Portugal								
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies	X	Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

5.12. Marine diesel (fuel blend)

Reference document					
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.					
Energy carrier		$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Marine diesel	2023	1,0	0,1	1,1	244
	2030	0,9	0,2	1,1	223
	2040	0,6	0,5	1,1	145
	2050	0,3	0,8	1,1	80

Choices related to the perimeter of the assessment										
Geographical area:	Portugal									
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren}$ = 0)		Direct equivalent ($f_{P;nren}$ = 1)	X	Technical efficiencies	X	Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

5.13. Jets (fuel blend)

Reference document					
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.					
Energy carrier		$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Jets	2023	1,1	0,0	1,1	250
	2030	1,0	0,1	1,1	235
	2040	0,6	1,2	1,8	138
	2050	0,2	2,5	2,7	52

Choices related to the perimeter of the assessment									
Geographical area:	Portugal								
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies	X	Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

5.14. Gaseous fuels

Reference document				
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.				
Energy carrier	$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Natural gas (fossil)	1,0	0,0	1,0	203
LPG (fossil)	1,0	0,0	1,0	255
Hydrogen (renewable)	0,0	1,4	1,4	0
Ammonia (renewable)	0,0	1,7	1,7	0
Biogas	0,0	1,0	1,0	1
Methane: cleaned biogas	0,0	1,1	1,1	1
Methane: methanation of biogas CO_2	0,0	1,2	1,2	1
Methane: methanation of captured CO_2	0,0	2,3	2,3	1

Choices related to the perimeter of the assessment									
Geographical area:	Portugal								
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies		Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

5.15. Gas from the public network (blended fuel)

Reference document					
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.					
Energy carrier		$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
Public network gas	2023	1,0	0,0	1,0	203
	2030	0,9	0,1	1,0	186
	2040	0,7	0,6	1,3	132
	2050	0,0	2,1	2,1	1

Choices related to the perimeter of the assessment										
Geographical area:	Portugal									
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies	X	Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot		Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

Note: The public grid initially contains only natural gas but then receives increasing amounts of (renewable) hydrogen, biomethane and RFNBO methane.

5.16. Cogeneration (mixed output)

Reference document				
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.				
Energy carrier: electricity / heat	$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
CHP electricity - Biogas	0,0	2,9	2,9	2
CHP electricity - Biomass, liquid fuels	0,0	3,4	3,4	1
CHP electricity - Biomass, solid fuels	0,0	3,6	3,6	1
CHP electricity - Natural gas	1,9	0,0	1,9	191
CHP electricity - Liquid fossil fuels	3,6	0,0	3,6	455
CHP electricity - Non renewable wastes	3,6	0,0	3,6	779
CHP electricity - Fuel cells	0,0	1,8	1,8	0
CHP electricity - Grid gas 2023	1,9	0,0	1,9	191
2030	1,6	0,3	2,0	162
2040	1,0	1,7	2,7	96
2050	0,1	3,6	3,7	10

Choices related to the perimeter of the assessment										
Geographical area:	Portugal									
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren} = 0$)		Direct equivalent ($f_{P;nren} = 1$)	X	Technical efficiencies		Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach		Other				
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot	X	Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

Reference document				
Trajectories of Energy Conversion and GHG Emission Factors for Portugal, DGEG, 2025.				
Energy carrier: electricity / heat	$f_{P;nren}$	$f_{P;ren}$	$f_{P;tot}$	K_{CO2} [kgCO2eq/ MWh]
CHP heat - Biogas	0,0	1,3	1,3	1
CHP heat - Biomass, liquid fuels	0,0	1,3	1,3	0
CHP heat - Biomass, solid fuels	0,0	1,2	1,2	0
CHP heat - Natural gas	1,1	0,0	1,1	107
CHP heat - Liquid fossil fuels	1,2	0,0	1,2	145
CHP heat - Non renewable wastes	1,5	0,0	1,5	312
CHP heat - Fuel cells	0,0	1,7	1,7	0
CHP heat - Grid gas 2023	1,1	0,0	1,1	107
CHP heat - Grid gas 2030	0,9	0,2	1,1	91
CHP heat - Grid gas 2040	0,5	1,0	1,5	53
CHP heat - Grid gas 2050	0,05	2,01	2,06	6

Choices related to the perimeter of the assessment									
Geographical area:	Portugal								
Geographical perimeter		European	X	National		Regional		Local		Other

Choices related to calculation convention								
Period considered:	2023 to 2050							
Time resolution		Hourly		Monthly	X	Annual		Other
Data source		Real historic	X	Simulated historic	X	Forward looking		Other
Net or gross calorific value	X	Net (LHV)		Gross (HHV)				

Choices related to data								
Available energy sources	X	Include all energy sources		Exclude self-consumption on-site generation		Exclude dedicated delivery contracts		Other
GHG considered		CO_2 only		CO_2 equivalent 20 years	X	CO_2 equivalent 100 years		Other
Conventions energy conversion		Zero equivalent ($f_{P;nren}$ = 0)		Direct equivalent ($f_{P;nren}$ = 1)	X	Technical efficiencies		Physical energy content
Conventions PEF exported energies	X	Resources used to produce		Resources avoided		Other		

Choices related to assessment methods								
Energy exchanges		Ignoring exchanges	X	Net exchanges		Gross exchanges		Other
Multisource generation		Average calculation approach				Other		
Multi-energy output system		Power bonus		Power loss simple		Power loss		Power loss ref
		Carnot	X	Alternate product		Residual heat		Other
Life cycle analysis (LCA)	X	No LCA		Full LCA		Other		

6. Conclusions

A detailed computational scheme for lower calorific values, primary energy factors and GHG emission intensity factors was mounted, adequate for the purposes of the EED and EPBD Directives. The most relevant technologies and energy value chains that are present at the Portuguese energy sector panorama are examined, as well as those foreseen by the strategic documents like the NECP and the carbon neutrality roadmap up to 2050. The results are reported in forms with the EN 17423:2020 format, as required by the EED. The primary energy factors are provided with two decimal places, but it is recommended to use only one, due to uncertainty and sensitivity to assumptions.

Figure 3 depicts a comparison of primary energy factors obtained for diverse fuels. It is plain that most values are within a close range of 1.1 to 1.2, except for (renewable) hydrogen and derived synthetic fuels (RFNBO), such as methane (various pathways), and especially ammonia, methanol and jet fuel.

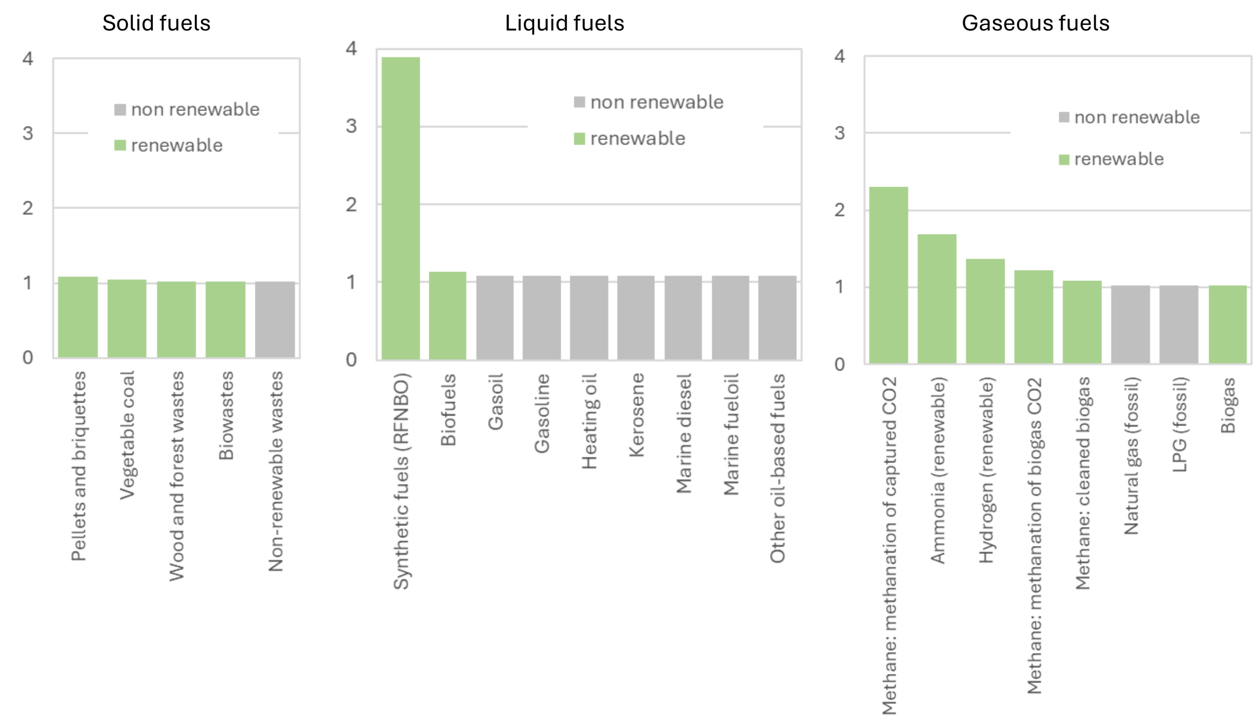

Figure 3. Comparison of primary energy factors for diverse fuels

This analysis refers to domestically produced fuels. For the corresponding imported versions, the primary energy factors are closer to 1.02, as the energy required for their extraction and processing is considered out of scope.

Regarding electricity production (on-site), Figure 4 shows the results obtained. They reflect mainly different energy conversion efficiencies. This is why, for instance, primary factors for waste or biomass incineration are larger than for liquid or gaseous fossil fuels. Renewable electricity from solar, wind, hydro or ocean sources have conventional 100% efficiency and thus display the lowest primary energy factors, close to 1. It could be thought that geothermal energy would also have a very low primary energy factor; however, in this case the conversion is to be made from geothermal heat as primary energy, and with an efficiency less than 10%, which explains the very high primary energy factor, almost 11.

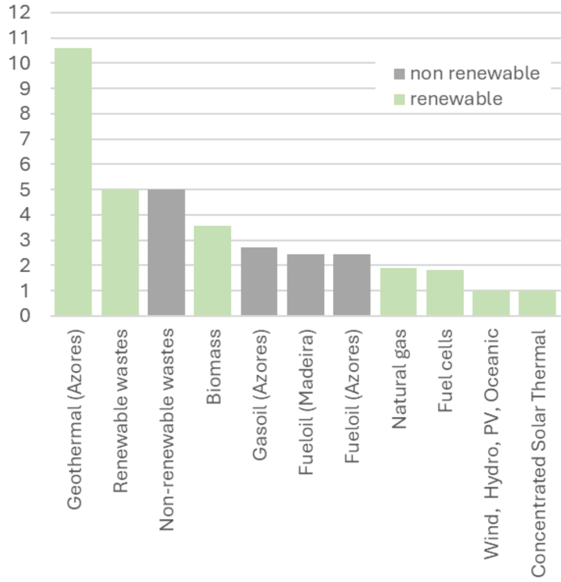

Figure 4. Primary Energy factor for diverse electricity on-site production technologies and energy sources.

This appreciation must be compounded with the corresponding GHG emission factors, depicted in Figure 5, and this of course shows the advantage of adopting renewable energy technologies.

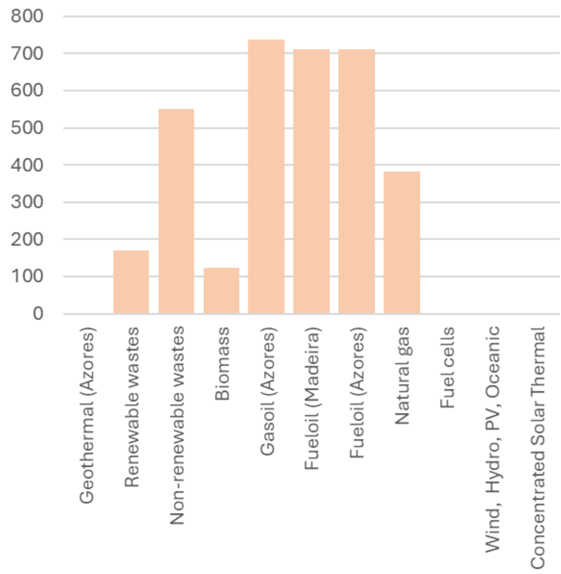

Figure 5. GHG intensity factor for diverse electricity on-site production technologies and energy sources (kg CO2eq/MWh of final energy)

While the previous analyses refer to single technologies / energy sources, there are mixed cases to consider. This includes fuel blends, like road gasoil, road gasoline, marine diesel, and jet fuel, with evolving properties across time. Especially important, are the final energy provided by public electricity and gas networks, as depicted in Figures 6 and 7. The respective decarbonization strategies lead to quite different results. While for public electricity the primary energy factor decreases up to 2040, and then stabilizes at a level close 1.1, for public gas, the primary energy factor rises sharply after 2030, reflecting the high primary energy factor of hydrogen and synthetic methane.

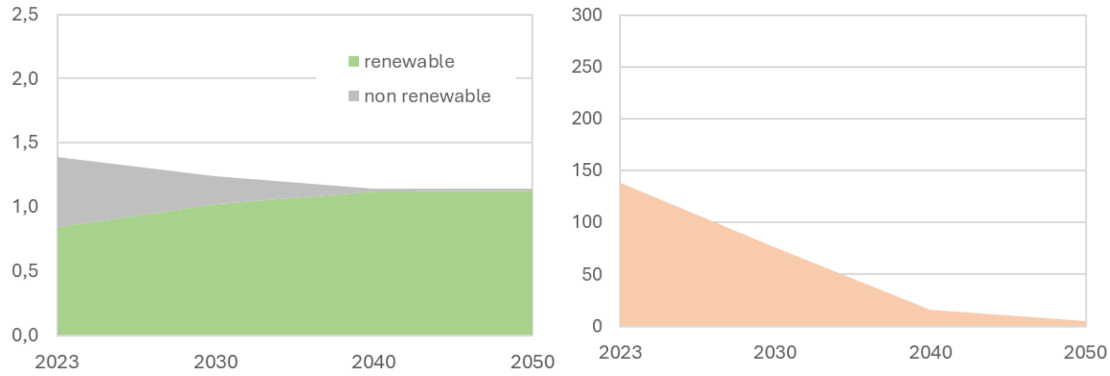

Figure 6. Evolution of Primary Energy and GHG intensity factors for public grid electricity (mainland)

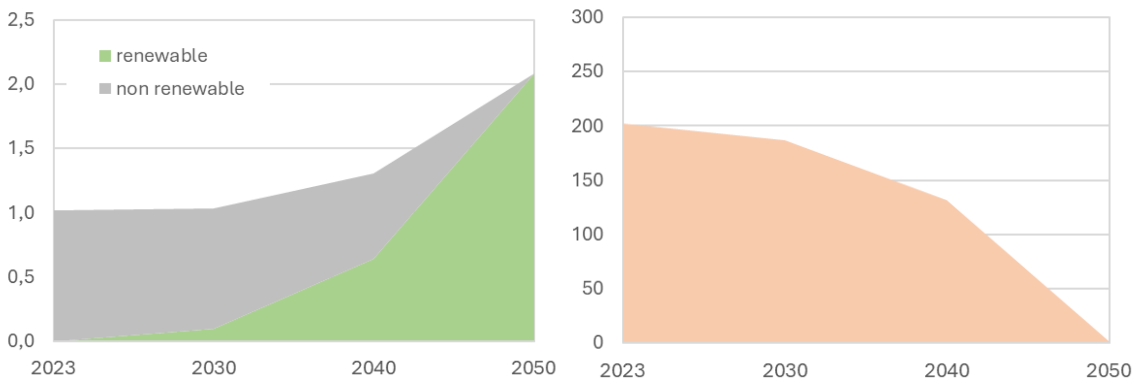

Figure 7. Evolution of Primary Energy and GHG intensity factors for public grid gas blend

Overall, the results obtained seem to express an apparent tension between decarbonisation goals and the «efficiency first» principle. Addressing hard-to-abate energy uses (mainly in industry, maritime and air transportation) by using renewable hydrogen and derived synthetic fuels, benefits from very low or zero GHG emissions, but implies large primary energy factors. Note that, under the EPBD, one of the main building performance criteria is an indicator of primary energy; thus, again, using such fuels is unfavourable, although it enables deep decarbonization.

However, what these situations really mean is that it is preferable to use directly electricity instead of using fuels – which is indeed in accordance with the «efficiency first» principle. Of course, technical and economic aspects may still advise using RFNBO fuels.

In any case, the results of this study support a choice of Portugal to implement EED energy savings obligations in term of final energy, instead of in terms of primary energy, given its decarbonization strategy.

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