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Energy Balance of Industry: Integrating Renewable Energies Enhancing Efficiency

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Abstract

In a context marked by the rise in the cost of energy, digitalization and the need to decarbonize the economy, so as not to depend on external agents, companies are betting on a decarbonized industry model. More than 80% of the companies that have participated in the energy consumption study are working to reduce greenhouse gas (GHG) emissions, mainly CO2. Companies plan to decarbonize and are already working on concrete plans to achieve it, but this study reveals that companies are unaware of the measures and procedures to improve energy efficiency, the importance and advantages and, for some companies, the regulatory obligation to incorporate renewable energy as a primary source, the differences and relationship between primary energy, transformation, final energy, consumption and useful energy, and how to compare and aggregate different fuels and sources of energy and their emissions.

Highlights

Towards a new decarbonized industry model.

Reducing energy demand and energy loses.

Using renewable energy as primary energy to generate renewable electricity.

Reducing energy import, to achieve self-sufficiency and energy security

Enhancing technological innovation and efficiency in renewable energy systems.

1 Introduction

1.1 European energy context

Just as we were finally catching our breath after the long shadow of COVID-19, 2022 hit the European Union with a harsh new reality. The conflict between Russia and Ukraine didn't just create a geopolitical rift; it sparked the most gruelling energy crisis we've seen in decades.

It was a massive wake-up call. Experts, including BP's Spencer Dale [BP 2022], pointed out the obvious: we couldn't just sit tight. We had to save energy, find new friends to buy it from, and move toward green power much faster than planned. Essentially, we had to break our addiction to fossil fuels, and we had to do it yesterday.

The response was surprisingly nimble. The EU launched the REPowerEU plan [EU Commission 2025a], backed by emergency laws that were passed at a pace you don't usually see in bureaucracy. And honestly? The effort paid off. By May 2023, we hit a milestone that felt almost impossible a few years ago: for the first time ever, the EU generated more electricity from wind and solar than from fossil fuels. That's a huge win.

But let's be real, the danger hasn't vanished. While the "worst" might be behind us, the ground beneath our feet is still shaky. Energy markets are twitchy, inflation is still biting, and our infrastructure is vulnerable. We must keep energy affordable for families sitting at their kitchen tables while making sure our industries don't lose their competitive edge.

According to the latest State of the Energy Union Report [EU Commission 2024a, EU Commission 2024b], here's what we managed to pull off in 2023:

· **Breaking up with Russian gas:** We've effectively swapped out Russian imports. Before the crisis, we were taking in 155 billion cubic meters; by 2023, that plummeted to around 40-45 billion.

· **New partnerships:** To keep the lights on, we leaned heavily on Norway and the US for natural gas and LNG.

· **Tightening the belt:** Both citizens and big industries stepped up. We managed to slash gas demand by over 18% compared to the previous five years. That's no small feat.

· **Raising the bar:** We aren't just reacting anymore; we're planning. The new goal is to hit a 42.5% renewable energy share by 2030.

The numbers tell a hopeful story. Greenhouse gas emissions are already down 32.5% compared to where they were in 1990. While the first official check-in on our national plans (the PNIECs) shows we have a mountain left to climb, the ambition is there. We are finally, stubbornly, on the path toward climate neutrality by 2050. It's been a tough few years, but the momentum is finally shifting.

1.2 National energy context

Back in late 2023, the European Commission took a long, hard look at the homework submitted by member states, their draft energy and climate plans (INECPs). For countries like Spain, the feedback was clear: the ambition is there, but we need to turn up the volume if we're going to hit those 2030 targets.

With final plans due in mid 2024, there's a sense of urgency in the air. We aren't just checking boxes anymore; after the global rallying cry at COP28, it's become obvious that this decade is our "now or never" moment to move the needle [EU Commission 2025a, EU Commission 2025b].

Taking the pulse: the 2023 energy balance

When you look at the numbers from 2023, you can see the shift happening in real-time. It's a bit of a mixed bag, but the trend is leaning toward a cleaner future.

· **Primary energy is dropping:** We saw a 3.2% dip in primary energy consumption. Why? Mostly because renewables are doing the heavy lifting in our power grid, and we aren't exporting as much energy as we used to.

· **A new low for intensity:** Here's some good news, energy intensity (how much energy we use to produce a million euros of GDP) hit its lowest point in 20 years. We're essentially learning how to do more with less.

· **The power of the wind:** For the first time, renewable electricity generation broke the 50% barrier. Wind power is the undisputed heavyweight here, making up nearly half of that total and successfully pushing coal and gas further into the background.

· **Solar's big moment:** Photovoltaic energy is absolutely surging. With a 37.6% jump in just one year, mostly fuelled by industries putting panels on their roofs, it's clear that businesses are voting for solar with their wallets.

Are we on track? (the reality check)

It's great to celebrate the wins, but we must keep an eye on the scoreboard. We're in a race against time, and the 2030 goals are looming large.

Objective	Where we are (2023)	The 2030 target	The gap
renewable energy share	23.8%	42%	We're a little over halfway there.
primary energy efficiency	32.7%	39.5%	Getting close but still work to do.
final energy efficiency	35.6%	41.7%	A steady climb remains.

We've built a solid foundation, especially with that 11% boost in total generation capacity this past year. However, the jump from "making progress" to "meeting the goal" is going to require a serious sprint.

1.3 Use and transformation of energy: the industry as a socioeconomic system

If we're going to move toward a model that protects the planet while keeping the lights on, we must look under the hood of how we use and create energy. It's not just about numbers on a spreadsheet; it's about understanding the "why" and "where" of every kilowatt. Mapping out these patterns isn't just an academic exercise, it's the roadmap we need to design strategies that work, rather than just looking good on paper.

Think of energy as the heartbeat of our modern world. It touches everything: our morning coffee, the heavy machinery in a factory, and the health of the air we breathe. When policymakers and business leaders can see exactly how energy flows through our society, they can stop guessing. They can start putting resources where they matter most, cutting carbon where it's thickest, and smoothing the transition to a future that doesn't feel like a compromise.

Ultimately, the way we produce and consume energy within our daily lives and our economy is what we call the Industrial Energy Model. It's a complex dance, and for it to be truly successful, it must stand on three very specific pillars.

Figure 1 shows the industry as a socio-economic system

The way in which energy is produced and consumed within the framework of the socio-economic system must be understood as the energy model of the industry.

Energy, as a resource, must contribute to these three pillars of sustainability that are shown in Figure 2: social, economic and environmental.

For an energy model to be truly "sustainable" it must do more than just survive; it must thrive in three directions at once:

· **Social sustainability:** At its core, energy is about people. It's about the comfort of a warm home and the freedom of mobility. We must ensure that every person has access to energy that is safe, reliable, and critically affordable. It's a basic ingredient for a decent life.

· **Economic sustainability:** There isn't a single business on earth that doesn't rely on energy. It is the fuel of competitiveness. Beyond just being a cost, the energy sector itself should be a massive engine for jobs and innovation, creating a whole ecosystem of companies that specialize in new technologies.

· **Environmental sustainability:** This is the non-negotiable one. The way we generate and use power must respect the natural world. If we don't ensure our processes are clean, we're essentially borrowing from a future we can't afford to pay back.

By balancing these three, we aren't just building a "greener" industry; we're building a more resilient society that can weather whatever comes next.

1.4 Energy units

Energy is delivered in many different fuels and sources and can be expressed in terms of volume, mass, energy or emissions.

Annex 1 contains conversion factors and energy units

1.5 Energy content

Conversions of fuel quantities from physical units to energy units require conversion factors expressing the heat obtainable from one fuel unit.

Annex 2 contains conversion factors in terms of energy content.

1.6 Emission factors for fuels

The table below shows emission factors for CO_2 produced from combustion of fuels. Definitions of energy units (kWh) and net calorific values (NCV) appear above. These emission factors include only direct CO_2 emissions from combustion of fuels and do not include indirect or upstream emissions, such as those from extraction, cultivation, transportation or processing of fuels.

These emission factors are for statistical purposes, such as calculating direct energy-related emissions on a sectoral and national level. The factors are not suitable for use under frameworks that are based on CO_2 equivalent of primary energy or life-cycle emissions: Energy Performance of Buildings Directive (EPBD); BER calculations; Public Sector Monitoring and Report; and greenhouse gas saving criteria under the Renewable Energy Directive. Factors to be used under the EPBD calculation framework are published separately under the BER Calculation methodologies.

SEAI does not currently provide emission factors for CH_4 and N_2O produced from combustion and recommends consulting the EPA's National Inventory Submissions (opens in a new tab) for details on sector-specific factors for CH_4 and N_2O.

Values for petroleum coke, milled peat, natural gas and electricity change annually. Unless otherwise stated, all values are calculated based on NCV.

1.6.1 Biomass fuels

The net emission of CO_2 from the combustion of biogenic carbon in sustainable biomass fuel (incl. solid biomass, biofuel, bioliquid and biogas) is considered to be zero, as it is assumed that the biomass itself absorbs an equal amount of CO_2 during growth as is emitted during combustion. Where biomass fuel is not sustainably produced, CO_2 emissions from combustion should be counted. This is consistent with guidelines for greenhouse gas reporting, such as the IPCC 2006 Guideline for National Greenhouse Gas Inventories & 2019 refinement (opens in a new tab) and EU Emission Trading System (opens in a new tab).

Table 1 shows the emission factors for liquid fuels, Table 2 the emission factors for solid fuels and Table 3 the emission factors for gas fuels. Data from IDAE Technologies [IDAE 2025].

Table 1. Emission factors for liquid fuels

LIQUID	gCO_2/kWh	gCO_2/MJ	$kgCO_2/kg$	$kgCO_2/l$	Note
Petroleum					
Crude oil	264.0	73.33	3.140	2.943	
Gasoline / petrol (100% petroleum)	251.9	69.96	3.119	2.311	
Kerosene	257.0	71.39	3.155	2.524	
Jet Kerosene	257.0	71.39	3.148	2.519	
Diesel / gasoil (100% petroleum)	263.9	73.30	3.174	2.683	
Residual fuel oil / fuel oil	273.6	76.01	3.134	2.951	
LPG	229.3	63.69	3.003	1.568	Assumes 70% propane & 30% butane by mas

Table 2. Emission factors for solid fuels

SOLID	gCO_2/kWh	gCO_2/MJ	$kgCO^2/kg$	Note
Fossil fuel				
Petroleum coke	345.0	95.83	3.075	Provisional value for 2023
Bituminous coal	340.6	94.60	2.634	
Anthracite	353.9	98.30	2.737	
Lignite	363.6	101.00	2.001	
Milled peat	475.6	132.12	0.717	Provisional value for 2023
Sod peat	374.4	104.00	1.363	
Peat briquettes	355.9	98.86	1.834	
Biomass				
Wood pellets & briquettes	-	-	-	See note above on biomass fuels
Wood logs & chips	-	-	-	See note above on biomass fuels

Table 3. Emission factors for gas fuels

GAS	gCO_2/kWh	gCO_2/MJ	$kgCO_2/m^3$	Note
Natural gas (GCV)	184.0	51.10	2.021	2023 values on GCV basis
Natural gas (NCV)	204.0	56.66	2.021	2023 values on NCV basis

1.7 Emission factors for electricity

The 'electricity consumption' factor published below includes scope 2 emissions (as defined in GHG Protocol Corporate Accounting and Reporting Standard (opens in a new tab)) from electricity generation, and scope 3 emissions from transmission & distribution losses, and from the plants' own electricity use. The study does not currently publish 'well to tank' factors for electricity, which account for scope 3 emissions from extraction, refining and transportation of fuels used for electricity generation.

Table 4 shows the emission factors for electricity. Data from IDAE Technologies [IDAE 2025].

Table 4. Emission factors for electricity

ELECTRICITY 2023	gCO_2/kWh	gCO_2/MJ	Note
Electricity consumption	254.8	70.77	2023 provisional value CO_2 per unit of electricity consumed Total CO_2 from electricity generation / total final consumption of electricity Use this factor to calculate the CO_2 corresponding to electricity consumption including generation, transmission and distribution losses, and own-use of electricity in power plants (scope 2 and 3 under the GHG Protocol).
Electricity generation	229.9	63.85	2023 provisional value CO_2 per unit of electricity generated Total CO_2 from electricity generation / gross electricity production (incl. net imports) Use this factor to calculate CO_2 for electricity generation only (scope 2 under the GHG Protocol).

1.8 Fuel densities

Conversion from volume (litres) to mass (tonnes) for liquid fuels requires the densities or specific volumes of the liquids. The most common fuels are shown here.

Table 5 shows fuel densities. Data from IDAE Technologies [IDAE 2025].

Table 5. Fuel densities

LIQUID	Density [kg/m3]	Specific volume [l/t]	Note
Petroleum			
Crude oil	937	1,067	
Gasoline / petrol (100% petroleum)	741	1,350	
Kerosene	800	1,250	
Jet Kerosene	800	1,250	
Diesel / gasoil (100% petroleum)	845	1,183	
Residual fuel oil / fuel oil	942	1,062	
LPG	522	1,915	Assumes 70% propane & 30% butane by mass
Biofuel / bioliquid			
Bioethanol	800	1,250	
Biodiesel ME	880	1,136	Methyl ester
Biodiesel HVO	846	1,182	Hydrotreated vegetable oil
Biodiesel CHVO	846	1,182	Co-processed hydrotreated vegetable oil
Biopropane	522	1,917	
Biojet HVO	800	1,250	Hydrotreated vegetable oil (jet fuel)
Blended petroleum & biofuel			
Road diesel (avg. biofuel content)	848	1,180	Average diesel-biofuel blend in 2023 (provisional)
Road petrol (avg. biofuel content)	744	1,343	Average petrol-biofuel blend in 2023 (provisional)

1.9 Primary energy conversion factors

Table 6 shows the energy conversion factors for electricity. All data are available in Annex 3.

Table 6. Energy conversion factors electricity

ELECTRICITY 2023	PE factor [-]	Note
Electricity consumption	1.888	- 2023 provisional value - Primary energy input per unit of available final energy consumption. - Electricity imports are not included in the calculation of this factor.
Electricity generation	1.706	- 2023 provisional value - Primary energy input per unit of electricity generated, before subtracting own use of electricity in power plants, and transmission & distribution losses. - Electricity imports are not included in the calculation of this factor.

2 Data and methods

2.1 Methodology

To define the methodology, the energy balance already prepared have been considered, as well as the criteria and considerations developed by the technical committee proposed by the Association of Spanish Energy Management Agencies (hereinafter EnerAgen). Based on this, a balance model has been proposed in accordance with the following points:

- The balance is of the final energy type.
- The periodicity is annual.
- The data is displayed in a two-dimensional table that has the following characteristics:

- The energy measurement units are toe, the conversion factors used to transform the own or physical units into energy are those indicated by IDAE (Industry for Diversification and Energy Saving) and collected in the corresponding point. [IDAE 2025].
- The format of the matrix is that recommended by Eurostat, adapted to the needs of the energy balance of in the place of study.

In this balance, the information presented appears structured in three large blocks, which separately collect the different energy flows that are generated in these phases of the energy cycle. These are:

1. **Production.** In this phase, the own energy resources or primary energy production are analysed, as well as energy import-export balances and annual stock variations until the gross domestic consumption of primary energy is obtained.

This last piece of information is essential for following trends in consumption, establishing self-sufficiency levels and making comparisons between different years and geographical or political environments through its relationship with economic indicators (Energy intensity based on domestic product rough).

2. **Transformation.** In this phase, the primary energy transformation processes are developed. It is the most complex part, where the successive transformations that the primary energy undergoes are considered, as well as the secondary energy recycled into other transformation processes, until it becomes final energy directly usable by the consuming sectors. The consumption of the transformations is also quantified, as well as the losses in distribution and shrinkage.
3. **Consumption.** Finally, in this phase a disaggregated structure of final energy consumption is contemplated by sectors of economic activity and final energy products, which, over a period of years, allows monitoring the evolution of final energy consumption. in each sector of activity and the different types of energy.

When talking about energy, we must distinguish between primary energy, final energy and useful energy:

- **Primary energy.** The one used to obtain other more refined forms of energy used at the end points of consumption.
- **Final energy.** Which is used at consumption end points for different purposes: thermal (produce heat), mechanical (produce movement), luminous (produce light), etc.
- **Useful energy.** The one that is really used at the end points of consumption, in which losses occur due to inefficiencies in energy use. For example, in the low consumption lamps the ratio between useful energy and final energy is much higher than in traditional incandescent lamps or, otherwise, the losses are many minors.
- Figure 3 shows the transformation and energy consumption: primary, final and useful energy.

There is energy that is used in its original form at the end points of consumption (industries, homes, means of transportation, etc.). This is the case, for example, of the gas used in domestic and industrial boilers. This is also the case of wind energy, where electricity is obtained directly from the wind without any subsequent transformation. In these cases, it is considered that the Primary energy is equal to final energy.

In other cases, a transformation of primary energy into final energy is carried out, whose example clearer are the thermal power plants, into which the energy contained in the fuel enters, obtains electricity and the difference between the output (final energy) and the input (primary energy) is lost.

The energy balances detail the process reflected in Fig. 3, that is, the way in which energy is produced, transformed and consumed, performing a breakdown of these flows by type of fuel/energy source and economic sector.

The most used unit is the ton of oil equivalent (toe), which is 10 million Kcal, as it is the unit in which the International Energy Agency (IEA) expresses its energy balances. In the graphs that deal specifically with electrical energy, the unit used is the MWh. The conversion from customary units to toe is based on the PCI (lower heating values) of the different fuels.

Table 7 shows the conversion factors that have been used in this study.

Table 7
Conversion factors used

Coal	**(toe/t)**
Coal	0,6162
Anthracite	0,6377
Petroleum coke	0,7050
metallurgical coke	0,7050
Petroleum products	**(toe/t)**
Fuel oil	0,960
Diesel A	1,035
Diesel B	1,035
Diesel C	1,035
Gasoline	1,070
Aviation kerosene	1,065
G.L.P.	1,130
Biofuels	**(toe/t)**
Biodiesel	0,879
Bioethanol	0,6401
Gas	
Natural gas	1 toe = 0,09 GCal P.C.S.
Electricity	1 MWh = 0,086 toe

2.2 Obtaining information

The data comes from the report of Government of Navarre about the energy balance of this state [navarre 2024].

- Solid fuels (coals and cokes)

Only the following fuels are considered:

- Metallurgical coke.
- Petroleum coke.
- Coal.
- Anthracite.

There is no own production of this type of fuel, so the supply of these comes entirely from abroad (Imports).

On the other hand, regarding final energy consumption, only a few companies in the industrial sector are consumers of this type of fuel and they are 100% located. These are the following:

- Calinsa
- Cementos Portland Valderrivas, S.A.
- Fagor Ederlan
- Magnesitas Navarras, S.A.
- Rockwool Peninsular, S.A.U.

These companies are within the Emission Rights Trading Regime (ETS) and have the obligation to report to the Department of Rural Development, Environment and Local Administration (hereinafter DRMAAL). Therefore, information on the consumption of this type of energy has been requested from said department.

- Petroleum products

Of the different types of products that this group includes, the following liquid derivatives and liquefied petroleum gases are considered:

- Fuel oil.
- Diesel C.

- Gasoline.
- Diesel A.
- Diesel B.
- Kerosene.
- Liquefied Petroleum Gases (LPG) packaged and in bulk.

As in the case of coal and coke, in this type of fuel there is a total dependence on the outside, given that in the place of study there is no production of these fuels.

The method of obtaining information for each of the fuels studied in this section is detailed below:

- Fuel oil: The global consumption published by the Corporation for Strategic Reserves of Petroleum Products (hereinafter CORES) is available in its "Hydrocarbon Statistical Bulletin"
- Diesel C: The total data on its supplies is obtained in the same way as fuel oil, through CORES.

As of 2018, information has been requested from CLH, the main party responsible for the distribution of PPL in in the place of study, being practically 100%. The data has been adjusted to the sectoral distribution provided by CLH.

The use of this fuel occurs mainly in the residential sector for air conditioning of homes.

A density of 0.84 Kg/l is used for unit conversion.

- Gasoline: The total data for this type of fuel is obtained in the same way as the previous fuels (CORES).

The total consumption of this fuel is allocated to sector 23 "Other Transport Companies".

A density of 0.75 Kg/l is used for unit conversion.

- Diesel A: In this case, like the previous one, the total data is obtained through the "Hydrocarbon Statistical Bulletin" of CORES.

The total consumption of this fuel is allocated to sector 23 "Other Transport Companies".

A density of 0.84 Kg/l is used for unit conversion.

- Diesel B: The total data is obtained in the same way as the previous fuels (CORES).

Starting in 2018, information has been requested from CLH, the most responsible for the distribution of PPL in the place of the study, with a percentage of 50. From the results analysed, it has been obtained that, although most of the subsidized diesel corresponds to sector 01 " Agriculture, Livestock, Forestry and Fishing, this fuel is also used for heating, to power industrial engines and construction.

A density of 0.84 Kg/l is used for unit conversion.

- Kerosene: In this case, the total data is obtained through the National Markets and Competition Commission (CNMC)

The total consumption of this fuel is allocated to sector 23 "Other Transport Companies".

- Liquefied Petroleum Gases LPG. (bulk and packaged): in this group, both bulk and packaged are considered Butane and Propane.

In this case, as with kerosene, the total data is obtained through the National Markets and Competition Commission (CNMC)

- Natural gas

This fuel comes entirely from abroad, since there is no own production.

The information on natural gas consumption is obtained through Ministry for the Ecological Transition and the Demographic Challenge (MITECO), where data related to the consumption of Natural Gas, sectorized, is provided. With this change the data is more reliable than in previous years.

The information on total consumption is compared with existing national statistics carried out by the National Competition Market Commission (CNMC).

On the other hand, there is information provided by companies that are within the Emission Rights Trading Regime (ETS) and have the obligation to report to the Department of Rural Development, Environment and Local Administration (hereinafter DRMAAL).

Additionally, sectoral distribution is also requested from Naturgy.

Crossing the consumption of the sources, the difference between them is practically nil.

- Electricity

Currently, the electrical energy consumed comes almost entirely from its own production through hydroelectric plants, wind farms, solar installations and thermal and cogeneration plants.

Since 2020, the data source has been changed to Spanish Electric Grid / Red Eléctrica Española (REE) and MITECO. This information is more reliable and obtains the data from a single source.

Additionally, the electrical consumption of the existing self-consumption and isolated installations has been considered. To do this, firstly, all existing installations from the BDFER database have been compiled, and subsequently, estimates of self-consumed electrical energy have been made.

- Biomass

Currently, the biomass consumed is divided between industrial biomass and biomass for uses in public and private residential and tertiary buildings.

Obtaining information on the consumption of this energy source is the most complex in the energy balance, mainly in the residential sector due to its atomization.

In the case of industrial biomass, information is obtained directly by requesting data from the main producing and distributing companies.

These companies are asked for biomass consumption data, breaking down, if possible, the part of it that originates in the place of the study and the part that comes from outside the Community.

Additionally, this year 2021, a new source of information has been incorporated. This is the Spanish Biomass Association (AVEBIOM), which has been requested data on import, export and consumption of biomass in in the place of study.

- Biogas

Currently, in the place of study there are conventional and cogeneration plants in which electrical energy or electrical energy and heat in the case of the latter are obtained from biogas. The most notable facilities are:

- Services of the Pamplona Region (Góngora)
- Commonwealth of La Ribera (El Culebrete)
- Services of the Pamplona Region (Arazuri)
- Bioenergía MENDY, S.L.
- HTN, S.L.

Agralco S. Coop. In 2022, information on Biogas consumption and generation of electricity and heat has been requested from MITECO.

Once the information obtained from the different companies has been prepared, the electrical energy production has been contrasted with the global data published by Red Eléctrica de España in its annual report “The Spanish electrical system”.

- Biodiesel

Currently, there are no active biodiesel production plants in the place of study.

Within this type of energy, Biodiesel is also considered, which is added to Diesel A in refineries.

To calculate this amount, CORES statistics will be used as a source of information, from which the average percentages published for national consumption will be obtained that will be applied to the consumption obtained for Diesel A.

- Bioethanol

As in the previous point with Biodiesel, this type of energy, although it is not produced in the in the place of study, is found in a mixture with the gasoline consumed and that comes from the different national refineries, so it is proceeds to its inclusion in the balance sheet.

The calculation of this data is carried out in the same way as Biodiesel, applying to the sale of Gasoline in the place of study, the same percentage provided by CORES for national consumption in its statistics.

- Solar thermal energy

To obtain production of this energy source, the annual data on the installed surface of thermal collectors is used and, considering an average production factor, it is transformed into the production results that are recorded in the corresponding row of Primary Energy Production.

The source of information to obtain this data will be the Industrial Planning, Energy Infrastructure and Mines Service, who also facilitates the disaggregation of the installed surface in the different sectors of activity.

- Geothermal

In this case, as in the previous one, the source of information for obtaining the production data of the facilities of this type of energy is the Industrial Planning, Energy Infrastructure and Mines Service, who also facilitates the disaggregation of the installed surface in the different sectors of activity.

3 Results

3.1 Energy balance

Below is a table with the final energy balance of the place studied for the year 2023.

The upper table (Available) shows where the various fuels/energy sources used come from: own or endogenous production (1) or exchanges (2). The sum of both factors gives the amount available for gross consumption or primary energy consumption (3).

The middle table (Transformation) reflects what happens to those fuels (natural gas, biomass and biogas) that, in part (4), are not used for final consumption, but are processed to obtain other forms of energy (electricity and/or heat) (5) in transformation plants (thermal and cogeneration).

Finally, the table below (Utilization) shows the final use of energy in the various sectors (11), once the exchanges (electricity export, 6), the consumption of the energy industry itself (7), the losses in the electrical transport and distribution network (8) and the possible non-energy uses (10) have been considered.

Table 8 shows the final energy balance.

Table 8
Final energy balance

Units: Tonne of oil equivalent (toe)			coals & cokes	petroleum & derivates	natural gas	electricity	biomass	biogas	biodiesel	bioethanol	solar thermal energy	g
Available	1	primary energy production				337221	126359	14480			2064	7
	1.1	Hydraulic				6059						
	1.2	Mini hydraulic				25014						
	1.3	Eolic				275484						
	1.4	solar photovoltaic				30663						
	2	recovery and exchanges					43387					
	3	available gross domestic consumption	76284	822303	1205262	337221	159097	14480	35526	1986	2064	7
Transformation	4	energy transformation entrance			763798		59460	13637				
	4.1	thermal centrals			667665		57171	11655				
	4.2	cogenerations			96133		2288	1983				
	5	energy transformation exit				461393						
	5.1	thermal centrals				393533						
	5.2	cogenerations				67860						
Consumption	6	exchanges and transfers				-356837						
	7	energy industry consumption				2780						
	8	transportation and distribution losses				45964						
	9	available for final consumption	76284	822303	441464	393033	99639	843	35626	1986	2064	7
	10	non-energy final consumption										
	11	final energy consumption	76284	822303	441464	393033	99638	843	35626	1986	2064	7
	11.1	agriculture	0	93695	1327	8822	8655	454	0	0	0	0
	11.2	industry	76284	38756	277537	216413	69764	389	0	0	52	3
	11.3	transport	0	664259	1402	5679	0	0	35626	1986	0	0
	11.4	administration and public services	0	1110	15598	18699	318	0	0	0	553	4
	11.5	domestic, trade and services	0	24484	145599	143421	20900	0	0	0	1459	2

3.2 Electricity generation

Below is a table showing the electricity generation for each energy source in toe.

The table shows that the demand has decreased by 7% compared to 2022. This is mainly due, as has happened at the national level, to the decrease in electricity exports, which in the case of Navarre has been reduced by 68%, going from 356,837 in 2022 to 211,925 in 2023.

Also highlight the notable increase in photovoltaic generation with an increase of 19% over the year 2022, mainly due to self-consumption and incentive policies for electricity generation facilities. this type. It is also relevant how the adjustment to demand has been carried out fundamentally on the cycles combined with a significant decrease over the year 2022.

On the other hand, we can see how exports have grown significantly in the last 10 years.

Moreover, the electricity generation of the last 5 years by type, practically all remain on a constant line, except wind and photovoltaic, which have grown. It is also seen as the energy source that fluctuates the most is combined cycles.

As renewable generation in the year 2023 has been higher than non-renewable generation, basically for those mentioned above. We see how in the year 2022, due to the energy crisis suffered in Europe due to the conflict between Russia and Ukraine, the countries had to generate more energy than usual to be able to export it to other countries like France. This excess generation mainly was produced through the combined cycles.

Table 9 shows the electrical generation by type of generation and year (toe).

Table 9
Electrical generation by type of generation and year (toe)

Units: toe	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Hydraulics	57.104	45.941	38.718	29.240	56.846	43.803	46.399	40.046	31.073	33.441
Wind	208.564	226.903	221.224	232.458	202.014	206.212	204.500	275.421	275.484	252.363
Solar photovoltaic	25.645	26.27	25.42	27.348	25.456	27.756	26.219	29.452	30.663	37.644
Other renewables	24.152	26.885	23.969	25.066	26.296	27.394	24.398	26.978	29.333	21.142
Renewable generation	315.465	326.006	309.337	314.112	310.612	305.165	301.516	371.896	366.554	344.589
Combined cycle	26.065	56.095	107.526	116.702	52.564	266.105	195.299	309.018	370.224	219.707
Cogeneration	67.216	67.258	78.365	78.246	78.642	82.719	71.560	71.560	61.837	60.996
Non-renewable generation	93.282	123.353	185.891	194.948	131.206	348.824	266.858	380.577	432.061	280.703
Exchanges and Transfers	-4.783	-36.686	-74.683	-78.948	-6.397	-199.029	-151.936	-310.879	-356.837	-211.925
Final Demand	403.964	412.673	420.545	430.112	435.421	454.959	416.439	441.595	441.777	413.368

Table 10
Installed power (MW) and production (MWh) in self-consumption. Data updated as of 03/27/24

Self-consumption	Until 2019	2020	2021	2022	2023
Installed Power (MW)	7,4	8,2	27,7	6 0,4	6 4,9
Installed Accumulated Power (MW)	168,5				
Estimated Production (MWh)	141391				

Table 10 shows the growth of self-consumption. We can see how until 2019 there were barely 7.4 MW installed and how by 2023 the total installed power amounts to 168.5 MW. This has meant that by 2023, the estimated production has been 141,391 MWh, representing 3% of the total electrical energy generated, discounting exports.

Table 10
Energy conversion factors for liquid fuels

LIQUID	PE factor [-]	Note
Petroleum		
Crude oil	-	
Gasoline / petrol (100% petroleum)	1.1	
Kerosene	1.1	
Jet Kerosene	1.1	
Diesel / gasoil (100% petroleum)	1.1	
Residual fuel oil / fuel oil	1.1	
LPG	1.1	
Biofuel / bioliquid		
Bioethanol	1.1	
Biodiesel ME	1.1	Methyl ester
Biodiesel HVO	1.1	Hydrotreated vegetable oil
Biodiesel CHVO	1.1	Co-processed hydrotreated vegetable oil
Biopropane	1.1	
Biojet HVO	1.1	Hydrotreated vegetable oil (jet fuel)
Blended petroleum & biofuel		
Road diesel (avg. biofuel content)	1.1	
Road petrol (avg. biofuel content)	1.1	

Table 11
Electric Generation Power by type and year (MW)

Units: MW	2020	2021	2022	2023
Hydraulics	238	238	238	238
Wind	1.298	1.305	1.355	1.557
Solar photovoltaic	181	204	220	289
Other renewables	49	49	51	51
Renewable generation	1.766	1.796	1.863	2.135
Combined cycle	1.236	1.236	1.236	1.236
Cogeneration	135	136	136	136
Non-renewable generation	1.371	1.372	1.372	1.372
Total Installed Power	3.137	3.168	3.235	3.507
% Renewable Power	**60.9%**			

Table 11 shows us the installed power depending on the source, during the last 4 years. As can be seen, the installed power has grown by 7.7%, representing 12.7% of the installed power with renewable sources. The increases are due to wind and photovoltaic energy, with 13% and 23.9% respectively.

Table 11
Energy conversion factors for solid fuels

SOLID	PE factor [-]	Note
Fossil fuel		
Petroleum coke	1.1	
Bituminous coal	1.1	
Anthracite	1.1	
Lignite	1.1	
Milled peat	1.1	
Sod peat	1.1	
Peat briquettes	1.1	
Biomass		
Wood pellets & briquettes	1.1	
Wood logs & chips	1.1	

3.3 Consumption of petroleum products

Table 12 shows the consumption of petroleum products by fuel type over the last 4 years. As is known from previous years, petroleum products account for more than 40% of final energy consumption.

Table 12
Energy conversion factors for gas fuels

GAS	PE factor [-]	Note
Natural gas (GCV)	1.1	
Natural gas (NCV)	1.1	

We can see how consumption with respect to the year 2022 has been reduced by 4.84%, standing at 777,041 TOE for the year 2023. By type of fuel, we can see how the one that has decreased the most compared to the previous year is Diesel C, which compared to 2022 has been reduced by 18.65%, although in terms

In absolute terms, the reduction in Diesel A is notable. As usual, the higher fuel consumption corresponds to this type, used for transportation

Table 12
Consumption of Petroleum Products by type and year

Unidad: TEP	Gasoline	Diesel A	Diesel B	Diesel C	Biodiesel	Bioethanol	Fuel oil BIA	TOTAL
2020	57.942	506.835	105.248	15.209	32.152	1.851	1.941	721.179
2021	90.195	658.595	116.149	14.157	42.922	2.079	2.053	926.148
2022	82.874	577.714	107.680	7.585	35.526	1.986	3.159	816.524
2023	84.441	558.879	87.602	9.784	31.468	2.255	2.613	777.041
% 2023/2022	1,89%	-3,26%	-18,65%	28,99%	-11,42%	13,53%	-17,28%	-4,84%

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3.4 Average price of electrical energy

Table 13 shows the energy prices by month and year.

Table 13
Average price of electricity per month and year (€/MWh). Tax included.

Units: €/MWh	2020	2021	2022	2023
January	46,96	70,3	210,07	89,68
February	41,4	36,82	205,9	142,91
March	33,24	52,02	294,53	102,79
April	25,3	71,54	203,03	84,87
May	27,35	74,05	195,75	84,25
June	36,02	87,23	203,27	101,96
July	40,02	96,41	216,52	98,57
August	41,06	111,34	250,89	104,7
September	47,45	160,71	216,27	112,53
October	42,65	209,29	161,29	104,44
November	48,11	203,8	131,9	145,96
December	49,02	252,19	145,96	85,38

As we can see, it was in 2022 when the price of energy was highest, because of the conflict between Russia and Ukraine. These are prices well above the average of previous years and which reached a maximum in March of that year, reaching almost €300/MWh.

We can see how in 2023, the price of energy has remained more stable with an approximate average price of €100/MWh.

3.5 Average price of fuels derived from petroleum

Table 14 shows the average price of petroleum fuels by type and year (€/L). Tax included.

Table 14
Average price of petroleum fuels by type and year (€/L). Tax included.

€/L	Gasoline 95	Gasoline 98	Diesel A	Diesel B	Diesel C
2020	1,17	1,33	1,06	0 ,68	0,78
2021	1,37	1,53	1,23	0 ,81	0,85
2022	1,80	1,95	1,79	1 ,37	1,42
2023	1,65	1,82	1,61	1 ,23	1,20
% 2023/2022	-8,32%	-6,43%	-10,20%	-10,32%	-15,14%

Table shows the price in €/L of the different fuels derived from petroleum. In addition, the table shows their evolution during the last 4 years. The table shows a considerable decrease in the price of fuels in general compared to 2022, which, as in the case of electricity, has its main reason in the Russian-Ukrainian conflict.

The most pronounced decreases are in Diesel C (15.14%) and 10.32% in Diesel B. However, they are higher prices than in previous years (2021 and 2020).

4 Conclusions

This report provides an analysis of the energy balances of an urban population of 650000 inhabitants from 2019, the year before COVID'19, and 2023, a period crucial on the path towards the energy transition and the search for environmental sustainability.

The results demonstrate the commitment of this urban population to renewable energies, and to the implementation of policies and projects that promote the responsible use of energy resources.

During 2023, the region continued its upward trajectory towards the diversification and decarbonization of its energy matrix, driven by a combination of internal and external factors, including technological advances, government policies and changes in market demands.

Through this study, the most used energy sources and consumption levels are examined, exploring production and consumption trends, and providing data at European and national level.

These findings reveal not only significant advancements in renewable energy adoption but also the importance of robust policies that support sustainable practices. The commitment to transitioning away from fossil fuels is evident, yet challenges remain in achieving complete energy independence and security.

Moreover, the analysis emphasizes the need for continuous education and community involvement to foster a culture of sustainability. By engaging citizens and stakeholders, the region can ensure that energy initiatives are inclusive and responsive to local needs.

Looking ahead, it is crucial to invest in innovative technologies and infrastructure that enhance energy efficiency and integrate renewable sources effectively. As urbanization continues to rise, prioritizing smart grid solutions will enable better management of energy resources and improve overall resilience against potential disruptions.

In conclusion, this report underscores the pivotal role of coordinated efforts among governments, industries, and communities in realizing a sustainable energy future. The path forward must be marked by collaboration, adaptability, and a shared vision for environmental stewardship and economic vitality.

Declarations

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Authors' Contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Dr. María Yoldi Sangüesa. The first draft of the manuscript was written by Dr. María Yoldi Sangüesa and Dr. Mariano González García commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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Ethical Approval*

This is not applicable

Consent to Participate*

This is not applicable

Consent to Publish*

This is not applicable

Competing Interests

The author certifies that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

Data Availability Statement

No data, text, or theories by others are presented as if they were the author's own. Proper acknowledgements to other works must be, quotation marks are used for verbatim copying of material, and permissions secured for material that is copyrighted.

The datasets used and/or analysed during the current study available from the corresponding author on reasonable request.

Clinical trial number

This is not applicable

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Figures

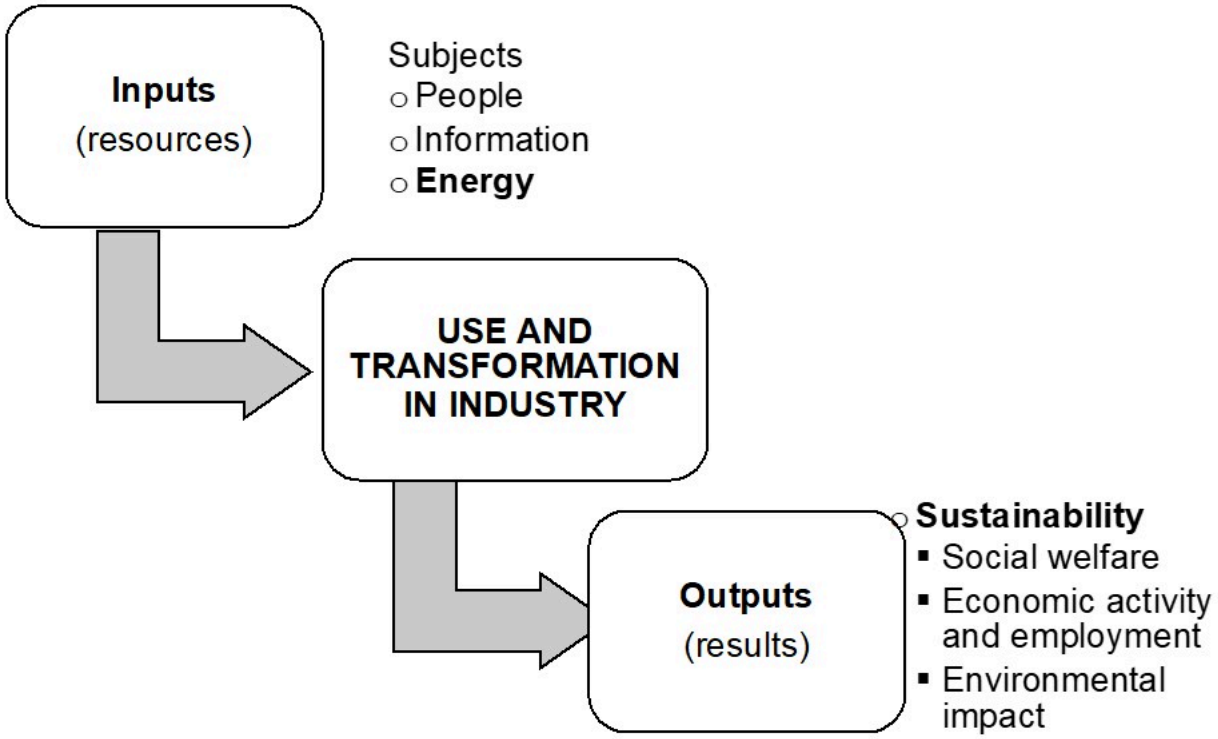


Figure 1

The industry as a socio-economic system

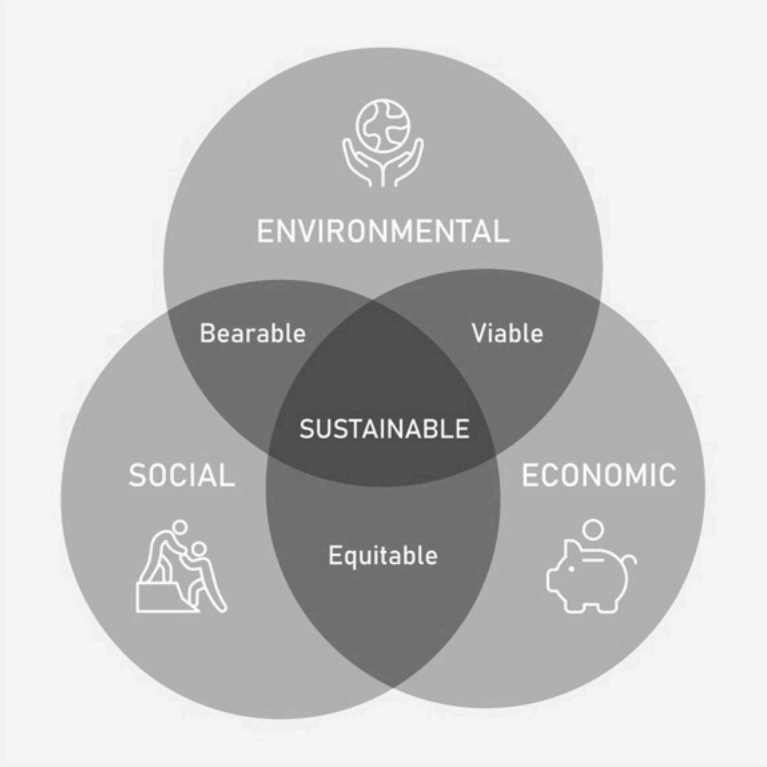


Figure 2

The three pillars of sustainability

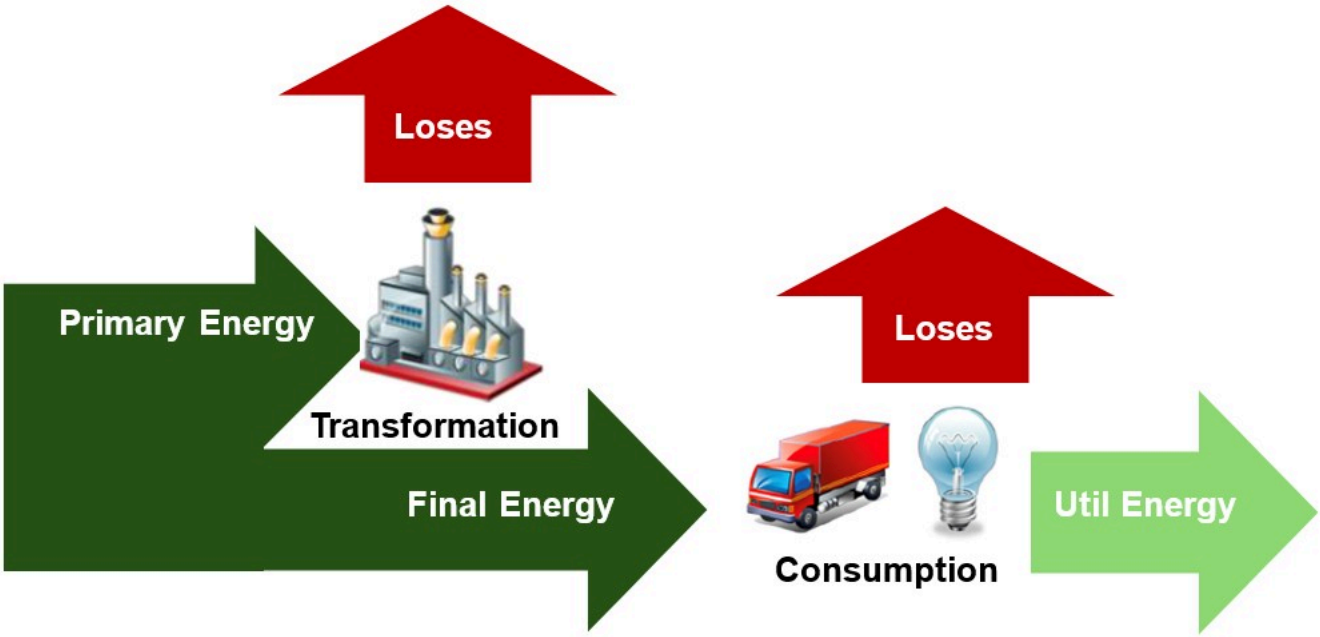


Figure 3

Primary, final and useful energy. Transformation and energy consumption.

Supplementary Files

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- Annexes.docx