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ORIGINAL PAPER

Twenty years of energy policy in Europe: achievement of targets and lessons for the future

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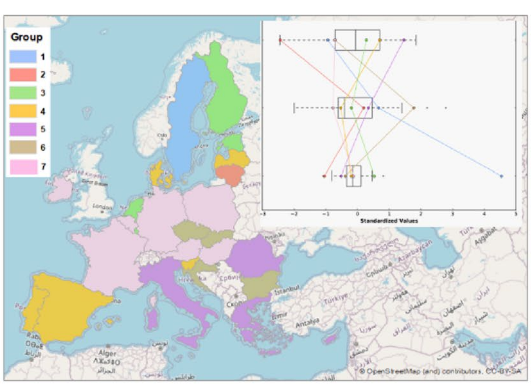
Abstract

The different energy transition efforts in the EU-27 countries are analysed, paying special attention to the achievement of set energy targets and the real influence on energy dependence and GHG reduction. Various methodologies were used, ranging from construction of timelines to geo-statistical analysis using Geographic Information Systems (GIS) and the implementation of machine learning techniques and models, using R. The results show how different modifications of the energy saving and efficiency targets, along with lower power consumption due to the COVID pandemic, resulted in that although most of the EU-27 countries have achieved their saving and efficiency targets, this has not been reflected in a real reduction in consumption (compared to 1990 levels). In addition, the fulfilment of the objectives has not resulted in a reduction in energy dependence, generating a false sense of security and satisfaction in the fulfilment of the targets. Concerning GHGs, almost all EU-27 countries decrease their GHG emissions per capita compared to 2000 (with the exception of Lithuania, Bulgaria, Croatia and Latvia), with this decrease being mainly related to the fulfilment of renewable energy targets in transport. The conclusion highlights the need to make greater efforts to achieve saving and efficiency in the near future; otherwise, higher power consumption via renewable energy sources, while helping meet future increases in energy demand, will not impact the reduction in energy dependence compared to current levels.

Graphical abstract

ACHIEVEMENT ON ENERGY TARGETS (RE, RES IN TRANSPORT AND ENERGY SAVINGS)



CONTRIBUTION TO GHG

MODEL	BEST MODEL	ADJUSTMENT	VAR. IMPORTANCE (ENERGY SAVINGS/RES/RES IN TRANSPORT)
Lithuania and Sweden not considered			
SVR	Radial; C=1; ε=0.5; γ=0.2	**0.995** (RSME=0.245)	(0.139, 0.321, 0.540)
All countries considered			
SVIR	Radial; C=1; ε=0.4; γ=0.2	0.487 (RSME=1.994)	(0.367, 0.288, 0.445)

CONTRIBUTION TO ENERGY DEPENDENCE

MODEL	BEST MODEL	ADJUSTMENT	VAR. IMPORTANCE (ENERGY SAVINGS/RES/RES IN TRANSPORT)
Lithuania, Sweden, Denmark, Netherlands, and Malta not considered			
SVR	Radial; C=1; ε=0.5; γ=1	**0.794** (RSME=7.785)	(0.063, 0.147, 0.790)
All countries considered			
ANN	3-1-1; δ=0.15	0.219 (RSME=37.40)	(0.181, 0.361, 0.457)

Achievement of energy transition targets. Contribution to the reduction in greenhouse gases and energy dependence.

Keywords Energy transition · Renewable energies · Saving and efficiency · Machine learning · Geographic Information Systems

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Introduction

The concern about ensuring countries' energy supply and efforts to transition to a more efficient, safe, and diverse energy system have shaped a very conducive context for the development of renewable energies (REs) in Europe (Frolova & Pérez 2008; Díaz et al. 2019). Furthermore, improving energy efficiency and renewable energies has been identified as effective measures to tackle environmental and climate change. While the prominent role of energy efficiency is recognised with the guiding principle "Energy Efficiency First" (Economidou et al. 2022; Mandel et al. 2022), renewable energies become the key, not only for development and social welfare, but also for the future sustainable economy (Saad and Taleb 2018).

At EU level, each member state has taken a different approach to promoting renewable energies, in line with the targets set for 2020, 2030 and 2050, making feed-in tariffs an important instrument for their inclusion in energy demand (Bersalli et al. 2020; Fleck and Annatolitis 2023).

Now that 2020, the last year in a target achievement period, is over, it becomes necessary to discern the efforts' real impact on energy production and consumption habits as well as their repercussions on supply security, energy dependence and slowing climate change, measured in terms of lower greenhouse gas (GHG) levels. In fact, the need to guarantee the supply, along with the sharp rise in electricity prices in Europe in recent years, aggravated by the invasion and war in Ukraine, have led to fast-track but critical decisions that will undoubtedly have economic, social and environmental repercussions in the years to come. Indeed, in May 2022 the European Commission proposed in its communication on the REPowerEU Plan (EC 2022a) the development of accelerated project authorisation procedures, the aim being to keep increasing the target for energy production using renewable energies, up to 45% by 2030. That will imply a major increase in deployment of renewable energies in the next several years, which has led to the development of specific legislation such as Regulation (EU) 2022/2577 (DO 2022) on making the requirements for installing RE facilities more flexible. Project processing will be made easier by the establishment of 'specific renewable energy zones' planned with strategic environmental assessment (SEA) and exemption from environmental impact assessment (EIA) of projects, reducing environmental obligations and the respective public participation.

Various authors have analysed the impact of rapid and disorderly introduction of renewable energy plants on territories and the landscape (Díaz et al. 2016; Díaz et al. 2018; Frolova et al. 2019) and on social acceptance (Wustenhagen et al. 2007; Devine-Solangi et al. 2015; Wright et al. 2017; Labussière y Nadaï 2018; Brudermann et al. 2019; Batel 2020), even with a more solid framework for public participation and environmental obligation. Those impacts are accordingly expected to multiply in coming years. In fact, the EU energy and climate policies are doubled together, with FIT for 55% package (EC 2021).

The purpose of this paper is to contribute towards this goal by analysing the drivers and barriers to the achievement of the EU energy and climate policy objectives in Europe. To that end, stages in the development and implementation of renewable energies are identified, contextualising them with the targets set for saving and efficiency. The extent of achievement of the set targets by the EU-27 and by the different member states is examined, along with their effect on energy dependence and GHG emissions.

In addition, the studies conducted by the European Commission on fulfilment of the targets for energy saving and efficiency (EC 2022b) and for renewable energies (EC 2022c), both published in November 2022, the bibliography contains few studies on attainment of the energy objectives for the EU-27 in 2020, perhaps because it is a recent occurrence. They can be grouped in three key points: analysis of achievement and evolution of one of the set targets (Economidou et al. 2022; Stec and Grzebyk 2022); assessment of the impacts of one of the targets on a pillar of the energy policy (Wang et al. 2022); and assessment of the feed-in tariffs' impact on achieving the targets (Fleck and Annatolitis 2023).

This paper focuses on analysing the extent of achievement of three key targets studied (energy saving and efficiency, percentage of consumption of renewable energies and percentage of consumption of renewable energies in transport) and their impact on two pillars of energy policy in the EU (reduction in energy dependence and of GHGs).

Data and methodology

The methodology carried out to achieve the stated objectives had three clearly distinct phases:

- In the first phase, the policies, regulations and extent of the energy transition targets' fulfilment at European level are reviewed. The use of timelines will facilitate examination of legal, political and administrative processes and structures that affect decision-making concerning implementation of the respective strategies.

Table 1 European milestones influencing Energy Transition (2000–2010)

2001	2002	2003	2006	2007	2009	2010
- Directive 2001/77/EC	- Ratification protocol of Kyoto - Directive 2002/91/EC	- Directive 2003/30/EC -Directive 2003/54/EC -Directive 2003/96/EC	- Directive 2006/32/EC	- Renewable Energy Road Map COM(2006) 848 final -An Energy Policy for Europe. COM(2007) 1 final - Gas crisis	-Directive 2009/28/EC -Effort Sharing Decision (DDE) no. 406/2009/EC European Energy and Climate Package (EU 2009)	-Directive 2010/31/EU

Source: Own preparation based on European regulations and planning

This departure point for that review will be the year 2000. Although Europe's commitment to renewable energies began earlier, no community directives were developed until that year.

- During the second phase, the achievement of set targets for renewable energies and for energy saving and efficiency is assessed for the EU-27. Information from Eurostat databases is essential to that end and will be processed and depicted using a GIS (in this case ArcGIS 3.10. of ESRI). However, it should be noted that the data collection process has been complex because the EU's own statistical website (Eurostat) contains information that differs depending on which data table is downloaded. For this work, authors have mainly used the data published in the Energy datasheet: EU countries updated to April 2023 (Eurostat 2023).

  Once the achievement of each target has been analysed by country, a group analysis will be conducted using the Grouping Analyst tool included in the Statistical Analyst module. This exploratory analysis tool carries out a classification procedure meant to find natural multivariate clusters in the data (ESRI 2021). The countries can thus be classified according to their fulfilment of the key targets analysed.
- In the third phase, different regression techniques are applied to analyse the real extent of the results obtained and the respective contribution to achieving the targets for reduction in GHG emissions and energy dependence. Software R 4.1.3. was used to develop this stage, and the best parameter combinations were tested in each of the proposed models: linear regression, support vector regression (Smola and Schölkopf 2004), random forest (Segal 2004) and artificial neural network (Specht 1991). These models were applied to reductions of GHG emissions and energy dependence as explained variables, using the achievement levels of each indicator as explanatory variables.

Stages in European energy policy

The analysis of European energy policy's evolution enables three distinct stages to be discerned, classified according to the different steps taken in the legislative and planning context at European level. Each of them will be examined in depth.

First stage (2000–2010)

This stage follows the inertia in efforts to accomplish what was set out in the Green Paper on Energy (European Commission –EC-, 1996) and the White Paper of 1997 (EC, 1997). It was the approval of Directive 2001/77/EC (European Parliament and the Council –EPC- 2001), on promotion of electricity generated from renewable energy sources in the internal electricity market that laid the foundation of a future community framework for promotion and use of renewable energies to produce electric power (Table 1). The Directive required member states to set indicative national goals for renewable electricity consumption and to take appropriate actions to meet them. Subsequently published were Directive 2003/54/EC (EPC 2003a), repealing Directive 96/92/EC (EPC, 1997), which established common rules concerning the generation, transport, distribution and supply of electricity; Directive 2003/96/EC (EPC 2003a), restructuring the community system for taxation of energy products and electricity; and Directive 2003/30/EC (EPC 2003b), on promoting use of biofuels and other renewable fuels for transport.

Concerning energy efficiency, in December 2002 the European Parliament and the Council adopted the Directive 2002/91/EC, Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings (EPC 2002), which sets out measures to act on improving the energy efficiency of buildings. This Directive was subsequently recast after a long legislative process between 2008 and 2010, resulting in the Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (EPC 2010), which is the main EU legislative instrument to reduce the energy consumption in new and existing buildings.

Later, the Directive 2006/32/EC (EPC 2006) facilitates the enhancement of energy efficiency in Member States through indicative targets, incentives, and institutional, financial, and legal regulations to remove barriers and market failures that hinder efficient energy end-use, resulting in cost-effective improvements.

This Directive created the conditions for the development and promotion of a market for energy services and providing energy efficiency improvement measures for final consumers. It provided for the submission by Member States of a first Energy Efficiency Action Plan (EEAP) in 2007 (followed by another in 2011 and 2014), in which each Member State should set a national indicative energy savings target (Economidou et al. 2022).

From the environmental standpoint, the concern about nonfulfillment of the Kyoto targets (ratified by the EU in 2002), along with the 2007 European gas crisis (Maltby 2013; Rodríguez-Fernández et al. 2020) and the need for a political compromise to ensure compatible energy targets for the European Union, drove the support for renewable energies throughout this stage and the energy efficiency policies. In addition, the EU emission trading scheme, a cornerstone of the EU climate policy, was adopted in 2003 and started operating in 2005 (Bertoldi 2022). In 2007, the European Union accordingly developed a set of community measures which highlight the importance of establishing an energy policy for Europe (EC 2007), based on achieving the following targets by 2020: 20% reduction in primary energy consumption compared to the forecasts for that year; increasing by up to 20% the percentage of renewable energies in total energy consumption; and lowering GHG emissions by at least 20%.

To help the member states achieve the 2020 targets for GHG emissions, the EU adopted the European Energy and Climate Package (EU 2009) in 2009. It defined a single target at EU level for GHG emissions and annual national targets for the member states up to 2020, based on the Effort Sharing Decision[1] (EPC 2009a). As for renewable energies, the Directive 2009/28/EC (EPC 2009b) –RED I-, which formed part of that package, set binding targets for each EU member state as well as indicative targets for 2011–2020.

[1] EPC (2009a). Effort Sharing Decision (DDE) no. 406/2009/EC sets annual greenhouse gas emission targets for the member states during the 2013–2020 period. Those targets refer to emissions from most of the sectors not included in the system for trading EU emission rights, such as transport, buildings, agriculture and waste. Not included are emissions from land use, land use change and forestry (LULUCF), nor international maritime transport.

Second stage: 2011–2016

At the beginning of this stage, the conclusions of the European Council of 4 February 2011 (European Council 2011) admitted that progress was not being made towards the Union's energy efficiency target and that resolute actions were required to take advantage of the considerable potential for boosting energy saving in buildings, transport and production and manufacturing processes.

Directive 2012/27/EU (EPC 2012) on energy efficiency was published in October 2012. Its aim was to create a new common framework to promote energy efficiency in the Union. Additional saving targets for the 2014–2020 period were established (Table 2). These targets implied a 20% reduction in EU primary and final energy consumption by 2020, but this time compared to energy consumption forecast in the 2007 PRIMES (price-induced market equilibrium system) scenario for 2020 (EC 2022b). To achieve this goal, each member state would need to establish an indicative national energy efficiency objective, based on primary or final energy consumption, primary or final energy savings, or energy intensity. The member states would take into account (a) that the Union's energy consumption in 2020 could not be more than 1,474 Mtoe of primary energy or 1,078 Mtoe of final energy, (b) the measures envisaged in the directive, (c) the steps taken to reach the national energy saving targets adopted per article 4, paragraph 1, of Directive 2006/32/EC (EPC 2006), and (d) other measures meant to promote energy efficiency in the member states and at Union level. Additionally, national circumstances affecting primary energy could also be considered, such as the remaining potential for cost-effective energy saving, GDP evolution and forecasts, changes in energy imports and exports, progress in all renewable energy sources, nuclear energy, carbon capture storage, and emissions trading and early action.

In 2013, due to tensions and imbalances seen in the energy sector and pressures from some member states, the green paper titled "A Framework for Climate and Energy Policies in 2030" (EC 2013) was published. The communication on "A Strategic Climate and Energy Framework for the 2020–2030 Period" (EC 2014) was also presented, proposing non-renewal of the national binding targets for renewable energies after 2020 and that only a mandatory Union-level target should be established, whereby 27% of energy would be of renewable origin in 2030, with flexibility for member states to set national objectives. Moreover, the states were provided with guidelines so that the RE objectives could be attained in line with parameters that ensure the system's stability; it was proposed that preference be given to tenders, regulated premiums and quota obligations with respect to the regulated fixed prices (Perez 2016).

Table 2 European milestones influencing Energy Transition (2011–2016)

2011	2012	2013	2014	2015	2016
Conclusions European Council	Directive on energy efficiency 2012/27/EU	Green paper "A Framework for Climate and Energy Policies in 2030" [COM(2013)0169]	"A Strategic Climate and Energy Framework for the 2020–2030 Period" [COM(2014)0015]	Directive (EU) 2015/1513 A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy. COM(2015) 80 final París Agreement (Dec, 2015)	COM(2016)0860 "Clean Energy for All Europeans" Proposal on promotion of use of energy from renewable sources

Source: Own preparation based on European regulations and planning

This greater share of renewable energy in the EU should encourage a greenhouse gas reduction target of 40%. Also, "the question of how best to deliver the optimal energy savings in 2030 will be analysed in greater detail in a review of the Energy Efficiency Directive to be concluded later in 2014" (EC 2014, 2.3).

Directive (EU) 2015/1513 (EPC 2015) was approved in 2015, amending Directive 2009/28/EC, thereby stipulating that biofuels used to meet the RE targets should mandatorily comply with sustainability criteria (ensuring a reduction in at least 35% in GHG emissions versus fossil fuels). This Directive also limits the quota for energy from Review originating in crops planted in farmland as main crops basically for energy purposes to at least 7% of final energy consumption for transport in 2020, the aim being to protect food-purposed croplands.

It is also important to note that this period saw the adoption of the Paris Agreement, a legally binding international treaty, signed by the EU, that superseded the Kyoto Protocol and in which many countries agree to limit global warming to a level significantly below 2 degrees Celsius. This further strengthened the EU's energy and climate policies. In the run-up to the Paris COP, countries agreed to limit global warming below 2 degrees Celsius. This agreement is known as Intended Nationally Determined Contributions (INDCs) (Bertoldi 2022; Forsell et al. 2016).

In late 2016, the commitment to renewable energies intensified. In a framework broader than that of the Union's energy strategy (EC 2015), the Commission presented the legislative package titled "Clean Energy for All Europeans" (EC 2016), also known as the 'winter package', marking a new drive towards the Union's energy transition; the Union directives on renewable energies and energy efficiency were reviewed and proposals put forward for a new design of the energy market, which should be suitable for renewable energies. The package included targets for 2030, at least achieve a 27% share of renewable energy and 30% energy efficiency, which will enable the EU to reach the 2030 targets for greenhouse gas emission reductions and energy and renewable energy targets for 2030. A strong improvement in energy efficiency is necessary if the EU is to meet the Paris Agreement, and it is also important as part of energy security.

Unlike 2020 framework, the EU's aim for renewable energies would no longer be based on binding national targets but should rather be achieved in a joint effort with a new governance system.

Third stage (2017–2020)

In Europe, at the end of 2016 (Table 3), some experts expressed in the Renewable Energy Progress Report concern that the 2020 targets would not be met (EC 2017;

Table 3 European milestones influencing Energy Transition (2017–2020)

2017	2018	2019
Renewable Energy Progress Report COM(2017) 57 final	Directive (EU) 2018/2001 Directive (EU) 2018/844 Directive (EU) 2018/2002 UN Climate Change Conference (COP24)—Paris Rulebook (in process)	Directive (EU) 2019/944 Regulation

Source: Own preparation based on European regulations and planning

Hinrichs-Rahlwes 2019), with even some of the leading countries, such as Germany and Spain, having little chance of catching up by 2020 (Panarello & Gatto 2023).

The Brexit vote and its implications on budget availability for emission projects, the election of Donal Trump as president of the USA and his declaration as a climate change denier, together with rising oil prices, will influence EU energy policy (Fernández 2018).

The following directives are noteworthy in line with the "Clean Energy for All Europeans" package, which was a significant move towards implementing the Energy Union strategy, released in 2015:

- Directive (EU) 2018/2001 (EPC 2018a)—REDII- on promoting use of energy from renewable sources once again set national objectives introducing new elements. Above all, it established a main target for EU RES in 2030 of at least 32.5% (compared to projections of forecast energy use in 2030), with a clause for a possible upward revision in 2023. It also defined the concept of the 'renewable energy community' to share energy in proximity via low and medium voltage networks. This concept would be included and broadened in Directive (EU) 2019/944 (EPC 2019a) of 5 June 2019, on common rules for the internal electricity market, which defines the figure of citizens' energy community and implies a clear commitment to distributed generation and demand flexibility through aggregators.
- Directive on Energy Efficiency 2018/2002 (EPC 2018b) was also agreed to update the policy framework to 2030 and beyond. The EU must achieve collectively the energy efficiency target for 2030, at least 32.5%, relative to the 2007 modelling projections.
- Directive 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency (EPC 2018c), where among other issues, Article 2 states that each Member State shall develop a long-term strategy to support the renovation of its national residential and non-residential buildings stock, both public and private, transforming them into energy-efficient and decarbonised building stock by 2050, facilitating the cost-effective transformation of existing buildings into nearly zero-energy buildings.

Furthermore, under the Regulation on Governance of the Energy Union and Climate Action (EPC 2019b), each EU country should establish a 10-year integrated national energy and climate plan (NECP) for 2021-2030 which indicates how it intends to contribute to the 2030 targets for energy efficiency, renewable energies and greenhouse gas emissions. Moreover, in December 2018, the operational details for the practical implementation of the Paris Agreement (Paris Rulebook) were agreed in Katowice (Poland) at the United Nations Climate Change Conference (COP24) and finalised at COP26 in Glasgow, Scotland, in November 2021 (United Nations).

Results and discussion

Evolution and fulfilment of the set targets—EU-27

Table 4 shows the evolution of final energy consumption and the share of renewable energy consumption for the EU-27 at each of the stages.

With respect to lower final energy consumption, throughout the first and second stages the EU-27 experienced an increase over the 1990 levels. It was much higher in the first stage (7.6%) than in the second stage (2.6%), due to the fact that in the second stage the EU-27 member states were severely affected by the global economic crisis. Despite this, Bertoldi and Mosconi (2020) stated that energy consumption in 2013 in Europe would have been about 12% higher in the absence of energy efficiency policies. It was not until the third stage, between 2017 and 2020, that the trend was reversed, with energy consumption falling by 4.8% from 1990 levels, mainly due to the COVID-19 effect in 2020, which explains the atypical drop in final energy consumption that year, compared to 2019 (EC 2022b).

In terms of target achievement, the country-by-country analysis (Fig. 1) shows the extent of fulfilment of the renewable energy target for transport; 14 of the 27 countries did

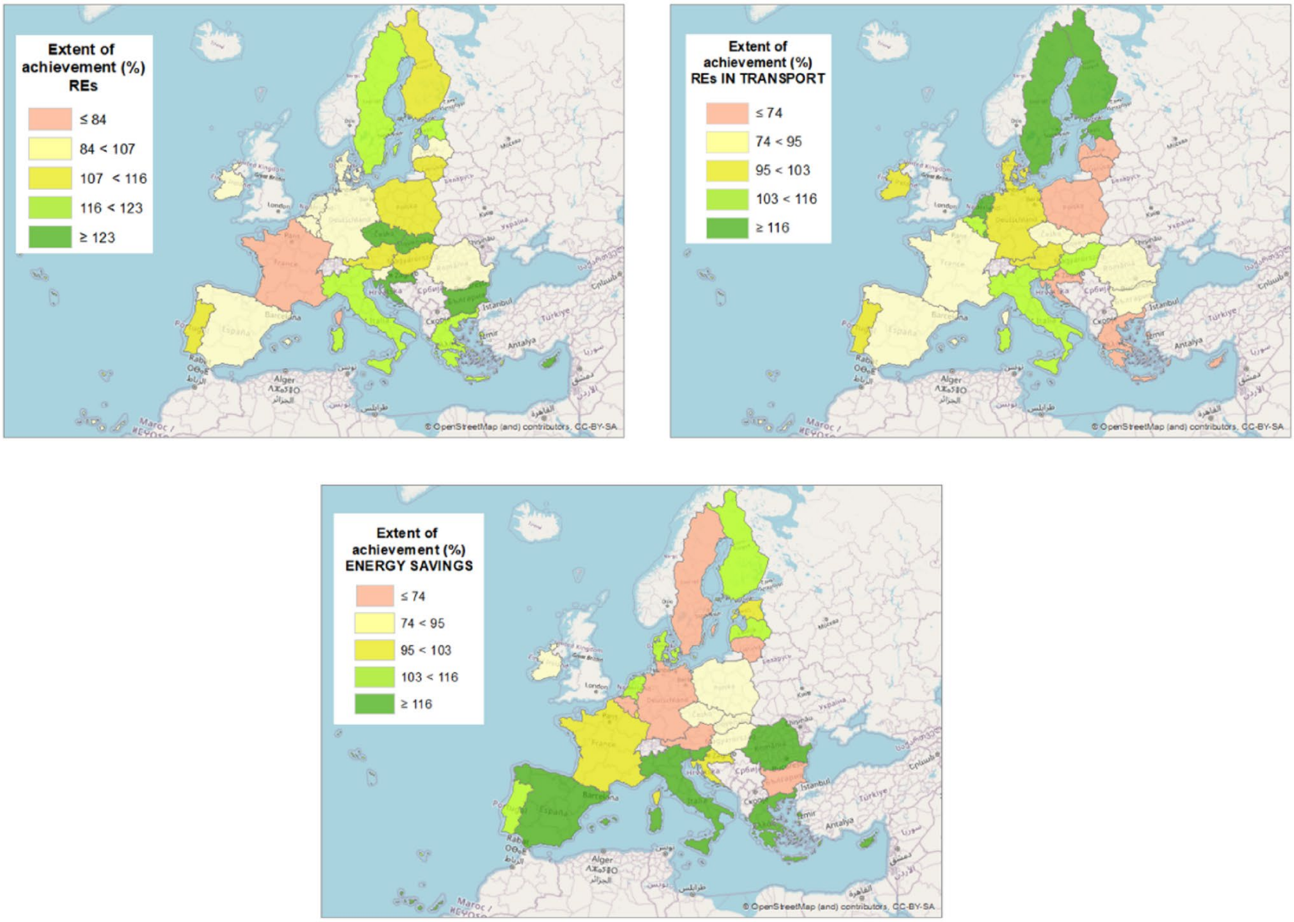


Fig. 1 Extent of achievement of set targets. Source: Own preparation based on Energy datasheet: EU countries updated to April 2023 (Eurostat 2023) and European Commission (2022b)

not meet the target (10% renewable energy in transport for all countries equivalent to 100% compliance), with Greece and Lithuania falling furthest from the target with respective compliance levels of 53% and 55%. The other countries that also failed to meet the targets had compliance levels ranging from 66% in Croatia and Poland to 97% in Denmark and Portugal. Conversely, Sweden and Finland are the most overachievers in meeting targets (319% and 143%, respectively).

However, regarding the target of 20% of final energy consumption from renewable energy sources (Fig. 1), all the countries met their individual objectives and even exceeded them, except for France, whose individual objective was to attain 23% in 2020, although it only reached 19% (Eurostat 2023), meaning an achievement level of 83%. Also, countries such as Croatia, Bulgaria, Czechia and Cyprus

Table 4 Final energy consumption and percentage of RES in total energy consumption, by stages, EU-27

Targets	1990	2010	FIRST STAGE Variation compared to 1990 [%]	2016	SECOND STAGE Variation compared to 1990 [%]	2020	THIRD STAGE Variation compared to 1990 [%]
Final energy consumption Mtoe	952,3	1024,5	+7,6%	976,9	+2,6%	906,3	– 4,8%
% REs in total energy consumption	0%	14,4	+14,4%	18,0%	+18,0%	22%	+22%
% REs in transport sector consumption	0%	5,5%	+5,5%	7,2%	+7,2%	10,3%	+10,3%

Source: Own preparation based on Eurostat (2023)

Table 5 Extent of achievement (%) of set targets by country

	Res	REs in transport	Efficiency
Italy	**120**	107	**121**
Slovenia	**100**	109	117
Malta	107	**106**	116
Netherlands	**100**	**126**	115
Finland	116	143	115
Luxemburg	106	**126**	111
Estonia	**120**	122	**105**
Ireland	**101**	**102**	**105**
Hungary	107	116	**101**

Source: Own preparation based on Eurostat (2023) and European Commission (2022b)

Bold indicates higher and lower target range values

had achievement rates of 155%, 145%, 133% and 130%, respectively.

As for energy efficiency, it must be stated that, as analysed in the previous section, the targets were updated several times over the years, spreading the efforts to achieve them across the EU. Hence, for example, the original target was to achieve a 20% reduction in primary energy consumption in 2020 [COM (2007) 1], while few years later, in 2012, Directive 2012/27/EU sets energy efficiency targets based on either primary or final energy consumption, primary or final energy savings, or energy intensity. Also, the country targets would then be indicative, due to the economic crisis situation. Following EC (2022b:2): "The EU's energy efficiency target for 2020 (Article 3 of the EED) corresponds to a 20% reduction in the EU's primary and final energy consumption by 2020 compared to the energy consumption projected in the 2007 PRIMES scenario for 2020".

To assess the extent of fulfilment of the energy efficiency targets by countries in this paper (Fig. 1), data from the Report on Achievement of the 2020 Energy Efficiency Targets (European Commission 2022b) were used, according to which 21 countries achieved their 2020 final energy consumption targets. It should be noted that the final energy consumption values for 2020 were heavily influenced by the COVID-19 pandemic and the subsequent lockdown measures imposed by national authorities, resulting in a significant decrease in energy demand due to reduced overall activity. However, the EU's final energy consumption (FEC) grew by 5% between 2020 and 2021. This represents the highest annual increase since full records are available (European Environmental Agency—EEA— 2022).

In general, only nine countries achieved all the set targets (Table 5), with Slovenia, Netherlands and Ireland the countries closest to not meeting the targets for renewable energy consumption over final consumption; Ireland and Malta, the countries closest to not meeting the targets for renewable energy in transport, and Hungary, Ireland and Estonia, the countries with lower levels of achievement in saving and efficiency.

To further explore the country study, the group of EU-27 countries was analysed according to the extent of achievement of each of the set targets. It was determined that the optimal number of groups was seven, with a pseudo-F statistic[2]; no spatial restrictions were used and the seeds were chosen randomly. Figure 2 shows the groups of countries thereby obtained, along with the box-and-whisker diagrams for each of the clusters. Table 6 shows the countries pertaining to each group as well as the mean achievement values for the set targets. Two groups are composed for only one country (Sweeden and Lithuania) because their objectives are very different from those of the others.

Group 1, comprising Sweden, performed best in terms of the renewable energy consumption target for transport, at 319%. It also far exceeded the target for renewable energy consumption. However, this country did not meet the energy saving and efficiency target.

Group 2, Lithuania met the renewable energy consumption target, with an achievement level of 116,5%, but the country did not meet the targets for renewable energy consumption in transport (this country was the furthest from achieving it) and energy saving and efficiency.

Group 3, comprising Finland, Estonia, the Netherlands and Luxembourg, amply exceeded the targets. All the countries in this group meet the targets. This was the second group with the highest level of achievement regarding renewable energies in transport.

Group 4, comprising of Portugal, Spain, Latvia, Malta, Slovenia and Denmark, was second in meeting the energy efficiency and saving target, and consumption originating in renewable energy sources. Four countries (Latvia, Spain, Portugal and Denmark) did not meet the target for renewable energy in transport, with Latvia being furthest from achieving it. Slovenia and Malta did meet all the set targets.

All the counties of Group 5 (Italy, Greece, Romania and Cyprus) met the targets for savings and efficiency and for the share of final energy consumption from renewable sources, but only Italy met the target for renewable energy consumption in the transport sector. The other countries have achieved performance levels ranging from 53% in Greece to 85% in Romania.

Group 6, composed of the Czech Republic, Slovakia, Bulgaria and Croatia, largely achieved the targets for final

[2] If there are no other criteria to guide the choice for the number of groups, it is appropriate to use a number associated with one of the highest pseudo-F statistic values. The highest F statistic index values indicate solutions that work better to maximise similarities within the group and the intra-group differences.

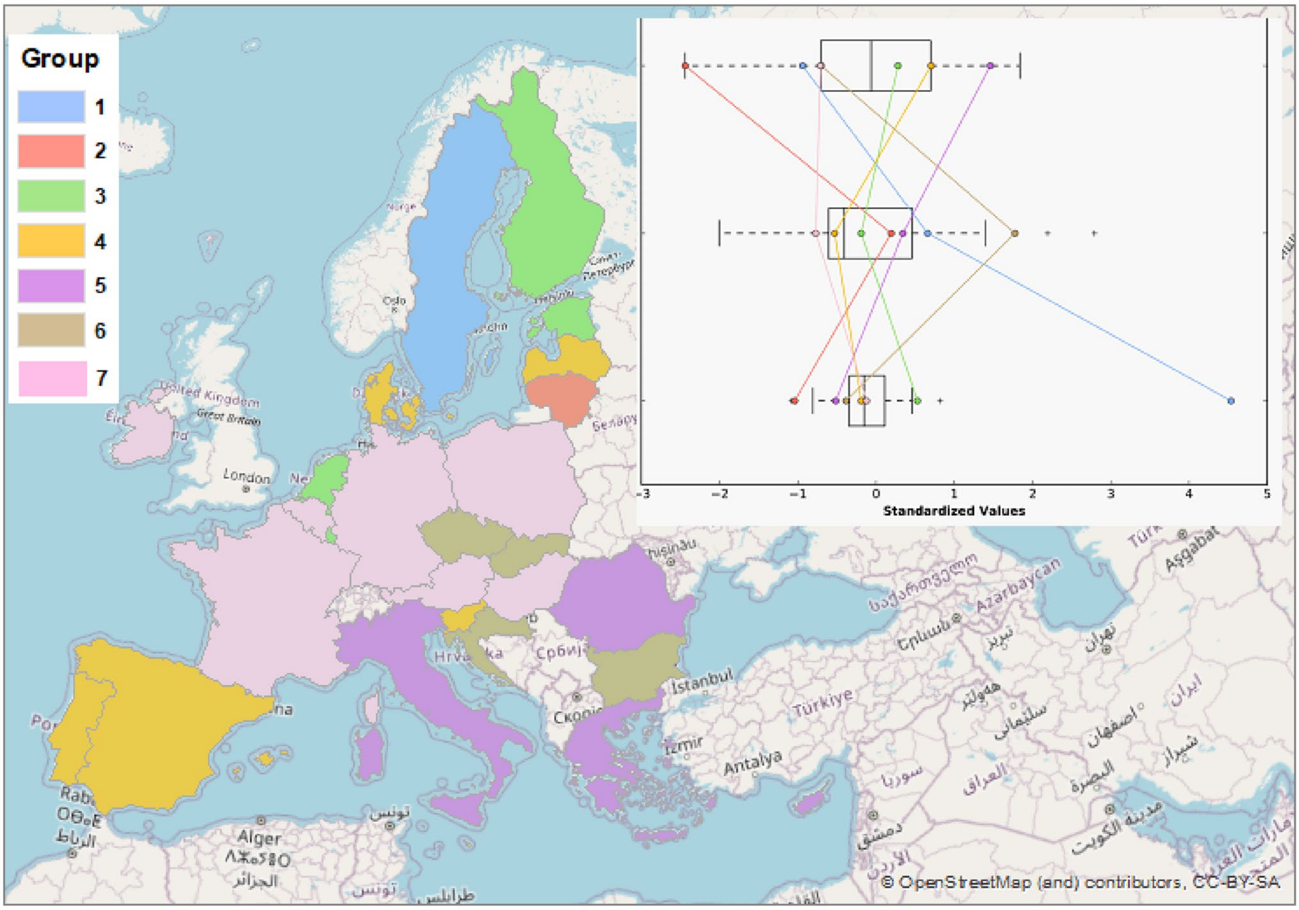


Fig. 2 Group analysis depending on the extent of achievement of the set targets. Source: Own preparation based on Eurostat (2023) and European Commission (2022b)

consumption of energy from renewable energy, ranging from 155% in Croatia to 124% in Slovakia. All except Bulgaria, 10 points below, achieved the energy savings and efficiency targets, with Croatia having the highest level (107.6%). However, none of them met the share of renewable energy in transport.

Finally, Group 7 (Ireland, France, Belgium, Germany, Austria, Hungary and Poland) has the lowest average level of achievement in terms of renewables share of final consumption (with the exception of France, which failed to meet the target). Only Hungary barely met all targets, and Austria, Belgium and Germany were on average 3.3 points below the energy efficiency and savings target.

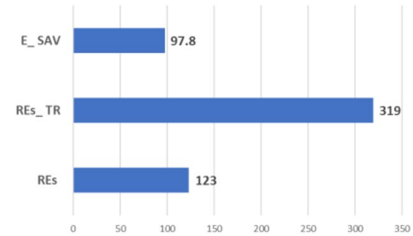
Repercussions on energy dependence and GHGs

In general figures, according to Eurostat (2023), despite achieving most of the set targets, energy dependence increased in the EU-27 group, rising from 57.8% in 2000 to 59.1% in 2020 (62.3% in 2019). So, this dependence was not reduced, though its growth was slowed. Also, GHG emissions were 31,7% lower than the 1990 levels (24.3% in 2019).

Fifteen countries were able to reduce their energy dependence in 2020 compared to 2000 (Fig. 3a), ranging from −2% for Cyprus to −23.5% for Estonia, while Malta, Denmark, the Netherlands and Poland are those whose energy dependence increased the most (respectively, +195,9%, +84,9%, +34,5% and +32,1%). In the cases of the Malta, Netherlands and Denmark, this is associated with the lower availability of own sources of fossil fuels and hence, increased dependence on petroleum and natural gas, while in the case of Poland the increased dependence is associated with lower carbon reserves and higher final energy consumption (despite having met the saving and efficiency targets), as it is a country that started with a socioeconomic development state much less advanced than the other two when it joined the EU in 2004—it nowadays counts a consolidated economy (Birger 2018).

With respect to GHGs, nearly all the EU-27 countries reduced their emissions per inhabitant compared to the year 2000, ranging from -8.8 t/inhab. in Luxembourg to -0.5 in

Table 6 Groups, countries and mean values

<table>
<tr><th>GROUP</th><th>COUNTRIES</th><th>REs</th><th>REs_ TR</th><th>E_ SAV</th><th></th></tr>
<tr><td>1</td><td>Sweden</td><td>123</td><td>319</td><td>97.8</td><td>
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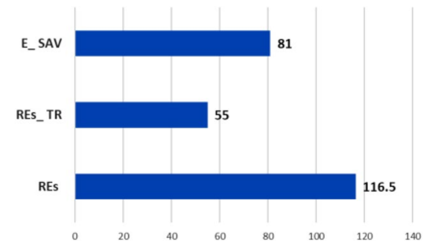
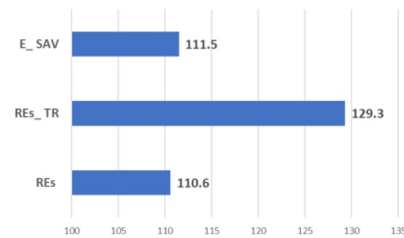
<tr><td>2</td><td>Lithuania</td><td>116.5</td><td>55</td><td>81</td><td>
</td></tr>
<tr><td>3</td><td>Finland, Estonia, Netherlands, Luxembourg</td><td>110.6</td><td>129.3</td><td>111.5</td><td>
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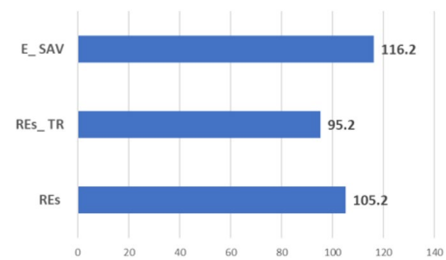
<tr><td>4</td><td>Portugal, Spain, Latvia, Malta, Slovenia, Denmark</td><td>105.2</td><td>95.2</td><td>116.2</td><td>
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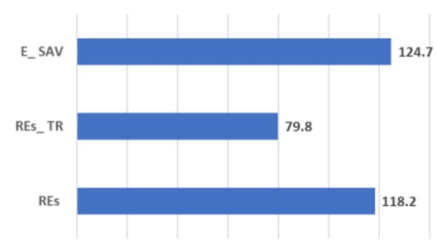
<tr><td>5</td><td>Italy, Greece, Romania, Cyprus</td><td>118.2</td><td>79.8</td><td>124.7</td><td>
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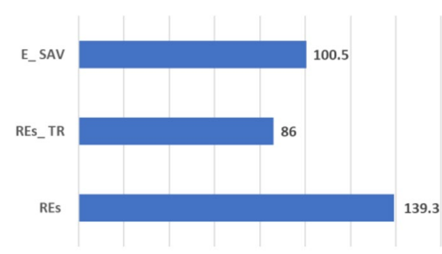
<tr><td>6</td><td>Czechia, Slovakia, Bulgaria, Croatia</td><td>139.3</td><td>86</td><td>100.5</td><td>
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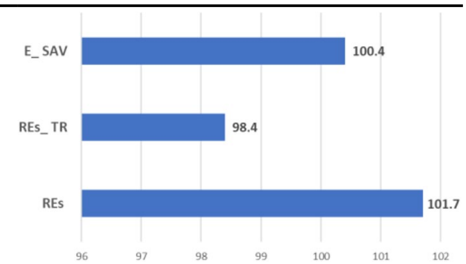
</table>

Table 6 (continued)

GROUP	COUNTRIES	REs	REs_ TR	E_ SAV
7	Ireland, France, Belgium, Germany, Austria, Hungary, Poland	101.7	98.4	100.4



Source: Own preparation based on Eurostat (2023) and European Commission (2022b)

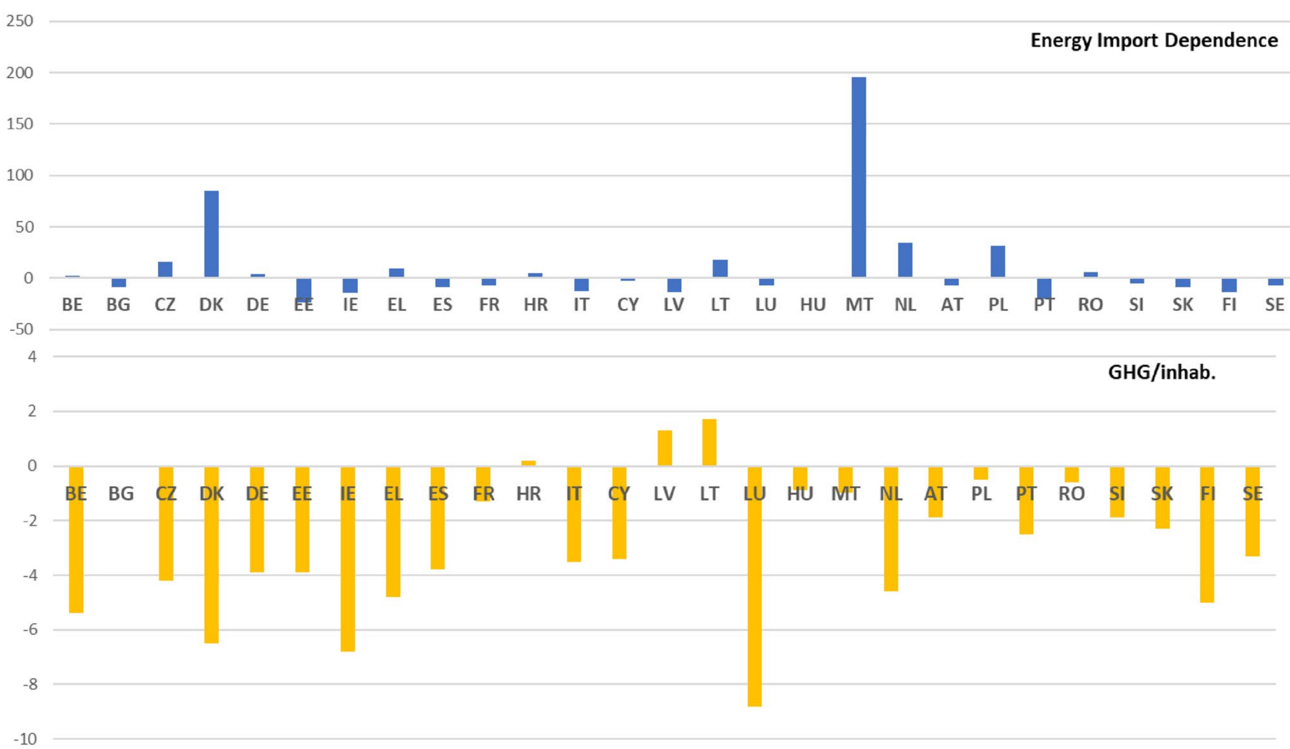


Fig. 3 Reduction in energy dependence (**a**) and GHG emissions (**b**) since 2000. Source: Own preparation based on Eurostat (2023) and European Commission (2022b)

Poland. Four countries were unable to reduce[3] GHGs per inhabitant compared to 2000: Bulgaria (0), Croatia (0,2 t/inhab.), Lithuania (+ 1.7 t/inhab.), and Latvia (+ 1.3 t/inhab.) (Fig. 3b).

Regarding the countries in Table 5 that met all the targets, the majority were able to lower GHG emissions and external energy dependence in 2020 except Malta, Netherland and Hungary what failed to meet the energy dependency target.

To further explore the extent of achievement of the set targets and respective contribution to lowering energy dependence and GHGs, various regression models were used. First, multiple linear regression models were tested. However, since the determination coefficient was low in these regressions, 0.03 and 0.29 for energy dependence and 0.18 and 0.181 for GHGs (with and without considering outlier countries, respectively, due to their specific results in the previous stages), and the data do not hold the necessary assumptions for a linear approach (p-value ≤ 0.05 in Shapiro–Wilk test of normality for residuals in regressions on energy dependence

[3] In 2019, five countries were still unable to reduce their GHG/inhab. values compared to 2000 (Lithuania, Bulgaria, Croatia, Latvia and Poland). The reduction in GHG/inhab. in the other countries ranged from − 0.3 t/inhab. in Belgium to − 5.7 t/inhab. (EEA 2022). Data updated to 1/12/2022.

Table 7 Regression of the achievement level of the set targets and their contribution to reducing energy dependence

Model	Best model	Adjustment	Var. importance
Lithuania, Sweden, Denmark, Netherlands, and Malta not considered			
SVR	Radial; C = 1; ε = 0.5; γ = 1	**0.794** (RSME = 7.785)	(0.063, **0.147, 0.790**)
ANN	3–1-1; δ = 0.15	0.503 (RSME = 8.687)	(0.022, 0.247, 0.731)
All countries considered			
SVR	Radial; C = 1; ε = 0.5; γ = 0.2	0.080 (RSME = 41.433)	(0.188, 0.567, 0.244)
ANN	3–1-1; δ = 0.15	0.219 (RSME = 37.40)	(0.181, 0.361, 0.457)

SVR hyper-parameters: Radial = kernel function used in regression; C = constant of the regularization term in the Lagrange formulation, i.e. cost of constraints violation; ε = parameter of the insensitive-loss function; γ = parameter of the radial kernel function; ANN parameters: a-b-c = layers and nodes of the neural network; δ = weight decay speed in each iteration of the backpropagation algorithm; VAR. IMPORTANCE: importance of explicative variables (savings achievement objective, renewable energy in final consumption objective, renewable energy consume in transport achievement objective) in the regression models

Table 8 Regression of the achievement level of the set targets and their contribution to reducing greenhouse gases

Model	Best model	Adjustment	Var. importance
Lithuania and Sweden not considered			
SVR	Radial; C = 1; ε = 0.5; γ = 0.2	**0.995** (RSME = 0.245)	(0.139, **0.321, 0.540**)
ANN	3–1-1; δ = 0.15	0.316 (RSME = 1.987)	(0.086, 0.381, 0.533)
All countries considered			
SVR	Radial; C = 1; ε = 0.4; γ = 0.2	0.487 (RSME = 1.944)	(0.367, 0.288, 0.445)
ANN	3–1-1; δ = 0.1	0.367 (RSME = 1.970)	(0.343, 0.249, 0.716)

SVR hyper-parameters: Radial = kernel function used in regression; C = constant of the regularization term in the Lagrange formulation, i.e. cost of constraints violation; ε = parameter of the insensitive-loss function; γ = parameter of the radial kernel function; ANN parameters: a-b-c = layers and nodes of the neural network; δ = weight decay speed in each iteration of the backpropagation algorithm; VAR. IMPORTANCE: relative importance of explicative variables (savings achievement objective, renewable energy in final consumption objective, renewable energy consume in transport achievement objective) in the regression models

considering all the countries) (Aggarwal and Ranganathan 2017), a further three regressions were performed: support vector regression (SVR) (Smola and Schölkopf 2004), random forest (Segal 2004) and artificial neural network (ANN) (Specht 1991). The main goal of this regression analysis is not to perform predictions but to make a clear and assess the extent of achievement of the set targets and their contribution to reducing energy dependence and GHGs.

It is thus very important to establish the influence of each explanatory variable (extent of achievement of set targets) on GHGs and energy dependence. This is not straightforward in nonlinear scenarios. In the following results, the importance of variables in SVR and RF is given by R function *importance* from the rminer library. This function uses sensitivity analysis, as described in Cortez and Embrechts (2013). Variable importance in artificial neural networks (ANNs) is calculated by deconstructing model weights using the Garson algorithm (Garson 1991). The relative importance of a specific explanatory variable for the response variable is thus determined by identifying all weighted connections between the nodes in which this variable acts. Also, to homogenise the adjustment measure, the correlation coefficient between actual values and predicted values was used in all models as a pseudo-determination coefficient.

The root mean square error (RMSE) is also provided, due to the different nature of each model and the nonlinearity scenario; it must be noted that lower RMSE may not lead to higher adjustment according to the adjustment measure provided (which is linear). This is especially true in random forest models. Random forest models generally perform well but are very volatile, i.e. predictions and metrics vary widely for the same model as a consequence of the bootstrapping technique in a small dataset, meaning that robust affirmation about variable importance in this model is not possible. Previous knowledge about variable importance, enabling inverse sampling probability weighting, is helpful for achieving good prediction performance of random forests models over a small dataset (Han et al. 2021), though determining such variable importance is one of the goals of the regression analysis developed. Also, as the model assigns the same prediction to each observation in the same final node, the dispersion between nodes also accounts for this discordance between the defined adjustment measure and RMSE. To reduce this volatility, the model was set to the minimum size of terminal nodes (one observation). However, results are still very dependent on the bootstrapping sample order and therefore, its use for the purpose of this study was finally rejected.

Tables 7 and 8 show the performance of support vector regression and artificial neural network models, as those are the models offering more adjustment. The analysis of the relationship between the extent of target achievement and energy dependence or GHG emissions cannot be shown in any model when we consider all the countries. However, by excluding Lithuania and Sweden as outliers from both analysis due to their results in the second stage, and also Denmark, the Netherlands and Malta from the energy import dependence analysis due to their outlier status in that variable, the SVR model obtains a significant adjustment. It becomes evident how lower energy dependence depends on factors beyond how far the set targets were fulfilled. Of the variables studied, renewable energies objectives are the ones that contribute the most to reducing it (mainly the energy consumption in transport -0.790-).

As for GHGs reduction, the SVR model shows a relationship between it and the targets' achievement level, especially dropping Lithuania and Sweden from the analysis. The renewable energy target for transport has the largest influence on the reduction (0.540), followed by the share of renewable energy (0.321).

It can also be seen how the achievement level of the target for energy saving and efficiency, even though it was reached and even exceeded by most of the countries, was unable to impact energy dependence or GHG emissions. This is clearly contradictory, because if consumption is lower, then energy dependence and GHG emissions would decrease, since most final energy consumption comes from fossil fuel sources. Indeed, as already commented in the previous section, in 2020 lower EU-27 energy consumption resulting from COVID-19 facilitated a drop in energy dependence compared to the year 2000 figures.

Concluding remarks

In the EU-27, the promotion of energy transition based on energy self-sufficiency and decarbonisation requires actions on production, but also on energy consumption habits, human population dynamics and trends, and governance systems, among others. Acting on just one of these drivers does not guarantee energy independence or the effectiveness of the fight against climate change.

The different models analysing the level of achievement of the targets set point to the limited role played by the energy savings and efficiency target in the energy transition, despite the fact that 21 of the 27 countries achieved it. It should be noted that the achievement of the energy savings and efficiency targets was largely influenced by the effects of the economic or pandemic crisis, as lower energy consumption during these phases simultaneously facilitated the increase in the share of renewables in total energy and transport. In fact, after the drop in demand in 2020, the EU returned to the same or higher consumption in 2021 than in 2019.

All this, together with the results obtained from the step-by-step analysis, shows that, although energy efficiency policies have reduced energy consumption growth rates (energy consumption would have been 12% higher between 1990 and 2012, for 29 states in the absence of energy policies), to date, compared to 1990 levels, EU-27 consumption has decreased in 2020 by 4.7%, and the main changes in the energy consumption trends were linked to periods of economic recession. Also, the fulfilment of the energy efficiency targets has not resulted in a reduction in energy dependence and according to the results obtained, meeting renewable energy targets has had an impact on emissions reduction.

As for eventual achievement of the 2030 target of 32.5% compared to the 2007 reference scenario, it is still too early to forecast for the EU as a whole or for the different member states. Following the 2022 report on the achievement of the 2020 energy efficiency targets, final and primary energy consumption in 2020, respectively, stood at 7.2% and 9.6% above the 2030 target levels. To achieve a substantial reduction in energy consumption, the EU will need to exert significantly more effort.

The EU-27 seems to have chosen renewable energy quotas as a driver of its energy policy. And although it is advisable to prioritise objectives, because not all targets can be met at the same time, due to their different nature and impact, it is noted that increases in production from renewable energy sources alone, without making further efforts to increase the efficiency and save energy, only will serve to satisfy the increase in demand needs and would not sufficiently impact energy independence.

Accordingly, the EU has recently introduced the "energy efficiency first" principle, as well as the "Fit for 55" package, with many new measures being finalised, including a new GHG target for 2050 of −55%.

It is important to analyse how the population's participation and involvement is managed, as it has been shown that involving the population in decision-making is key to achieving the set targets. Shared self-consumption or not and energy communities are a key step towards reducing market pressures on citizens, increasing the share of renewables in total energy consumption and reducing the need to reinforce high voltage grids, as energy exchanges and flows are limited to low and medium voltage grids. Furthermore, self-consumption improves the resilience of the population, which understands and accepts the limits on power generation and consequent security problems, adjusting respective consumption habits to peak powers and times available from their installations, thereby becoming a part of the solution.

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Author contributions All the co-authors participated in the conception and design of the study and have carefully read and fully approved of it. We also warrant that the manuscript is original and that is not submitted anywhere other than the Clean Technologies and Environmental Policy. We would of course be ready to provide further information about our data and methods once requested.

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Data availability The datasets and R scripts generated during and/or analysed during the current study are available in the OSF repository: https://osf.io/96ng5/?view_only=2ad543ec5eef4f5ba58934552204610b.

Declarations

Conflict of interest The authors have not disclosed any conflict of interest.

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