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The Multi-dimensional Oil Dependency Index (MODI) for the European Union

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ABSTRACT

Oil constitutes more than one third of total energy available in the European Union (EU), which continues to depend heavily on fossil fuels. Russian exports have known a remarkable growth in the last two decades, making this country crucial – as the war in Ukraine has recently shown – in deciding the energy future of the EU. In this regard, we provide a comprehensive and dynamic measure of oil dependency, constructing the Multi-dimensional Oil Dependency Index (MODI) for EU-28 countries (including the United Kingdom) during the period 1999–2019. This composite index considers four different key dimensions of oil dependency, *i.e.* energetic, economic, international and geopolitical dependencies, exploiting the multivariate technique of the Principal Component Analysis. The subsequent determination of rankings and their variation over time can be useful for policymakers to identify key areas where to intervene and reduce dependency, as well as to set benchmarks for policy actions. Our analysis reveals some interesting findings: first, the EU has still much to do to decouple oil consumption from GDP growth and achieve the environmental targets set by the European Green Deal; second, EU countries present very different degrees of oil dependency and, in several aspects, trends are not aligned; third, international and geopolitical dependency on oil constitute a worrisome problem for EU's energy security.

1. Introduction and background

The spread of the Covid-19 and the outbreak of the war in Ukraine have conferred a new emphasis to security concerns, in addition to profit maximization, in determining production and distribution choices. If this different vision may be applied across all economic dimensions, it appears particularly true in relation to energy resource supply. For this reason, we decide to focus our attention on oil, which represents the most widely used energy resource within the European Union (EU), making it particularly exposed to shocks occurring in foreign exporting countries. First, despite its leading role in the energy transition and the consequent increase in the importance of renewable energy, oil has always represented the primary energy source in Europe (Eurostat data shows that, in 2019, it accounted for more than one third in the total available energy). Second, the majority of EU countries relies on imports to satisfy their internal oil needs, leading many scholars in the energy field to address the issues of oil vulnerability and dependency.[1] Third, the EU is often considered as a unique group of countries, but the energy transition undertaken by its member states proceeds at very different speeds (Pérez et al., 2019). For instance, Papież et al. (2018) find that EU countries endowed with fossil fuel resources within their borders find it harder to shift to renewable energy generation. The reasons for choosing this energy resource as the main focus of our analysis are also based on the fact that diversification tends to be more feasible in the case of oil and solid fuels, while the same is not true for gas (Celi et al., 2022). As a consequence, our idea of developing a dynamic indicator that takes into account– among other things – the major changes in the network of supplier countries over time is stronger and more meaningful in relation to oil.

The concept of vulnerability has its origins in research on natural disasters in the Sixties (Janssen et al., 2006). The economic literature does not provide a unique and clear definition of energy vulnerability (Cherp and Jewell, 2010). In general terms, vulnerability can be defined as the inability of a system to cope with selected adverse events (Gnansounou, 2008). Gatto and Busato (2020) extend this definition, interpreting vulnerability as the degree to which a system is exposed to

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[1] A more in-depth descriptive analysis of oil dependency in the EU will be provided in Paragraph 2.

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adverse events or changes with the risk of economic, social, environmental and governance consequences. However, the selected events must be reasonably probable to occur to be effectively considered as factors contributing to vulnerability (Gnansounou, 2008). In terms of energy vulnerability, this means that oil-importing (and consuming) countries are highly sensitive to exogenous shocks and are not able to manage unexpected changes in the supply of the energy product without negative economic consequences. Since the concept of energy vulnerability involves many aspects, several dimensions must be accounted for (Percebois, 2007). This multidimensional nature justifies the need of a composite indicator to assess oil vulnerability (Nardo et al., 2005). In this regard, Gupta (2008) identifies two major risks that contribute to the overall vulnerability of an economy: on the one hand, market (or economic) risk, that entails the risks of macroeconomic repercussions due to the volatility of oil market prices; on the other hand, supply risk, that involves the risks of scarcity of oil supplies. From this perspective, vulnerability and dependence become two closely linked concepts, where vulnerability can be interpreted as a consequence of a high dependency framework. Vulnerability clearly needs high degrees of dependency under multiple scenarios to be verified; dependence is therefore a necessary but not sufficient condition for overall vulnerability. In any case, the two concepts must be distinguished, since a country can be dependent without being vulnerable and be vulnerable without being dependent (Percebois, 2007).[2] Energy vulnerability remains a qualitative concept, while dependency is related to a quantitative one.

The Oil Vulnerability Index developed by Gupta (2008) represents one of the main important attempts to assess oil vulnerability: considering 26 net oil-importing countries for the year 2004, the author employs a multivariate analysis to estimate a composite index on the basis of various indicators related to the concept of energy vulnerability. Roupas et al. (2009) apply the same methodological framework to the European Union over the period 1995–2007 to estimate a similar measure of oil vulnerability. This statistical approach has been also used by Gatto and Busato (2020) to construct a global energy vulnerability index, taking into consideration 265 countries over the period 1960–2016. Grounding on a subjective weighting and Euclidean distance to the benchmark country, Gnansounou (2008) estimates energy demand/supply weaknesses as a proxy of energy vulnerability for the year 2003 and 37 OECD industrialised countries. Energy vulnerability has been also measured by Iqbal et al. (2020) in oil importing South Asian countries and by Wang et al. (2017), who consider the industrial ecosystem of coal mining in China. To the best of our knowledge, no other author has specifically focused on the oil sector, addressing the notion of dependency, which remains a subject less explored. Formally, on the one hand, oil vulnerability assigns an economic connotation to oil consumption, especially in relation to the risks of various nature the economy runs when oil supplies are uncertain and oil prices volatile. In this context, oil vulnerability is usually considered in relation to oil-importing countries only. On the other hand, oil dependency is not limited to the economic risks related to oil consumption, but also considers aspects related to energy dependency. For instance, while oil vulnerability only focuses on oil market and supplies, oil dependency also evaluates changes in the availability of alternative energy sources within countries' energy mix to progressively abandon oil as a key energy source. In this respect, a comprehensive vision of oil (and fossil fuels in general) dependency is essential for evaluating progresses towards a clean energy transition. The two macro-categories of economic and energy dependency on oil are then connected to other international and geopolitical aspects which contribute to making countries increasingly dependent on oil in one of the two aspects, or both. Hence, unlike oil vulnerability, oil dependency can be a matter of concern for both oil-importing and oil-exporting countries.

The aim of this paper is to provide a comprehensive and dynamic measure of oil dependency, which accounts for all the aspects involved in making countries reliant on oil as either an energy or an income source, or both. For the purpose of our analysis, we construct the Multidimensional Oil Dependency Index (MODI) for EU-28 countries over the period 1999–2019 and we evaluate trends and ranking of countries in terms of the overall MODI index and its individual dimensions. The main purpose of the MODI is to appraise relative positions of European countries in terms of overall oil dependency and the dynamic assessment over a 20-year period allows to identify changes and trends over time. In particular, defining rankings and their change over time can be useful for policymakers to identify key areas where to intervene and reduce dependency, and to set benchmarks for policy actions. Compared to previous studies analyzing the vulnerability of oil supply, we limit our study to those dimensions that are essential for evaluating dependency, without necessarily implying vulnerability. Some of these dimensions (i.e., energetic, economic, and geopolitical dimensions) are common to the vulnerability assessment performed by Gupta (2008) and Roupas et al. (2009), although in their cases they are complemented by other factors specific to oil supply. In our case, these three dimensions plus the international one are broad enough to deal with the sole issue of multidimensional oil dependency and, more importantly, to be evaluated in relation to both oil importing and exporting countries. Further, by limiting the analysis to a reduced number of dimensions specific to dependency, we avoid a proliferation of indicators that, once aggregated, make it difficult to understand the overall phenomenon and to define the right emphasis to be assigned to each of them (Saisana et al., 2005).

The paper is structured as follows. Section 2 illustrates the data used to construct the MODI index and some key trends and its dimensions. Section 3 derives the MODI index by using Principal Component Analysis (PCA) and describes the main results. Section 4 discusses the policy implications and concludes.

2. Data and descriptive analysis of oil dependency in EU

Despite the rise of renewable energies in the energy mix of EU member states, oil still constitutes more than one third (35% in 2019) of total available energy in EU (Fig. 1a). The share of oil in fossil fuels has remained more or less constant at around 50% over time; the progressive decrease in the share of fossil fuels in total available energy is the result of a decline in the use of solid fossil fuels rather than oil and natural gas (Fig. 1b).

It is straightforward that the EU depends heavily on fossil fuels, especially on oil. Since the majority of member states are net importers, it is interesting to preliminarily examine from which countries the EU has most imported during the last two decades (Fig. 2). The Organisation of the Petroleum Exporting Countries (OPEC) has always represented the most important source of crude oil for all the European countries. This primacy has been preserved despite the fact that, over a period of 20 years, its incidence on total imports has almost halved (in 2019, 31.7%). While exports from Norway and the United Kingdom remained substantially stable with a slight negative trend, the previous decrease has been offset by a very strong growth in Russian exports and, in the last few years, by the progressive importance of the United States in the global oil market. Currently, the key role played by Russia in oil supply makes this country crucial in deciding the energy future of the EU. In any case, it should also be emphasised that the doubling of the share of imports from Russia in the total (in 2019, 23.9%) has been accompanied by a modest reduction in comparison to the peak of 2006 (30.5%).

In order to construct the MODI index, we collect data from the Observatory of Economic Complexity (OEC), Eurostat and the World Bank on four key dimensions of oil dependency for EU-28 countries in the

[2] For example, a country may be dependent on an energy source but not vulnerable if it imports most of its energy at low cost from a well-diversified group of countries; conversely, a country may be independent but vulnerable if it produces most of its energy at high cost or using old technologies.

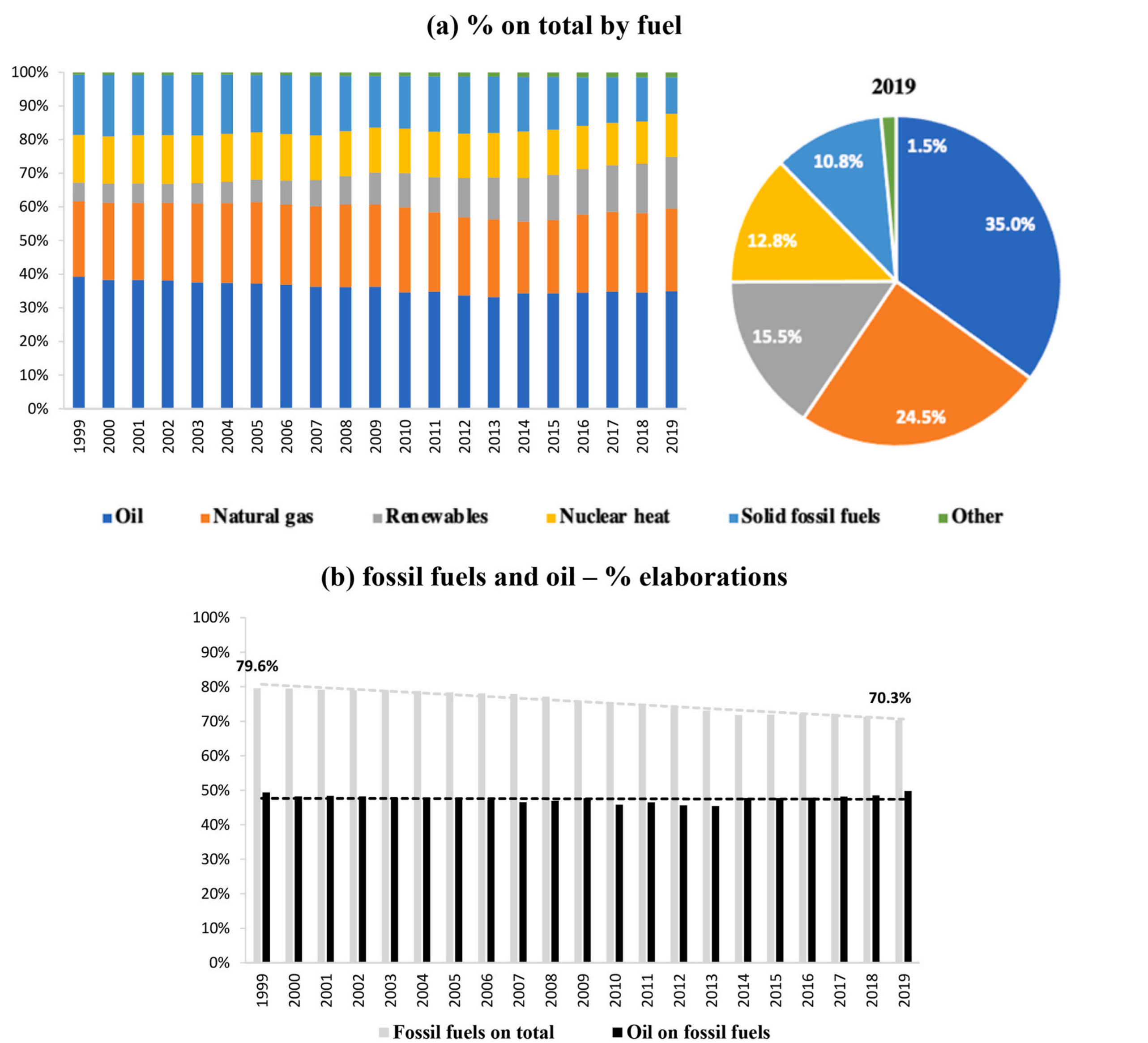

Fig. 1. Total available energy in the European Union.
Note: total available energy is also known as gross inland (energy) consumption. It is estimated as primary production plus recovered products, net imports and variations of stocks minus maritime bunkers. For certain member states the category 'Other' can assume negative values due to net exports of electricity. (a) "Oil" is the abbreviation for "oil and petroleum products". (b) Fossil fuels is the sum of solid fossil fuels, natural gas and oil and petroleum products (oil).

period 1999–2019, whose main descriptive statistics are reported in Table 1.

- **Energy dependency** (*EneD*) – Gross Available Energy (GAE) from crude oil (proxy of oil consumption) on GAE from all the energy sources;
- **Economic dependency** (*EcoD*) – oil intensity of GDP: GAE from crude oil (proxy of oil consumption) on real GDP;
- **International dependency** (*ID*) (also known as Energy Imports Dependency) – net imports of crude oil on net GAE from crude oil, showing the share of total energy needs of a country met by imports from other countries (negative value indicates net exporter, *i.e.* country that exports more fuels than it consumes)[3];
- **Geopolitical dependency** (*HHI_import* and *HHI_import_PS*) – Herfindahl-Hirschman import Index (*HHI_import*) adjusted for the political stability of exporting countries (*HHI_import_PS*).

2.1. Energy dependency

Energy Dependency (*EneD*) relates GAE deriving from crude oil, which can be considered a proxy of the overall oil consumption within a given country, to total GAE, which approximates the use of all available

[3] Net Gross Available Energy (GAE) is calculated net of 'change in stock' and 'recovered & recycled products' and then includes only net imports and primary production. In any case, the differences between the two series are negligible. We decide to take into consideration the net series so as to avoid cases of countries with values higher than 100% mostly due to the build of stocks.

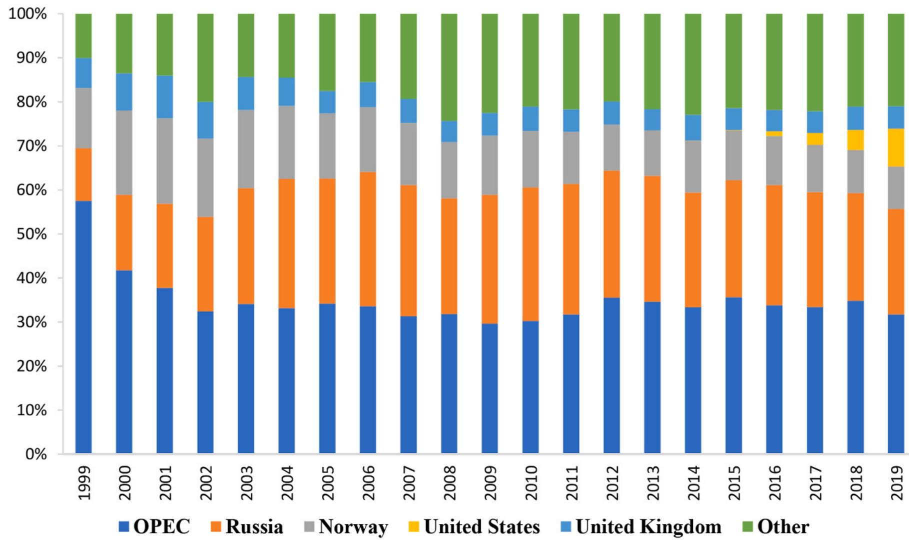

Fig. 2. Main oil exporting countries to the European Union.
Note: trade of crude oil has been calculated on the basis of quantity and not value.[4]

Table 1
Summary statistics of the oil dependency variables.

Variable	Obs	Mean	Min	Max	Std. Dev.	Source
HHI_import	588	5074	729	10,000	3151	OEC - Eurostat - The World Bank
HHI_import_PS	588	2323	210	7227	1875	OEC - Eurostat - The World Bank
ID	588	66.8	−143.3	100	49.3	Eurostat
EneD	588	31.2	0	129.6	23.2	Eurostat - The World Bank
EcoD	588	0.0514	0	0.293	0.050	Eurostat - The World Bank

Table 2
Energy Dependency in the European Union – Country level.

	1999	2019
	EneD	
Austria	29.9%	26.7%
Belgium	51.0%	53.3%
Bulgaria	31.4%	36.6%
Croatia	62.9%	30.0%
Cyprus	49.3%	0.0%
Czechia	15.3%	18.5%
Denmark	37.7%	43.2%
Estonia	0.0%	0.0%
Finland	32.9%	35.4%
France	32.4%	19.8%
Germany	31.4%	28.9%
Greece	53.5%	87.6%
Hungary	26.8%	25.4%
Ireland	20.5%	17.1%
Italy	49.7%	42.6%
Latvia	0.0%	0.0%
Lithuania	53.4%	119.5%
Luxembourg	0.0%	0.0%
Malta	0.0%	0.0%
Netherlands	62.3%	66.1%
Poland	17.9%	26.6%
Portugal	51.2%	46.0%
Romania	28.1%	35.8%
Slovakia	30.5%	30.1%
Slovenia	4.3%	0.0%
Spain	48.1%	49.4%
Sweden	38.0%	31.8%
United Kingdom	36.5%	29.3%

energy source. In this sense, *EneD* captures for each country how much of the total available energy directly depends on the use of oil. At country level, the use of crude oil within national energy resources shows a fairly mixed picture (Table 2). It is possible to distinguish three groups of countries. First of all, there are those countries whose crude oil use is equal to 0: this group has increased over time, reaching the count of six countries (Cyprus has reduced its energy dependency from 49.3% in 1999 to 0% in 2019).[4] The second group of countries is characterised by an energy dependency whose values range from 15% to 35/40%. It is the largest group and it has not known numerous changes in dynamic terms. Among these changes, we highlight Croatia, whose energy dependency from oil has more than halved (30%, in 2019), and France, which has been able to reduce it by about 13 p.p. (19.8%, in 2019). Finally, the last group of countries displays values above 40 per cent. In 2019, Lithuania seems to be more an outlier than part of a common system, being the only country characterised by an energy dependency well above 100 per cent (119.5%); this suggests how this country is dependent on crude oil not only in energy but also in commercial terms.[5] After Lithuania, Greece is the second country which significantly increased its energy dependency from crude oil (from 53.5% in 1999 to 87.6% in 2019) but it is not the only one: the Netherlands (+3.8 p.p.), Belgium (3.8 p.p.), Spain (1.3 p.p.) and Denmark (5.5 p.p.) also increased their use of crude oil.

In the aggregate, we have estimated the energy dependence of the

[4] It should be made clear that there is no single country in the EU that is completely independent from oil. This result stems from the choice of having considered crude petroleum (Harmonized System 1992 nomenclature 2709) and not refined oil (HS 2710). Crude petroleum has always been over time one of the most important traded products worldwide. In 2019 it accounts for more than 990 billion dollars. Consistent with this choice, GAE includes energy deriving from crude oil instead of oil and petroleum products.

[5] If a country processes crude oil into other energy sources and immediately trades them abroad, it will have more GAE from crude oil than overall gross energy.

European Union in two different ways: on the one hand, we calculate a simple unweighted measure where the yearly total of the index has been divided for the number of member states; on the other hand, we have adjusted each national indicator for the share of each country's annual GAE deriving from crude oil in the total European GAE deriving from the same energy resource. While the first adjustment gives equal importance to each country, in the second case countries that use relatively more oil as an energy source will weigh more in the final index result. A substantial stability in the energy dependence of the European countries emerges (Fig. 3).

The unweighted and the weighted indicators show that European countries have not been able to significantly diversify their energy dependence on this type of resource during the period under consideration. Both indicators show constant values over time, around 30% (*EneD_unweighted*) and 40% (*EneD_weighted*). To be more precise, the weighted *EneD* is characterised by a mild downward trend until 2013; since then, the 2019 value is slightly above the 1999 one. Moreover, the comparison between the two indices suggests another important feature: the higher energy dependence comes from those countries that account for the largest share of total oil consumption in Europe – in 2019, Germany (15.3%), Italy (11.6%), Spain (11.4%) and the Netherlands (10%). Except for Germany, these are also the countries that are characterised by a higher oil exploitation in the energy mix of national resources.

2.2. Economic dependency

Economic Dependency (*EcoD*) relates GAE deriving from crude oil, which can be considered a proxy of the overall oil consumption within a given country, to real GDP. In this way, we estimate the oil intensity of GDP, to measure the amount of oil a given country needs to produce one unit of real GDP. Table 3 displays how economic dependency (*EcoD*) has changed between 1999 and 2019 on a national level. In interpreting the results, it is important to remember that both indicators share the same numerator. The Lithuanian real GDP is strongly based on the use of crude oil. This country's primacy, however, continues to make it an outlier compared to the European context: in 2019, the average value of the other countries (0.0364) is more than five times lower than the one from Lithuania (0.1983). In dynamic terms, Greece is the only country that has increased its economic dependency from oil. With the exception of those countries that did not rely on oil for their national product in 1999 (Estonia, Latvia, Luxembourg and Malta), all other countries have managed to decouple their economic growth from oil consumption, decreasing their economic dependence. From this point of view, the most important decreases are in Croatia (−0.0987), Cyprus (−0.0813) and Bulgaria (−0.0778). In any case, the latter country firmly occupies the second place among the countries most economically dependent on oil.

In overall terms, we have estimated the economic dependence of the European Union based on the previous distinction between weighted and unweighted index values. While the first adjustment gives equal importance to each country, in the second case countries that use relatively more oil as an energy source will weigh more in the final index. The overall decrease in the economic dependency of most countries implies a significant subsequent reduction at European level (Fig. 4).

The unweighted and the weighted measures provide exactly the same feature: the dotted lines show a similar negative slope, denoting the general tendency of a reduced economic dependence on oil. Once we compare the different weights, an interesting information emerges. The two tendency lines intersect in 2010, highlighting a difference among European countries. In particular, if until 2010 countries that are characterised by higher shares of GAE deriving from crude oil on the related European GAE were less economic dependent from this natural resource, from that year onwards this relation reverses. In any case, the progressive decrease of European economic dependency remains stable.

2.3. International dependency

Since the oil crises period of 1970s, foreign dependence on oil imports has become one of the most important issues in world energy supply security (Ediger and Berk, 2011). The excessive foreign reliance on one or more exporting countries may determine a situation where oil can potentially be used as a political weapon, influencing the vulnerability of the entire economic system (Löschel et al., 2010). From this point of view, Bohi and Toman (1996) identify two main aspects that could undermine energy security, that is the volume of energy imports and the related price variability. In their reasoning, these two elements might expose national welfare to a significant deterioration. This interpretation highlights that, in the Seventies and Eighties, the main concern was related to the potential costs of supply interruptions, associated with an over-dependence on oil imports. More recently, new issues are shaping the traditional global energy security structure related to the changing geopolitical context (Umbach, 2010). It is no longer just a question of dealing with possible supply shocks but also of facing the complexity of diplomatic relation. For example, increasing its dependency on oil suppliers such as Russia, the European Union may have lost political power to face these countries, threatening its diplomatic freedom (Acevedo and Lorca-Susino, 2021).

The Energy Imports Dependency (*EID*) shows the share of total energy needs of a country met by imports from other countries. In other words, it shows the extent to which an economy relies upon imports in order to meet its energy needs. Since crude oil represents our variable under examination, we estimate the *EID* in relation to this energy source. This indicator is calculated as net imports divided by GAE. Negative values indicate net exporters, that is countries that export more fuels than they consume. In general, the GAE comprises four elements: net imports, primary production, change in stock and recovered and recycled products. Since the last two elements may determine a situation where the *EID* assumes values higher than 100% (especially in the case of increasing storage), we decided to take as a benchmark the GAE net of them.

From now on, we will denominate this indicator "*International Dependency*" (*ID*) since it captures how much of the available oil-based energy depends on net imports of the same source of power. In this sense, it may represent a factor that contributes to foreign energy dependence, exposing the importing country to potential supply shocks. This dependency factor becomes even more important when read together with the figure characterising the market concentration of oil imports (*geopolitical dependency*). In any case, the *ID* introduces important features on its own, highlighting the reliance of a country from oil foreign sources. Within the European Union, most countries cover their energy needs almost entirely by relying on net oil imports: except for a few countries that do not rely on oil as their energy source (Estonia, Latvia, Luxembourg and Malta) and for Denmark and the United Kingdom that, at least initially, were net oil exporters, the rest of the European countries are characterised by a high and significant foreign oil dependence on their energy needs (Table 4). Only two countries have been able to significantly reduce their international dependency between 1999 and 2019: Cyprus (−100 p.p.) and Slovenia (−99.6 p.p.). On the contrary, the most important increases occurred in Denmark (+116.6 p.p.), the United Kingdom (+62.5 p.p.) and Romania (+30.3 p.p.).

The same variable can be analysed at the European level (Fig. 5). From this point of view, it is possible to aggregate the previous indicator in two different ways, that is through a simple arithmetic mean (*ID_unweighted*) and by taking into consideration the share of each country's annual net imports in the total European net imports of crude oil (*ID_weighted*). As before, the comparison between the two measures provides useful insights. On the one hand, the unweighted *ID* shows only a slight increase over the period, remaining nearly stable below 70% (in 2019, 69.7%). On the other hand, once we weight the average, crude oil dependency from foreign countries significantly rises, displaying a

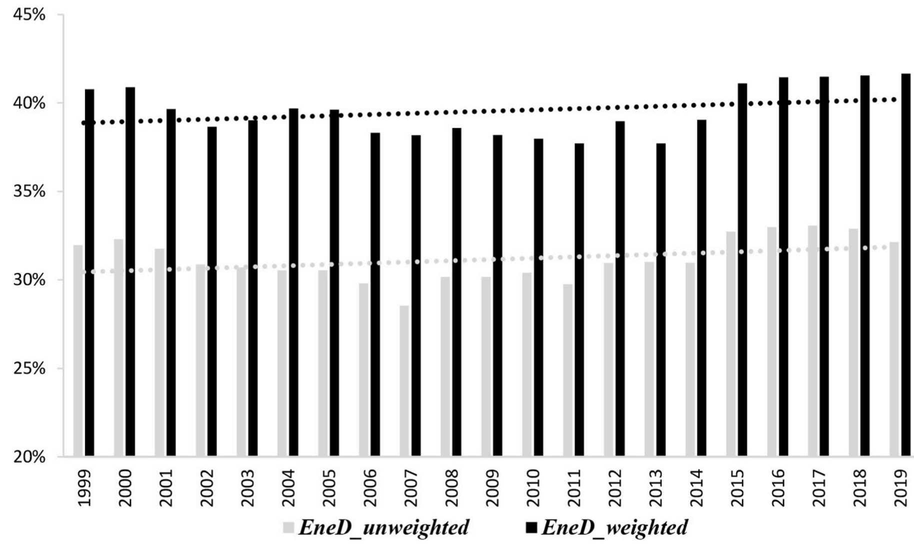

Fig. 3. Energy Dependency in the European Union – Aggregate level.
Note: histograms represent Energy Dependency (*EneD*) from crude oil. The dotted lines represent the related linear tendency lines.

Table 3
Economic Dependency in the European Union – Country level.

	1999	2019
	EcoD	
Austria	0.0291	0.0223
Belgium	0.0916	0.0700
Bulgaria	0.1982	0.1204
Croatia	0.1450	0.0463
Cyprus	0.0813	0.0000
Czechia	0.0494	0.0369
Denmark	0.0318	0.0233
Estonia	0.0000	0.0000
Finland	0.0594	0.0481
France	0.0421	0.0192
Germany	0.0391	0.0246
Greece	0.0822	0.1121
Hungary	0.0787	0.0462
Ireland	0.0197	0.0070
Italy	0.0483	0.0351
Latvia	0.0000	0.0000
Lithuania	0.2012	0.1983
Luxembourg	0.0000	0.0000
Malta	0.0000	0.0000
Netherlands	0.0906	0.0691
Poland	0.0620	0.0486
Portugal	0.0708	0.0514
Romania	0.1026	0.0546
Slovakia	0.1133	0.0517
Slovenia	0.0090	0.0000
Spain	0.0649	0.0501
Sweden	0.0566	0.0300
United Kingdom	0.0382	0.0170

strong positive trend: the increase between 1999 and 2019 is about 15 p. p., getting close to 90 per cent. This means that European countries accounting for the majority of total net imports are highly dependent on the foreign market: considering 1999, the top five net importing countries are Germany (18.1%), Spain (13.9%), Italy (13.1%), the Netherlands (12.1%) and France (10.3%), whose energy needs are met on average by net oil imports for more than 97%.

2.4. Geopolitical dependency

Diversification is supposed to fasten energy security, especially in oil-importing countries (Vivoda, 2009). From this point of view, an indicator that measures market concentration may help to understand the state of energy security of a country. Generally speaking, the identification of specialisation in international trade is comparable to a similar issue in industrial organisation, that is the need for a theoretical and empirical measure of market power. In this regard, the Herfindahl-Hirschman Index (HHI) represents a typical example (*i.e.*, Magee and Magee, 2008).[6] In a trade framework, the HHI can be applied both to the export and to the import side, accounting for the number of exporting or importing countries, as well as their concentration. Since we are interested in the oil dependence of European Union (EU) member states, we will use this indicator, focusing our attention only on the import side of trade. The HHI of oil imports of a certain EU country *j* (*HHI_import*) is calculated by squaring and summing the shares of oil volume imported by partner countries *i* (our market shares) as follows:

$$HHI\_import_j = \sum_{i=1}^{n} (MS_i * 100)^2 \tag{1}$$

where MS_i represents the market share of exporting country *i* to country *j* and *n* the number of all worldwide partner countries. The HHI gives much heavier weight to countries with large market shares than to countries with small shares as a result of squaring the market shares. This feature of the HHI corresponds to the theoretical notion in economics that the greater the import concentration in a small number of countries (a high HHI), the greater the likelihood that, other things equal, competition in a market will be weak. In contrast, if concentration is low, reflecting a large number of countries with small market shares (a low HHI), competition will tend to be significant. The HHI ranges from a maximum value of 10,000 in which one country has 100 per cent of the market (monopolistic situation) to the minimum value of 0 which occurs when a purely competitive market exists with infinite countries with small market shares.

Market concentration from the import side represents only one side of the coin when relating to geopolitical dependency. It is also important to take into consideration the level of political stability of the exporting countries. A significant percentage of EU oil imports derives from geopolitically unstable countries that have seen an exacerbation of

[6] The index has been developed independently by the economists Hirschman and Herfindahl. Hirschman presented the index in his book (1945), while Herfindahl presented it in his unpublished doctoral dissertation (1950). More details about the background of the index can be found in Hirschman (1964).

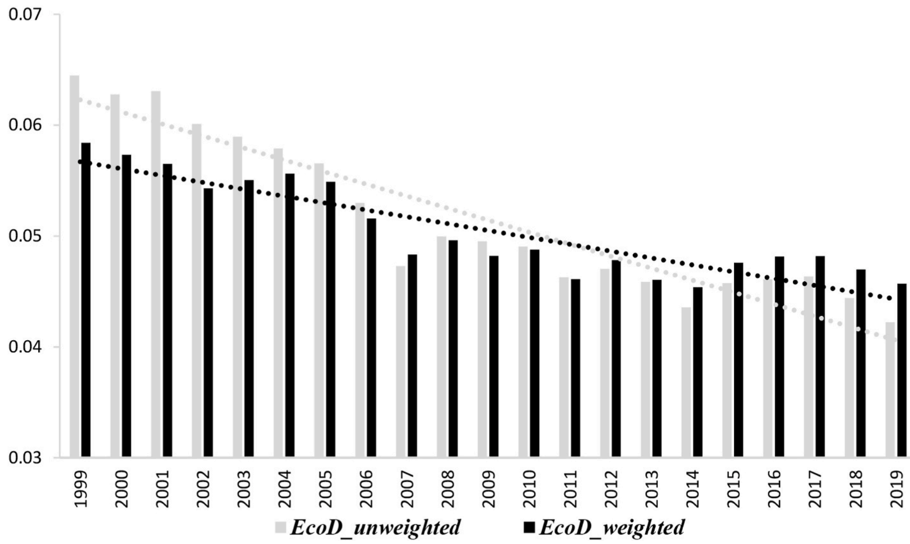

Fig. 4. Economic dependency in the European Union – Aggregate level.
Note: histograms represent Economic Dependency (*ED*) from crude oil. The dotted lines represent the related linear tendency lines.

Table 4
International dependency in the European Union – Country level.

	1999	2019
	ID	
Austria	88.4%	93.1%
Belgium	100.0%	100.0%
Bulgaria	99.2%	100.0%
Croatia	78.7%	73.9%
Cyprus	100.0%	0.0%
Czechia	97.0%	99.0%
Denmark	−81.3%	35.3%
Estonia	0.0%	0.0%
Finland	100.0%	100.0%
France	98.2%	98.5%
Germany	97.4%	97.8%
Greece	99.9%	99.3%
Hungary	82.3%	86.4%
Ireland	100.0%	100.0%
Italy	94.2%	93.7%
Latvia	0.0%	0.0%
Lithuania	94.7%	99.6%
Luxembourg	0.0%	0.0%
Malta	0.0%	0.0%
Netherlands	97.1%	98.7%
Poland	97.4%	96.4%
Portugal	100.0%	100.0%
Romania	41.9%	72.2%
Slovakia	98.8%	99.9%
Slovenia	99.6%	0.0%
Spain	99.5%	99.9%
Sweden	100.0%	100.0%
United Kingdom	−55.4%	7.1%

terrorism, internal and border conflicts or wars (McGovern et al., 2020). For this purpose, the previous equation is modified in the following way:

$$HHI\_import\_PS_j = \sum_{i=1}^{n} (MS_i * 100)^2 \cdot PS_i \quad (2)$$

where PS_i represents the political stability of the exporting country *i*. This indicator has been estimated using the dimension "political stability and absence of violence/terrorism" of the Worldwide Governance Indicators (WGI) developed by the World Bank. In particular, the *PS* variable is the result of the following steps: firstly, we reverse the meaning of the original range from −2.5 (weak political stability) to 2.5 (strong political stability) by multiplying the total score for −1; secondly, we set 0 as the minimum value and 1 as the maximum one. The last two procedures may be justified in the following way: on the one hand, the reversing relationship stems from the requisite of obtaining a measure that penalises instable exporting countries; on the other hand, the normalisation procedure allows us the keep the same range of the original HHI so as to facilitate their subsequent comparison. In this way, the *HHI_import_PS* maintains the same meaning of the *HHI_import*, making it independent from the latter variable in an economic and statistical meaning: values close to 10,000 suggest the presence of a monopoly in crude oil imports, while values close to 0 a fully competitive market.

In any case, it should be noted that the direct comparison between the two indices should be taken with caution. The two indicators assume, in fact, the exact same value if and only if all the *i* countries from which country *j* is importing crude oil are characterised by maximum internal instability. This extreme case is practically impossible, which always places *HHI_import_PS* below *HHI_import*. This feature is visible in Table 1, which introduces the main summary statistics of oil dependency variables. The *HHI_import* actually covers its entire range of variation (729-10,000), with a mean of 5057 and a standard deviation equal to 3144. *HHI_import_PS*'s maximum is lower (7,227) while its mean is almost the half (2,323), which suggest that, on average, European Union countries are importing crude oil from exporting countries characterised by a political stability value of 0.50. This different positioning should not be interpreted as an improvement of the diversification process, but only as a result of the recalibration process. In particular, one way to solve this comparison issue is to relate *HHI_import_PS* to *HHI_import* in percentage terms, interpreting the results (i) between countries and within the same year, and (ii) between years and within the same countries (Table 5).[7]

Generally speaking, the higher the percentage value the smaller the difference between the two indices in the same country, meaning that the country under consideration is importing crude oil from highly unstable countries. As anticipated, this finding alone is not very informative per se but assumes much more importance when compared with other information.

[7] We are reporting 1999 and 2019 for illustrating purpose and to consider the overall change between these years. Anyway, each indicator has been estimated yearly for our entire sample, representing one of the element of the MODI for the European Union.

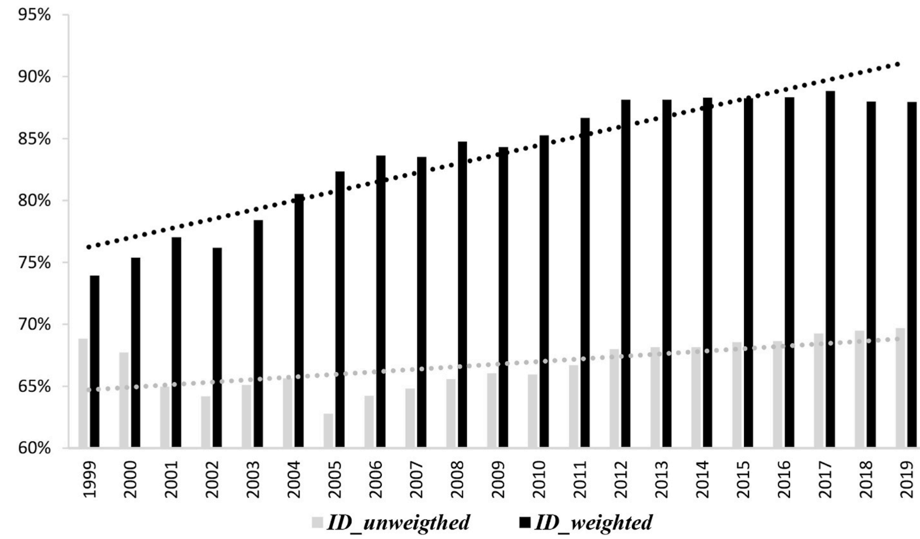

Fig. 5. International dependency in the European Union – Aggregate level.
Note: histograms represent International Dependency (*ID*) from crude oil. The dotted lines represent the related linear tendency line.

Table 5
The relationship between the HHI and the HHI adjusted for political stability of exporting countries.

	1999			2019		
	HHI_import	*HHI_import_PS*	%	*HHI_import*	*HHI_import_is*	%
Austria	1633	887	54.3%	2637	1447	54.9%
Belgium	3167	260	8.2%	4446	1077	24.2%
Bulgaria	4571	2745	60.1%	3525	1737	49.3%
Croatia	4088	2429	59.4%	2339	1176	50.3%
Cyprus	3791	1687	44.5%	8317	1461	17.6%
Czechia	7408	4488	60.6%	3686	1755	47.6%
Denmark	6620	597	9.0%	3036	785	25.9%
Estonia	9971	6055	60.7%	3719	1359	36.5%
Finland	2658	601	22.6%	7045	3327	47.2%
France	2149	714	33.2%	1097	582	53.1%
Germany	1884	725	38.5%	1541	758	49.2%
Greece	2876	1309	45.5%	3177	2612	82.2%
Hungary	9976	6058	60.7%	5084	2442	48.0%
Ireland	4450	805	18.1%	5455	1858	34.1%
Italy	1375	612	44.5%	1258	693	55.1%
Latvia	9501	5767	60.7%	9783	4674	47.8%
Lithuania	9614	5836	60.7%	5068	2407	47.5%
Luxembourg	9725	1635	16.8%	9996	5072	50.7%
Malta	9648	4884	50.6%	9992	5220	52.2%
Netherlands	2578	795	30.9%	1876	821	43.8%
Poland	8021	4862	60.6%	4293	2055	47.9%
Portugal	1233	550	44.6%	1091	534	48.9%
Romania	4129	2250	54.5%	3576	1585	44.3%
Slovakia	9771	5933	60.7%	9350	4466	47.8%
Slovenia	3214	1714	53.3%	5700	1901	33.4%
Spain	2199	806	36.6%	949	610	64.3%
Sweden	3095	358	11.6%	2226	556	25.0%
United Kingdom	3828	873	22.8%	2812	610	21.7%

(i) take the case of Austria and Belgium in 1999. Within this year, the first country is characterised by one of the highest percentage values (54.3%) while Belgium by the lowest one (8.2%). In general, Austria is importing crude oil in a balanced manner by many (18) countries (*HHI_import* is equal to 1633), but a high share of these countries are significant unstable: in descending order, the top five exporters are Iraq (26.6%), Libya (19.6%), Kazakhstan (17.1%), Nigeria (11.2%) and Russia (4.7%), whose *PS* values are considerably high, 0.68, 0.48, 0.35, 0.57 and 0.61 respectively. On the contrary, Belgium's imports are skewed to a few and stable countries (*HHI_import* is equal to 3167): the Netherlands supplies more than 50% of total imports and the other two most important exporters are the Norway and the United Kingdom, whose political stability is remarkably high, 0.05, 0.09 and 0.19 respectively);

(ii) take the case of Cyprus between 1999 and 2019. During this period, the concentration of oil imports has significantly increased (*HHI_import* passed from 3791 to 8,317, which almost represents a monopolistic situation), while the indicator adjusted for the internal stability of exporting countries has known a slight decrease. In 1999, Cyprus imported from highly unstable countries (*i.e.*, Egypt, which accounted for half of total imports, Russia and Syria). Its import strategy has changed completely over a period of twenty years: on the one hand, the need for oil has drastically reduced; on the other hand, this reduced need was only covered by two very stable countries (the Netherlands and

Sweden). This radical change is represented by the related percentage shift: the ratio between *HHI_import_PS* and *HHI_import* decreased from 44.5% in 1999 to 17.6% in 2019, highlighting that the high concentration of the oil market was compensated by maximum political stability of exporting countries.

Geopolitical dependency can be also analysed at the European Union level. In this regard, the two overall concentration indices have been estimated in two different ways: on the one hand, through an unweighted mean where the yearly *HHI_import* total has been divided for the 28 European Union countries (Fig. 6a); on the other hand, through a weighted mean where the adjustment coefficient is represented by the share of each country's annual imports in the total European imports (Fig. 6b). The comparison between the two figures may suggest some interesting features.

First of all, the unweighted measure of the *HHI_import* highlights its slight decrease over the considered period, remarking the overall rising differentiation in the crude oil imports structure (a). This negative trend is followed also by the *HHI_import_PS*, whose relative distance from the original indicator tends to increase: in 1999 their ratio is equal to 46.3%, while in 2019 to 43.5%, underlying a general improvement in the choice of more stable exporting countries. Secondly, once we take into account the weighted measures, a different picture emerges (b). The two concentration indices are now lower, suggesting that low-importing countries are those that differentiate less while the opposite characterizes high-importing countries. Conversely to what has been seen before, their ratio shows an increasing trend (in 2019, 46%). Comparing these two pieces of information, if it is true that high-importing countries differentiate more, it is also true that they base this differentiation process on less reliable exporting countries (*i.e.*, France, Germany and the Netherlands have known an increase in the ratio between *HHI_import* and *HHI_import_PS* during our period of analysis).[8]

3. The Multidimensional Oil Dependency Index (MODI)

3.1. Constructing the MODI using Principal Component Analysis

The Principal Component Analysis (PCA) is a multivariate technique firstly introduced in the works of Pearson (1901) and Hotelling (1933). The aim of PCA is to reduce the number of p quantitative variables observed on n units into k latent variables, called principal components, which are built as a linear combination of the original p variables. The maximum number of principal components that can be obtained is p, therefore $k \leq p$:

$$C_h = a_{h1}X_1 + a_{h2}X_2 + \ldots + a_{hp}X_p = \sum_{i=1}^{p} a_{hi}X_i \ (h = 1, 2, \ldots, k) \tag{3}$$

The resulting principal components (C_h) are a set of new variables, independent from the original ones and with their own statistical meaning. In addition, the components C_h are uncorrelated (their covariance is equal to zero) and hierarchically ordered with respect to variance. Principal components are built in such a way as to reproduce the total variance of the p original variables:

$$\sum_{i=1}^{p} var(X_i) = \sum_{i=1}^{p} var(C_i) \tag{4}$$

Once obtained p principal components based on p original variables, data are synthetized by choosing only the first k principal components, which contain the highest information contribution as they preserve a high amount of the cumulative variance of the original variables ($k < p$).

In order to prevent one variable to exercise a disproportionate influence on principal components (OECD, 2008), we perform a min-max transformation so that all variables have zero means and unit variances:

$$X_{ij} = \frac{X_{ij} - min\ (X_i)}{max(X_i) - min\ (X_i)} \tag{5}$$

where X_{ij} is the standardized value for the i selected variables observed for j countries and ranges between 0 and 1. Since all variables are positively correlated with oil dependency, the value of 0 is associated to the lowest levels of the corresponding variable and the value of 1 is associated to the highest levels. Then, to compute the MODI, we need to conduct some preliminary tests to verify the suitability of PCA. First of all, original variables need to be correlated in order for the PCA to be meaningful. Hence, we perform the Pearson's correlation test to check for correlations among original variables. Results shown in Table 6 indicate that all pairs of variables show statistically significant correlation. The highest correlation is found between *EcoD* and *EneD*, with a coefficient of 0.795.

As a second step, we need to check for the presence of outliers that could affect the interpretation of PCA. For this purpose, we compute the Mahalanobis distance to identify outliers to be excluded from the analysis, and we exclude 49 observations.[9] We then use the correlation matrix in Table 6 to solve the following determinantal equation:

$$|R - \lambda I| = 0 \quad for\ \lambda \tag{6}$$

In this way, we obtain the eigenvalues, which are displayed in Table 7, and the corresponding eigenvectors, displayed in Table 8. As shown in Table 7, the first component accounts for 63.9% of total variance, the maximum variance of the original variables. The first two components account for 87.8% of the cumulative variance of the original variables.

Finally, the MODI index is computed, for each country i and time t, as a weighted sum of the four principal components C_h, with weights represented by the eigenvalues (the variances) associated to each component:

$$MODI_{i,t} = \frac{\lambda_1 C_{1i,t} + \lambda_2 C_{2i,t} + \lambda_3 C_{3i,t} + \lambda_4 C_{4i,t}}{\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4} \tag{7}$$

After PCA, we perform two postestimation tests - the squared multiple correlation (SMC) of each variable on all other variables to check that all variables can be explained well by other variables and the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy to compare the correlations and partial correlations between variables - to verify the validity of our analysis. Both tests confirm that our data are suitable for a low-dimensional representation through PCA.

3.2. Trends and rankings of the MODI in the EU

Results from our analysis show that, throughout the period considered, the European Union on aggregate has managed to reduce its dependency on oil. As shown in Fig. 7, indeed, the MODI index in 2019 is negative, although the decreasing trend is not stable over time but partly dependent on year-specific conjunctural circumstances (for instance, in 2017 the MODI is positive again). However, if we look at each EU country individually, the trend in the MODI between 1999 and 2019 is very heterogeneous, as shown in Figure B1 in Appendix B. For instance, while some countries (e.g., Estonia, Latvia, Luxembourg, Malta, Slovenia and United Kingdom) display negative values in the MODI for the whole period of analysis, others (e.g., Belgium, Croatia, Finland, Greece, Italy, Netherlands, Portugal, Spain and Sweden) display positive values for the whole period. The remaining countries have a fluctuating trend.

[8] See Table 5.

[9] We exclude observations for Bulgaria between 1999 and 2008 and in 2014, Cyprus in 2008, Denmark between 1999 and 2011, Greece in 2018 and 2019, all observations for Lithuania except in 2007, and Malta in 2014.

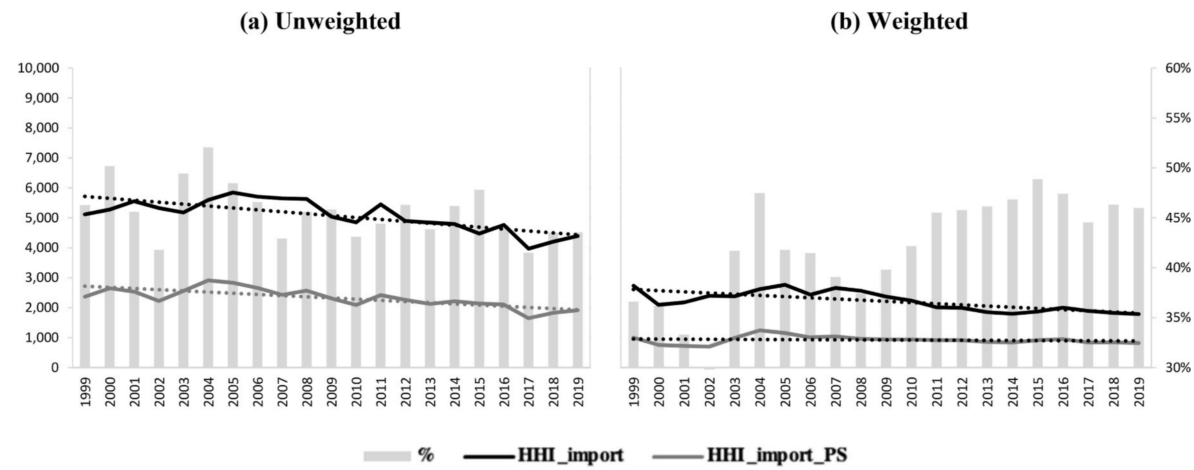

Fig. 6. Geopolitical dependency in the European Union.
Note: the right-hand and the left-hand scales are the same between the two figures.

Table 6
Pairwise correlations.

Variable	(1)	(2)	(3)	(4)
(1) ID_st	1.000			
(2) EneD_st	0.492*	1.000		
	(0.000)			
(3) EcoD_st	0.477*	0.795*	1.000	
	(0.000)	*(0.000)*		
(4) HHI_PS_st	−0.139*	−0.240*	0.175*	1.000
	(0.001)	*(0.000)*	*(0.000)*	

Note: p-values in parentheses. *p < 0.1, **p < 0.05, ***p < 0.01.

Table 7
Eigenvalues.

Component	Eigenvalue (λ)	Proportion	Cumulative
Comp1	2.557	0.639	0.639
Comp2	0.955	0.239	0.878
Comp3	0.372	0.093	0.971
Comp4	0.116	0.029	1.000

Table 8
Eigenvectors.

Variable	Comp1	Comp2	Comp3	Comp4	Unexplained
ID_st	0.532	0.124	0.838	0.009	0
EneD_st	0.589	−0.051	−0.374	0.715	0
EcoD_st	0.53	0.433	−0.395	−0.613	0
HHI_PS_st	−0.298	0.891	0.054	0.337	0

Fig. 8 ranks EU-28 countries in terms of MODI in 1999 and 2019. Some interesting results emerge: Netherlands, Belgium and Portugal rank in the top-five positions both in 1999 and 2019, classifying as the most oil-dependent countries in the EU-28. On the opposite, Malta, Latvia and Luxembourg occupy the bottom-four positions in both 1999 and 2019. Interestingly, Croatia passed from occupying the first position in 1999, with a MODI equal to 2.83, to occupying the eleventh position in 2019, with a MODI equal to 0.34. The escape from oil dependency undertaken by Cyprus is even sharper: it passed from ranking sixth with a value of the MODI equal to 1.75 in 1999 to registering negative values in 2019, with a MODI equal to −2.32.

To understand which factors contribute the most in making EU countries dependent on oil and what are the single dimensions that have driven changes over time, it is also worth disaggregating the MODI. If we look at the energy dimension, while European Union as a whole is certainly dependent on oil as the main energy source, not all its member states necessarily are. It is the case, for instance, of Estonia, Latvia, Luxembourg, and Malta (joined in 2019 by Slovenia, as well), who do not rely at all on oil from an energy perspective (Fig. 9)[10]. At the other extreme, in 1999, we find Croatia and Netherlands: while the former more than halved its energy dependency on oil in the period under scrutiny, the latter further increased it in 2019. On average, increases have compensated reductions as, overall, EU-28 countries have increased their energy dependency on oil by 0.4% over the period 1999–2019.

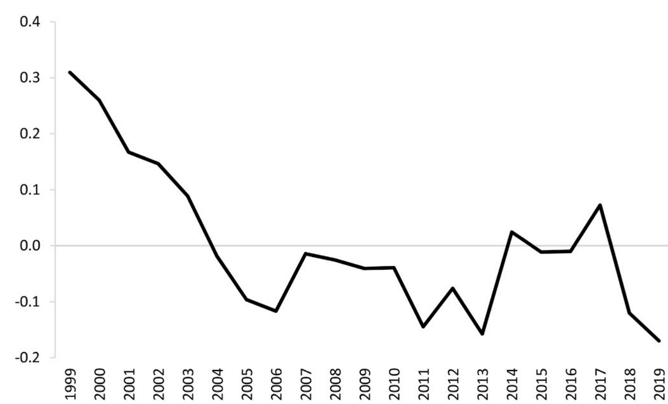

Fig. 7. Trend in the MODI for the EU-28.

At first glance, as Fig. 10 shows, all member states in EU seems to have successfully undertaken the road of decoupling GDP growth from oil consumption between 1999 and 2019. On average, EU-28 countries have reduced their economic dependency on oil by 34.4% over the 20-year period. This result gives hope about the important efforts undertaken by the EU in the ecological transition. Nonetheless, if we read this result together with the previous one on energy dependency, we can immediately observe that no absolute decoupling has happened, but only a relative one. Indeed, in line with fundings by Papież et al. (2022), both oil consumption and GDP have increased over the period considered, but at different speeds.

Fig. 11 ranks EU-28 countries in terms of international dependency

[10] If this can appear as environmentally virtuous, it is nonetheless necessary to underline that their energy needs are met almost completely by natural gas (Pérez et al., 2019).

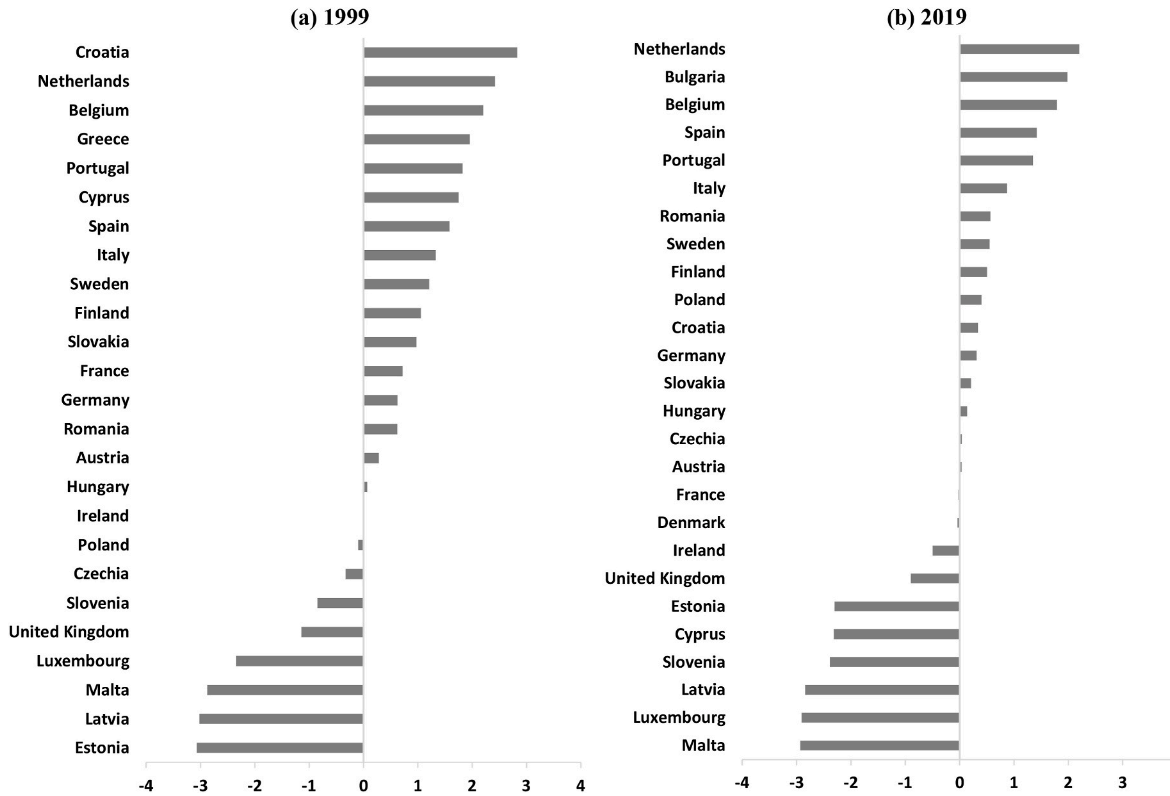

Fig. 8. MODI ranking of EU countries.
Note: some countries display only a limited number of years due to their exclusion as outliers, as resulted from the Mahalanobis distance test during the phase of index construction (see Section 3.1).

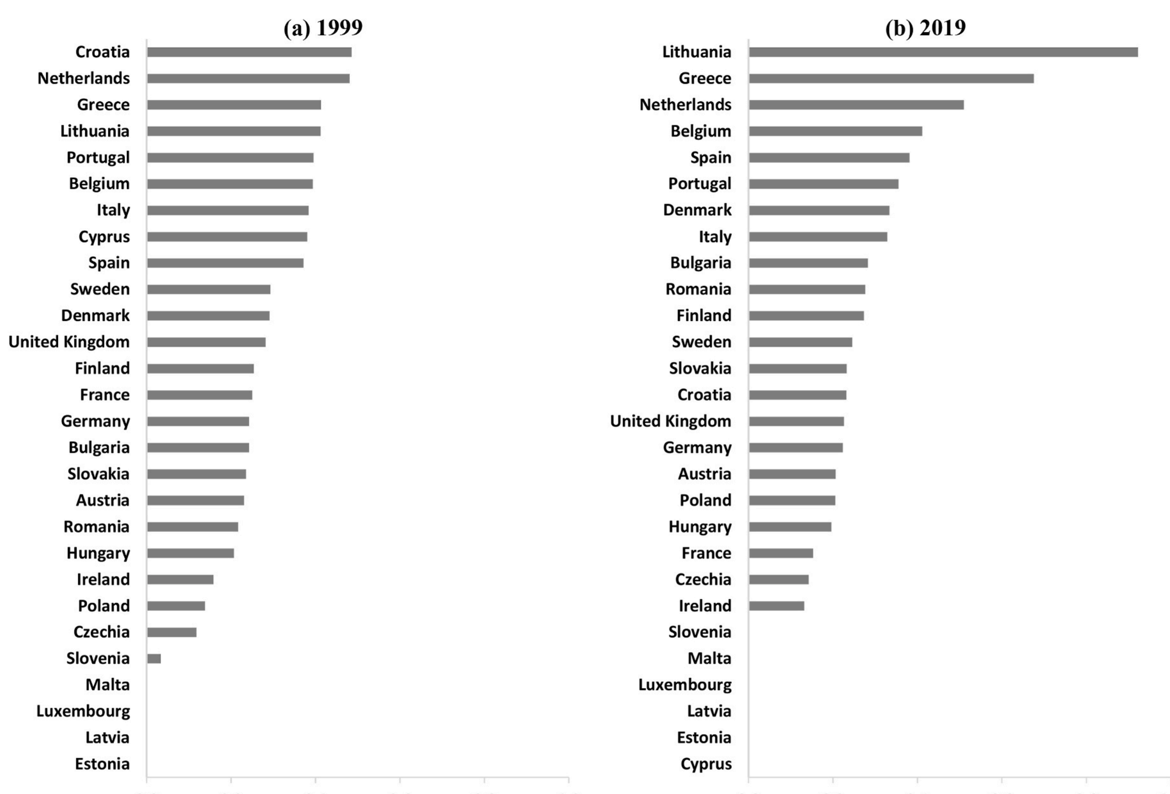

Fig. 9. Ranking of EU countries in terms of energy dependency on oil.

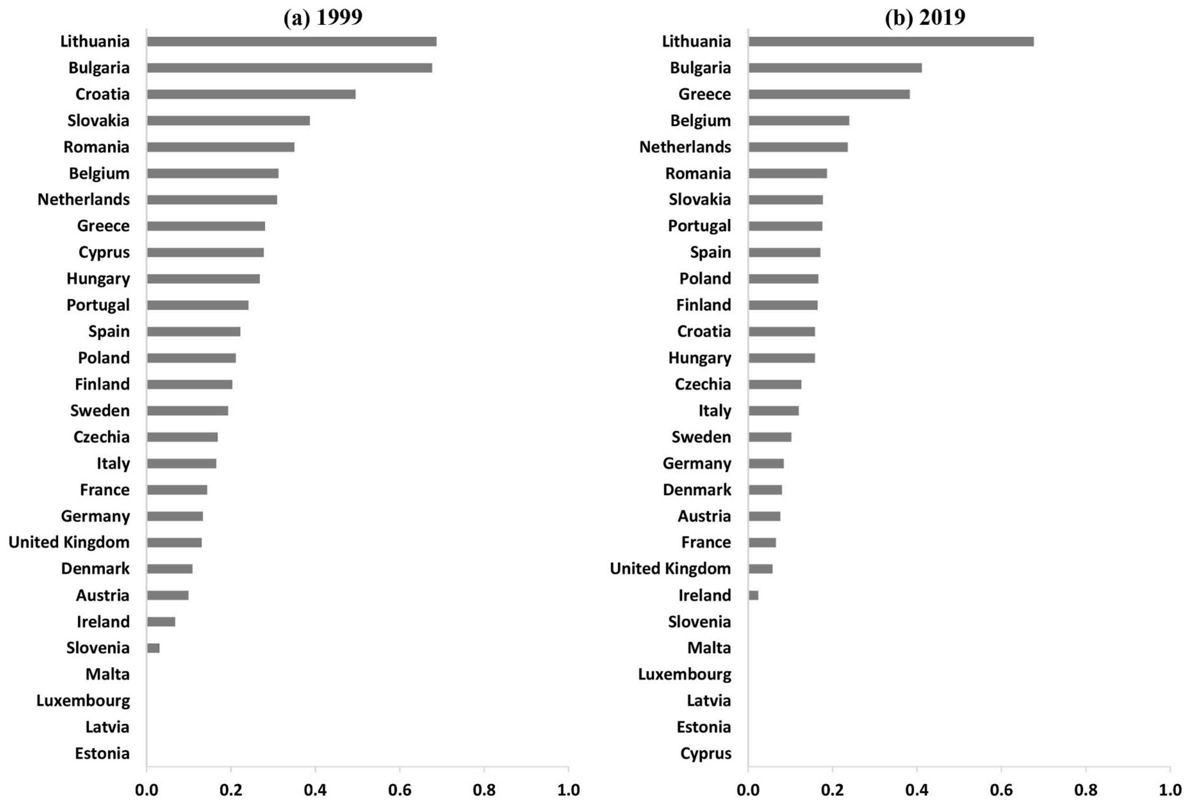

Fig. 10. Ranking of EU countries in terms of economic dependency on oil.

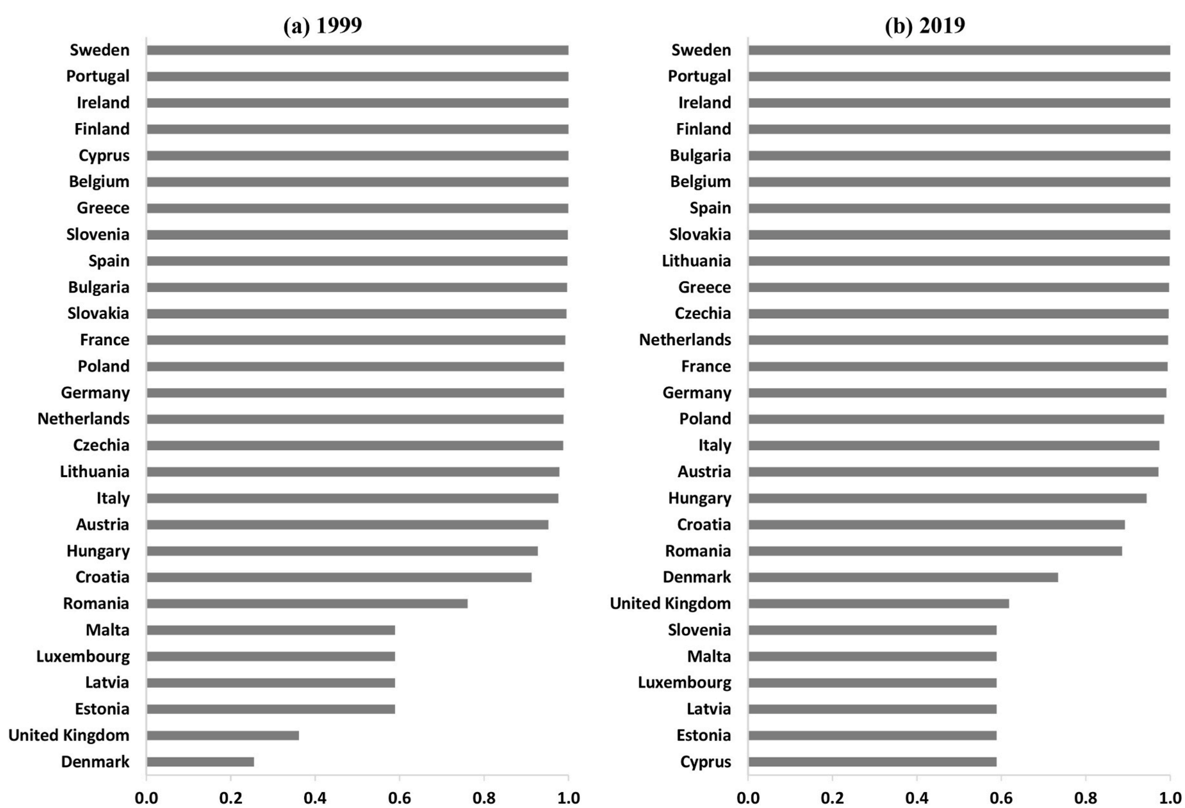

Fig. 11. Ranking of EU countries in terms of international dependency on oil.

on oil in 1999 and 2019. It is interesting to notice here that all EU countries are strongly dependent on imports to satisfy their internal demand of oil. In most of the countries, imports account for the totality of energy needs met by crude oil. In 1999, Denmark and the UK were the countries less dependent on imports to satisfy their internal oil needs. Despite their divergent trends in oil consumption (as shown in Fig. 9, Denmark has increased its energy dependence in 12-year period, while UK has reduced it), they have both increased their international dependency in 2019, aligning with other EU countries.

Finally, given the high international dependency on oil that characterizes EU countries, the degree of diversification of importing countries and their level of political stability is relevant to understand the vulnerability of oil supply. In this respect, we can notice from Fig. 12 that the situation is rather heterogeneous: some countries (e.g., Hungary, Estonia, Slovakia, Latvia, Malta, Poland and Czechia) present either a very high concentration of imports or a lower concentration but from very unstable countries, or else a high concentration of imports from unstable countries. On the other hand, other countries (e.g., Belgium, France, Germany, Italy, Netherlands, Portugal and Sweden) have managed to either successfully diversify the countries they import from throughout the period of analysis or import from a few countries but politically very stable.

If we compare our results with those obtained by other studies addressing oil vulnerability, some interesting insights emerge. To ease comparisons, Table 9 summarizes countries' rankings in terms of the MODI and its dimensions in 1999 and 2019. What we observe is that some countries classified as very vulnerable in Gupta (2008) and Roupas et al. (2009) rank very low in terms of MODI and vice versa. Differences in countries' rankings are mainly ascribable to the different dimensions included as well as their number, which affects the relative importance assigned to each dimension, and the different time horizon considered. For instance, Czechia and Poland are among the most vulnerable European countries in terms of OVI (Gupta, 2008; Roupas et al., 2009), while they display negative or barely positive values of MODI. In line with Gupta (2008), both countries present high geopolitical dependency and medium-low economic dependency. They also display a very high international dependency, that makes these countries dependent on imports to satisfy their internal needs of oil. However, their energy dependency on oil is very low, indicating that their energy needs are met mainly from other sources. Netherlands constitutes another interesting case, as it ranks 17th in terms of OVI (Gupta, 2008) and 1st in terms of MODI. Even in this case, the largest difference in driven by the dimensions of energy and international dependency that, in this case, are very high. Similarly, Belgium's oil dependency is very high, but the vulnerability of its oil supply is very low (Roupas et al., 2009). Overall, these results highlight the need to distinguish between the concepts of oil dependency and vulnerability of oil supplies, as being oil dependent does not necessarily imply that oil supply is also vulnerable (Percebois, 2007). Accordingly, addressing the two concepts entails adopting very different policy responses.

4. Discussion and conclusions

Tackling oil dependency has important implications for the EU's energy transition and requires a holistic assessment that comprehends issues related to both economic and environmental and energy aspects. It is important to integrate discourses on oil vulnerability, which typically address energy security and the economic risks connected to any shock in oil supplies, with a broader understanding of dependency in energy and environmental terms. Such a holistic assessment of dependency has implications that call into question aspects related not only to oil markets and trade but also embrace a broad range of issues, including technological lock-in, cultural shifts in energy consumption for industrial, residential and mobility purposes, energy savings, etc. For this purpose, we build the MODI for EU-28 countries between 1999 and 2019 to highlight key rankings and trends that help policymakers identify main weaknesses of each EU member state in several aspects regarding oil dependency. Our analysis reveals some interesting

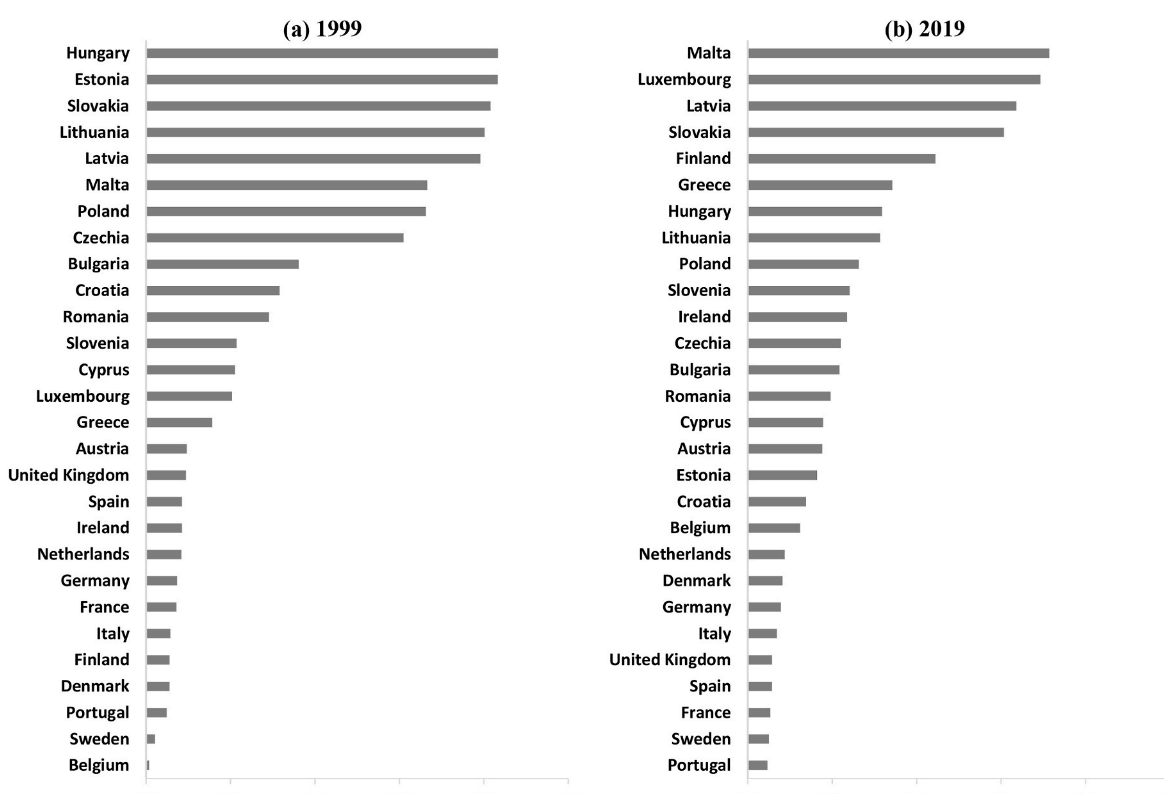

Fig. 12. Ranking of EU countries in terms of geopolitical dependency on oil.

Table 9
MODI and individual indicator ranking of countries, 1999 and 2019.

Country	MODI		EnerD		EcoD		ID		HHI_PS	
	1999	2019	1999	2019	1999	2019	1999	2019	1999	2019
Austria	15	16	18	17	22	19	19	17	16	16
Belgium	3	3	6	4	6	4	6	6	28	19
Bulgaria	–	2	16	9	2	2	10	5	9	13
Croatia	1	11	1	14	3	12	21	19	10	18
Cyprus	6	22	8	28	9	28	5	28	13	15
Czechia	19	15	23	21	16	14	16	11	8	12
Denmark	–	–	11	7	21	18	28	21	25	21
Estonia	25	18	28	27	28	27	26	27	2	17
Finland	10	21	13	11	14	11	4	4	24	5
France	12	9	14	20	18	20	12	13	22	26
Germany	13	17	15	16	19	17	14	14	21	22
Greece	4	12	3	2	8	3	7	10	15	6
Hungary	16	14	20	19	10	13	20	18	1	7
Ireland	17	19	21	22	23	22	3	3	19	11
Italy	8	6	7	8	17	15	18	16	23	23
Latvia	24	24	27	26	27	26	25	26	5	3
Lithuania	–	–	4	1	1	1	17	9	4	8
Luxembourg	22	25	26	25	26	25	24	25	14	2
Malta	23	26	25	24	25	24	23	24	6	1
Netherlands	2	1	2	3	7	5	15	12	20	20
Poland	18	10	22	18	13	10	13	15	7	9
Portugal	5	5	5	6	11	8	2	2	26	28
Romania	14	7	19	10	5	6	22	20	11	14
Slovakia	11	13	17	13	4	7	11	8	3	4
Slovenia	20	23	24	23	24	23	8	23	12	10
Spain	7	4	9	5	12	9	9	7	18	25
Sweden	9	8	10	12	15	16	1	1	27	27
United Kingdom	21	20	12	15	20	21	27	22	17	24

findings, some of which concerning specific states and others the entire EU. First, the EU has still much to do to achieve the environmental targets set by the European Green Deal. In this vein, an important result is that decoupling of oil consumption from GDP growth is happening only in relative terms and is the consequence of an increase in GDP, rather than a reduction in oil consumption. This poses serious problems in terms of the emission targets set in the package *fit-for-55*, given that energy dependency on oil and the consequent burning of fossil fuels has increased between 1999 and 2019. Second, efforts are needed to reduce divergences in the multi-speed transition highlighted by Pérez et al. (2019), since our analysis shows that EU countries present very different degrees of oil dependency and, in several aspects, trends are not aligned. This is evident from results on energy and economic dependency: Croatia, Netherlands and Belgium that, in 1999, where the most oil-dependent countries, followed three different pathways. Croatia managed to more than halve its oil consumption for energy needs and to drastically reduce the amount of oil needed to produce one unit of GDP, obtaining important results in its overall oil dependency (it passed from the 1st to the 11th position between 1999 and 2019). Netherlands reduced its economic dependence against an increase in the share of oil consumption in its own energy mix, which translated in an overall increase in its oil dependency. Finally, Belgium slightly increased its energy dependency and slightly reduced its economic dependency on oil, resulting in no significant movement in terms of the energy transition. Third, our results confirm that countries exhibiting a high level of vulnerability of oil supply are not necessarily highly dependent on oil and vice versa. This highlights the need to address the two issues separately and adopt policy responses specific for the issue to be addressed. Fourth, oil dependency constitutes a worrisome problem for EU's energy security, as evident from results and trends on international and geopolitical dependency on oil. The problem of geopolitical dependency is not new within European institutions but has emerged in full force in recent months due to the war in Ukraine. This event and the speed of its escalation have demanded a fast reaction by the EU Commission, which has presented the plan *REPowerEU*, with the threefold aims to diversify EU's energy supply, increase energy savings and produce clean energy locally. Given the urgency posed by the climate crisis and geopolitical tensions, a great deal of research is needed to understand the factors behind countries' multi-speed transition to clean energy sources and the reduction of their multidimensional dependence on fossil fuels. This would help policymakers identify key points of action to accelerate the transition and enable its convergence among all EU member states. The fast reaction of the EU Commission in response to the Covid-19 crisis and, to a lesser extent, to the Russian-Ukrainian war, have highlighted that the mobilization of huge amounts of resources, as well as effective coordination among member states is possible, even in the short-run. As suggested by Cucignatto and Garbellini (2022), rethinking national industrial policies may help to simultaneously address the need of diversification of oil supplies and the adoption of a holistic assessment of oil (and fossil fuel) dependency to effectively undertake the ecological transition.

Author statement

The authors have no conflicts of interest to declare that are relevant to the content of this article.

Federica Cappelli: Conceptualization, and, design of study, Data curation, Formal analysis, and/or, interpretation of data, Writing – original draft, Revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published.

Giovanni Carnazza: Conceptualization, and, design of study, Data curation, Formal analysis, and/or, interpretation of data, Writing – original draft, Revising the manuscript critically for important intellectual content, Approval of the version of the manuscript to be published.

Declaration of competing interest

The authors whose names are listed immediately below certify 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

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resourpol.2023.103480.

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