“the Green Paradox Phenomenon: A European Union Empirical Application”

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11 **application”**
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13 **ABSTRACT:** The green paradox describes an undesirable and socially inefficient phenomenon
14 caused by the expansionary reactions of the Supply as a response to the various mechanisms that
15 combat climate change. This article seeks to understand and aggregate the different drivers of this
16 phenomenon portrayed in the literature, as well the empirical evidence associated and the proposed
17 solutions. For this purpose, compilation and systematization of the various scientific contributions
18 up to date in this context have been elaborated, which led to the identification of five major drivers
19 of the paradox: (i) Environmental Taxes, (ii) Green Supports, (iii) Uncertain Property Rights, (iv)
20 Temporal Lag and (v) Emission limits (Cap). Moreover, we evaluate its effective impact on the
21 European scenario in the last two decades, and we have obtained evidences that the hiatus in the
22 implementation of the European emission cap mechanism has generated a strong green paradox.
23 Moreover, a robust reflection regarding the economic and environmental adequacy of green supports
24 should be considered due to its questionable net benefits. Lastly, we offer some recommendations of
25 public environmental policies that escape the paradoxical phenomenon, through the enunciation of
26 the conditionalities of these provocateurs.

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30 **KEYWORDS:** green paradox, externalities, environmental taxes, emission limits, non-renewable
31 resources, energy policy
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1. Introduction

When we are confronted with (negative) externalities in the non-renewable natural resources market, we assume that in the light of the seminal literature, the best alternatives would be to implement instruments such as the taxes/subsidies of Pigou, or the market for CO₂ permits (Carter, 2007). However, when we look more closely at the state of the art of the benefits of these economic incentive instruments in this market, we understand that some authors, such as Sinn (2008), have pioneered the existence of a Green Paradox, thus deteriorating the increase in social welfare of the environmental measure. Moreover, it is also possible to identify in seminal literature, the discussion of the "unintended effects", prior to this concept, through Strand in 2007. Although he does not coin the term, he deductively demonstrates how the implementation of an alternative technology can cause an acceleration of fossil fuel extraction at the present time, as fast as the rate of innovation of this same technology is (Strand, 2007). In this way, Sinn conceptualizes the controversial "green paradox" that gives rise to recent research around the concept. This aggregator phenomenon tends to incorporate the expansionist reaction of the supply as a response to the various mechanisms for combating negative externalities, also known as drivers or provokers of the paradox. It is in this context that the study, mostly deductive, of the German economic advisor, alerts us to the strategic and rational behaviour of the supply side which reacts offensively to these economic instruments in response to the announced appropriation of its present and future rents (Sinn, 2008). This manoeuvre can be seen both in the increase of the extraction (more usual) and/or in the geographical displacement of the extraction unit to another country with less environmental regulation, also known as carbon leakage, as demonstrated (Eichner & Pethig, 2011), (Ritter & Schopf, 2014), (van der Ploeg & Withageny, 2015), (Sen, 2016) and (Fujisaki, 2018). To this physical remobilisation it can also be attributed the terminology "spatial green paradox" as opposed to the green paradox whose consequence is only an increase in the production of the targeted resource (Ritter & Schopf, 2014).

Still with regard to the seminal study of Sinn, it is important to note that it considers the paradox to be particularly problematic, not only because it culminates in the opposite effect to the desired, but mainly because it leads to an increase in negative externalities generated at the present time, instead of smoothing over time the amount of emissions released into the atmosphere. This situation becomes even more weary when we relate this adverse phenomenon to the scientific expectation that in the future society will have better technologies capable of mitigating the impact of these externalities, whereby socially it will not make much sense to anticipate the extraction of these resources. From another point of view, the evolution of greener alternative technologies may allow the total replacement of these resources in the future, whereby their early consumption may jeopardize the main motivation for the development of those (Sinn, 2008).

However, if on the one hand there is a strong consensus in the literature on the need to avoid the occurrence of this paradox, on the other hand it is possible to find some divergence in the categorisation of which are the great provocateurs of it, the solutions to be implemented, the appropriate methodology, or even its effective incidence on the real economy.

While some authors, such as Sinn (2008), Hoel (2010) or Edenhofer & Kalkuhl (2011), among others, deduce their conclusions (favourable to the paradox) from the Hotelling model, others strongly oppose its use in the study of this phenomenon. One of the most critical voices in the use of this model, and its premises, in the study of the non-renewable resources market has been that of Cairns (2014) accompanied also by James Smith (Cairns & Smith, 2019). They claim that the assumptions of this Hotelling paradigm are unrealistic and limiting, leading to results incompatible with reality, especially in the problem of the sunk capital, which translates into an invariable production capacity in the short term. Thus, while the seminal authors ignore this fixed cost, and consider that the only link between the (two) periods is the stock of the existing resource, Cairns and Smith try to analytically incorporate the proper conditionalities to the extraction of natural resources, which requires a decision, a planning and a sunk investment in the periods prior to the extraction (Cairns & Smith, 2019). This significant change in the assumptions of the model has allowed these authors to deductively refute the idea of a green paradox, which as we will see below has been relatively unusual.

The present article thus offers literature a narrative review compiling the various scientific contributions around the concept of Green Paradox. In this way, promoting a discussion of the significance of this phenomenon in climate public policies in its broad scope. Moreover, this article seeks to understand and

aggregate the different drivers of this phenomenon portrayed in the literature, as well the empirical evidence associated and the proposed solutions. The evaluation of the effective impact of these drivers is also made on the European scenario in the last two decades, and we have obtained evidences that the hiatus in the implementation of the European emission cap mechanism has generated a strong green paradox. Truly, the major contributions of this article lie in the pioneering explicitness of the various drivers that promote the paradox, as well as their conditionalities. This construction is especially innovative given the absence of a compiler article on the present topic. Furthermore, there is a scarce literature that empirically study the green paradox and its drivers for the European context. The structure of this article is as follows: following the present introduction, we present a literature review with an inaugural description of the methodologies used in the study of the paradox, the statement of the main drivers and the empirical evidence regarding those, and a brief discussion of the eventual solutions to this phenomenon; in the third section we present the methodology and data for the empirical approach, followed of the results presentation and discussion, and finally, the main conclusions and limitations of this work.

2. Literature Review

2.1 Methodologies Adopted in the Green Paradox Study

Given its relative emergence, this theme has invited certain authors to explore both the analytical and deductive side of the problem as well as its empirical validation. In addition, it also stands out in a smaller dimension some descriptive case studies carried out. In fact, the first years of discussion of the paradox were essentially filled with algebraic deductions usual in the elaboration of new concepts, as was the case with the green paradox. The Sinn's (2008) study is naturally the reference investigation, but it is also possible to identify the research by Hoel (2010) and Edenhofer & Kalkuhl (2011) whose analysis further deepens the seminal literature and presents new conditionalities for the verification of the paradox, such as certain characteristics of the environmental tax (the main driver of the paradox). In fact, an analytical context has been elaborated whenever new determinants for this adverse phenomenon are presented. Di Maria et al. (2012) explain the pioneering link with the time lag in this way, Grafton et al. (2012) also mention the interconnection of green subsidies to this paradox in this regard, and Smulders et al. (2012) similarly opt for this methodology to corroborate the phenomenon also described in not scarce natural resources.

Nevertheless, since the conceptualisation of the paradox in 2008, the paramount importance of validating this phenomenon through various empirical studies in different regions has been reiterated. This is a task that however has been proved difficult for the scientific community (Österle, 2012). Nonetheless, it is crucial to highlight the economic relevance that the few empirical studies have had on this topic. Emphasising the empirical assessment of Di Maria et al. (2014) and Grafton et al. (2014) who, in addition to proposing two years earlier new determinants of the paradox in a theoretical way, also succeed in empirically validating the relations suggested deductively as that of the time lag (Di Maria et al., 2012) and the green subsidies (Grafton et al., 2012). Two recent research studies (Zhang et al., 2017) and (Chen et al., 2020) also stand out in this methodological order. These, although not accompanied so clearly by an analytical illustration, are examples of contemporary empirical studies whose approach to the green paradox incorporates some of the conditionalities of the region studied. While Zhang et al. (2017) link fiscal decentralisation to the phenomenon, Chen et al. (2020) incorporate a non-linear effect of environmental regulation. As these variables, due to their particular character, are difficult to corroborate deductively, the empirical methodology adopted here is extremely useful.

Finally, to a lesser extent in this area, there are also some case studies, of descriptive analysis, such as that of Fujisaki (2018) in the Japanese region, and although they do not show a clear causal relationship (driver-paradox), they may serve as a basis for future studies in the region.

2.2. Paradox Drivers

Since the conceptualization of this paradox, the scientific community has questioned the factors that could effectively provoke it. Sinn initially reiterates the environmental tax as the main cause of the paradox, or in a

similar way, the expectation of an increase in this tax. This link is also accompanied in his research by green financial support, or subsidies for cleaner technologies. Although not fully corroborated in his article, the author suggests that the effects of these environmental aids would have a similar effect to the economic disincentive measure, since both would create incentives for present extraction in favour of future extraction (Sinn, 2008). Indeed, the presence of the expectations of economic agents, and in particular the owners of natural resources, has been a relevant component in the work of Sinn and the subsequent authors. Besides, this is unanimously regarded by researchers as valid and assertive, as this expectation derives directly from the definition of efficient equilibrium in the instruments of Pigou (1920). The increase in marginal externality is accompanied to the same extent by an increase in the tax/subsidy to be applied, and as the unitary environmental impact of emissions is increasing, so will the amount to be applied by the economic (dis)incentive measure (Klepper et al., 2006). Without prejudice to the main drivers mentioned here, the seminal research also alerts to the problem of uncertain property rights. This issue, also related to the natural risk aversion of economic agents, indicates that owners with greater insecurity regarding the maintenance of their own resources choose rationally to extract more at present compared to those with less instability, a concept first developed by Long (1975).

Currently, it is possible to find in the state of art of literature five great drivers of the green paradox. These aggregate not only those mentioned above in the seminal articles of Sinn (2008), but also other dynamics whose authors over time such as Eichner & Pethig (2011), Di Maria et al. (2012) or Grafton et al. (2012) among others, have corroborated both analytically and empirically, albeit less frequently. These are in a summary structure: the environmental tax; the green subsidies; the uncertain property rights; the time lag and finally the implementation of an emissions cap.

Environmental Tax

The most well-known and immediately related provocateur of the paradox is the tax, or the expectation of a tax increase. This, as we have seen before, was first identified by Sinn, who offers the literature the general traits for the future study of this driver. If on the one hand this instrument creates a depressive effect on the present market, displacing supply in a northwest direction to faithfully represent its marginal costs, on the other hand it conceives a clear incentive to present extraction in anticipation of an even greater decline in this market in the future. In other words, it generates a reduction in the opportunity cost of retaining the resource in the mineral deposit. The author concludes "unless the last effect (paradox) is dominated by the first (sector depression) these policies cannot be proposed as a means to mitigate the greenhouse effect" (Sinn, 2008, p. 377).

Yet in the same sphere, some discussion has arisen about the characteristics of the tax that effectively encourage early extraction. Distancing themselves from Pigou's (1920) definition of an efficient tax emerge the authors Hoel (2010) and Edenhofer & Kalkuhl (2011) who study the relationship between the tax and the paradox without the classic conception that it must necessarily equal the amount of negative externality in order to achieve a social optimum. In this way, the analytical research listed above endorses the thesis that the actual cause of the phenomenon described is not the tax, but in turn its characteristics and conditions.

Hoel shows how a low tax level at the present, together with a sufficiently quick growth of it, or its expectation, surely generates conditions for the anticipation of extraction described in the paradox. However, the same does not occur when the tax is sufficiently high, regardless of the agent's future expectations of its growth or the format of the firm's cost function. This is due to the impossibility (and illegality) of the supply to carry average costs higher than the price charged, and therefore virtually prevented from expanding its production from this point onwards. Hoel also offers, in 2010, based on the prices of coal, oil and the respective rents, an estimate of these tributary figures: \$49 and \$179 per tonne of CO₂ emitted to coal and oil, respectively, at the time. The author also highlights the inaccuracies in his approximations, which are excessive, but points to the wide discrepancy between the figures applied fiscally (around \$19 per tonne of CO₂ for oil in 2010) and those suggested (between \$109 and \$179 per tonne of CO₂). Indeed, we can consider to some extent that "the possibility of a green paradox is not an argument against the use of carbon tax, but rather against its insufficient definition" (Hoel, 2010, p. 4).

Edenhofer and Kalkuhl also follow this idea, and beyond specifying the situations in which the tax causes the paradox, they also analyse its relationship with the discount rate. Truly, the research mentioned here resembles that of Hoel in what concerns the reduced risk of early extraction at a high tax level compared to a considerably lower one (Edenhofer & Kalkuhl, 2011). However, this differs slightly from the above-mentioned literature by specifying in even more detail the conditions inherent in provoking the green paradox through a tax. Whereas upstream, Hoel points out that a low but fast-growing tax level is responsible for the paradoxical phenomenon, Edenhofer & Kalkuhl concretely define the speed of this same growth. The specific conditions for the paradox are thus described as: a relatively low level of tax and a permanent increase of it above the discount rate for the resource owners (Edenhofer & Kalkuhl, 2011).

In addition to this discussion, Chen et al. (2020) support most of the conditions presented by Hoel and Edenhofer on the relationship between the level of the tax and an early extraction. Thus, the recent research cited illustrates this condition in quadratic form. Empirically linking the level of environmental regulation with the CO₂ emitted into the atmosphere the study concludes an inverted U relation. This trend is in line with the conditions presented upstream, as reduced regulations encourage owners to extract increasingly in advance until a peak extraction/emission is reached, which is only reversed by high regulations that effectively force extraction to be reduced (which raises prices to sustainable values once more), or forces the closure of less efficient enterprises, which in turn also generate a significant reduction in emissions (Chen et al., 2020).

Green Supports

Another relevant driver in the literature focuses on the assistance for "green" technologies. These incorporate not only the financial side through subsidies, but also the allocation of resources for the innovation of these technologies. In fact, this provocative of "unintended environmental effects" is highlighted even before the conceptualization of the green paradox by Sinn (2008), when in the previous year Strand warned us about the harmful results of this increasingly popular economic policy. This study, focusing its approach on the relationship between the rate of innovation of an alternative technology and the extraction of fossil fuels, deduces a positive relationship between the two, the higher the said rate of innovation is. This is a result of the vision that the owners of energy resources have of an under development alternative technology, which turn out to be an inherent threat to their business model (Strand, 2007).

Despite the relevance of Strand's (2007) research, a slight omission of the long-term effects of developing a clean alternative to fossil fuels can be identified. In fact, although in the immediate coming the creation of this generates an anticipation of extraction, in the later it will make the consumption of these redundant, a phenomenon that only happens if the rate of innovation of the alternative is effectively positive. It is in this context that Gerlagh (2011) offers us a useful classification of a green paradox as a way of responding to this temporal problem of environmental costs and benefits in the short and long term. In this way, it is then possible to distinguish between a weak green paradox and a strong green paradox. The first, of lesser environmental severity, arises when "the anticipation of cheaper alternative energy technology increases emissions at the present time". The second, of greater concern, arises when "anticipating cheaper alternative energy technology increases cumulative emissions damage on a net present environmental level value (NPV)" (Gerlagh, 2011). This distinction allows for a better understanding of the effective implication of green supports in the paradox. Thus, the main concern should not arise from the emergence of a weak green paradox, since it only reflects the immediate result of the measures, completely ignoring the future benefits of such innovation. On the contrary, it is the occurrence of a strong paradox that needs to be highlighted. It is therefore feasible to decide rationally, on the basis of this division, whether or not an alternative technology should receive public support. If its emergence causes fossil fuel extraction to occur to such an extent that a strong paradox arises, then it incorporates a negative externality that may even be taxed, as van der Ploeg & Withagen (2012) suggest. If, on the contrary, only a weak paradox emerges, then it adds a positive externality that should be supported in order to internalize the social benefits produced (Gerlagh, 2011).

Another way of exposing the effects of green support on the economy is illustrated by Grafton et al. (2012), which break them down in two ways: the direct effect and the indirect effect. The direct effect, also called "pro-green" effect by author, aggregates the benefits of reduced demand for fossil fuels (shifting the demand function southwest, resulting from the development of substitute energy). The indirect one, identically called the "anti-

green" effect, is enshrined in the strategic decision of the supply to reduce the equilibrium price of the above-mentioned fuels, and consequently increase the quantity traded. Thus, it is also fair to say that the green paradox effectively only occurs from this driver when the weight of the indirect effect exceeds that of the direct effect (Grafton et al., 2012).

In addition to what has been said so far about this provocateur, it is also important to note that it can be expressed in many ways in the economy. The mechanism of encouraging early extraction through the emergence of a substitute energy has been described by several authors and it is stressed in the literature that this is not the only way in which the paradox is expressed in the green support aspect. In a short case study of the Japanese region, Fujisaki reflects on the possibility that the introduction of renewable energy into national electricity production may lead to the relocation of Japanese companies to other countries (Fujisaki, 2018). If an eventual causal relationship between the two is confirmed, one of the major limitations of the above-mentioned research, the possibility of a spatial green paradox through carbon leakage to foreign states can be observed from the stimulation of alternative energies.

Finally, it's worthy to note the multifaceted character that the concept of green support can have. As we have seen, it incorporates not only the technological innovation of energy alternatives, but also subsidies to them, or the inclusion of these in national energy production. In addition, we can frame a series of other measures referred by Sinn in 2008 that fall into this category: more efficient insulation of dwellings, reduction of road traffic, architectural implementation of solar panels in public buildings, etc. These, by constituting measures that encourage the reduction of demand for fossil energies, act with a similar effect to those referred to by Strand (2007) and Grafton et al. (2012) causing the aforementioned anticipation of extraction for fear of this green threat (Sinn, 2008).

Uncertain property rights

Property rights are intertwined with the paradox fundamentally through Sinn, as few authors have subsequently been able to confer further reflections on it. Thus and as already briefly mentioned upstream, the greater the uncertainty about the maintenance of the rights of extraction and ownership of the resources, the sooner their owners will draw the subsequent income from their extraction. Faced with the apprehension of a possible democratic revolt, the fall of a dictatorial political regime, armed conflicts, or a regicide, an entrepreneur with the exploitation of mineral resources will rationally guard himself against the future, trying to extract as soon as possible before external conditions prevent him from doing so permanently. Thus, linking the natural aversion of economic agents to risk, one conjures up a positive relationship between instability/uncertainty of property rights and the occurrence of a green paradox (Sinn, 2008). A determining factor in this link is the difficulty of these fossil entrepreneurs to sell mineral deposits quickly, and to recover their sunk costs in the geological evaluation and prospecting prior to the extraction. Thus, faced with a high risk, there is no other option on the table than to hurriedly remove the resources from the subsoil and sell them at a lower price than initially planned (and earlier), occurring moreover in a green paradox.

However, it is also possible to see, in literature prior to the concept of paradox, a relationship with the opposite sign between risk/political instability and the speed of resource extraction. Bohn and Deacon in a broad empirical study show that "contrary to conventional knowledge, property risk slows down the use of mineral resources" (Bohn & Deacon, 2000, p. 257). This negative correlation evidenced by the authors can be explained by the pre-exploitation investment that occurs in most fossil fuel enterprises, as highlighted in (Cairns & Smith, 2019). Thus, political unrest demotivates the start of new oil drilling projects, and suspends mineral location studies that would continue if this geopolitical uncertainty did not arise (Bohn & Deacon, 2000).

Still, Sinn (2008) notes from the above-mentioned research of Bohn and Deacon that after further decomposition of the political risk effects on extraction, it can be seen that in dictatorial regimes more oil is kept underground than in democracies (Bohn & Deacon, 2000). Sinn's interpretation of this result focuses on the fact that democracies are more likely to challenge the ownership rights of existing "clans" than dictatorial regimes, which sometimes even live closely with them through close family and business relationships. In this way, a fully democratic regime constitutes a risk of ownership, which encourages early extraction, in a manner equivalent to the unrest mentioned by the author. Sinn concludes that "if this interpretation is assertive, the empirical results of Bohn and Deacon are in favour of the view that an increasing risk of property leads to the

green paradox” (Sinn, 2008, p. 371). Moreover, it is still possible to relate the inherent link between dictatorial regimes and monopolies in the energy sector, in contrast to the substantially more competitive economic environment that exists in most democracies. In fact, and taking into account Lewis (1976) seminal elations, which indicate a propensity on the part of monopolists to extract non-renewable resources in a more lenient way than economic agents in competitive markets, there is a strong possibility of the paradox to come naturally with greater emphasis in modern democracies. Thus, the monopolist's action as a "resource saver" in distancing itself from the competitive equilibrium imposes a benign limitation on the amount of resource marketed, and hence of the externality generated (Lewis, 1976).

Finally, it is possible, in a similar way to green support, to find a multiplicity of expressions by which this driver manifests itself in the economy. One of these is the exploitation of common goods. These are part of a classification of goods, which considers the parameters of exclusivity and rivalry. In certain circumstances, such as the discovery of common deposits, it is difficult to apply the condition of exclusivity effectively to this property. In this way, and simultaneously to a clear association of this with an opportunity cost and consequent rivalry, it becomes inevitable to prevent recurrent problems of the existence of a non-renewable common good. Sinn (2008) warns that it is extremely important to define the property rights of these resources in a concrete and definitive way, so that the owners of these resources can consummate the condition of exclusivity and make it a private good. Indeed, the existence of a non-renewable common good will encourage its extraction until the point where the next unit of resource will marginally cost more to extract/produce than the price of it. The static balance will be in $\text{Price} = \text{Average Cost}$ with industry profits being zero, as until this equilibrium economy will bring new agents into the operation and/or additional extraction units. Thus, compared to the scenario of defined property rights of a private good, we have an excessive and anticipated use of mineral resources susceptible to a green paradox (Sinn, 2008).

Temporal Lag

Another mechanism for triggering the green paradox focuses on the time gap between the announcement and the implementation of an environmental measure, be it a tax (Smulders et al., 2012), green subsidies or an emissions cap (Di Maria et al., 2012), which will be discussed later in this paper. In fact, it is rarely advisable for legislators to communicate their strategy before putting it into practice, and when this happens it usually has a purpose of provoking a planned, and intended, reaction from the others economic actors. In this way, and considering the current environmental situation, it becomes inconceivable that the established time gap is purposeful, since it only generates socially negative effects such as the green paradox. The prior announcement of a policy enables the entrepreneurs to prepare their future investments by incorporating the future consequences of the policy into their business plan. Moreover, if on the one hand this business preparation can move in the direction of an early compliance with the environmental measure, to diminish the changes to be made, on the other hand it can intensify, during the interregnum period, the activities negatively targeted by that measure. The authors cited here therefore stress that, in order to mitigate the effect of this driver, the legislator should avoid the early announcement of the measures, and as Eli Wallach suggests in the movie *"The Good, the Bad, and the Ugly"*: "If you have to shoot, shoot, don't talk" (Smulders et al., 2012).

By analysing this driver in detail we understand, even if the effect caused varies according to the measure in question, that it is possible to decompose its consequences in a generic way, through the analytical contribution of Di Maria et al. (2012) who define two major effects of the time gap, both of which are subject to the paradox. The most obvious, classified by abundance effect, is characterised by the excessive extraction of the resource in the period in which it is not constrained or limited. Thus, when a policy that creates obstacles to the extraction of fossil fuels is announced, whether through a tax or an emission limit, "more of the resource will be extracted in other (unrestricted) periods" (Di Maria et al., 2012, p. 105). In addition, the ordering effect arises, of particular relevance when the targeted mineral resource has distinct properties depending on its age, such as coal, whose carbon intensity increases as it forms underground. Thus, this effect states that it may be rational for the owners of these deposits to protect the less polluting mineral deposits for the period targeted by the measure, "dispatching" first and, prior to the measures, the extraction of the comparatively most polluting resources (Di Maria et al., 2012). In this way, both effects mentioned anticipate emissions whose omission from the time gap would have prevented. However, it is also necessary here to recall the notions already

presented of a weak and strong green paradox, which underline the paramount importance of assessing as a whole the net updated benefit, before sentencing the aforementioned measure (Gerlagh, 2011). Indeed, although the existence of a time lag in this area does not contribute positively to social welfare, it should not always be a reason to overturn the carbon tax policy, or emissions cap. At times, this gap, which is even legally necessary, given the publication required in the Journal of the Republic before the law came into force, causes "merely" a weak paradox, with that measure as a whole making a long-term contribution to the global mitigation of environmental damage, and a social positive improvement.

In addition, the work of Smulders et al. (2012) which, in parallel with the study of this driver, promotes an algebraic evaluation of the occurrence of the green paradox in goods that are not scarce (or with little scarcity, as in the case of coal), through the time lag, should also be highlighted. This study, linking households' decisions with the prior announcement of a tax, distinguishes two different situations, in which both occur in paradox. In the case of certainty about the chronology of this tax, households tend, according to the authors, to reduce total consumption and increase savings in the periods before the measure, in order to mitigate the loss of future utility. Thus, the growing savings in the economy leads to an increase in investment (and capital) in the different sectors of activity, which in turn leads to a slight economic growth accompanied globally by an increase in the consumption of the resource taxed in the future. In the scenario of uncertainty about the timing of the measure, there are successive jumps in resource consumption up to the moment when tax policy is definitively implemented. Thus, despite occurring in opposite directions, both situations incur an increase in consumption and emissions at present, regardless of the scarcity of the said good (Smulders et al., 2012).

Emission Limits (Cap)

Finally, there is a link between the implementation of an emission limit, also called an environmental cap, and the occurrence of this paradox. In fact, the employed order of exposure of the paradox drivers in this literature review promotes a fluid interconnection between them and their consequent concepts, which is precisely what occurs in a green paradox caused by the restriction of emissions. The present links occur with the carbon leakage, which causes a spatial paradox, or even with the temporal gap, which is in itself a provocateur of the same, and when together with the cap, acts as an amplifier of its effects.

Starting with the relationship that this driver has with the green (spatial) paradox, the articles by Eichner & Pethig (2011), Ritter & Schopf (2014) and Sen (2016) stand out, as those resemble the essential deductions taken in this aspect. In fact, the link presented here is first modelled through a general equilibrium methodology with two periods, and three "groups" of countries. In this way, Eichner and Pethig distinguish a region that exports fossil fuels, another associated with an emissions cap, such as the countries belonging to the Kyoto Protocol, and finally all the other territories that do not adhere to it, and therefore operate without any environmental restriction at this level. In this model, carbon leakage occurs when the emission limit is restricted in the first period and there is effectively a reallocation of the release location when emissions are constrained at the present time. This phenomenon essentially occurs through the relocation of emitting companies (from different sectors) from countries within the cap mechanism to others without the same commitment, in order to reduce their private costs for pollution mitigation, or the acquisition of emission allowances (Eichner & Pethig, 2011).

However, it is important to point out that, similarly to previous drivers, the circumstance of a green (spatial) paradox does not necessarily imply the embargo of the present mechanism. In reality, as Sen (2016) stresses, carbon leakage may occur "only" partially, leading to some emissions being in fact displaced to other regions, while another remaining portion is reduced as a result of the (financial or strategic) impossibility of internationalisation of several enterprises that are forced to remain in the target country. Thus, and in a way similar to the duality of weak and strong paradoxes, the carbon leakage is particularly worrisome when it occurs totally or, even partially, in a considerable portion (Sen, 2016).

Finally, Ritter & Schopf's (2014) research also emerges, developing the model previously mentioned by Eichner and Pethig, this present study refers to the temporal component of this driver. In this way, and as described above, the time gap regarding a certain (or uncertain) implementation of an emission limit leads entrepreneurs of non-renewable resources to change their extraction path to the present. Moreover, this anticipation phenomenon occurs simultaneously with "immediate decision making", which is the same as the

author specifies: without any time lag between the announcement and the implementation of this emission limitation mechanism (Ritter & Schopf, 2014). In this way, it is also possible to highlight the possibility of a weak green paradox, and under certain conditions (generally related to the intertemporal elasticity of supply and demand) a strong paradox through the implementation of emission restrictions (Ritter & Schopf, 2014). Despite the results obtained by the above-mentioned authors, it is important to highlight the appeal they leave when analysing their own results. In fact, the geographical coexistence of groups of regions with different restrictive environmental standards will permanently encourage carbon leakage, the main solution to which would derive precisely from the abolition of these disparities. It is therefore "imperative to bring developing economies into the environmental discussion and the implementation of strict restrictions" (Ritter & Schopf, 2014, p. 146). This "resolution" discussed below is further complemented by Sen with monetary and technological compensation to these economically less developed countries in order to counterbalance the loss of welfare that these agreements would have in their already weakened economies (Sen, 2016).

2.3. Evidence of the Paradox

The analysis, both methodological and algebraic, of the effect of previous drivers on the economy has offered the literature different results in different directions. Thus, it is possible to briefly divide the literature into two groups. On the one hand, the studies offering evidence of the effective occurrence of the green paradox are gathered, and on the other hand, a small fraction of them emerge that refute this hypothesis initially conceived by Sinn. Thus, in this second set a rather restricted number of authors are added, given the difficulty both empirically and analytically of conceiving a scenario in which Supply does not react strategically to the implementation of an environmental measure. In this context, Cairns (2014) and Cairns & Smith (2019) stand out as offering an effective challenge to the paradoxical phenomenon, through the introduction of an intertemporal component related to prior investment. These, convinced of the inadequacy of the application of the Hotelling model in the markets of non-renewable natural resources, choose to redirect their study so that the stock of the resource is not the only component that interconnects the various periods of time, but on the contrary, appears accompanied in this environment by prior sunk investment whose present capital would inherently depend. Thus, it was possible to demonstrate in the authors model that "almost any form of tax generates a reduction in the level of development and production (of the resource)", consequently making the existence of a green paradox rather small, if not inexecutable (Cairns & Smith, 2019, p. 2).

Despite this fruitful challenge, most of the evidence in the literature remains in the direction of corroborating the paradoxical phenomenon. Sinn (2008), as the "father" of the concept, naturally evidences it, in an algebraic way, underlining the importance of empirical confirmations to it, which would reach the scientific community to a lesser extent. In the following years relevant contributions to it appear, some already alluded to in the present review, such as the specification of the properties of the tax in which it effectively succeeded in paradox, such as those of Hoel (2010) and Edenhofer & Kalkuhl, (2011). These, although alluding to the specific context that the paradoxical phenomenon requires, reinforce its presence and significance. At the same time, Eichner & Pethig (2011) exhibit a general equilibrium model that strengthens the role of the implementation of emission limits in the paradoxism alluded. Similarly, over time, several authors have reinforced the relevance of the concept presented by identifying the drivers already presented, such as Di Maria et al. (2012) in the interconnection with the time gap, or Gerlagh in (2011) in the case of green supports, among others. In fact, it is possible to observe a relative abundance of analytical articles that seek, through the introduction of new concepts and different variables, to explore the different contexts in which the paradox may occur. It is, however, in the empirical field that the scientific literature lacks studies that either validate the phenomenon described or refute it.

In this context, stand out the researches of Di Maria et al. (2014), Grafton et al. (2014), Zhang et al. (2017) and Chen et al. (2020) who evaluate the paradox in different areas. In the connection with the temporal lag, Di Maria assesses the possibility of the phenomenon through the temporal lag in the implementation of the Acid Rain Programme, which would have been announced 5 years earlier (1990-1995). This, testing the hypotheses of the decomposition of the said driver (abundance and ordering (Di Maria et al., 2012)), the study evaluates not only the quantity of resource consumed, but also its sulphuric density, which indicates its unitary pollution.

However, the results of this study are presented in the middle term in the validation of the paradox. While the prices of the resource in question (coal) fell during the interregnum period, demand, which in this case is essentially centred on power stations, did not react substantially to this fall, thus not seeing an increase in the amount of resource consumed during this time interval. On the ordering side, this article has a rather similar effect: a clear indication of prices by means of a reduction in sulphur-intensive coal (the most polluting), accompanied by an inaction of demand, which has led to an unchanged quantity of coal traded, or even, to some extent, to a variation in the opposite direction. Based on their findings, the authors thus reply to themselves: "Should we be concerned about the green paradox? Yes...well, maybe...probably not!" (Di Maria et al., 2014).

Another relevant link is also empirically tested for the US universe. This time, Grafton assesses the impact of green support on US fossil fuel production from 1981 to 2011. Thus, following Gerlagh's (2011) division in the previous year, this author empirically distinguishes between a weak green paradox and a strong green paradox. In relation to the former, the results of his research unequivocally show a causal relationship between support, in the form of subsidies, for an alternative technology, which in the case consists of bio fossils, and the increase in the production of fossil fuels, through positive elasticity in both the short and long term. A strong green paradox is also confirmed for the phenomenon in the most worrying form, and in line with the conditionality presented by itself, but only in cases where the technology developed offers a reduction in emissions compared to conventional fuels of less than 26% and 57% in the short and long term respectively (Grafton et al., 2014). However, it is imperative to note the limitation in the choice of variables in this study, which considers biofossil production to be a suitable proxy for subsidies, which may to some extent call into question the link exposed by the author.

Finally, two relatively recent evaluations have emerged in China covering the relationship between the paradoxical phenomenon and the tax, more precisely environmental regulation as a whole. First, Zhang et al. (2017) in a 1995 to 2012 analysis of the country which shows a negative causal relationship between environmental regulation and the amount of CO₂ emissions into the atmosphere, thus refuting the green paradox through the provocateur targeted. However, they highlight the impact that the change in the way this regulation is applied has on the amount of emissions generated, resulting in a significant increase in these, particularly during the fiscal decentralisation of the said regulation (Zhang et al., 2017). Chen et al. (2020) decide, unlike the previous study, to evaluate not a linear relationship but a quadratic link between the level of environmental regulation and the volume of emissions for a relatively similar sample (2000-2014 in the same country). In this way, they expose a parabolic, positive concavity impact, which coincides not only with the occurrence of the paradox at certain levels, but also with the tax conditionalities presented by Hoel (2010) and Edenhofer & Kalkuhl (2011), already discussed upstream (Chen et al., 2020).

2.4. Solutions?

On the one hand, the literature has offered new links and paradoxical mechanisms to this subject, but on the other, it has also been prolific in presenting solutions to this adverse phenomenon. Sinn, first of all, stresses the importance of applying a decreasing ad valorem tax over time, as this would reverse the incentive of extraction in time for the future moment, which would allow not only to avoid the paradox, but also to reduce the amount of emissions at the present time (Sinn, 2008). In line with this reasoning, Hoel and Edenhofer, already mentioned in the present review, proclaim in their research properties required by the tax to cause paradox, implicitly presenting themselves solutions to it. Among these, the implementation of a sufficiently high tax that has a small growth over time, if not even a decrease (Hoel, 2010), (Edenhofer & Kalkuhl, 2011), stands out. Still on the tax side the proposal to tax the rents of capital are considered. In this formulation Sinn distinguishes between man-made capital gains (material capital) and natural capital gains, arguing that an increase in the tax on the former would make it "less attractive (for owners) to convert their mineral resources in deposits into investment capital" (Sinn, 2008, p. 384) . However, some resistance can be found in the literature to this proposal, notably from Edenhofer who, while reaffirming that the capital tax can effectively slow down extraction, stresses that it is not able to achieve "sufficiently low stabilisation targets" (Edenhofer & Kalkuhl, 2011). From another point of view, more vehement state solutions emerge from China, and as a

result of its own economic doctrine. Thus, in order to regulate the problem that fiscal decentralisation has caused in terms of emissions (Zhang et al., 2017), a movement in the opposite direction is suggested: fiscal centralisation in the implementation and monitoring of environmental regulation.

Another order of contributions to the resolution of the paradox arises from the allocation of subsidies. In this field, the proposals to subsidize the mineral resource underground stand out, since its permanence in the deposit reflects an absence of negative externality in society that is worth encouraging. However, the authors promptly warn that the implementation of such measures would be politically unthinkable (Sinn, 2008), (Edenhofer & Kalkuhl, 2011). Edenhofer goes even further, saying that given substantial environmental concerns at the present it may be more efficient to tax green alternatives and subsidise underground mineral resources in order to avoid early extraction at all costs (Edenhofer & Kalkuhl, 2011).

In the problem of the mechanism for implementing an emissions cap causing a spatial paradox, the literature reaffirms the need to sign common international agreements covering all countries, and not just those within a common economic integration, as has been the case until then. In fact, this indication has been common to almost all the authors of this theme, since it would be the only effective resolution to the "carbon leakage" (Sinn, 2008), (Edenhofer & Kalkuhl, 2011), (van der Ploeg & Withageny, 2015). However, the state of the art highlights the difficulty of this inclusion, as developing countries with delicate industrialisation needs would not have sufficient incentives to limit their own carbon emissions. Incentives and financial compensation for these countries may thus be necessary to avoid this spatial paradox (Sen, 2016).

Finally, it should also be highlighted the link between energy efficiency (and energy consumption efficiency) of conventional fuels and the delay in the occurrence of the adverse phenomenon described, which happens, according to the author of this link, even when it is pushed by the provocateurs pointed out upstream. In fact, this efficiency boost not only "significantly delays the emissions released but also slows down the adoption of an alternative technology" by not giving fossil fuel owners the incentives for early extraction (Fischer & Salant, 2012).

3. Data and Methodology

In order to validate the green paradox discussed, the present investigation promotes the application of an empirical methodology that aims to assess the effective impact of the five mentioned provocateurs. In this way, a multiple econometric analysis is instilled in this study, which aims to examine the propensity of the paradoxical phenomenon in the European continent under the time horizon referring to the period from 1996 to 2018. First, the individual stationarity of the variables is analysed through tests to the unitary roots, then the cointegration in their long-term relationships is accessed, and finally we proceed with the estimation of the impacts of the referred drivers in the propensity of the paradox.

3.1 Specification of the Empirical Model

Considering the possible linear relationships between the drivers indicated and the dependent variables found, the following econometric models are developed, indicated by equations (1) and (2) :

$$oil_{it} = \beta_1 oil_{i,t-1} + \beta_2 tax_{it} + \beta_3 supports_{it} + \beta_4 rights_{it} + \beta_5 captrade_{it} + \beta_6 lag_{it} + \varepsilon_{it} \quad (1)$$

$$CI_{it} = \beta_1 CI_{i,t-1} + \beta_2 tax_{it} + \beta_3 supports_{it} + \beta_4 rights_{it} + \beta_5 captrade_{it} + \beta_6 lag_{it} + \varepsilon_{it} \quad (2)$$

where the subscript it in the variables symbolizes the i -th country, in year t , ε represents the perturbation term and $\beta_1, \beta_2 \dots \beta_6$ the estimated coefficients. The selected variables are described in the subsequent sub-chapter, and in Table 1.

3.2 Variables

The used database consists in a balanced panel for 28 countries in Europe over 23 years (1996 to 2018 inclusive, this being the largest and most current possible period with data for all considered variables). EUROSTAT was the primary source of data but also for the variable Property Rights, the Economic Freedom Index developed by The Heritage Foundation was used (The Heritage Foundation, 2021). Proxies for all provocateurs identified

in the state of the art were incorporated in this study: (i) Environmental Taxes, (ii) Green Support, (iii) Uncertain Property Rights, (iv) Emissions Limit (Cap) and (v) Temporal Lag. In order to assess the trend of paradox events, the dependent variables used are: (1) the ratio between the annual production/extraction of a non-renewable natural resource (oil), and the consumption of primary energy, and (2) the carbon dioxide (CO₂) intensity, measured by the ratio between the CO₂ annual emissions, in tons, and the gross domestic product (GDP) in thousands of euros. The evaluation of the effects in these two variables occurs due to the need to include both the paradoxical phenomenon through the noticeable increase in oil production, and the latent realization of it through the increase in CO₂ emissions. The imposition of this coverage derives from the attentive that the state of the art of literature praises both in theoretical reflections and in the rare empirical studies. See Table 1 for a resume of all variables considered.

Table 1. Summary of variables in the study models

Variable	Abbreviations	Measure Units	Source	References
Extraction of the non-renewable natural resource "Oil" in relation to Primary Energy Consumption	oil	Ratio (in %)	EUROSTAT	Di Maria et al., 2014 Grafton et al., 2014
Carbon Intensity (CO ₂ emissions to GDP)	CI	Ratio (CO ₂ kg/GDP €)	EUROSTAT	Grafton et al., 2014 Zhang et al., 2017 Chen et al., 2020
Environmental Tax revenue as a share of Total Tax Revenue	tax	Ratio (in %)	EUROSTAT	Zhang et al., 2017 Chen et al., 2020
Government Expenditure on Environmental Protection as a share of Total Government Expenditure	supports	Ratio (in %)	EUROSTAT	Grafton et al., 2014 Fujisaki, 2018
Property Rights	rights	Mapped Index	Heritage Foundation	Bohn & Deacon, 2000
Existence of an Emission Limit System	captrade	Dummy Variable		
Hiatus in the Implementation of the Emission Limit System	lag	Dummy Variable		Di Maria et al., 2014

Environmental Taxes

This driver is potentially the most studied mechanism regarding the green paradox, however the empirical examples referring to it do not abound. The articles by Zhang et al. (2017) and Chen et al. (2020) regarding this driver focuses predominantly on environmental regulation. These authors promote as a proxy for this variable the rate of industrial removal of sulfur dioxide, and the proportion of investment in the control of industrial pollution in total industrial production, respectively. Now, even though these methodological approaches are significant given the high existing correlation, it is not entirely absurd to reiterate that these parities are considerably alienated from the initial connotation proposed by Sinn (2008) and attested later, in their conditionalities, by Hoel (2010) and Edenhofer & Kalkuhl (2011).

In this way, the accomplishment of this study favors the use of data that portray the present driver as faithfully as possible, thus opting for the incorporation of the percentage of environmental tax revenue compared to the total state tax revenue. These statistics made available individually by EUROSTAT cover taxes whose tax base is levied on economic activities with a scientifically proven negative impact on the environment, and the sum of total taxes collected, respectively. The creation of the aforementioned ratio allows, on the one hand, to control possible effects of size and on the other hand to measure more accurately the evolution of the incidence of the relative environmental tax burden, thus avoiding changes through systemic economic effects.

Green Support: Environmental Protection Expenditure

Concerning the impact of green supports on the existence of a green paradox it was verified a scarcity of empirical studies, however it is possible to highlight in this context the investigation by Grafton et al. (2014). These authors promote a study of the impact that subsidies to bio-fossils had in the first instance on North American oil production and ultimately on the country's CO₂ emissions. For this, the total production of bio-fossils is promoted as a proxy for these subsidies due to the “superior availability of data for this indicator and the relative correlation with the desired variable” (Grafton et al., 2014, p. 552). In a similar light, the Japanese case study by Fujisaki (2018) encompasses the ratio of renewable energy in national electricity production, reinforcing the empirical trend of applying this type of proxies. However, it is also possible to identify in this driver a respectable variant that denotes the possible harmful consequences of the various measures aimed at environmental protection and reductions in pollution, such as those noted in the previous chapter referring to Sinn's suggestion (2008). These proposals, still to be empirically corroborated, present a great scientific relevance to further investigation.

Thus, this study chooses to use as proxy the ratio between the expenditure of the government in environmental protection and the total government expenditure. These indicators provided by EUROSTAT cover expenditure on reducing pollution, protecting biodiversity and the landscape, as well as on research and development (R&D) related to environmental protection; and the sum of total expenses incurred, respectively. In this way, the referred variable is adequate to the Sinn proposals mentioned above, in addition, it is also possible to point out the parity between the algebraic deduction of Strand (2007) regarding the innovation rate of an energy alternative, and the R&D component covered by the variable in use. The composition of this ratio also assumes, in a homologous way to that elaborated in the previous variable, particular relevance given its ability to control both the dimension effects and the macroeconomic effects of systemic nature.

Uncertain Property Rights: Economic Freedom and Rights Index

The literature referring to this driver, with regard to the study of the green paradox, has so far not presented empirical evidence related to its analysis. However, it is possible to highlight the extensive investigation preceding the conceptualization of the paradox of Bohn & Deacon (2000). This, although without the clear intention of corroborating the paradoxical phenomenon, promotes a meaningful analysis that encompasses, on the one hand, the property risk and on the other, the democratic magnitude prevailing in the territory.

Due to the high democratic homogeneity experienced in Europe in the last twenty years, this study chooses to use as a proxy for this driver the quantitative index referring to Property Rights promoted by The Heritage Foundation in the scope of the measurement of Economic Freedom over time. This annual measurement promotes an assessment of the legal capacity of economic agents to “acquire, maintain and use private property effectively”, including the “probability of expropriating property” (The Heritage Foundation, 2021). The developed index is formulated by averaging an equal proportion (20%) of the following sub-factors: tangible property rights; intellectual property rights; robustness of investor protection; risk of expropriation and; quality of land administration. The calculation of each subfactor is obtained under the following expression:

$$Subfactor_i Score = 100 \times (Subfactor_{Max} - Subfactor_i) / (Subfactor_{Max} - Subfactor_{Min}) \quad (3)$$

where Subfactor i is the initial data for that country, Subfactor Max and Subfactor Min show the maximum and minimum thresholds in the respective category, and finally, the Subfactor i Score represents the effective result of the country in this subfactor (The Heritage Foundation, 2021). It should also be noted the dissimilar interpretation that the estimated coefficient of this variable offers given its disparate nature. In this way,

warning first about the distinctions existing in the interpretation of variables in the form of an index, we pay particular attention to corroborating the paradox to come in the form of a negative impact of this driver on the selected dependent variables, contrary to what happens in the others. This stems from the literature's expectation that well-defined property rights would prevent the paradoxical phenomenon from occurring more successfully than inferiorly defined rights would.

Emission Limits (Cap): European Union Emissions Trading Scheme

The study of the implementation of the emission limit in the paradox has been made by deductive analysis and/or by general equilibrium models, such as the one by Eichner & Pethig (2011), or by Sen (2016), vilifying the empirical corroboration to the various emission limit implementation systems. In fact, it is possible to highlight in this context the mechanisms developed by the United States of America in 1990 regarding the acid rain program, by the European Union in 2005 and by New Zealand in 2008 (Emissions Trading Scheme - NZETS) or by Tokyo, Japan, in 2010, among other significant emission limits relevant to scientific analysis. Thus, and given the geographical horizon chosen for this study, an analysis of the effect of the implementation of the EUETS is promoted. This mechanism aiming at the execution of the objectives outlined in the Kyoto Protocol is based on a system that composes not only the limitation of emission licenses, but similarly the free commercialization between them, guaranteeing considerable flexibility to the economic agents (Teeter & Sandberg, 2017). If it is possible to specify the entry into force of this protocol, and of the EUETS in particular, on February 16, 2005, a dummy variable is generated that assumes a value of 1 in the relevant years (2005 to 2018, inclusive), and the value of 0 in the rest (1996 to 2004, inclusive). This inclusion aims at even more relevance given the debate promoted in Sinn's seminal work (2008) in relation to the target protocol, whose empirical evidence has not followed the theoretical discussions surrounding it until then.

Time Lag: Hiatus in Implementation

In contrast to the antecedent driver, it is possible to find some research that deals with the impact of the time gap in the implementation of a measure to combat pollution. However, the empirical lack of validation of the same in order to understand its magnitude in the real economy is notorious. One of these rare empirical examples resides in the research by Di Maria et al. (2014) that aiming at the aforementioned Acid Rain Program in the USA, analyses the possibility of its early announcement (5 years of hiatus) leading to an effective paradox. Similarly, and for the geographical context of the present study, an analysis of the effect of time lag between the announcement of the EUETS and its effective implementation is promoted. Thus, it is possible to highlight the beginning of 2005 as the effective year of implementation of both the protocol and the trade system, while its ratification dates from March 15, 1999 (*The Kyoto Protocol: Status of Ratification*, 2009). In this way, a dummy variable is generated, which takes the value 1 in the time gap years (1999 to 2005, exclusive), and the value of 0 for the rest.

3.3 Descriptive Statistics

Measures of central tendency (mean), variability (standard deviation, asymmetry, minimum and maximum) and the referring number of observations resulting from panel data are presented for the used variables. It is possible to conceive 644 individual observations resulting from the analysis of 28 countries over 23 years in most variables, with the exception of the lagged ones whose chronological magnitude naturally falls under 22 years.

In relation to the measures of variability, the component of asymmetry is emphasized, generally described under the expression “skewness”, which measures the lack of symmetry related to the tails of the distribution. In this way, a positive value indicates a longer and heavier right tail, while a negative value would indicate homologous behavior of the left tail. Another relevant aspect to note in this set of measures comes from the minimum values of 0 in the variables referring to the extraction of oil in relation to the consumption of primary energy and also the ratios of revenues/environmental expenses. These values are indicative of the existence of some countries whose oil extraction has remained null in some periods, such as Portugal or Luxembourg, and in another aspect, the sporadic presence of budget systems that do not include any kind of environmental support (such as Estonia in 2010 and 2011, resulting from the budget crisis), or do not foresee this type of specific taxation.

Table 2. Descriptive statistics

Variable	Observations	Mean	Standard deviation	Asymmetry (Skewness)	Minimum	Maximum
oil	644	22.23	94.30	5.64	0	768.21
oil-1	616	22.60	95.65	5.60	0	768.21
CI	644	0.63	0.71	3.38	0.09	5.91
CI-1	616	0.65	0.72	3.32	0.09	5.91
tax	644	1.72	1.43	1.82	0	8.68
supports	644	1.68	0.80	0.61	0	4.90
rights	644	72.52	17.74	-0.67	30	95
captrade	644	0.61	0.49	-0.45	0	1
lag	644	0.22	0.41	1.37	0	1

Evolution of CI and Oil Extraction

In a graphical analysis it is possible to verify that the evolution of the Carbon Intensity in the referred sample reveals a generally decreasing trend over the last two decades. This declining propensity is even more evident as of 2005, a date coinciding with the implementation of the EUETS and related to the Kyoto Protocol. However, it is possible to identify in a similar way a slight stagnation in this same indicator in the period before the introduction of the referred mechanism (see figure 1). This trend indicates the possible existence of 2 periods that are completely different from each other: the gap between the announcement and the implementation of the mechanism; and the subsequent period resulting from its entry into force, incorporated under the aforementioned dummy variables.

Figure 1. Evolution of Carbon Intensity - annual average

Source: Own elaboration with data from EUROSTAT

With regard to the Oil Extraction ratio, it is possible to observe a similar provision. The general evolution is extremely negative over time, especially after 2005, suffering from a slight increase in the interregnum phase of the execution of the targeted mechanism (see figure 2).

Figure 2. Evolution of Oil Extraction compared to Primary Energy Consumption, in percentage - annual average

Source: Own elaboration with data from EUROSTAT

3.4 Unit Roots Panel Tests

To analyze the stability/stationarity of the selected variables, this study proceeds to four unit roots panel tests: Levin, Lin & Chu (LLC); Im, Pesaran and Shin (IPS); Fisher - Augmented Dickey – Fuller (ADF); and Fisher - Phillips – Perron (PP). The common null hypothesis is that the target variable has a unit root, which translates, in the case of non-rejection of the referred hypothesis, in the non-stationarity of the variable. Otherwise, the stationarity is concluded. The importance of these tests lies predominantly in the evasion/rejection of future spurious regressions, whose cause-effect relationships would be meaningless (Yule, 1926), where high values of statistics would have no economic significance (Granger & Newbold, 1974). Thus, the LLC test equation (Levin et al., 2002) is expressed as follows:

$$\Delta F_{it} = a_i Y_{it-1} + \sum_{L=1}^{mn} b_{ip} \Delta Y_{it-L} + c_{pi} d_{pt} + e_{it} \quad , \quad p = 1,2,3 \quad (4)$$

where a_i , c_{pi} , d_{pt} , and e_{it} reflect the model's autoregression coefficients, and the corresponding vectors. To avoid eventual redundancy, the IPS test equation is omitted (Im et al., 2003) due to its high similarity with that previously described. Finally, it is possible to point out the Fisher tests, developed either by Phillips and Perron (Phillips & Perron, 1988) or by Dickey and Fuller:

$$Fisher - ADF = -2 \sum_m^p \log(X_m) \rightarrow P \quad (5)$$

$$Choi - ADF = T_{m-1}^{(-0.5)} \sum_{m-1}^K \lambda^{-I} (X_m) \rightarrow K(0,1) \quad (6)$$

where λ^{-I} symbolizes the standard normal probability distribution, and the common term X_m is the p-value of the respective test.

3.5 Cointegration Panel Tests

To assess the existence of a cointegrated (and stable) relationship in the long term, the present study also carries out panel tests on cointegration. These consist briefly of the test groups developed by Kao (1999) and Pedroni (1999, 2000) whose paramount relevance resides once again in refusing spurious regressions. This connection arises from Granger's axiom (1981) where series can only be shown to be cointegrated if there is a genuine (and not spurious) relationship between them, and cointegration can be described as the sharing of a stochastic tendency between 2 or more variables / time series (Stock & Watson, 2015).

In this way, it is possible to expose the seven statistical tests of Pedroni (1999) analysed under the following equations:

panel v:

$$T\sqrt{N}(\sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2)^{-1} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \quad (7)$$

panel-ρ

$$(\hat{\sigma}_{N,T}^2 \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2)^{-\frac{1}{2}} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \quad (8)$$

panel-t:

$$(\hat{\sigma}_{N,T}^2 \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2)^{-\frac{1}{2}} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \quad (9)$$

panel-ADF:

$$\frac{1}{\sqrt{N}} \sum_{i=1}^N (\hat{\sigma}_i^2 \sum_{t=1}^T \hat{e}_{i,t-1}^2)^{-\frac{1}{2}} \sum_{t=1}^T (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \quad (10)$$

group-ρ:

$$\frac{1}{\sqrt{N}} \sum_{i=1}^N (\sum_{t=1}^T \hat{s}_i^{*2} \hat{e}_{i,t-1}^{*2})^{-\frac{1}{2}} \sum_{t=1}^T \hat{e}_{i,t-1} \Delta \hat{e}_{i,t} \quad (11)$$

group-t:

$$T \frac{1}{\sqrt{N}} \sum_{i=1}^N (\sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^2)^{-1} \sum_{t=1}^T (\hat{e}_{i,t-1} \Delta \hat{e}_{i,t} - \hat{\lambda}_i) \quad (12)$$

group-ADF:

$$(\hat{s}_{N,T}^{*2} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^{*2})^{-\frac{1}{2}} \sum_{i=1}^N \sum_{t=1}^T \hat{L}_{11i}^{-2} \hat{e}_{i,t-1}^* \Delta \hat{e}_{i,t}^* \quad (13)$$

Their distribution is then normalized under $N(0,1)$. The statistical test by Kao (1999) is usually exposed using the following equation:

$$ADF = \frac{t_{\rho} + \sqrt{6N} \hat{\sigma}_v / (2\hat{\sigma}_{0v})}{\sqrt{\hat{\sigma}_{0v}^2 / (2\hat{\sigma}_v^2) + 3\hat{\sigma}_v^2 / (10\hat{\sigma}_{0v}^2)}} \quad (14)$$

3.6 Models Estimation: Generalized Method of Moments

Dynamic panel models are of particular relevance in the context of correcting the estimation endogeneity, and also of possible multicollinearity between the independent variables. In this way, and taking into account the considerable correlation existing between some endogenous variables in equations (1) and (2) (see tables 3 and 4), it is decided to host a dynamic model in order to integrate all the drivers mentioned in the study, without prejudice to statistical significance.

Table 3. Correlations between the explanatory variables referring to model (1)

Pearson Correlation	oil	tax	supports	rights	captrade	lag
oil	1***					
tax	0.1993***	1***				
supports	-0.0438	0.0166	1***			
rights	0.204***	0.2889***	-0.0072	1***		
captrade	-0.0623	-0.1534***	0.1246***	-0.0008	1***	
lag	0.0426	0.0731*	-0.0604	0.0269	-0.6573***	1***

Note: ***, **, * represent significance at a level of 1%, 5% and 10%, respectively

Among the dynamic models, the one that is regularly adopted in the literature and whose effectiveness stands out is the generalized method of moments (GMM) model, suggested by Blundell & Bond (1998) and Bond et al. (2001). It is possible to point out its application in homologous analysis referring to the paradox, such as the one elaborated by Zhang et al. (2017).

Table 4. Correlations between the explanatory variables referring to the model (2)

Pearson Correlation	Cl-1	tax	supports	rights	captrade	lag
Cl-1	1***					
tax	-0.2567***	1***				
supports	0.0341	0.0166	1***			
rights	-0.4679***	0.2889***	-0.0072	1***		
captrade	-0.3721***	-0.1534***	0.1246***	-0.0008	1***	
lag	0.1497***	0.0731*	-0.0604	0.0269	-0.6573***	1***

Note: ***, **, * represent significance at a level of 1%, 5% and 10%, respectively

4. Results and Discussion

In order to complete the empirical validation previously proposed, the results referring to the parameters of equations (1) and (2) are presented in this chapter, concentrated on the impacts of provocateurs on oil extraction, and on carbon intensity, respectively.

4.1 Results of Unit Roots Panel Tests

There is a homogeneous tendency with regard to the stationarity of the analysed variables. The null hypothesis specified in the previous chapter is rejected for the first differences. In this way, the effective evasion of possible spurious regressions resulting from unit root variables is inferred, confirming the legitimacy of the subsequent analysis to cointegration.

In this same context, the particular character of the variables related to the Temporal Lag and the implementation of the Cap & Trade mechanism is also emphasized, whose binary nature prevents a statistical interpretation similar to the other variables. The full results can also be seen in Table 5.

Table 5. Unit Roots Panel Test Results

Variable	Test method	At level		At 1st difference	
		t-Statistic	Prob.	t-Statistic	Prob.
oil	LLC	-3.97227***	0.0000	-16.3325***	0.0000
	IPS	-2.11275**	0.0173	-15.2057***	0.0000
	ADF	56.4602**	0.0273	256.047***	0.0000
	PP-Fisher	88.7483***	0.0000	273.359***	0.0000
oil-1	LLC	-3.73787***	0.0001	-14.2889***	0.0000
	IPS	-2.27063**	0.0116	-12.8448***	0.0000
	ADF	57.7117**	0.0211	216.789***	0.0000
	PP-Fisher	105.194***	0.0000	267.350***	0.0000
CI	LLC	-14.7301***	0.0000	-15.5608***	0.0000
	IPS	-8.97185***	0.0000	-15.7909***	0.0000
	ADF	218.748***	0.0000	326.021***	0.0000
	PP-Fisher	433.611***	0.0000	651.054***	0.0000
Cl-1	LLC	-14.7714***	0.0000	-12.8051***	0.0000
	IPS	-8.92853***	0.0000	-13.3726***	0.0000
	ADF	218.081***	0.0000	277.710***	0.0000
	PP-Fisher	411.325***	0.0000	695.398***	0.0000
tax	LLC	-4.05052***	0.0000	-20.1095***	0.0000
	IPS	-2.17651**	0.0148	-17.1845***	0.0000
	ADF	83.3543**	0.0103	348.151***	0.0000
	PP-Fisher	60.8773	0.3048	400.457***	0.0000
supports	LLC	-7.56573***	0.0000	-27.2662***	0.0000
	IPS	-7.2543***	0.0000	-19.8943***	0.0000
	ADF	188.299***	0.0000	593.928***	0.0000
	PP-Fisher	145.088***	0.0000	1100.42***	0.0000
rights	LLC	1.08332	0.8607	-13.7903***	0.0000
	IPS	0.86267	0.8058	-12.6107***	0.0000
	ADF	66.6147***	0.0052	244.182***	0.0000
	PP-Fisher	49.1073	0.1531	498.248***	0.0000
captrade	Dummy Variable				
lag	Dummy Variable				

Note: ***, **, * represent significance at a level of 1%, 5% and 10%, respectively

4.2 Results of Cointegration Panel Tests

The analysis referring to cointegration uniformly reveals a genuine and stochastic trend among the variables of the analysed regressions. It is possible to observe the rejection of the condition of absence of cointegration, referring to the null hypothesis, in the ADF and t-statistics tests, simultaneously with the non-rejection of an effective relationship between the endogenous variables and the variable explained in the v-statistics tests, and p-statistics. In this way, and in addition to the foregoing investigation, it is feasible to confer an estimated validity on the regressions proposed below. The full results can be seen in Tables 6 and 7.

Table 6. Results of the Cointegration Tests referring to equation (1)

Pedroni Cointegration Test	Value	P-value
panel-v	-0.872348	0.8085
panel-p	2.593416	0.9952
panel-t	-9.316522***	0.0000
panel-ADF	-8.439903***	0.0000
group-p	3.370383	0.9996
group-t	-16.29041***	0.0000
group-ADF	-11.36809***	0.0000
Kao Cointegration Test		
	Statistic	P-value
ADF	-13.89963***	0.0000

Note: ***, **, * represent significance at a level of 1%, 5% and 10%, respectively

Table 7. Results of the Cointegration Tests referring to equation (2)

Pedroni Cointegration Test	Value	P-value
panel-v	0.886130	0.1878
panel-p	0.538632	0.7049
panel-t	-17.15672***	0.0000
panel-ADF	-14.13425***	0.0000
group-p	1.902736	0.9715
group-t	-28.0662***	0.0000
group-ADF	-19.29363***	0.0000
Kao Cointegration Test		
	Statistic	P-value
ADF	-12.583***	0.0000

Note: ***, **, * represent significance at a level of 1%, 5% and 10%, respectively

4.3 Estimation Results

The estimated regressions, evidenced in detail in the previous chapter, when arise from the application of the generalized method of moments (GMM), are accompanied by the Sargen-Hensen test (Hansen, 1982; Sargan, 1958), by the first and second order tests by Arellano – Bond (Arellano & Bond, 1991) and by the respective test of global significance. These aim to guarantee the econometric adequacy of the estimated model by assessing possible statistical violations.

The Sargen-Hensen J test results indicated the non-over-instrumentalization in the statistical model, therefore avoiding the identification of excessive restrictions. Thus, and under the null hypothesis that the applied instrumentalization is valid, we can observe in the estimated equations a non-rejection of the referred hypothesis.

With respect to the first and second order Arellano-Bond tests, there are homologous signs of consistency in the estimators through the absence of correlation between the terms of disturbance of the observations.

Therefore, and under the null hypothesis that the target correlation is negligible, in the estimated equations there is a non-rejection of the referred hypothesis for both the first and the second order. Regarding the Wald global significance test applied, the statistical significance of the models is clearly seen through the rejection of the null hypothesis regarding the econometric insignificance of the implemented variables. As a complement, these tests mentioned above confer global validity to the estimated regressions, making it possible to identify in the literature the same statistical procedure both within the scope of the green paradox (Zhang et al., 2017) or in a global perspective combined with the different economic domains (Blundell & Bond, 2000; Doan, 2020).

With regard to the individual evaluation of the impacts of the identified provocateurs, evidenced in the estimated coefficients, the statistical significance of the variables used is generally observed (see tables 8 and 9). In fact, it is possible to point out the rejection of the null hypothesis, referring to the condition $\beta_k = 0$, for all variables incorporated in models (1) and (2), with the singular exception of Property Rights in the model referring to the paradoxical impact on extraction oil (1). Hence, it becomes feasible to draw from this model preponderant lessons in the empirical validation of the green paradox in the European context.

In the first instance, the results tend to indicate a negative trend in the direction of the relationship of the majority of the drivers studied, signalling the apparent absence of this socially undesirable phenomenon, and consequently the effective political and economic adequacy of the measures in force to combat pollution, with the singular exception of the time gap in the implementation of the emission limit system in the European Union, in the implementation of the Kyoto Protocol.

In a singular perspective, the negative value of the coefficient referring to the Environmental Taxes variable, for both models, attests to the initial interpretation presented upstream. In this way, it is inferred that the targeted taxes contributed to the decrease, both in oil extraction and carbon intensity, in Europe, in the analysed time horizon. This result accompanies some literature that confirm that the tax promotes the effective occurrence of the green paradox, which could arise only when the tax level is conceived as low enough, simultaneously with a constant growth of the tax above the discount rate of resource owners (Edenhofer & Kalkuhl, 2011). Taking into account the relative stagnation/decrease over the years of the average level of environmental tax revenue compared to the total tax revenue, it is plausible to consider that the necessary conditions for the green paradox proliferation were not met, through Environmental Taxes. Allied to this explanation, the hypothesis already mentioned upstream that the explorers of mineral resources act in the short term under castrating geological conditions (Okullo et al., 2015) might have contributed complementarily to the inexistence of the paradoxical phenomenon. This political adequacy of environmental taxes, resulting from the paradoxical absence in this driver, is still verified in some empirical evidence external to the green paradox such as that conceived by Morley (2012) regarding the effectiveness of this measure in combating pollution, in a very similar geographical horizon.

With regard to the variable referring to Green Supports, the conclusions drawn differ tangentially from the general disposition presented, and, similarly, from the conclusions drawn from the previous provocateur. The coefficients referring to this variable in model (1) and (2) indicate the existence of a weak green paradox in the impacted sample caused by this driver. This concept, coined initially by Gerlagh (2011), incorporates both the temporal aspect of the impact of green support on emissions (increasing temporarily in the short term), and the extractive component, of greater relevance in the targeted conjunction (increasing in resource extraction, however with emission reduction). In this context, and taking into account the coefficients signs, it is possible to infer that these contributed in an increased way to oil extraction, even though they have encouraged the reduction of carbon intensity, in Europe, in the analysed time horizon, showing a weak green paradox. This tends to occur with a greater propensity precisely in this provocateur, given that it focuses on “expenses on reducing pollution, protecting biodiversity and the landscape, as well as on research and development (R&D) related to environmental protection”, as mentioned in the previous chapter. Thus, it becomes quite plausible to understand that this public effort, despite fulfilling its primary objective of combating pollution, indirectly encourages the extraction and subsequent consumption of fossil fuels, as they now become comparatively less environmentally harsh. In fact, we can still recover the observation of Sinn (2008) where it is stated that the resource supply is encouraged to anticipate its extraction in face of these developments, not only by covering

up its acts in the effective number of emissions, but also by the future fear that this support will lead to an effective technological utopia in which fossil energies become obsolete and/or in low demand. This pronouncement is coupled with the threat of evolution of an energy alternative, also present in this provocateur through the R&D component. This can lead the market incumbent supply to increase its extraction in order to guarantee the present profitability and/or decrease the equilibrium price in the current market with the purpose of establishing a limit price for new entrants (Andrade de Sá & Daubanes, 2016).

Table 8. Estimation results for model (1), through GMM

Model (1)	Coefficient	t-Statistic	Prob.
oil _{t-1}	0.903402*** (0.0000178)	50665.39	0.0000
tax	-1.233639*** (0.00292)	-423.1744	0.0000
supports	1.062469*** (0.01529)	69.4758	0.0000
rights	-0.032648 (0.02476)	-1.31874	0.1878
captrade	-3.74342*** (0.04064)	-92.1202	0.0000
lag	1.489218*** (0.01465)	101.6287	0.0000
Robustness Tests		Statistic	Prob.
A-B AR(1) Test		-1.020585	0.3075
A-B AR(2) Test		1.02289	0.3064
Sargen-Hansen J Test		14.12289	0.440597
Global Significance		Prob.	
Wald chi2(6) Test		0.0000	

Note: ***, **, * represent significance at a level of 1%, 5% and 10%, respectively.
Standard deviation statistics are indicated in parentheses.

Table 9. Estimation results for the model (2), through the GMM

Model (2)	Coefficient	t-Statistic	Prob.
Cl _{t-1}	0.813037*** (0.000795)	1023.27	0.0000
tax	-0.022409*** (0.001005)	-22.2929	0.0000
supports	-0.003275*** (0.001075)	-3.0475	0.0024
rights	0.000559*** (0.0000391)	14.29516	0.0000
captrade	-0.042065*** (0.001206)	-34.8879	0.0000
lag	0.013219*** (0.000513)	25.7613	0.0000
Robustness Tests		Statistic	Prob.
A-B AR(1) Test		-1.65947	0.097
A-B AR(2) Test		0.718025	0.4727
Sargen-Hansen J Test		25.71714	0.264025
Global Significance		Prob.	
Wald chi2(6) Test		0.0000	

Note: ***, **, * represent significance at a level of 1%, 5% and 10%, respectively.
Standard deviation statistics are indicated in parentheses.

This phenomenon is still in line with some empirical evidence in the literature, such as that developed by already mentioned study of Grafton et al. (2014) in a North American geographical scope. Therefore, this paradoxical occurrence, even if it does not question the adequacy of the current policy, it alerts legislators to

the paramount importance of strong reflection in relation to the net benefits of this type of measures, given that the present evidence reiterates similar previous investigations.

Regarding the coefficients referring to Property Rights in the models (1) and (2), the general conclusion of the absence of paradoxical phenomenon is recovered. This time, it is inferred that the poor definition of property rights does not contribute to the increase, neither of oil extraction, nor of carbon intensity, in Europe, in the analysed time horizon. In fact, if in the case of the first model this evidence is removed as the coefficient is not significant, in the second model, it is even possible to point out a relationship with the opposite direction to the theoretically expected: a decrease of this dependent variable when deterioration in the definition of those rights. These results can be explained primarily by the manifest absence of armed political revolutions in Europe in the last two decades, a central pillar in the seminal formulation of this provocateur by Sinn (2008), whose occurrence would considerably widen the difference regarding the security of the maintenance of petroleum resources. Additionally, the absence of significant records in the sample period related to the exploitation of mineral resources in the form of a common good, with the subsequent inability to fulfil the exclusivity criterion, similarly suppress this component in the referred driver. Moreover, the estimated coefficients are further elucidated through the empirical ratification of the evidence by Bohn & Deacon (2000) regarding the positive relationship between the oil extraction rate and property security, thus associating the need of prior investment and geological planning of mineral deposit entrepreneurs (Cairns & Smith, 2019). In summary, it is not possible to verify that a degradation of property rights indicates a green paradox, and it is even possible to corroborate the opposite in relation to the carbon intensity, because of the political and economic stability needed by the owners to project their strong investments. This evidence confirms that no responsibility for increasing extraction, and/or release of CO₂ emissions should be placed, on the impacted horizon, in the risk associated with maintaining ownership of mineral resources, whether this comes from tenuously softer legislation or from increasing public pressure to expropriate property. It is even feasible, based on the presented results, to congratulate the economic agents that over the years have brought an effective risk to oil entrepreneurs, preventing them from consuming all their strategic investments, and with that, from conceiving numerous additional negative externalities.

Finally, the evidence regarding the dummy variables in models (1) and (2) confirm the theoretical expectation that led to their inclusion. The implementation of the EUETS, through the implementation of the Kyoto Protocol in 2005, lead to the subsequent reduction in both the targeted extraction and the carbon intensity. This marked inference derives from the negative signs in the coefficients related to the binary variable for the existence of a Cap and Trade system. This result, although expectedly, given the consummate legal imposition, aims at both the empirical confirmation of this aspect and the statistical complementarity of the other provocateurs.

Regarding the gap in the implementation of this policy, we are witnessing the theoretical confirmation of the paradoxical phenomenon in its fullness. It is possible to infer an increase in the targeted extraction and carbon intensity resulting from the lag between the public announcement of the emission limit system and its effective entry into force. Thus, and taking into account the coefficients indicated in the respective variable, the seminal notion is corroborated, that is, economic agents, and in particular mineral entrepreneurs, when obtaining information on future legislation in advance tend to act strategically in the present, incorporating this recent constraint in maximizing the profitability of their enterprise. Accordingly, and taking into account the conceptualization proposed by Di Maria et al. (2012), in models (1) and (2) there is a strong green paradox through the abundance effect, whose nature is expressed by the additional extraction (and carbon emission) in the period of non-restriction. In this sense, the signalled paradoxical evidence warns of the imperial need for the speedy and streamlined implementation of this type of mechanisms, thereby avoiding such long periods between the officialization of the measure and its implementation. Alternatively, in complex political-strategic scenarios, as in the case of the Kyoto Protocol, where the pluralist nature requires arduous and prolonged negotiations, it is recommended to try stakeholders' discretion, in addition to delaying the public announcement of any definitive decisions. However, attention is paid to the sensitive and socially controversial nature of the suppression of this gap, insofar as this omission in the public announcement could provoke the encouragement of conspiratorial forces, eroding the already weakened public perception of the European institutions. In

addition, the delay in an official pronouncement regarding the implementation of relevant environmental measures can be a complex political challenge, given the high social pressures in the environmental sphere, and a relevant trade-off can be deduced between the net benefit of the non-existence of the gap, and the political benefit of its pompous announcement. Despite this conclusion regarding the lag, it is further emphasized that these results indicate only the socioeconomic inadequacy of this time interval, and not the full emission limit mechanism.

Finally, the coefficients of the lagged dependent variables show individual significance. Thus, and taking into account the respective values in models (1) and (2) close to 0.9 and 0.8, respectively, it is inferred that both the variation in oil extraction and the previous carbon intensity generate a positive increase and practically unit in the analysed variables, *ceteris paribus*. This conclusion reconfirms the statistical adequacy of incorporating the respective lagged variables in the model (Keele & Kelly, 2006), as well as the theoretical hypothesis that fossil developments require smooth continuity over time, prompted by previous investment (Cairns & Smith, 2019).

5. Conclusions

In this article the different drivers of the green paradox are identified and empirically validated, accessing their effective impact on the European scenario in the last two decades, thus contributing to an adequate theoretical and empirical framework, filling the scientific gap in this geographical and temporal horizon.

In this context, the compilation and systematization of several scientific contributions to date have led to the identification of five major drivers of the green paradox: (i) Environmental Taxes, (ii) Green Support, (iii) Uncertain property rights, (iv) Temporal lag and (v) Emission limits (Cap). These controversial provocateurs, portrayed in the literature generally individually, assume a strong simultaneity in the current economic context, so that their analysis in a global framework takes on special importance. This theoretical compendium emphasizes the multifaceted nature of the components that can effectively incite the green paradox, based, however, on the same logical premise that economic conditions or expectations are created by legislators (albeit unintentionally) that make the present resource extraction comparatively favourable in relation to a future extraction, or alternatively, an incremental external emission compared to an internal reduction.

It is concluded that it is necessary to reinforce the reflection inherent to the benefit of implementing measures to fight pollution, climate change, or globally, negative environmental externalities. The incorporation of the strategic decision of the resources supply in the economic-environmental analysis in view of the implementation of these policies is crucial in order to be able to foresee and anticipate certain expansionist supply behaviour.

The subsequent empirical evaluation carried out took into account the European geographical scenario, in the last 23 years, indicating in general an apparent absence of the paradoxical phenomenon, with the particular exception of the lag between the announcement and the effective implementation of EUETS, following the implementation of the Kyoto Protocol. In this way, political adequacy is given to most of the pollution control instruments applied.

In the case of the environmental taxes, there is an effective fulfilment of the legislator's intentions, with a significant decrease in the carbon intensity resulting from this tax burden. Thus, and taking into account the circumstances previously indicated by which the tax may incite the paradox, it is recommended to maintain this robust tax level in the European framework, and when changes are needed, they should occur smoothly, as has been happening so far. It is also essential that the main political actors resist, in a preventive way, to the radical discussion on the increase of this type of taxes, given that the economic agents expectation can be similarly crucial for the occurrence of the paradox.

The results regarding the green support, it is not so clear that all the legislators' intentions have been fully implemented. If, on the one hand, the fundamental objective has been achieved (reduction of pollution), on the other, the incentive to anticipate oil extraction is presented as the main setback of this instrument. Therefore, the occurrence of a weak green paradox warns of the need to fully review the net benefits of this type of measures, which can even culminate in the interruption of these green supports. Added to the relevance of this challenge is the reiteration of the empirical study by Grafton et al. (2014), in this same provocateur, who finds in another similar geographical horizon the conclusion of a potential weak green paradox. In this context, it is

now recommended to significantly reinforce this component, especially in the context of R&D support, which prevents, with immediate effect, the economic viability of expansionary movements of the current supply (Andrade de Sá & Daubanes, 2016). If this is not financially conceivable, it should be kept the same level of support, in order to avoid a potential worsening of this weak paradox. Finally, and in line with the challenge launched for environmental taxes, political agents are asked to discretion in the advance announcement of green supports, given that their expectation may also contribute to the weak paradox empirically verified. In relation to the paradoxical engine of uncertain property rights, it is concluded that there is not enough reason to instil responsibility in this component. Thus, and contrary to the seminal conclusions of Sinn (2008) in this context, it is understood that any revolutionary movements should not be deterred on the pretext of avoiding an incitement to the occurrence of this paradox. In fact, if any conclusions can be drawn from this driver, it is precisely due to the decrease in carbon intensity resulting from greater uncertainty, and inefficient definition of property rights, and it is even the opposite, that is, an environment of economic stabilization, accompanied by secure property rights, which can lead to increased emissions. Finally, and in view of what has been analyzed in relation to the implementation of the EUETS, it appears that the delay in its effective implementation had negative environmental effects. In fact, the time gap between the announcement, consummated by the ratification of the protocol, and its entry into force prompted an increase in both extraction and carbon intensity in Europe. Therefore, and without prejudice to the adequacy of the target mechanism, it is recommended that these chronological intervals be eliminated, or when this is not possible, to narrow this gap, so that economic agents are not given sufficient time to act in advance. Allied to this challenge, the promotion of agile negotiations with less bureaucratic burdens appears similarly as a decisive indication in the prevention of this adverse phenomenon. In spite of the aforementioned, it is still necessary to pay attention to the political domain, and to the benefits in the popularity of the main governmental actors that a populist and advance announcement of measures, or environmentally innovative agreements, can provide. As a result, it is emphasized that the upstream recommendations have as their effective purpose the increase of the net economic and social benefit, of utmost relevance to a state governance, disregarding the eventual personal and political interests (unfortunately) recurring in the current context. In short, the problem of the green paradox assumes, based on the empirical evidence highlighted, considerable relevance in the context of the unwanted consequences of measures to solve the environmental externalities, so it is essential to encourage greater reflection on the adequacy of this type of instruments and their form of implementation. Regardless of what was pointed out in this article, the main limitations of this study are the omission of the short and long term component of carbon intensity, which could provide detailed lessons on the temporal impact of green supports; the non-inclusion of countries outside the EUETS, which would allow an in-depth analysis of possible carbon leakage; or even, the absence of a robust empirical evaluation precedent in the literature, especially in the target territory, which would allow a better comparison both methodologically and of the results obtained. As a future research, in addition to removing the limitations presented, an in-depth assessment of the quadratic impact of taxes on carbon intensity is highlighted, as well as empirical validation in other non-renewable natural resources besides oil, such as coal or natural gas.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and analysed during the current study are available in the following data sources and corresponding links, for each variable in the table below:

Variable	Source	
Extraction of the non-renewable natural resource "Oil" in relation to Primary Energy Consumption	EUROSTAT	appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_cb_oil
		appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nrg_bal_o
Carbon Intensity (CO2 emissions to GDP)	EUROSTAT	appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_air_gge
		appsso.eurostat.ec.europa.eu/nui/show.do?dataset=nama_10_gdp
Environmental Tax revenue as a share of Total Tax Revenue	EUROSTAT	appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_ec_tax
		appsso.eurostat.ec.europa.eu/nui/show.do?dataset=gov_10a_taxag
Government Expenditure on Environmental Protection as a share of Total Government Expenditure	EUROSTAT	appsso.eurostat.ec.europa.eu/nui/show.do?dataset=gov_10a_exp
		appsso.eurostat.ec.europa.eu/nui/show.do?dataset=gov_10a_main
Property Rights	Heritage Foundation	www.heritage.org/index/
Existence of an Emission Limit System	Dummy Variable	unfccc.int/process/the-kyoto-protocol/status-of-ratification
Hiatus in the Implementation of the Emission Limit System	Dummy Variable	unfccc.int/process/the-kyoto-protocol/status-of-ratification

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

All authors contributed to the study conception and design. Material preparation and data collection were performed by ART. Data analysis was performed by ART and by MR. The first draft of the manuscript was written by ART and MR commented on previous versions of the manuscript. All authors read and approved the final manuscript.

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