Ecological Economics and Social-Ecological Movements

Sciencie, policy and challenges to global processes in a troubled world

David Barkin
Graciela Carrillo
Coordinadores

Casa abierta al tiempo

Are climate change policies counterproductive? A critical approach to the Green Paradox

Jordi Roca Jusmet*

1. Introduction: fossil fuel supply and climate change policies

The problem of climate change is mainly due to CO_2 emissions from fossil fuel combustion. Future emissions of greenhouse gases will depend on many factors – such as deforestation or reforestation, waste management, the use of fertilisers in agriculture or diets – but the use of fossil fuels is definitely the key one at least for the next decades.

The total amount of carbon that can be emitted being compatible with a target of limiting the temperature increase is usually known as "carbon budget" (UNEP, 2017). For example, we can speak about the carbon budget for a maximum variation of 2ºC for the 21st century in comparison with preindustrial temperature, the main reference objective of the 2015 climate change Paris Agreement. Its exact value is impossible to determine because of the uncertainties of climate models and other factors.[1] However, there is scientific consensus that the 2ºC objective –not to speak about the 1.5ºC objective-[2] implies that most fossil fuel reserves should remain underground (McGlade and Ekins, 2015). Accessible fossil fuel resources are very limited and they are being exploited at an accelerated rate that will lead to their depletion in the not too distant future (especially in the case of oil, as evidenced by the debate on the peak oil: Kerschner and Capellán Pérez, 2017) but they are not at all scarce enough to avoid the risks of experiencing catastrophic climate change. In this regard, as in others, Boulding was a visionary highlighting more than 50 years ago: "Oddly enough, it seems to be in pollution

* Department of Economics, Universitat de Barcelona. E-mail: jordiroca@ub.edu

1 If we refer strictly to CO2 fossil fuel emissions, the amount of carbon emitted compatible with a certain temperature level also depends on what happens with other gases and natural carbon sinks. The optimists also consider new technologies for carbon capture and storage, but the precautionary principle needs to be very sceptic about these possibilities.

2 A recent IPCC (2018) report urges efforts to limit temperature rise to 1.5ºC above pre-industrial levels.

rather than in exhaustion that the problem is first becoming (...) And the atmosphere may become man's major problem in another generation" (Boulding, 1966, p.12).

Given the relationship between fossil fuel burning and climate change, it is unavoidable to conclude that the only guarantee of a successful policy against this problem would be a restriction on the global supply of fossil fuels. A way to achieve this rationing would be to establish a global carbon emissions target and to distribute it through compulsory maximum national quotas of carbon emissions which – to make policy less rigid – could be marketable. Perhaps in the future there might be an agreement to limit global emissions at a sufficient level but this is not at all the situation today with the Paris Agreement based on purely voluntary and insufficient national contributions (UNEP, 2017).

Moreover, there are more and more social mobilisations in many places in the world aimed at blocking the extraction of fossil fuels, or the construction of infrastructures for their transport (such as oil or gas pipelines) that sometimes lead to making some projects inviable (Klein, 2014; EJOL, 2015). These mobilisations will probably increase and paralyse some projects and could even lead to formal banning of certain techniques (such as fracking) at national or regional level or the exploitation of certain sensible areas. This can be very important to preserve fragile natural areas and the life and health of communities affected by some projects and also could be key -much more than it is usually thought as we will see later- for reducing the future supply of fossil fuels. However, it is difficult that these type of mobilisations could be enough to reduce global carbon emissions in the necessary magnitude.

In the absence of global limits on carbon emissions, many actions and policies have been raised at regional, national, and local levels such as regulatory energy standards, incentives for renewable energies and investments in energy efficiency, carbon taxes or carbon cap and trade systems. It is expected that these policies will reduce fossil fuels use.[3]

Obviously all these policies have several difficulties. First of all, climate change is a global problem and for this reason, political decisions are possible, but in the absence of global compulsory requirements, they must overcome the free-rider problem. There are also other obstacles. For instance, an increase in energy efficiency will tend to provoke a rebound effect that will partially compensate –or even in some extreme cases, it could more than compensate- the decrease in energy demand (Sorrell, 2007). Another significant problem is the potential carbon leakage: if one region, nation or town decides to introduce a carbon tax (or any policy that increases costs for domestic enterprises), part of domestic production could be replaced by imports increasing emissions elsewhere and consequently global emissions would decrease less than expected (or in the worst case they would increase). All these difficulties are very real and it is necessary to take them into account in order to apply effective policies.[4]

Last years, the German economist Hans-Werner Sinn (2008, 2012) has raised a very different type of concern. Climate change policies could be counterproductive, increasing and not decreasing emissions due to the reaction of fossil fuel owners faced with these policies. He uses the term "green paradox" to refer to this counterproductive effect.[5]

3 In this article I do not refer to the greenhouse gases emissions other than carbon emissions from the use of fossil fuels.

4 For example, carbon leakage could be combated by introducing carbon border taxes to "level the playing field" between different countries. See Rocchi et al. (2018).

5 Sinn introduced the term green paradox. The name was new, but the idea of the possible perverse effects of climate policies due to the supply reaction was not new: see Sinclair (1992).

After this introductory section, I explain the green paradox concept and the conclusions about climate change policies that Sinn derives from this concept. According to this author (almost all) climate policies could be not only ineffective but even counterproductive (section 2). In section 3 I present the theoretical explanation of the green paradox using a very simple exhaustion resource Hotelling model (section 3). The following sections use three different arguments to explain that the pessimistic conclusions of the simple model can hardly be extended to the real world. The first one is that the conclusions about the effects of climate change policies obtained in a very simple Hotelling model with homogeneous resources cannot be extended for more realistic assumptions (section 4). The second argument is that the concept itself of equilibrium price in this type of model is very problematic taking into account the uncertainty of the future, a limitation that usually is completely forgotten or at least much undervalued (section 5). The third argument is that fossil fuel extraction industries have some characteristics that prevent quick -and much less immediate- adjustments and without costs as those foreseen in the usual Hotelling models (section 6). In section 7, I consider these very different critiques to argue that green paradox is a theoretical possibility to take into account but that in most cases it is very unlikely that climate change policies backfire due to green paradox. Finally, section 8 concludes.

It is worth emphasising that this article does not question the green paradox concept or even its potential existence as it considers that there is a case for the green paradox. What is questioned is the great practical relevance that the green paradox according to Sinn would have. Since the initial contributions of this author, there has been extensive literature on the subject that in many cases has been aimed precisely at qualifying or criticising the conclusions of Sinn. However, his seminal contributions continue to have strong influence.

2. The green paradox according to Sinn

Hans-Werner Sinn popularised the term green paradox in articles published in several newspapers and magazines in various countries, in his 2008 book *Das Grüne Paradoxon*, which generated much political debate in Germany, and in its English version *The Green Paradox* published in 2012. The term also provoked much academic debate, an example of which is the 2015 special issue of the *Review of Environmental Economics and Policy* (Jensen *et al.*, 2015).

The reasonable point of departure of Sinn (2008, 2012) is that it is naive to think that the effects of demand[6] and tax policies will not depend on how the fossil fuel owners react. Supply matters. This is indisputable, as can be seen in a very extreme example. Let me assume that fossil fuel supply was totally inelastic, that is to say, owners continue to sell exactly the same quantities after the announcement or implementation of climate change policies. In this case, the unique effect of these policies would be the fall in fossil fuels prices but not in the quantities sold or, in the case of taxes, the effect would be purely redistributive: resource owners would earn less money at the expense of tax revenues without varying amounts sold.

But Sinn's argument goes far beyond pointing out the clear –but many times forgotten- importance of supply. Sinn argues that the effect of demand and tax policies will likely accelerate climate change if policies become stronger over time, as it is often proposed, and seems reasonable for the practical viability of a global transition to a decarbonised energy

6 I use the term demand policies in this article in a very broad sense even including social movements that promote less carbon intensive lifestyles.

model. In his own words: "Policies aimed at limiting or reducing the possibility of generating resource-derived revenues in the future will induce resource owners to bring their sales forward to the present. This, in turn, will depress current market prices and increase resource demand, thus accelerating global warming" (Sinn, 2015, p.240). The idea is the following. Fossil-fuel owners will prefer to sell their valuable resources when policies against climate change are still relatively timid for fear that in the future, when policies are stronger, their rents will be lower, or will completely disappear. By using his own comparison, from the point of view of resource owners, the prospect of an increasingly ambitious climate change policy can be seen as the perspective of a future "expropriation" of their resources; and given this perspective it would be better to sell the resource as soon as possible and thus the amount sold, and in consequence the carbon emissions, would increase.

The Green Paradox book distils first of all a critique of German "green" policies that according to the author would imply enormous costs for the country but whose only results would be to increase emissions of countries that do not make the same commitments (carbon leakage)[7] and at the global level would not lead to less emissions but more emissions to the extent that there is an expectation that the measures will harden and generalise in the future as is precisely their intention. "Green" policy would be well-intentioned, but not effective: "The road to hell, after all, is paved with good intentions" (Sinn, 2010, p.232). The conclusion on climate change policies is very pessimistic and not only for regional or national policies but also for policies such as global carbon taxes defended by many economists (Baranzini *et al.*, 2017; Boyce, 2018). Almost the only exception would be an effective global emissions rationing policy[8] and even in this case if the period between the announcement of this policy and its effective implementation were too long, the problem of the green paradox would appear.

3. The green paradox in a very simple Hotelling model

The contributions of Sinn (2008, 2012) and the most part of the green paradox literature is based on the model of Harold Hotelling (1931) that still today remains the indisputable reference of neoclassical economic theory on the price of non-renewable resources. Although the model is well known, it is worth remembering its basic points. For that, I will use a very simple version of the model, which is sufficient to understand the green paradox concept.

A situation of perfect competition is assumed, in the sense that the resource owners have no market power, that is, they think that their individual decisions do not affect the price at all. All the resource stock is homogenous and the unit extraction cost is constant. The scarcity *of the resource gives rise to a resource rent* (or royalty), a positive difference between the selling

7 Sinn (2012) does not use carbon leakage in the most usual sense of substitution of domestic productions by imports not affected by the domestic policy (as myself in section 1). His explanation is linked to the global character of fossil fuel markets. He argues that when demand for fossil fuels declines in a country, global demand will decline and prices will fall and this will offset the decrease in sales and emissions in the country in favour of emissions in other countries. A partial carbon leakage in this sense is a real possibility especially in the short term, but carbon leakage is not the object of this article and I will limit myself to the green paradox concept in Sinn´s definition. However, some authors analyse carbon leakage and green paradox in the same conceptual framework: "We define leakage as the shift in emissions from the future to the present (temporal leakage) or from conforming to non-conforming countries (spatial leakage)" (Michielsen, 2011, p.3).

8 The emissions trade systems in only a country or region would be affected -according to Sinn (2012)- by the same problems as most policies because they do not stablish a global limit for carbon emissions.

price and the extraction cost. Moreover, it is assumed that the quantity demanded is null if the price is higher than a price that is normally known as the choke price.

Hotelling analyses the path or trajectory of prices and extractions of "equilibrium"[9] that it is compatible with a maximising behaviour of the owners, that`s to say, with the objective of maximising the present value of their resource rents. The path will depend on the interest rate i, the total resource stock and the present and future demand functions and extraction costs. The two conditions are:

1) The resource rent r (net price of extraction cost) must increase at a rate equal to the interest rate i: $r_t = r_o (1+i)^t$ or, in continuous terms, $r_t = r_o e^{it}$

In other words, the discounted rent should be constant along the time. This is the famous *Hotelling rule*. The reason for this condition is that if the price grew at a higher rate, there would be opportunities to increase the present value of the rent by postponing sales; and in case the price grew at a slower pace, it would be profitable to advance sales.

2) The resource stock should be completely exhausted just at the time the price reaches the choke price. If the resource is exhausted before the price is so high that the demand is null, as if there is a part of the stock that remains as unsold resource, some owners could increase their rents delaying or advancing some sales.

Using this type of model, we can see how climate change policies will affect the equilibrium fossil fuel price path. Let me look at the case of global carbon taxes in which Sinn focuses especially using it as a benchmark for most climate change policies. We can compare a situation without carbon taxes with a situation in which a global carbon tax is introduced. In this new situation, it is the net price not only of the extraction cost but also of the tax which should follow the Hotelling rule. The mathematical conclusion is that if the carbon tax grew over time at a rate higher than the rate of interest, the tax will lead to advance and not delay the extraction of fossil fuels. Therefore, the current final prices (including the tax!) should fall to reach a new equilibrium compatible with the maximisation of present value of resource rents: lower prices will imply more fossil fuel use and more emissions. This is the green paradox.

It is important to emphasise that the conclusion refers in fact not to any introduction of carbon taxes but only to the introduction of taxes that significantly increase over time. For instance, a constant carbon tax would reduce current extraction in favour of future extraction. In any case, if the model implications were applicable to the real world, it would be very bad news for many carbon tax (and other climate change policy) proposals. It is very difficult that people accept high taxes (and in general strong climate change policies) immediately and a way of reducing resistance to carbon taxes is phasing them over time (Carattini, Carvalho and Fankhauser, 2018).

4. Beyond the simplest Hotelling models

Several authors have emphasised that carbon taxes –and other climate change policies- will have, using the Edenfhoer and Kalkuhl (2011) terms, not only a *timing effect*, affecting intertemporal reallocation of resource extraction but also a *volume effect*, lowering cumulative future extraction.

9 Later, I will deal critically with the implicit concept of equilibrium in Hotelling (1931) which characterises the economic theory on non-renewable resources inspired by his article.

The possibility of a volume effect could raise even in a simple Hotelling model with a homogeneous resource as it is assumed in the previous section. Even in this case, an exclusive focus on the timing effect is only justified if we assume that the scarcity resource rent is always positive. However, if the carbon tax was sufficiently high, the resource rent would disappear and the final price would increase and be determined by the sum of the extractive cost and the tax.[10] (Hoel, 2012; Edenfhoer and Kalkuhl, 2011).

However, the main objection to forgetting the volume effect is that coal, oil or gas resources are not homogenous at all. The extraction costs are very different in different sites. Using a Hotelling model with heterogeneous resources, Hoel (2012) concludes that "some resources that would have been extracted if there were no carbon tax will thus be left unextracted with a positive carbon tax. Total emissions therefore decline as a response to a carbon tax, no matter what time profile the carbon tax has." (Hoel, 2012: 8). The effect of carbon taxes could be extended to other climate change policies (see also van der Ploeg, 2013).

Sinn focused only on temporal reallocation of resource extraction and doubted about the practical relevance of the previous considerations, basically arguing that we do not know the technologies and preferences in a very distant and uncertain future and in consequence we cannot assume that some resources will never be exploited (Sinn, 2015: 243; see also Sinn, 2012, pp.203-207). Of course, nobody knows what could happen in the next centuries or even millenniums, but the relevant thing, in political terms, is how climate policies can influence the amount of fossil fuels that now and in the coming decades –we could say in this century, adopting the usual temporal perspective of the carbon budget concept- will be extracted.

As several authors have emphasised, we should distinguish between green paradox in a weak sense and green paradox in a strong sense (Gerlgh, 2010; Baranzini and Carattini, 2014; Jensen *et al.*, 2015). A policy against climate change could cause the paradox in a weak sense by advancing emissions in some period but its global effect on climate change could be judged beneficial if emissions are later sufficiently reduced.[11] In this case, green paradox did not backfire the benefits of the policy even though it would reduce these benefits and it would be very relevant to analyse how to avoid –or at least reduce- green paradox.

5. Hotelling models: a problematic idea of equilibrium

The 1931 Hotelling article was a very important contribution because it emphasised that owners of exhaustible resources should look not only at the present, but also towards the future, if they want to maximise their rents. But, as we have seen, he went far beyond this important idea. He used his model as a theoretical tool for explaining the effective price path of non-renewable resources (in conditions of perfect competition). Thus, his theory has been interpreted as a theory about the market equilibrium prices. This is certainly the case of Sinn,

10 Obviously, the final price should also cover other costs such as transport cost that have not been considered in this article for the simplicity of the argument.

11 Gerlagh (2010) defines green paradox in a strong sense when a policy not only provokes more current emissions but also "increases cumulative damages associated with emissions as well, evaluated at the net present value" (p. 3). I use the term more loosely without a precise definition because I consider this definition very problematic. Climate change affects different generations and discounting the future in social evaluation (as in calculations of social cost-benefit analysis) can be considered discriminatory against future generations. See Azar and Sterner (1996), Martínez Alier and Roca Jusmet (2013) and Llavador, Roemer and Silvestre (2015).

who focuses on how different policies affect the "market equilibrium (in the sense of the Hotelling rule) in which the resource owners are indifferent between selling now and selling later" (Sinn, 2012: 193).

However, the Hotelling price path can hardly be considered an equilibrium path in the usual sense of the term "equilibrium", that is to say, in the sense that there are some forces that press to move the price towards the equilibrium price when the current price differs from this one. One thing is that there is a single price path that ex post is compatible with maximising the (present value of the) rents by all the owners, and another very different thing is that there are some mechanisms that determine that effective market price will tend to this path when the future is uncertain. This is the key theoretical weakness of the Hotelling model that has almost always been forgotten or at least much undervalued.[12]

The fact is that nobody knows whether the price is or is not the "right" one in the sense that it does not allow to obtain more rents by delaying or advancing the sales of the resource. The reason is very simple: nobody has, nor can anyone have, the relevant information, including how demand and extraction technologies will evolve in the future. The usual explicit or implicit idea to try to answer this criticism is replacing the lack of information about the future with the expectations about the future. But this does not solve the problem. Any reasonable idea of equilibrium in a competitive market should be based on plausible responses by individual price-takers to signals provided by the market itself and not in complex mathematical calculations using uncertain variables.

Actually, owners make decisions in a context in which their expectations about the future are diverse and generally poorly defined. This is not to say that ideas about the future and positive or negative news for owners do not influence their decisions There is no doubt that new important data (or new dominant expectations) on –for instance- renewable energy technological development, discovery of new reserves or climate change agreements can influence the owners´ decisions and the prices, but it is not clear at all in which magnitude or even in which direction.[13] I think it is a misguided view of the market dynamics to try to explain these changes as a movement from an initial equilibrium path in which everyone is maximising their rents to another defined equilibrium path that permits to maximise rents according to the new data (or expectations). However, this is –as we have seen- the approach used by Sinn in explaining the effect of climate change policies in fossil fuel supply and in consequence in carbon emissions.

6. The delay between the decision to exploit fossil fuel reserves and their effective exploitation and the importance of sunk costs

Usual Hotelling models and Sinn's explanation of the green paradox have another serious limitation. In the words of Cairns (2014): "The key assumption, usually glossed over, is that output can be re-arranged as desired. It implies that the output decision is made period-by-

12 Only a few authors such as E.J. Mishan (1981, chap. 62-65) highlighted the problem: "There are not forces arising simply from the operation of competitive mining firms, which act to bring the path of market prices over time into line with the Hotelling-efficient price path" (Mishan, 1981, p.492) (see also Roca, 1991).

13 For instance, if one thinks that it is better to extract as soon as possible taking into account expected future aggressive climate change policies, one also could think that the other producers could react in the same way and prices could dramatically fall precisely when the extractions begin to take place.

period, with no restriction other than exhaustibility. The sole physical limit to the level of output is held to be the level of remaining reserves" (p, 81). Thus, current price and expected future prices (nets of taxes and extraction costs) would be the only variables that would determine if the current extraction would increase or decrease.

However, this is totally away from reality as "technological models" have emphasised.[14] The basic characteristics of fossil fuel extraction sectors could be summarised as follows. In each period, there are some resources in exploitation and their potential output or extraction capacity is limited by previous investments that involved important sunk or irreversible costs. In consequence, very short-term supply can be considered totally inelastic above capacity. Extraction marginal costs are usually far below the fossil fuel price and price-taker producers tend to extract the maximum possible resource except if the prices fall so much that they decide to close the exploitation.[15] Thus, for a wide range of prices, the quantity supplied in a competitive context will be basically constant and insensitive to the price and expected future prices; the relevant options –"corner" solutions- are to produce at the maximum extraction capacity or do not produce at all.[16]

If we go beyond the very short term, the evolution of the extraction capacity over time will depend on two factors. On one hand, the extraction capacity tends to decrease over time because extraction declines as exploited resources are running out. On the other hand, the development of new reserves adds new extraction capacity but this development requires investment decisions that will result in additional extractions only some years later. [17]

Even if we accepted –following Sinn- that many climate change policies would incentive owners to increase current fossil fuel extraction, the limitations to act in this sense are considerable. Quoting again Cairns: "In a technological model, the extent to which the industry can act upon the incentive is limited. Contrary to a Hotelling model, it is not possible to increase production from reserves that are currently in production: the capacities are fixed by previous investment. Moreover, for development investments that are currently in progress (…), the incentive cannot move production toward the present because it is already being implemented in the present. For the great bulk of production in the near term, then, the tendency of the tax is not to increase but, if anything, to decrease production. Responding to the increase requires irreversible investment at new reserves" (Cairns, 2014: 84).

14 This type of models has mainly analysed the petroleum industry (see for instance Adelman, 1990; Thompson, 2001 and Cairns, 2014), but the main aspects can be extended to other fossil fuel resources.

15 Of course, global fossil fuel markets are not perfectly competitive especially in the case of oil where prices in some periods have been strongly affected by strategic supply decisions from Saudi Arabia or OPEC as a cartel. However, the assumption in this and in previous sections has been a competitive price taker behaviour for two reasons. First, because Sinn's analysis is based on this assumption. Secondly, because in most situations the assumption that most individual sellers do not act to influence global fossil fuel prices is not far from reality.

16 This explains that when demand falls abruptly, as happened with the financial crisis of 2008, the quantity supplied in the short term is not normally very affected and prices fall dramatically.

17 In section 1 I referred to actions to block certain fossil fuels projects. There, I indicated that it was difficult for these actions to be sufficient to reduce radically global emissions at least in the near future. However, it can now be highlighted that since developing resources to be exploited implies a lot of investment and time, blocking some projects will reduce emissions at least to the extent that it will be impossible to quickly replace the avoided extraction with the exploitation of other resources that replace it (and/or constructing alternative infrastructures for transporting fossil fuels). Moreover, as we will see later, the actions could have a great indirect effect creating more risk for future investments.

Thus, a green paradox, in case it occurred, would not affect the amount of resources supplied in the market until years after knowing the news on climate change policies that would justify the decisions of the owners to sell as soon as possible.[18] Moreover, and even more important, the decision for the owners is not if it is better to sell now taking into account the current costs and prices but it is whether or not to invest now in developing new reserves for selling them years (and probably decades) later without any guaranty of covering important sunk, irreversible costs. The timing and level of investment will determine extraction capacity for the following decades. If some owners have the expectation that policies –for instance carbon taxes- will be significantly stronger in the future than nowadays there could be a green paradox in the sense that climate change policies result in advancing or increasing investments in fossil fuel extraction sectors. This is possible, but the question is whether this is or it is not a probable outcome.

The first condition for investing in new extraction capacity is to expect to have a positive present value during the long period between the start of investment and the projected lifetime of the reserve.[19] In general, we can think that climate change policies –even when its initial impact is limited- will increase the risk of economic losses that could be very important taking into account that fossil fuel extraction is a very capital-intensity activity and a great part of costs are sunk costs. In this sense climate change policies would most likely have a "disinvestment" effect[20] reducing future potential supply and carbon emissions. This "disinvestment" in fossil fuel extraction sectors could be provoked not only by climate change policies in the traditional sense but also by grass-roots social and political movements oriented to block or ban fossil fuels activities because they certainly increase the risk of failed investments. Thus the importance of these movements goes much beyond their direct effects of paralysing certain projects, generating a greater "political risk" of the investments.

7. Is the green paradox so relevant for climate change policy?

One assumption of a part of green paradox analysis is that the global supply of fossil fuels is very elastic in the short term, while the long term supply is completely inelastic. Resource owners could freely change the temporal profile of extraction of total stock, and this temporal profile would be the only important factor for climate change. Thus, perhaps we could talk about the paradox of (some) green paradox analysis because –as we have seen in the previous sections- the short term supply is rather inelastic while the effective long term supply is elastic because the total amount of resources that will be exploited sometime (or, if one prefers, during

18 In fact, this is only completely true in a situation where all the producers are operating at the maximum extraction capacity. When there are strategic behaviours of a cartel or a "dominant" company – or country- that deliberately maintains significant exceeding productive capacity, supply could be increased even in a very short term. It could be that the cartel –country or company- responded to climate change policies by increasing the amount supplied. However, it does not seem likely at all that a deliberate restriction of the supply to keep prices will be relaxed or abandoned precisely in the context of policies that reduce owners´ rents.

19 Let me call 0 the present moment and let me assume that the delay between the moment in which an investment decision is implemented and the moment in which fossil fuel extraction begins is equal to x years, and that the projected life of the exploitation is y years. The prices and taxes that are relevant for the present value of investing now are prices and taxes during periods [x, x+y] and [x+t, x+y+t] respectively.

20 Another activity that can be affected by "disinvestment" is the exploration on new reserves and this will have consequences for the potential supply in the long term.

a certain long period such as the 21st century) depends on economic, social and political factors. Cumulative extraction is obviously limited by geology, but the relevant total supply will depend on these factors.

Thus, Sinn is right in arguing that a successful climate change policy requires to reduce the amount of fossil fuels sold in the global market, but he does not focus on the key question: how different policies could affect how much fossil fuels will remain underground? Of course, the timing of extraction is important for climate change and for the possibilities of human adaptation to it, but when we are referring to the climate change during the present century we probably can assume that: "Research of climate scientists suggests that leaving more fossil fuel unexploited is more important than how fast a given amount of carbon reserves is extracted and released into the atmosphere" (van der Ploeg, 2013: 8).

Another surprising feature of Sinn's analysis is that the positive or negative effect of climate change policies did not depend at all on the intensity of these policies but only on the temporal evolution of the implementation of these policies. Thus, as we have seen, a global carbon tax would provoke the green paradox when the tax (or more exactly the expected future tax) increases at a rate higher than the rate of interest independently on the level of taxation; on the contrary, a constant carbon tax (or better a decreasing tax!) would always reduce current extraction.

But as Hoel (2012) clearly argues "if a sufficiently high carbon tax is introduced, emissions will for sure decline" (p.22). Following the example of this author, we can assume that on average a ton of coal generates about 2 tons of CO_2. With a global carbon tax of $\$50/tnCO_2$ the price of coal should be considerably higher than the current one to be able to cover extraction costs.[21] Extraction costs and taxes set a minimum threshold below which fossil fuel prices cannot go down.[22] This is an easy but very important conclusion.

Many authors propose carbon taxes exceeding $\$100/tnCO_2$ (Baranzini *et al*. 2017; Howarth et al., 2014; van den Bergh and Botzen, 2014)). If we were able to implement these proposals at a global level, coal prices would more than double over current ones. In the case of oil, emissions per barrel are approximately 0.43 tons of CO_2 so a tax of $\$100/tnCO_2$ would correspond to about $43 per barrel (Hoel, 2012). The impact would be much smaller than in the case of coal, but also very significant. In the last decade world prices have sometimes been below this value so there is no doubt that a tax of this magnitude would have increased the final prices of oil products and, in consequence, the quantity demanded and emissions. One characteristic of the oil industry is that at the same time there are exploitations with very different unity costs.[23] Thus, even with relatively high prices, the exploitation of some deposits of unconventional oil –such as tar sands or shale oil- could become ruinous with so high carbon tax.

But now we should return to the general debate on the importance of green paradox.

21 According to the World Bank the 2018 average price of coal from Australia was $107,6 per ton and the price of coal from South Africa was $89.9 per ton http://pubdocs.worldbank.org/en/550191549309123169/CMO-Pink-Sheet-February-2019.pdf.

22 To simplify the argument, I am assuming that the tax is applied on the extraction or first sale of fossil fuel. Moreover, in the short term it could be that the net prices of taxes do not covering all the extraction costs but at least they should cover the marginal costs of extraction.

23 By the way, we can observe that this fact enters in contradiction with the conclusions of competitive Hotelling models according to which less expensive deposits are always exploited first.

As we have seen the only possible effect of climate changes policies in the very short term could be –and certainly would be if policies are sufficiently strong, as the previous example demonstrates- to reduce extraction and emissions. The simple reason is that extraction capacity can hardly increase in the short term or can only increase due to investment decisions taking it years before.[24]

It seems clear that the context most favourable to a green paradox would be to announce a strong policy -in a credible way- for a distant future, while not acting or acting in an extremely weak way during several decades.[25] Thus, there is a case for the green paradox. Perhaps the current situation in which international agreements are so insufficient, but most discourses speak on a decarbonised economy for the second part of this century, could be associated with this situation; but I would make the qualification that not acting now -or acting in a very weak way- does not favour expectations on an effective transition to a decarbonized economy some decades later.

In practice there could be a trade-off between the intensity of policies and the capacity of introducing them quickly. The implementation of very strong global policies can hardly be done immediately. Moreover effective climate change policies will normally generate expectations on stronger policies in the future. Only with strong policies can we expect an important disinvestment effect in fossil fuel extraction industry that is an unavoidable condition for an energy transition to a decarbonised economy. The green paradox concept is useful for advising on the dangers of delaying the policies a lot but renouncing to strong climate change policies because the fear of the green paradox would be renouncing to disinvestment in fossil fuel extraction industries and, in consequence, to an effective climate change policy.

Here it is also important to introduce a distinction between different fossil fuels. In Sinn´s model all fossil fuels are considered as an aggregate as if a unique market existed. However, as Michelson (2011) pointed out, the characteristics of, on the one hand, conventional oil and natural gas and, on the other hand, coal and unconventional oil are very different. Conventional oil and natural gas are far more scarce and the weight of scarcity rents in the final price are much more important than in the case of unconventional oil and gas and coal, which are much more abundant, but also much more expensive to extract and dirtier.[26]

Thus, we can expect that the green paradox is much more probable in the case of conventional oil and natural gas than in the case of the most problematic fossil fuels in terms of carbon emissions in which prices are much more determined by extractive costs and carbon taxes. That is good news because a green paradox for some fossil fuels could occur at the same time as a reduction in the use of their most problematic (imperfect) substitutes so that total carbon emissions do not increase even temporally.

---

24 Unless there are owners who are restricting supply in order to maintain prices. See note 19.

25 And one even could doubt about the relevance of the term "paradox" in this case because the increase in emissions would not be a consequence of climate change policies but the consequence of a very long period without policies, or very weak ones.

26 The carbon emissions by unit of energy of coal are much higher than the emissions from other fossil fuels. In the case of unconventional oil, the EROI (energy returned on energy invested) is very low in comparison with conventional oil and in consequence the emissions by unit of net energy are higher. This article only analyses climate change but it can be pointed out that other environmental impacts are also much more important for coal and unconventional oil and gas than for conventional oil and gas.

Let me finish this section with an illustrative example. Imagine that a global carbon tax of \$20/tnCO_2 was now implemented and there was a credible agreement of increasing it a 10% yearly for the next decades (the value in 20 years would be about \$135\$). According to Sinn this tax policy would be counterproductive (assuming an interest rate lower than 10%) due to the reaction of owners advancing extraction. I think the previous analysis highlights that the conclusion is not only contrary to common sense but really is in all probability completely wrong. Obviously, for climate change it would be better to introduce a tax of 135/tnCO_2 immediately, but if this were politically unfeasible I do not believe at all that it justified giving up a tax that grew progressively from \$20 to \$135.In more general terms, the green paradox does not justify at all to renounce climate change policies or weaken them at all but it certainly also gives an additional argument to reduce the temporal delay between the political debate and the announcement of policies and their effective implementation as much as possible.

8. Conclusions

Hans-Werner Sinn raised correctly the importance of fossil fuel supply reactions in front of climate change policies and he introduced the concept green paradox to indicate that these reactions could provoke an increasing of carbon emissions. This is certainly a possibility and it is a merit of this author to stimulate the debate about it.

Sinn gave enormous importance to the green paradox as a great obstacle to implement effective climate policies. Since his seminal contributions, the debate has been very rich and many authors have expressed sceptical positions about the practical importance of the green paradox. However, many references to the concept still have a very pessimistic bias.

There are many reasons to be very alarmed about climate change. The problem is very serious and there are many obstacles to apply effective global policies against it. However, the arguments of this article point to conclude that in the real world the possibility that climate change policies provoke a green paradox advancing and not delaying the global extraction of a fossil fuel is low. Moreover, it is important to emphasize two more aspects that made more unprovable the backfire of climate change policy due to the green paradox. The first one is that, even in the case of a certain temporal green paradox in the global extraction of a fossil fuel, its negative effects on climate change could be more than compensated by a posterior reduction in its extraction. The second one is that a green paradox for some fossil fuels (such as conventional oil and natural gas) could coexist with a decrease in the extraction of other fossil fuels (such as coal and unconventional oil and natural gas) resulting in a permanent decreasing of carbon emissions.

In any case, the green paradox concept gives an additional argument for trying to reach an effective and ambitious global rationing of fossil fuel extraction and/or carbon emissions. I agree with Sinn that this difficult political objective would be the best policy. However, while this is not possible, it is necessary to act as quickly and strongly as possible using different tools including demand and carbon pricing policies, changes in individual lifestyles and social movements to block fossil fuel projects.

References

Adelman, M- A. (1990). Mineral Depletion, with Special Reference to Petroleum. *In The Review of Economics and Statistics*, 72(1): 1-10.

Azar, C. A. and Sterner, T. (1996). Discounting and distributional considerations in the context of global warming. In *Ecological Economics* 19(2): 169-184.

Baranzini, A., Van den Bergh, J. C. J. M., Carattini, S., Howarth, R. B., Padilla, E. and Roca, J. (2017). Carbon pricing in climate policy: seven reasons, complementary instruments and political economy considerations, WIREs. *In Climate Change*, 462. doi: 10.1002/wcc.462.

Baranzini A., Carattini S. (2014). Taxation of Emissions of Greenhouse Gases In: Freedman B. *In Global Environmental Change.* Handbook of Global Environmental Pollution, 1.

Boulding, K. E. (1967). The Economics of the Coming Spaceship Earth. In Economy :3-14. Available at: http://arachnid.biosci.utexas.edu/courses/THOC/Readings/Boulding_SpaceshipEarth.pdf.

Cairns, R. D. (2014). The green paradox of the economics of exhaustible resources. In *Energy Policy*, 65: 78-85.

Carattini, S., Carvalho, M. and Fankhauser, S. (2018). Overcoming Public Resistance to Carbon Taxes, *Wiley Interdisciplinary Reviews: Climate Change.*

Edenhofer. O. and Kalkuhl, M. (2011). When do increasing carbon taxes accelerate global warming? A note on the green paradox. In *Energy Policy,* 39: 2208-2212.

EOJOLT (2105). Refocusing resistance for climate justice, In *Ejolt Report*, 23.

Gerlach, R. (2010), Too much oil, *Nota di Lavoro* 14.2010. Italy: Fundazione Eni Enrico Mattei.

Hoel, M. (2012), Carbon Taxes and the Green Paradox in Hahn, R. W. and Ulph, A. (ed), *Climate Change and Common Sense: Essays in Honour of Tom Schelling*, Oxford University Press.Hotelling, H. The Economics of Exhaustible Resources. In J*ournal of Political Economy*, 22(9): 137-175.

Howarth R. B., Gerst M. D., Borsuk M. E. (2014). Risk mitigation and the social cost of carbon. In *Global Environmental Change*, 24: 123-131.

IPCC (2018). *Global Warming of 1.5°C An IPCC Special Report on the Impacts of Global warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty.* Genève: IPCC,.

Jensen, S., Mohliny, K., Pittelz, K. y Sterner, T. (2015). An Introduction to the Green Paradox: The Unintended Consequences of Climate Policies. In *Review of Environmental Economics and Policy,* 9(2).

Kerschner, C. and Capellán Pérez, I. (2017). Peak-oil and ecological economics In Spash, C. L. Routledge: Routledge: *Handbook of Ecological Economics*.

Klein, N. (2014). *This Change Everything: Capitalism vs Climate*. EEUU: Penguin Books.

Llavador, H., Roemer, J. E. and Silvestre, J. (2015). *Sustainibility for a warming planet*. EEUU: Harvard University Press

Martínez Alier, J. y Roca Jusmet, J. (2013). *Economía ecológica y política ambiental*, tercera edición. México: Fondo de Cultura Económica.

McGlade, C. and Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2 °C". In Nature, 517: 187.190, doi:10.1038/nature14016.

Michielsen, T. (2011). Brown Backstops versus the Green Paradox. Paris: CentER Discussion Paper Series.

Mishan, E. (1981). *Introduction to Normative Economics*. EEUU: Oxford University Press.

Roca Jusmet, J. (1991). La teoría económica sobre el precio de los recursos no renovables: un comentario crítico. In *Cuadernos de Economía*, 19(54): 111-123.

Rocchi, P., Serrano, M., Roca, J. and Arto, I. (2018). Border Carbon Adjustments Based on Avoided Emissions: Addressing the Challenge of Its Design, In *Ecological Economics*,145: 126-136.

Sinclair, P. J. N. (1994). On the Optimum Trend of Fossil Fuel Taxation. In *Oxford Economic Papers,* 46: 869-877.

Sinn, H-W. (2008). Public Policies against Global Warming: a supply side Approach. *In International Tax and Public Finance*, 15: 360-394.

Sinn, H.-W. (2012). The Green Paradox. A *Supply-Side Approach to Global Warming*. *Massachusetts*: MIT Press.

Sinn, H.-W. (2015). Introductory Comment–The Green Paradox: A Supply-Side View of the Climate Problem. In *Review of Environmental Economics and Policy*, 9(2): 239-245.

Sorrell, S. (2007). The Rebound Effect: An Assessment of the Evidence for Economy-Wide Energy Savings from Improved Energy Efficiency. Project Report. UK: Energy Research Centre.

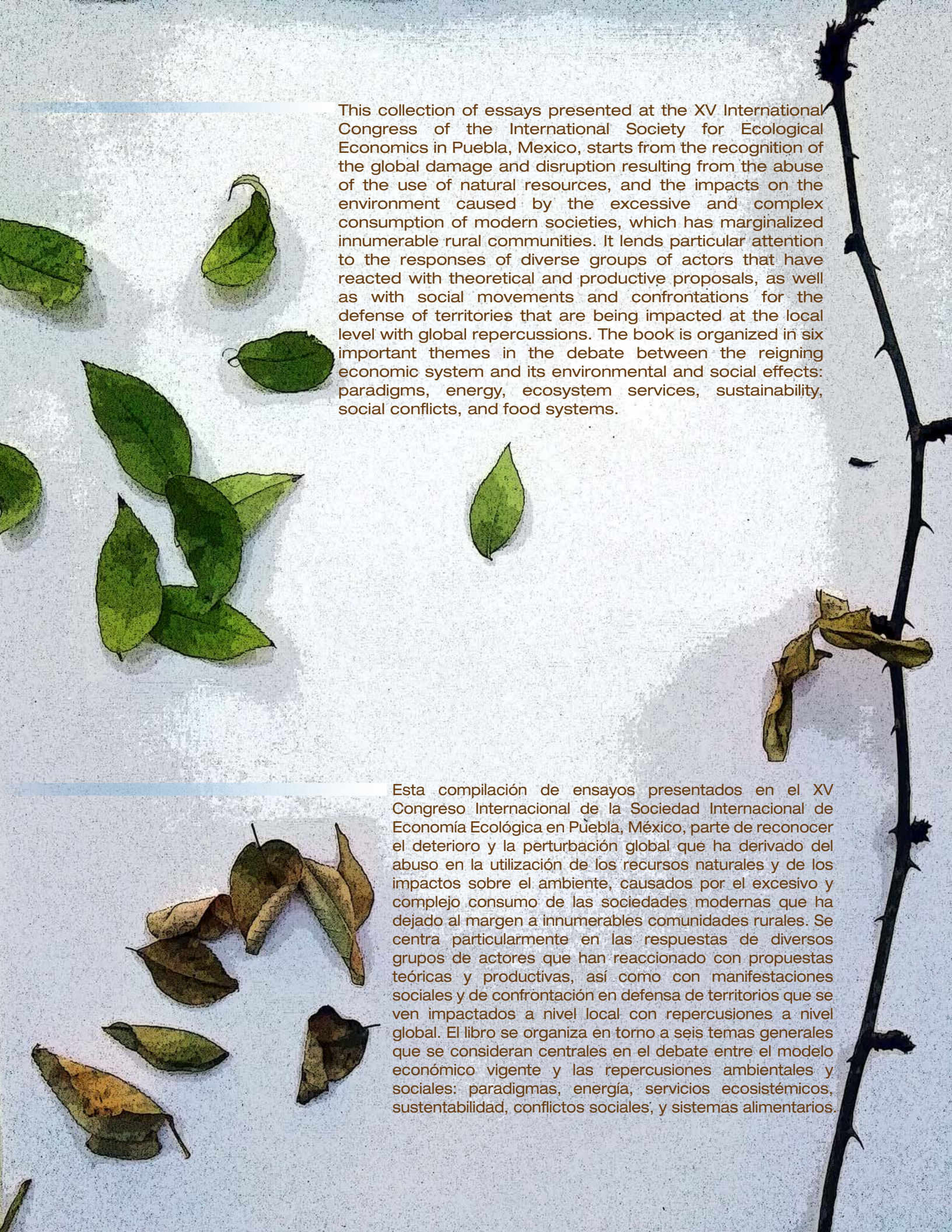
UNEP (2017). *The emissions gap report 2017*. United Nations Environment Program (UNEP), Nairobi. Available at: https://www.unenvironment.org/resources/emissions-gap-report

Van den Bergh J. C. J. M. and Botzen, W.J.W. (2014). A lower bound to the social cost of CO2 emissions. In *Nature Climate Change*, 4(119): 253-258..

Van der Ploeg, F. (2013). Cumulative Carbon Emissions and the Green Paradox, OxCarre Working Papers 110, Oxford Centre for the Analysis of Resource Rich Economies. EEUU: University of Oxford.

Acknowledgements

I thank Stefano Carattini, Emilio Padilla, Joaquim Silveste and Alfons Barceló for their very helpful comments on earlier versions of this paper.



This collection of essays presented at the XV International Congress of the International Society for Ecological Economics in Puebla, Mexico, starts from the recognition of the global damage and disruption resulting from the abuse of the use of natural resources, and the impacts on the environment caused by the excessive and complex consumption of modern societies, which has marginalized innumerable rural communities. It lends particular attention to the responses of diverse groups of actors that have reacted with theoretical and productive proposals, as well as with social movements and confrontations for the defense of territories that are being impacted at the local level with global repercussions. The book is organized in six important themes in the debate between the reigning economic system and its environmental and social effects: paradigms, energy, ecosystem services, sustainability, social conflicts, and food systems.

Esta compilación de ensayos presentados en el XV Congreso Internacional de la Sociedad Internacional de Economía Ecológica en Puebla, México, parte de reconocer el deterioro y la perturbación global que ha derivado del abuso en la utilización de los recursos naturales y de los impactos sobre el ambiente, causados por el excesivo y complejo consumo de las sociedades modernas que ha dejado al margen a innumerables comunidades rurales. Se centra particularmente en las respuestas de diversos grupos de actores que han reaccionado con propuestas teóricas y productivas, así como con manifestaciones sociales y de confrontación en defensa de territorios que se ven impactados a nivel local con repercusiones a nivel global. El libro se organiza en torno a seis temas generales que se consideran centrales en el debate entre el modelo económico vigente y las repercusiones ambientales y sociales: paradigmas, energía, servicios ecosistémicos, sustentabilidad, conflictos sociales, y sistemas alimentarios.