COMMENT

The Challenge of the Century and Economics

Aude Pommeret*

Abstract – The work of climate economists, on the social cost of carbon in particular, is expanding and recent academic research is being taken on board and used by government bodies. In France, for example, the Quinet Commission on the value of carbon, the Criqui Commission on the sectoral costs of cutting emissions and the Pisani-Ferry and Mahfouz Commission on the assessment of the cost of the transition were set up for use in public policy. However, interest in the challenge of the century seems to stop at economics, the recommendations from which are ultimately rarely applied. While contributing to academic research, the articles contained in this issue also contribute to ensuring that climate costs are taken into account in public policies and propose solutions to help the energy transition is achieved in the best way possible.

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* *IREGE-USMB and France Stratégie.* Correspondence*: aude.pommeret@univ-smb.fr*

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While the importance of environmental economics as a topic for study is not fully recognised (Timbeau, 2024), it must be noted that it is not only a sub-discipline, considered to be one application among others falling within the framework of public economics, but it is also a topic that is interdisciplinary in nature, which does not simplify the task of economists who study it. For example, in order to properly model the dynamics of global warming, or to take into account the critical nature of the materials used in the construction of solar panels, wind turbines or batteries needed for the energy transition, or to evaluate the cost of thermal renovation of buildings, these economists must work closely with climatologists, geologists, thermodynamics specialists, etc. While such collaboration is already a challenge in itself, generating interdisciplinary publications that are recognised by the academic world is another.

However, economists have been studying natural resources for several decades, developing concepts that can now be used by climate economists. Moreover, the latter are currently expanding their work, notably to measure the social cost of the "greatest and largest market failure ever seen" (Stern, 2006), and there is a broad consensus appearing among economists in favour of carbon pricing, through a tax on carbon dioxide (CO_2) emissions[1] or an emission allowance system, as the best – or even the only – climate policy. For example, the European Association of Environmental and Resource Economists published a statement on carbon pricing in 2021.[2]

In practice, however, it seems that carbon pricing is popular only among economists. In France, against a backdrop of reducing the public deficit, there is no strong support for the energy transition, and the "yellow vest" movement sounded the death knell of the climate-energy contribution (the name given to the tax on carbon emissions introduced in 2014 in France), which has since been static at EUR 44.6 per tonne of CO_2. With current public debt problems preventing the funding of subsidies to support the energy transition, and standards, whether in relation to low-emission areas or agricultural standards, having proved to be unpopular, we can perhaps hope for a return to the forefront of carbon pricing, but through the back door. Carbon pricing has had more wind in its sails in recent years at European level, with initiatives such as the Carbon Border Adjustment Mechanism or the EU-ETS2.[3] However, the ecological or energy transition was not a key topic in the 2024 European elections and one can only hope that the policies that were envisaged will be maintained.

The problem, therefore, has perhaps less to do with the lack of work by economists than with the use of that work for public policy. Interest in the challenge of the century seems to stop at economics, the recommendations of which still face barriers and are not applied. The articles in this issue seek to overcome such barriers. The articles not only contribute to academic research, but also contribute to ensuring that climate costs are taken into account in public policies and propose solutions to help the energy transition.

Advances in Research on Climate Damages

There are several specific methods that can be used to assign a price to carbon. The first is to adopt a cost-benefit approach that aims to determine the social cost of carbon, in other words, the cost that allows the adoption of the socially optimal trajectory for greenhouse gas (GHG) emissions at global level, by constantly ensuring equality between the marginal abatement cost, that is, the cost of reducing GHG emissions by one tonne, and the discounted sum of the future marginal damage of one tonne of GHGs emitted today. This approach is not easy to reflect in the form of public policy; on the one hand, there is nothing to guarantee that the emission reduction trajectory entailed in the social cost of carbon is compatible with the international, European and national objectives that countries set themselves. On the other hand, this approach poses methodological problems in relation to computational complexity. In particular, the prices obtained from academic research are not yet stabilised, even though such research is extremely active.

The social cost of carbon is a good example of a topic on which climate economics research is particularly abundant… and interdisciplinary. Indeed, the work first sought to improve the

1. Climate change stems from greenhouse gas (GHG) emissions, including CO_2. However, it is possible to convert all GHGs, in accordance with their effect on global temperature for a given time horizon, into CO_2 equivalent (CO_2eq), which is often inaccurately referred to as simply CO_2. In this article, GHGs or CO_2 will generally be used indifferently.

2. See https://www.eaere.org/statement/

3. The Carbon Border Adjustment Mechanism (CBAM) aims to tax emissions from imported products at a level equivalent to that applied to domestic products subject to carbon pricing, with the primary objective of tackling carbon leakage. The EU-ETS2 is a new EU-wide emissions trading scheme, which was created to cover emissions from buildings, road transport and other sectors and will be operational in 2027. In its current form, the EU-ETS covers emissions from the electricity and heat production, industrial manufacturing and aviation sectors, which account for around 40% of total GHG emissions in the EU.

modelling of the dynamics of the terrestrial climate system (Otto *et al.*, 2013; Dietz *et al.*, 2021b; Ricke *et al.*, 2018; Hänsel *et al.*, 2020). Until now, the major economic models have largely overestimated the time between carbon emissions and warming, while ignoring the saturation of natural carbon-absorbing reservoirs (so-called carbon sinks) that occurs when the atmospheric concentration of CO_2 increases. Due to this saturation, the marginal effect of cumulative emissions on warming is constant. Assuming that damages are a convex function of warming, this implies that the optimal price of carbon increases faster than overall production.

In addition, the way in which uncertainties that affect the damage function are taken into consideration has been improved significantly. First, tipping points and uncertainties in relation to damages were incorporated into the modelling (Nordhaus, 2019; Lemoine & Traeger, 2016b; Cai *et al.*, 2015; Dietz *et al.*, 2021a) and uncertainty itself has been modelled at a more granular level by taking into account ambiguity and learning new information (Rudik, 2020; Lemoine & Traeger, 2014 and 2016a; Berger *et al.*, 2017; Lemoine & Rudik, 2017). Finally, more complex utility functions and the consideration of damages distribution have made it possible to not only identify preferences in terms of risk and time (Cai & Lontzek, 2019; Crost & Traeger, 2014; Daniel *et al.*, 2019), including a utility function in the manner of Epstein-Zin, but also to incorporate aversion to inequality (Ricke *et al.*, 2018; Moore & Diaz, 2015; Dietz & Stern, 2015; Moyer *et al.*, 2014).

Progress has also been made in taking into consideration the consequences of climate change on the economy. In some models, it is now assumed that the rate of economic growth (through investment productivity or capital depreciation) – and not just the level of production – is affected by climate damage (Ricke *et al.*, 2018; Dietz & Stern, 2015; Moyer *et al.*, 2014).

The calibration of aggregate climate damage has been improved through the use of recent economic and scientific data (Ricke *et al.*, 2018; Rudik, 2020; Moore & Diaz, 2015). Finally, advances have been made in taking into account the climate damages caused to non-commercial items, such as natural systems or cultural heritage, which cannot be identically replaced with goods traded on the market (Sterner & Persson, 2008; Bastien-Olvera & Moore, 2021; Weitzman, 2010; Drupp & Hänsel, 2021).

These advances have led to higher estimates of the social cost of carbon, frequently with values in excess of USD 100 per tonne of CO_2. Tol (2023) and Moore *et al.* (2024) perform meta-analyses on several thousand estimates of the social cost of carbon. Tol (2023) shows that over the last ten years, estimates of the social cost of carbon have increased from USD 9/tCO_2 to USD 40/tCO_2 for a high discount rate and from USD 122/tCO_2 to USD 525/tCO_2 for a low discount rate. Moore *et al.* (2024) obtain a truncated average (i.e. excluding the top and bottom 0.1% of the distribution) of USD 132/tCO_2 with a thick tail-end of distribution to the right. Most importantly, the range of estimates is wide and has remained so over the years or even widened.

To overcome the still imperfect understanding of climate damages, a second approach, which differs from the cost-benefit approach, consists in starting with a GHG emissions or concentration target, then determining the trajectory of carbon prices to reach this target at the lowest cost. This approach, known as the cost-effectiveness approach, makes it possible to avoid an exercise to determine the value and discounting of damage, in so far as the marginal damage curve is replaced by an emissions target. Its relevance is based, first, on the legitimacy of this target and, second, on a good assessment of the marginal abatement costs linked, in particular, to the portfolio of available and foreseeable technologies. The cost-effectiveness approach has been the subject of academic work in Europe in particular, initiated by Michel Moreaux.[4]

Assessments Carried Out by Government Bodies

Recent academic work is being taken on board and accepted by government bodies for use in public policy, for example by the EPA (Environmental Protection Agency) in the United States (on the basis of the cost-benefit approach), the Green Book in the UK or France Stratégie in France. In France, there is a shadow price of carbon,[5] developed in 2008 and then updated in 2019 under the name of *Valeur de l'Action pour le Climat* [6](Value for Climate Action – VAC, the Quinet Commissions) and based on a cost-effectiveness approach, a measure of abatement costs (Criqui Commission) by major carbon emitting

4. *See, for example, Chakravorty* et al. *(2005) or van der Ploeg (2021).*
5. *The value of actions to combat climate change has historically been developed, under the name of a shadow price, for the socio-economic assessment of public investments. However, this assessment was then extended to all possible actions, to set the right priorities, encourage useful actions and schedule them over time.*
6. *The 2024 update is ongoing.*

sectors and an assessment of the cost of the transition (Pisani-Ferry and Mahfouz Commission).

The Value for Climate Action

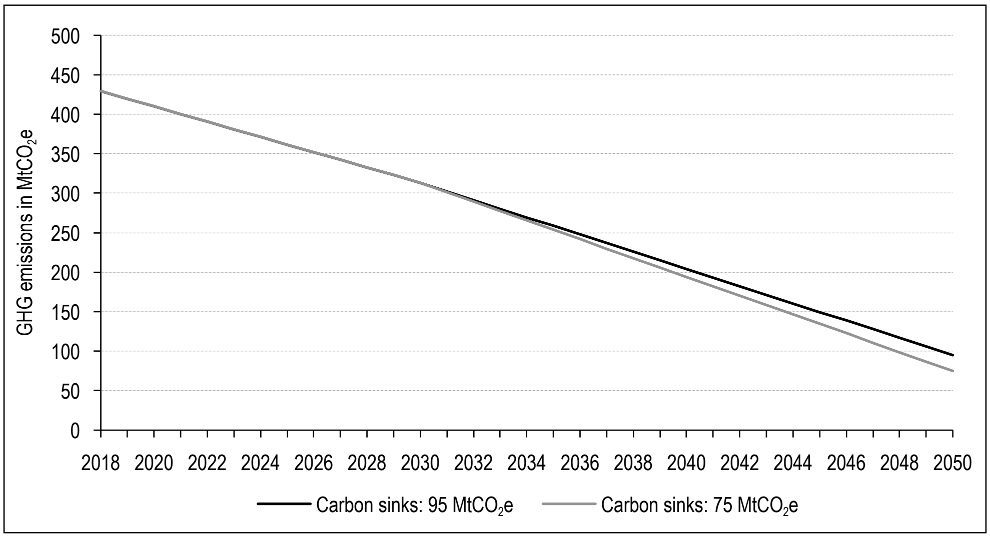
The Value for Climate Action determined by the 2019 Quinet Commission,[7] which falls under the cost-effectiveness approach, consists of setting a fictitious carbon price trajectory that triggers technological or behavioural changes compatible with a politically established gas emissions trajectory aimed at achieving net zero emissions by 2050. The relevance of this approach relies on an accurate assessment of the marginal abatement costs, that is to say the costs of reducing CO_2 emissions linked in particular to the portfolio of available and foreseeable technologies. The negative impacts of CO_2 are implicitly taken into account by the target, but climate damages ares not explicitly incorporated.

The 2019 Quinet Commission was based on a global approach incorporating, beyond the theoretical and empirical developments available, original modelling work and a prospective analysis of the available decarbonisation technologies based on the definition of an emissions trajectory. The Commission took into account a smooth emissions reduction trajectory, with an intermediate point in 2030 (−43% gross emissions compared to 1990 emissions, see Figure I), consistent with the Climate Plan of July 2017 and leading to net zero emissions (NZE) in 2050. The emissions taken into consideration concern all greenhouse gases (translated into CO_2 equivalent) and correspond to all emissions occurring on French territory, net of carbon sinks available on the national territory. The target covers all sectors, without ex-ante incorporation of sectoral targets, since one tonne of carbon (emitted or avoided) is the same regardless of the sector of origin.

Simulation and foresight exercises were carried out using both macroeconomic models and techno-economic models, which can be used to determine the temporal trajectory of the carbon price, making it possible to follow an emission reduction pathway consistent with the French NZE target. The macroeconomic models incorporate an increase in the relative price of carbon options and show how different sectors adapt to this relative price increase, invest and decarbonise. The techno-economic models use a detailed description of technologies to assess the cost of deploying the technologies necessary for decarbonisation, but are less rich in economic mechanisms. The initial simulations were supplemented with technological or techno-economic foresight exercises,[8] making it possible to assess the costs of different decarbonisation technologies – and therefore the carbon prices that trigger the abandonment of carbon solutions in favour of decarbonised solutions. Finally, the trajectory obtained was discussed with stakeholders including researchers, economists, representatives of trade unions and employers' organisations, certain professional federations and representatives of the government bodies concerned, in order to judge its relevance and the conditions for its implementation. The trade-off

7. See also Quinet (2019b).
8. Such as those conducted at global level by the International Energy Agency (IEA) or at French national level as part of the preparation of the National Low Carbon Strategy (Stratégie Nationale Bas-Carbone, *SNBC*).

Figure I – **Target trajectory for GHG emissions**



Source: Quinet (2019a).

between a Value for Climate Action with an initial jump but a moderate gradient and a Value for Climate Action that is smooth at the start but with an initial steep gradient was a particular topic of debate. The gradient of the trajectory is as important a parameter as the mean value, because any assumption of growth in the Value for Climate Action implies a rate of exchange between one tonne of GHGs saved today and one tonne of GHGs saved in a year's time that measures the efforts that one wishes to put in for an early effort.

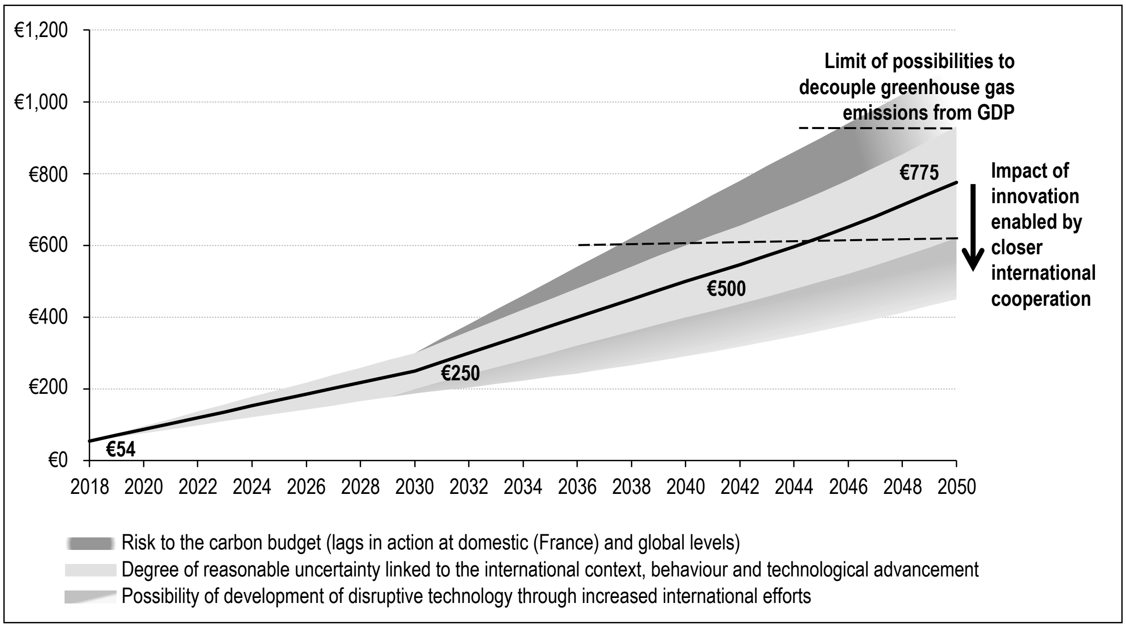
On the basis of the modelling work carried out, the Commission proposed, starting from EUR 54 in 2018,[9] setting a target Value for Climate Action of EUR 250_{2018} in 2030 (see Figure II): taking into account the changes in targets and techniques, as well as the delay in comparison with the desirable trajectory for our emissions, the trajectory defined by the Quinet Commission (2019a) therefore leads to a clear upward revision of the target shadow price, since the target set for 2030 in 2009 was EUR 100. Beyond the 2030s, the proposed price gradually aligns with a rule of growth based on the socio-economic discount rate.[10] By 2050, it is in line with the foreseeable costs of technologies allowing the recovery of CO_2 from the air – a conservative range of EUR 600 to 900_{2018}/tonne of CO_2e. In Figure II, the shaded clusters reflect uncertainties, which increase as the horizon extends beyond 2030. Greater international cooperation, allowing faster production and dissemination of innovations, while enabling groundbreaking technologies at lower cost, would achieve the same targets with a lower Value for Climate Action. In contrast, the lower availability of critical materials needed for investments or infrastructure to be built for the energy transition (solar panels, wind turbines, batteries, etc.), or a degradation of the forest carbon sink would increase the cost of technologies and imply a higher Value for Climate Action.

The Value for Climate Action is currently undergoing further revision to reflect changes in targets and context that have taken place since 2019. It consists essentially in a more precise and ambitious definition of targets, particularly at European level (−55% of emissions by 2030 compared to 1990), of technological changes, and of taking into account the unfavourable development of the forest carbon sink (the forest carbon sink in France has halved over the last ten years due to exceptional mortality in forest ecosystems and increased removals). Furthermore, the work of the Criqui Commission on sectoral abatement costs, which uses the Value for Climate Action, has made it possible to assess the practical difficulties posed by a Value for Climate Action that does not increase in line with the socio-economic discount rate over the

9. The actual value of the specific carbon pricing at that time, taking into account inflation.

10. This is Hotelling's rule, in other words, the rule for good management of an exhaustible resource in a theoretical framework (with the carbon budget then corresponding to the stock of the exhaustible resource), the value of which is intended to grow at the pace of the socio-economic discount rate.

Figure II – **The Value for Climate Action**



Source: Quinet (2019a).

whole period,[11] which does not guarantee the intertemporal neutrality of efforts.

Sectoral Abatement Costs

As recommended in the 2019 Quinet Commission's report on the Value for Climate Action, a commission on GHG emission abatement costs was established in September 2019 to identify key policy options, on a sector by sector basis, and to measure the socio-economic costs. This commission, chaired by Patrick Criqui, developed a methodology for calculating abatement costs and made estimates for five strategic sectors. The latter were chosen due to their importance in French GHG emissions, or their importance in decarbonising the energy system: transport, power grid, hydrogen production, housing and industry (see Figure III). This work, which takes on a socio-economic perspective for France, contributes to a better identification of the determining factors of abatement costs in these different sectors and makes it possible, from a planning perspective, to prioritise actions with different time horizons on the carbon neutrality trajectory.

The work of the Criqui Commission has resulted in the identification of certain specific issues regarding the assessment of abatement costs. First of all, it must be connected with the Value for Climate Action. Indeed, it is the comparison (which is less trivial than it seems, see the "Methodology" chapter of the Commission's report) of abatement costs with the Value for Climate Action that makes it possible to determine whether or not the adoption of a technology is relevant. In addition, the assessment of abatement costs is complex and shrouded in uncertainties, first, because it is necessary to take into account the evolution of the costs and performance of the different options or technologies without omitting the endogenous dimension of technical progress, notably through "learning effects". Second, the abatement is achieved through carrying out investments that are characterised by the phenomena of inertia, dynamic effects and interdependencies. It is therefore often necessary to undertake costly actions to unlock access to cheaper options. This is the case, for example, with regard to investments in transport infrastructure (for example cycle paths) that are necessary to trigger modal switches (from cars to bicycles), which will then lead to reasoning in terms of non-marginal investment: the ranking of these isolated actions in order of merit, in the manner of McKinsey's "MAC curve", which apparently responds to the concern for efficiency, therefore loses its relevance. Sometimes, it is not even possible to construct the calculation on the basis of the comparison of two isolated technologies: if we consider the complete decarbonisation of the power grid with a very high degree of penetration of renewable energies, for which the generation of electricity varies over time (it depends in particular on the weather), it is necessary to take into account the "system costs" linked to the need to constantly ensure a balance between the supply of and demand for electricity. Finally, the socio-economic approach involves taking into account external costs and benefits, the quantification of which is difficult since they do not have a market value. Valuation attempts carried out so far suggest that while these costs may be very high, they are marked by high levels of uncertainty.

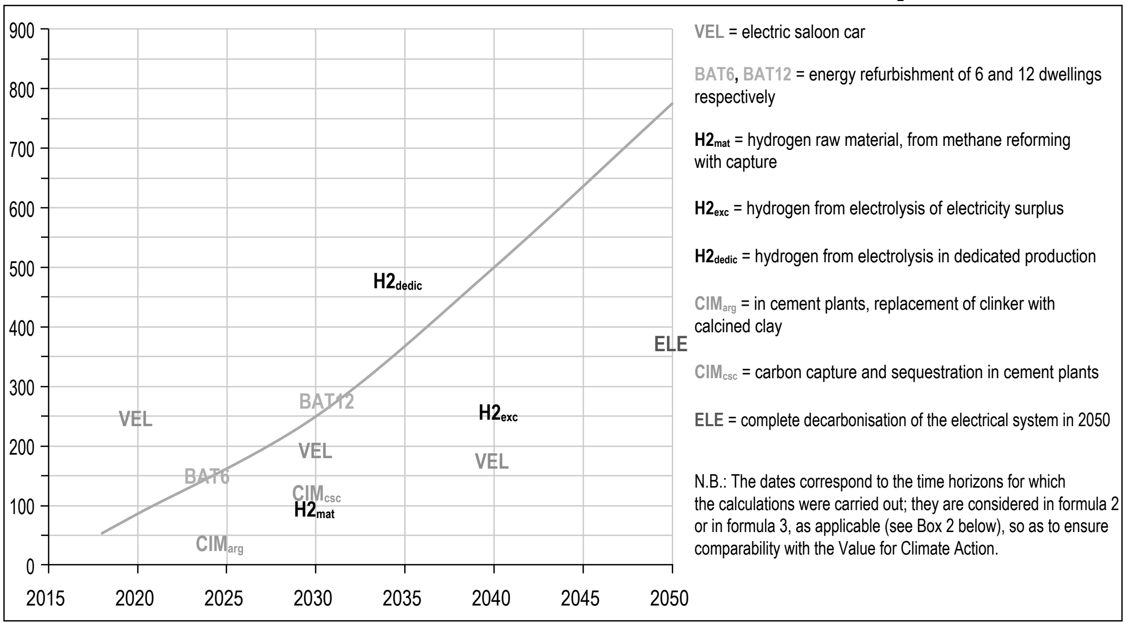
Figure III shows the abatement costs resulting from the deployment of certain technologies, which are flagship technologies for the sectors studied. They are calculated for a specific date that may differ by technology and in accordance with a fairly complex methodology that allows them to be compared directly to the Quinet (2019a) Value for Climate Action for that date. This comparison therefore makes it possible to determine, contingent upon the Quinet (2019a) Value for Climate Action trajectory, whether each of these technologies is desirable from a socio-economic point of view. The Criqui Commission finds that by 2030, the abatement costs are in the range of EUR 150/tCO_2 to EUR 250/tCO_2 for the main options in the final energy consuming sectors or for the decarbonisation of hydrogen used as raw material. As the Quinet (2019a) Value for Climate Action trajectory reaches EUR 250/tCO_2 in 2030, this graph shows that the implementation of the options studied, although costly, is therefore desirable from the point of view of the community.

The Macroeconomic Costs of the Energy Transition

Once the roadmap for the investments needed for the transition has been drawn up, questions arise about the cost of these investments, the speed of their implementation and how to cover their costs. In France, the Pisani-Ferry and Mahfouz report highlights that the climate transition is a major transformation, analogous in magnitude to the industrial revolutions of the past, which must be driven at an accelerated pace due to the delay in taking action and the new geopolitical context (Pisani-Ferry & Mahfouz, 2023).

11. *See the "Methodology" chapter of the Criqui Commission's report.*

Figure III – **Value for Climate Action and abatement costs (in €/tCO_2)**



Source: Criqui Commission.

This transition will be based on three main mechanisms. First of all, the replacement of fossil fuels with capital will require a substantial increase in investments for France, which will be necessary for achieving the objectives of the previous National Low Carbon Strategy (*Stratégie nationale bas-carbone*, SNBC 2), of around EUR 70 billion, at the 2021 EUR value, per year (2.5 GDP points) until 2030. Around half of this sum is expected to be covered by the public coffers, with the remainder coming from the private sector. Most of the technologies to be implemented by 2030 are already available. Second, technical progress will be redirected in an accelerated manner both towards alternatives to fossil fuels and towards improving energy efficiency. A significant role is assigned to energy sufficiency: according to this report, the main vector by 2030 will most certainly be the replacement of fossil fuels with capital, but energy sufficiency could contribute to the reduction of emissions by between 12% and 17%.

There is no guarantee, however, that the emissions trajectory chosen will ensure that the transition is achieved at minimal cost, which is precisely what the two articles in this issue call into question.

Research in Service of Public Policy

The article by Riyad Abbas, Nicolas Carnot, Matthieu Lequien, Alain Quartier-la-Tente and Sébastien Roux studies the impact on the costs of the transition of the emission reduction trajectory adopted (Abbas *et al.*, 2024). Without calling into question the cost-effectiveness approach, the article examines the way in which, the Net Zero Emissions in 2050 target should be interpreted in terms of modelling, not only to ensure compliance with the Paris Agreement, but also to minimise the costs of the transition. The assessments by the French government bodies are based on the French Energy and Climate Strategy (*Stratégie française sur l'énergie et le climat*, SFEC), which proposes a decarbonisation pathway and therefore amounts to imposing additional constraints. The article examines the consequences of these constraints on the speed of brown capital disposal and green capital investment. In the simple model proposed, these two forms of capital may have different productivity levels and are imperfectly substitutable. The investment is irreversible in the sense that turning brown capital into green capital or consumption is impossible, but brown capital can be disposed of, or "stranded", according to the applicable vocabulary. Their model can be used to examine how brown and green investments and capital stocks change over time, depending on the type and severity of the constraint specific to each decarbonisation scenario. It is calibrated to French national level: in particular, a stylised estimate is proposed of brown capital as a share of productive capital, based on the national accounts and the climate investment trajectories by I4CE (2022). The various scenarios studied, with varying levels of constraints, lead to the following conclusions. Unsurprisingly, it is in the least constrained scenario (once the scenario aimed at achieving Net Zero Emissions alone, which does not make much sense under the Paris Agreement, has been eliminated), that is to say, with intertemporal management of the carbon budget, that the disposal of brown capital and green investment are undertaken quickly, which limits the cost of the transition.

This raises the question of another type of cost: that of accepting the energy transition. If it is too high, it can simply prevent this transition. However, this article shows that the introduction of ad-hoc constraints leads to sudden disposal, which makes acceptance of the transition more difficult. The results can therefore be interpreted as a plea for management of the transition in the manner of a "carbon budget". The Hotelling's rule resulting from this also gets rid of any inconsistency in growth rate between the Value for Climate Action and the discount rate (see above). However, there is nothing preventing the imposition of an annual trajectory compatible with intertemporal management of the carbon budget. In particular, this would make it possible to verify the progress actually made in relation to that expected, on an annual basis, or even to record climate debt, a practical and convincing indicator, in these times of budgetary restrictions.

The article by Gert Bijnens and Carine Swartenbroekx also examines the issue of the transition path by looking at the disposal of brown capital: the authors seek to measure the extent of the reduction in CO_2 emissions if production were reallocated from the most polluting companies in a sector to the least polluting companies in the same sector (Bijnens & Swartenbroekx, 2024). In the background, there is the idea of a carbon price, since their "brown zombie" companies could be defined as companies that would no longer be competitive if the carbon price were imposed on them in the form of a tax (or emission permit). This concept of "brown zombies" can therefore be compared to the internal carbon prices used by some companies to verify their sustainability in anticipation of future binding climate policies: if their net result remains positive once the costs of their carbon emissions, valued at their internal price (i.e. defined by the companies themselves, but the social cost of carbon or the Value for Climate Action are good avenues), have been added to their other costs, their economic model would withstand an environmental policy for which the level of constraint would correspond to this internal price.

The authors conclude that a limited reorientation within a sector towards the least polluting companies, to the detriment of the most polluting companies, could lead to a 38% reduction in European emissions. Like those of the previous article, the authors insist on the need to pay attention to capital disposal and recommend not only focusing on green investment. Above all, this article is a genuine plea for the implementation of a carbon price rather than a subsidy for green investment: this price would spontaneously cause the "brown zombies" to disappear from the economy, in favour of less polluting companies in the same sectors.

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While economics research is largely devoted to assessing the climate cost and, to a lesser extent, the abatement costs, such as by incorporating critical materials and their recycling into renewable energy infrastructures (see Pommeret *et al.*, 2022), government bodies create carbon prices, assess abatement costs and measure the macroeconomic consequences of the transition. What's next? The articles in this issue attempt to go further, removing the barriers between recommendations and effective policies, and getting closer to practical recommendations regarding the pathway to the decarbonisation of the economy.

The two articles do not explicitly focus on the carbon price – which is unpopular with the public – but rather on green investments and the disposal of brown capital, and they arrive at similar conclusions: brown capital must be disposed of as soon as possible. While the economic effectiveness of this recommendation is unquestionable, it is difficult to envisage ways in which it would be more readily accepted, such as in the form of regulation, than as a carbon price (which could itself lead to optimal stranding).

Undoubtedly, the disciplines with which environmental economics has links should shift from hard sciences to social sciences: political science, sociology or psychology would no doubt be better able to remove the barriers and prevent interest in the challenge of the century from stopping at economics. ☐

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