Carbon Pricing and Green Subsidies: What Is the Optimal Combination of the Two?

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Abstract – Policies encouraging carbon mitigation by means of carbon pricing come up against a number of difficulties, such as loss of competitiveness, carbon leakage and lack of social acceptability. To address these challenges, more and more governments are opting for incentives in the form of green subsidies. Using the Vulcain computable general equilibrium model, we evaluate the relative efficiency of these two types of mechanisms and study whether it is worth combining the two. Green subsidies alone cannot achieve ambitious carbon mitigation targets. Combining the two policies allows to reach a GDP optimum for a given mitigation target. Green subsidies overcome the problems of loss of competitiveness and carbon leakage arising from carbon pricing. A portion of carbon pricing revenues are redistributed to make this measure more socially acceptable. Finally, we show that in the absence of international cooperation, countries have an incentive to make an excessive use of green subsidies.

JEL: C68, C72, D58, D62, E13, F18, F64, H23, Q43, Q54
Keywords: reducing emissions, carbon pricing, green subsidies, computable general equilibrium model, international cooperation

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Climate change poses an unprecedented challenge to humanity that needs to be addressed on a global scale. The increased concentration of greenhouse gases (GHG) in the Earth's atmosphere, mainly composed of CO_2, is leading to higher temperatures and climate destabilisation, regardless of where in the world the GHGs are emitted. This means that the environmental and economic consequences of climate change will eventually affect all countries, albeit in different ways. Among the many studies on the subject, Alestra *et al.* (2020) estimate the loss of global GDP associated with climate change at 13% in 2100 if governments do not take any action. Well-being loss and the impacts on biodiversity and availability of resources will be considerable all over the world. In light of this, the consensus among economists is that there is an urgent need to take action. For example, Germain & Lellouch (2020) recommend that France devote 4.5% of its GDP each year to climate spending, compared with 1.9% in 2018. Furthermore, taking account of the deterioration in the environment and climate, these authors also estimate that average wealth per capita is decreasing at least since the 1990s, both in France and worldwide. Thus, ambitious efforts to reduce our GHG emissions would allow us to find the path to sustainable prosperity.

It is today clear that the lack of intervention by public authorities would lead to catastrophic levels of GHG emissions. Indeed, stocks of available fossil fuels are far from depleted, while without public aid, technical progress in renewable energies is slow. While the need for intervention from public authorities is consequently clear, the question is raised of what form this should take. What political and economic instruments should be used to reduce GHG emissions? There are two types of challenges: firstly, the policy put in place needs to be efficient - in other words, able to reduce GHG emissions at the lowest economic cost; secondly, the measures taken must be socially acceptable, in particular by avoiding people placing an excessive share of the burden on the poorest populations, at the risk of these measures being rejected by the public.

A wide range of instruments can be used to reduce GHG emissions. Firstly, instruments such as price signals can be used to encourage carbon mitigation. In accordance with the carrot and stick paradigm, these price signals can either make green production methods more attractive (carrot), particularly by means of subsidies, or make brown production methods less attractive (stick), for example through excise taxes on fossil fuels, emissions trading systems or CO_2 malus on vehicles with very high emissions. Other instruments seek to encourage or direct the voluntary initiatives by private sector operators by means of information campaigns or ecolabels. Finally, others are based on more direct government intervention in the form of standards and regulations, or by means of the government's own public spending. In France, for example, we can see a combination of all these instruments. A carbon component, generally referred to as the "carbon tax", was introduced in 2014 in energy excise taxes and the level rose each year until 2018. An emissions trading system was established almost 20 years ago in the European Union covering industry, the energy sector and flights within Europe. It has made it possible to achieve prices of around €90 per tonne of CO_2 emitted for these sectors in 2023. Regulations have been introduced concerning not replacing oil-fired boilers, banning the renting out of poorly insulated homes and ending sales of new petrol and diesel cars in 2035. Information campaigns were carried out during the 2022 energy crisis to encourage the public to be careful with their energy use. The government is investing heavily the thermal renovation of its buildings and striving to make its public contracts greener. Finally, significant subsidies have been granted to help reduce the carbon impact of the 50 most emitting industrial sites, or to attract battery factories to the country.

Among all these instruments, economic literature has clearly established that measures aimed at putting a price on GHG emissions are the most effective. Baranzini *et al.* (2017) summarised the arguments supporting this: unlike regulations, government investment and subsidies, by setting a carbon price equal to its estimated social cost, each economic agent (firm, household, local authority) is free to make its own decision taking into account the social cost of its actions. If it chooses to emit one tonne of carbon, it makes this choice taking on board how much this costs society. This means they do not do it if decarbonising their operations is too costly compared with the value that society attaches to reducing emissions. Meanwhile, if it is not very costly to reduce its emissions compared to the social cost of these emissions, the economic agent chooses to decarbonise its operations so as not to have to pay the carbon price. Carbon pricing is therefore more flexible, makes it possible to adapt to different situations and does not require public authorities to know fully how to determine the least costly decarbonisation strategies.

However, carbon pricing raises the question of how to use the revenues generated. A major field of economic literature has looked at the possibility of obtaining a double dividend if environmental tax revenues are used to reduce taxation of labour or capital (Tullock, 1967; Terkla, 1984; Pearce, 1991). Not only does environmental taxation make it possible to reduce pollution that harms people's well-being but it also generates revenues which allow to reduce the most distortive taxes, and therefore encourages investment and labour. However, policies to reduce GHG emissions, the positive effects of which will only be seen in the distant future, can have a high economic cost in the short term. This is why there are doubts about the real possibility of a double dividend in the case of carbon pricing. For example, Goulder (1995) estimates that the gains made possible by cuts in taxation do not fully make up for the economic cost of introducing carbon pricing. Above all, the choice of using carbon tax revenues to reduce taxes on labour or capital favours the wealthiest, as demonstrated by Carbone *et al.* (2013) and Metcalf (1999), which gives rise to the question of whether this measure is socially acceptable.

The main problem with carbon pricing is that it is a form of regressive levy (Douenne, 2020; Berry, 2017; Metcalf, 1999), which means that it hits the budgets of low-income households harder in proportion to their disposable income than those of wealthy households. These anti-redistributive effects significantly limit the social acceptability of carbon pricing. It is in this context, for example, that France had to abandon its gradual increase in the carbon component of the excise tax on energy following the "yellow vest" protests. These anti-redistributive effects can, however, be offset by redistributing carbon pricing revenues on a lump-sum basis between all households, or even redistributing such revenues to low-income households in a more targeted manner, but at the risk of reducing the economic gains from the mechanism (Nordhaus, 1993). At the European Union (EU) level, as part of the creation of a new carbon market including direct household emissions, it is planned that a portion of tax revenues will be used to support the lowest-income households in their energy transition by setting up a Social Climate Fund.

Another major shortcoming of carbon pricing policies becomes apparent when they are applied unequally across the world as a whole, with some countries introducing a much higher carbon price than others. As it becomes more ambitious, carbon pricing therefore faces a growing risk of "carbon leakage", which means that the benefit of reducing GHG emissions in a "climate-friendly" region is partially or completely lost due to a rise in emissions in other regions with less stringent environmental requirements (OCDE, 2020). There are two main channels through which this leakage can occur. Firstly, a loss of competitiveness for firms exposed to a high carbon price compared with foreign firms not subject to the tax, and therefore a risk of factories being relocated to countries with the lowest environmental standards (Ederington *et al.*, 2005; Dechezleprêtre & Sato, 2017; Carbone & Rivers, 2017). Secondly, a "green paradox" (Jensen *et al.*, 2015) in its broad acceptance: carbon pricing reduces domestic demand for fossil fuels, which encourages producers of these energies to lower their prices to avoid being squeezed out, and therefore has the rebound effect of increasing demand elsewhere in the world (Eichner & Pethig, 2011).

Given the many difficulties arising from carbon pricing, a number of governments have turned, to varying degrees, to the use of green subsidies. For instance, the United States launched the Inflation Reduction Act (IRA) in 2022, a legislative package introducing $370 billion of spending to combat climate change, mainly by means of green subsidies. These subsidies are aimed at firms that generate energy from renewable sources as well as industries using technologies to capture their GHG emissions, or even those that manufacture electric cars locally. These mechanisms of subsidising green investments can currently be seen in most countries that have decided to decarbonise their economy, not only France but also Saudi Arabia and China. In China, the huge subsidies granted to the solar panel and electric car industries raise questions about the right stance to take for trade partners. The main appeal of these green subsidies is that they do not hamper the competitiveness of the targeted firms, but even increase it. Green subsidies are also strongly supported by citizens (Dechezleprêtre *et al.*, 2022; Douenne & Fabre, 2020; Abou-Chadi *et al.*, 2024; Leiserowitz *et al.*, 2010; Mahmoodi *et al.*, 2018).

However, ex-ante economic studies of the environmental and economic potential of green subsidies unanimously consider them to be of limited interest. Overall, they appear to be considerably less effective than carbon pricing (Fischer & Preonas, 2010; Kalkuhl *et al.*, 2013; Goulder & Parry, 2008; Baranzini *et al.*, 2017). In addition to the greater flexibility offered by carbon pricing, this finding relates in part to the existence of a significant "green paradox" phenomenon in the case of green subsidies granted in a closed economy, with energy prices reacting more strongly than in an open economy. Furthermore, this measure reduces the average energy price and therefore encourages increased energy consumption, which makes reducing emissions even harder. Nevertheless, the existing literature has only considered the issue on the basis of closed economy simulations, i.e. looking at a single region, with no trade with other countries and therefore no risk of relocations or carbon leakage. The question of whether these green subsidies are relevant in a competitive international framework consequently remains completely open. The relevance of combining green subsidies with carbon pricing has also not been widely studied, particularly in ex-ante literature. However, Stechemesser *et al.* (2024) show on the basis of an ex-post study that this combination represents a large proportion of effective climate policies.

We use the Vulcain computable general equilibrium model, in which EU industries are in competition with those in the rest of the world, in order to look at the potential of green subsidies in an open economy context. On the basis of a given EU emissions reduction target, we estimate that green subsidies alone are of limited interest compared with carbon pricing, particularly in terms of economic cost. Nevertheless, they help to protect the EU's trade balance, which deteriorates significantly when carbon prices are high. We then study the possibility of using a portion of carbon pricing revenues to finance green subsidies, with remaining revenues being redistributed to households on a lump-sum basis. We find that in terms of EU GDP, there is an interior optimum when 40% of revenues are used to finance green subsidies. This is due to a balanced mix between domestic consumption supported by the lump-sum redistribution of revenues to households, and the competitiveness of European industries supported by green subsidies. The use of green subsidies is also beneficial for employment, makes it possible to contain the increase in energy prices, and results in lower global carbon emissions. Finally, we show that even when international cooperation is possible on carbon mitigation, coordinating the measures to be taken remains a challenge. There can be a kind of prisoner's dilemma in which countries have a shared interest in cooperating by adopting limited green subsidies, but in which each country has an individual incentive to make greater use of these subsidies than in the cooperative optimum.

1. The Vulcain Model

The structure of the Vulcain model is as simple as possible, but sufficient to represent the main macroeconomic mechanisms relating to the energy transition in the long term, in the spirit of the recommendations issued by Mahfouz & Pisani-Ferry (2022).[1] The stylised nature of the model makes it easy to understand the main economic mechanisms at work and to have a clear overview of the assumptions leading to the results. The downside is that this type of model is not suitable for precise quantitative analysis. It is thus the qualitative results and the shapes of the curves that should be looked at and analysed.

As reducing emissions is a long-term process, assuming structural changes in behaviour, means of production, transportation and consumption, models with a clear theoretical structure should be favoured over more econometric models when looking at climate policies. These models are more able to represent the economic agents that could drastically change behaviour following structural changes in the economic landscape. That is why Vulcain is a computable general equilibrium model with a strong theoretical basis.

Many models used in economic literature, in particular the most stylised, assume a closed economy framework: just one region is simulated, with no trade with the rest of the world. This is the case in particular in studies on green subsidies (Acemoglu *et al.*, 2012; Kalkuhl *et al.*, 2013; Schneider & Goulder, 1997; Kverndokk *et al.*, 2004). However, climate policies are still particularly uncoordinated between regions, with major differences in terms of levels of ambition and measures implemented. In this context, it is essential to be able to analyse the effectiveness of the instruments when climate policies vary around the world. Therefore, Vulcain is a global model based on several regions that are involved in trade and able to implement diverging climate policies.

Many macroeconomic models are based on a very detailed description of economic sectors. This is the case, for example, with CIRED's IMACLIM model (Ghersi, 2014), the ThreeME model developed by the French economic policy think tank OFCE (Reynes *et al.*, 2013), CEPII's MIRAGE model (Decreux & Valin, 2007), the OECD's ENV-Linkages model (Château *et al.*, 2014) and the World Bank's ENVISAGE model (Van der Mensbrugghe, 2008).

1. *"The right method is probably to create toy models to specifically represent the fundamental economic mechanisms at work in carbon mitigation [...]".*

In order to remain in a logic of stylising key energy transition mechanisms, the model distinguishes a small number of sectors. Two dimensions are taken into account: the exposure to international competition and the type of energy used. The first dimension leads to a distinction between goods that are "exposed" to international competition and those that are not, which we will refer to here as "sheltered" goods. The second dimension leads to a comparison between "brown" goods, production of which involves fossil fuels and therefore results in a high level of GHG emissions, and "green" goods, production of which involves electricity and is therefore less carbon intensive. However, electricity is not generated in an entirely carbon-free way, as it can come in part from fossil fuels. Nevertheless, "green" goods are initially less carbon intensive than "brown" goods, and present better opportunities for carbon mitigation thanks to the possibilities of greening the energy mix.

The crossover of these two dimensions results in four goods:[2] two that are exposed - one brown and one green - and two that are sheltered - one brown and one green as well. As each of the four stylised goods requires energy in order to be produced, the model also includes an extractive sector producing a generic fossil fuel and an energy generation sector using a variety of sources: nuclear power, renewable energy and fossil fuels. These stylised dichotomies between brown and green goods, and between exposed and sheltered goods, seem relevant on the basis of existing economic literature (Abbas *et al.*, 2024; Blanchet & Pesme, 2024; Branger & Quirion, 2014).

Therefore, the sector breakdown applied makes it possible to account for the main energy transition mechanisms: 1) reducing energy consumption when the energy prices rise, primarily by means of carbon pricing policies; 2) using electricity instead of fossil fuels; 3) decarbonising the energy mix by increasing the use of renewables.[3]

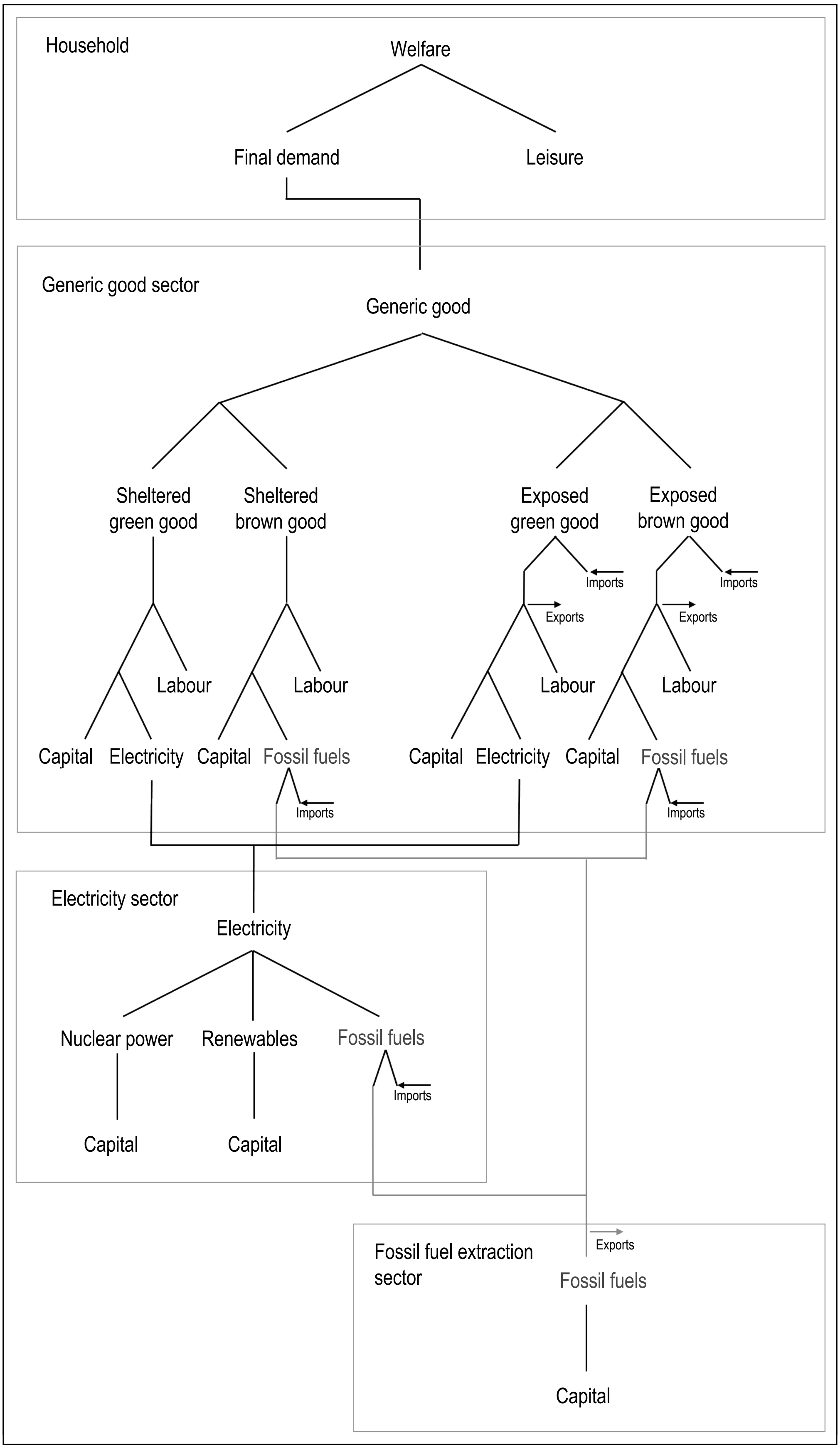
Vulcain is a computable general equilibrium model. The structure of the model is based on nested CES (Constant Elasticity of Substitution) utility and production functions, which are maximised by agents under budget constraints for households and under production technology constraints for firms. This Walrasian analytical framework guarantees the existence of an equilibrium and its uniqueness. At the equilibrium, supply equals demand in each market and factors of production are paid according to their marginal productivity. In each sector, firms in a given region are supposed to be in perfect competition, which means that profits after payment of factors are zero. Primary factors of production (capital and labour) are considered perfectly mobile between sectors but are not mobile between regions. The trade balance in each region is balanced in terms of value but can be subject to variations in terms of volume. The main existing taxes (taxes on earned income and capital income, energy taxes and VAT) are modelled and all revenues generated are redistributed to households on a lump-sum basis. Finally, only CO_2 from the combustion of fossil fuels is modelled. It is emitted whenever a unit of fossil fuel is consumed in the model, whether directly by a firm or in order to produce electricity. These are common assumptions for a computable general equilibrium model and well suited to stylised modelling. The intention is not to perfectly represent how a real economy works but it allows for a basic understanding of the main mechanisms at work. Furthermore, these assumptions - particularly the lack of inter-sectoral rigidity of factors of production and the fixing in value of the trade balance- are consistent with the modelling of medium or long-term equilibria. The overall production structure of the model for each region is shown in Figure I, and in more detail in the Online Appendix (link to the Online Appendix at the end of the article), as well as the choices made concerning the calibration of economic data for the initial equilibrium and the structural parameters of the model.

2. Carbon Pricing and Green Subsidies Used Separately

We begin by presenting the effects of the two measures taken separately in the European Union. Carbon pricing is modelled on the basis of an emissions trading market, applied to the economy as a whole. This allows for an emissions target to be set, letting the market carbon price to be determined endogenously. This trading market is in addition to the excise tax that already exists in the sheltered sector, which remains unchanged. By default, carbon pricing revenues are redistributed to households on a lump-sum basis in order to make this measure more socially acceptable. As for green subsidies, they are modelled by a reduction in

2. It is understood that in reality there is a continuum characterised by varying levels of exposure to international competition and carbon content.
3. These three mechanisms can be compared to some extent with those identified by Mahfouz & Pisani-Ferry (2022): moderating use and consumption, substituting capital for fossil fuels (a consequence of electrification), redirecting technical progress towards decarbonised energies and energy efficiency.

Figure I – **Overall structure of the Vulcain model by region**



taxation applied to earnings from green capital, intended to encourage investment in low-carbon production methods. This measure simulates the choice made by some governments to grant large subsidies to low-carbon energy producers or electric vehicles.

For the purpose of symmetry with carbon pricing, green subsidies are financed by means of a flat-rate household contribution.[4] In both cases, this measure is only applied within the EU in order to create a credible situation in the absence of international cooperation. Cases of cooperation are studied in part 4.

Simulations are carried out in comparative statics, in other words with fixed primary factors of production and fixed productivity levels . Within this analytical framework representing the medium term, the long-term beneficial effects of reducing GHG emissions in relation with limiting the increase in the Earth's temperature are not yet apparent. As a result, policies to reduce GHG emissions seem costly, as this is an effort that needs to be produced by the economy in the medium term in order to decarbonise, and the benefits of which will not be observable until the longer term.

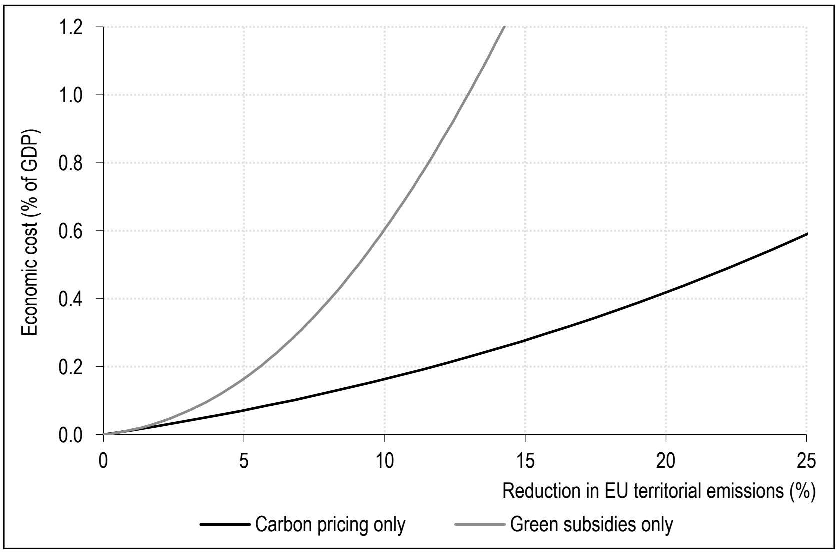
2.1. Carbon Pricing Is Much More Effective Than Green Subsidies

Whatever measure is used, reducing carbon emissions in the EU carries a macroeconomic cost associated with introducing a distortion compared with the initial economic situation (Figure II). Carbon pricing increases the cost of fossil fuel inputs in production and therefore reduces production capacities in the EU, thus making European industries less competitive than their foreign competitors. The marginal economic cost becomes higher and higher as the emissions cap is lowered, as it becomes increasingly difficult to decarbonise production once the main sources of energy savings are gone. For example, a 5% reduction in EU emissions by means of carbon pricing results in a loss of 0.07 points of GDP in volume terms, while a 25% reduction implies a loss of 0.59 points of GDP and generates public revenues equivalent to 1.2 points in GDP. The loss of production capacity affects household incomes through lower wages and returns on capital, and thereby reduces final demand, which falls by around 0.5% in volume in the scenario of EU emissions decreasing by one quarter. Furthermore, in this same scenario, EU exports in volume terms fall by 2.2%, while imports decline by a more modest 1.5%, resulting in a deterioration in the trade balance.

Green subsidies, meanwhile, increase the profitability and competitiveness of green firms but at the cost of an economic distortion in relation to brown firms. In the medium term, in other words not taking account the long-term environmental benefits of these changes in behaviour,

4. *This flat-rate contribution is deducted from the lump-sum transfer to the household from the tax revenues included in the model (taxes on earned income and capital income, energy taxes and VAT).*

Figure II – **Comparison of the economic cost of the two mechanisms used separately (as a percentage of GDP)**



Reading note: The 5% reduction in EU territorial CO_2 emissions by means of a carbon pricing mechanism results in a loss of 0.07% of EU GDP. The same reduction achieved by means of green subsidies results in a loss of 0.17% of GDP.
Source: CGDD's Vulcain model.

the incentive provided by green subsidies leads private sector operators to move away from the most productive situation. What is more, the reduction in taxation is financed by a fall in net household incomes, which curbs consumer spending and savings. In addition, the marginal economic cost of this measure increases more and more as efforts are made to reduce carbon emissions using this mechanism alone. For example, a 2.5% reduction in EU emissions achieved by means of green subsidies has an economic cost of 0.05 points of GDP in volume terms, while a 5% reduction has an economic cost of 0.17 points of GDP and represents a fiscal effort equivalent to 2 points of GDP. Nevertheless, the EU's trade balance is improving slightly, with exports up 0.2% in volume terms, while imports are stable. Reduced taxation of green capital makes European firms more competitive on the market for green goods but the distortion created by green subsidies penalises the European economy's total production and therefore affects all commercial exchanges.

For a given emissions reduction, green subsidies have a much more negative economic impact than carbon pricing policies, and this gap widens as climate ambition increases. A 5% reduction in EU emissions achieved by means of carbon pricing therefore corresponds to a marginal cost of reducing emissions of €57 per tonne of CO_2 avoided, compared with €206 per tonne of CO_2 avoided in the case of green subsidies. By directly targeting emissions without stipulating how they should be reduced, carbon pricing gives economic agents more leeway to reduce them in the cheapest way possible. This makes it much less distorting than a policy of forcibly increasing green investment with no guarantee that this is the cheapest way to reduce emissions. This result has already been clearly identified by economic studies (Fischer & Preonas, 2010; Kalkuhl *et al.*, 2013; Goulder & Parry, 2008; Baranzini *et al.*, 2017), as stated in the introduction.

2.2. Carbon Pricing Activates More Channels of Carbon Mitigation

The aggregate effects mask wider changes in the composition of European production and trade. The table disaggregates these changes at sectoral level in the case of a 5% reduction in EU territorial emissions. Both measures have the effect of redirecting European production from brown sectors to green sectors but this resetting is particularly significant in the case of green subsidies. This clearly illustrates the mechanisms by which each of these measures reduces emissions. In the case of green subsidies, decarbonisation of the economy is achieved mainly by switching from brown sectors to green sectors, and to a lesser extent by decarbonising each type of sector. Carbon pricing, on the other hand, is designed to encourage the whole economy to decarbonise and first mobilises the decarbonisation lever of each type of sector, before transitioning from brown to green sectors.

Green subsidies lead to a reallocation of capital from brown sectors to green sectors, particularly in the energy sector. The electricity generation sector is favoured, while the fossil fuel extraction sector suffers a decline in production, which has to be offset by an increase in fuel imports.

Overall, green subsidies therefore appear to be a not very appropriate solution. However, limited use of these subsidies may be justified in addition to carbon pricing if there are distortions that do not favour green investment. In particular, one may wonder whether using green subsidies as an additional measure to carbon pricing might

Table – **Comparison of the economic effects of the two mechanisms used separately to reduce CO_2 emissions by 5%**

		Carbon pricing (%)	Green subsidies (%)
Territorial emissions	Brown sectors	−3.26	−5.47
	Electricity sector	−12.64	−2.93
	Total	−5.00	−5.00
Added value [(1)]	Brown sectors	−0.42	−6.18
	Green sectors	+0.33	+8.14
	Electricity	+5.43	+16.80
	Extraction of fossil fuels	−3.64	−48.22
	Total	−0.07	−0.17

[(1)] in volume terms.
Reading note: A 5% reduction in the EU's territorial CO_2 emissions achieved only by means of a carbon pricing mechanism results in a 3.26% reduction in emissions from brown sectors and a 0.42% reduction in their added value.
Source: CGDD's Vulcain model.

not be justified in a context where the rest of the world is not making a similar climate effort.

3. Combining the Two Policies

We now simulate the implementation of a combination of the two measures within the European Union. Unlike carbon pricing, green subsidies represent an expense for governments, which means that the two measures could complement each other by using some of the revenues from carbon pricing to finance green subsidies. We simulate the effects of a carbon pricing mechanism applied to the whole of the EU with the aim of reducing regional emissions by 25%. As before, this pricing takes the form of a system of emission quotas applied to the entire EU economy. However, some of the tax revenues generated by this pricing can now be used to finance green subsidies, with the remainder redistributed to households on a lump-sum basis.[5] We vary the proportion of revenues allocated to green subsidies from 0% to 100%. In this section, the climate effort is always assumed to be made by the EU alone. Cases of international cooperation are studied in section 4.

3.1. Existence of an Interior Optimum

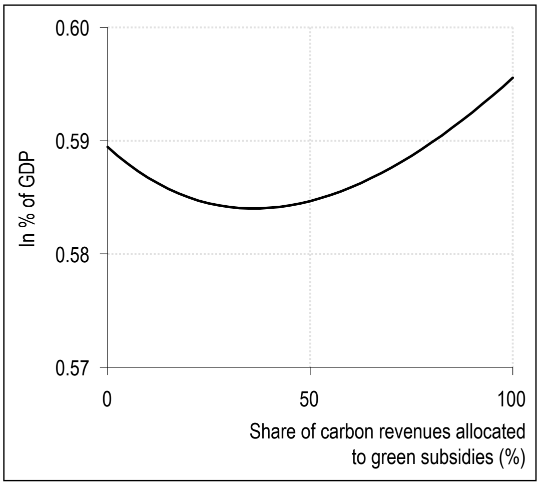
The macroeconomic effect of the choice of how to allocate revenues appears secondary compared with the primary effect of introducing carbon pricing (Figure III). Whatever allocation is chosen, the macroeconomic cost of reducing EU emissions by a quarter falls within a relatively narrow range around −0.6 points of GDP. Nevertheless, there is an economic optimum, in other words, a smaller fall in GDP for an intermediate allocation system: around 40% of revenues paid back in the form of green subsidies and 60% redistributed to households on a lump-sum basis.[6] The marginal macroeconomic cost of reducing emissions is €131.2 per tonne of CO_2 avoided when all carbon revenues are redistributed to households, and €133.7 per tonne when they are spent entirely in the form of green subsidies, compared with €130.1 per tonne when 40% of revenues are allocated in the form of green subsidies. It therefore seems appropriate from an economic efficiency viewpoint to combine carbon pricing and green subsidies.

This relevance of using both measures is the result of two opposing phenomena. On the one hand, as seen above, final demand deteriorates more and more as economic balances are distorted by lower taxation on green capital and as household incomes are tapped to encourage less and less productive investment. When all revenues are redistributed to households, final demand falls by 0.49% in volume terms, compared with 0.50% when 40% of revenues are used for green subsidies, and 0.53% when all revenues are used for this purpose (Figure IV). On the other hand, we have already seen that green subsidies have a positive effect on the EU's trade balance in volume terms, by making European firms in the green sector more competitive and reducing the amount that households can spend on imports. However, this benefit decreases more and more as the level of subsidies increases. Therefore, when all revenues from carbon taxes are redistributed to households, the trade balance falls by 0.103 points of GDP in volume terms, compared with 0.085 points of GDP when 40% of revenues are allocated to green subsidies, and 0.062 points of GDP when all revenues are used for this purpose.

It is the intersection of these two curves, the concave and decreasing final demand curve and the concave and increasing trade balance curve, that leads to the existence of an interior optimum in terms of GDP. This corresponds to an equilibrium in which green subsidies enable European firms to be competitive in order to meet increased demand from European consumers for green

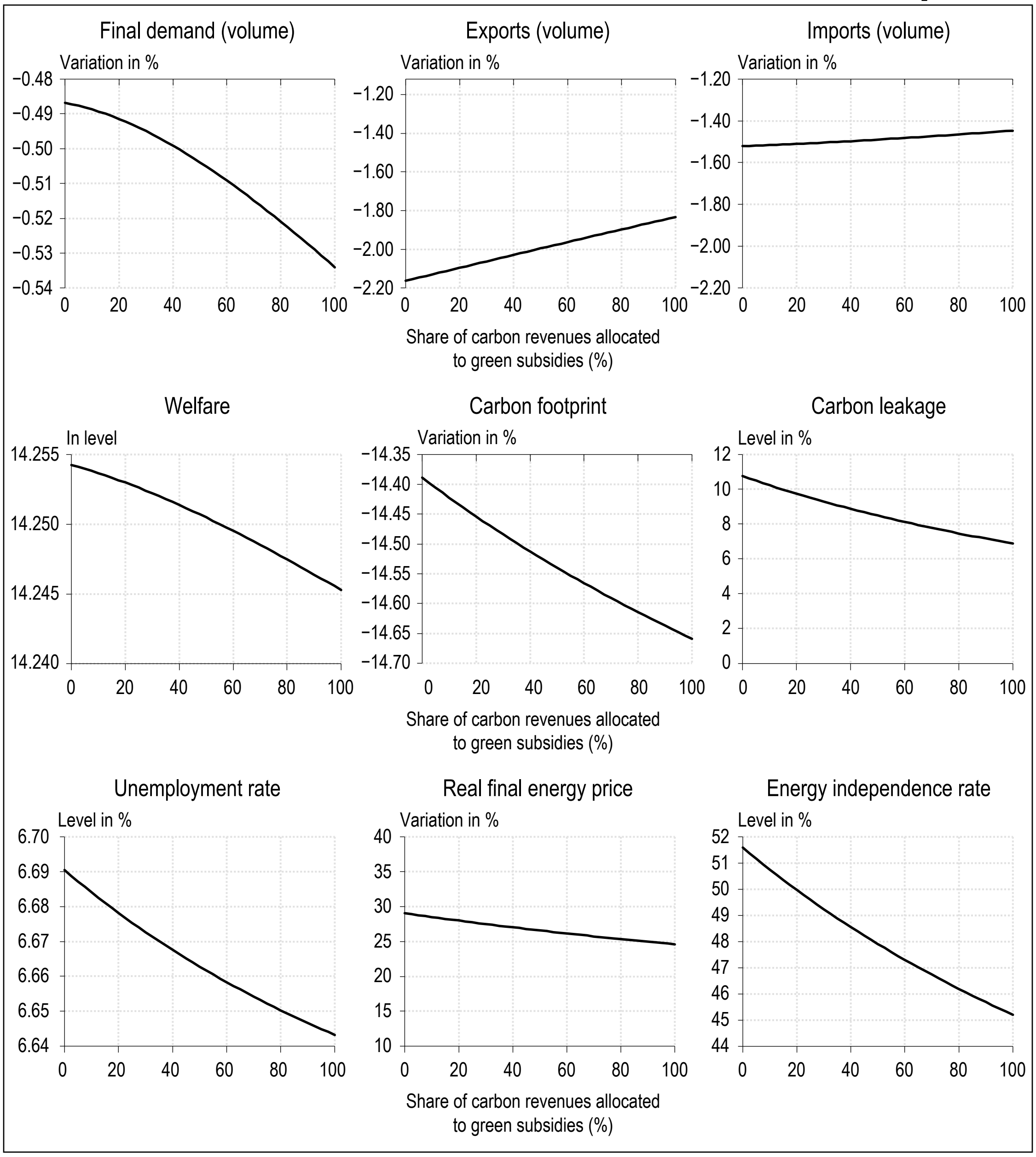
5. *For a given level of emissions, recycling carbon pricing revenues by means of green subsidies also makes it possible to slightly reduce the level of pricing required, insofar as part of the emissions reduction is achieved through green subsidies. This economic mechanism was identified by the High-Level Commission on Carbon Prices (Stiglitz* et al.*, 2017).*
6. *Sensitivity analyses of this result are provided in the appendix.*

Figure III – **Economic cost of a combination of the two mechanisms for a 25% reduction in CO_2 emissions (as a percentage of GDP)**



Reading note: When 80% of revenues are redistributed in the form of green subsidies and the remainder directly distributed to households, a carbon pricing mechanism allowing for a reduction in the EU's carbon emissions by one quarter has a macroeconomic cost of 0.59% of GDP for the EU.
Source: CGDD's Vulcain model.

Figure IV – **Economic effects of a combination of the two mechanisms for a 25% reduction in CO_2 emissions**



Reading note: When the EU reduces its CO_2 emissions by 25% by means of a carbon pricing mechanism and 50% of revenues are redistributed in the form of green subsidies and the remainder directly distributed to households, the EU's carbon footprint is reduced by 14.54%, the unemployment rate reaches 6.66%, and the real final energy price rises by 26.6%.
Source: CGDD's Vulcain model.

goods following the implementation of carbon pricing. This optimum enables the European economy to avoid a double pitfall. If revenues are used entirely to finance green subsidies, lower taxation on their capital makes companies in the European green sector highly competitive. However, European consumers' budgets are reduced by carbon pricing, without receiving the revenues, and domestic demand is therefore weakened without sufficient compensation from the outlets found on the external market. Conversely, when all revenues are redistributed to households, European consumers maintain their spending capacity, but this domestic demand will be largely met by imports from foreign countries that do not apply such high carbon prices.

3.2. Contrasting Effects Depending on the Economic and Environmental Indicators

The choice of how to allocate carbon pricing revenues has contrasting consequences on global carbon emissions, social acceptability for households and the energy markets.

Despite its potentially positive effects on GDP, the use of green subsidies nevertheless leads to a decline in welfare (measured as an aggregate of final demand and leisure volumes, see Figure I), even when they are used at low levels. Green subsidies indirectly lead to a fall in purchasing power vis-à-vis foreign countries, due to a weaker exchange rate. Although the trade balance and industrial activity are preserved in terms of volume, competitiveness is maintained due to a fall in the price of exports and a concomitant rise in the price of imports. This reduces household purchasing power, even when GDP is growing strongly.

Furthermore, green subsidies appear to be detrimental to the EU's energy independence. The EU's energy independence, i.e. the ratio of domestic primary energy production to consumption, has risen to almost 52% following the introduction of the carbon pricing mechanism, compared with 43% initially. When all carbon pricing revenues are used for green subsidies, Europe's energy independence falls to 45%, which is close to the initial level. This is due to a reduction of more than 40% in the volume of fossil fuels extracted from EU soil, as a result of the reconversion of capital dedicated to extraction towards green energies. Therefore, choosing to redistribute carbon pricing revenues to households is beneficial for their purchasing power and for the European Union's energy independence.

Conversely, redistributing revenues in the form of green subsidies helps to reduce carbon leakage, i.e. preventing some of the emissions reduced within the EU from being moved to other countries, mainly as a result of factories being relocated. When all revenues are redistributed directly to households, carbon leakage is almost 11%, which means that 11% of emissions reductions achieved in the EU are offset by emissions increases in the rest of the world. This is reduced to 7% if all revenues are allocated to green subsidies. Green subsidies help to preserve Europe's industrial fabric by stimulating production in the green sector. As green subsidies increase, European green sector industries will gain market share both locally and abroad, thereby reducing relocations, while the fall in local consumption will lead to a decline in imports of carbon-based goods produced abroad. Green subsidies therefore make it possible to reduce not only carbon leakage but also the EU's carbon footprint.

In addition, green subsidies help to limit the rise in the real price of final energy. This rise of 29.1% when all revenues are redistributed to households is reduced to 24.6% when all revenues are used to finance green subsidies. Green subsidies thus make it possible to reduce the use of carbon pricing to cut emissions, and also to finance the development of renewable energies at very competitive costs, so that the pre-tax production price of energy falls.

Lastly, green subsidies are good for employment because they help maintain industrial activity. In fact, it is by maintaining jobs that they have the greatest positive impact on GDP. By carrying out simulations in which the total amount of labour supplied by the European economy is fixed, this intermediate optimum for GDP disappears. Therefore, despite its negative effects on household purchasing power and energy independence, the use of green subsidies is not without advantages. On the one hand, it makes it possible to reduce the total quantity of carbon emissions worldwide in situations of climate non-cooperation. On the other hand, it can make carbon pricing more socially acceptable by limiting the rise in energy prices and protecting industrial jobs. This is in line with and complements the findings of a number of studies that have shown that green subsidies are more socially acceptable than carbon pricing (Abou-Chadi *et al.*, 2024; Leiserowitz *et al.*, 2010; Mahmoodi *et al.*, 2018). In particular, Douenne & Fabre (2020) showed that carbon pricing is well supported if revenues are used to finance public transport (64% in favour), renewable energies (59%) or renovation of buildings to make them more heat efficient (56%). However, there seems to be less support for the most lump-sum measures: uniform lump-sum payment (38%), reducing the public deficit (44%), targeting the 50% lowest-income households (45%).

4. International Cooperation

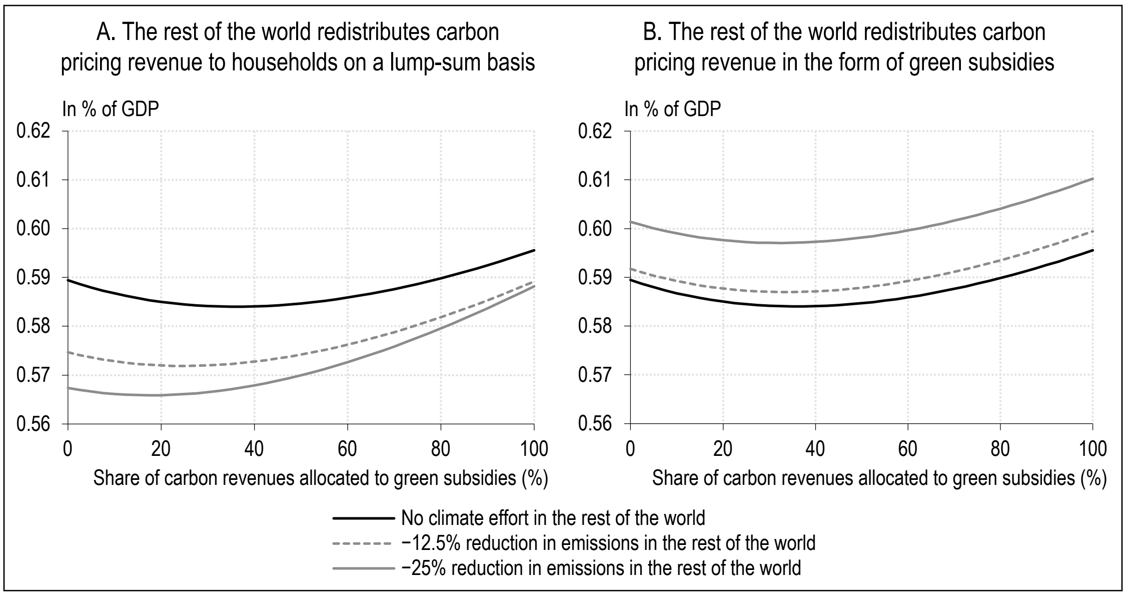
We now look at the scenarios in which the rest of the world (non-EU) also makes a climate effort by introducing its own carbon pricing mechanism. To simplify, we study in turn the two polar cases in which the rest of the world uses respectively 0% and 100% of its carbon pricing revenues to implement green subsidies (with the remainder redistributed on a lump-sum basis to households), while we continue to increase the proportion of EU carbon revenues used in the form of green subsidies continuously from 0% to 100% (with the remainder redistributed on a lump-sum basis to households, as before).

When the rest of the world redistributes all carbon pricing revenues to households, its climate effort has immediately beneficial economic effects for the EU. A 12.5% reduction in emissions in the rest of the world would therefore reduce the macroeconomic cost to the EU of its own climate effort from almost 0.59 points of GDP to less than 0.58 points of GDP (Figure V). This cost is reduced to less than 0.57 points of GDP when the rest of the world reduces its regional emissions by 25%. This positive effect for the EU is essentially connected to the reduction in carbon leakage and the associated loss of competitiveness. When the rest of the world makes a significant climate effort, or even an effort equivalent to that of the EU, it is no longer as advantageous for industries to move their production outside the EU. For this reason, it is less and less useful to use green subsidies as the rest of the world steps up its climate effort. When the EU and the rest of the world reduce their emissions to a similar extent, the optimum in terms of GDP is to use just 20% of carbon pricing revenues to finance green subsidies, compared with 40% if the rest of the world makes no climate effort. The EU can therefore still hope to win export market share in the green goods market, but there is much less need to protect itself from relocations.

Conversely, if the rest of the world uses all its carbon pricing revenues to finance green subsidies, then the climate efforts of the rest of the world have a negative impact on the European economy in the medium term. In fact, the higher the carbon price implemented in the rest of the world, the more revenues the rest of the world will have available to reduce taxation of firms in the green sector. Paradoxically, competition facing the EU in green goods is even fiercer when the rest of the world raises its carbon prices while using revenues to finance green subsidies. In this scenario, the beneficial effects of eliminating carbon leakage are more than offset by this exacerbated tax competition. Once again, there is an optimum for the EU in terms of GDP when around 40% of carbon pricing revenues are redistributed in the form of green subsidies in order to protect itself from this tax competition.

We can therefore see that even when countries cooperate to reduce their carbon emissions, it is possible to observe a form of non-cooperation on how to achieve this carbon mitigation. The situation then becomes a form of prisoner's dilemma: the economic situation of the different regions of the world would be better if no country introduced green subsidies, but each region has an advantage in unilaterally introducing this type of policy. Furthermore, the introduction of green subsidies elsewhere in the world encourages each region to increase its own subsidies even more. The existence of this suboptimal competitive equilibrium carries

Figure V – **Economic cost of a combination of the two mechanisms for a 25% reduction in CO_2 emissions, depending on the rest of the world's level of climate action (as a percentage of GDP)**



Reading note: When 40% of revenues are redistributed in the form of green subsidies and the remainder directly distributed to households, a carbon pricing mechanism allowing for a reduction in the EU's carbon emissions by one quarter has a macroeconomic cost of 0.59% of GDP when the rest of the world does not take any climate action. This cost is reduced to 0.57% of GDP when the rest of the world also reduces its regional emissions by one quarter by redistributing revenues from its own carbon pricing to households. It is increased to 0.60% of GDP when the rest of the world also reduces its regional emissions by one quarter but by redistributing revenues from its own carbon pricing in the form of green subsidies.
Source: CGDD's Vulcain model.

the risk of undermining climate cooperation and reducing the effectiveness of the global energy transition. A proposition such as creating a climate club (Nordhaus, 2015), applied not only to the level of carbon pricing but also to how the revenues are used, could provide an interesting solution to this kind of non-cooperation.

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The use of a stylised computable general equilibrium model has made it possible to highlight a number of results regarding the relevance of green subsidies and the place they should be given in designing policies to reduce carbon emissions. Although they are not very effective on their own, introducing a limited amount of green subsidies would be a potentially useful measure in addition to carbon pricing. In particular, green subsidies may protect industrial jobs from the risk of relocation and make carbon pricing more socially acceptable by limiting the rise in energy prices.

Therefore, while there is a great temptation for decision-makers to make extensive use of green subsidies rather than more unpopular measures to curb carbon emissions, we have seen that these do have their place in climate policy, provided that they remain limited in scope and are in addition to sufficient carbon pricing. Furthermore, to avoid harmful tax competition between countries that tends to be exacerbated by these green subsidies, their fair level could be the subject of international discussions. Otherwise, an extensive and unilateral use of green subsidies risks degenerating into a form of trade war, as illustrated recently by the debates surrounding the US Inflation Reduction Act and electric vehicles produced in China.

However, three limitations of this analysis should be mentioned. Firstly, capital is considered to be perfectly mobile between sectors, and in particular between green and brown sectors. This does not take into account the difficulties that the economy could face in the short term in making its energy transition, and in particular the problem posed by stranded brown sector assets, in other words assets that are scrapped before they are fully depreciated. Secondly, these simulations do not take into account the potential effects of critical market size or endogenous technical progress. There may be fierce competition between countries to attract an entire industrial sector to their region, generating returns of scale and shared technological benefits for the sector. In reality, this is likely to contribute to more intense competition in the allocation of green subsidies. Thirdly, these comparative statics simulations do not change the total amount of capital available in the economy. As a result, green subsidy mechanisms give rise to a complete crowding-out effect in which green investments are made to the detriment of brown investments. In practice, lower taxation on green capital is likely to increase savings and investment to the detriment of consumer spending, or to attract foreign investment by increasing the expected return on capital. This limitation leads us to underestimate the interest of using green subsidies. □

Link to the Online Appendix:
www.insee.fr/en/statistiques/fichier/8562093/ES545_Abbas-et-al_OnlineAppendix.pdf

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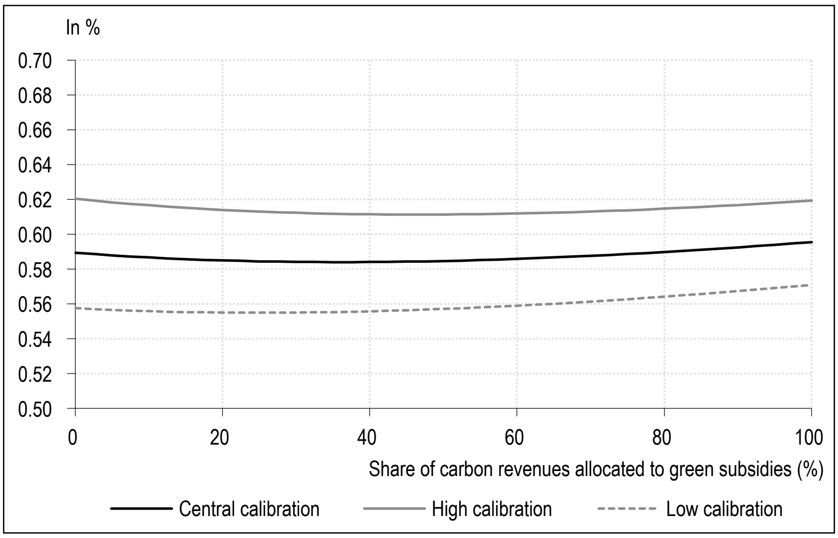
SENSITIVITY ANALYSIS OF RESULTS TO CALIBRATION

Sensitivity analysis of the main result of the article is performed for the different model elasticities, divided into four groups:
- Elasticity of substitution in the household utility function, between labour supply and leisure demand;
- Elasticity of substitution of the upper nodes of the production function of the generic good;
- Elasticity of substitution between energy and capital and between forms of energy;
- Armington elasticity of substitution between foreign and domestically produced goods.

For each of these groups, the calibration used for our simulations is compared with a higher calibration, in which substitution elasticities are increased by 25%, and a lower calibration, in which substitution elasticities are reduced by 25%. Sensitivity analysis is performed for the main figure in the study, i.e. Figure III illustrating the macroeconomic cost of a 25% reduction in EU regional emissions obtained by means of a carbon pricing mechanism, using comparative statics and with the rest of the world not making any climate effort.

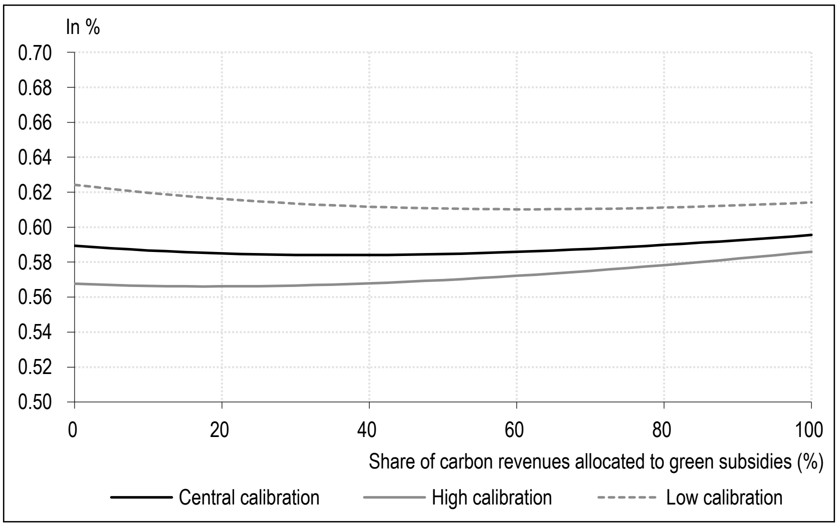
The existence of an interior optimum for GDP is maintained regardless of the calibration chosen. This optimum moves within a range of 20% to 70% of carbon pricing revenues allocated to green subsidies. Green subsidies are of more interest when the labour supply is more elastic, and vice versa (Figure A-I). Green subsidies are of less interest when the types of goods are easier to substitute, as well as labour and the capital-energy aggregate (Figure A-II). Green subsidies are of more interest when energy can be more easily substituted with capital, and when sources of electrical energy become more substitutable with each other (Figure A-III). Finally, green subsidies are of even more interest when goods produced domestically can be easily substituted by goods produced abroad (Figure A-IV). Overall, the most sensitive calibration is that of substitutability between energy and other factors of production.

Figure A-I – **Sensitivity analysis of figure III to the calibration of the elasticity of substitution between labour and leisure**



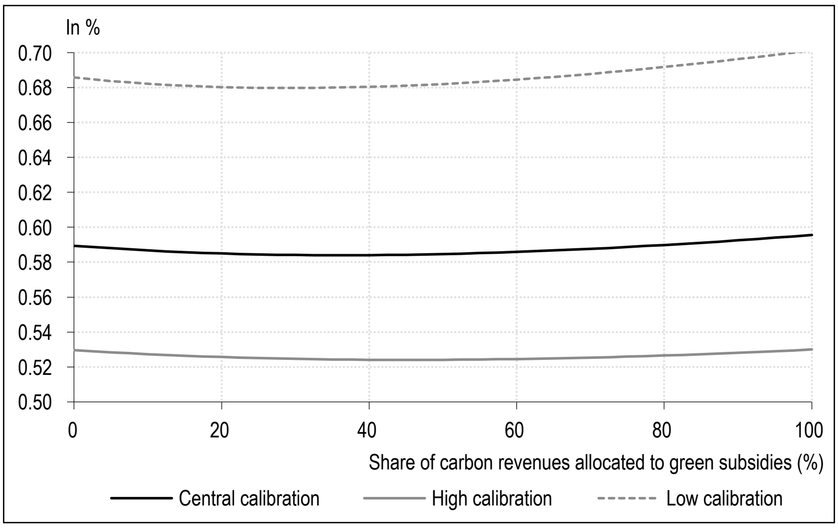
Source: CGDD's Vulcain model.

Figure A-II – **Sensitivity analysis of figure III to the calibration of the elasticity of substitution between types of goods and between labour and capital-energy aggregate**



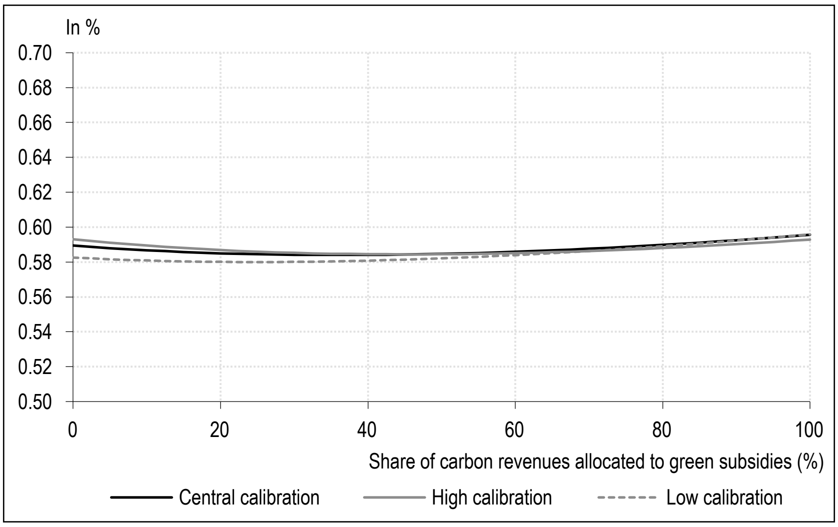
Source: CGDD's Vulcain model.

Figure A-III – **Sensitivity analysis of figure III to the calibration of the elasticity of substitution between energy and capital and between different sources of electrical energy**



Source: CGDD's Vulcain model.

Figure A-IV – **Sensitivity analysis of figure III to the calibration of the Armington elasticity of substitution**



Source: CGDD's Vulcain model.