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# Sustainability, Globalization, and the Energy Sector Europe in a Global Perspective

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## Abstract

In this article, we analyze the socioeconomic effects of energy sustainability challenges raised by oil depletion and climate change at the European and global levels. We assess macroeconomic impacts at different period markers from 2010 to 2100 and under different visions of the future of globalization. Fragmented capital markets affect the pace and direction of change and induce additional economic losses in the long term. Regionalized good markets have a positive effect in the long term because less intense international trade moderates the effects of fossil fuel constraints. A sustainable energy future will require implementing policies and measures that are able to (a) provide correct incentives for long-term investments by resorting to other signals than current market prices, (b) incorporate sectoral measures that act complementarily to pricing scheme measures for sectors confronted with biased agents' behaviors or strong inertias, and (c) foster globalization patterns that are consistent with energy sustainability objectives. The challenge consists in articulating the objectives and the instruments of these different policy and measures triggering the transition toward a sustainable future.

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The emergence of global environmental issues on the political agenda goes back to the Stockholm Conference in 1972 in an attempt to provide a political answer to the alarm by the Club of Rome about the "Limits to Growth" in a context of a finite ecosystem (Meadows, Meadows, Randers, & Behrens, 1972). Against this background, the political interest was focused essentially on issues raised by the exhaustion of nonrenewable resources, especially fossil energies, in line with the emergence of geopolitical tensions about oil, as illustrated by Richard Nixon's State of the Union address in 1970. Despite debates about the Malthusian nature of the approach supporting the analysis of the Club of Rome, the Stockholm Conference recognized the legitimacy of concerns about the interface between growth, environment, and resources. The concept of *ecodevelopment* introduced in 1972 by Maurice Strong to stress the need to adopt development patterns respecting natural ecosystems was an attempt to go one step further. Although initially linked predominantly to local problems, this notion was rapidly extended to global challenges (Sachs, 1980). The interest in the trade-offs between economic, social, and environmental dimensions across generations evolved in the late 1980s with both the emergence of climate change on the political agenda and the concept of sustainable development defined in the 1987 Brundtland Report "Our Common Future" (World Commission on Environment and Development, 1987). Sustainable development has become a key concept in international governance since the Earth Summit of Rio de Janeiro (1992). It is evidently not accidental that this interest in sustainability issues reappeared at the same time with renewed concerns about geopolitical conflicts for the access to cheap oil and gas (Schlessinger, 1989).

However, 20 years after the Earth Summit, the recent Rio + 20 conference has confirmed the difficulty to lay out a coherent roadmap forward for addressing global challenges in the framework of sustainable development (Clémençon, 2012b). In particular, two major division lines drive the debate about environmental sustainability issues. On one hand, different approaches have been proposed to formalize more explicitly the concept of sustainability. This has resulted in the emergence of two polar visions, weak versus strong forms of sustainability. The former assumes substitutability of human-made and natural capital, whereas the latter considers that a minimum level of natural capital must be preserved, acknowledging the specificities of natural capital (Pearce & Atkinson, 1993). On the other hand, the opposition between promarket liberals and antimarket social greens about the compatibility between sustainability, free markets, and trade liberalization has remained a major source of controversies

(Clapp & Dauvergne, 2005; Harris & Wise, 2001). In particular, the Rio process since 1992 has failed to achieve a comprehensive way between free market, trade liberalization, and governmental regulation (Clémençon, 2012a). This failure emphasizes the necessity to explore more in depth the link between sustainability and globalization processes.

This article considers energy as a nodal point of the relations between sustainability and globalization processes. We focus on global environmental constraints related to the energy sector and, more specifically, on the twofold sustainability challenge caused by oil depletion and climate change. The socioeconomic effects of these limitations are analyzed both at the global and European levels, in relation to the energy security concerns of a major oil-importing region and the transition from a carbon-intensive to a low-carbon economy. Beyond the agreed-upon role of green measures to foster competitiveness of the European economy in the short term,[1] we analyze the long-term challenges posed to Europe by oil dependency and climate change in the context of socioeconomic and political globalization (Brown, 2008).[2]

The interplay between economic trajectories, globalization processes, and environmental issues has been investigated in the literature following Copeland and Taylor (1994, 1995), who consider global environmental constraints ("transboundary pollution" in their words) and focus on the role of trade costs on pollution. Their approach provides useful insights on the environmental consequences of economic growth and international trade (Copeland & Taylor, 2004) but suffers from important limitations to policy analysis of sustainability and trade. First, their two-sector formulation differentiates pollutive and nonpollutive goods but fails to capture the complexity of trade interactions between varieties of goods. Second, their static approach fails to capture the dynamic processes that are central for the analysis of sustainable trajectories. Finally, their approach pertains to a weak vision of sustainability, where the environment is considered as a form of a natural capital, partially substitutable with human-made capital.

In this article, we adopt the computable general equilibrium (CGE) model IMACLIM-R, which provides a multisectoral, dynamic modeling approach for thinking the link between growth, globalization, and energy constraints given the limited availability of fossil resources and carbon mitigation policies. This framework captures four crucial determinants of the interplay between the energy sector, sustainability objectives, and globalization processes: (a) nonmarginal deviations with respect to current socioeconomic trends produce room for deep technical change over the course of the century[3]; (b) beyond technological improvements, the integration of lifestyles, consumption patterns, and preferences in driving the material content of economic activity is captured (Mitchell, 2012); (c) limitations in the flexibility of technicoeconomic adjustments during transition processes affect the adaptability of the economy to sustainability constraints because of market imperfections, technical inertias, and imperfect expectations; and (d) the competitiveness of opened economies on international markets impacts the balance of goods and capital.

The following section sketches the core mechanisms of the interplay between the energy sector, the sustainability of socioeconomic patterns, and globalization processes. The next section presents the modeling approach by detailing both the macroeconomic structure and the representation of energy dimensions under investigation, namely, oil sector and climate policies. Then, the long-term profiles of oil markets and their macroeconomic effects in the absence of carbon constraint for different visions of globalization processes are presented. The subsequent section extends the results to the case where a climate policy is implemented. The last section provides policy insights and concluding remarks.

## The Energy Sector, Sustainable Patterns of Development, and Globalization Processes

### *Oil Resource Scarcity and Climate Policies, Two Closely Interrelated Sustainability Challenges*

On one hand, heavy reliance on international markets to satisfy oil-dependent development patterns and constraints on supply imposed by investment decisions and reserve availability are expected to create tensions on the oil market. This context raises main political concerns as illustrated by the debates on Peak Oil (see Al-Husseini, 2006, for a review) and energy security in oil-importing countries. It has been revived by the strong volatility of oil markets and the spectacular spikes of prices in recent years (up to $140 per barrel in 2008). These issues are even more crucial when adopting the long-term perspective considered in this study because of supply-side constraints (depletion of conventional oil reserves, uncertainties on the deployment of nonconventional resources, and concentration of production in politically sensitive regions) and the specificities of oil demand (low price elasticity, captive uses in transport, and access to oil-based mobility in emerging economies).

On the other hand, despite the implementation of policies designed to slow down the rate of carbon emissions in some regions (e.g., EU Emissions Trading Scheme [EU-ETS] for the industry sector in Europe), $CO_2$ emissions have continued to grow in the past decade even more rapidly than predicted (Peters et al., 2012; Raupach et al., 2007). This context is the result of both the difficulty to decouple growth and carbon emissions in developed regions, where development styles cannot be changed overnight, and the rapid carbon-intensive growth patterns of emerging countries. This situation raises strong doubts on the sustainability of business-as-usual development patterns in terms of long-term climate effects (N. Stern, 2006). It also highlights the necessity to implement ambitious measures to trigger a strong bifurcation away from carbon-intensive development paths (International Panel on Climate Change [IPCC], 2007).[4] Despite this scientific consensus, the implementation of ambitious global carbon emission reduction targets remains highly uncertain as shown by the difficulties to reach a global climate agreement under the United Framework Convention on Climate Change (UNFCCC), and in particular since the failure of the Copenhagen Conference in 2009. This is essentially due to the concerns about (a) significant welfare and economic losses consecutive to carbon restrictions and (b) the interplay of climate measures with other sensitive political issues such as the financial crisis, poverty alleviation, job creation, energy and food security, or health and local environmental protection (e.g., see the dilemma of the climate development Gordian knot discussed in Hourcade, Shukla, & Mathy, 2008). Thus, one key challenge of the post-2012 climate policies is to examine the facets of the call for a *paradigm shift* of climate negotiations included in the Cancun agreement,[5] which is the precondition to overcome this dilemma (Skea, Hourcade, & Lechtenböhmer, 2013).

Far from being independent, the two previously defined sustainability challenges posed by the energy sector—oil depletion and climate change—are closely intertwined dimensions. Indeed, they both focus on the decline of fossil energy as the major source of anthropogenic greenhouse gas emissions. They are also a key determinant of international trade flows and a crucial component of the energy mix. In particular, the moderation of fossil fuel consumption caused by an ambitious climate policy has the potential cobenefit of lowering dependency on importations in energy-importing countries. This cobenefit of climate policies has remained a major political obstacle for the adoption of ambitious post-2012 climate targets in oil-importing countries, even during periods of low oil prices.[6]

The crucial methodological challenge is then to investigate the synergies and trade-offs between the tensions and future shocks on oil markets and the socio-economic effects of ambitious climate policies. The climate policy indirectly delays the exploitation of oil and slows down its depletion rate while giving an early signal of the long-term scarcity of this exhaustible resource. In addition, it affects the geopolitics of oil markets by calling for a strategic response of major oil producers to this threat on their exportation revenues. This interplay plays a crucial role in climate negotiations as demonstrated by the Organization of the Petroleum Exporting Countries (OPEC) countries' claim for monetary compensations in exchange for their compliance to climate agreements in Article 4.8 of the UNFCCC and Article 3.14 of the Kyoto Protocol (see Waisman, Rozenberg, & Hourcade, 2012, for an analysis of the specific issues raised by such compensation mechanisms). Conversely, constraints on oil availability make long-term objectives of a climate policy easier by limiting the amount of oil-related carbon emissions. However, a side effect may be higher transition cost toward a low-carbon economy. It may force a larger decrease of oil with respect to coal and gas even though this source of energy is the most difficult to abstract from in the short and medium term because of its captive uses (in particular in the transport sector).

## Globalization Processes and the Energy Sector

Globalization is a decisive driver of the future of energy markets in the transition toward low-oil and low-carbon development patterns. Indeed, at a global level, (a) oil markets are internationally integrated so that oil prices and quantities depend on the interaction between supply and demand at the world level (e.g., this is different for gas markets, which remain divided into independent regional markets because of distribution constraints), (b) climate impacts result from global emissions so that low-carbon trajectories must be set at the world level, and (c) their implementation involves rethinking trade interactions among regions that would be affected in a different way by a carbon constraint. These changes in trade flows therefore raise issues of the compatibility between climate policies with the rules of World Trade Organization [WTO] (James, 2009; World Trade Organization [WTO] & United Nations Environmental Programme [UNEP], 2009). We therefore analyze the interplay between these energy concerns and the transition toward sustainable futures under different visions of the globalization process. These are captured by alternative assumptions on trade and capital flows, between the pursuit of current globalization trends characterized by market integration and a reversal of international flows toward a correction of capital imbalances at a regional level.

The link between international trade, capital mobility, and environmental quality has been conventionally examined with theoretical approaches focusing on two major effects: the environmental Kuznets curve, which extrapolates the inverted U-shaped Kuznets curve to environmental issues, and the pollution haven hypothesis (see Cole, 2004, for an analysis of the link between these approaches). The environmental Kuznets curve states that fast growth favored by freer trade worsens environment problems in the first stages of the development process, whereas at high wealth levels it has a positive effect as the demand for environmental quality increases and the affordability of costly investments in environmental protection improves. However, there is little evidence that the relationship holds true for natural resource use or for greenhouse gas emissions (see Dinda, 2004, for a survey and D. Stern, 2004, for a historical review of this approach). On the other hand, the pollution haven hypothesis analyzes the effect of asymmetric environmental policies on trade flows (Taylor, 2004). It points out the risk that trade liberalization shifts environmentally intensive industries to countries with relatively weak environmental policy. This is the so-called race to the bottom effect as countries weaken their environmental policy in response to freer trade to shelter their industry from international competition. These approaches nonetheless neglect the distribution of natural and technical endowments among regions (natural resource, capital, technology, infrastructure, or distance to major markets) as driving the direction of trade and its intensity.

We adopt in this article a complementary approach of globalization patterns by endogenizing technical and consumption choices and making explicit their interplay with development pathways and their environmental consequences. This is done through a CGE approach applied to the world economy that represents endogenous technical change as an outcome of investment decisions under imperfect foresights and cumulative processes such as learning by doing. This explicit representation allows describing the interaction between the determinants of oil markets (oil supply and demand), carbon emissions from energy uses, and their macroeconomic impact given the global dynamics of the world economy, including trade flows and capital markets.

## An Energy-Economy Model to Investigate Sustainability Transitions in a Globalized Economy

Long-term transition toward sustainable future analysis raises the question of the representation of important departures from current trends in consumption patterns, technological choices, and lifestyles, triggered by long-term complex interactions between multiple factors. This concern has given rise to a specific corpus of scientific studies developing different focus on multilevel development of technologies and management of the transition (see, e.g., Geels, 2002; Kemp, Loorbach, & Rotmans, 2007; Rotmans & Loorbach, 2009). Different sector-based applications are proposed in this special issue: Brunelle, Dumas, and Souty (2014) for agriculture; Köhler, Walz, and Marscheider-Weidemann (2014) for eco-innovation in the case of biofuels; and Köhler (2014) for international transport.

The specific role of the energy sector in long-term transitions has been addressed by a large set of modeling experiments that have been developed after the first oil shock and the emergence of climate change in the political agenda. Econometric approaches based on the extrapolation of past trends are widely used for the analysis of the interactions between energy and the economy (see, e.g., Hamilton, 2008, for the relationship between oil and the macroeconomy). However, these econometric approaches are unable to consider large-scale structural and technical changes such as the ones to be considered in long-term socioeconomic interactions. Alternatively, integrated assessment models (IAMs; Weyant et al., 1996) have the twofold advantage of (a) providing an endogenous representation of technical change in relation to its structural, behavioral, and technological dimensions and (b) capturing path dependencies through an explicit accounting of cumulative effects of past investment choices on current economic settings. Those models are in particular widely used in energy and climate change communities for their ability to represent large departures from past and current socioeconomic trends as a result of carbon mitigation policies.

### *The Modeling Framework* IMACLIM-R

In this article, we adopt the IAM energy-economy model IMACLIM-R, which adopts a dynamic, multiregion, and multisector representation of the world

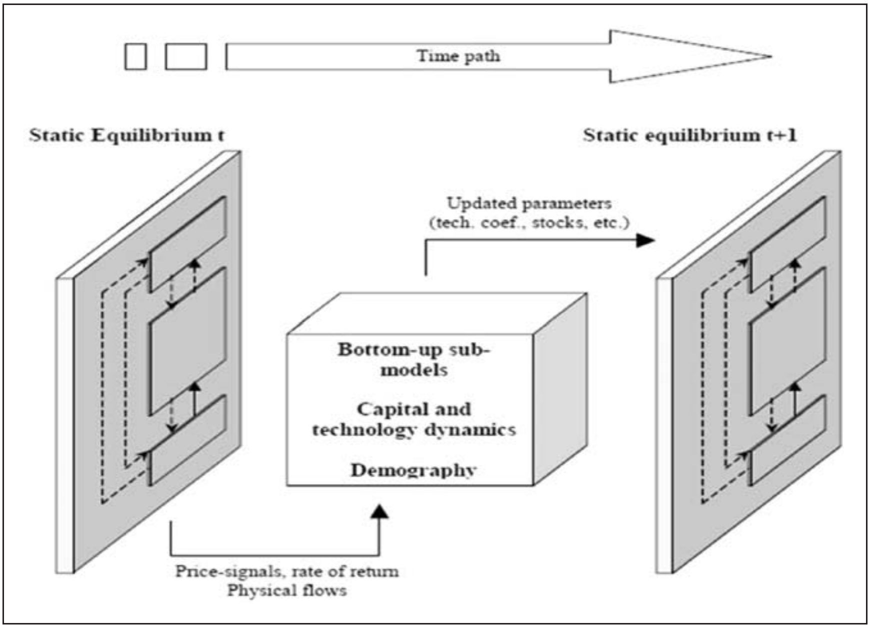

**Figure 1.** The recursive and modular structure of the IMACLIM-R model.

economy[7] on the backbone of a CGE framework (see Waisman, Guivarch, Grazi, & Hourcade, 2012, for an extensive description). It provides a consistent vision of economic and energy trajectories in yearly steps from 2010 to 2100 through the recursive succession of a top-down annual static equilibrium providing a snapshot of the economy at each yearly time step and through bottom-up dynamic modules informing on the evolution of technical parameters between two equilibria (Figure 1).

The static equilibrium represents short-run macroeconomic interactions at each date $t$ under technology and capacity constraints. It is calculated assuming Leontief production functions with fixed intermediate consumption, labor inputs, and mark-up in nonenergy sectors. Households maximize their utility through a trade-off between consumption goods, mobility services, and residential energy uses considering fixed end-use equipment. The equilibrium is given by market clearing conditions on all markets (including energy), which provides a snapshot of the economy at date $t$ in terms of relative prices, wages, employment, production levels, and trade flows.

The dynamic modules are reduced forms of bottom-up models, which describe the evolution of structural and technical parameters between $t$ and $t + 1$ in response to past and current economic signals. At each year, the regional capital accumulation is given by firms' investment, households' savings (controlled by exogenous saving rates like in Solow, 1956), and international capital flows. On that basis, the across-sector distribution of investments is governed by expectations on sector profitability and technical conditions as described in sector-specific reduced forms of technology-rich models (see details in the supplementary material of Waisman, Guivarch, 2012). These modules represent the evolution of technical coefficients resulting from agents' microeconomic decisions on technological choices, given the limits imposed by the innovation possibility frontier (Ahmad, 1966). The new investment choices and technical coefficients are then sent back to the static module in the form of updated production capacities and input–output coefficients to calculate the $t + 1$ equilibrium.

This modeling framework differs from conventional IAMs in several features that make it relevant to investigate important specificities of sustainability transitions. First, the consistency of the iteration between the static equilibrium and dynamic modules relies on hybrid matrices, which ensure an explicit representation of the material and technical content of production processes through a description of the economy in consistent money values and physical quantities (Sands, Miller, & Kim, 2005). Second, the equilibrium does not necessarily correspond to economic optimality because inertias on capital stocks limit the pace of technical change, the stickiness of the labor market affects labor adjustments, and market power leads to departures from marginal cost pricing. This means that production factors (production capacity and labor force) are not fully used, which ensures the possibility to represent idle capacities and unemployment. Third, contrary to the conventional assumption of intertemporally optimizing models, agents have imperfect knowledge about the future and may take investment decisions according to biased expectations. This allows representing bifurcations, lock-ins, and potential cobenefits in the course of sustainable trajectories. Fourth, the hybrid structure of the model allows making explicit the technical assumptions behind the trajectories, which can be informed by sector-based information and expert views about, for example, asymptotes on ultimate technical potentials, learning-by-doing mechanisms, saturation in efficiency progress, the impact of incentive systems, and the role of market or institutional imperfections. Given the uncertainty on the long-term dynamics of these dimensions, their explicit representation allows considering variants of scenarios suited to capture alternative views on these controversial parameters. Finally, contrary to the common approach of a unique composite good, the detailed multisectoral structure distinguishes productive sectors (agriculture, heavy industries, manufacturing, and services) according to their economic characteristics and their exposure to international trade. This allows a more precise description of the determinants of international trade.

The next sections detail the modeling options adopted for the three core dimensions of the present study, namely, oil markets (Modeling the

Long-Term Dynamics of Oil Markets), climate policy (Climate Constraints and Carbon Price), and international trade (Specifications for International Trade).

## *Modeling the Long-Term Dynamics of Oil Markets*

Market mechanisms in the oil sector are driven by the utilization rate of production capacities, given by the ratio of total demand to production capacities: the higher the utilization rate, the higher the scarcity rent and the profit margin for oil producers (Kaufmann, Dees, Karadeloglou, & Sanchez, 2004). We picture oil price formation through an explicit description of its geopolitical, technical, and economic determinants on both the supply and the demand. We represent (a) the heterogeneity of oil reserves as a function of their cost of exploitation and conventional versus nonconventional nature; (b) the limitations on the short-term adaptability of oil supply due to the geological nature of reserves; (c) the market power of Middle East producers until the depletion affects the deployment of their production capacities; (d) technical change affecting the demand for liquid fuels in industry, residential, transport, and power sectors; and (e) the potentials and obstacles to the diffusion of biofuels and coal-to-liquid fuels as oil substitutes. These features of the representation of oil supply/demand dynamics are more extensively described by Waisman, Rozenberg, Sassi, and Hourcade (2012).

In this article, we adopt median assumptions on the crucial determinants of oil price dynamics, namely, the amount of reserves (Table 1), geological inertias (assumed to be the same for conventional and nonconventional reserves), and the short-term price targeted by Middle East producers (assumed to be stabilized around its 2010 level).

**Table 1.** Assumptions About Oil Resources (Trillion Barrels).

| | Recoverable resources beyond 2001[a] | | | | |
|---|---|---|---|---|---|
| | Conventional oil | | Nonconventional oil (heavy oil and tar sands) | | |
| Resources extracted before 2001 | Middle East | Rest of the world | Canada | Latin America | Rest of the world |
| 0.895 | 0.78 | 1.17 | 0.220 | 0.38 | 0.4 |

[a] Recoverable resources are 2P reserves (Proven + Probable) remaining in the soil, which has been identified as the relevant indicator to investigate global oil peak (Bentley, Mannan, & Wheeler, 2007).

## Climate Constraints and Carbon Price

Carbon emissions arising from the production and use of fossil energies—coal, oil, and gas—are counted via coefficients capturing their respective carbon content.[8] When climate policies are applied, a constraint on the profile of carbon emissions is imposed as a function of the chosen climate stabilization target. For the comparability of results, this article considers a unique climate objective. It consists of limiting the temperature increase with respect to preindustrial levels to +2.5 °C, which is commonly believed to be more realistic than the +2 °C normative objective.[9] Following Barker et al. (2007, Table TS2), this objective is translated into a carbon emission profile characterized by a peak of world $CO_2$ emissions between 2010 and 2030 and a stabilization in 2050 with respect to 2000 levels (Figure 2). Note that this approach of climate constraint in the form of an imposed carbon emission trajectory that must not be exceeded whatever the costs corresponds to the critical sustainability concept. This approach acknowledges that different forms of natural capital are not merely an economic input but often a general prerequisite of human life and economic activity (Lerch & Nutzinger, 2002).

This constraint on carbon emissions is satisfied thanks to the introduction of a market-based instrument in the form of a carbon price, which is considered by economists as the most efficient way to tackle the diversity of emissions of greenhouses gases and abatement sources in the economy (Aldy & Stavins, 2012). The carbon price increases the cost of final goods and intermediate consumption as a function of the carbon content of the energy used, and favors the adoption of carbon mitigation options in carbon-intensive sectors (industry, residential, power generation, and transport). Since 2010, at specified dates the

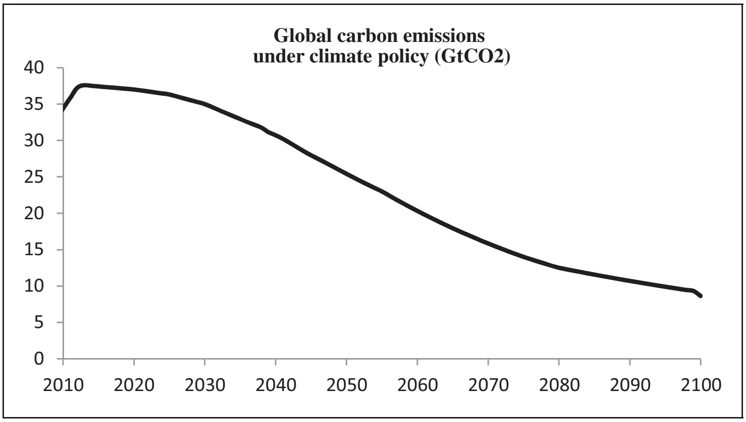

**Figure 2.** Carbon emission profile under climate policy.

carbon price value is endogenously calculated to curve carbon emissions according to the prescribed objective, and associated revenues are collected by the government, which then reallocates them to households or firms through transfers.

A climate policy applied uniformly to all regions and sectors and relying on a world-level carbon price instrument is obviously a simplification of what can be reasonably expected in the future and is chosen for the sake of simplicity. It poses in particular a number of questions that are far beyond the scope of this article but are worth noting here: (a) monetary transfers to gain compliance of emerging countries;[10] (b) tax exemptions to protect certain specific activities (on the pattern of the EU-ETS for industrial activities); and (c) the role of accompanying measures to climate policies such as fiscal reforms (Combet, Ghersi, Hourcade, & Théry, 2010), specific labor market policies (Guivarch, Crassous, Sassi, & Hallegatte, 2011), or complementary infrastructure policies (Waisman, Guivarch, & Lecocq, 2013).

## *Specifications for International Trade*

All intermediate and final goods are internationally tradable, and the total demand for each good is satisfied by a mix of domestic production and imports. Domestic and international markets for all goods are cleared (i.e., no stock is allowed) by a unique set of endogenous relative prices (the terms of trade), which adjust to maintain the equilibrium of the balance of payments defined by the sum of trade flows and capital flows.

Trade flows are represented in physical quantities for energy flows (MToe), whereas all other goods are described with Armington (1969) specifications to capture imperfect substitutability among goods produced in different regions. We consider two parametric options to capture alternative visions of trade globalization:

- A high value of Armington elasticities representing high substitutability between goods produced in different places. This assumption favors a pursuit of current trends of international trade with intense competition and important export/import flows in all world regions (assumption M+).
- A low value of Armington elasticities representing low substitutability between goods produced in different places and a preference for local goods. This assumption comes down to envisage a slowing down of international trade and a re-regionalization of production close to demand markets (assumption M−).

The endogenization of capital flows has hardly been integrated in global-scale energy-economy models[11] because of a lack of shared empirical evidence[12] and unresolved controversies in the economic literature.[13] Following this diagnosis,

**Table 2.** Scenario Definition.

| | | Assumption on capital markets | |
|---|---|---|---|
| | | K+ | K− |
| Assumption on goods markets | M+ | Continued Globalization | Fragmented Capital |
| | M− | Regionalized Trade | De-globalization |

we adopt exogenous assumptions on the dynamics of capital flows, defined by the net balance between capital exports and imports, including the return to foreign direct investments. Base year imbalances on capital flows are explicitly represented through the calibration of capital imports/exports at the initial date. Their dynamics are ruled by two alternative assumptions:

- A constant-over-time share of exported capital to picture a pursuit of current international capital imbalances (assumption K+).
- An exponential decrease of all capital flows to represent a progressive correction of international capital imbalances by 2050. This assumption corresponds to a vision of fragmented capital markets imposing financing of local investments with local capital (assumption K−).

By combining the assumptions on trade and capital flows, we define four scenarios representing four visions of the future of globalization processes (Table 2). The scenario "Continued Globalization" can be viewed as a benchmark case in the sense that it assumes a pursuit of current trends in both goods trade and capital flows. Other scenarios consider changes in the globalization process, either through a fragmentation of capital markets ("Fragmented Capital") or a regionalization of trade flows ("Regionalized Trade"). Finally, the scenario "De-globalization" combines both breaks in the globalization process.

## Long-Term Oil Profiles and Macroeconomic Trajectories

In this section, we start by considering the case where climate policy is not implemented so that no constraint on carbon emissions is imposed. We investigate the dynamics of oil markets and their macroeconomic effects on the transition toward low-oil development patterns as imposed by constraints on oil availability.

### *Dynamics of Oil Markets*

In all scenarios, the world oil production follows an inverted U-shape reaching a maximum around 2030 (the so-called Peak Oil) before a continuous decrease over the long term. Oil prices follow a slightly increasing plateau around $100 per barrel before a sudden increase at the moment of Peak Oil and a stabilization above $300 per barrel controlled by the diffusion of alternative fuels. These outcomes are illustrated for the "Continued Globalization" scenario in Figure 3.

To analyze the effect of globalization assumptions, we compare production and price trajectories in the three other scenarios with the preceding trends (Figure 4).

The trends for the "Regionalized Trade" scenario (black dotted line) prove that less intense international trade favors a moderation of oil demand and around 10% lower oil prices in the long term. Indeed, the increased preference for local goods favors a reduction of international trade and hence triggers a lower dependence on fuels for transportation activities. This is confirmed by the significantly lower energy intensity of the gross domestic product (GDP) in the long term (Figure 5). On the contrary, the trends for the "Fragmented Capital" scenario (gray dotted line) show that the decrease of capital transfers causes a

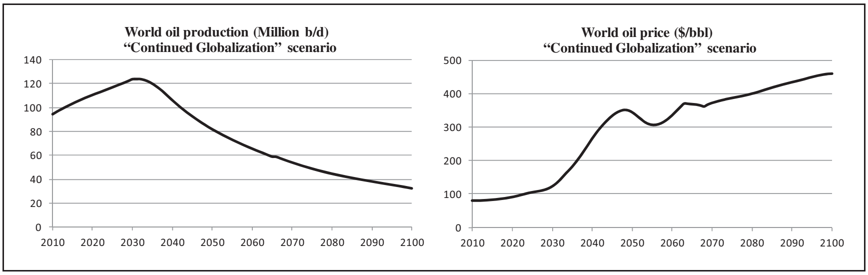

**Figure 3.** World oil production and oil price in the "Continued Globalization" scenario.

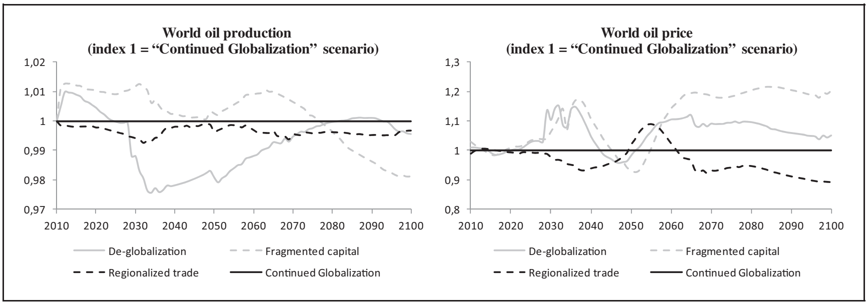

**Figure 4.** World oil production and oil price in the four globalization scenarios.

higher energy intensity of GDP. Indeed, less capital fluidity slows down the pace of technical change and triggers a higher dependence on oil, which results in (a) a significantly higher oil demand in the first 20 years, (b) a strong increase in oil prices after Peak Oil, and (c) 20% higher long-term oil prices. The “De-Globalization” scenario combining both fragmentations represents a mix of both effects described previously.

## Long-Term Impacts of Oil Markets on Economic Activity

We now investigate the consequences of the sustainability challenge posed by oil availability on the stability of socioeconomic trajectories, as measured by trends of GDP. The time profile of global growth rates (first row in Table 3) defines four periods between 2010 and 2100: (a) a fast economic growth during the short-term period (2010–2030) driven by moderate energy prices, (b) a deep economic crisis consecutive to Peak Oil (2030–2040) during which a surge in oil price halves growth rates, (c) a recovery phase (2040–2050) fostering a post-crisis catch-up with a temporary acceleration of economic growth once the economy has adapted to high oil prices, and (d) a long-term regime (2050–2100) in which the economy follows a smooth path in absence of new shocks. Europe follows qualitatively the same trends but with lower absolute values of growth rates as a developed region[14] (third row of Table 3).

To have a better understanding of the socioeconomic consequences behind these aggregated figures, we compare the effective growth rate of the economy with its natural growth rate, given by population and labor production growth.

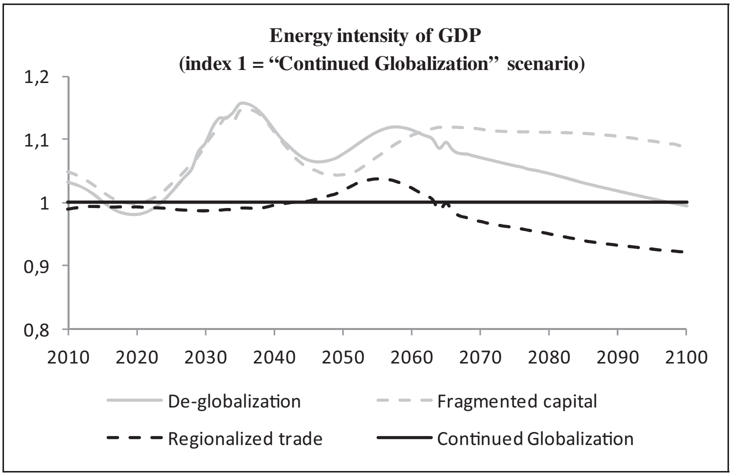

**Figure 5.** Energy intensity of GDP in the four globalization scenarios.

**Table 3.** Growth Rates in the "Continued Globalization" Scenario.

| | | 2010–2100 | 2010–2030 | 2030–2040 | 2040–2050 | 2050–2100 |
|---|---|---|---|---|---|---|
| World | Effective growth rate (%) | 2.41 | 3.87 | 1.94 | 2.88 | 1.83 |
| | Natural growth rate (%) | 2.43 | 3.35 | 3.11 | 2.57 | 1.90 |
| Europe | Effective growth rate (%) | 1.66 | 2.46 | 1.34 | 1.61 | 1.42 |
| | Natural growth rate (%) | 1.63 | 2.05 | 1.89 | 1.65 | 1.41 |

We use this indicator to assess the sustainability of growth patterns. An effective growth remaining closer or lower than its natural rate indicates that constraints affect the economy and prevent exploitation of the productivity potentials, causing unemployment and losses of purchase power . Indeed, it captures the impossibility of absorbing the total labor force at constant wages due to particularly large adaptation difficulties in sectors or regions below the average growth. At the global level, it turns out that this situation happens on average over the whole period with particularly significant gaps in the post-Peak Oil period and in the very long term. It means that the world economy then experiences long periods of unsustainable trajectories characterized by socioeconomic tensions. This analysis remains true for Europe where growth rates remain below (or close to) their natural rate after 2030. In particular, the recovery phase is relatively moderate as captured by the growth rate failing to exceed natural rates from 2040 to 2050. Indeed, the European economy is particularly vulnerable to oil price variations as a major importer.

To test the effect of globalization on these outcomes, we compare world and European GDP levels in the three other scenarios with the ones obtained in the benchmark case (Figure 6).

The effect of fragmented capital markets (gray dotted lines) is of great importance during the transition with 10% lower global GDP around 2030 (13% lower in Europe). This is the result of the constraints this assumption imposes on capital availability for investments in technical change. They affect the resilience of the economy to rising oil prices, especially in oil-importing economies such as Europe. This effect is persistent at a long-term horizon (6% and 8% decrease in GDP in 2100 at the world and European levels, respectively) due to the cumulative effect on technical change. This is again the logical consequence of the higher energy intensity of economic activity in a context of higher energy prices (see previous section), which affects households' purchase power and firms' production costs.

The assumption on the regionalization of good markets has crucial effects in driving the reaction of the European economy to Peak Oil (black dotted lines). Indeed, in this context of high energy prices, the value of European energy importations significantly increases, resulting in a parallel increase of industrial exportations necessary to restore the equilibrium of the balance of payments.

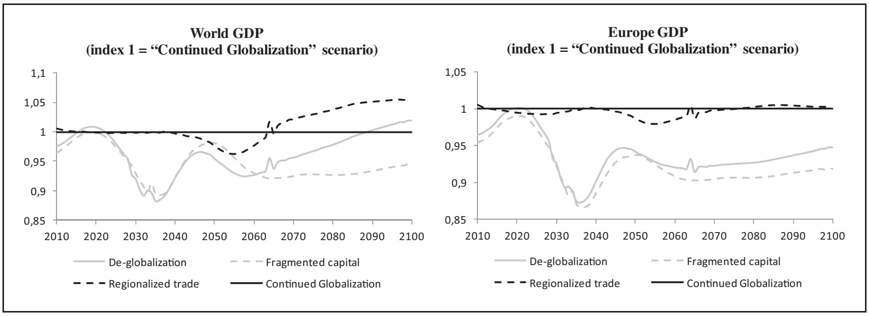

**Figure 6.** World and Europe GDP levels in the four globalization scenarios.

In the "Regionalized Trade" scenario, which assumes preference for local goods, this can only occur through significant gains of competitiveness as measured by a decrease of the terms of trade (ratio of local to international goods). This means large real wage adjustments causing economic losses as captured by lower GDP levels after 2030. At a longer term horizon, the overall effect of goods fragmentation is, in contrast, positive (5% higher global GDP in 2100). The economy relies less on international trade, as local production mostly meets the demand. This indeed entails lower oil demand and prices, which drives down energy dependency and production costs, and enhances households' purchase power. This long-term positive effect is less significant at the European level. It is offset by obstacles, in a mature industrial system, to the development of local production capacities able to deal with local demand.

These outcomes demonstrate that the globalization processes are far from being neutral for both transition and long-term growth trajectories. However, changes in globalization patterns do not modify the orders of magnitude (e.g., the maximum gap in GDP levels,10%,corresponds to only 0.1% lower average growth rate over the century). This proves that acting on globalization processes is insufficient to avoid important socioeconomic costs due to the sustainability challenge raised by oil availability.

## The Transition Toward a Low-Carbon Society

We now investigate the impact of implementing a climate policy in the form discussed in the Climate Constraints and Carbon Price section, which aims to stabilize temperature increase at +2.5 °C with respect to preindustrial levels.

### Carbon Pricing and Natural Resource Exploitation

We start by analyzing the consequences of the introduction of a constraint on carbon emissions in the "Continued Globalization" scenario. The constraint on

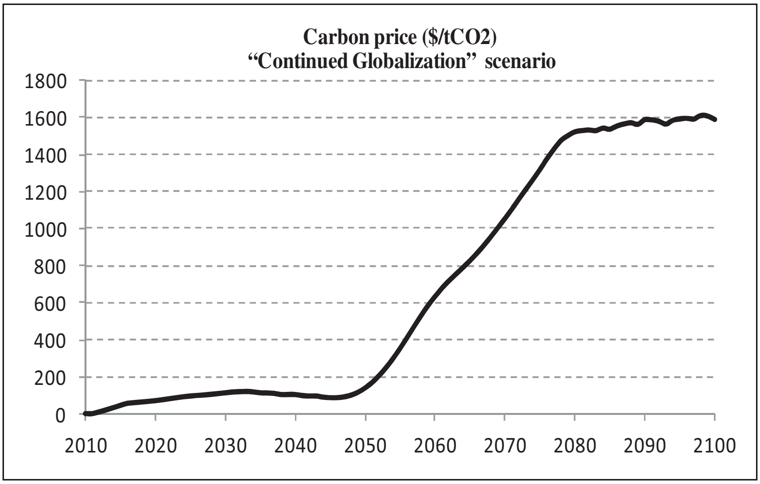

**Figure 7.** Carbon price in the "Continued Globalization" scenario.

carbon emissions is met through the introduction of a carbon price (Figure 7), for which four distinct phases can be distinguished, consistent with the climate policy analysis by Waisman, Guivarch, et al. (2012).

During the first years (2010–2030), the carbon price progressively increases to reach \$120 per $tCO_2$ around 2030, with hardly no effect on oil prices, which remain controlled by Middle East producers. This carbon price level is necessary to tap most mitigation potentials in power, residential, and industrial sectors, which represent the core of emissions reductions at that time point (IPCC, 2007). Between 2030 and 2050, the carbon price stagnates and even slightly declines without hampering emission reductions. Indeed, two mechanisms combine to sustain the decarbonization process: (a) the cost decrease of carbon-free options implied by the cumulative effect of learning by doing and (b) the sudden rise of oil prices following Peak Oil although moderated as the climate policy stimulates fossil-free technical change. Between 2050 and 2070, to reach the high-cost mitigation potentials in the transportation sector, maintaining efforts to reduce emissions is necessary based on a steep increase in carbon prices up to \$1,400 per $tCO_2$. Indeed, the weak sensitivity of transport activities to energy prices and the low oil prices at this time point (around \$70 per barrel) caused by the accumulation of low-oil technical and structural changes fostered by the climate policy require strong carbon prices. After 2070, carbon prices, albeit high, reach a constant value around \$1,500 per $tCO_2$. This level is sufficient to maintain total emissions below 10 Gt $CO_2$ as imposed by the long-term emission constraint in Figure 2.

The production patterns of oil, coal, and gas show that the implementation of a climate policy significantly moderates the exploitation of these fossil

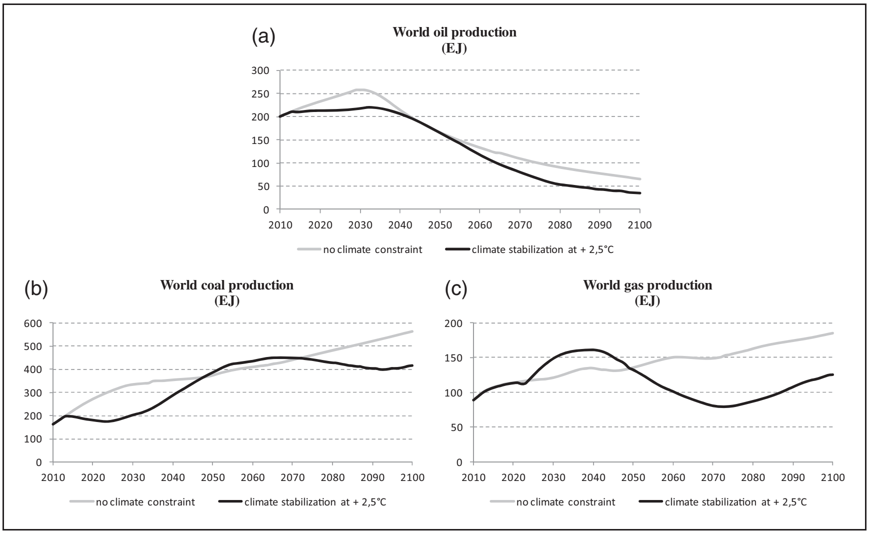

**Figure 8.** (a) Oil production, (b) coal production, and (c) gas production.

nonrenewable energies (Figure 8). Until 2030, the carbon price fosters meaningful lower oil and coal production under climate policy with, in particular, a plateau instead of a peak oil production profile. Gas demand increases as a substitute for oil and coal, given the competitiveness advantages of this low-carbon energy. The situation is opposite between 2030 and 2050, when the stagnation of carbon prices favors the return of coal. Finally, after 2050, carbon prices are so high that the use of the three carbon-intensive energies progressively declines.

As a result of these trends, the share of 2001 reserves that would remain after the 2001–2100 period highlights the effect of a climate policy on the sustainability of fossil resource exploitation (Table 4). The most prominent effect impacts oil, for which the climate policy avoids the critical depletion experienced in the baseline scenario (18% of 2001 oil reserves remain in the soil in 2100 vs. only 6% in absence of climate policy). For coal and gas, which are much more abundant than oil, the climate policy also contributes to a significant slowdown of the exhaustion process. Note that these conclusions are robust to different assumptions on globalization trends.

## *Macroeconomic Effects of Climate Policies on Europe*

Climate policies decrease the average growth rate from 1.66% to 1.51% in the "Continued Globalization" scenario. This demonstrates that maintaining the global temperature at an acceptable level comes at a moderate cost for Europe.

**Table 4.** Fossil Energy Uses in the "Continued Globalization" Scenarios.

| | | Remaining reserves in 2100 (EJ) [share of 2001 reserves] | |
|---|---|---|---|
| | Reserves in 2001 (EJ) | No climate constraint | Climate stabilization at +2.5 °C |
| Coal | 83,652 | 46,631 [56%] | 51,664 [62%] |
| Oil | 16,850 | 1,060 [6%] | 3,103 [18%] |
| Gas | 24,241 | 9,795 [40%] | 12,734 [52%] |

In addition, because we do not assess the benefits provided by avoiding damage caused by climate change, it seems reasonable to consider that the overall effect of the climate policy is not negative in terms of sustainability.

Beyond this aggregate picture, climate policies have different macroeconomic effects depending on the time marker considered (Table 5). At a short-term period (2010–2030), they significantly slow down economic growth (from 2.46% per year without climate policy to 2.08% per year). This is the result of the introduction of the carbon price, which impacts the carbon-intensive European economy. However, growth rates remain above their natural level. At a medium-term time point (between 2030 and 2050), climate policies trigger a much faster economic growth. This is a cobenefit of low-carbon measures that fosters a decreased oil dependency and moderates the effects of Peak Oil. Interestingly, economic growth remains above its natural rate during the entire 2010–2050 period under climate policies (contrary to baseline cases examined previously where temporary crises are experienced after Peak Oil). This underlines the role of climate policies in preparing a sustainable future by building a hedge against the uncertainty concerning oil supply (Rozenberg et al., 2010). The picture changes when considering the long-term period, after 2050. Indeed, Table 5 indicates that a climate policy may cause important losses as captured by the low growth rates (1.3% per year and 1% per year). In particular, these values remain below the natural rate during the last 50 years, picturing a long-lasting socioeconomic crisis. This is in particular due to the necessity to control transport-related emissions, which requires a fast increase in carbon price given the weak effect of price signals on this sector.

## Macroeconomic Effects and Globalization

We finally turn to analyze the effect of globalization assumptions on these results by comparing economic growth trends in the four scenarios under climate policy. Although the assumptions on globalization prove to hardly affect the average trends (as demonstrated by the very close values of average growth

**Table 5.** European GDP Growth Rates Under Climate Policy in the "Continued Globalization" Scenario.

| | 2010–2100 | 2010–2030 | 2030–2050 | 2050–2070 | 2070–2100 |
|---|---|---|---|---|---|
| Growth rate climate stabilization at +2.5 °C (%) | 1.51 | 2.08 | 1.78 | 1.33 | 1.05 |
| Natural growth rate (%) | 1.63 | 2.05 | 1.69 | 1.53 | 1.34 |

**Table 6.** European GDP Growth Rates Under Climate Policy in the Four Globalization Scenarios.

| | 2010–2100 | 2010–2030 | 2030–2050 | 2050–2070 | 2070–2100 |
|---|---|---|---|---|---|
| De-globalization (%) | 1.48 | 2.01 | 1.80 | 1.19 | 1.11 |
| Fragmented Capital (%) | 1.47 | 2.02 | 1.79 | 1.16 | 1.10 |
| Regionalized Trade (%) | 1.51 | 2.05 | 1.72 | 1.40 | 1.09 |
| Continued Globalization (%) | 1.51 | 2.08 | 1.78 | 1.33 | 1.05 |

rates), the analysis of time profiles helps to identify the major effects of globalization under climate constraint (Table 6).

In the short to medium term, fragmented capital markets essentially undermine growth until 2030 (2.02% vs. 2.08% over 2010–2030). Indeed, this period requires a fast technical change to start the decarbonization of the economy. Restrictions on the availability of capital slow down this process and are particularly hindering at this time marker. In particular, they impose significantly higher carbon prices in 2030 (around \$150 per $tCO_2$ in the "Fragmented Capital" scenario vs. \$120 per $tCO_2$ in the "Continued Globalization"). At the same time point, the dominant effect of the assumption on trade regionalization occurs after 2030. As we have discussed in the absence of climate policy, growth differentials between "Regionalized Trade" and "Continued Globalization" scenarios happen when oil price are high after Peak Oil. Under climate policy, the moderation of oil demand consecutive to the introduction of carbon price delays this price increase by around 10 years. As a consequence, the period during which growth rates are lower in the "Regionalized Trade" scenario happens around 2040 with relatively lower average growth rates over 2030–2050 (1.72% vs. 1.78%).

In the long term, different visions of globalization do not radically change the conclusions of a long-lasting crisis with growth rates below their natural level. Indeed, the assumptions about globalization do not modify the basic cause of this outcome, that is, the necessity to control transport-related emissions.

It is, however, worth noting the mechanisms at play between 2050 and 2070, when the dominant effect is due to the fast increase in carbon prices to control transport-related emissions. Less intense international trade in the "Regionalized Trade" scenario then proves beneficial (1.40% vs. 1.33% in the "Continued Globalization" scenario). The lower reliance on international transport indeed reduces the overall dependency of the economy on transport. In contrast, fragmented capital markets have strong negative impacts at this time point (1.16% vs. 1.33% in the "Continued Globalization" scenario) because they limit the pace at which the economy can adjust to the deep changes imposed by fast-growing carbon prices.

## Discussion, Policy Insights, and Concluding Remarks

This article has identified several salient features of macroeconomic adjustments in Europe under the constraints imposed by the depletion of fossil fuel resources, carbon emissions reduction targets, and different visions of globalization. Building on the main results of the article, this section provides principles to frame the implementation of climate and energy policies at the European level consistent with the challenges raised in the Green Paper "A 2030 Framework for Climate and Energy Policies" (European Commission, 2013, p. 16).

### *Benefits and Risks of Global Price Signals*

The modeling exercise considers market prices as major determinants of changes, whether it be international energy or carbon price. These economy-wide instruments provide a signal affecting agents' behaviors in different components of economic activities. The economic theory also advocates them as the most efficient way of addressing environmental constraints. The analysis of the results demonstrates that these types of instruments can trigger deep changes required under energy and climate constraint. The results presented in the Long-Term Oil Profiles and Macroeconomic Trajectories section show that, even under imperfect expectations about oil scarcity, average GDP growth rates remain above their natural level. This means that oil price signals are sufficient to support a transition toward sustainable low-oil patterns. The results reported in The Transition Toward a Low-Carbon Society section also show that a global carbon price entails carbon emissions reduction with respect to an ambitious stabilization target at +2.5 °C while allowing sustained economic development throughout the century.

However, the analysis also reveals that market price instruments may induce risk of large economic downturns when the environmental constraint (depletion of fossil fuel resources and carbon constraint) forces drastic but unanticipated economic changes. Indeed, market prices may provide wrong incentives likely to induce allocations of investments that may be ill adapted to future energy-economy conditions. This is notably the case in the Long-Term Oil Profiles and Macroeconomic Trajectories section, where moderate oil prices during the first decades do not prepare the economy for oil disruptions that occur during the Peak Oil period. This causes low medium-term growth rates that remain well below their natural level, revealing large socioeconomic tensions. This is also the case during the first stages of the introduction of a carbon price in The Transition Toward a Low-Carbon Society section, which induces low growth rates to force the economy to adjust to this constraint. These results show that price signals that translate to market adjustments may not be suitable to provide correct information on future energy conditions. They may also result in the wrong allocation of investments, hampering growth and welfare.

Combining both sides of the analysis, we can conclude that a global price signal is a useful tool to frame the transition processes toward a sustainable energy future. However, market mechanisms may not be the best way to set such signals. This calls for introducing investment incentives that depart from pure market price signals and include long-term views on fossil fuel resources and climate through a politically agreed-upon value of the social cost of carbon.[16] The EU-ETS illustrates the limit of signals given by a carbon price. It brings a uniform carbon price for large industrial and power-generating plants, and the progressive decline of the cap offers a guarantee that global carbon emissions will decrease according to the predefined objective. However, the EU-ETS has failed so far to provide a correct price signal. Indeed, the excess of allowances has resulted in a low and volatile carbon price, which does not give investors sufficient incentives to develop low-carbon projects. This hence generates risks of carbon lock-in.

Given these drawbacks of market price signals at the global level, complementary instruments must be considered both at the local (national or regional) level through sectoral measures and at the global level through nonpricing policies.

## Complementary Local Policies

The rationale for local policies is to provide incentives to induce changes in crucial sectors for energy and climate issues, especially those faced with behavioral biases (e.g., imperfect foresights of future energy prices) and technical inertias. The EU has already implemented a large set of such sectoral measures.[17] The modeling exercise helps to identify two key challenges for their design regarding long-term sustainability objectives.

On one hand, sectoral measures should not be a no regret option only but should also anticipate energy futures and reduce the vulnerability of the economy to the short- and long-term changes of the global energy system. A key result of the Long-Term Oil Profiles and Macroeconomic Trajectories section highlights that short-term market prices give biased information of future energy-economy conditions and are therefore insufficient to accelerate a technical change toward low-oil dependency of the economy in due time. Given the inertias in the buildings and transport sectors, sectoral measures should not be postponed until the emergence of a clear price signal, but rather should anticipate the changes of economic conditions to foster the diffusion of energy efficiency in due time.

On the other hand, sectoral measures should not be limited to energy efficiency but also include infrastructure policies affecting the structure of socioeconomic interactions and its exposure to energy and climate constraints. This is particularly true for transport, which is a high-energy and carbon-intensive sector characterized by weak price sensitivity. Specific measures are therefore necessary to control mobility. In The Transition Toward a Low-Carbon Society section, a steep rise of carbon prices is required to curb transport-related emissions. It causes a drastic slowdown of economic growth under climate policy after 2050. The core of these costs can be avoided provided that the deployment of infrastructures favoring sustainable cities and low-transport production systems starts in the early phase of the policy (Waisman et al., 2013). Green logistics and sustainable supply chain management to move toward sustainable transport (international shipping and long-haul aviation) also provide potential answers to this issue (Köhler et al., 2014). In general, these results echo the current debates on the lack of ambitious programs of infrastructures at the European level.

To go further into the assessment of these policies, the model could be improved to represent infrastructure networks and behaviors associated with the building and transport sectors. The objective would be to capture explicitly the role of crucial sectoral measures for energy and climate issues. This means in particular incorporating an explicit representation of mechanisms related to urban dynamics and production structure, including the logistics organization.

## Complementary Global Policies

We considered in this article nonpricing global measures that can be put in place to tackle the issues raised by globalization as a crucial dimension of sustainable pathways. Sensitivity tests on the four scenarios of globalization in the Long-Term Oil Profiles and Macroeconomic Trajectories and The Transition Toward a Low-Carbon Society sections help to identify basic mechanisms that link globalization and macroeconomic trajectories under energy and climate constraints.

Moving toward more regionalized trade where local firms are less exposed to international competition has two major effects. On one hand, in a context of high energy imports consecutive to fossil fuel price increases caused by scarcity effects, obstacles to trade may undermine the balance of payments. Less efficient competitiveness gains would not induce exportation increases able to compensate energy-related flows. On the other hand, the reduction of trade volumes goes with a decoupling between consumption patterns and transport, which has the advantage of reducing transport-related energy and carbon uses. Regarding capital flows, fragmented markets limit the access to capital and delay technical change. This affects the resilience of the economy to rising oil prices, especially in oil-importing economies such as Europe. This effect is persistent in the long term because of the cumulative effects on technical change.

To go further into this analysis of globalization patterns under energy constraints, the model could be improved by representing explicitly all determinants of capital allocation to analyze the conditions of an allocation of investments in accordance with energy-sustainability objectives. Hourcade and Shukla (2013), building on Hourcade, Perrissin, and Rozenberg (2012), show the crucial role of organizing a low-carbon finance able to generate a sufficient amount of capital and to direct capital funds toward the funding of low-carbon infrastructures. The redirection of investment still needs specific devices. For example, a social cost of carbon as part of a climate-friendly architecture may enhance investors' confidence in low-carbon projects and reduce the attractiveness of speculative investments.

### *Toward a Policy Mix to Tackle Long-Term Energy Sustainability Issues*

The above analysis identifies challenges that require a policy mix that resorts to a plurality of complementary instruments. For this purpose, two main characteristics should be taken into account.

First, the mix of policy instruments to tackle the twofold challenges posed by resource scarcity and climate change must be designed to benefit from potential synergies between both objectives. In particular, the analysis of the medium-term effect of a climate policy in The Transition Toward a Low-Carbon Society section has showed the potentials for cobenefits of carbon control measures. They can act as a hedging strategy against the scarcity of oil reserves. Thus, policy instruments based on the synergies between different objectives to combine the benefits of each of the instruments must be favored. This is in line with the statement of the G&P that "the 2030 framework must identify how best to maximize synergies and deal with trade-offs between the objectives of competitiveness, security of energy supply and sustainability" (European Commission, 2013).

Second, the articulation and the time sequencing of policy instruments must be a key concern when designing the policy mix to ensure a sustained action throughout the century. For example, any pricing scheme must be conceived according to its compatibility with the EU-ETS, which already proposes some forms of pricing for energy-intensive industrial sectors. In addition, price instruments have an immediate effect, whereas policies targeting long-lived infrastructure involve a gap between their implementation and their ultimate effects. This is why, in particular, early investments on transport infrastructure to support climate action are required to ensure that they generate benefits in the middle of the century when they become crucial to controlling transport-related emissions.

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## Notes

1. The European Union (EU) has published a series of official documents putting forward the articulation between climate change policies, energy policies, and competitiveness. In addition to the 20-20-20 policy objectives adopted in 2008 (20% emissions reductions, 20% renewables in the total energy consumption of Europe, 20% energy savings by 2020), the "Europe 2020" strategy adopted in 2010 (European Commission, 2010) sets five ambitious objectives—employment, innovation, education, social inclusion, and climate/energy—to be reached by 2020. "The Roadmap for Moving to a Competitive Low Carbon Economy in 2050" (European Commission, 2011) adopted by the Commission proposes to extend these objectives to 2050, while the recent G&P (European Commission, 2013) "A 2030 Framework for Climate and Energy Policies" proposes objectives to 2030.
2. Indeed, given that imports supply 40% of European primary energy, corresponding to 2.8% of the EU GDP, energy security is a policy priority for the EU and its member states as put forward in recent official texts (see, e.g., the 2013 G&P).
3. Technical change is a change in the amount of output produced from the same inputs. Such a change is not necessarily technological but might include organizational transformations or be the result of a change in a constraint such as regulation, prices, or quantities of inputs.
4. At stabilization levels around 400 ppm $CO_2$eq or below, global mean temperatures are likely to stay below 2 °C, and there is a 50% probability of exceeding a 2 °C temperature increase at levels of around 450 ppm $CO_2$eq. (IPCC AR4 WGI 2.12).
5. "The Conference of the Parties . . . realizes that addressing climate change requires a paradigm shift towards building a low-carbon society that offers substantial opportunities and ensures continued high growth and sustainable development, based on innovative technologies and more sustainable production and consumption and lifestyles, while ensuring a just transition of the workforce that creates decent work and quality jobs." Advance unedited version, Draft decision -/CP.16—Outcome of the work of the Ad Hoc Working Group on Long-Term Cooperative Action under the Convention, Article 10 http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf
6. This is illustrated by the Gleneagles Communiqué following the G8 summit in 2005, which explicitly links energy security and climate change: "(a) Climate change is a serious and long-term challenge ... We know that increased need and use of energy from fossil fuels contribute in large part to increases in greenhouse gases associated

with the warming of our Earth's surface; (b) Global energy demands are expected to grow by 25% over the next 25 years. This has the potential to cause a significant increase in greenhouse gas emissions associated with climate change ...; (c) Secure, reliable and affordable energy sources are fundamental to economic stability and development. Rising energy demand poses a challenge to energy security given increased reliance on global energy markets ... "

7. The version of the IMACLIM-R model used in this study divides the world in 12 regions (the United States, Canada, Europe, Organisation for Economic Co-operation and Development [OECD] Pacific, former Soviet Union, China, India, Brazil, Middle East, Africa, rest of Asia, and rest of Latin America) and 12 sectors (coal, oil, gas, liquid fuels, electricity, air transport, water transport, other transport, construction, agriculture, energy-intensive industry, and services and light industry).
8. Those coefficients count only the emissions actually released in the atmosphere, with the exception of those captured either biologically (biofuels) or technologically (carbon capture and sequestration).
9. The adoption of an ambitious global agreement on climate reduction emissions by 2015 and strong assumptions on technical change are indeed necessary to comply with the 2 °C objective, which leaves little flexibility in terms of action (Edenhofer et al., 2010; Guivarch & Hallegatte, 2013).
10. See, for example, Luderer et al. (2012) for an analysis of different cap-and-trade schemes and their consequences on climate policy costs.
11. A notable exception is McKibbin, Ross, Shackleton, and Wilcoxen (1999).
12. For example, in a historical study of capital flows over the long term (1865–1992), Hogendorn (1998) demonstrates that no simple rule emerges for capital flow dynamics, given the fluctuations of capital mobility over time in parallel with different phases of international monetary and financial governance: high capital mobility during the gold standard period (1880–1913), almost closed economies during the interwar and Bretton Woods periods (1914–1969), and increasing mobility in the modern period (1970–1992).
13. The issue of capital mobility has given rise to a large controversy since the econometric study by Feldstein and Horioka (1980), who demonstrated low capital mobility from 1960 to 1974, in contradiction with widely shared ideas. This "puzzle" was the starting point of a large body of literature trying to identify the major drivers of capital flows, but which has failed to reach consensual answers (see Apergis & Tsoumas, 2009, for a survey).
14. In the model, the natural growth is driven by labor productivity assumptions. We assume that the United States remains the world leader in productivity per worker with a steady growth of 1.7% per year, whereas the dynamics of productivity in other countries is driven by a partial catch-up. This means that regions with lower absolute productivity per worker in a country experience the faster labor productivity growth. Europe is close to the United States in terms of productivity and experiences low labor productivity growth (Waisman, Guivarch, et al., 2012).
15. See, for example, Quinet et al. (2008).
16. For example, in the directives on the EcoDesign of Households' Equipment (2009/125/EC), the Energy Labelling of Households' Equipment (2010/30/EU), the Renewable Energy Sources (RES; 2009/28/EC), the Energy Performance of

Buildings (2002/91/EC), and the Energy Efficiency (2012/27/EU), as well as through the Regulations on Performance Standards for Light Duty Vehicles in Transport (510/2011).

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