Energy Security Scenarios of Future Europe.

Assessing the impacts of societal processes

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Abstract

Energy security has become a policy priority for the European Union due to growing concerns about environmental challenges and the fact that the EU imports about half of its energy needs. In particular, the EU is dealing with climate policy and energy security jointly: both the Climate and Energy Package and the Energy Roadmap 2050 endorse the goals of reducing greenhouse gases emissions while at the same time ensuring security of energy supply. However, low-carbon transition and energy security are not always faces of the same coin. As a matter of fact, successful policies aiming at the former may undermine the conditions at the basis of the latter, and vice versa. Developed in the framework of the MILESECURE-2050 project, the proposed contribution focuses on this conundrum, exploring the impact of societal processes and various governance regimes and policy mixes aiming at energy transition towards a low carbon economy, in view to provide a better understanding of aspects and potential trade-offs for energy security in Europe. The IMACLIM-R model provides some innovative features to embark dimensions (such as urban form, environmental policies, human behaviours) that enables a broader pluridisciplinary dialog among a large socio-scientist community as required in the MILESECURE-2050 project. From the study of local experiences, the report introduces three scenarios that include different assumptions on the energy transition and the implementation of climate policies. Preliminary results are provided through the lens of energy security challenges. Finally, the policy implications of the presented scenarios are sketched out and discussed.

Keywords: energy security, integrated assessment models, climate policies, scenarios, societal processes, Milesecure 2050

1. Introduction

Energy security has recently become a policy priority for the European Union (EU) due to growing concerns about environmental challenges (in particular climate change) and the fact that the EU imports about half of its energy needs. Energy security and climate policy are thus frequently presented as two aspects of the same issue. The EU is particularly involved in such an approach: both the Climate and Energy Package (EU, 2008) and the Energy Roadmap 2050 (EU, 2011) endorse the goals of reducing greenhouse gas emissions while ensuring the security of energy supplies. Climate policies and Energy security undeniably share a common root cause: decreasing global demand for energy. However, they do not always go hand in hand. Policies aiming at improving energy security and those focusing on the reduction of greenhouse gases emissions do not necessarily share the same set of actions. As a matter of fact, while in many cases synergies between the two spheres may be exploited, policy-makers are very often asked to decide about potentials trade-offs.

Energy security is a polysemic concept that is about limiting the risk of internal and external energy shocks.Gracceva and Zeniewski (2014) define an Energy secure system as one "*evolving over time with an adequate capacity to absorb adverse uncertain events, so that it is able to continue satisfying the energy service needs of its intended users with 'acceptable' changes in their amount and prices*". This does not necessarily imply a reduction of emission and an increase in the use of sustainable energy sources, issues that lay at the heart of the concept of energy transition towards a low carbon society. Furthermore, low energy and carbon transition implies to envisage significant bifurcation in lifestyles not only triggered by the penetration of a range of low carbon technologies but also by societal processes, an assumption that add further complexity to the picture.

Aware of the above discussion, this contribution aims at shedding some light on the mentioned complexity. It does so by envisaging the interactions between climate policies and energy security issues through the lens of a methodological approach developed within the framework of the MILESECURE-2050 FP7 project[1]. In particular, the contribution bring forward some of the interim results of the project, providing the reader with new scientific knowledge on the matter by developing new European scenarios using multiple perspectives which support and enable energy security. The three scenarios proposed were developed through the IMACLIM-R model, building on a set of narratives that takes into the societal processes analysed by MILESECURE-2050 researchers.

After this brief introduction, the second section of the paper presents the narratives developed on the analysis of societal processes conducted in the MILESECURE-2050 project, and introduces the three scenarios. Then, section 3 describes the IMACLIM-R model and its specificities more in details, and discusses the methodology through which the three scenarios were developed. Section 4 presents some

[1] The present paper is indeed based on the interim results of the FP7 Project MILESECURE-2050: Multidimensional Impact of the Low-carbon European Strategy on Energy Security, and Socio-Economic Dimension up to 2050 perspective (www.milesecure2050.eu). Overall aim of the project is to understand and overcome the political, economical and behavioral traits and trends that led Europe to its difficulties in reducing fossil fuel consumption, and in diversifying its energy balance at rates which guarantee European energy security in the next years (more specifically at the horizon 2050), reduce the threat of climate change, and diminish the risk of an energy gap in the coming decades. The MILESECURE-2050 consortium is led by Politecnico di Torino (Italy), and composed by ten project partners: Instytut Energetyki IEn (Poland) EnergSys (Poland); ENEA (Italy); Laboratorio di Scienze della Cittadinanza LSC (Italy); Maastricht University MUSTS(The Netherlands); The University of Salford USAL (United Kingdom); Paris-Lodron Universitat Salzburg – PLUS (Austria); EU Joint Research Centre JRC (EU); Ecologic Institute (Germany); Société de Mathématiques Appliqués et de Sciences Humaines – SMASH (France).

preliminary results of the scenario activity, focusing on future potential trade-offs between energy security and low carbon transition. A conclusive section rounds off the contribution discussing some of the implications of the presented results for policy-making as well as opening perspectives on future research.

2. From narratives to scenarios

2.1. Key features of a low carbon transition: the importance of the 'human factor'

One of the main steps of the MILESECURE-2050 project consisted in analyzing drivers and barriers of the energy transition based on a range of so called local 'anticipatory experiences'[2]. This range includes a large number of concrete experiences at the local level, collected throughout Europe and already experiencing a low carbon transition (or, at least, some of its features) and having specific characteristics compared to other sustainable energy initiatives (operationality, social impact, transparency, systematicity) (Caiati et al., 2013; 2014).

The analysis of these experiences reveals some salient features of societal processes in the energy and low carbon transition thatwere used to guide the building of the scenarios, mainly through technical adjustments of the IMACLIM-R model in order to catch the role played by the 'human factor' (see Section 3 and 4). More in detail, societal processes are at the basis of multi-dimensional changes regarding development pathways: this affects various dimensions, as individual or collective behaviors, types of energy use and production, governance modes. At a local level, anticipatory experiences pave the way, to varying extents, for more global social and technological changes in the coming decades with respect to current energy intensive lifestyles and behaviors. As the performed analysis clearly shows, drivers of the underlying changes of these experiences are not only technology oriented but also, and often more relevantly, based on social dynamics. Studies particularly underlined the role of the human factor in relation to 'Social, Political Movement and Grassroots Factors' (in other words: citizens' orientation to change, engagement in movements and projects at the local level, willingness to pay in part for initiatives), as a key dimension of the governance of energy production and consumption (Caiati et al., 2013).

2.2. The key dimensions of energy transition narratives

The first step of building scenarios consists in elaborating narratives for each of them. Storylines or narratives can be defined as qualitative descriptions of future changes in economy and lifestyle, policies and institutions, technology, environment and natural resources. They describe the evolution of aspects of society that are difficult to project quantitatively (such as the quality of institutions, political stability, environmental awareness, etc.) and provide the logic underlying those elements of scenarios that are quantifiable and their relationships to each other (Alcamo et al., 2001, O'Neill et al., 2015).

After a thorough analysis of the qualitative information collected through the mentioned anticipatory experiences, it was possible to identify three key societal dimensions of the low carbon transition, that where then used to structure the narratives of the scenarios (see Figure 1).The first dimension relates to

[2] 90 experiences from 19 European countries already experimenting, at least partially, an energy transition process have been assessed according to a set of criteria such as type of actions, anticipatory awareness, visibility, types of energy involved, sources of funding, and replicability. For a detailed overview of the MILESECURE-2050 anticipatory experiences see Caiati et al. (2013, 2014)

the governance of energy systems. The choice between centralized and decentralized energy production systems is a key challenge of the low energy and carbon transition. Local experiments in the field of low carbon energy experimenthave received growing attention over the past decade, with an accent on urban experiences (Burch, S., 2010; Middlemis and Bradley, 2010; Nadaï et al., 2015).

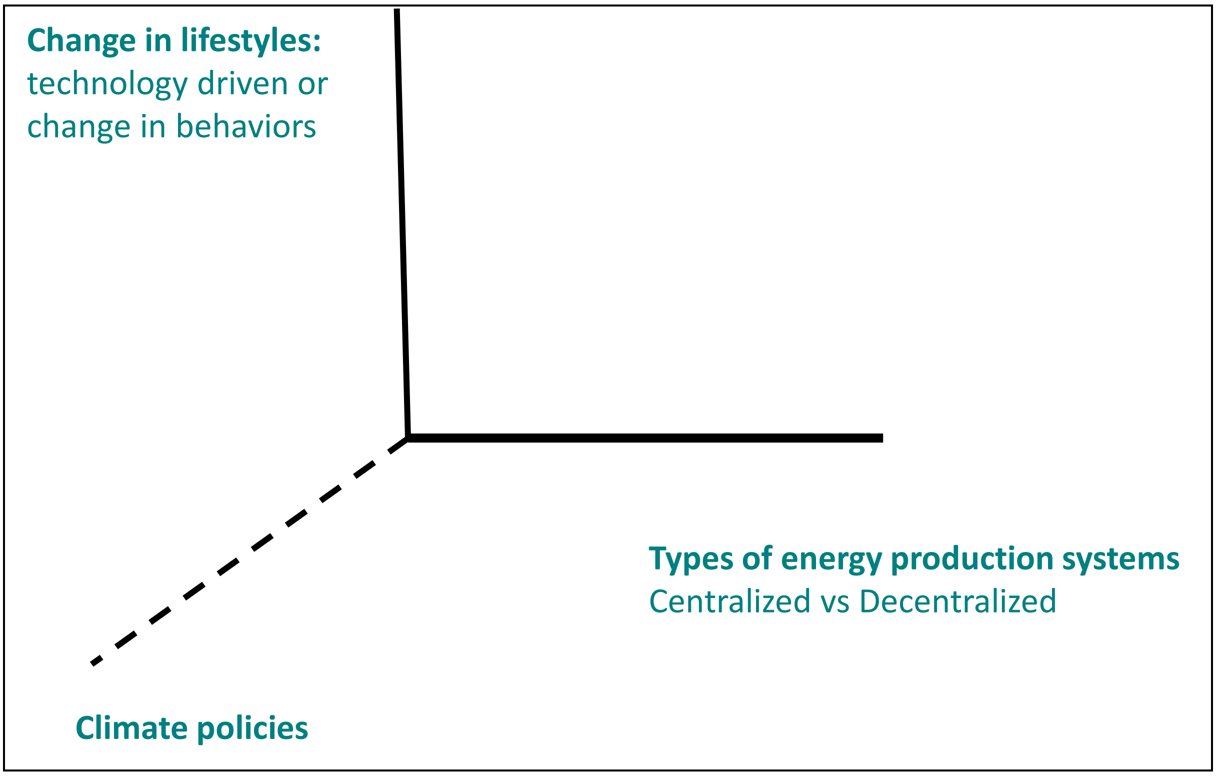

Figure 1: The three key dimensions of energy transition narratives (Source: Authors' own elaboration)

In European countries, energy production is historically relatively centralized (marked by a monopoly or an oligopoly in the production as well as in the distribution) albeit with some variation (Crivello et al., 2013). However, in recent years, a range of factors has opened a window for debate about the degree of centralization of the energy system in Europe: new energy technologies (smart technologies, distributed energy production technologies) are emerging; liberalization has opened the electricity market and sector to new entrants, the EU climate energy policy has supported the integration of Renewable Energy Sources (RES) technologies (EU, 2009). At the same time, these factors paved the way for the emergence of a heterogeneous set of innovative local experiences in the climateand energy field. However, one should not forget that a concrete shift from a centralized to a decentralized energy system is confronted toa range of difficulties and potential lock-ins: these range from forms of knowledge and expertise, forms of experiences and references caught in the centralized style of network and grid management with varying degrees among European countries and technical problems such as the management of intermittent production from RES, the integration of decentralized energy production systems in networks and smart grids (Nadaï et al., 2015; Crivello et al., 2013). In addition, the literature points out that energy systems can be highly path-dependent as they inherit the historical evolution of technologies and infrastructures (for a review see Grubb et al., 2014). Thus, changing paths of energy production and use require a pervasive transformation: production and carrier systems, consumption patterns, technologies, institutions, andpotential trade-offs in the shift between centralized and decentralized system can ultimately emerge.

Finally, a main component of the centralized/decentralized dichotomy relates to the organization of the production system. Centralized systems are predominantly managed by big public or private companies in a top-down fashion. Although each member states has its own energy policy and energy production organization, EU policies encourage coordination among systems, in particular through the development of networks interconnections (Armao et al., 2014). Research shows how, in decentralized systems, a new structure of producers and consumers of energy gradually emerges within a micro and small and medium-sized energy production system. Decentralized systems can also be driven by more direct forms of democracy comparing to the current centralized systems (e.g. production cooperatives for instance).

The second main dimension identified through the analysis of the anticipatory experiences relates to the content of development pathways, either technologically driven or marked by radical changes in behaviors. This distinction depends whether we believe that changes will come predominantly from the supply side or from the demand side. On one extreme of the spectrum, the energy transition is characterized by the development and the penetration of low energy and carbon technologies but with limited changesin the demand side. On the other extreme, the transition is driven mainly by changes in the demand side, such as those described in the case of societal processes that underline anticipatory experiences. The main components of the changes in demand patterns are the use of new types of energy modes (soft modes like biking, walking, involvement in energy communities etc…) that will also impact the types of energy carriers, infrastructures, institutions and regulation.

A last dimension structuring the narratives deals with institutional and geopolitical issues, and in particular throughclimate policies that accompany the transition towards a low carbon society. Mitigation scenarios are usually defined as a description and a quantified projection of how green-house gases emissions can be reduced with respect to a baseline scenario. We consider that the EU will comply with its current objectives adopted in the 3*20 package in 2008 (EU, 2008), the Roadmap 2050 (EU, 2011) completed recently by Frame2030 (EU, 2013). It is assumedthat other parties (except the least developed countries) apply their Copenhagen pledges[3] and the content of the INDCs[4] they will deliver before the next climate conference in Paris in December 2015.

2.3 Introducing the three scenarios

On the basis of the three dimensions sketched out in the section above, three scenarios were developed as follows.

2.3.1 The Business-As-Usual scenario

The Business-As-Usual scenario (Mile-BAU) represents a "reasonable" prospect for the future without efforts to support the low energy and carbon transition. In other words, the Mile-BAU consists in a continuation of "current state of affairs". Regarding the three dimensions identified above, there is no significant change in the energy production systems (no bifurcation towards one specific model),

[3] As part of the Copenhagen Agreement concluded in 2009 at the 15th Conference of the Parties (COP15) on Climate Change, Parties agreed to provide non legally binding emission to submit emissions reductions targets. From now, nearly 50 parties have submitted specific mitigation pledges under the Accord.

[4] As part of the Durban platform (COP17) parties (including developing countries) agreed at Warsaw (COP19) to prepare national contributions, the so-called Intended Nationally Determined Contributions (INDCs) at Lima COP20 which will include the so called "Copenhagen pledges", and action plans for 2020, in time for Paris COP21in 2015.All Parties to the UNFCCC are invited to initiate or intensify domestic preparations for their Intended Nationally Determined Contributions […] and to communicate them well in advance of the twenty-first session of the Conference of the Parties " COP Warsaw (2013: Decision 1/CP.19, Para. 2b)

people's behaviors and consumption styles, and no major changes in technologies (limited penetration of low carbon technologies for instance).

In that scenario, we do not consider climate policies. Not considering any climate policy at the beginning of the period is admittedly not realistic, but this should not bias our findings since the purpose of this work is neither to forecast emissions, nor to simulate reality. It is rather to compare scenarios in order to shed some lights on the mechanisms at work, and to reflect on the potential trade-offs in terms of energy security.

2.3.2 The Centralized Energy Transition) scenario

The Centralized Energy Transition scenario (CENT) features a centralized energy transition for Europe and member states, mainly driven by technologies and the implementation of large interconnection projects. National and EU regulations in the energy sector predominantly favor low carbon energy large-scale technologies, including large meta-network projects and object-oriented projects as Northsea, DESERTEC (Crivello et al., 2014), whereas the development of small power units is limited by the inadequateness ofregulation and support mechanisms. For instance, according to this scenario, incentives for innovation at the local level are relatively low as R&D efforts are directed mainly to the development of large-scale technologies (RES, cross-border networks etc.). Similarly, the scenario does not assume relevant changes in people'slifestyle; the development of human energy is particularly limited. Both top-down political and technically features of this scenario delay the involvement of local communities in participation processes regarding energy transition issues.

Regarding the geopolitical context, the EU continues to play an exemplary leadership role in the climate negotiations (Gupta et al., 2000). Assuming that a global agreement will besigned at the next climate conference in Paris (COP21) in December 2015, Europe will more specifically apply its own climate objectives included in the EU 3*20 package, the Roadmap 2050 and the Frame 2030, that consist in a reduction of the emissions of -20%, -40% and -80% respectively in 2020, 2030 and 2050 (compared to2005 levels). However, the scenario assumes that the efforts adopted by all parties as a consequence of the framework of the Paris agreement will not be sufficient to comply with the 2°C target[5]. Parties will in most cases apply their Copenhagen pledges within the framework of their own INDCs. The least developed countries, according to the common but differentiated responsibilities included in the Rio Convention in 1992, are not constrained.

2.3.3 The Social Energy Transition scenario

Contrary to the CENT scenario, the Social Energy Transition (SET) scenario features a decentralized energy transition mainly driven by changes in lifestyles and changes in governance modes. It assumes an increase in the development of local communities, grass-roots initiatives, participation processes of decision-making concerning energy transition. This gradually impacts the content of the regulations that increasingly favor the development of energy transition in the direction of micro and small low carbon energy solutions. Strong efforts are also implemented to develop green infrastructures, in particular concerning rail transport in passenger and freight, and public transport in cities. More generally, public infrastructures at the regional and local level are increasingly modernized. Regarding climate policies, we consider the sameconditions that were assumed by theCENT scenario.

[5] Parties to the UNFCCC (except Bolivia) have agreed to pursue the aim of limiting global warming to 2°C above the pre-industrial level at the UNFCCC in Copenhagen (COP-15) and Cancun (COP-16) (UNFCCC 2009, 2010).

3 A modelling framework to simulate energy transition pathways

3.1 Modeling framework and methodology

IMACLIM-R (IMpact Assessment of CLimate Policies) is an Energy-Economy-Environment (E3) model based on a hybrid modelling framework (Figure 2).

This framework allows for transitory partial mis-adjustments of the economy triggered by the interplay between choices under imperfect foresight and inertia of technical systems[6]. Imperfect foresights, in particular, become crucial when acknowledging that capital stock and infrastructures cannot be changed overnight and that wrong anticipation cannot be corrected without frictions due to technical and behavioral inertias.[7]

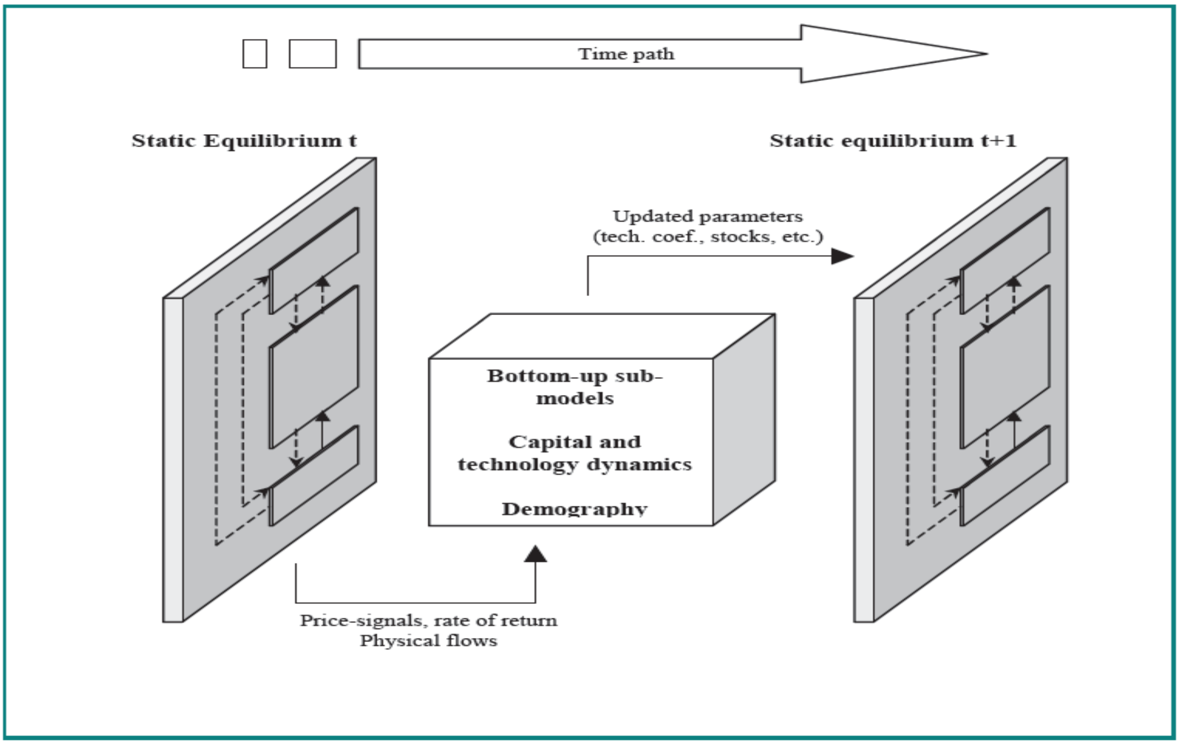

Figure 2: Recursive and modular architecture of the IMACLIM-R (source: Waisman et al., 2012)

The design of IMACLIM-R stems from the necessity to better understand, amongst the drivers of baseline and policy scenarios, the relative role and the interplay between:

- technical parameters in the supply side and in the end-use equipment,

[6] Note that imperfect foresights are a consequence of (i) uncertainties about future relative prices, final demand and investments profitability, (ii)``noises'' coming from signals other than carbon and energy prices (e.g. prices of land and real estates, distributional issues), and (iii) non-economic determinants of public decisions in transportation and urban planning (Jaccard et al., 1997).

[7] The reader can refer to Waisman et al. (2012) and its supplementary online material for a full and detailed description of the IMACLIM-R model.

- structural changes in the final demand for goods and services (dematerialization of growth patterns),
- microeconomic behaviors with imperfect foresight,
- macroeconomic dynamics with potential disequilibrium in opened economies.

The model is built to facilitate and allow the dialog between engineers and economists. It also aims at embarking other dimensions (such as urban form, environmental policies, human behaviours etc…) that enables a broader pluridisciplinary dialog among a large socio-scientist community (e.g. sociologists, geographers, political scientists…), as required in the MILESECURE-2050 project.

3.2 A focus on the transportation sector: a way to embark energy consumption and urban organizations

The salient features of the social processes underlying anticipatory experiences raise the issue of the nature and pace of structural change under a range of constraints (social, economic, spatial dynamics). Structural change of the economy (dematerialization of growth patterns) is the result of the interplay between technological, institutional and spatial dynamics and patterns (Grubb et al., 2014; Sassi et al., 2010, Hourcade, 1993).In order to represent part of the societal processes described in the previous section, we concentrate on scenarios that focus on the "lifestyle" dimension. This is done through an important vector that is linked to territorial and urban zoning policies, as well as to issues related to energy consumption, namelythe transportation sectors. Indeed, transport is a key issueto consider when dealing with bifurcation in lifestyles (IPCC, 2014).

IMACLIM-R proposes a framework that helps disentangling the role of transport in long-term socio-economic trajectories and the potentials offered by specific measures on these sectors to face fossil fuel depletion issues as well as emissions mitigation costs. This is why a detailed description of this sector and its dynamics are given in this section.

Contrary to most ofE3 models that are used for energy security issues and for carbon mitigation assessments, IMACLIM-R embarks a stylized representation of "behavioral" determinants to explicitly represent the interplay between transportation, energy and growth patterns (Waisman et al., 2013). This is a real added value, since most modelling tools are mainly based upon sectoral approaches that have either a 'technology-based' or a 'behavioural-based' nature (IPCC, 2014). The advantage of IMACLIM is that it joins both natures with a macro-economic closure, ensuring thus a robust assessment of the challenges posed to the economy by energy security and climate change.

Furthermore, in climate policy and energy security analysis, the dual approach adopted by this model (both in money values and physical quantities) is crucial for energy goods to represent explicitly their carbon-to-energy ratio (Malcolm and Truong, 1999). Thus, since the transportation sector is another key sector for climate and energy security issues, the model has extended this dual representation to transport by adopting an explicit representation of passenger and freight mobility (expressed in passenger-km and ton-km respectively).Important stylized facts of passenger mobility are captured thanks to the following constraint elements:

- The *rebound effect*on mobility due to energy efficiency improvements: More efficient vehicles trigger lower households' fuel expenditures and thus free up resources to increase the overall consumption, and the mobility demand in particular. The budget constraint allows indeed capturing this effect and shows that higher disposable households' income allows an increase of all goods and services consumption, including demand for transportation.

- The *induction effect* of infrastructure deployment on mobility demand: for a given transportation mode, the deployment of new additional infrastructures increases the capacity of the corresponding network and decreases the congestion constraint. The average speed allowed by the available infrastructures is thus higher and the passenger.kilometers in that mode are less time-consuming. This allows households to increase their overall travel demand within their time budget constraint.

- The *modal distribution* between different modes: The four considered modes (air, road, public and non-motorized) are explicitly differentiated according to their *(i)* costs, *(ii)* provided mobility service measured by their average speed, and *(iii)* the availability of infrastructures that determine congestion levels. Effective modal distribution then results endogenously from a tradeoff within the twofold constraint: income budget and travel time budget. The *constrained mobility* induced by firms' and households' localization choices: This concerns daily travels that households have no choice but to realize to satisfy specific travel purposes (essentially commuting and shopping). They are exogenously represented by the basic needs parameter

In IMACLIM-R, passenger daily mobility (commuting, shopping and access to services) and the transport intensity of production are therefore defined by the spatial distribution of housing, transport and industrial infrastructures.

Regarding more specifically the freight transport, in IMACLIM-R, three freight transportation modes are considered: air, water and terrestrial transport. Moreover, production functions of all the sectors have fixed equipment stocks and fixed intensity of labour, energy and other intermediary inputs in the short-term[8]. This means in particular that, at a given point in time, the freight transportation intensity of production is measured by input-outputs coefficients $IC_{j,Sec}$, which define a linear dependence of freight mobility in a given mode *j* to production volumes of sector *Sec*. The higher the production volumes, the higher the freight mobility demand if no specific policy towards reducing this volume is implemented.

This freight mobility representation *via* input-output coefficients of production captures implicitly two important features that drive the modal breakdown and the intensity of freight mobility needs:

- The spatial organization of the production processes in terms of specialization/concentration of production units.
- The constraints imposed on distribution in terms of distance to the market and just-in-time processes

To provide the mobility service, four transportation modes are considered: terrestrial public transport[9], air transport, road transport (private vehicles) and non-motorized transport (walking and biking).Scenarios developed in the framework of this study implied specific assumptions for the transport sector that are presented in the following section.

[8]These Leontief specifications (with fixed inputs per unit of production) are nevertheless characterized by flexible utilization rates of installed production capacities.

[9]"Public transport" includes both urban public transports (buses, metros… etc.) and inter-city trains because the model does not differentiate between inter- and intra-city trips.

4 Results

4.1 Selection of indicators to measure energy security

In this section, we quantitatively assess the scenariosintroduced in section2, through the lens of energy security. Recent energy security literature has been focused on proposing dozens of indicators to measure and assess these latter[10]. Our selection of indicators is necessarily based on a number of arbitrary choices, and other indicators could also be appropriate. Nevertheless, they are representative of the indicators frequently discussed in the literature, although not generally examined all together[11]. The indicators that aim at measuring dimensions of energy security in this paper are based on four dimensions (after Sovacool and Brown, 2010; Kruyt et al., 2009; Chester, 2010, Guivarch et al., 2013), as summarized in table 1.

We include in the availability dimension the concept of diversity of imports. This concept can concern the whole range of suppliers of one type of energy – the more suppliers there are, the more resources will still be available if tensions appear concerning one of them, but also the range of energy types on which a sector, or the whole economy, relies.[12] Then, we use the ratio of production over resources for oil to measure its physical availability worldwide[13]. We add a diversity component to this dimension, measured by the concentration of oil markets. We use the Herfindahl-Hirschmann index, calculated as the sum of squared market shares of oil producers. Note that this index increases when the market is dominated by a small number of producers. These two indicators are global and not specific to Europe.

For the dependence dimension, the energy intensity of GDP (the ratio of total primary energy supply, TPES, over GDP) measures the dependence of the economy on energy, and the share of imports in TPES measures the dependence of the energy supply on imports.

For the affordability dimension, instead of the absolute prices of energy types that do not account for the fact that some energy types might become expensive over time but also less used, we focus on the energy import bill as a share of GDP and on the share of households' budget devoted to energy.We chose two indicators for the sustainability dimension: the carbon content of TPES and the installed nuclear capacity, a technology that involves problems of acceptability.

The indicators summarized in table 1 are calculated such that an increase (respectively decrease) in their value indicates a worsening (respectively improvement) in the dimension of energy security they measure.

[10] See Sovacool and Mukherjee (2011) who list 320 indicators relevant to measure energy security.

[11] The selection presented here results in a trade-off proposing (i) a limited number of indicators to ensure the results are readable, (ii) a variety of indicators covering the four axes of the energy security concept, (iii) indicators that can be calculated with the model used in this article.

[12] For instance, Jewell et al. (2014) use the diversity of energy sources in the total primary energy supply, electricity generation and the transport sector.

[13] It is more common to present the inverse ratio, i.e. resources over production, expressed in years of reserves remaining at the current rate of extraction. However, we present the ratio of production to resources, so that the value of the indicator increases when the availability dimension worsens.

Dimensions of Energy Security concept	Selection of indicators
Availability and Diversity	- Production/Resources (Fossil Fuel) - Diversity of Imports (Herfindhal - Hirshmann index - market concentration)
Dependence	- TPES/GDP - Imports/TPES
Affordability	- Households energy budget (share of revenues) - Energy imports bill/GDP
Sustainability and Acceptability	- Carbon content of TPES - Installed nuclear capacity

Table 1: Indicators to measure energy security issues (source: Authors' own elaboration based on Guivarch et al., 2013).

4.2 Impact of scenarios on energy security parameters

This section shows preliminary results of the quantified scenarios. We investigate in the SET and CENT scenarios the macro-economic effects of the implementation of a quite stringent climate policy for Europe, while the rest of the world is less constrained. More precisely, we implement a climate policy that aims at reducing CO_2 emissions for the different world regions at the horizon 2050:

- Europe has to reduce its emissions by 20%, 40% and 80% respectively in 2020, 2030 and 2050, in comparison to 2005 (consistent with EU Roadmap2050 and Frame 2030).
- The rest of the world is less constrained and implements the Copenhagen pledges. It should be noted that the Middle East, Russia, Africa and the rest of Asia are not constrained at all.

These regional pledges, including for Europe, are translated into regional CO_2 emissions profiles that are prescribed exogenously for the period 2010-2050: for each constrained region, at each date, a maximum level of CO_2 emissions from the production and use of fossil energies (coal, oil and gas) in final goods and in transformation processes is prescribed.

In order to comply with the imposed carbon emission profiles, regional CO_2 prices are endogenously calculated by the model so that the increase in the cost of fossil energies triggers a decrease of their use consistent with the CO_2 constraint (one price per constrained region and per year).

The transition towards a low carbon society in the CENT scenario occurs within the framework of:

- Centralised energy production modes;
- High fossil fuel dependency;

- No specific actions on infrastructures (transport in particular).

This transition is quite different in the SET scenarios since it considers the deployment of local anticipatory experiences with significant changes in:

- Consumption patterns and
- Energy production modes (e.g. more decentralized)
- Location issues (activities, housing…)

These differences are taken into account within the IMACLIM-R framework through two main vectors:

(i) Transportation module

Some characteristics of the anticipatory experiences are implemented through urban organization policiesthat aim at controlling the 'behavioural' determinants of the mobility demand. More precisely, we consider:

- A progressive reduction of households' basic mobility(essentially commuting): to represent a spatial reorganization at the urban level (more dense cities) and soft measures towards less mobility-dependent conglomerations[14]
- Shifts in the modal structure of investments in transportation infrastructures favoring public modesinstead of private vehicles
- Areorganizations in production/distribution process/logisticsallowing a decrease of freight transportation needs

(ii) Energy production modes

We consider much more optimistic options for the SET scenario in terms of low-carbon technologies (availability and penetration). The levers for action are summarized in the table 2 below:

Dimension	Technology	Parameters
Power generation decarbonization	Nuclear	Maximum Market Share [min-max]
	Renewables	Maximum Market Share of renewables, Learning rate for renewables investments costs
	Carbon Capture and Storage	CCS learning rate, start date, max market share at the end of the bottleneck phase, growth phase, max market share at the end of the growt phase, mauration phase, mx market share at the end of the maturation phase
Low Carbon end-use technologies	Electric Vehicles	EV "bottleneck phase", Maximum market share at the end of the period, growth rate, maximum market share at the end of the period, maturation phase, maximum market share
	Energy Efficiency	Freight energy consumption, Freight fuel consumption elasticity to fuel prices, Buildings energy consumption per m2
	Biofuels	Time scale of reactive anticipation for biofuels production, biofuels supply
Alternative liquid fuel supply	Coal-to-liquids	Oil price threshold for CTL production start, Maximum production growth in 2030, 2035, 2050

Table2: Technology parameters (source: Authors' own elaboration)

[14] In the final version of the model, depending on the technical feasibility, we will try to implement some changes in Households' preferences for transportation modes (i.e. an increase of soft modes like biking, walking)

Results show that the SET scenario triggers a much better context than when the EU has to face energy security issues with simple pricing instruments (e.g. a mitigation policy, based on carbon pricing) in the CENT scenario. For instance, we find that the assumptions made on the demand side (urban planning policies and infrastructure transportation measures) in the SET scenario play a key role in terms of energy consumption spending, in particular at the household's level. As we can see in table 3, the share of energy in household's budget is lower during the whole period and particularly at the end of the period where it is almost halved (24% in the CENT vs.13% in the SET). Note that this share is higher in the two climate scenarios than in the Mile-BAU. This is due to the impact of carbon price on energy prices. However, this carbon price is necessary in order to trigger lower and more efficient energy consumption.

	2010	2020	2030	2050
BAU	9%	10%	10%	7%
CENT	9%	24%	20%	24%
SET	9%	22%	14%	13%

Table 3: Share of Energy in Households' Budget for Europe (Author's own elaboration)

Furthermore, the assumptions made on the supply side (e.g. the more optimistic low carbon technologies penetration…) trigger a more energy secure Europe in the SET than in the CENT scenario. This is particularly illustrated in figure 3, where we observe a lower energy imports bill related to GDP during the whole period.

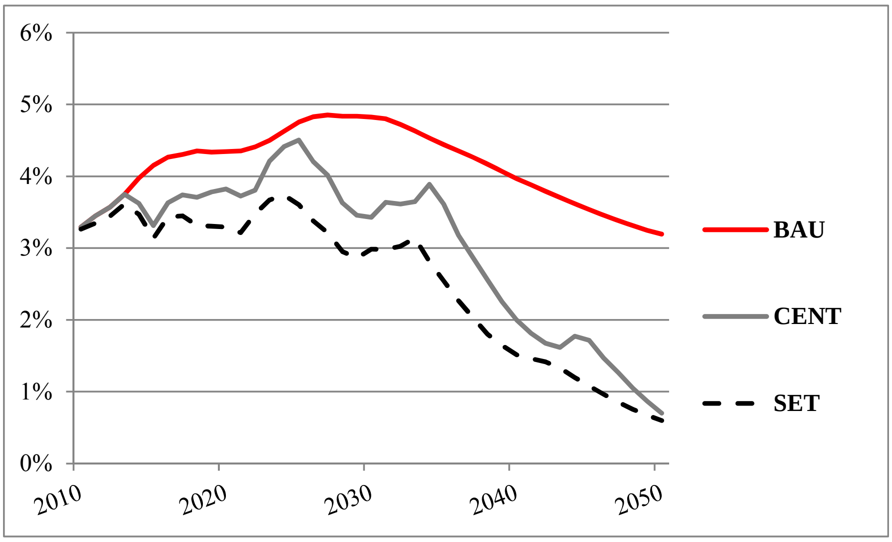

Figure 3: Energy imports bill/GDP for Europe (Author's own elaboration)

These few features contribute to generate a better macro-economic situation in the SET scenario. We can observe it when looking at the GDP losses with respect to the BAU scenario obtained under the two policy scenarios (see figure 4). The implementation of voluntary and complementary policies allows indeed for a 35% reduction of the losses on average over the whole period.

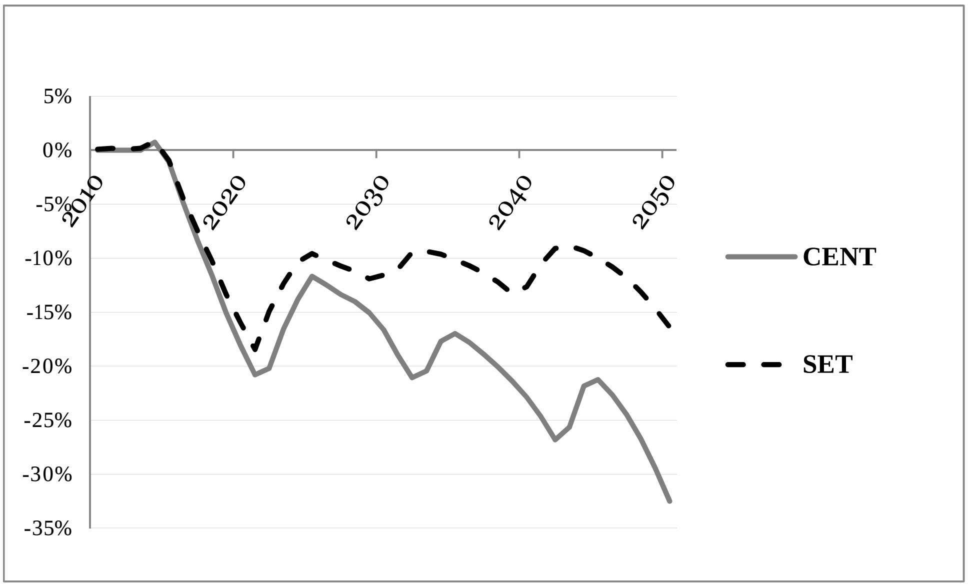

Figure 4: GDP variation with respect to the BAU scenario (Author’s own elaboration)

5 Discussion and conclusion

The transition towards a low carbon society requires a radical overhaul ofthe existing system. The interim results of the MILESECURE-2050 project shows how Herculean efforts in policy-making, technological innovation and behavioral change are all necessary to move away from today's situation, in which82% of all useful energy in the world is derived from fossil fuels – oil, coal and natural gas - and towards a more diversified system based on significant amounts of renewable energy sources (RES), such as wind, solar and hydropower.

However, Energy transitions of this scale are extremely complex phenomena and, despite being often dealt hand-in-hand with the increase of energy security in supranational policy documents, they portend significant challenges for the long-term security of theexisting system. The present contribution tried to shed some light on this matter, simulating the interactions between climate policies and energy security issues through the application of the Economy-Energy-Environment Model IMACLIM-R and the development of three different scenarios.

Particularly relevant for the analysis has been a consideration of the so-called ‘human factor’, i.e. of the role that societal processes and variables may play in favoring or constraining both energy transition and energy security. On the basis of the analysis of over 90 anticipatory experiences spread all around Europe, it was possible to develop narratives upon which to calibrate the scenarios, which take these elements into account. This proved to be particularly relevant, as the resultsof the scenarios’ activity show how, in the long-term, a transition pivoted around a more decentralized approach (as in the Social Energy Transition scenario) is supposed to produce better results than one that counts on top-down imposed measures (as in the Centralized Energy Transition scenario).

All in all, one of the merits of the presented work and, more relevantly, of the research activity developed in the framework of MILESECURE-2050, is to acknowledge how an effective low carbon transition would imply huge behavioral changes for virtually all stakeholders – firms, consumers, and governments – and, if not carefully steered, may generate unintended consequences[15]. Due to the vast complexity of the domain of inquiry – i.e. the world energy system – as well as the dynamic synergies and trade-offs between low-carbon policies and energy security, conceptual precision and analytical rigor is therefore required to effectively navigate this terrain.While indicators can reveal the trade-offs and synergies between technological, political and social dimensions, in order to meaningfully assess how climate change policies may impact on energy security and vice versa, a conceptual and methodological framework must be developed which accounts for the multi-dimensional, polysemic nature of energy security.

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[15] For example, the increased electrification of final energy consumption in a low-carbon system may shift the focus from the security of energy supply to the security of energy transformation, which is determined not only by the availability of primary sources but also on the stability of complex interconnected infrastructures.

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