PROJECT FINAL REPORT

Grant Agreement number: 213106

Project acronym: ENCI-LOWCARB

Project title: European Network engaging CIvil society in Low Carbon scenarios

Funding Scheme: FP7

Date of latest version of Annex I against which the assessment will be made:

Period covered: from 01/04/2009 to 31/03/2012

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[2] The home page of the website should contain the generic European flag and the FP7 logo which are available in electronic format at the Europa website (logo of the European flag: http://europa.eu/abc/symbols/emblem/index_en.htm logo of the 7th FP: http://ec.europa.eu/research/fp7/index_en.cfm?pg=logos). The area of activity of the project should also be mentioned.

I. Final publishable summary report

1. Executive summary: Energy scenarios – changing approaches and exigencies

In recent years an ever-growing number of energy scenarios has been published. The urgency of the effects of climate change translates into more and more contrasting, complementary and even opposing narratives for the necessary energy transition.
In most cases, the scenarios are technically feasible and respecting physical boundaries, but this does not mean that they are necessarily politically, economically or socially acceptable.

For this reason, some energy scenarios are going beyond a pure technocratic approach and are increasingly integrating public or stakeholders consultations in order to verify their acceptability. Unfortunately few of these exercises show *how* these consultations are being integrated in the models and thus are influencing the scenario design.

Within the FP7 project ENCI-Lowcarb (Engaging Civil Society in Low-carbon Scenarios) researchers and civil society organizations (CSOs) developed and applied a reproducible methodology for a collaborative scenario creation process that aimed to integrate civil society input in a transparent way. Energy scenarios were developed for Germany and France that had transparently integrated opinions from national stakeholders into the applied modeling tools and so into the resulting climate change mitigation scenarios.

The main outcomes of the project were:

- Developing and refining innovative hybrid modeling tools Remind-D and Imaclim-R that represent explicitly monetary values and physical quantities so as to capture the specific role of the different energy sectors and their interaction with the rest of the economy.
- Establishing a cooperative relationship between CSOs and researchers to build energy scenarios together despite diverging cultural approaches. A reproducible methodology for collaborative scenario creation processes was developed.
- Collaboratively creating energy mitigation scenarios for Germany and France and ensuring a sense of ownership for these scenarios among the participating stakeholders.

The French scenario mainly focuses on the necessary composition and interaction of specific acceptable sets of policy measures (laws, taxes and economic incentives) aimed at getting France on a climate friendly pathway. Several bottlenecks and leverage points were identified, such as the imminent need to adopt a carbon tax that could trigger funding for a transition. Importantly, if only those measures that were judged acceptable by the consulted stakeholders were implemented, France would only achieve a 68% CO_2 emission reduction compared to 1990, significantly less than the French climate objective (75% of greenhouse gas emissions in 2050). An important challenge is to create stronger commitment among stakeholder for more ambitious policy measures.

The three German mitigation scenarios all achieved a fixed 85% CO_2 emission reduction objective. Their focus is on the interdependencies of the different sectoral activities and trade-offs that have to be made between energy sectors if stakeholders consider a specific development likely or desirable. The stakeholder dialogues revealed strong discrepancies between likely ('continuation scenario') and desirable future developments (paradigm shift scenarios) in the transport and electricity sector.

Carbon lock-in in the 'continuation scenario' would slow down economic growth and bear severe socio-political externalities. To overcome these trade-offs, carbon lock-ins have to be avoided and, additionally, energy efficiency and renewable deployment growth rates have to increase. Participating stakeholders pointed out that in order to resolve the carbon lock-in, major paradigm shifts are needed, which in turn require concerted political as much as societal will.

The methodology for collaborative scenario creation processes that was developed and applied during this project is replicable and could serve as a possible blueprint for the development of scenarios that are open to stakeholder participation (such as official multi-stakeholder scenario creation processes coordinated by the government, regional scenario development processes led by local authorities, or even EU-wide scenario developments like the EU energy roadmap).

The ENCI-LowCarb research project identifies a number of principles that should guide scenario-building processes to ensure they are inclusive and participatory:

- The knowledge and understanding on what are the main drivers of the modeling tool that is used must be shared among the stakeholders that participate in a scenario creation process.
- There should be transparent rules on how to integrate stakeholder contributions in the modeling features that are systematically applied in practice.
- The scientists and coordinators responsible for a collaborative scenario creation process must be neutral when it comes to the technology choices and must not state preferences on policy measures or climate or energy objectives (unless a number of basic values and non-starters are decided before the scenario-building exercise).
- The core of the future scenarios should be built based on stakeholder contributions. It is the role of the project team to translate the visions of different stakeholders into the modeling tool.

2. A summary description of project context and objectives

Acceptable mitigation pathways – changing approaches and exigencies

Climate change has already become a reality, we are suffering biodiversity loss, besides we continue to deplete our resources, and we are accepting incredible injustices concerning the development levels of the different continents with billions of people suffering and over-consuming in the same time.

Even institutions like the IEA raise alarm. Fatih Birol, the IEA's chief explained: "What I see now with existing investments for plants under construction...we are seeing the door for a 2 degree Celsius target about to be closed and closed forever." [3]

Also the OECD states that without additional measures the CO2 concentration at the end of the century will achieve 685ppm which corresponds to an average temperature increase about 3 to 6°C.[4]

More and more people become aware of this approaching disaster for nature and humanity and the last decade is characterized by an always-growing number of energy scenarios and visions. The urgency of the upcoming impacts of climate change translates into more and more contrasting, complementary and even opposing narratives on the necessary energy transition.

In most cases these scenarios are technically feasible and respecting physical boundaries but this does not mean that they are politically, economically or socially acceptable.

This is why energy scenarios are now in many cases based on public or stakeholders consultations in order to check or assure their acceptability. However, few exercises attribute importance to the scenario design process and explain in a transparent way how stakeholder contributions are taken into account and integrated in the modeling tools, that is to say how the translation process was carried out from an idea supported by contributors to its representation in the resulting scenario.

Within the FP7 project ENCI-Lowcarb (Engaging Civil Society in Low-carbon Scenarios) researchers and Civil Society Organisations (CSOs) developed and applied a reproducible methodology for collaborative scenario creation processes aiming at overcoming this limitation. Energy scenarios for Germany and France were developed based on a transparent translation of contributions of national stakeholders into the used modeling tools and so into the resulting mitigation scenarios.

Technical feasibility is no longer considered being a sufficient trigger for transformation – governments and stakeholders have to initiate the transformation process as a collective project for a common future; political, economic and social acceptability is essential. As a first step acceptable mitigation scenarios are needed supported by the ownership of national stakeholders.

But the French case study also shows that if pathways are only built on a set of policy measures that is acceptable by a majority of stakeholders then the resulting CO2 emission reductions won't be ambitious enough to ensure the necessary French contribution for respecting the limit of a 2°C average temperature increase.

Objectives and results:

Objectives of the project:

1. Develop and refine hybrid modeling-tools that are able to represent technical sectoral details and at the same time the interplay with an economic system.
2. Create a reproducible methodology for a collaborative scenario design process.
3. Raise awareness among the community of researchers and CSOs about the importance of collaborative scenario creation processes – between researchers and NGOs, and between both

[3] Interview on Reuters "Door to 2 degree temperature limit is closing – IEA », May 16th 2012

[4] OECD (2011) « Environmental Outlook to 2050: The Consequences of Inaction »

and other stakeholders - and their design. Spread knowledge about the project results and the reproducible methodology for a collaborative scenario design that was developed, via seminars and a mailing list.

4. Elaborate acceptable mitigation scenarios for France and Germany in a collaborative process including an internal cooperative process between researchers and CSOs and a second external collaborative step between the project team and national stakeholders.

<u>The main outcomes of the project are:</u>

1. The development and refinement of the innovative hybrid modeling tools Remind-D and Imaclim-R France that represent explicitly values and physical quantities so as to capture the specific role of energy sectors and their interaction with the rest of the economy.
2. The establishment of a successful cooperation of CSOs and researchers on the topic of energy scenarios benefitting from cross-fertilization between the diverging approaches of project partners from distinct professional culture backgrounds. The development of a blueprint project design enabling quantitative modelers, social scientists, and non-governmental organization members to jointly develop project-specific interdisciplinary research methods for addressing technological and sociological dimensions at once. Within this process the main result was the development of a reproducible methodology for a collaborative scenario creation design.
3. Dissemination of the project results was effectuated via regular newsletters, project websites, a "low-carbon-network" mailing list, the organization of EU stakeholder seminars, low-carbon network seminars and project conferences.
4. The elaboration of collaboratively built energy mitigation scenarios for Germany and France. Creation of ownership for these scenarios among the participating stakeholders:

1. <u>Development and refinement of hybrid modeling tools</u>

The modeling tool **Remind-D** for Germany was developed by the Potsdam Institute for Climate Impact Research (PIK). It is a Ramsey-type growth model that integrates a detailed bottom up energy system module, coupled by a hard link. It facilitates an integrated analysis of the long-term interplay between technological mitigation options in the different sectors of the German energy system as well as general macroeconomic dynamics. The objective of REMIND-D is to maximize welfare, i.e. the intertemporal sum of discounted logarithmic per capita consumption.

Strengths of the Remind-D model compared to other macroeconomic/energy-system models refer especially to the mechanism of optimization and furthermore to the endogenous representation of the sectors in the energy system and macroeconomics. Furthermore it can be shown which technologies could contribute to emission reduction and how a welfare-optimizing transformation could look like.

The modeling tool **Imaclim-R** for France was developed by the International Centre for Environment and Research (CIRED). It is a computable general equilibrium model and it calculates the evolution of the French economy split into 15 sectors: energy sectors, transport sectors, construction, energy-intensive industries, agriculture and services.

The Imaclim-R model computes, between 2004 and 2050, the evolution of the economy and the energy system with a strong consistency. That means it is explicitly representing both monetary values and physical quantities so as to capture the specific role of energy sectors and their interaction with the rest of the economy.

The existence of explicit physical variables (e.g. number of cars, number of dwellings or energy efficiency of technologies) allows an incorporation of sector-based information about how final demand and technical systems are transformed by economic incentives. In Imaclim-R, each year the equilibrium provides a snapshot of the economy and gives GDP, sectoral prices, sectoral investments, households' consumption in each sector, unemployment rate and international trade. Two successive annual equilibria are linked by "dynamic sectoral modules". These sectoral modules represent the specific sector dynamics given economic and physical constraints.

A limitation of Remind-D and Imaclim-R France is that it computes only energy-related CO_2 emissions and other greenhouse gases are not represented.
The modeling tools were developed and refined by the research partners of the project.

2. Reproducible methodology for a collaborative scenario creation design

A collaborative scenario creation methodology was developed based on a transparent integration of contributions of national stakeholders in both countries.
The process was divided in four phases:

Phase 1: Intra-group development of the project team

A first necessary step was the conscious group-formation process, which is of particular importance for collaboration across project partners from different communities.

Phase 2: Technological Framework Conditions

Within the ENCI-LowCarb project, one challenge was the use of macro-economic hybrid models for the scenario design task (IMACLIM-R and REMIND-D), which are often characterized as "black-boxes". This implies the necessity to organize at least a basic introduction to the model dynamics at the attention of the NGO project partners and the participating experts and stakeholders. The form and limits of the modeling tool indeed shape the form of the dialogue.
During this project phase the modeling tools were refined. In France and Germany sectoral expert meetings were organized in order to assess the degree of economic and technical realism of the modeling tools and to correct and to update exogenous hypotheses (costs, potentials, investments, learning curves etc.) as well as dynamics of the models itself.

Phase 3: Political Framework Conditions and Corresponding Scenarios

A central issue in Phase 3 of the collaborative scenario definition process was to apply a framework that makes it possible to integrate in a transparent way, stakeholder contributions in the scenario modeling process. The term stakeholders refer to societal actors like trade unions, consumer associations, private businesses, banks, local authorities and energy companies etc.
The two country groups for Germany and France applied slightly different methods due to the use of different modeling tools:

In France: The collaborative scenario creation process within phase 3 of the project **in France** was divided in different steps: The first step consisted in **indentifying the national stakeholders**. In order to select and to invite those stakeholders who play an essential role in the energy sectors at stake (residential, transport, electricity), a stakeholder mapping via a "power-interest-grid" was adopted to identify those key actors. In a second step **sectoral stakeholder workshop** were organized. During these meetings, stakeholders could express their vision on the evolution of technology choices, policy measures and economic incentives necessary and acceptable to reduce CO_2 emissions. The meetings were recorded in order to collect a maximum of viable information, all stakeholders answered a questionnaire and minutes were taken from the ongoing discussions. It was decided to limit the number of stakeholder to 15 to foster in-depth discussions. Between the evaluation of the contributions of stakeholders and the modeling exercise, an important step was the **translation of the stakeholder visions into model parameters**. The information gathered within the sector specific stakeholder meetings was translated by the project team in model parameters and added together to a first version of the scenario. Points of disagreement were laid open and translated in different scenario variants. After this translation process a **cross-sectoral feedback seminar** was organized. The main objective of the meeting was to get a transversal feedback on the first version of the scenario. The stakeholders' comments were then implemented into the model and into a new scenario. Points of disagreement arising from the evaluation of the outcomes of the first meetings were presented in the form of scenario variants.

In Germany: A central issue in Phase 3 of the collaborative scenario definition process **in Germany** was the elaboration of different and potentially controversial political framework conditions with relevant stakeholders (CSO and stakeholders from the economy). The political framework conditions relate to the quantitative model by applying **translation rules from model parameters to "real-world implications".** Coherent sets of political framework conditions form one scenario, differing with respect to the articulated level of social (un-)acceptability of mitigation options. The integrated scenarios are again evaluated by the stakeholders. The project team identified sectors of the domestic energy system that are of particular interest or controversy regarding social acceptance. Together with a neutral moderator, the national sub-teams developed concrete workshop agendas. The social scientist selected suitable methods for capturing stakeholder's assessments during the workshops: a **questionnaire with Likert scales**, measuring the level of agreement or disagreement of the respondent towards specific statements. Per item, two Likert scales were employed: Stakeholders were asked to indicate whether they find the proposed development *realistic* and once whether they would *welcome* it from the point of view of their organization. Stakeholders were unlikely to express a uniform opinion, so several different sectoral **"scenario building-bricks"** in terms of political framework conditions emerged from the workshops. During the second sectoral stakeholder workshops, ideally attended by the same CSO representatives, the developed scenarios were presented, discussed, and evaluated. This **feedback loop** ensures that the social acceptance considerations are actually realized and gives the CSO representatives a chance to indicate their assessment of social (un-)acceptance of the integrated scenarios.

3. Dissemination of the project results

The dissemination activity of the project took different forms: Annually EU stakeholder seminars were organized to discuss with EU stakeholders scenario related topics and project results. Also every year a "low-carbon network" seminar took place, gathering members of the network created by the project team composed by researchers and CSOs working on energy scenarios. Additionally a specific seminar for eastern European NGOs was organized seeking support for collaborative scenario creation processes. Project results were communicated via quarterly newsletters, the project websites and the project mailing list. Besides the final public conference and the research seminar that were organized to present the project results to specific publics the project team participated in EU events like the EUSEW and the EU Green week.

4. Mitigation scenarios for France and Germany

Mitigation scenarios were developed collaboratively for France and Germany by the project team based on stakeholder contributions. The used modeling tool shaped the specific form and focus of the different scenario processes.

French acceptable mitigation scenario: The French scenario is mainly focusing on the necessary composition and interaction of specific acceptable sets of policy measures (laws, taxes and economic incentives) aiming at getting France on a climate friendly pathway.

If only those measures that are judged acceptable by the consulted stakeholders are implemented a 68% CO_2 emission reduction compared to 1990 can be achieved which is less than the French climate objective (75% of greenhouse gas emissions in 2050). Moreover this level of reduction is highly sensitive to energy prices and technology assumptions. An important challenge is to create stronger commitment among stakeholder for more ambitious policy measures.

Several bottlenecks and leverage points were identified for example the imminent need for the adoption of a carbon tax triggering funding for transition or the need for the adoption of a refurbishment obligation for dwellings.

German likely and desirable mitigation scenarios: The three German mitigation scenarios are all achieving a fixed 85% CO_2 emission reduction objective. Their focus is on the interdependencies of the different sectoral activities and trade-offs that have to be made between energy sectors if stakeholders consider a specific development likely or desirable. The stakeholder dialogues revealed strong discrepancies between likely ('continuation scenario') and desirable future developments (paradigm shift scenarios) in the transport and electricity sector. Carbon lock-in leads in the 'continuation scenario' will slow down economic growth and bear severe socio-political externalities. To overcome these trade-offs, carbon lock-ins have to be avoided and, additionally, energy efficiency and renewable deployment growth rates have to increase. Participating stakeholders pointed out that in order to resolve the carbon lock-in, major paradigm shifts are needed, which in turn require concerted political as much as societal will.

3. A description of the main S&T results/foregrounds

1. Methodology

The last decade is characterized by an always-growing number of energy scenarios and visions. The urgency of the upcoming impacts of climate changes and the end of cheep fossil fuel resources, translate into more and more contrasting, complementary and even opposing narratives on the necessary energy transition.

In most cases these scenarios are technically feasible and respecting physical boundaries but this does not mean that they are politically, economically or socially acceptable.

This is why many energy scenarios are today based on public or stakeholders consultations in order to check their feasibility. However, few exercises attribute importance to the scenario design process and explain in a transparent way how contributions are taken into account and integrated in a modeling tool, that is to say how the translation process was carried out from an idea supported by contributors to its representation in the modeling tool.

A first question one might ask is: "Why is stakeholder involvement important when discussing energy scenarios?" First, most stakeholders can provide additional expertise to the technical and economic hypotheses as well as initiate discussions around sensitive issues. Second, the exchanges with stakeholders bring to light the main cleavages and obstacles to reaching a decarbonized society. Thus, the dialogue can lead to finding a common ground for possible solutions and outlining a robust strategy. Finally, consultation with stakeholders enhances the ownership of the created scenarios by the stakeholders.

In conclusion, there are many reasons why stakeholders should be consulted and if possible actively integrated in the scenario-making process. Today, the challenge is to avoid limiting the influence of stakeholders to a non-interactive communication (as in the case of online consultations). If scenarios aim at representing the contributions of stakeholders, a deeper thought has to be given to the design of the process to make it interactive. Gathering people for multi-stakeholder discussions, collecting their contributions and then elaborating the scenario behind closed doors can be a source of disengagement for participating stakeholders.

Therefore, the innovation of the ENCI-LowCarb[5] project resides besides the resulting energy scenarios in the process itself. The project hypothesis consisted in stating that if national stakeholders can recognize their contributions (even if those were amended by the contributions of others) in the resulting scenarios they would eventually be more supportive of this scenario than in a case where a non-transparent procedure was followed. Using collaborative procedures can increase stakeholders' acceptance and generate political support for energy scenarios and the resulting policy measures. Reaching this positive outcome also implies more involvement for both stakeholders and modelers – particularly in terms of time and shared understanding of the issues at stake and of the functioning of the used modeling tool.

A transparent stakeholder consultation process requires the existence of a common ground: model parameters and input variables of the model have to be carefully translated into tangible, real-life, implications which stakeholders can assess. The considerations emerging from the stakeholder

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[5] Engaging Civil Society in Low Carbon Scenarios – financed by FP7 cooperation – www.enci-lowcarb.eu

consultation can then be translated back into technical model parameters, i.e. political framework conditions, which will result in different low carbon energy system scenarios. This "translation work" is necessary to work with such modeling tools and needs a considerable effort of communication to avoid the feeling that all contributions are entering a black box without any traceability.

The aim of the ENCI-LowCarb Projet was to develop a collaborative scenario creation methodology and to develop scenario for France and Germany based on a transparent integration of contributions of national stakeholders in both countries.

2. Project phases

The project team of ENCI-Lowcarb was composed by research institutes and NGOs:
- Potsdam Institute for Climate Impact Research (PIK) and International Centre for Research on Environment and Development (CIRED),
- Climat Action Network France, Germanwatch and International Network for Sustainable Energies – Europe (INFORSE Europe)

Table 1. Phases in the collaborative scenario definition process within the ENCI LowCarb project.

	Phase 1	Phase 2	Phase 3	Phase 4
Objective	Intra-group development of the project team	Model building "What is technologically possible?"	Stakeholder workshops "What is socially desired?"	Synthesis, communication of scenarios
Leadership	Fragmented	Research Institution for sub-team in each country	NGO for sub-team in each country	Joint responsibility
Events	Kick-off meeting, Planning workshop	Expert workshops, Planning workshop	Repetitive CSO stakeholder workshops	Synthesis workshop, Communication
Deliverables / Output	"Wish-Lists" and feedback	Workshop summaries, model with description	Workshop summaries, national scenarios	Country reports, Comparative report
Time Horizon	6 months	12 months	12 months	6 months

ENCI LowCarb had two main project objectives: developing a reproducible methodology for engaging civil society, and preparing the German and French integrated energy system scenarios.

Phase 1 - Intra-group development of the project team

Albeit the intra-group development of project teams is a fairly standard procedure, a conscious group-formation process is of particular importance for collaboration across project partners from different communities. A suitable organizational structure is proposed in Figure 1. It resembles a matrix structure and enables vigorous communication flows between all project partners; the color codes visualize the different communities and countries. Tuckman (1965)[6] observed that groups generally develop by passing through four distinct stages: forming, storming, norming and performing. Given project partners from different communities with their respective cultural backgrounds, the first three stages need special attention for being successful in the fourth.

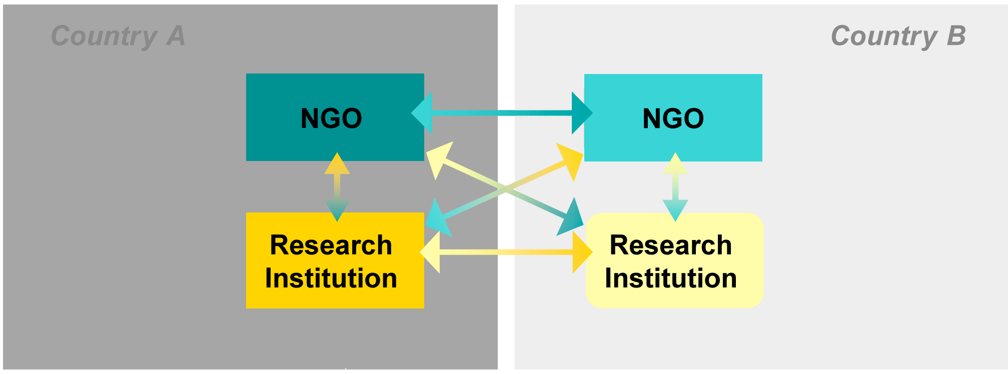

Figure 1. Organizational structure during Phase 1 of the collaborative scenario definition process.

A promising format to foster viable cross-cultural communication is to employ formal "wish-lists". The research institution (the quantitative modeler) receives features that the NGO partners would like to see in the model and what kind of results they expect. The social scientist receives ideas on how social acceptance is defined and will be explored, interpreted and measured. The NGO member receives considerations on what kind of stakeholders to consult. Thereby, each project partner gets a good understanding on how the others *perceive* his/her discipline. Each project then presents what he/she originally planned to contribute in the project and relates this to the "wish-list" items.

Finally, in thematic sessions, the history and status quo of the domestic energy system can be presented, so one learns facts and *context* of the other country's challenges. During the "wish-list" process, the project partners have a chance to develop a common language and gain realistic expectations of the abilities of the quantitative model, the concept of social acceptance and the stakeholder landscape. In repetitive exchange, project partners develop a joint idea of the research methods they will employ. In the end they pass the norming stage of group development, characterized by cohesiveness and in-group feeling, on to the performing stage, during which group energy is channeled into the task (Tuckman 1965).

Phase 2: Technological Framework Conditions

Within the ENCI-LowCarb project, one challenge was the use of macro-economic hybrid models for the scenario design task (IMACLIM-R[7] and REMIND-R[8]), which are often characterized as "black-boxes"[9]. This implies at least a basic introduction[10] to the model dynamics at the attention of the NGO project partners and the invited experts and stakeholders: What are the main mechanisms? What is the degree of detail of the sectoral representation? What are exogenous and endogenous variables? etc. The form of the modeling tool indeed shapes the form of the dialogue.

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[6] Tuckman, B 1965, 'Developmental sequence in small groups', *Psychological Bulletin*, vol. 63, no. 6, p. 384–99. doi:10.1037/h0022100
[7] http://www.imaclim.centre-cired.fr/spip.php?article129&lang=env
[8] http://www.pik-potsdam.de/research/sustainable-solutions/models/remind
[9] Sandrine Mathy, Meike Fink, Ruben Bibas (2011): "Quel rôle pour les scénarios Facteur 4 dans la construction de la décision publique ?", Revue Développement Durable et Territoires, Numéro Spécial sur le Facteur 4; Vol. 2, n° 1 | Mars 2011: http://developpementdurable.revues.org/8802
[10] A description of the model dynamics of Remind-D and Imaclim-R is part of the following chapter.

Large and complex quantitative models are a very powerful tool for pursuing integrated system analyses, however, the models and their output are often meaningful only to the expert or insider. Outsiders are not trained to judge the quality and validity of model results, and either have to believe the modelers, or not. During the ENCI LowCarb project, it was very important for the NGO members to learn more about quantitative models in general, and the models of the project partners in particular, so that modeling results can be put into perspective. It was a rather time-intensive process for the quantitative modelers to explain the models and was perceived as a real cross-cultural communication effort. During this process, it was very enlightening for the modelers to learn about the requirements from an NGO perspective, which sometimes differs substantially from academic peer group discussions.

In France and Germany sectoral expert meetings were organized in order to assess the degree of economic and technical realism of the modeling tools and to correct and to update exogenous hypotheses (costs, potentials, investments, learning curves etc.) as well as dynamics of the models itself: investments in the electricity sector or the dynamics of the residential sector. The task is to refine the national quantitative models and bring them to a stage, in which they are applicable to stakeholder consultations, fulfilling as many "wish-list" items as feasible, driven by the overarching question of "What is technically possible in the future?". Figure 2 proposes an organizational structure during Phase 2; with the core structure prevailing, but now the national sub-teams, indicated in green, have formed a tighter entity. This ideally results from the intense communication flows during Phase 1. The yellow shading of the consulted experts symbolizes the notion that they will most likely be closer to the researchers in terms of "professional culture" than to NGO members.

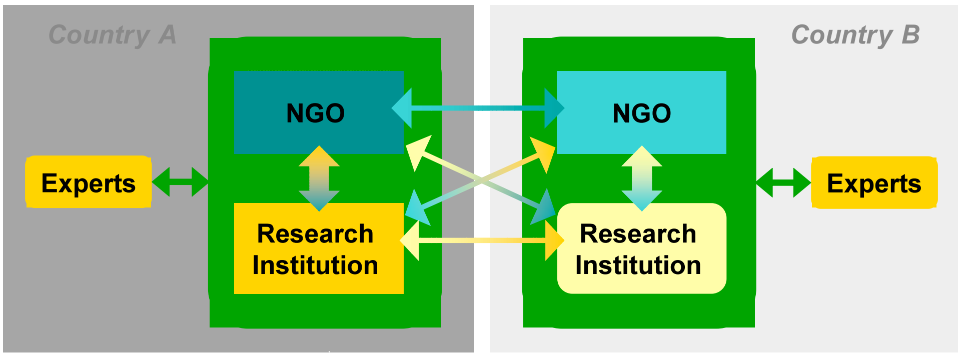


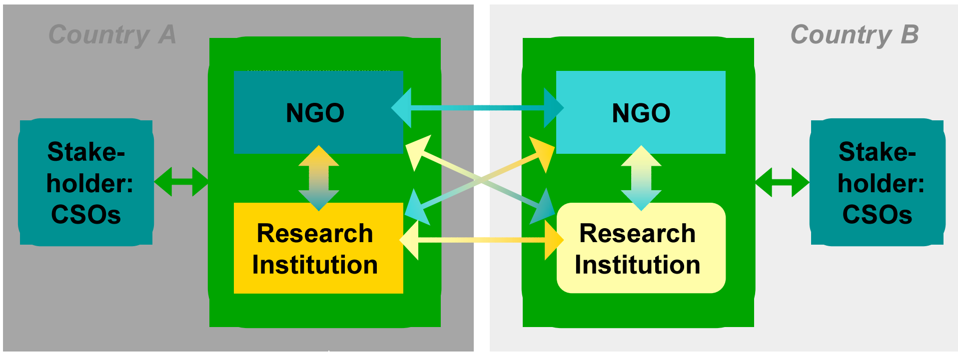
Figure 2. Organizational structure during Phase 2 of the collaborative scenario definition process.

The modeling teams learned a lot and sometimes revised the models according to the experts' opinions. For the NGOs, it was important to point out the sometimes questionable neutrality of experts, who are in fact also stakeholders, e.g. technical subjects like the necessary length of new transmission lines are a politically critical subject and even experts are not able to exclude this dimension from their opinions. It was also important for the NGOs to realize that the modeling tools were not static "scenario machines" but based on a "work in progress principle".

Phase 3: Political Framework Conditions and Corresponding Scenarios

A central issue in Phase 3 of the collaborative scenario definition process is to apply a framework that makes it possible to integrate in transparent way stakeholder contributions in the scenario modeling process. The term stakeholders refer to societal actors like trade unions, consumer associations, private businesses, energy companies etc. Figure 3 proposes an organizational structure: The blue shading of the contributing stakeholders indicate that they are culturally close to the NGO project members; these indeed serve as facilitators in a two-step interaction.

Figure 3. Organizational structure during Phase 3 of the collaborative scenario definition process.



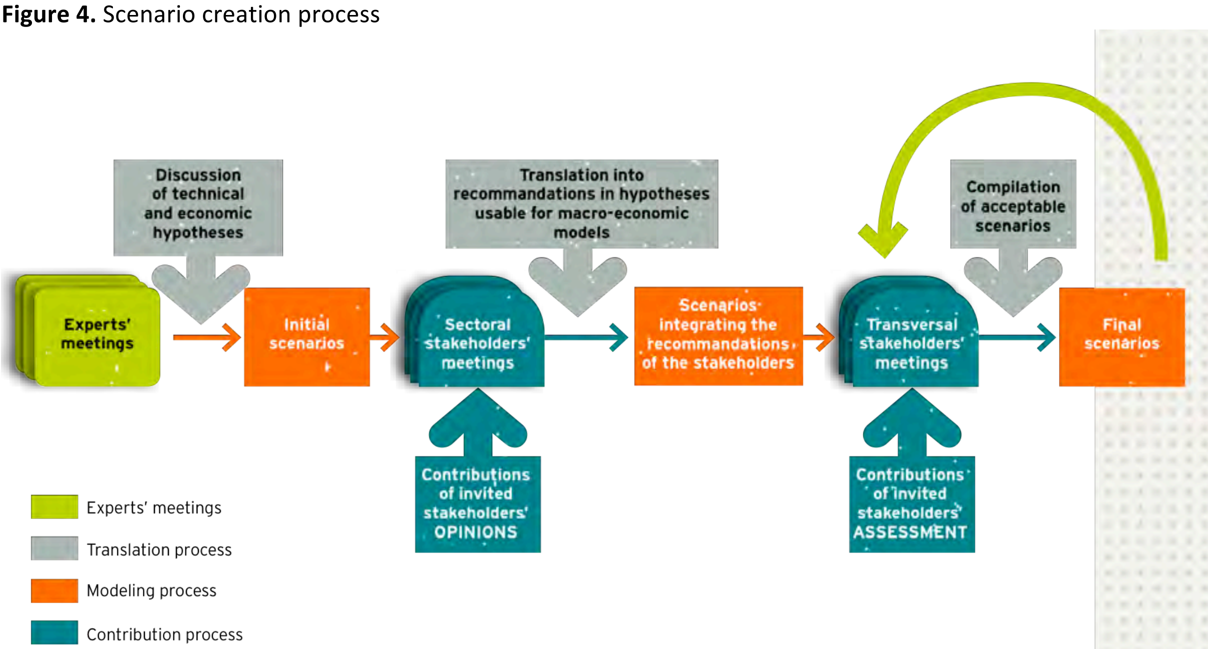
Obviously the practical design and the content of the stakeholder workshops that were organized during phase 3 of this process is guided by the limits of the modeling tools. This is why this project phase is diverging in France and Germany; both teams using different types of hybrid models (short description of the modeling tools in the following chapter).

Project process in France

The collaborative scenario creation process within phase 3 of the project in France was divided in different steps:

1. Stakeholder mapping - Identification of the national stakeholders
2. Organization of sectoral stakeholder meetings
3. Translation of stakeholder contributions in modeling parameters
4. Organization of a transversal feedback seminar

Figure 4. Scenario creation process



1. Selection of the stakeholders

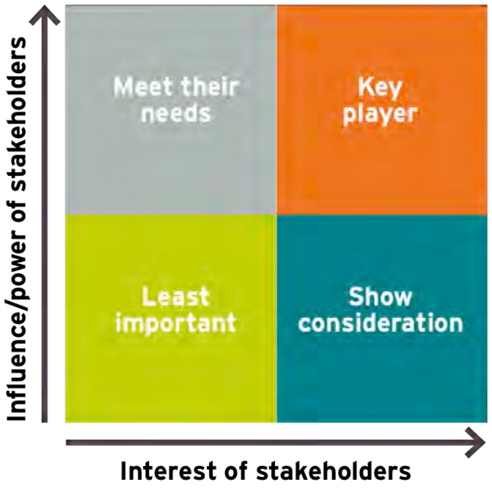


Figure 5. "Power versus interest grids"

In order to select and to invite those stakeholders who play an essential role in the energy sectors at stake (residential, transport, electricity), a stakeholder mapping via a "power-interest-grid" was adopted. Based on this analysis, main stakeholders were identified and a contact list was established. "Power versus interest grids typically help determine which players' interests and power bases must be taken into account in order to address the problem or issue at hand."[11]

The aim of the ENCI-Project was to select mainly those stakeholders situated in the quadrants to the right: "Key-Players" and "Show consideration" (Figure 5). As the evaluation concerning the "interest and influence" of specific actors is highly personal, the interviews were repeated with different experts of the concerned sector in order to crosscheck the evaluations.

Structure of the interviews:

- Discussion on the main challenges of the specific sector
- Establishment of a list of actors, development of a typology of those actors (private companies, ministries, associations, trade unions, banks…)
- Mapping of the identified actors on the power-interest grid

2. Organization of the stakeholder workshops

In order to create scenarios with a high degree of "stakeholder acceptance" the project team ENCI-LowCarb invited the selected representatives of national stakeholder organizations to sector specific meetings (transport, residential, electricity etc.). During these meetings, stakeholders could express their vision on the evolution of technology choices, policy measures and economic incentives necessary and acceptable to reduce CO2 emissions.
The meetings were recorded in order to collect a maximum of viable information, all stakeholders answered a questionnaire and minutes were taken from the discussions.

It was decided to limit the number of stakeholders to 15 to foster in-depth discussions.

The meetings were divided in three steps:

1. Presentation of the project methodology
2. Open discussion concerning the main sector specific topics
3. Detailed presentation of several selected subjects and discussion with the invited stakeholders

[11] Bryson, J. (1995) Strategic Planning for Public and Nonprofit Organizations, San Francisco, CA: Jossey- Bass

For each of the subjects under point 3 a questionnaire was developed. Based on the answers of the stakeholders to these questionnaires, which were collected at the end of the meetings and the content of the ongoing, moderated discussion on the subjects, energy scenarios were modeled.

3. <u>Translation of stakeholder contributions in modeling parameters</u>

Between the evaluation of the contributions of stakeholders and the modeling exercise, an important step was the translation of the stakeholder visions into model parameters.
The information gathered within the sector specific stakeholder meetings was translated by the project team in model parameters and added together to a first version of the scenario. Points of disagreement were laid open and translated in different scenario variants.

Example translation process: residential sector – refurbishment
One of the main obstacles for the refurbishment of houses identified by the stakeholders is the still predominant aversion of homeowners to refurbish their houses or apartments even if many financial incentives exist. The aversion is even higher if one is only tenant. A barrier for owners is that the access to tax incentives and subsidies depends often on high personal financial contribution. Even the access to a zero interest loan is difficult without collaterals. The stakeholders recommended solutions to overcome this barrier: the creation of an obligatory refurbishment fund for jointly owned buildings and a long-term third party financing. As these solutions cannot be integrated one-to-one into the modeling tool, alternative modeling strategies had to be developed. For instance it is possible within the Imaclim-R tool to change the specific “risk-aversion level” of the different agents (house owners, tenants etc.). The refurbishment obligation did not reach consensus of the majority of stakeholders. However, an important minority was in favor. In addition, it can be a very impactful tool for triggering the needed structural change in the residential sector. Therefore, the refurbishment obligation was included in the less consensual, more ambitious scenario.

4. <u>Organization of a transversal feedback seminar</u>

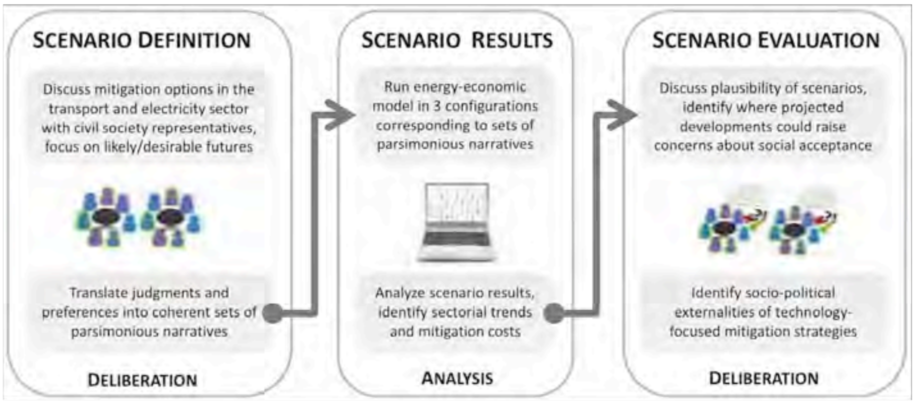
As the first round of stakeholder meetings was sector specific, the second one was transversal in order to overcome the artificial separation of energy system related questions between sectors. It is difficult to overlook existing interactions between transport and residential choices concerning topics like “urban sprawl” or electricity and housing related issues considering the question of “electric heating”. However, it was important to break down the energy system in “sub-sectors” from the beginning in order to be able to define clear visions and policies.
The main objective of the transversal meeting was to get a feedback on the first version of the scenario. The stakeholders’ comments were then incorporated into the model. Points of disagreement arising from the evaluation of the outcomes of the first meetings were presented in the form of scenario variants.
Unfortunately, the emissions reduction in the scenario only based on policy measures that are acceptable in the eyes of at least half of the stakeholders was too low to achieve neither the necessary reduction consistent with the recommendations of the IPCC nor the French objective for 2050 – a reduction about -75% of the emissions against 1990.
Indeed, the policy measures that were judged acceptable only achieved a CO2 emission reduction about 68%.
Within the ENCI-LowCarb project we decided to present in a transparent manner additional measures that are not considered acceptable by a majority of the stakeholders but which are necessary to achieve ambitious climate targets. These measures need further political discussion

beyond the limits of the ENCI-LowCarb project. The main objective of this transversal meeting was to get a feedback on the initial scenario from the same stakeholders that were invited to the first round of sector specific meetings. The comments of the stakeholders (during the meeting and by e-mail) were then again reintroduced in the model.

Project process in Germany

A central issue in Phase 3 of the collaborative scenario definition process was the elaboration of different and potentially controversial political framework conditions with relevant CSO stakeholders (Figure 6). The political framework conditions relate to the quantitative model by applying the aforementioned translation rules from model parameters to "real-world implications". Coherent sets of political framework conditions form one scenario, differing with respect to the articulated level of social (un-)acceptability of mitigation options. The integrated scenarios are again evaluated by the CSO stakeholders.

Figure 6. Stylized overview of the applied scenario creation process



Before inviting CSO stakeholders, the sub-national project teams identified sectors of the domestic energy system that are of particular interest or controversy regarding social acceptance. Together with a professional and neutral moderator, the national sub-teams developed concrete workshop agendas. The social scientist selected suitable methods for capturing stakeholder's assessments during the workshops. A practical format that was chosen was a questionnaire with Likert scales (Likert 1932)[12], measuring the level of agreement or disagreement of the respondent towards specific statements. The specific statements were then translated "real-world implications" and postulate particular and tangible developments[13]. Per item, two Likert scales were employed: Stakeholders were asked to indicate whether they find the proposed development *realistic* and once whether they would *welcome* it from the point of view of their organization. Stakeholders were unlikely to express a uniform opinion, so several different sectoral "scenario building-bricks" in terms of political framework conditions emerged from the workshops.

Due to the small sample size, the data is not suited for econometric analysis. Instead, descriptive statistic measures of central tendency were employed. Mean, standard deviation, and mode give an indication of whether the perceptions of likely and desirable developments diverge and whether

[12] Likert, R., 1932. A technique for the measurement of attitudes. Archives of Psychology 140, 1–55.
[13] An example from the transport sector workshop of the ENCI LowCarb project is "Cycling and Walking will contribute substantially to the Modal Split. Please indicate your perception whether this is *realistic* and, separately, *welcome*, from the point of view of your organization on a 7-point scale from Yes to No.".

there is a degree of agreement across stakeholders. Along with the qualitative information obtained during the discussions as well as expert judgments from the literature, the elicited data serves as a basis for generating a set of parsimonious narratives on likely developments, and one on desirable developments in the transport and electricity sector. Finally, the modeling team translates these into corresponding input parameters for the model REMIND-D.

During the second sectoral stakeholder workshops, ideally attended by the same CSO representatives, the developed scenarios were presented, discussed, and evaluated. This feedback loop ensures that the social acceptance considerations are actually realized and gives the CSO representatives a chance to indicate their assessment of social (un-)acceptance of the integrated scenarios.

The stakeholder workshops were the focal point toward which all efforts in the ENCI LowCarb projects were directed to. However, it was absolutely necessary to go through the first two phases of intra-group and model development for reaching a stage in which the project team was enabled to understand the stakeholders' requirements and translate them into coherent quantitative model scenarios. The preparation of the first stakeholder workshop was very demanding, as the agenda set here would determine the success of the collaborative procedure. The translation rules, from "the model" to "the real-world" and vice versa, had to be thematically summarized to determine those energy sectors (e.g. transport, electricity, heat) for which a feedback process was technically possible. It would not have been adequate to promise the stakeholders implications of low carbon scenarios that in the end cannot be represented in the quantitative model. For developing the agendas of the first sectoral CSO stakeholder workshops, the project team had to strike a balance between anticipating the areas in which social acceptance is problematic, and being prescriptive in the selection of topics. Furthermore, it was challenging to decide on how the stakeholder assessments would be collected, formalized, and grouped for constructing the integrated scenarios.

Phase 4: Synthesis

The last Phase is concerned with the synthesis of results obtained throughout the collaborative process. The project results were presented at a project conference in Paris and during other conferences and seminars to policy makers, stakeholders, and the wider public. The project publications were published on the project websites (www.lowcarbon-societies.eu and www.enci-lowcarb.eu) and send via e-mail and mail to national and European stakeholders.

Possibly valuable extensions for the collaborative process are to evaluate the political feasibility of the scenarios' political framework conditions and to elaborate the reasons for social (un-)acceptance of specific mitigation options in more detail. Here, one could extend the socio-political point of view adopted during the collaborative scenario definition process, and analyze market and community acceptance.

3.1 German scenarios

1.2REMIND-D –description of the model dynamics

REMIND-D is a Ramsey-type growth model that integrates a detailed bottom up energy system module, coupled by a hard link (Bauer et al., 2008). It facilitates an integrated analysis of the long-term interplay between technological mitigation options in the different sectors of the German energy system as well as general macroeconomic dynamics. A detailed description of REMIND-D is provided in Schmid et al. (2012). REMIND-D builds on the structural equations of the state-of-the-art IAM REMIND-R (Leimbach et al., 2010)[14], which are reported in Bauer et al. (2011)[15]. The objective of REMIND-D is to maximize welfare, i.e. the intertemporal sum of discounted logarithmic per capita consumption.

In general all types of models, for example climate models, energy-system models or economic models, feature a strong reduction of complexity in comparison to the real world. They are stylized illustrations of the most important mechanisms of action, which can be observed in reality. In order to solve a mathematic problem numerically, this approach is unavoidable. In this case of a coupled macroeconomic energy-system model certain underlying assumptions are made to achieve such a reduction of complexity. These assumptions are shortly outlined below. In macroeconomic modeling they are current praxis. In spite of the sometimes strongly simplifying assumptions, models help analyzing complex thought experiments which results are relevant in reality. Depending on the specific type of model, restrictions and strengths can vary as well as the question that could be answered.

An underlying assumption of the macroeconomic production function of Remind-D regards Germany as a closed economy without individual actors demanding or producing any commodities. The national GDP, produced from the three production factors: capital, labor, and energy, has to cover the costs of energy systems and investment in the macroeconomic capital stock. The rest remains to increase welfare. Thereby the welfare of the whole society is being maximized, not only the GDP. There is one representative household and furthermore full employment is assumed. Of course these adoptions are not in accordance with reality; nevertheless they are necessary for optimization models. Restrictions resulting from this remain especially that Remind-D can neither analyze effects on employment of climate change policies nor does it consider the role of individual actors (companies or households) or the question of distribution. Moreover, the algorithm of optimization leads per se to more climate mitigation costs in ambitious scenarios of CO_2 emission reduction, as it would be the case in less ambitious scenarios.

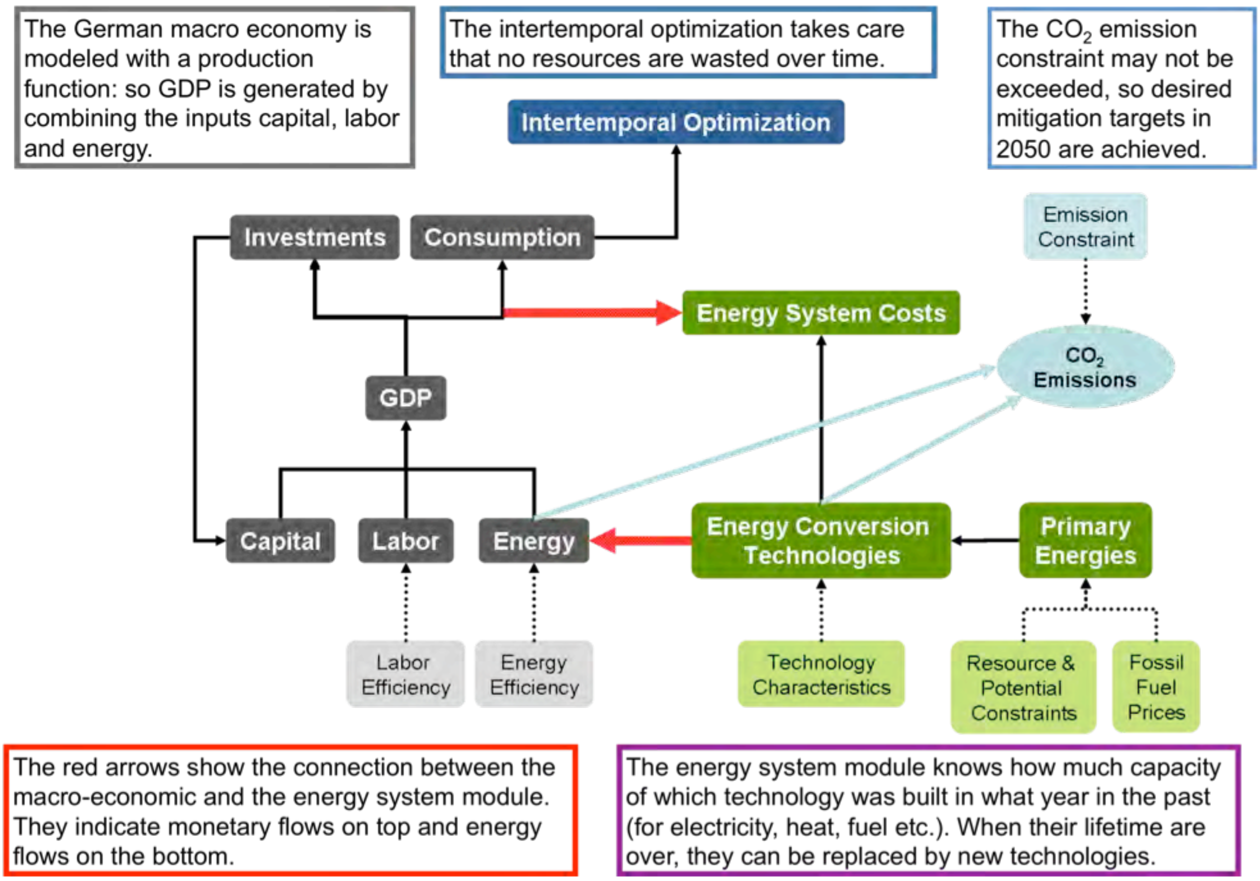
Strengths of the Remind-D model compared to other macroeconomic/energy-system models refer especially to the mechanism of optimization and furthermore to the endogen representation of the sectors in the energy system and macroeconomics. While not included in other models, Remind-D offers various mechanisms of feedback. Additionally the model allows an analysis of the long-term effects of investment decisions. Thereby the model results set a "benchmark" how a transformation, which generates optimal (maximal) societal welfare, could look like in the best case. Thus they are no prospects but projections, which are dependent of certain assumptions. According to German efforts

[14] Leimbach, M., Bauer, N., Baumstark, L., Edenhofer, O. (2010): Mitigation Costs in a Globalized World: Climate Policy Analysis with REMIND-R. Environmental Modeling and Assessment 15, 155-173.

[15] Bauer, N., Baumstark, L., Haller, M., Leimbach, M., Luderer, G., Lueken, M., Pietzcker, R., Streer, J., Ludig, S., Koerner, A., Giannousakis, A., Klein, D. (2011): REMIND: The equations. Tech. rep., Potsdam Institute for Climate Impact Research.

on climate protection such indications are conceptually helpful. Consequently, statements can be made referring to the impact of different frame conditions in differing scenarios on the allocation of emission reduction on sectors of the energy system. Furthermore it can be shown which technologies could contribute to emission reduction and how a welfare-optimizing transformation could look like.

Figure 7. Model dynamics – REMIND-D



Mitigation is enforced by means of a strict emission budget of 16 $GtCO_2$ over the time horizon of analysis, 2005-2050, resulting in roughly 85% emission reduction. The budget approach is inspired by the work of Meinshausen et al. (2009)[16]. When budgeting emissions, the model can choose annual emissions endogenously, allowing for exibility in the selection of mitigation options. In REMIND-D, future scarcities of energy carriers and CO_2 emissions are anticipated through shadow prices, implying perfect foresight. Hence, REMIND-D features optimal annual mitigation effort and technology deployment as a model output. Available mitigation options fall into four categories: (i) deploying alternative low-emission technologies, (ii) substituting final energy and energy service demands, (iv) improving energy efficiency, and (v) reducing demand. The model generally avoids the latter, as demand reductions have negative impact on GDP.

The energy system module of REMIND-D is endowed with a variety of alternative technologies that it may deploy endogenously. Endogenous capacity deployment is subject to potential and resource constraints for renewable primary energies, and fuel costs for fossil primary energies. The Carbon Capture and Sequestration (CCS) technology is available for the electrification and liquefaction of coal, lignite, gas and biomass. According to the decisions of the German Government, nuclear

[16] Meinshausen, M., Meinshausen, N., Hare, W., Raper, S. C. B., Frieler, K., Knutti, R., Frame, D. J., Allen, M. R. (2009): Greenhouse-gas emission targets for limiting global warming to 2°c. Nature 458 (7242), 1158-1162.

capacities are phased out until 2022. Domestic renewable energy potentials include lignocelluloses, oily and sugar & starch biomass, manure, deep and near-surface geothermal, hydro, wind onshore, wind offshore, and solar irradiation. The model accounts for fluctuation of renewable electricity generation on short time scales explicitly via a residual load duration curve approach (Ueckerdt et al., 2011)[17].

2.2 Ambitious and acceptable mitigation scenarios for Germany

Three model-based mitigation scenarios for Germany were developed within the ENCI-Lowcarb project. All three achieve 85% CO_2 emission reduction in 2050 relative to 1990. These scenarios were defined and evaluated in a participatory process with CSO stakeholders from the transport and electricity sector. During dialogues, their preferences on future mitigation options were discussed and elicited. Along with findings from the literature, the input from the CSO stakeholders built the basis to generate parsimonious narratives on possible future developments of key variables in the transport and electricity sector.

These parsimonious narratives, consisting of contextual information on anticipated key future developments and corresponding quantitative projections for boundary conditions, were central to the scenario definition process applied within the ENCI-Lowcarb project.

Three scenarios emerged out of the stakeholder process:

The **'continuation' scenario** is characterized by a set of developments that are deemed highly likely by all participants. These include the dominance of motorized individual transport, unabated coal electrification, moderate energy efficiency growth rates, local resistance against windmills and transmission lines as well as the continuation of coupled freight transport and GDP growth rates. Already coal electrification and fossil fuel based freight transport mileage induce 8.8 Gt CO_2 of committed emissions. This carbon lock-in accounts for 55% of the total CO_2 emission budget over the time horizon of analysis, from 2005 to 2050. As a consequence, non-technical mitigation options slowing down economic growth are exploited by REMIND-D for meeting the budget constraint. These include significant energy service demand reductions in passenger transportation as well as final energy demand reductions for electricity and the provision of heat. Additionally bound to moderate energy efficiency improvements, the 'continuation' scenario exhibits mitigation costs of 3.5 % cumulative GDP losses over the period 2005-2050, as compared to a reference case that achieves 40% CO_2 emission reduction in 2050 relative to 1990.

The two **'paradigm shift'** scenarios reproduce future developments judged as desirable by participating stakeholders. These include a decrease in total freight transport mileage, a shift in the modal split of freight transport sector from road to rail, a substantial increase of public and non-motorized transport in the modal split of passenger transportation, a phase-out of conventional coal electrification until 2020, a rapid and large-scale deployment of renewable electricity generation and transmission line capacities as well as a fourfold increase in energy efficiency growth rates. REMIND-D immediately exploits these mitigation options whereby mitigation costs decrease by more than half when compared to the 'continuation' scenario, with 1.4 % of cumulative GDP losses. The **'paradigm shift+'** scenario, which additionally allows for the use of CCS and large-scale biofuel production, achieves even lower mitigation costs of 0.8 %. However, CSO stakeholders remain

[17] Ueckerdt, F., Brecha, R., Luderer, G., Sullivan, P., Schmid, E., Bauer, N., Böttger, D. (2011): Variable renewable energy in modeling climate change mitigation scenarios. In: Proceedings of the 2011 International Energy Workshop in Standford, US.

skeptical whether these technologies are feasible in large scale, also due to social refusal. Thus the following conclusions can be drawn.

- Model results corroborate that achieving an ambitious mitigation target of 85% German CO_2 emission reduction by 2050, relative to 1990, is technically feasible. However, this research unravels that critical socio-political externalities may pose a significant barrier to ambitious domestic mitigation.
- Deliberative stakeholder dialogues reveal strong discrepancies between likely and desirable future developments in the transport and electricity sector. Increasing fossil-fuel based freight mileage and the continuous electrification of coal, deemed likely but not desirable, will lead a cumulative carbon lock-in of 8.8 Gt CO_2 until 2050, accounting for 55% of the total CO_2 emission budget.
- Model results indicate that enforcing ambitious mitigation targets in the face of this carbon lock-in leads economic growth to slow down and bears severe socio-political externalities. To overcome these trade-offs, the carbon lock-in has to be avoided and, additionally, energy efficiency and renewable deployment growth rates have to increase.
- Participating stakeholders point out that in order to resolve the carbon lock-in, major paradigm shifts are needed, which in turn require concerted political as much as societal will.

In the following 3 examples (evolution of the freight transportation mileage, the role of biofuels and the development of thermal electricity generation capacities) on how the discussions with stakeholders were translated in scenario bricks composing the parsimonious narratives of the 3 developed scenarios.

Table 1: Selected results of the Likert-Scale questionnaire of the CSO stakeholder dialogue on the transport sector. All statements relate to the time horizon until 2050. 1 indicates disagreement, 4 neutrality, and 7 agreement. STD = Standard Deviation, MS = Modal Split, MIT = Motorized Individual Transport, PT = Public Transport

	Likely			Desirable		
Future Development	Mean	STD	Mode	Mean	STD	Mode
Annual t-km truck increases	6.55	0.69	7	3.09	2.25	1
Shift t-km from road to rail	3.73	1.74	3	6.09	1.38	7
Decouple freight&GDP growth	4.09	1.3	3/4	5.90	1.87	7
MS MIT decreases to $\leq 50\%$	3.91	1.64	3/5	4.73	2.28	7
MS PT increases significantly	3.64	1.75	5	5.64	1.63	7
MS cycling&walking increases	4.55	2.07	2/7	5.64	1.97	7
Bioethanol $\geq 50\%$ share	3.33	1.55	2	3.33	2.33	1
Biodiesel $\geq 50\%$ share	3.33	1.79	3/5	3.33	2.33	1
Hydrogen dominant fuel	3.55	1.92	3	3.64	1.45	3

Is an increase of total annual freight mileage unavoidable? Historically, freight transportation and GDP growth rates correlated strongly, however, their causal relationship is not straightforward (Feige, 2007)[18]. As indicated in Table 2, decoupling freight and GDP growth rates by reducing annual

[18] Feige, I. (2007): Transport, Trade and Economic Growth - Coupled or Decoupled? Springer, Berlin Heidelberg.

truck mileage and shifting freight from road to rail is perceived as a desirable mitigation option by CSO stakeholders. Yet, they anticipate annual ton-km (t-km) mileage with fossil-fuel based trucks to increase continuously until 2050. This scenario is corroborated by expert judgments. Lenz et al. (2010)[19], e.g., predict a dramatic increase in diesel truck mileage from 466 Bn t-km in 2005 to 787 Bn t-km in 2030, constituting a severe carbon lock-in. In the 'continuation' scenario, this trend is enforced by an exogenous linear increase of annual freight transport with trucks up to 787 Bn t-km in 2050, as a conservative estimate. However, the CSO stakeholders strongly advocated policy efforts directed at reducing total transport mileage and achieving a shift from road to rail. They claim that viable solutions exist, but lack of political will impedes their implementation. Holzhey (2010)[20] finds that a doubling of freight transport with rail in Germany until 2030 is technically possible, even though concerted investments are required. Consequently, in the two 'paradigm shift' scenarios, it is assumed that freight transport and GDP growth can be decoupled in the future.

Which alternative low-carbon fuels ought to be dominant in the future? Instead of a shift in the mode of transportation, less carbon-intensive fuels for conventional vehicles are another technological mitigation option. CSO stakeholders are controversial about the desirability of first-generation biofuels and doubt that second-generation biofuel technologies (e.g. biofuels from lignocellulose) will be available in large scale. Likewise they doubted the technological feasibility of a hydrogen future (e.g. Fischedick et al., 2005)[21], exploiting overproduction of REG capacities via electrolysis. Since the desirability of these technological options was contested, they are available to the model only in the 'paradigm shift+' scenario.

Which thermal electricity generation capacities are acceptable in the next decades? Due to the phase-out of nuclear until 2022, these generation capacities need to be replaced within the next decade.

CSO stakeholders oppose the built-up of new CO_2 emission intensive coal power plants. Instead, they consider it both likely and desirable to deploy gas power plants, which are not only less CO_2 intensive, but are also better capable of balancing fluctuating REG (dena, 2010)[22]. 47% of total German CO_2 emissions in 2010 were incurred by lignite and hard coal power plants. The option of decommissioning them before the end of their techno-economic lifetime, and replacing them with REG capacities, albeit hardly discussed, constitutes an effective mitigation option. Even though CSO stakeholders judged this option as desirable, they consider it as moderately realistic. To simulate a carbon lock-in from persistent coal electrification, existing hard coal and lignite power plants are subject to a must-run constraint in the 'continuation' scenario. This must-run constraint implies that the coal power plants may not be put out of service before the end of their technical lifetime. A large-scale deployment of the CCS technology was judged as neither particularly likely nor desirable and is hence available to the model only in the 'paradigm shift+' scenario, from 2025 onwards.

Table 2 summarizes the model constraints defining the three scenarios.

[19] Lenz, B., Lischke, A., Knitschky, G., Adolf, J., Ceng, F. B., Stöver, J., Leschus, L., Bräuninger, M. (2010): Shell Lkw-Studie - Fakten, Trends und Perspektiven im Straßengüterverkehr bis 2030. Tech. rep., Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) and Shell Deutschland and Hamburgisches WeltWirtschaftsInstitut (HWWI).

[20] Holzhey, M. (2010): Schienennetz 2025/2030; Ausbaukonzeption für einen leistungsfähigen Schienengüterverkehr in Deutschland. Tech. rep., Umweltbundesamt.

[21] Fischedick, M., Nitsch, J., Ramesohl, S. (2005): The role of hydrogen for the long term development of sustainable energy systems- a case study for Germany. Solar Energy 78 (5), 678-686.

[22] dena (2010): dena Grid Study II - Integration of Renewable Energy Sources in the German Power Supply System from 2015 - 2020 with an Outlook to 2025. Tech. rep., Deutsche Energie-Agentur.

Table 2: Summary overview of the model constraints that define the three scenarios, resulting from the participatory process. FT = Freight Transport, PT = Public Transport, MS = Modal Split, REG = Renewable Electricity Generation, PP = Power Plant, CCS = Carbon Capture and Sequestration.

Model Constraint	Continuation	Paradigm Shift	Paradigm Shift+
Decoupling FT&GDP	no	yes	yes
PT share in MS	constant	increase	increase
REG potential	medium	high	high
Energy efficiency	medium	high	high
Decommission Coal PP	no	yes	yes
CCS by 2025	no	no	yes
Biofuel potential	low	low	high

2.1. Scenario Results

The model REMIND-D finds an optimal solution for each of the scenario configurations, despite the strict emission budget of 16 $GtCO_2$. All scenarios achieve 85% CO_2 emission reduction in 2050 relative to 1990; corroborating the finding that ambitious domestic mitigation in Germany is technically feasible. Yet, the scenario results in the following Sections indicate that a continuation of historical trends in the freight and electricity sector, deemed likely, leads to a carbon lock-in that renders ambitious mitigation extremely challenging.

2.2. CO_2 Emissions by Sector

Mitigation shares of the three sectors transport, electricity and heat structurally differ across scenarios, as illustrated in Figure 8. The y-axis measures annual CO_2 emissions in Mt CO_2, whereas the x-axis displays the three sectors for each scenario. Time is indicated by color-coding. First, Figure 8 visualizes the structure of the sectoral relationships in one scenario, highlighted by the connecting lines in the years 2005, 2020 and 2050. Second, the sectoral trends over time can be compared across scenarios. And third, it emphasizes the speed of the transformation: the larger the white areas are within a bar, the faster is the CO_2 emission reduction between two time steps. CO_2 emission reductions between 2005 and 2015 are similar in all scenarios - a fast decrease of emissions of 29-32% in the electricity sector, 29-32% in the industrial, residential and commercial heat sectors, and 4-9% reduction in the transport sector. From 2015 onwards, there are structural differences between the developments in the 'continuation' and both 'paradigm shift' scenarios. The speed of emission reduction in the electricity sector stagnates in the 'continuation' scenario, due to the must-run constraint for the existing lignite and hard coal power plants. Additional committed emissions in the 'continuation' scenario stem from the prescribed increase in freight transport with trucks.

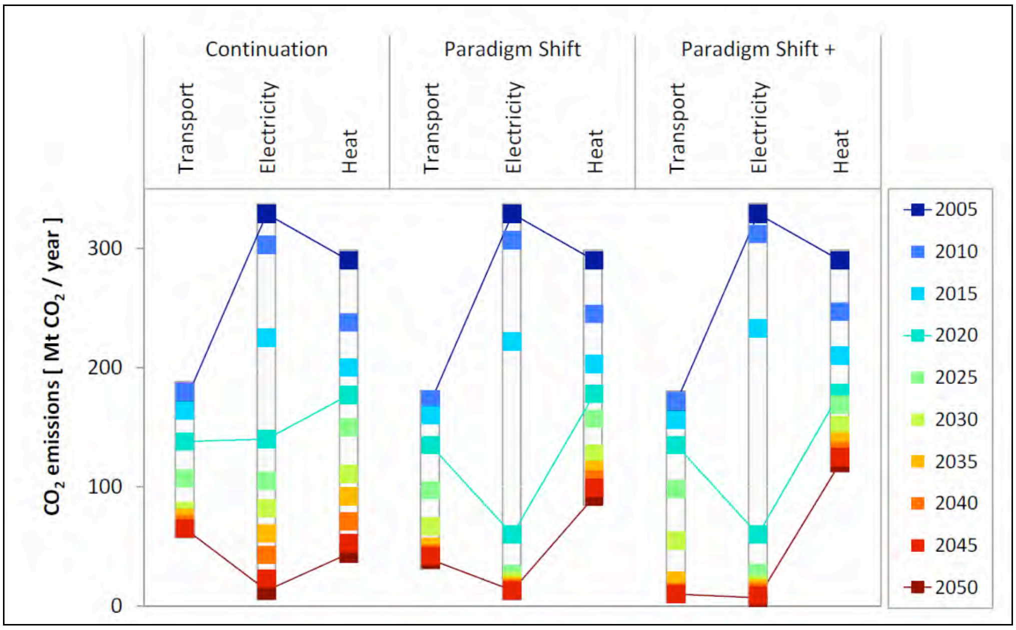


Figure 8. Annual CO_2 emissions from energy in Germany for 2005-2050 in Mt per year, by scenario and sector. These model results are obtained with REMIND-D.

The total carbon lock-in over the time horizon of analysis, 2005-2050, amounts to 6.15 $GtCO_2$ from coal electrification and 2.67 $GtCO_2$ from fossil fuel based freight transport. In sum, these 8.8 $GtCO_2$ deplete 55% of the total emission budget. Consequently, the heat sector needs to deliver a substantially higher mitigation effort in the 'continuation' scenario than in the two 'paradigm shift', in order to meet the total CO_2 emission budget. In the two 'paradigm shift' scenarios, the electricity sector decreases CO_2 emissions much faster than in the Continuation scenario delivering a reduction of 80% between 2005 and 2020. Therefore, more CO_2 emissions can be incurred in the heat sector, providing process heat for industry and residential heating. This structural effect is even more pronounced in the 'paradigm shift+' scenario; here the availability of new low-carbon technologies leads to an almost complete decarbonization of the freight and electricity sectors by 2035. These findings illustrate the advantage of an integrated approach to mitigation modeling, allowing for an analysis of the interplay between different sectors.

2.3. Transport Sector

Until 2050, total CO_2 emissions within the transport sector decrease by 47% in the 'continuation', 73% in the 'paradigm shift' and 93% in the 'paradigm shift+' scenario versus 2005. The majority of annual reductions are achieved during the next two decades, yet the drivers differ across the three scenarios. Clear structural breaks emerge in both modal splits in the two 'paradigm shift' scenarios.

In all scenarios, freight transport by inland water navigation remains constant, as illustrated by Figure 9. In the 'continuation' scenario, freight train capacities also remain at today's levels, however, freight transport with trucks increases continuously, as enforced by the scenario assumption of coupled GDP and freight transport growth rates. As a consequence, the freight sector's annual emissions remain constant at 60-70 Mt CO_2, as the availability of alternative low-emission fuels is limited in this scenario. These committed emissions are avoided in both 'paradigm shift' scenarios. Here, the decoupling indicator (t-km/GDP) does not increase by 20% from 2005 to 2050, but decreases by 20% and 10% respectively. Apart from keeping freight transport mileage constant at today's level, through a restructuring the economic system towards less transport-intensive value chains, mitigation is enabled by massive rail infrastructure expansions allowing for train mileage to tripe until 2030. In the 'paradigm shift+' scenario, the truck mileage remains at higher levels than in the 'paradigm shift' scenario, due to the availability of alternative low emission fuel technologies, e.g. second-generation biofuels and liquefaction of lignite in combination with the CCS technology.

Annual per capita passenger transport decreases from 13,000 km in 2005 to 11,000 km in the year 2050 in both 'paradigm shift' scenarios; the parsimonious narrative foresees that one part of the difference will be substituted by non-motorized traffic, i.e. cycling and walking. In the 'continuation' scenario, however, the per capita p-km are forced to decrease down to 9000 p-km in 2050, due to mitigation pressure induced by the carbon lock-in in the freight and electricity sector.

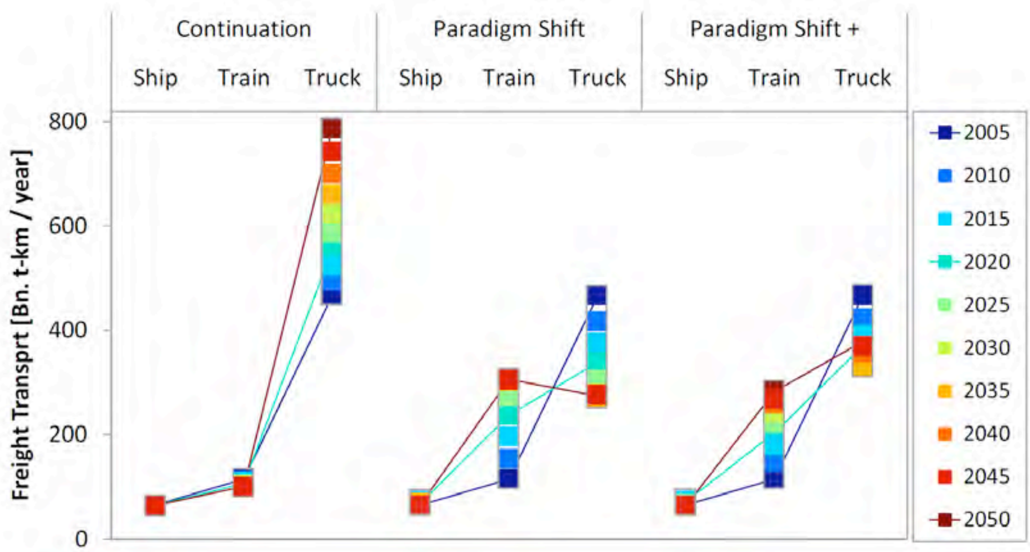


Figure 9. Annual freight transport mileage for 2005-2050 in Bn ton-km (t-km) per year, by scenario and mode. These model results are obtained with REMIND-D.

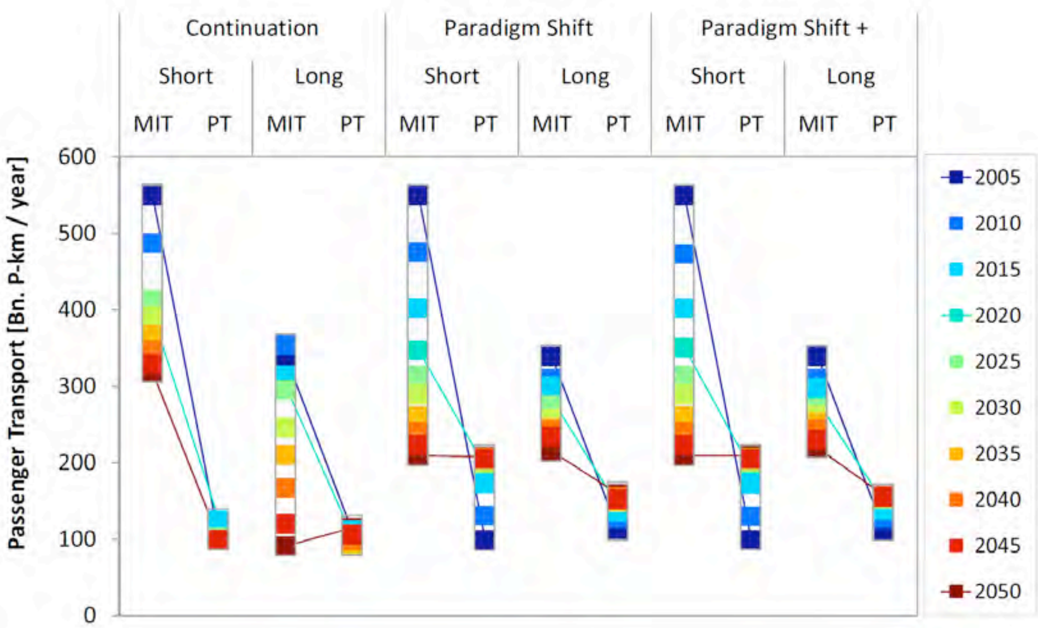


Figure 10. passenger transport mileage for 2005-2050 in Bn passenger-km (p-km) per year, by scenario and mode. These model results are obtained with REMIND-D. MIT = Motorized Individual Transport, PT = Public Transport

The total annual p-km by transport mode for each scenario are illustrated in Figure 10. Here, the structural change in both 'paradigm shift' scenarios becomes evident: MIT decreases until 2050 and

PT steadily increases until 2020, remaining constant thereafter. Hybrid buses, electrified light rail and regional trains deliver additional short distance PT. Together, they account for roughly 50% of the modal split of short distance transport in 2050. Incremental long distance PT will be delivered with electric trains. In all scenarios, anticipated carbon budget restrictions and implicit carbon pricing make conventionally fuelled cars too expensive to operate, so they are phased out entirely until 2030. Diesel cars, predominantly suitable for long distance driving, are first substituted by diesel hybrids and then by hybrid gas cars in all scenarios. Petrol cars are replaced with hybrid-plug in gasoline cars, which are electric cars with a petrol-fuelled rage extender. In the 'paradigm shift+' scenario, they are partly replaced with hydrogen hybrid cars, as hydrogen is produced from lignocelluloses with CCS here, with the ability to extract CO_2 from the atmosphere and producing de-facto "negative" CO_2 emissions. In all scenarios, there is a trend to gradually electrify the transport sector, with the total demand of electricity for transport increasing by several orders of magnitude until 2050, yet never exceeding 15% of total electricity production.

2.4. Electricity Sector

The aggregated technology mix of the electricity sector for the three scenarios is illustrated in Figure 11. In the two 'paradigm shift' scenarios, where the model is given the option to decommission existing hard coal and lignite power plants from 2015 onwards, these capacities are shut down by 2020. They are temporarily replaced by gas turbines, about 25 GW of capacity are built between 2015 and 2020. Once enough REG capacity is installed, the gas turbines go out of service again in both 'paradigm shift' scenarios by 2030. In the 'continuation' scenario, there is no such temporary increase in gas capacities, as existing coal and lignite power plants continue to produce electricity. In all scenarios, REG is rapidly expanded and doubling over the next five years.

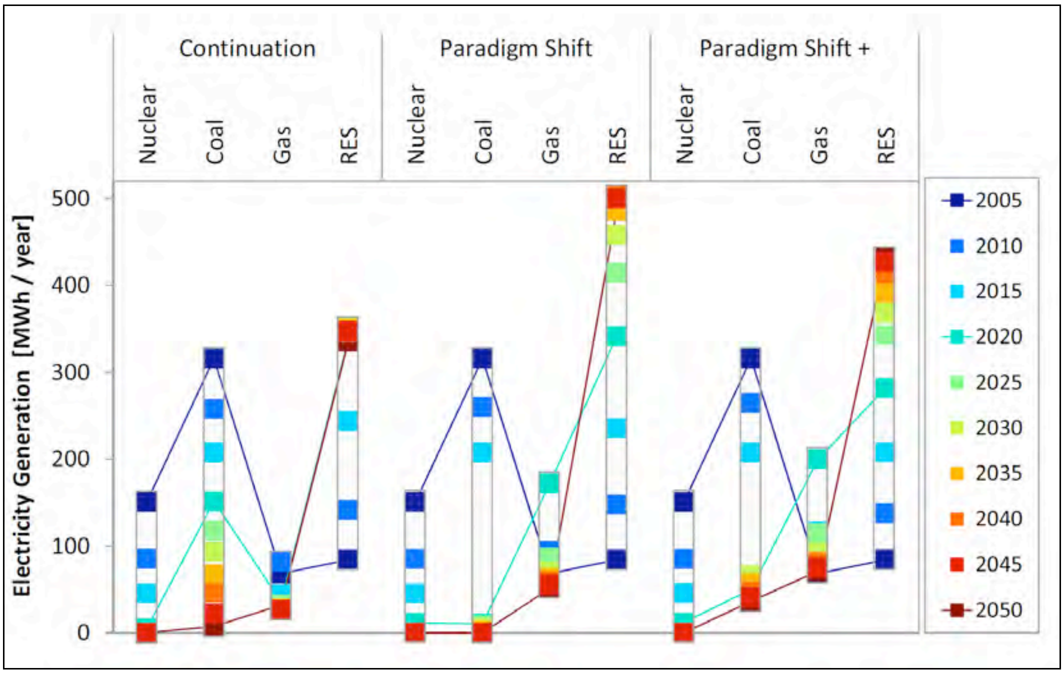


Figure 11: Annual electricity generation for 2005-2050 in MWh per year, by scenario and aggregated technologies. These model results are obtained with REMIND-D.

From 2020 onwards, the installed REG capacities stagnate in the 'continuation' scenario. This is due to the moderate potential in the scenario definition, motivated by a restrictive public attitude that constrains the incremental deployment of RE capacities and transmission lines. Total electricity production is forced to decrease from 620 MWh in 2005 to 375 MWh. Because of the carbon lock-in from freight transport and coal electrification, the model cannot afford to allocate more CO2 from the emission budget to the electricity sector for covering gas turbines. These could provide more balancing capacities so that solar potentials could be fully exploited, which is not the case in the 'continuation' scenario. Instead, REMIND-D opts for the least attractive mitigation option: imposing electricity demand reductions in all sectors, including industry. A consequence of this is a reduction in GDP growth.

In both 'paradigm shift' scenarios, REG capacities continuously expand, especially offshore wind, and total electricity production stabilizes between 530 and 560 MWh. The slightly reduced demand is due to high efficiency growth rates. In 2050, onshore wind capacities reach a maximum of 100 GW in both 'paradigm shift' scenarios. Offshore capacities reach 150 GW in the 'paradigm shift' scenario and 180 GW in the 'paradigm shift+' scenario. Geothermal electricity production also plays a vital role in all scenarios with 20-35 GW installed capacity. REMIND-D installs 110 GW of solar photovoltaic in the 'continuation' scenario by 2050. In the 'paradigm shift' scenarios, other less expensive technologies e.g. wind onshore and offshore, provide sufficient electricity generation potential and solar photovoltaic plays only a minor role. Biomass electrification plays a subordinate role in all scenarios, as REMIND-D prefers to use all available biomass for fuel production. In the 'paradigm shift+' scenario, 14 GW of lignite power plants with the Oxyfuel CCS technology are installed, as well as 25 GW of natural gas combined cycle plants with CCS. When compared to the 'paradigm shift' scenarios, these capacities somewhat reduce the need for REG capacities.

2.5. Mitigation Costs

Comparing the results of two scenarios that differ only with respect to the emission constraint, allows the determination of the effects of different mitigation choices. One measure of economic mitigation costs is the cumulative difference in discounted GDP losses (referred to as cumulative GDP losses hereafter), between two scenario runs that have the same restrictions, except for the size of the CO_2 emission budget. Macroeconomic mitigation costs in terms of cumulative GDP losses for the 'continuation', 'paradigm shift' and 'paradigm shift+' scenario amount to 3.5%, 1.4% and 0.8% between 2005 and 2050. The respective reference case with a larger carbon budget leads to moderate 40-45% CO_2 emission reduction in 2050 relative to 1990. Figure 6 illustrates how cumulative GDP losses between scenarios diverge with increasingly strict carbon budgets. For ease of interpretation, the x-axis displays the respective % of CO_2 emission reduction achieved in 2050 relative to 1990. For moderate mitigation targets up to 65% CO_2 emission reduction in 2050, GDP losses remain below 0.5% in all scenarios. Mitigation costs in this order of magnitude are also found by global IAM analyses (e.g. Edenhofer et al., 2010; Luderer et al., 2012)[23].

[23] Edenhofer, O., Knopf, B., Barker, T., Baumstark, L., Bellevrat, E., Chateau, B., Criqui, P., Isaac, M., Kitous, A., Kypreos, S., Leimbach, M., Lessmann, K., Magné, B., Scrieciu, S., Turton, H., van Vuuren, D. (2010): The Economics of Low Stabilization: Model Comparison of Mitigation Strategies and Costs. The Energy Journal 31 (Special Issue 1).

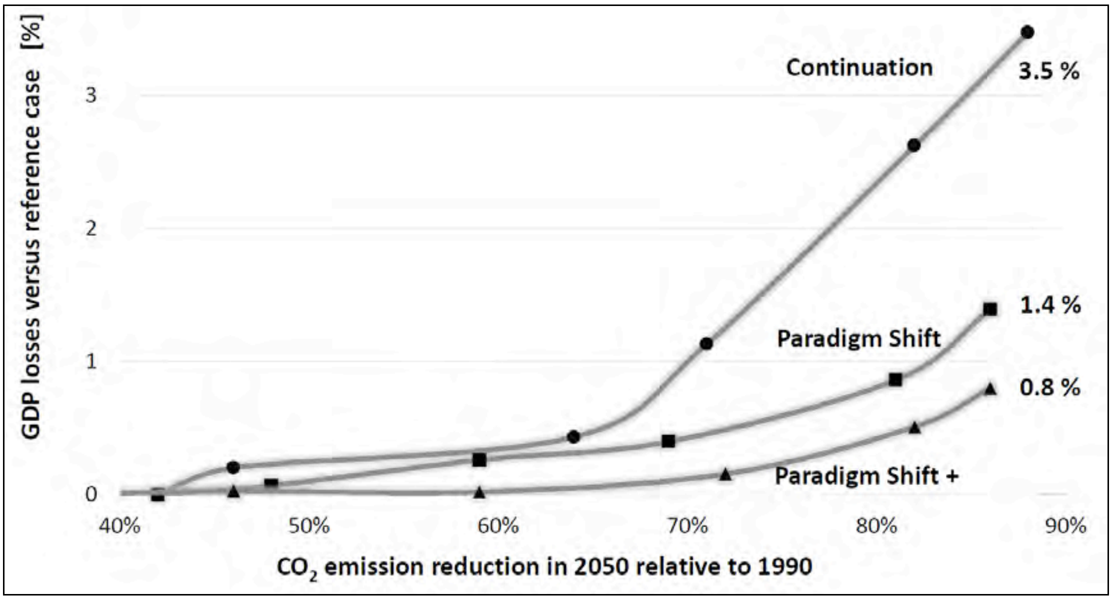


Figure 12: Mitigation cost curve for the three scenarios, in terms of cumulative discounted GDP losses compared to a respective reference scenario with 40-45% CO_2 emission reduction in 2050. These model results are obtained with REMIND-D.

However, for more ambitious targets, the mitigation costs in the 'continuation' scenario increase relatively faster than in the two 'paradigm shift' scenarios. This divergence is induced through the differences in scenario assumptions.

The main drivers for increasing GDP losses in the 'continuation' scenario are moderate efficiency growth rates and endogenously enforced demand reductions due to the aforementioned carbon lock-in in the freight and electricity sector. GDP losses remain significantly lower for all mitigation targets in the 'paradigm shift' scenario. Higher efficiency growth rates in all sectors of the economy, larger REG potential and the option to avoid the carbon lock-in are responsible for this. In terms of the underlying parsimonious narratives, the results indicate that ambitious mitigation in Germany can be achieved at relatively lower costs if structural changes in modal splits of the freight and passenger transportation sector and a fast decarbonization of the electricity sector are pursued. Mitigation costs in the 'paradigm shift+' scenario remain even lower than in the other two scenarios for all levels of mitigation ambition. This is due to additionally available technological mitigation options in the form of CCS and larger biofuel potentials. Yet the incremental effect is not as decisive as moving from the 'continuation' to the 'paradigm shift' scenario.

2.6. Scenario Evaluation

CSO stakeholders perceive three projected developments in the 'continuation' scenario as implausible, due to socio-political externalities that conflict with other policy arenas. First, the model results indicate a strong decrease of motorized individual transport that is not compensated for by more public transport mileage. Massive state intervention would be necessary to induce behavioral changes of such magnitude, e.g. through carbon pricing policies entailing prohibitively high transport costs. In such a world, individual mobility would become a luxury good. The CSO stakeholders assess that such policies will lack social acceptance and strongly emphasize the value of individual mobility in modern societies. Second, the required electricity and heat demand reductions are considered as politically not enforceable in reality. To induce such a development, again, rigorous carbon pricing policies would be required, which would increase the price of electricity and heating. Several stakeholders pointed out the dangers of energy poverty if any such mitigation policy is not accompanied by effective redistribution schemes. Third, the CSO stakeholders doubt that the projected CO_2 emission reductions and efficiency improvements in the heat sector can be realized, seeing institutional barriers as for example the well-known landlord-tenant conflict of responsibility.

In sum, these critical socio-political externalities motivated the CSO stakeholders to assess the 'continuation' scenario as highly undesirable, despite the fact that it reaches the required mitigation target. Yet they reconfirmed the likeliness of its projected developments in the freight transport and electricity sector, leading to a lock-in into current behavior and carbon-intensive infrastructure. In consequence, they conclude that, if the carbon lock-in becomes reality, ambitious mitigation targets will be out of reach.

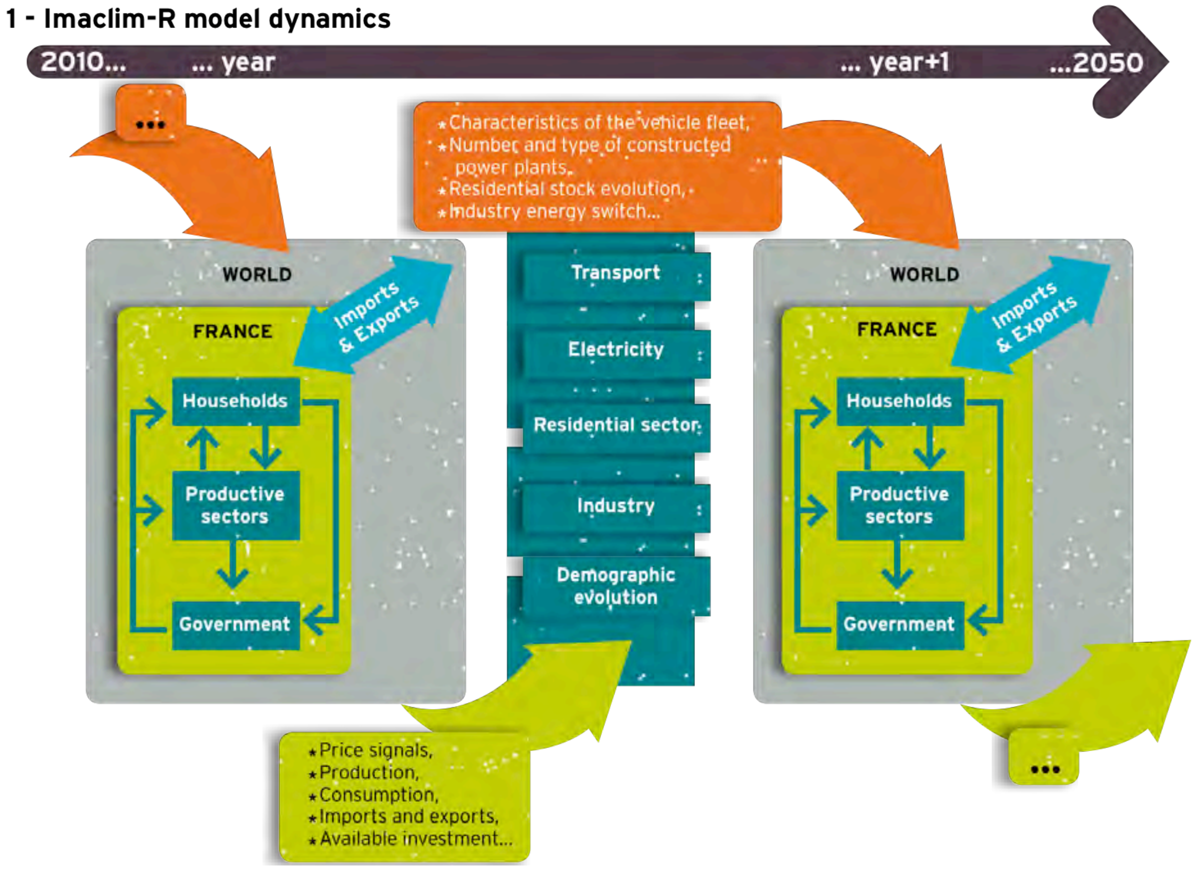
The 'paradigm shift' scenarios see the carbon lock-in resolved. CSO stakeholders prefer the 'paradigm shift' scenario over the 'paradigm shift+' scenario as they predict substantial public protest against the large-scale deployment of CCS infrastructure and biofuel production. They argue that the incremental effect on decreasing mitigation costs may not outweigh the direct and indirect costs of public protest. CSO stakeholders articulated several concerns for policies that aim at inducing the structural breaks from historical trends inherent to the 'paradigm shift' scenario. The quality of public transport services needs to increase significantly, both in urban environments and in rural areas. Inter alia, this would require a redirection of infrastructure investments from road to rail, an issue considered long overdue by the CSO stakeholders. Furthermore, they raised concerns regarding the projected rapid decommissioning of existing coal power plants, as it may entail increasing regional unemployment rates in Germany's structurally weak lignite mining areas. Finally, CSO stakeholders considered a fast deployment of renewable electricity generation and transmission line capacities as socially acceptable - if procedural justice is high throughout the process. This however implies transparent planning and installation as well as institutionalized possibilities for local communities to participate. In order to deliver, the different policy arenas need to become more intertwined and resolve their conflicting goals.

3.2 French scenarios

1. IMACLIM-R – description of the model dynamics

Imaclim-R France[24] is a computable general equilibrium model. This model was used for the collaborative scenario design process of French energy scenarios within the project ENCI-LowCarb.

Figure 13: Model dynamics – IMACLIM-R



It models the evolution of the French economy split into 15 sectors: energy sectors (crude oil, refined oil, gas, coal, and electricity), transport sectors (freight terrestrial transport, water transport, air transport, public road passenger transports, and rail passenger transport), construction, energy-intensive industries, agriculture and services.

The Imaclim-R model computes, between 2004 and 2050, the evolution of the economy and the energy system with a strong consistency. This is why Imaclim-R is what is called a hybrid model compared to economic models or to technical models. The first type of models focuses on economic dynamics but includes a weak representation of the energy system. The second type of models focuses on technologies and energy but has a poor representation of economic constraints and dynamics (particularly the interaction between prices and demand for energy and commodities). In

[24] Imaclim-R France is part of the Imaclim models family developed by the CIRED. www.imaclim. centre-cired.fr/spip.php?article129&lang=env

Imaclim-R, energy is explicitly representing both: values and physical quantities so as to capture the specific role of energy sectors and their interaction with the rest of the economy.

The existence of explicit physical variables (e.g. number of cars, number of dwellings or energy efficiency of technologies) allows a rigorous incorporation of sector-based information about how final demand and technical systems are transformed by economic incentives. In Imaclim-R, each year the equilibrium provides a snapshot of the economy and gives GDP, sectoral prices, sectoral investments, households' consumption in each sector, unemployment rate and international trade. Two successive annual equilibria are linked by "dynamic sectoral modules" such as an electricity module, a residential module, etc. These sectoral modules represent the specific sector dynamics given economic constraints (including available investment in the sector, intermediate consumptions and energy prices) and physical constraints (e.g. inertia in technological infrastructures and appliances limiting the extent of energy efficiency).

Imaclim-R France is an open economy model. Thus, an important modeling assumption is that crude oil; gas and coal prices are exogenous and are calibrated on the World Energy Outlook report by the International Energy Agency (2011).

A limitation of Imaclim-R France is that it computes only energy-related CO2 emissions and other greenhouse gases are not represented.

The collaborative scenario design process relies on Imaclim-R France for integrating all the inputs from stakeholders. Therefore, the modeling tool strongly determines the form of the interaction with stakeholders, the format of the meetings as well as the manner to discuss the issues. Indeed, the fact that Imaclim-R is built recursively with dynamic sectoral modules prompted us to organize sectoral experts' meetings first, then sectoral stakeholders meetings so as to embrace the vastness of debates when decarbonizing triggers a structural transformation of the sector. Then, with all the richness of the debate embarked in the model, a step back was taken to look at the interactions between all the different sectors in a cross-sectoral feedback seminar. The following part describes this process in more details.

2. Ambitious and acceptable mitigation scenarios for France

The energy scenario for France that has been developed within the ENCI-Lowcarb projects presents a set of policy measures and technical variables that were judged "acceptable" by at least half of the selected stakeholders.

No emission budget or target has been fixed in advance to the scenario process. The emission reductions in the scenario are only based on those policy measures that are acceptable in the eyes of the stakeholders and one of the main results is that these "consensus measures" are not ambitious enough to achieve neither the necessary reduction consistent with the recommendations of the IPCC nor the French objective for 2050 – a reduction about -75% of the emissions against 1990. Indeed, the policy measures that were judged acceptable only achieved a CO2 emissions reduction of 68% compared to 1990.

But even if those measures are not ambitious enough to achieve the necessary climate targets some of them are still too ambitious for the actual policy agenda (especially a carbon tax).

2.1. World vision

During the stakeholder meetings that were organized within the interactive scenario creation process stakeholders were asked to outline their vision on the evolution of the global climate framework (existence of an international climate agreement, evolution of fossil fuel prices and consumption patterns in industrialized economies but also in developing countries). Stakeholders considered that consumption styles in Europe and in France remain material-intensive. This is why changes in consumption styles or consumers' preferences were not part of this scenario. Nevertheless a decoupling of growth and resources use was further investigated in a sensitivity analysis. In this French mitigation scenario no global climate agreement is reached; climate policies coordination only exists at the EU level. This situation leads to a world with a high-energy demand, and to high fossil energy prices. Energy prices follow the "Worldenergy outlook" 2011, as required by the stakeholders. Crude oil prices reach 160€/barrel in 2050. Because of this high fossil energy prices, technological innovation focuses on renewable and energy efficiency, as well as on carbon capture and sequestration.

2.2. Emission reductions

The integration of all measures considered acceptable by at least half of the stakeholders lead to CO2-related energy emissions equal to 126 Mt CO2. The following figure shows the sectoral contributions leading to this 60% decrease in emissions compared to 2010 and -68% compared to 1990.

Table 3: Sectoral emission reductions

	2020	2030	2040	2050
Industry	-33%	-37%	-59%	-57%
Manufacture and services	-36%	-39%	-49%	-49%
Agriculture	-24%	-30%	-42%	-40%
Transport	-19%	-35%	-55%	-60%
Residential	-44%	-62%	-72%	-75%
Electricity	49%	-68%	-100%	-86%
Total	-15%	-39%	-59%	-60%
Total (compared to 1990)	-31%	-50%	-67%	-68%

The decarbonization of the electricity sector is difficult between 2015 and 2025 with the first wave of nuclear plants decommissioning. During this transition period, gas plants are built which induces new emissions for the electricity sector. To limit these "transition emissions", priority has to be given to very ambitious energy efficiency measures to decrease electricity demand during this transition period and to the development of renewable energies on the short term. The main difficulty for decarbonization is the transport sector, where emissions still represent 60 MtCO2, i.e. half of 2050 total CO2 emissions.

The CO2 emissions gap in 2050 between reaching a Factor Four and this mitigation scenario represents 28 MtCO2. Until 2042, the CO2 emissions trajectory of the mitigation scenario is consistent with a Factor Four trajectory. The trajectory even achieves a 31% CO2 reduction in 2020 (compared to 1990).

2.3. Policy measures

A wide range of policy measures and economic incentives has been judged acceptable by at least half of the stakeholders that participated in the scenario creation process. In the table below you can see the list of these measures for each sector.

Table 4: Acceptable policy measures in the mitigation scenario

Residential sector	**Tax credits:** The purchase of refurbishment elements is eligible to income tax credits. Increased rates and an extended eligibility base are modeled from 2009 until 2050 through a uniform tax rebate of 30% of the investment.
	Zero-interest loans for retrofitting actions: 0% interest rates apply for retrofit packages with a maximum amount at 30,000€ per dwelling. The credit duration period is about 10 -15 years.
	Thermal regulation for new buildings: From 2012 maximum primary energy consumption level: 50 kWh/m²/year of primary energy. After 2020: new buildings have to be net producers of energy.
	Implicit representation of **obligatory renovation funds for jointly-owned buildings availability of third-party financing** which reduces the risk aversion of the agents.
	Biogas: The biogas penetrates gradually between 2012 and 2050. Its share reaches 17% in the gas in 2050.
	Urban planning: Economic incentives and regulations slow down urban sprawl until 2030. After 2030 urban density increases again.
	Urban transports investment program: Investments in urban transports (buses, tramways) are doubled during 15 years from 2012.
	Teleworking: one day of work out of ten.
	Vehicles occupation rate: increase of the cars occupation rate for urban transport from 1.25 to 1.5.
	Kerosene tax: A tax on kerosene consumption for air transport is introduced in 2012. It represents 400€/toe.
	Heavy truck environmental tax: an eco-tax on the liquid fuel consumption of heavy trucks is introduced in 2012. It is calibrated to bring in 1.2 billion € in 2012.
	Rail investment program: Investments in road infrastructures are limited to maintenance of infrastructures. Investments are shifted from road to rail for 20 years.
	All **collective transports investments** are deducted to the **road infrastructures investments.**
	Bonus-malus: is extended until 2050. A positive annual financial balance for the government budget or at least close to 0 is obtained.
	Logistics: annual decoupling of freight transport needs of 1% for all sectors.
	Infrastructures: the modal share of rail transport in freight reaches only 20% in 2030 (exogenous assumption).
	Biofuels: Biofuels penetrate following the biofuel development scenario in the "World Energy Outlook 2006". Production is about 5 Mtoe in 2020 and 16 Mtoe in 2050 (respectively 9% and 39% of total refined petroleum products).
Electricity	**Expectations:** The electricity sector is assumed to receive clear carbon tax signals and expects the exact value of the carbon tax for the whole period.
	Existing nuclear plants lifetime extensions: 40 GW out of 63 GW have their lifetime extended for 0.7 bn€/GW.
	Feed-in tariffs: Feed-in tariffs for renewable energies are economic incentives to facilitate the market penetration of these technologies to accelerate the learning effect. Feed-in tariffs are normally decreasing over time and end when the technologies achieve price competitiveness with other technologies.
	Demand side management: implicit measures (interruptible contracts, smart metering) are used to flatten the load demand curve.
	Interdiction of electric heating: Electric heating is not globally banned but the implementation of the thermal regulation up from 2012 is de facto excluding electric heating (exception heat pumps).
	Grid construction: The construction of renewables triggers additional grid investments, thus increasing the electricity price for 3€/MWh in the mitigation scenario.
Overall policy measures	**Carbon tax:** 32€/tCO_2 in 2012, 56€/tCO_2 in 2020, 100€/tCO_2 in 2030, to 200€/tCO_2 in 2040 and to 300€/tCO_2 in 2050.
	Progressive tariff: For all households, any consumption above 60 kWh/m² is more expensive: 5% after 2014 and of 10% after 2030.
	Carbon tax recycling: The carbon tax income is recycled in a lump sum towards households (each person receives an equal share of the total perceived amount).

These measures either need investments (feed in tariffs) or produce incomes (taxes; even if some taxes decrease over the time as the consumption tax on petroleum products du to lower consumption); but the table below shows that the overall economic balance of the scenario is positive. The main income factor is the carbon tax, which increases considerably until 2050 representing an income about 34,8 bn€ in 2050.

Table 5: Policies and measures financial balance (mitigation scenario) in bn €

	2010	2020	2030	2040	2050
	TRANSPORT				
Heavy trucks eco-tax	0	1.3	1.1	1.1	1.2
Kerosene tax	0	1.6	1.1	1.4	1.3
Impact on domestic consumption tax on petroleum products	23.8	21.4	17.9	13.4	12.9
	INFRASTRUCTURE INVESTMENTS				
Urban transports	+3 billion € each year from 2012 until 2030			-	-
Railways	+3 billion € each year from 2012 until 2030			-	-
Road transports	-6 billion € each year from 2012 until 2030			-	-
	ELECTRICITY				
CSPE Income = feed-in tariffs expense	2.9	1.9	7.2	17.8	12.7
	RESIDENTIAL SECTOR				
Tax credit	-	-3.3	-2.5	-0.8	-0.5
Eco-loan	-	-3.3	-1.9	-0.6	-0.4
Construction	-	-9.5	-9.4	-7.7	-6.3
Refurbishment	-	-14.9	-10.3	-3	-1.8
	OVERALL MEASURES				
Carbon tax	0	13.7	18.1	23.9	34.8
BILAN	**26,7**	**8,9**	**21,3**	**45,5**	**53,9**

2.4. Electricity sector

The total electricity production increases over the scenario period from 50 Mtoe to 60 Mtoe in 2050. This increase of 20% is relatively low compared to the threefold increase in the same amount of time between 1973 and 2010. The main sectors responsible for the increase are the industrial and tertiary consumption mainly because gas is substituted by electricity.

The stakeholders disapproved the construction of new power plants for exports so the electricity exports in this scenario are rapidly declining.

France is no longer a net exporter of electricity after 2020; some imports (for less than 1 Mtoe or 12 TWh) remain throughout the period. The electricity imports (the part of the graph under zero in the figure 14) are used to satisfy the peaking heating demands in winter. The retrofitting of the residential sector that is increasing energy efficiency for heating and the switch from electric heaters to heat pumps reduces the electricity peak in winter. But approaching 2050 the peak increases due to a replacement from gas heating by heat pumps reaching a maximum of 103 GW.

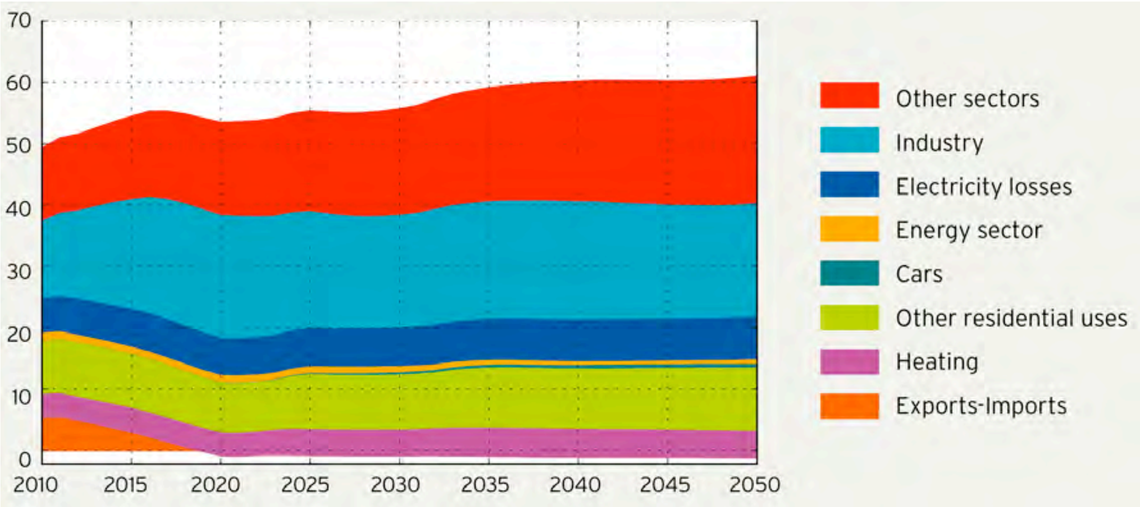
The partial fuel switch from gas to electricity in the industry sector takes place before 2020. On the contrary, the consumption of the services steadily increases at a rate exceeding 2% before 2025 and around 1% afterwards. The electricity consumption of energy producing industries (for example oil refineries) decreases slowly. Electricity transport losses are following proportionally the increasing electricity consumption.

Residential uses other than primary heating decrease before 2020 (from 9 to 8 Mtoe) and increase until 10 Mtoe after 2020.

Due to more and more new electricity devices (especially multi-media), the consumption especially for these energy services increases over the scenario period. Traditional domestic electricity services like lighting, washing, cooking etc. decrease with increasing energy efficiency.

Before 2030, the consumption of electric vehicles does not appear on the graph since it does not represent with 0.4 Mtoe an important share of the overall consumption. It increases until 2040 and stabilizes at 0.6 Mtoe. In this scenario, the charging occurs evenly during 24 hours a day since the electric vehicles fleet corresponds to car sharing systems. Thus, the supplementary demand due to charging adds to base load, and does not worsens peak imbalances thanks to the diversity and the dispersal of the demand.

Figure 14: Electricity demand disaggregation (Mtoe)



The **electricity prices** for households show a sharp increase between 2010 and 2020, climaxing at 41% in 2020 compared to 2010. The price stabilizes thereafter around 160€/MWh (16c€/kWh). It represents an increase of 34% compared to the price in 2011. The peak in prices around 2020 is due to the combination of (i) the penetration of gas combined cycle replacing some of the nuclear capacities (ii) the acceleration in the installation of renewable capacities and (iii) the oil-fuelled turbine to face the variability of renewables. The stable long-term increase is due to renewables being more expensive than the old nuclear thermal power generation units and the need for new capacity building during the period.

The share of **renewables** in the electricity mix is 20% in 2020 and 50% in 2050. In addition, 43 GW of nuclear plants are extended during 20 years for 700 million € per GW[25]. Renewables and nuclear plants extension constitutes the bulk of the investment until 2050. In addition, 9 nuclear plants (European Pressurized Reactor) are built to compensate part of the decommissioning occurring between 2020 and 2030 for 2,9 bn €/GW[26], each of them with a capacity of 1630 MW. The investment amount steadily rises from 8 billion € in 2010 to almost 17 billion € in 2026 to finance the transition. After that, it steadily decreases to 6 billion in 2050.
The period between today and 2025 is the most critical one. Indeed, the beginning of nuclear plants' decommissioning, in addition to the growing share of variable renewables and the uncertainties surrounding the electricity supply market induce the construction of power plants fuelled by fossil energies. Between 2010 and 2020 more than 10 GW of oil-powered gas turbines and gas-fuelled combined cycles plants are built, which explains the emissions peak with an increase of 49% in the electricity sector. This reinforces the emergency in implementing energy efficiency and demand- side management to avoid building these carbon-intensive power plants. However, this transition from a nuclear-dominated mix to a mix relying also on renewables is short-lived, with emissions receding after 2030. The fast decommissioning of the extended nuclear plants after 2040 creates some tensions in the electricity supply, leading to a return of some emissions in the electric sector, because of gas (mainly gas with CCS).

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[25] Sensitivity analysis with extension costs about 1400 million € per GW are presented in the final report.
[26] Sensitivity analysis with construction costs about 4500 million € per GW are presented in the final report.

Figure 15: Electricity production mix (TWh)

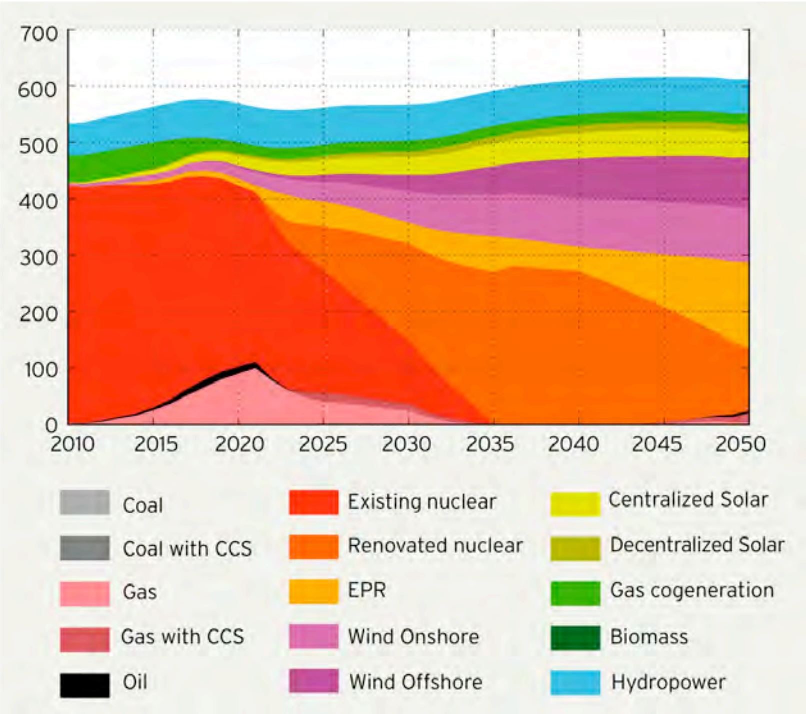
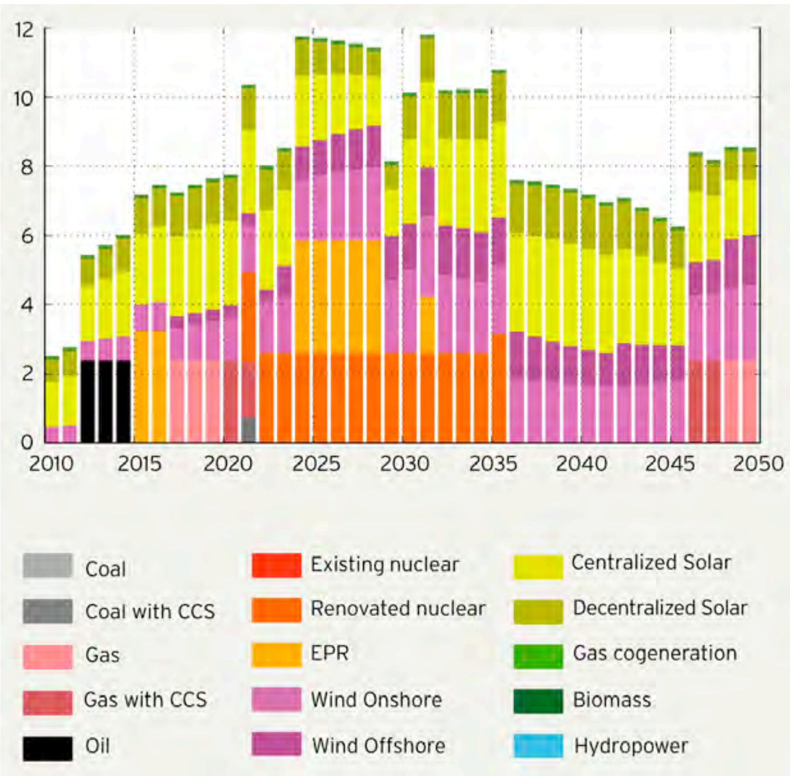


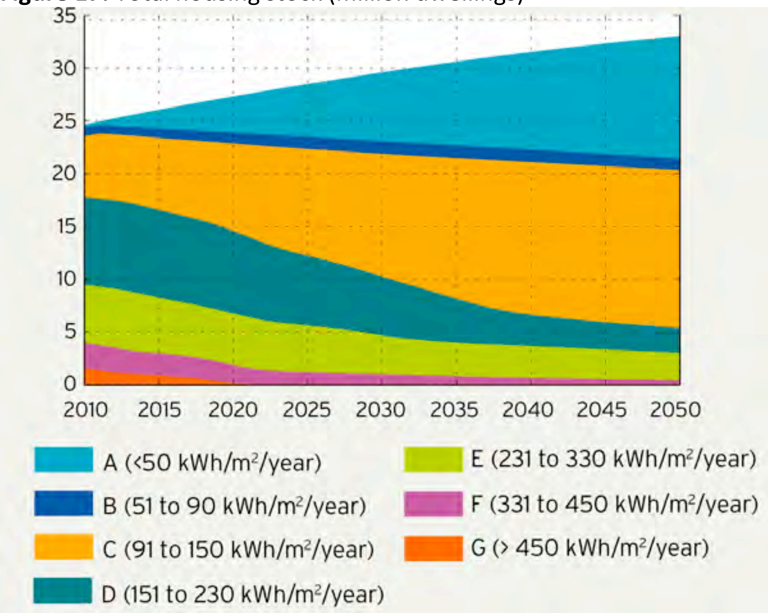
Figure 16: Investment in new capacities (GW)



2.5. Residential sector

Energy efficiency gains arise from retrofitting of inefficient dwellings and from fuel switches.
Over the scenario period, the existing building stock shows a progressive disappearance of the low-efficiency classes G to D, and a gradual penetration of classes C due to economic incentives and learning-by-doing which decreases retrofitting costs. Most of the retrofitted stock reaches class C in 2050. Nearly no ambitious retrofit to class B or A appear, since these retrofitting options remain too costly for households given the economic incentives and energy prices in the scenario. Even the existence of an obligatory renovation fund for jointly-owned buildings and the availability of third-party financing do not decrease the risk aversion of the owners of individual houses and jointly-owned buildings enough to make such ambitious transitions happen.

Figure 17: Total housing stock (million dwellings)



The pace of the transition is highest for social housing, this being consistent with the French legislation, which requires refurbishment of all social housing to reduce the energy consumption of the dwellings exceeding 230kWh/m2/year before 2020 to 150 kWh/m2/year. Furthermore, this share of the residential building park is the most structured and is not facing the same challenges as it is the case for jointly-owned buildings were complicate decision making procedures delay action.
In all subcategories of existing buildings (individual houses, social housing, jointly-owned buildings), transitions to upper energy classes appear jointly with an important energy substitution from gas and fuel towards electricity for heating that corresponds in the model to a significant penetration of heat pumps (7 millions). This substitution is driven by the evolution of relative final energy consumption prices.
At the end of the period, the final energy consumption per m2 for heating is divided by 3.2, total final energy for heating by 2.4 and total primary energy for heating by 1.8.
Given a behavior function, the model computes the gap between the theoretical energy consumption for heating and real energy consumption after a retrofit action or in new energy efficient buildings, e.g. the rebound effect. In this scenario, given the assumptions of high global prices for fossil energy, and additional fiscal measures (progressive tariffs on electricity and carbon tax on fuel and gas), the rebound effect is quite limited.
It is negative until 2034 and is limited to 4% on final energy consumption in 2042.
Concerning energy uses other than primary heating in residential, the shares of gas and fuel (mainly for cooking and for secondary heating devices) remain stable. The specific electricity consumption

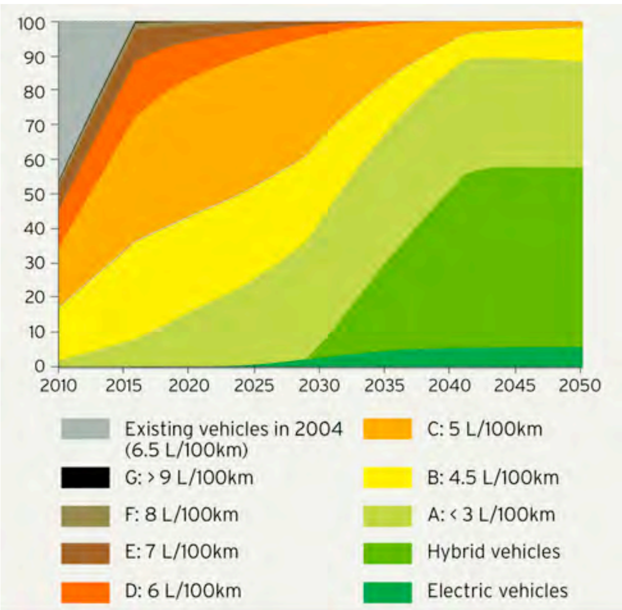
slightly increases until 2050 (+24% compared to 2010). This evolution is the combined effect of improved energy efficiency (autonomous following current trends and induced by a 40% increase in electricity prices between 2010 and 2020), which is more than compensated by the development of new electric appliances, mainly multimedia devices and the population increase (+15%).
Globally, the final energy consumption (heating and other uses) per capita is divided by 2 and the total final energy consumption decreases by 37% between 2010 and 2050. The CO2 emissions of the residential sector (excluding electricity emissions that are included in the power sector) decrease of 75% between 2010 and 2050.

The households' expenditures for energy consumption, refurbishment and construction in the residential sector decrease over the scenario period from 6 to 4,5% of the overall household budget.
The energy expenditures peak in 2012. Energy efficiency measures reduce the energy consumption and thus the allocated energy budget of households.
The expenditures for construction and refurbishment peak later in 2022 which is consistent with the transformation process of the residential building stock and the investments necessary for the switch from class D to C.

2.6. Transport sector

In the scenario, two mitigation strategies are implemented for passenger mobility: Limiting current increase in individual mobility with urban planning and incentives to limit voluntarily mobility demand.

Figure 18: Composition of the vehicles fleet (%)



1. Penetration of decarbonized vehicles

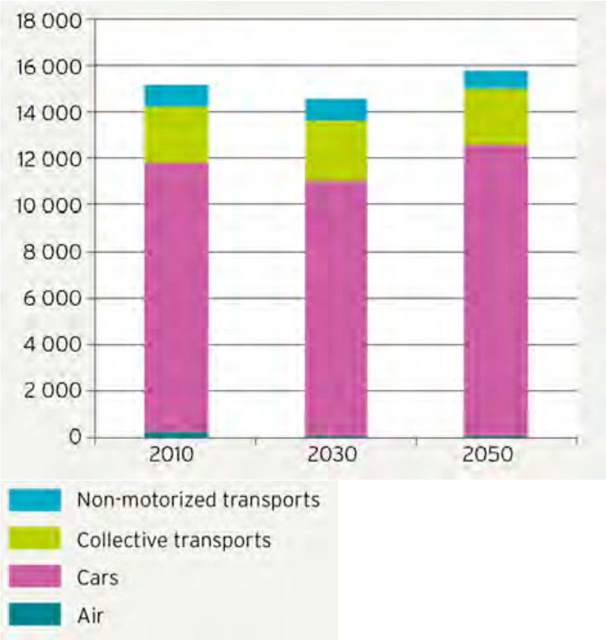
The bonus-malus measure is calibrated from 2010 to 2050 to result in a positive or neutral financial balance for the government. It is reevaluated every five years to favor energy efficient vehicles. Electric vehicles occupy only niche markets for urban mobility with a penetration limited to 5% of the total vehicles fleet in 2050. They refer to car sharing systems in urban areas. Hybrid range extender vehicles massively penetrate after 2030. They are best suited to urban use but can also be used for long journeys.

2. Biofuels development

The scenario is based on the biofuel development scenario in the "World Energy Outlook 2006".
The biofuel consumption in the here presented scenario is about 5 Mtoe in 2020 and 16 Mtoe in 2050 (respectively 9% and 39% of total refined petroleum products). A technology switch takes place around 2030 concerning the first-generation ethanol production (from agricultural sugars and starches) towards second-generation biofuels (ligno-cellulosic ethanol) as production costs of the latter decrease. The use of second-generation biofuels attenuates most of the negative impact of the

biofuels first generation: competition with food production, use of agricultural production and additional emissions due to land use change (that can even exceed those of classical fossil fuels).

Figure 19: Annual total individual mobility (km)



3. Evolution of the individual mobility
On average, the mitigation scenario leads to a slight increase of individual mobility on the long term (+3% compared to 2010 level). This translates with the population growth into a 19% increase of total passengers' mobility. Nevertheless, in the middle term (2030), the increase of energy prices and the inertia in developing alternative collective transports lead to a constrained mobility with a 4.5% decrease in individual mobility and a 4% increase in total passengers mobility compared to 2010 levels.

4. Urban and local mobility
The objective of policies and measures implemented for urban mobility is the limitation of the increase of urban sprawl, while favoring more collective transport infrastructures. Because of the inertia of the existing system, these measures begin to have a significant impact only after 2030. The mobility in urban areas mainly refers to a constrained mobility (daily commuting). The two determinants of the total urban mobility are the demographic trends in urban areas and the urban sprawl. The urban sprawl has an ambivalent impact over time: it keeps increasing, particularly urban areas outside Paris, until 2030, and starts decreasing after 2030. Congestion increases for all transport modes in urban areas, until more collective transports are available. In the short run, avoiding the impact of increasing oil prices relies on reducing mobility by teleworking and the increase of the vehicles occupation rate. These measures translate the generalization of employee transport plans in firms.

5. Long distance mobility
The widening of congestion in urban areas decreases the time available for long journeys particularly with a more expensive air transport (kerosene tax) and inertia in the development of road alternatives. This explains partly the decrease in total passengers' mobility in 2030. After 2030, more train transport capacity is available and part of the time constraint is released. Passenger transport emissions decrease by 66% between 2010 and 2050. This reduction results from the combination of (i) an average 70% reduction in oil consumption of individual cars, (ii) the penetration of biofuels and (iii) a 23% increase in car passengers-km. Emissions reductions in air traffic are the results of a slight decrease of demand and of a 40% energy efficiency improvement.

6. Freight transport
The eco-tax for heavy trucks enhances technical change towards more efficient technologies. In 2030, the energy efficiency of heavy trucks is 25% higher.
Overall, the emissions of the freight terrestrial sector decrease by 40% between 2010 and 2050. This results from (i) a 9% increase of the freight demand during the period, (ii) a 30% energy efficiency

improvement for road transport per unit of good transported, (iii) a modal shift towards rail for 7% and (iv) 12% for biofuel penetration.

The fiscal measures applied to the transport sector positively impact the financial balance of the government, except for the domestic consumption tax on petroleum products whose receipts decrease significantly over time. Thus, the income of this tax decreases about 50% in 2050 fully attributable to the decrease in consumption of imported petroleum product. For the infrastructural investments, all the operations are done neutrally if compared to the reference scenario. Indeed, the total amount of investment does not change, only the repartition between transport modes. 6 billion € are withdrawn from the road investment and dedicated half to urban road collective transports and half to railroads.

2.7. Economic and employment impacts

The population follows the 2010 INSEE central demographic scenario and equals 72.3 million in 2050, i.e. a 15% increase compared to 2010. In the reference scenario (also called Business As Usual scenario, i.e. without climate policies), the average annual economic growth rate is about 1.24% between 2010 and 2050. The overall economic impact of the mitigation measures is positive, except in the short-term, with a negative impact until 2017 due to the introduction of the carbon tax in 2012. Thereafter, GDP is higher and unemployment is lower than in the reference scenario.
The impact is particularly positive from 2025 to 2035. At this date, the electricity price in the mitigation scenario is around 25% lower than in the reference scenario. Moreover, fossil energy prices get much more expensive than in the reference scenario because of the carbon tax. The combination of both factors induces a substantial energy switch towards electricity for productive sector and households. In addition, energy efficiency measures induce a decrease of the energy expenditures:

- In the household budgets (which is not compensated by the increase in construction and additional renovation costs).
- For services industries that are not energy-intensive, which furthermore reinforces the international competition of French goods.

The development of non-fossil energies in conjunction with energy efficiency measures constitutes a protection against the negative impacts of the increase in energy prices and of the French import dependency. In the reference scenario, the energy import values represent more than 5% of GDP between 2019 and 2035.
In the mitigation scenario, the energy import intensity of the GDP peaks in 2020 at 4.7% and gradually declines to a stable level 1.7% after 2040.

Figure 20: Household expenditures

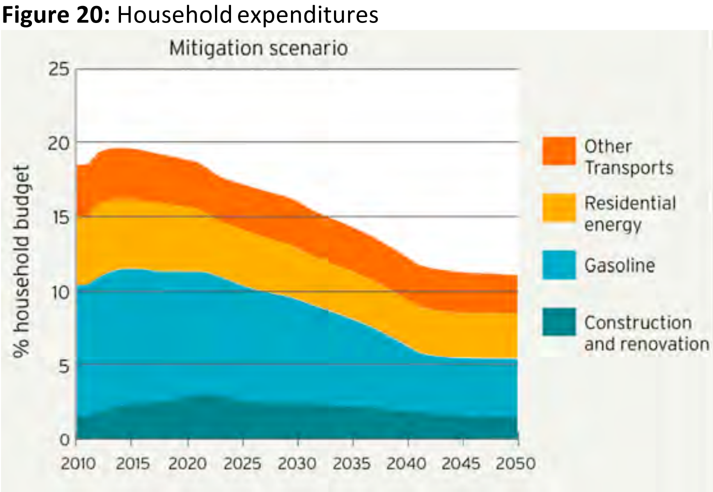
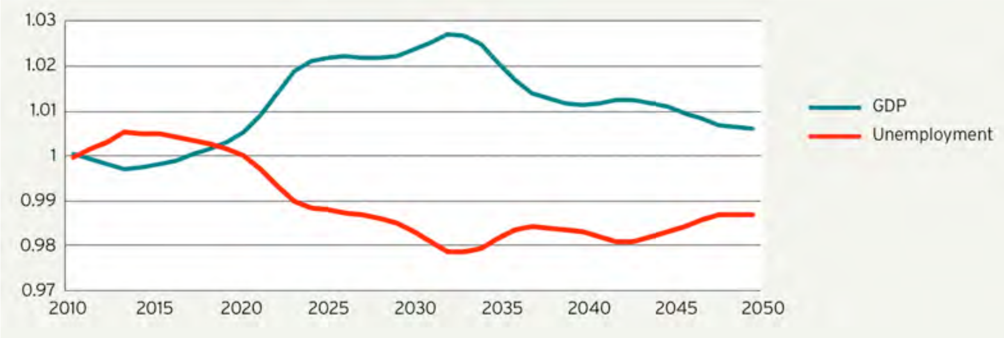


Figure 21: Macroeconomic trends in Mitigation scenario / Reference (base 1 in 2010)



A number of policies have been suggested to address concerns over competitive losses due to one country introducing a carbon tax while another country does not. In this variant, the impact of the implementation of a **border tax adjustment** (BTA) at the EU27 level was analyzed. The role of a BTA is to address the competitiveness losses, which stems from the price distortion induced by the carbon taxation. This BTA taxes imported goods in the manufacturing sector. Highly energy-intensive industrial goods are not subject to the BTA, as we consider that European imports mainly consist of manufactured goods. The level of taxation is subject to the additional carbon content compared to EU average carbon content. This additional measure is computed alone in a first scenario, and a second scenario gathers the BTA and previous assumptions related to decoupling and reshoring. Logically, the direct impacts of the BTA are a rein- forced international competitiveness, but also an increase of consumer prices. As the BTA is applied only for the manufactured goods (and not on industry), manufacturing increases, but the energy-intensive industry production decreases.
Due to the relative weights of these sectors in the French economy, the global outcome on the longer term is a slightly increased economic growth, with a more significant emissions decrease.

2.8. Reconciling stakeholders' acceptance & ambitious climate objectives

A question that is outwearing the end of this scenario creation exercise and that needs further research is how to reconcile stakeholders' acceptance and ambitious climate objectives.
As the "acceptable mitigation scenario" is not ambitious enough to reach the necessary climate targets in terms of emission reductions, a second scenario was developed including additional measures (retrofitting obligation and a carbon-energy tax instead of a carbon tax). These measures that were not approved by the stakeholders achieve nevertheless a 75% CO2 emission reduction in 2050 compared to 1990.

A carbon-energy tax (CET): the carbon tax is replaced by a carbon-energy tax to give a further incentive to reduce energy consumption. It taxes the energy content and the carbon content of the energy and is applied to all the forms of energy (coal, gas, oil, nuclear) except renewable energies.
This CET is calibrated in order to align the energy part of the tax with the amount of the carbon part of the tax on average. The CET induces a tax level corresponding to a doubling on average of the previous carbon tax for fossil fuels. For carbon-free energy, the CET adds a tax valued as the energy part of the CET on fossil fuels. The CETaims at introducing more sufficiency in households' behaviors, particularly concerning specific electricity consumption, and more energy efficiency in industry and in the tertiary sector.

A **refurbishment obligation** is applied to the building stock. The planning of the obligation is organized following the type of building (individual houses, collective dwellings and social houses) and the energy label of the building, beginning with the less energy-efficient classes. The refurbishment aims at reaching label B (80 kWh/m2/year). Implementation dates are given in the following table. Refurbishments are calibrated in order to leave enough time for the firms in the construction sector for restructuring and training to be able to face this vast national action plan.

Table 6: Dates for the refurbishment obligation

	G	F	E	D	C
Social housing	2016	2016	2016	2020	2020
Collective dwellings	2020	2024	2024	2028	2032
Individual houses	2018	2022	2026	2030	2034

The total number of refurbishments remains below 200.000 until 2020. After 2020, this number gradually increases until 2040 with 900.000 renovations a year. Thereafter, the number of annual renovations declines. At the end of the period, 16.1 million of buildings are retrofitted.
With these two additional measures, emissions reductions reach the Factor Four.

2.9 Conclusion

The emissions reductions following the implementation of all the measures that were judged acceptable by at least half of the stakeholders come close but fail in reaching the Factor Four target. The package of measures leads to a 68% CO_2 emissions reduction only in 2050 compared to 1990. Nonetheless, the Factor Four is reached in the residential sector as well as the power sector. The crucial issues lie with the contributions of the transport sector and the productive sectors to tackle emissions. In the transport sector, the evolution of emissions will heavily depend on mobility, strongly driven by urban sprawl.
The predominance of road for transportation and the yearning for more mobility, intertwined with the transformation of urban patterns in France will determine the shape of the energy transition. This scenario does not represent a paradigm shift in the development pattern. Indeed, GDP per capita is projected to increase by 41% between 2010 and 2050, and consumption is not reduced but redirected towards less energy-intensive products and services. Climate policy measures, especially through higher fossil energy prices, promote the development of low-carbon technologies and energy demand reduction, which contribute to reducing the overall energy bill and the energy budget of households. In addition, these policy measures alleviate the economic detrimental consequences of the rise of fossil fuels prices. Also investing in energy efficiency drives GDP growth and reduces unemployment. The trigger for this evolution is the implementation of a carbon tax to redirect investments towards less carbon-intensive options by increasing the cost of fossil fuels. A low carbon transition cannot be initiated without this crucial leverage, which is supported by a majority of the contributing stakeholders.
This project has revealed elements of consensus regarding climate mitigation policies but also some cleavages. Two measures that were not consensual among stakeholders appear crucial in actually reaching the Factor Four objective: the refurbishment obligation for the existing building stock and the energy-carbon tax (instead of a carbon tax only).
This report reveals the need for a strong political commitment to leverage the decarbonization of the energy system. The responsibility lies with the stakeholders and the government to decide on a hierarchy of values and actions fed by scientific evidence and public concerns. The question of the precedence of long-term interests (e.g. protecting the needs of future generations) over short-term considerations is an ethical issue, which should be subjected to public scrutiny. In any case, scientific evidence shows today that urgent and far-reaching action is necessary. This project shows that a consensus about the acceptability of ambitious measures cannot be easily found among stakeholders, especially if their activity is directly impacted.
However, it is the responsibility of the government to act as a mediator to implement the measures that are needed to achieve climate objectives and to define the required compensations to overcome the identified cleavages.

4. The potential impact and dissemination activities

1. Potential socio-economic impact and the wider societal implications of the project

Need for stakeholder implication in scenario creation processes

The last decade is characterized by an always-growing number of energy scenarios and visions. The urgency of the upcoming impacts of climate changes, translate into more and more contrasting, complementary and even opposing narratives on the necessary energy transition.

In most cases these scenarios are technically feasible and respecting physical boundaries but this does not mean that they are politically, economically or socially acceptable.

We are facing a situation were scientifically founded energy scenarios exist that are based on available technology choices often even being source of economic and social benefits – but the political framework and support is lacking to adopt them.

Long-term interests are colliding with short-term economic concerns; stakes of specific interest groups are impeding a comprehensive transition approach.

The ENCI-LowCarb project deployed one strategy to find a commonly accepted solution – a participative methodology starting from the hypothesis that a scenario co-developed by researchers and stakeholders is more likely to be accepted by the wider public. If stakeholders develop ownership for the energy scenario because their vision is integrated part of the presented pathways and they share a common understanding on limits and necessary decisions then chances are higher for a political support.

The gathering of stakeholders in the frame of the scenario workshops in France and Germany showed the existing awareness of stakeholders. The project team noticed a common understanding concerning the urgency for action against climate change but many actors feel trapped in the actual system based on fossil energy consumption.

The ENCI-Lowcarb project brought stakeholders and researchers together in an "open discussion space". During the scenario workshops the Chatham house rules were applied which enabled the participating stakeholders to be honest about their motivations and visions. These meetings created exchanges and connections between societal actors and researchers lasting also beyond the end of the project

Need for clear translation rules in collaborative scenario processes

One of the major outcomes of the ENCI-Lowcarb project with potential implications on other scenario creation processes is the need for clear translation rules.

If stakeholders are associated to a scenario process aiming at integrating their visions in a comprehensive scenario it is important that all participants know the “rules of the game”.

- How contributions will be weighted and used for the co-construction of a scenario?
- Following to which set of criteria decisions for the orientation of the scenario will be taken and by whom?

A transparent definition of the framework in advance to the process is important to provide a common staring point for all stakeholders. This framework should include clear information on the translation rules and the form stakeholder contributions should take in order to match with the model requirements and the scope of the process.

Even if this claim seems evident, within our investigation about existing scenario processes at the beginning of the ENCI-Lowcarb project we have not found one single process that made a clear statement on the translation process.

The process on the EU roadmap for a low carbon economy led by the European Commission contained a large consultation phase: 400 stakeholders and individuals answered the online consultation, existing scenarios were analyzed etc. but no information was given on how the modeling team interpreted this amount of often contradicting information.

The requirement to clearly state in advance the translation rules should be integrated in all stakeholder based scenario processes; especially those initiated by the government or other official public bodies.

These translation rules should be as clear as possible within the limits of the used modeling tool; for example: “Only if at least 50% of all present stakeholders are in favor of a specific policy measure it will be considered acceptable within the scenario creation process.” A structured framework by using for example a questionnaire facilitates the translation process.

<u>Need for conscious design of scenario creation processes in line with the scope of the exercise</u>

The design of a scenario creation process has to be conscious about:

- What is the aim of the process? What do we need for achieving this aim?
- Which stakeholders have to be invited?
- How and for what purpose should stakeholders be consulted? Do they need training on specific issues to be able to fit our specific needs?
- How much time do we have to / can we dedicate to the process?
- What are the limits of the modeling tool?
- How is the translation process organized? Who is part of the facilitating team?
- What “form” of input is needed from stakeholders?

It is not enough saying that stakeholders have to be consulted or associated to a process: the means have to be coherent with the objective of the project.

If a scenario process is based on stakeholder consultations there should be an ex-ante acceptance concerning the choices of the stakeholders. If the scenario result is already known at the beginning of the process the choice of the participating stakeholders or the process in itself will be biased; in this case one should preferably speak of a normative scenario based on stakeholder contributions rather then of a collaborative scenario process.

One message of the ENCI-Lowcarb project is that stakeholder participation is not an end in itself; it has to be used wisely and when it is needed. If not stakeholders will reasonably doubt the sense of further implication in such processes.

<u>Need for a transparent explanation of limits and opportunities of the modeling tools</u>

Substantial differences exist in the approaches and underlying assumption for energy economic modeling. The European project RECIPE compared three macro-economic modeling tools and captured their different behavior under the same set of variables.[27] Also both modeling tools that were used within the ENCI-Lowcarb project were part of the model selection.

- IMACLIM-R is a recursive-dynamic computable general equilibrium model with a special focus on inertia in the development and deployment of new technologies. Semi perfect-foresight is assumed in the power sector, i. e. investment decisions are based on a 30-years time horizon, while all other agents are assumed to be myopic, i. e. they have imperfect foresight and base their investment decisions on the assumption that current prices and market conditions are the best indicator for the future development. Among the three models considered, it features the highest sectoral detail.

- REMIND, by contrast, is an optimal growth model that simulates optimal development pathways for maximizing intertemporal welfare. They operate under the assumption of perfect foresight and full internalization of external effects. REMIND is characterized by a flexible description of the macro-economy and the assumption of a large number of mitigation options in the energy system.

Figures 22 and 23 show clearly the diverging approaches of both modeling tools. IMACLM-R is not based on perfect foresight and computes important economic transition costs in the beginning of the scenario period in order to overcome system inertia. Nonetheless in the end of the period the losses are lower than concerning the other two models because the transition speed was higher. But the overall consumption losses of the REMIND-R scenario are still lower because it is based on intertemporal optimization – that means the model presents as outcome the pathway that is optimizing welfare over the whole scenario period.

Figure 22: EU Consumption losses 450 ppm

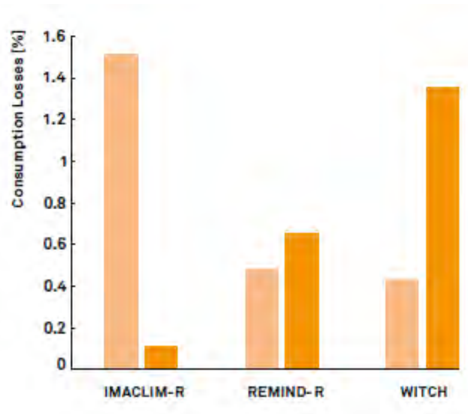
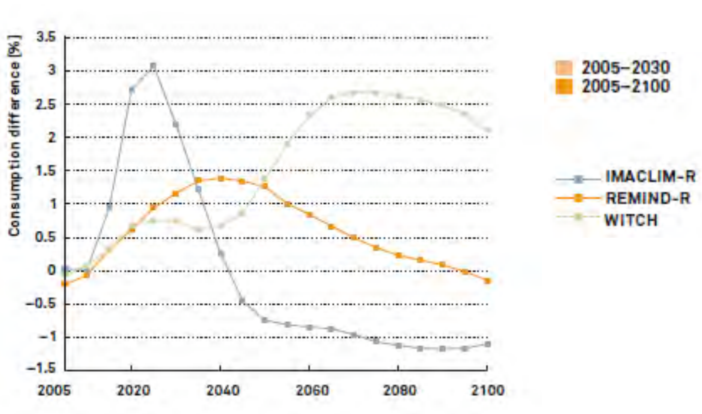


Figure 23: Aggregated EU Consumption losses 450 ppm



[27] Edenhofer, O., C. Carraro, J.-C. Hourcade, K. Neuhoff, G. Luderer, C. Flachsland, M. Jakob, A. Popp, J. Steckel, J. Strohschein, N. Bauer, S. Brunner, M. Leimbach, H. Lotze-Campen, V. Bosetti, E. de Cian, M. Tavoni, O. Sassi, H. Waisman, R. Crassous-Doerfler, S. Monjon, S. Dröge, H. van Essen, P. del Río, A. Türk (2009): RECIPE - The Economics of Decarbonization. Synthesis Report.

Hence it is not surprising that the choice of the modeling tool also has an impact on the organization of the stakeholder contributions.

The ENCI-Lowcarb project shows the importance of a transparent presentation of the opportunities and limits of the modeling tool:

- For all involved members of the project team
- For the invited stakeholders

Stakeholders have to be aware of the dynamics and drivers of the used modeling tool in order to avoid the feeling that they are dealing with a "black box" and that their contributions have no impact and will in any case not be traceable.

One recommendation of the ENCI-Lowcarb project is to provide the stakeholders with a short written description of the modeling tool and to allocate time for an in-depth presentation and discussion at the first stakeholder meeting.
This can enhance ownership of stakeholders towards scenarios developed within such a collaborative scenario creation processes.

Need for highlighting interdependencies and "branches in the scenario road"

The energy scenarios that were developed within the ENCI-Lowcarb project for Germany and France contain a number of policy relevant messages:

The **French scenario** is mainly focusing on the necessary composition and interaction of specific acceptable sets of policy measures (laws, taxes and economic incentives) aiming at getting France on a climate friendly pathway. Several bottlenecks and leverage points were identified:

- To overcome the inertia of the energy system it is of eminent importance that as soon as possible a carbon tax is adopted whose amount has to rise until 2050 in order to finance the reconstruction of the energy system, retrofitting of the residential sector etc.

- If only economic incentive are developed and no planned retrofitting obligation is adopted house-owners won't exploit the whole energy efficiency potential of the retrofitting because raising the energy efficiency level from class C to A represents an important over-cost.

- Stakeholders are not in favor of an electrification of the transport sector. There was an overall consensus for the development of highly efficient hybrids.

- Stakeholders are in favor to stop investments in road construction and a reallocation of this funding for public transport.

- Stakeholders believe that a reduction of electricity production for electricity exports is desirable. In the acceptable scenario exports are nearly stopped and imports are limited to satisfy peak consumption needs especially due to the development of heat pumps that will progressively replace gas, fuel and traditional electric heating (maximum peak demand 103 GW). To avoid power shortages this orientation needs in parallel a strong European coordination, which is supported by the participating stakeholders.

- The allocation of carbon tax revenues has an impact on consumer electricity prices and unemployment rate: If the revenues are used to reduce payroll taxes a positive effect on the job market is induced if revenues are used for energy efficiency and renewable energy subsidies the consumer electricity process decrease.

- The economic balance of the mitigation scenario remains positive over the time period. The mains factor is the carbon tax whose revenues are steadily increasing until reaching 34,8 bn€ in 2050.

- The scenario shows that if there will be a lack of planning of the electricity production facilities transition emissions will be generated due to the necessary construction of fossil power plants (event with CSC they are not carbon neutral). These emissions are not limited in time, as these capacities won't be shut down after the transition period; their lifetime depends beside technical limits on the return of investment period. Especially in 2040 a tradeoff has to be made between investment in energy efficiency (which appears following to the model parameters as the more expensive option) or an increase of power related emissions.

- If only those measures that are judged acceptable by the consulted stakeholders are implemented a 68% CO2 emission reduction in comparison to 1990 can be achieved which is less than would be necessary and even less than the French climate objective (75% of all GHG). A 68% CO2 emissions reduction in 2050 represents a 46% reduction of the total French GHG emissions and of only 29% of the total consumption-related French GHG emissions. An important challenge is to push stakeholder acceptance further to create consensus around even more ambitious policy measures.

The **three German mitigation scenarios** are all achieving an ex-ante fixed 85% CO2 emission reduction objective. Their focus is on the interdependencies of the different sectoral activities and trade-offs that have to be made between energy sectors if stakeholders consider a specific development likely or desirable.

Table 7: Summary overview of the model constraints that define the three scenarios, resulting from the participatory process. FT = Freight Transport, PT = Public Transport, MS = Modal Split, REG = Renewable Electricity Generation, PP = Power Plant, CCS = Carbon Capture and Sequestration.

Model Constraint	Continuation	Paradigm Shift	Paradigm Shift+
Decoupling FT&GDP	no	yes	yes
PT share in MS	constant	increase	increase
REG potential	medium	high	high
Energy efficiency	medium	high	high
Decommission Coal PP	no	yes	yes
CCS by 2025	no	no	yes
Biofuel potential	low	low	high

As said before: all scenarios (continuation, paradigm shift and paradigm shift+) achieve the same emission reduction target. Nonetheless the liberty chosen by the first parsimonious narrative or scenario to accept a continuation of climate-damaging activities, is at the origin of several so said carbon lock-ins in some of the sectors (increase of freight transport and no decommission of coal power plants before the end of their life time) which is thus requiring "buy-backs" on other sectors to respect the overall carbon budget.

Further increasing freight transport mileage as enforced by the scenario assumption of coupled GDP and freight transport growth rates are producing committed emissions. These emissions are counterbalanced by highly restricted per capita passenger km transport:

Annual per capita passenger transport decreases from 13,000 km in 2005 to 11,000 km in the year 2050 in both 'paradigm shift' scenarios; the parsimonious narrative foresees that one part of the difference will be substituted by non-motorized traffic, i.e. cycling and walking. In the 'continuation' scenario, however, the per capita p-km are forced to decrease to 9000 p-km in 2050, due to mitigation pressure induced by the carbon lock-in in the freight and electricity sector.

The electricity sector in the 'continuation' scenario is also representing a carbon lock-in leading to a sub-optimal emission allocation: In the two 'paradigm shift' scenarios, the model is given the option to decommission existing hard coal and lignite power plants from 2015 onwards, these capacities are shut down by 2020. These power plants are temporarily replaced by gas turbines. Once enough renewable energy capacity is installed, the gas turbines go out of service again in both 'paradigm shift' scenarios by 2030. But in the 'continuation' scenario, there is no such temporary increase in gas capacities, as existing coal and lignite power plants continue to produce electricity.

From 2020 onwards, the installed REG capacities stagnate in the 'continuation' scenario. This is due to the moderate potential in the scenario definition, motivated by a restrictive public attitude that constrains the incremental deployment of RE capacities and transmission lines. Because of the carbon lock-in from freight transport and coal electrification, the model cannot afford to allocate more CO_2 from the emission budget to the electricity sector for covering gas turbines. These could provide more balancing capacities so solar potentials could be fully exploited, which is not the case in the 'continuation' scenario. Instead, the model opts for the least attractive mitigation option: imposing electricity demand reductions in all sectors, including industry. A consequence of this is a reduction in GDP growth.

During the discussion stakeholders had considerable doubts concerning the acceptability of the CSC technology and biofuel development and its large-scale development. This is why it was decided to add the third 'paradigm shift +' scenario which exploits these options.

The stakeholder dialogues revealed strong discrepancies between likely ('continuation scenario') and desirable future developments (paradigm shift scenarios) in the transport and electricity sector. The carbon lock-in leads in the 'continuation scenario' will slow down economic growth and bear severe socio-political externalities. To overcome these trade-offs, carbon lock-ins have to be avoided and, additionally, energy efficiency and renewable deployment growth rates have to increase.
Participating stakeholders pointed out that in order to resolve the carbon lock-in, major paradigm shifts are needed, which in turn require concerted political as much as societal will.

<u>Need for bringing the outputs in the actual policy debate</u>

The stakeholder dialogues organized within the ENCI-Lowcarb project showed that the detailedness of the visions and the existence of a consensus among the invited stakeholders about concrete steps, decisions and a schedule leading towards a climate friendly future varies depending on the sector.

For instance concerning the transport sector uncertainties about technology choices and the possibility of total decoupling of freight transport and economic growth dominate the discussions.

As the future development of fossil fuel prices also the evolution of investment costs for different technology options are both reflections of different worldviews, and object to unforeseeable contextual evolutions. The best way of avoiding division among the participating stakeholders is to present results of price sensitivity analysis.

Globally even if all interest groups agree that it is necessary to take urgent action there is still a lot of uncertainty concerning the whole picture of the future energy system and the concrete schedule of actions that have concretely to be taken.

The work of the ENCI-Lowcarb scenarios allowed identifying bottlenecks in France & Germany. These subjects have to be discussed further and brought to the policy agenda:

- A decoupeling of freight transport and GDP growth (reshoring, dematerialization of consumption etc.)
- Making an early decommissioning of coal power plants acceptable
- Adoption of a progressive carbon tax on energy consumption
- The need for a planned retrofitting obligation for buildings

2. Dissemination activities and exploitation of results

During the project the main dissemination activities were:

- The organization of regular EU stakeholder seminars in Brussels,
- The participation in EU events like the Green Week and the EUSEW,
- The organization of regular "Low carbon Society Network" seminars; promoting use of the project methodology for NGOs and researchers that are registered for the project's Lowcarbon Society Network.
- Dissemination of results over project newsletter, the mailing list of our ENCI-LowCarb network and other relevant mailing lists,
- The presentation of preliminary results in other scenario related contexts (research seminars etc.)
- Dissemination of results over the project websites
- Meetings with public institutions to discuss the recommendations of the scenarios
- Presentation of the project results and especially of the collaborative scenario creation methodology for interested parties (In eastern European countries and India)
- Assisting interested NGOs and researchers involved in the development of low carbon scenarios and strategies with stakeholder involvement in European countries. This has lead to proposals for such projects with expected use of the project methodology for the countries Bulgaria, Italy, and Latvia, as well as South East Europe (covering Bosnia-Herzegovina, Macedonia, Serbia and eventually other countries):

The project has inspired a number of initiatives for collaborative development of low-carbon scenarios and strategies with stakeholder involvement.
Based on contacts made during the project, in the spring of 2012, INFORSE-Europe developed a project proposal for developing scenarios with stakeholder involvement together with national partners in Bulgaria, Italy, and Latvia for these three countries.
For Latvia and Bulgaria, INFORSE-Europe and the national partners have developed national scenarios previously, and they want to use the experiences of the ENCI project on stakeholder involvement to develop new scenarios that can achieve large support from stakeholders.

Concerning Italy, INFORSE is in contact with national partners that would like to develop scenarios with stakeholder involvement after the 2011-referendum on nuclear power, after which Italy needs a new strategy for its low carbon development.

The proposal was submitted to a private fund (Minor Foundation), but was not accepted for funding by now. INFORSE-Europe and the national partners are working further on scenarios for these three countries, but have decided to continue the work as three separate projects rather than one, as it seems more likely to get funding for the three countries individually. New funding applications are planned in the fall of 2012.

In parallel to this, INFORSE-Europe has become associate partner to a project to develop scenarios for the South East European countries, including Serbia, Macedonia, Bosnia and other countries. The purpose of involving INFORSE-Europe is to disseminate the ENCI Project's methodology to this new project. Funding for the project was applied to EU EuropeAid. After the concept note was accepted, a full application is now submitted.

The ENCI Project also inspired a Hungarian INFORSE member to develop low-carbon scenarios for Hungary, that have been presented at several events in Hungary and in a Hungarian publication in 2011. The Hungarian organization sent representatives for a number of the ENCI Project events, including the final conference.

Additionally, Polish CSOs have been interested in the ENCI project, and some participated in project events. One of them will use the experience from the project for a new project on local energy scenarios in Polish municipalities.

Also INFORSE-Europe is using methods and lessons from the project for its projects with local scenarios and strategy projects. In the fall of 2012 INFORSE-Europe has become leader respectively partner in two projects for local low carbon strategies, involving national partners and municipalities in respectively Belarus and Poland (INFORSE-Europe's Polish project is different from the one mentioned above). In these projects INFORSE-Europe will use experience from the project, both regarding stakeholder involvement and regarding local scenarios and strategies.

IDFC (Infrastructure Development Finance Company) an Indian investment company is planning to develop a multi stakeholder climate scenario for India focusing on infrastructure development. RAC-F had several e-mail exchanges and a phone conference with this entity to transmit the core experiences of the ENCI-LowCarb project.