Towards post carbon cities: Why? How?

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Abstract

The emerging concept of a transition to a so-called "post-carbon" society has gradually been gathering steam (EC, 2007). The concept discussed in this paper, "post carbon cities" in France, follows the next objectives: by 2050, a reduction of greenhouse gas emissions by a Factor 4 compared to 1990 levels, a near self-sufficiency in carbon fuels (oil, gas, coal) and the capacity to adapt to climate change. These issues will be treated in two main parts; in the first one, we will focus first on the "why" "post carbon cities" could be relevant to address these challenges, and then "how", cities already act, and can go beyond.

Considering cities in foresight analysis is quite recent. But a strong dilemma exists about the potentials of local initiatives for the energy transition. On one side, cities can be considered as a lever thanks to the impact of local actions and to their international networks for promoting best practices. On the other side, the urban ecosystem is very inert, probably more as the energy system production. Almost 70 % of the "city" of 2050 is already built in France.

The research programme *Rethinking cities in a post carbon society*, launched in 2008 by the Ministry of Sustainable Development and the French Environment and Energy Management Agency (ADEME), analysed the role of cities in the post carbon transition through: thematic seminars, on-site research projects and scenario building. This paper describes some results from this foresight programme and particularly the six transition paths developed in a workshop with several energy and urban experts. Considering the case of French cities, we present an in-depth analysis of the role urban stakeholders' play, or could play, in promoting profound changes on the path to a post-carbon society. We highlight two major challenges related to the achievement of this goal: coordinating the three timeframes – short, medium and long term – and different spatial scales – from individual to global scale.

Introduction: the concept of the post carbon cities

Post carbon transition has gained momentum in the institutional spheres and researchers, as "an adoption of new forms of energy and adaptation to the climate change that is already taking place" (EC, 2007). More particularly on cities (EC, 2012), the question is more about the means (type of technologies, price, infrastructures, ways of life …) than on the objectives. But to be more precise about the target, we proposed in this paper, and it was the framework of the foresight programme Rethinking cities in a post carbon society, three target that must be reached by cities by 2050. Post carbon cities must reach a massive reduction of greenhouse gas emissions (GHG) by a factor in 2050 of four compared to 1990, a near self-sufficiency in carbon fossil fuels -oil, gas, coal-and develop the capacity to adapt to climate change. Post carbon cities is proposed as a concept allowing to put in a nutshell energy and climate issues. But post carbon cities is not only a new concept beyond "low carbon", it implies a paradigm shift about relationships between energy and city. Energy and climate would become an essential issues, at the same time as long term target (reduction of GHG) and as short term requirements (resilience with regards to oil price rising and supply disruption).

But cities can only be key actors in this post carbon transition under certain conditions. A link has to be established between the global level, like climate change and energy related issues, and the local level. Between this macro level and the micro level, city stakeholders are in a key position to integrate local initiatives from different communities and coordinating them in a global perspective.

We will describe in this paper how this issue has been addressed within the foresight programme *Rethinking cities in a post carbon society*, launched in 2008 by the Ministry of Sustainable Development and the French Environment and Energy Management Agency (ADEME). It analysed the role of cities in the energy transition by several means: thematic seminars, territorial researches and scenario building workshop. In this paper, we will focus first on the "why" post carbon cities could be relevant to address these challenges, and then "how", cities already act, and can go beyond

In the first part, we will present the energy and climate issues and the reasons why cities cannot be indifferent to them. Then, interesting pioneer local initiatives is presented as a first step in the post carbon transition. Last, the six scenarios developed in the workshop of the foresight programme are described to give an overview of the levers that cities have to mobilise to go further towards more integrated policies. Some highlights from several research projects from the programme are included as references; and particularly a modelling based on scenarios. Finally, we will propose some perspectives regarding timeframe and scales coordination.

Why post-carbon cities: reasons and controversies

ENERGY AND CLIMATE RELATED ISSUES

In Europe, where the urban transition (major share of urban population) is largely underway, the prospect of adapting cities to the post-carbon revolution can spark controversy. Objections concern less the transition's goals, but the cities responsibilities (a city has to be understood here from the point of view of the "city ecosystem" including local authorities, other urban stakeholders and the citizens living in an urban area) and the possibility of taking action at this level.

On the climate issue, recent trends have only increased the legitimacy of the strict objectives initially set by scientists and then backed by national, European and political leaders[1]. During the previous decade, GHG and their concentration in the atmosphere have reached levels that even the most pessimistic projections of the Intergovernmental Panel on Climate Change (IPCC) did not expect. To achieve the objective, seen as essential, of limiting warming to 2 °C by the end of the century, it would be necessary to reduce significantly global greenhouse gas emissions, starting in the years 2015–2020 at the latest (Rogelj, 2011). Even if some reductions have already been observed in some countries, the overall trends are more than ever on the rise (IEA, 2012). Meeting this deadline by 2050 now seems impossible, which means that we are headed towards global warming of 2–4 °C in 2100, with impacts becoming severe after 2050 but beginning to be felt earlier. It means that even with a strong global agreement and especially actions in the next coming years to reduce GHG, the impacts of climate change will be in any case important. As a result, it will be necessary to make massive efforts in the areas of prevention and adaptation in an uncertainties context.

Furthermore, considering the peak oil, pessimistic or optimistic scenarios only differ from one or two decades (Figure 1), tensions are inevitable. Partial or total substitutions are possible from gas, coal (gas to liquid (GTL) or coal to liquid (CTL) by the reaction of Fisher Tropsch) or non-conventional fuel oils (heavy oils, tar sands or oil shale) and but emit more GHG than conventional oil combustion. And these substitutions are not compatible with the French national target to divide by four national greenhouse gas emissions by 2050 compared to 1990 emissions.

VULNERABILITY AND ROLE OF CITIES

These global climate and energy challenges do have an impact on cities, their residents and their elected representatives. Urban areas as a whole account for nearly 60 % of energy use and 70 % of CO_2 emissions. In Europe, the finding is even more important. 69 % of primary energy was used in cities in 2006 (IEA, 2008). In France, concerning the demographic context, more than 80 % of the population lives in large urban areas while less than 5 % of the population live in fully rural environment (INSEE, 2011).

Considering climate and particularly adaptation issues, cities are particularly exposed to the effects of climate change (heat waves, flood …), but most of all, they do not know exactly to what kind of evolution and extremes events they have to deal with (Hallegate, 2007) as showed in Figure 2. Moreover, considering energy vulnerability, the availability and price of energy is particularly crucial for cities which totally import their primary energy. While certain cities in France will be more affected than others, all will find it necessary to adapt in a context of uncertain impacts.

If on the one hand, cities are directly affected, on the other hand, cities hold the keys to a successful transition to a post-carbon society. Cities already have an important role to play in implementing new energy technologies (for instance, the infrastructure for electric vehicles) and city governments also largely control the key levers, including land and urban planning, public transport, social housing, hazard protection and water systems, green areas, urban heating, local mobility management and taxation. Besides, with their regulatory or economic role, city government influence many others actors at the local scale (THINK, 2011). In addition, they are clearly in the best position to educate and mobilise local residents and companies and to coordinate civil society initiatives. Finally, creating a bridge between the post-carbon city and the green economy could undoubtedly work best at the regional level. Instead of buying imported fossil fuel energy, developing energy efficiency and renewable technologies can produce more wealth and have a double effect, or double dividend: reduction of oil imports and creation of jobs (Lutz, 2012). More generally, regions would be best suited to address energy and climate issues as they can act on economic development, quality of life and employment.

1. The "factor of 4" appeared for the first time as a national objective in France in the planning law of 13 July 2005 establishing the directions of French energy policy and was confirmed by the Grenelle 2 law of 12 July 2010.

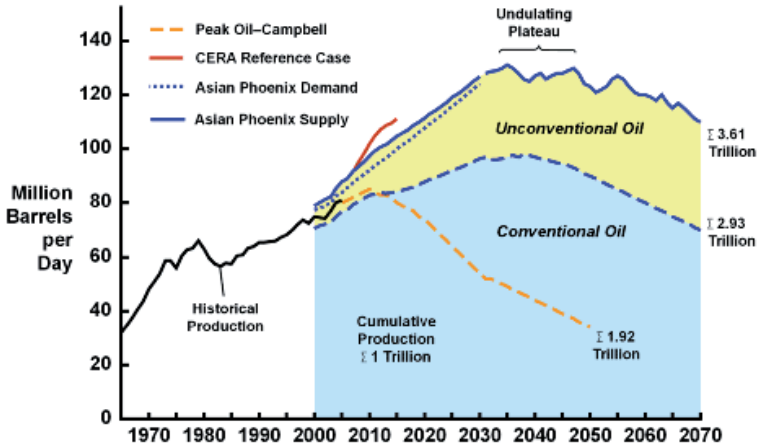

Figure 1. Two contrasted visions of peak-oil, a same issue before the middle of the century. Source: HIS – Cambridge Energy Research Associates (2009).

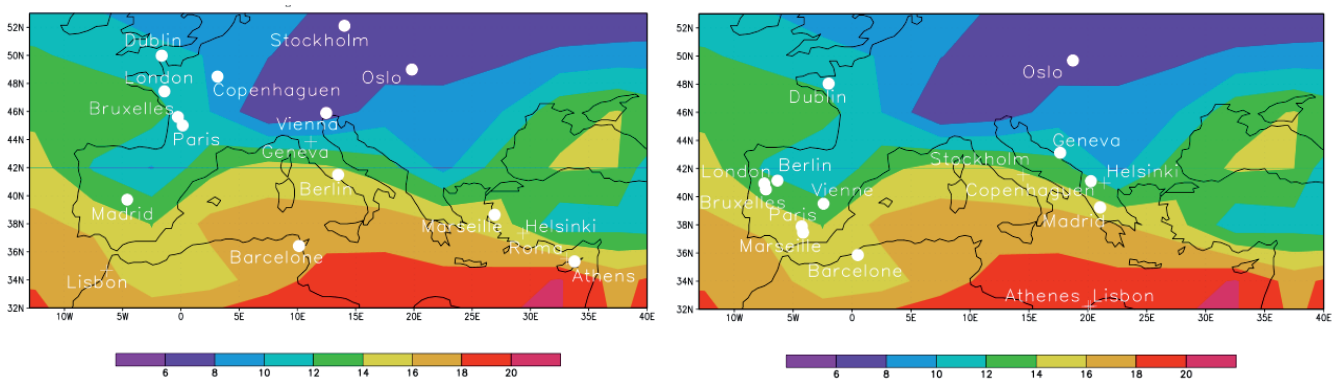

Figure 2. Climate Analogues in 2070, model from Hadley Centre (left) and Meteo-France (right), Scenario SRES A2. Source: Hallegatte, Hourcade, Ambrosi (2007).

How cities engage

STRONG ACTIONS ARE ALREADY LAUNCHED

Cities, not only as local authorities bus as local ecosystem of inhabitants, companies, public utilities and local governments, were among the first to become aware of the significance and especially the implications of the above-mentioned challenges. Drawing support from associations or active networks such as Local Governments for Sustainability (ICLEI) in the 1990's, Climate Alliance and Energy-Cities, some of them voluntarily became involved in Climate Plans, energy-transition experiments, eco-district projects and, more recently, "resilient cities" (Emelianoff, 2013). Some of these initiatives and experiments have become iconic, including Freiburg im Breisgau and Hanover in Germany; Vaxjo, Malmo, Gothenburg and Stockholm in Sweden; Bristol, Woking and the eco-district BedZED (Beddington Zero [fossil] Energy Development) in the United Kingdom; Copenhagen in Denmark; Boulder, Colorado in the United States; and Masdar in the United Arab Emirates. But the movement has far higher aspirations, as evidenced by the fact that nearly 4,000 European cities have signed the "Covenant of Mayors"[2] and have committed to exceeding the carbon-reduction objectives (20 %) set by the European Commission for 2020. When considering the cities and districts that take part in the more grassroots "cities in transition" (Hopkins, 2006) movements, a strong momentum is clearly gaining ground.

Drawing on these pioneering experiences and encouraged by the European Union, the European Member States have taken over the reins in the past decade to increase participation and develop the necessary national policies. The success of post-carbon societies depends on the successful collaboration between the national and local levels. In France, the Grenelle laws of 2009–2010 serve as a good tentative. They expanded the Local Climate Plans, initiated in 2004, towards all towns with more than 50,000 inhabitants and developed a wide range of incentives and standards to promote low-carbon mobility, thermal retrofit of buildings and the creation of eco-districts.

2. The Covenant of Mayors (for sustainable local energy) was initiated in 2008, under the leadership of the European Commission. It requires signatory cities to submit, within one year, an energy action plan for reducing CO2 emissions by 20 % or more by 2012. They must then submit a report evaluating the results every second year. http:/www.conventiondesmaires.eu/index_fr.html.

More than 350 local Climate-Energy Plans, including a mostly complete "adaptation to climate change" section, have been implemented in France and some 400 eco-district projects have been launched.[3] While these initiatives are sometimes rather technical, and not enough participative, and are currently facing limits imposed by the economic crisis, they are taking part in a changing "urban culture".

The difficulties, however, must not be ignored. Local authorities directly control only a small part of GHG emitted in their area (roughly some 2 % coming from local authorities' buildings or infrastructures, as well as from municipal services (Paris, 2007) (Rennes, 2011). Even if they have a much broader capacity for action (considering their skills and their role, it can be about ¼ considering all the others levers quoted before – from transport policy to district heating, etc.), the scope of their ambitions and the obstacles they face – physical, technical, social, economic, institutional and cultural – leave many local players confused. The understanding and acceptance of their respective role begins by raising awareness in relation to the remaining work to be done as well as the advantages that come from shared effort.

Six transition paths to go further

THE RELEVANCE OF BACKCASTING SCENARIOS

The amount of on-going initiatives demonstrates, at least in Europe, awareness in relation to the challenges involving the low- or post-carbon city- and the political will to address them. The array of solutions that has emerged at the local, national and European level is impressive. But a quick assessment of the projects underway (Climate Plans, eco-districts, new mobility services, etc.), as certain cities themselves have realised (Emelianoff, 2013), show that we usually remain very far from the efforts needed to achieve the set targets by 2050. While the EU Climate and Energy package[4] set for 2020 both by the European Commission and the Grenelle environmental laws in France have a high likelihood of being achieved, due to or despite the crisis, the dramatic changes that will be essential for meeting the challenges of the post-carbon city have yet to be undertaken. After having reached the threshold of 20 %, the question "how do we go further" arises. That is why backcasting scenarios has been developed, to determine ways with articulation of technologies, urban organisation, and ways of life, partly determined by policies and measures, to reach an ambitious target (post carbon transition)

METHOD OF CONSTRUCTION OF SCENARIOS

One of the activities implemented by the foresight programme *Rethinking cities in a post carbon society* was to develop scenarios applying backcasting methods (Lovins, 1976) (Robinson, 1990). The process involved exploring the consequences of various assumptions related to different contexts, i.e. the economic situation, technological breakthroughs, energy prices, political decisions, and changes in values. In practice, it then led to create, compare and partly evaluate a number of possible strategies for achieving the post carbon society (i.e. the three objectives mentioned before for 2050). The aim was not to produce and describe images of the post-carbon city in 2050, as this would only have limited significance, given the wide variety of existing cities. The main purpose was to bring these strategies up for discussion, to develop new ones and to assess the players' degree of flexibility considering opportunities and obstacles. The backcasting instrument consists in devising transition pathways with a timeframe of 30–40 years, also called backcasting scenarios. The procedure consists in starting with the ultimate objective and identifying the pathways to reach this objective.

An expert group with almost 25 persons (researchers, academics, energy experts and practitioners from local authorities), with several area of expertise (economists, engineers, town planners) met regularly (every second month) during two years in workshop sessions. The process adopted by the working group can be described in four main phases, as show in Figure 3.

With such a distant time horizon, uncertainty and a high variety of representations of the future naturally play a major role in the strategies being developed. The basic assumption adopted for creating scenarios was that the transition pathways will mainly depend on how stakeholders (in particular, local authorities) perceive the uncertainties of the situation, their opportunities and their degree of flexibility six scenarios were developed. They express scepticism or acceptance in relation to the possibility of profound transformation of urban and energy infrastructure. They are defined as combination between 3 degrees of flexibility (on economics tools, urban infrastructure and planning, and lifestyles) and 2 types of context (baseline or favourable to innovation) (Table 1). Thus, the economics, technics, cultural and social aspects of the city can be – at least partly – considered among the different scenarios.

In an initial configuration (Scenarios 1 and 2), a little flexibility for transformational policies at the urban level is considered: local authorities, businesses and residents adapt smartly to incentives, constraints and opportunities, which are mainly external (energy and carbon prices, new technologies, technical standards, etc.). A second configuration (Scenarios 3 and 4) envisions massive transformation of urban and energy infrastructures in more or less decentralised contexts, but remains cautious about the possibility of changing lifestyles or the ways of using space. A third configuration (Scenarios 5 and 6) explores the conditions and expected impacts of large-scale changes in these latter two areas. Each scenario presented in Table 1 is described by a set of components, a combination of components describe in Table 2.

By creating very different pathways to reach a goal (post carbon society), selecting different and coherent components in a given context, the best possible combination, according to the panel of experts associated with the exercise, is developed. The presentation of the qualitative result of the backcasting exercise is then summarized. Details are available in the reports from the workshop (Futuribles, 2010) (MANA, 2012).

3. See Map of the Observatoire des plans Climat-Energie territoriaux (regional climate-energy plans monitoring system). http://observatoire.pcet-ademe.fr/. List of top eco-districts in France in 2011. Website: http://www.developpement-durable.gouv.fr/Palmares-national-EcoQuartier-2011.html.

4. Improve energy efficiency by 20 %; raise the share of final energy consumption produced from renewable resources to 20 %; and reduce greenhouse gas emissions by 20 % compared to 1990 levels.

Phase 1: Definition of system variables

Two meetings were necessary to build a first system of 70 variables influencing the post carbon transition. The 70 variables were grouped into 15 components or group of variables classified in 3 types: contextual, transversal and thematic.

Phase 2: Hypothesis / groups of variables

The objective of phase 2 was to build micro group of variables or partial scenarios. To do so, contrasted assumptions (A, B, C, D, E) for each component (C1 to C15) were built to have a "scenario Blueprint". For instance, considering the component (C1 International regulation), a set of 5 hypothesis has been done. A consistent description was done for each assumption of component.

Phase 3: Seminar 'frames of the scenarios

A seminar (a day and half) was dedicated to the definition of the scenarios (articulation of the 15 components).

Additional interviews were conducted with experts (external from the initial group if needed) when issues required it (biomass, carbon tax, mobility, rehabilitation of the housing).

Phase 4: Detailed Description of the paths of the scenarios/Issues and tracks for public action

A synthesis has been proposed by the coordinator of the workshop (Mana). Some last interactions with experts has been done (two times a half-day, with one focused on the energy system – generation and uses – due to its importance considering the topic), to be sure, narrative description of scenarios is relevant and coherent for all scenarios.

Throughout the process, the working formats have evolved from the more open formats (brainstorming) to some others more focused on a topic (thematic working group).

Figure 3. Phases of the back-casting exercise.

Table 1. Six scenarios towards a post-carbon city.

		Degrees of flexibility – Possibility of action		
		Major role of context (Limited possibility of action on technologies and price signals)	**Possibility of action on investments and infrastructures**	**Possibility of action on urban planning, and lifestyles**
Context	**Baseline (trend)**	Scenario 1 Intelligent wait-and-see	Scenario 3 New climate and energy infrastructures	Scenario 5 Self-contained city
	Radical change favourable to innovation	Scenario 2 Carbon creativity	Scenario 4 Biopolis	Scenario 6 Frugal Urbanity

Two scenarios of contextual response: "Intelligent wait-and-see" and "Carbon creativity"

In the first scenarios (Scenario 1 and 2), the national or international context plays a decisive role. For economic, sociopolitical or financial reasons, any massive transformation of the existing living environment or urban structures is considered unrealistic. Actions are therefore limited to a reactive management of external opportunities and constraints, including those related to inter-city competition. In addition to experiments and Climate Plans, this means that the local authorities must cleverly carry out any feasible initiatives at low cost and support changes involving either the emergence of new technologies and the implementation of new standards or changes in energy and carbon prices. With technological innovation and large cities' desire to establish a reputation for local innovation, price signals thus serve as a major decisive factor in the change process. These factors lead to the creation of two scenarios that are significantly different in anticipation of the future.

With the first scenario ("Intelligent wait-and-see") cautious and regret-avoiding behaviours are supported by the economic situation (continuation of the crisis), a relative and temporary moderation in oil price, and a lessening of concern about greenhouse gases. Following on current trends, all possible solutions that do not require a massive investment are nevertheless tested, then expanded on a wider scale, such as the development of eco-friendly means of transport (walking, cycling, etc.), greater access to public transport, speed limits, parking restrictions in the city centre, car-pooling and cars on demand, incentives to encourage telecommuting and e-commerce, as well as compliance with new housing standards (low consumption buildings -50 kWh PE/m^2/year- and positive energy buildings in 2020), the use of renewable energies in public buildings and public transport, "greening" and logistics optimisation. A new generation of Climate Plans is being implemented, with much more effective and individualised assessment systems and information tools, which fosters public awareness and

Table 2. Scenario blueprint. Micro scenario (A to E) items and names.

Type of component	Items	A	B	C	D	E
Contextual	**C1 International regulation (energy-climate)**	Climate sceptic	Copenhagen vision	European climate policy	Climate-compatible	Climate region
	C2 National and international economic context	Crisis and big shift	Stop-and-go and competitive debt reduction	Green New Deal	Socio-ecological protectionism	New technological revolution
Transversal	**C3 National public policies**	Priority: reducing deficits and oil bill	Continuation of Grenelle and green growth	Carbon taxation and economic regulations	Ecological transition policy	Priority: social and employment policy
	C4 Decentralisation and local governance	Good governance and institutional simplification	Alignment with the "European model"	Metropolitan power	Local autonomy and energy decentralisation	Selective recentralisation
	C5 Urban systems (city hierarchy and organisation)	City-region and urban sprawl	Archipelago of digitally interconnected medium-sized cities	Network of densely populated cities	Tight-knit rural communities and geographic divide	Urban exodus
	C6 Lifestyles and values	Green consumerism and economic rationality	Self-preoccupation and rise in nationalist sentiment	Ethnic segregation	Simple and eco-friendly society	Socially responsible urban living
	C7 Adaptation to climate and global warming change	Raising of public awareness	Regulation through insurance	Bioclimatic regional development	Protection and defence	Business transition and lifestyle changes
Thematic	**C8 Productive systems**	Specialisation and concentration	High technology (including green technologies) and innovative SMEs	New service economy	Network of local and regional economies	Use of regional revenue and resources
	C9 Energy systems	Centralised and high-carbon with reduction in oil	Partly low-carbon and replacement essential	Centralised and very low-carbon	Centralised and low-carbon	All renewables & withdrawal from nuclear
	C10 Urban and land policies	Project-based urban development and ineffective planning	Cooperative development: coordinated, negotiated, compensated urban development	Massive urban renewal	City over the city: effective planning and location-based taxation	Eco-planning and new land appraisals
	C11 Transport technologies	Efficient and clean transport	Light and slow	”Liveable ”cars	Revolution in alternative fuels	Revolution in alternative fossil fuels
	C12 Mobility policies	Travel optimisation and sustainable mobility	Massive shift toward public transport	Economic regulation of local mobility	Mobility shared public good	New infrastructure paradigms
	C13 Residential and commercial buildings (project management)	Basic renovation and energy efficiency	Technological challenge	Massive rehabilitation, demolition and reconstruction	Sharing and networking	Bio-logis (green homes) & bioclimatic housing
	C14 Housing policies	High level of home ownership	Package of housing-mobility services	State as builder	Public-private partnership	Co-renting
	C15 Social and energy poverty policies	Withdrawal from direct financing, privatisation, contracting	Appropriations (fair and effective)	Priority: disadvantaged and vulnerable populations	New rights & reintegration through social policy	Local, community-based initiatives

stakeholders participation. All these factors, however, do not provide sufficient preparation for the possibility of a sudden crisis by 2030–2040 resulting from oil supply shortages, intolerable price hikes or a recurrence of extreme weather events – crises that have very serious socioeconomic effects as well as major repercussions for cities.

With the second scenario ("Carbon creativity") which benefits from a more favourable economic and technical context, economic incentives, especially carbon taxation, are used proactively in anticipation of future constraints and in support of earlier behavioural and technology changes (electric vehicles, new materials, efficient engines or production systems, digital technologies, etc.). At the national level in France, the domestic tax on petroleum products and the carbon tax are being gradually combined, with a "floating" tax and are partially replacing labour charges, providing a double dividend. Economic instruments, such as taxes, tolls and tariffs, are systematically being used to guide consumer choices, foster innovation and prioritise local initiatives based on their cost-benefit ratio. The large-scale use of information technologies and "yield management" (variable price according rate of uses) makes these instruments more effective. Protected by countervailing duties at the borders, a sort of green economy that focuses on products and services is taking shape. Even though this second case is still characterised by a configuration with levers largely outside the cities' control, the cities nevertheless have a major role to play in supporting local innovation and setting locally oriented pricing and toll policies, while taking into consideration the most vulnerable populations.

To achieve a post carbon transition, the potential from these two scenarios should not be underestimated. There are, however, at least three factors that undermine it. First, they are vulnerable to all kinds of uncertainties (physical, technological, political, economic and tax-related) because not any local anticipation is really engaged. Second, they both pass on to future generations the burden of unavoidable infrastructure investments, which over time will only become more cumbersome and ineffective in reducing GHG. Last, and above all, there are fears that these pathways will lead to so many inequalities and social problems that they will eventually become unacceptable.

These two scenarios, very different in economic terms, face the same economic problems: the fact that the most disadvantaged populations find it impossible to adapt to and gain access to the most expensive innovations, the development of "eco-status", the difficulty of designing tax and toll systems that do not penalise the most vulnerable, and finally, the general risk of rising energy poverty and exposure to serious crises.

Two scenarios of massive investments: "New energy and climate infrastructures" and "Biopolis"

The opportunism of the two previous scenarios stands in contrast to the proactive nature of the next two scenarios. These two scenarios envision massive renovation of existing buildings as well as urban and energy infrastructures. In an environment that is more favourable to public and private investments, viewed as a solution to the crisis and unemployment, the response involves large-scale, simultaneous changes inspired by initiatives already undertaken in several cities:

- a massive thermal retrofitting of buildings with the aim of reducing their fossil fuel use by at least a factor three;
- a change of scale in local energy supply and production systems, with a much larger proportion for renewable (or non-fossil) energy networks;
- a massive investment in infrastructures and systems protecting the population against the effects of climate change (protection against increased flood and fire risks, urban vegetation, energy and transport infrastructures built to withstand extreme weather events, etc.);
- a change of scale in the financing of public transport infrastructures, with the objective, whenever possible, of meeting the three-thirds standard currently in use in Freiburg im Breisgau (one-third cars, one-third public transport and one-third eco-friendly methods).

These investment strategies would be profitable over the long term because they would lead to a permanent reduction in energy and transport costs and would generate large numbers of jobs that cannot be outsourced. But the strategies could have very different outcomes on the ground depending on whether priority is given to centralised or highly decentralised solutions, with in the two cases, investments both on demand side and supply side.

The first scenario ("New climate and energy infrastructures") assigns a key role to the State's public incentives, to the major energy players and to investments by households, social landlords and large cities. Building on existing programmes, this involves developing all the tools necessary for making the thermal retrofitting of the relevant buildings compliant with the most ambitious standards, beginning with social housing to deal with fuel poverty. This would include the creation and support of training programmes, subsidised loans, energy savings certificates, feed-in tariffs, labels, etc., and a requirement to make improvements before selling a home with the creation of a public energy bank. Funded by specific resources (sustainable development accounts, etc.), this public bank, which specialises in long-term projects, could combine venture capital financing, a third-party payer system, energy certificate management and an insurance system. Both nuclear energy and the centralised production of renewable energies, such as marine wind farms and solar power plants, take priority, large eco-city projects arise and equipment obsolescence programmes accelerate (cash-for-scrap scheme, demolition of the most energy-inefficient buildings). The scenario also involves making city centres more attractive, reducing unsafe conditions and improving networks through energy retrofitting and the construction of new infrastructures. In the long run, it may prove easier to finance European and global carbon market schemes by including cities.

In the second scenariot ("Biopolis") decentralised solutions take priority. Organised into urban regions (the city and its hinterland), the local authorities are assigned energy generation responsibilities. The division between urban and rural disappears, and complementarity is considered. Natural areas and biomass are used in all their forms (vegetation, biofuels, wood, biomaterials, etc.) to generate energy from renewable sources, mitigate the effects of global warming, create protection zones, and store carbon. The services provided by nature are taken into consideration and assigned value, particularly through land

taxation. Short distribution channels and local relationships are expanded, but prove unsuccessful in reducing travel needs, only a small proportion of which can be met with alternatives to oil. Unlike the previous ones, this scenario assumes very profound institutional and cultural changes in production models.

These two scenarios have the great advantage of not imposing restrictions on companies' and residents' choice of location and of satisfying medium-term concerns about quality of life and employment. It will most certainly be costly and time-consuming to implement each of these strategies, with many institutional and financial problems as well as a lack of skilled staff, energy market regulation, development of new networks and owner-tenant relations. As a result, these strategies risk to be less effective than anticipated. With regard to this risk, it is necessary to weigh one of these strategies' most common disadvantages – ignoring the consequences of urban sprawl and uncontrolled growth, especially the Scenario 4 through the choice maintained for individual houses. The reduction in CO_2 emissions and energy expenditures expected from a massive energy retrofitting of the existing building stock could approximate the additional costs and emissions that may result from the anticipated (and continually accelerating) expansion of the cities, especially the major metropolitan areas. And this does not even take "embodied energies" into account.

The choice of a different urban lifestyle: "Self-contained city" and "Frugal urbanity"

The final two scenarios assign a central role to lifestyle changes and the reshaping of urban regions during the transition to post-carbon cities. These are the images that spontaneously come to mind when thinking about such cities: more compact and evenly balanced urban areas built around several hubs interconnected by efficient public transport networks, combining functional and social diversity, and populated by residents living more urban and simple or "frugal" lifestyles. A mix of policies and measures can have a strong impact on CO_2 emissions: ground rent management to control density; containment of urban growth around the main motorways and interchange stations ("finger plan" development); strong disincentives to driving (speed limits, parking restrictions); mixed-employment and mixed-housing development in the inner ring suburbs (with social diversity and reclamation of urban and industrial wastelands); and strong control over commercial districts and major traffic generators, such as hospitals, universities, employment hubs and business centres. At first glance, this is a very stimulating vision about the management of the land and its rent. But a whole set of obstacles standing between the model and its implementation have to be considered, including a large number of scientific controversies on the impact of urban forms, the inadequacy of government systems, the weight of inertia, the difficulty of changing lifestyles and last, scepticism over the possibility of managing long-term change. For that reason, the long-term planning group again created two very different pathways.

In the first scenario ("Self-contained city") the local authorities and urban planners are the key drivers behind the transition, using spatial planning, ground rent management, housing policies, and an effective combination of transport and urban development policies. In general, the local tax code is revamped to take location into account. Urban development projects are strictly dependent on public transport, land policies are transferred to the inter-city level, and urban and employment areas and housing are concentrated around higher-density hubs based on a polycentric model. An integrated approach encompasses energy, climate and urban quality-of-life issues at all levels: block (energy sharing), district (neighbourhood services), city and suburbs (consistency of employment, housing and services), urban region (control over urban forms and infrastructures) and the entire territory (organisation of leisure, urban structure, city/country relations) (Wiel, 2006). At the same time, measures are taken to facilitate relocation. The idea is to make a new urban lifestyle socially desirable. This process requires the prior condition of a redistribution of resources between city-centre and suburban districts and profound institutional reform particularly in land and urban management.

In the second scenario ("Frugal urbanity") the residents themselves and changes in their lifestyles are the decisive factor in the urban transformation process, giving local governments the impetus to act. Three factors lead to profound changes in current lifestyles in this scenario: consumers' economic rationality during a prolonged crisis (green, but simpler consumerism), the emergence of more eco-friendly and frugal values in the younger generations, and finally the anticipation of much stronger future restrictions on the access to food and energy resources (driven by movements such as "cities in transition"). At a given time, these restrictions take concrete form as "carbon credit cards" and the development of local currency systems that promote energy and carbon savings. Short distribution channels, telecommuting, massive energy savings, driving restrictions, another relationship with time (particularly working time), self-build projects, local recreational facilities, etc. All have an impact on the development of new services and business models (service/circular economy, etc.) and methods of empowering residents to play a more active role in their communities.

This pathway enables the city to greatly reduce its long-term vulnerability to climate crises and short-term reliance on oil, while also giving local authorities and residents an opportunity to create a much more attractive and resilient model of urban living. Its major difficulty lies in its assumption of economic transitions, which are hard to imagine at this point. The scenario does, however, open up promising new avenues relative to this issue.

CONFRONTATION BETWEEN QUANTITATIVE AND QUALITATIVE METHODS

Beyond the qualitative analysis and the description of the six scenarios, with the participation of the expert group mentioned before, a quantitative evaluation of scenarios has been done with a macroeconomic model to try to evaluate contributions of some local measures to a global objective, in this case, a post carbon transition. The six scenarios described have been translated in the model according to a global set of hypothesis on the twelve more important cities in France (CIRED, 2012). Hypothesis have been set in coherence with the qualitative scenarios described before.

To study the relationships between the spatial patterns at the urban and regional scale and the oil market, a spatial model that can be incorporated in a Computable General Equilibrium (CGE) framework for climate policy analysis has been developed (Sassi, 2010). The IMACLIM model used in this work is

a dynamic recursive model where savings and investments affect the capital stock as function of income only in the current period. It is based on an explicit representation of the economy both in money metric values and physical quantities linked by a price vector. This dual vision of the economy, which comes back to Arrow-Debreu theoretical framework (Arrow and Debreu, 1954), guarantees that the projected economy is supported by a realistic technical background and, conversely, that any projected technical system corresponds to realistic economic flows and consistent set of relative prices. The spatial model, developed for this study, disaggregates national economies into a rural area and multiple interrelated urban agglomerations. In line with the New Economic Geography and Urban Economics (Fujita, 1999), the approach considered the economies of agglomeration that arise from economic agents, both firms and households, being located close together, as benefits. The oil price and infrastructure investments modify the Economy's spatial organization, as housing and transport costs set households' and firms' locations. Economic geography has deep links with the GDP. Firms located close together benefit from "agglomeration effects" which increase workers' productivity. Reorganizing the economic geography may intensify or lower those effects. It also impacts the oil consumption because workers' commuting distances and goods flow intensity drive oil demand.

Translation from qualitative to quantitative scenarios

A set of macroeconomic variables corresponding to country-level averages in 2004 is obtained for France as a result of a calibration process: the domestic production size, the production price, labor requirements for production and the aggregate wage. The disaggregated local economies at the urban scale are consistent with the aggregate macroeconomy at the country scale. Agglomerations correspond to the urban area classification as defined by the National Institut of Statistic and Economic Studies (INSEE). The analysis is restricted to the twelfth most important agglomerations in terms of employment and population. To the carrying out the calibration, a set of empirical equations defining the main economic and spatial characteristics of the agglomerations considered is defined. So, each agglomeration is characterized by its population, labor force, production, number of firms, size and wage. This data is provided by INSEE. This ensures a distribution of economic activity coherent with empirical facts.

The quantitative assumptions translating scenarios in the model are detailed in the full report (CIRED, 2012), an overview is given there. For instance, assumptions on technologies are detailed in the Table 3 for the scenario 1 to 4 (those for which the model is the most relevant as subsequently described).

Macroeconomic results

From this exercise, we are able to obtain interesting dynamics about the different scenarios. More than the absolute value, it is interesting to see the order of magnitude of results and the trends that a "wait and see" scenario can cause in a middle term (Figure 4).

Around 2025, the strong decrease in GDP is due to the incapacity of economy to cope with a high oil price. On the opposite, Scenario 2, where high price of energy in short term is due to carbon price, the loss of GDP are significant in short term, but the absolute level is really higher in a second period (2020–2050). In Scenario 1, the underlying evolution of the spatial organization has implication on growth of the GDP and the oil consumption. However, after 2030, big cities shrink and the "agglomeration effects" lower. The GDP thus decreases. In Scenario 2, the GDP drop occurs at the beginning of the 2010–2050 period when the oil price increases sharply. But the development of alternative car engines limits the impact of oil price on growth. Scenario 4 faces the same evolution than Scenario 2 until 2020, but then the GDP increases compared to Scenario 1 and 2, as urban areas become bigger and the economy benefits from "agglomeration effects". In Scenario 3, GDP growth reaches the highest values. Cities develop significantly and the economy is not constrained by the oil price at the beginning of the period.

The quantitative analysis, even with a strong reduction about the hypothesis translated into the model due to the logic of modelling, can show that the spatial dimension of the economy matters in the energy security and oil scarcity debates. It differs from earlier work, which focused on a global aggregated approach, by introducing production, consumption, trade and urban-related external costs for multiple cities within regions.

But if the four first scenarios could be modelled without too many difficulties in such a model (even if results must be considered with all necessary precautions), the two last scenarios can hardly be applied in the model because of hypothesis which would imply new rationalities and new relations between stakeholders (i.e. a new economic model). Beyond technics and economics, the evolution of cultural aspects has to be considered as well. For instance, it means that elasticity can no longer be set according to historical data.

Conclusion

POTENTIALS OF QUALITATIVE AND QUANTITATIVE METHODS TO THINK THE TRANSITION

The results from the dialogue between qualitative and quantitative methods are multiple. Even used in a backcasting approach, qualitative and quantitative exercises appearing as often antagonistic (modeling scenarios may seem frustrating, even simplistic, on the opposite, qualitative description can seem unrealistic), scenario construction and modeling can be complementary and be mutually enriched.

Thus, modeling does not just give orders of magnitude on the expected emission reductions between the scenarios but allows respecting an overall consistency, to see convergence between actions and measures, and also to observe sometimes counter-intuitive results. In addition, qualitative method of scenarios opens creative field, allows considering breaks and improving the conceptual, necessarily rigid and conservative, modeling framework. This dialogue is useful, both for the overall coherence it involves between economy, technology and urban organization, but also for unexpected, new answers and especially questions it allow to appear.

REDUCE CONTROVERSIES AND ACT UNDER UNCERTAINTIES

The in-depth exploration of transition pathways up to 2050 enables us to get a better idea of the major remaining obstacles ahead. These include: controversies that are still open (about climate change impacts, frequency of extreme events, oil depletion …), the difficulty to develop coherent innovation and

Table 3. Main hypothesis of Scenario 1, 2, 3, 4 in the modeling exercise.

	Scenario 1	Scenario 2
Transport	Low Development of Electric Vehicles (5%) Reduction of uses of private cars Development of Coal To Liquid and Biofuels (10% each)	Development of electric vehicles (40% of the fleet) Reduction of uses of private cars Development of biofuels (20%)
Building	Reduction of energy consumption of buildings (-25%)	Reduction of energy consumption of buildings (-35%)
Energy	Low development of renewable energy (<20% of primary energy mix)	Development of nuclear power plants
	Scenario 3	**Scenario 4**
Transport	Development of electric vehicles (2(% of fleet in 2050) Development of alternatives fuels (20% Coal To Liquid and 10% biofuels)	Important Development of Electric vehicles (40% of fleet) Increase of uses of private cars Alternatives fuels (30% of biofuels)
Building	Reduction of energy consumption (50%) by thermal retrofitting (renovation rate 0,6%/year up to 2030, then 1,5%/year)	Reduction of energy consumption (50%) by thermal retrofitting (renovation rate 0,6%/year) More deconstruction/reconstruction
Energy	Development of renewables production with reduction of nuclear production (75% of electricity generation) Development of Carbon Capture and Storage	Important development of renewable energy Decrease of nuclear production (50% of electricity generation)

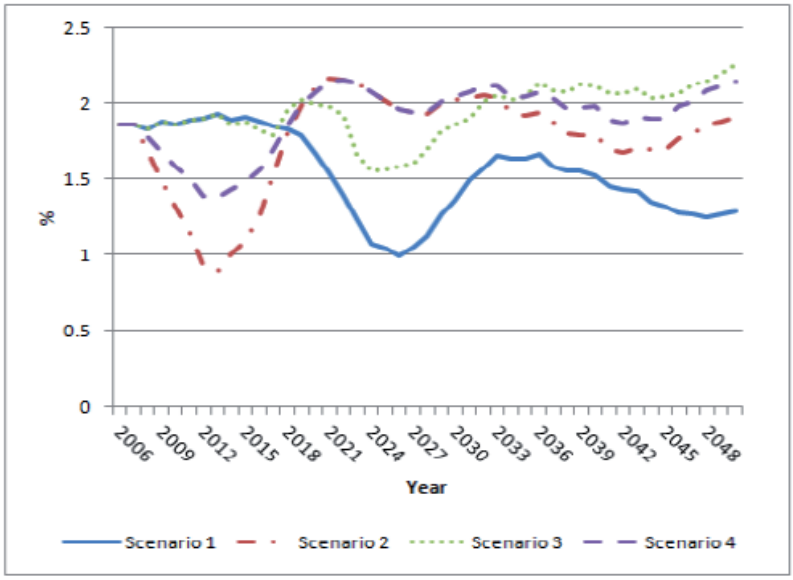

Figure 4. Growth of Gross Domestic Product according to different Scenarios. Source: CIRED, Enjeux, obstacles et leviers de la ville post-carbone (2012).

to position strategies for the green economy, inadequate local governance (especially regarding land use), inadequate programmes for brokering long-term investments, the difficulty of combining effective incentives with social justice, and an overly vague perception of expected benefits in terms of job creation, a more attractive city, social cohesion.

As far as the scenarios are concerned, a number of solutions recommended show the breadth of decisions still to be taken to set the cities on the post-carbon path. But uncertainty and controversies cannot be eliminated in a more and more complex world. All the solutions must be considered as an insurance against risks and a way to improve, once again, resilience … particularly in a country, like France, where energy dependency is a huge issue.

GET COHERENCE IN MULTISCALE GOVERNANCE

It seems that the cautious strategy – intelligent wait-and-see – is not a viable one, even as a temporary solution on the path to a post-carbon city. According to the group of experts and results from the model, it seems to make roughly one-third of

the way towards Factor 4 and it is too slow in taking key decisions. But none of the other scenarios, including the one closest to current policies (Scenario 3), is sufficient. It will therefore be necessary to combine several strategies, at different scales: carbon tax (Scenario 2), energy decentralisation (Scenario 4) and local and land governance (Scenario 5). In all of the scenarios, the success of the transition will require major lifestyle changes (Scenario 6) and the move toward more frugal urban living would maybe close the gap between results and objectives (CLIP, 2012) (EIFER, 2011).

Therefore, frugal lifestyle can be the fastest way for the population to acquire resilience when faced with the prospect of a severe crisis (that cannot be ignored as showed with peak oil debates). But all these levers will produce expected results only in coordination, via multilevel governance. Combining the different spatial scales is essential: from the building and block all the way up to Europe and the world. Cities seems to be an efficient level to do that, between the local and the global. In addition to the implied democratic aspects, this represents an invitation for all parties concerned to integrate multiple scales in their efforts over and above initiatives already undertaken.

ARTICULATE MEASURES AT DIFFERENT TIMEFRAMES

Next, and this is clearly the main message from this forecasting program, there is a need to coordinate the three timeframes despite the current crisis: short-term emergencies, medium-term Climate Plans and long-term strategies. In terms of energy and climate change, we know that it will take time before transitions will produce significant results, mainly due to inertia of energy and urban systems. But we also know that anything accomplished as quickly as possible will have a much higher impact than anything done in one or several decades, because of the cumulative nature of GHG and the risk that crises could occur earlier than expected. As a result, the most effective transition would be the one that would simultaneously do everything possible over the short term and at low cost, while also setting in motion the profound changes that will be essential over the long term. At the same time, it will be necessary to take measures to avoid irreversible problems in the future, such as urban sprawl.

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