The transportation sector as a lever for reducing long-term mitigation costs in China

(draft paper)

Meriem HAMDI-CHERIF[*], Ó BROIN Eoin [*,#]

** Centre International de Recherche sur l'Environnement et le Développement (CIRED, ParisTech/ENPC & CNRS/EHESS) – 45bis avenue de la Belle Gabrielle, 94736 Nogent sur Marne CEDEX, France. hcmeriem@centre-cired.fr,*

[#] *EnvEcon - 11 Priory Office Park, Stillorgan Road, Blackrock, Co. Dublin, IRELAND*

Abstract.

Chinese transport activity has grown rapidly in recent years, and curbing CO_2 emissions from this sector is a major challenge. This paper investigates the potentials offered by both technological solutions and changes in infrastructure deployment strategy that can address this challenge. The research is carried out by using the IMACLIM-R energy-economy-environment (E3) model which includes a detailed description of passenger and freight transportation dynamics. The standard representation of transport technologies is supplemented with an explicit representation of the "behavioral" determinants of mobility. Although they drive transport demand, these determinants are often disregarded in mitigation assessments. This framework considers *(i)* the spatial organization of housing and production, *(ii)* modal choices induced by transport infrastructures and *(iii)* the freight transport intensity of production and distribution processes. It is found that supplementing carbon pricing with measures promoting a modal shift towards low-carbon transport modes and a decoupling of economic activity from mobility needs, change the sectoral distribution of mitigation efforts and significantly reduce the macro-economic mitigation costs.

Keywords: transport, mitigation policy, infrastructure, spatial organization, China

1 Introduction

Chinese economic development goes hand in hand with *(i)* a growth of the production that is accompanied by an increase in freight transportation, and *(ii)* an more affluent population and fast-growing urbanization that induce increased demand for passenger transport (notably an increase of the motorization rate). Given the high reliance of transport on oil products, its increasing energy demand and CO_2 emissions, the transportation sector is a crucial sector for China, particularly regarding energy security and climate change issues. In its attempts to have a sustainable development, the transportation sector is indeed particularly challenging for China. To avoid important "lock-ins" in carbon-intensive pathways, especially given the high coal availability (to produce Coal-To-Liquid fuels) and the important life span of infrastructures (cf. the great ability of China to develop roads), China has to redouble its efforts with voluntary schemes promoting mobility growth control. In particular, specific transportation infrastructure policies and urban planning should be encouraged, since they can provide major contributions to mitigation (IPCC, 2014a).

In the lead-up to their announcement on Greenhouse gases (GHG) emissions reductions as part of their Nationally Determined Contribution (NDC), China had already been setting many targets for low carbon options, notably in its 12th Five Year Plan (Hong et al., 2013; Han et al., 2014). In this regard, most energy planning efforts have been made in the electricity and industry sectors because of their major contribution to economic growth and energy consumption (Liu et al., 2013). However the Chinese transportation sector has been given increasing attention since it has become the fastest energy consuming sector (Ou et al., 2010) and one of the most challenging in terms of decreasing its dependence on fossil fuels (Mathiesen et al.,2008). Moreover, China faces many challenges related to traffic congestion, air pollution and climate change (He et al., 2013). In the last decade, growth rates for both passenger and freight transportation in China have been close to GDP growth rates (Bai and Qian, 2010) while the period 2000-2011 carbon emissions from transport have increased by a factor of 2.5 (CAIT, 2014) and are expected to continue this trend in the future (IPCC, 2014a). Although China has over the same period significantly expanded its railway network for both passenger and freight transport (in terms of length and technical efficiency), it has expanded its road network to an even greater degree in response to the significant increase in demand for transportation that has

accompanied its economic development (Bai and Qian, 2010, Hu et al., 2010). In light of this and given the long life span of transportation infrastructures, China might be locking itself in carbon intensive development pathways if its development continues on this trajectory. This highlights the critical importance of current infrastructure development options, because over the long-term the huge reduction of carbon emissions necessary to achieve low stabilization targets cannot be reached without drastically reducing transport related emissions (Waisman et al., 2013).

A large body of literature (see below) explores mitigation policies and options for the Chinese transportation sector and emphasize that ambitious reductions in greenhouse gas emissions would require actions on the "technology" side to decrease both the energy intensity of transportation modes and the carbon content of fuels, but also on the "behavior" side to reduce the volume of mobility and foster the adoption of low-carbon modes. The studies that incorporate modelling mainly involve sectoral models that have either a "technology-based" or a "behavioral-based" focus. In the latter case, the modelling can assess behavioral changes that may result from structural development. In particular such modelling is able to show that urban forms and infrastructure changes can play a decisive role in the mitigation process (IPCC, 2014a). However, sectoral models cannot by their very nature estimate, transport emissions reductions with respect to the amounts that other sectors could contribute. Moreover, given the important interactions between transport and the rest of the economy, it might be assumed that energy-economy-environment (E3) models would provide a complimentary tool to investigate the role of transportation in the transition to a low-carbon economy. However, to date E3 models have been limited when it comes to exploring the full mitigation potentials of the transport sector because they mostly focus on assessment of the "technology" side (e.g. Schafer et al., 2009) and generally don't integrate the "behavior" side of the issue. Schafer (2012) suggests that such tools have to be complemented with a representation of the "behavioral" determinants of transportation dynamics to provide a more comprehensive vision.

In light of this background, this article revisits the role of the Chinese transportation sector in low-carbon pathways. It's objective is to bridge the gap between current E3 modelling and studies on mitigation options and policies. This is done using the E3 general equilibrium model IMACLIM-R (Hamdi-Cherif and Waisman, 2016; Waisman et al., 2012), which, in contrast to most models used for carbon mitigation assessments, includes a stylized representation of "behavioral" determinants to explicitly represent the interplay between transportation, energy and growth patterns. The model accounts for the rebound effect of energy efficiency

improvements on mobility, endogenous mode choices in relation to infrastructure availability, the impact of investments in infrastructure capacity on the amount of travel, and the constraints imposed on mobility needs by firms' and households' location. Using this framework, the analysis demonstrates the risk of high GDP losses if using carbon price as the sole policy instrument, and investigates the potentials offered by a broader combination of measures. Thus beyond carbon pricing, we consider actions to control the "behavior" determinants of transportation in the course of the Chinese transition to a low-carbon economy. More specifically, we consider *(i)* spatial reorganizations at the urban level and soft measures towards less mobility-dependent agglomerations, *(ii)* reallocation of investments in favor of public modes at constant total amount for transportation infrastructure and *(iii)* adjustments of the logistics organization to decrease the transport intensity of production/distribution processes.

This analysis provides a first step towards the identification of non-technical determinants of Chinese mitigation costs and is organized as follows. It first reviews the literature on climate policies (in China in particular) and the transportation sector, to delineate the determinants and obstacles to CO_2 emissions reduction in that sector (section 2.1) and emphasize the potential role of different policies, especially on the "behavior" side of transportation dynamics (section 2.2). Section 3 describes the IMACLIM-R modeling framework used including how the transport sector is modelled. Section 4 provides results of an application that assess the role of transportation in low-carbon pathways, in particular in terms of macro-economic costs. Finally, Section 5 concludes with policy implications and a roadmap for further integrating transportation, housing and urban dynamics issues into macroeconomic assessment of climate policies.

2 The transportation sector and mitigation policies

2.1 Reducing carbon emissions in the transport sector: determinants and hindrances

In order to highlight various feasible options for emissions' reductions in the transportation sector, but also to identify the major obstacles preventing this, we disaggregate carbon emissions from transport activities[1], into: *(i)* the carbon intensity of fuels, *(ii)* the energy intensity of mobility, *(iii)* the modal structure of mobility and *(iv)* the volume of mobility.

[1] Disaggregation is common in energy system analysis. We use the "ASIF approach", which decomposes emissions into: A (total Activity), S (modal Structure), I (modal energy Intensity), and F (carbon content of Fuels). (Schipper et al., 2000; Kamakaté and Schipper, 2009).

Following Chapman (2007) and Schafer (2012), these four essential determinants can be separated in two groups: the first two have to do with "Technology" while the latter two are connected with "Behaviors".

2.1.1 Technological determinants

The ***carbon intensity*** of transport depends on the primary energy sources used to produce the final energy used for fuel vehicles. Today, this final energy comes primarily from oil refining. Volatile oil price increases, the possibilities of resource depletion and potential climate policies, have however pushed the Chinese government to invest in and set targets for low-carbon alternatives such as for liquid fuel supply (biofuels) and on the diffusion of alternative energy carriers (electricity and hydrogen) in its 12th Five Year Plan (Hong et al., 2013; Han et al., 2014). However the scale-up of low-carbon transport fuel options remains in doubt because of controversies surrounding biofuels (IPCC, 2014a, Qiu at al. 2012). e.g. no scientific consensus on the technical potential of biomass production due to large uncertainty in future yield improvements, the production potential of degraded land and climate change feedbacks (Chum et al., 2011); the disputed lifecycle impact of biomass on GHG emissions (see Searchinger et al., 2008; Tilman et al,. 2009); and land-use and water-use competition with other usages and objectives like timber production, forest conservation or food provision (Koizumi, 2013). In addition, nuclear power and renewable energy, the main carbon-free power technologies, are limited by political acceptability and intermittency, respectively (Sun and Zhu, 2014; Sovacool, 2009) while hydrogen faces important difficulties like competitiveness issues and safe storage systems with the appropriate end-user infrastructure (Ren et al., 2015). Put together, all these obstacles highlight the risk that the supply of long-term end-use energy for transport in China may in the future rely on carbon-intensive options or even resort to coal-to-liquid fuels (Qi et al., 2012). Currently natural gas which is a resource that is limited in China, is primarily used for taxis and buses (Chen et al., 2014).

The ***energy intensity*** of mobility on the other hand results from the technical characteristics of the vehicle fleet, which depend on vehicles' design (e.g. vehicle weight and drive train efficiency) and also on the way vehicles are operated (e.g. flying altitude of planes, traffic management). The energy intensity of transport may thus be limited by a ceiling on technical progress and inertias on the deployment of new energy-efficient vehicles. Furthermore the market potential for energy-efficient vehicles might be only a fraction of its economic potential because purchase decisions are influenced by considerations other than solely energy

consumption (e.g. safety, performance and size) and because they are taken under partial information and imperfect expectations about the future of energy costs (Allcott, 2010; Anderson et al, 2011; Allcott, 2011). Therefore, future energy savings due to vehicle efficiency may implicitly be undervalued (Greene, 1998) and often not accounted for in purchasing practices (Turrentine and Kurani, 2007). Nevertheless, despite technological, industrial and social challenges, the Chinese government deploys policies and planning guidance to favor the development of new energy vehicles for a sustainable future, including for instance energy efficiency standards for vehicles (Yuan et al. 2015; Wang et al., 2014).

2.1.2 Behavioral determinants

The ***modal structure of mobility*** can be divided between energy-intensive options (air and road transport) and low-energy options (public transport and non-motorized modes for passengers; rail, shipping and inland waterways for freight). Modal shift from high to low-energy intensive modes requires that the alternative mode provide similar or even better transport services which can include spatial coverage, speed, reliability and flexibility of each mode. This means in particular that the promotion of low-carbon modes needs dedicated investments in infrastructure for public modes (IPCC, 2014a). However, inertias in the renewal of long-lived infrastructure and the absence of intermodal synergies can favor the expansion of the installed network over the maintenance of alternative modes in parallel (e.g. it is cheaper to maintain and expand road infrastructures than to develop rail infrastructures to be connected with roads). Therefore, if decisions mainly rely on short-term economic optimization, and lack strong political will to redirect investment choices, path-dependencies and lock-ins in energy intensive mobility options may arise. This is particularly true for China where specific efforts have been made during recent decades on the development of transportation infrastructures. In fact, the 12th Five Year Plan insists specifically on the development of urban transport but without any capping of the relative energy consumption or carbon emissions (Li and Wang, 2012). This has led to a huge increase in road transportation infrastructure accompanied with a similar increase in private vehicles and trucks: for example, in the ten years from 2000, the length of available highways has increased by 155%. At the same time the average annual growth rate in volume of road passenger traffic and road freight traffic has been 7.2% and 8% respectively (Hu et al., 2010).

The ***volume of mobility*** is highly dependent on the spatial distribution of housing, transport and industrial infrastructures, which are themselves long-lived and hence may impose strong inertia on the dynamics of mobility. Specifically, the volume of mobility results from two components:

(i) Households' tradeoffs between passenger transport and the demand for other goods and services (under budget and time constraints). Mobility needs that are linked to location choices, are decided as a function of a tradeoff between transport and housing expenditures. The decrease in transport prices in real term (with respect to income) – e.g. the price of a car, combined with an increase in housing prices in built up areas are behind urban sprawl and thus trigger an increase of mobility needs (Brueckner, 2000). These trends could be reversed only if the dynamics of transport and housing sectors are reversed (Waisman et al., 2013). Moreover, when the temporal dimension is taken into account, it imposes that passenger mobility decisions are constrained by a constant travel time budget as it has been originally showed by (Zahavi and Talvitie, 1980). This stability of the time devoted to mobility has been confirmed by further and more recent studies (Metz, 2008; Schäfer et al, 2009; Schäfer, 2012) and for China in particular (Zhang et al., 2007)[2]. Hence, speed gains allowed by infrastructure deployment may give rise to increased distances traveled with longer daily travels and more occasional trips; it may also be accompanied with modal shifts in favor of fast modes within the time constraint, like for instance aviation.

(ii) Firms' freight mobility needs in the production and distribution process. The organization of logistics plays a major role regarding the volume of freight mobility. Obviously, the more intensive the production and distribution processes in transport are, the bigger the volume of freight mobility there is. Hence, the specialization and concentration of production, as well as the tradeoff between inventories and just-in-time manufacturing organizations determine the total vehicle-kilometers travelled for the production and distribution of a given volume of goods (McKinnon, 2010; Piecyk and McKinnon, 2010).

Furthermore, two well-known feedbacks affect the volume of mobility (Hymel et al., 2010). First, the "induced demand effect" (Goodwin, 1996), which is a response to infrastructure building or upgrade and may trigger an increase in mobility. In fact, the structure and volume of mobility are crucially dependent upon the availability of transport infrastructures. Hence,

[2] See Mokhtarian and Chen (2004) for an extended discussion about the stability of travel time budget.

building new infrastructure may trigger an increase in mobility needs by enhancing accessibility and improving the services provided by a given mode. In the long run, enhanced accessibility also changes the economic value of land, affecting the locations of activities and housing and hence mobility needs (Noland, 2008). Second, the "rebound effect", which is a response to energy efficiency measures (Greening et al, 2000) which captures the increase of mobility consecutive to reductions in the marginal costs of travel allowed by a reduction of fuel consumption due to improved efficiency. The magnitude of the rebound effect can be significant and synonymous with an increase in the volume of transportation. In this case it can offset the majority of expected reductions in energy consumption (and CO_2 emissions) from efficiency improvements. This has been shown for the case of China, in *(i)* Wang et al. (2012), where the average rebound effect for passenger transport by urban households has been estimated at around 96%, and in *(ii)* Wang and Lu (2014), where the rebound effect for road freight transport has been estimated to be 84%. Note that both authors suggest that the rebound effect should be higher in China than in developed countries.

This general picture illustrates that beyond energy prices and revenue levels, transportation patterns can be highly influenced by crucial determinants such as spatial organization, housing costs and the availability of transport infrastructure.

2.2 Mitigation policies in the transport sector

A very large literature explores mitigation options and policies in the transportation sector at different spatial scales. Many publications concern the global level (e.g. IEA, 2009; Schafer et al., 2009; Johansson, 2009; IEA, 2012a,b,c), but also the regional or the national level (e.g. Banister, 2000 for Europe; Hidalgo and Huizenga, 2013 for Latin America; Liu et al., 2013 for Eastern Asia; Greene and Plotkin, 2011 for US) and the city scale too (IEA, 2013).

Concerning the specific case of China, there is a huge literature. Indeed, the transportation sector and its relation with CO_2 emissions reductions have been widely studied in recent years both at the national and regional scale. (Lin and Xie, 2014) explores the main factors affecting carbon dioxide emissions and find that there is huge reduction potential in the Chinese transportation sector in the future. Regarding the national level, (Yuan et al., 2015) encourage the development of new energy vehicles to favor a sustainable transportation industry, while Liu et al. 2013 recall the adverse effect of vehicle energy efficiency improvements, namely the rebound effect, and they thus suggest the necessity to develop measures to control private

vehicle demand as Zhang et al., (2014a) did in their paper. Yan and Crookes (2009) found also that measures such as a cap on the number of private vehicles, a fuel economy regulation or fuel taxation would be effective ways to reduce emissions. Concerning tax instruments, (Mao et al., 2012) highlight that taxing CO_2 could be an effective policy tool, but that politically acceptable rates are unlikely to provide sufficient emissions reductions. He et al., (2013) emphasize the behavioral aspect of the issue and promote public transportation and actions to optimize urban forms, while (Tian et al., 2014) call for the optimization of production and distribution process as well as recourse to multimodal transport for freight. Many other studies highlight the importance of the modal breakdown and the implementation of measures to encourage modal shifts towards sustainable transport modes as well as policies aimed at travel reduction (e.g. Wang et al., 2011; Loo and Li 2012). As early as 2008, (Han and Hayashi, 2008) were already recommending the use of a policy mix to have efficient CO_2 mitigation in the transportation sector (using both fuel taxes and infrastructure development for railway as well as measures to slow down highway development). For similar suggestions at the regional or city level, one can refer for example to (Feng et al, 2013; Guo et al, 2014; Hao et al. 2014; Zhang et al., 2014c).

All these studies lead to the conclusion that a mix of *(i)* technological solutions (reducing the carbon intensity of energy and the energy intensity of transport modes) and *(ii)* actions on the modal structure and volume of mobility (grouped under the label "behavior") will be required to achieve the goal of an effective reduction of CO_2 emissions in the transportation sector. But besides the issue of the relative importance of actions on the "technology" side vs. actions on the "behavior" side, the question of the policy instruments to trigger emissions reductions is central.

2.2.1 Price signals: are they an appropriate mitigation instrument in transport sector?

To reduce emissions in the transportation sector, market policies are economically more efficient than fuel carbon intensity standards (Holland et al., 2009; Sperling and Yeh, 2010; Chen and Khanna, 2012; Holland, 2012; IPCC, 2014a). However, a crucial specificity of this sector is that travel demand and fuel consumption for vehicles tend to be weakly sensitive to energy prices (Creutzig et al., 2011; Yeh and McCollum, 2011). Indeed, even if it appears that this sensitivity increases when price augmentations are planned and certain (Sterner, 2007), drivers are relatively inelastic to fuel taxation (Hughes et al., 2006; Small and van Dender, 2007). Dahl, (2012), presents econometric estimates of long-run price elasticities for gasoline and diesel demand, for different price and income levels and for 120 countries and finds income

elasticities to be much higher in absolute values (around +1). (Dargay, 2007; Barla et al., 2009; IPCC, 2014a) note that there is a strong relation between travel and income that can be explained by the positive income elasticities and the relative price inelastic nature of passenger travel. The higher income elasticities illustrate that, even at a long-term horizon, fuel consumption reductions triggered by price increases may be offset by wealth effects, particularly in fast growing economies. A more recent study specifically dedicated to China has confirmed these conclusions for an intermediate-run horizon. (Lin and Zeng, 2013) find indeed that the price elasticity of demand for gasoline in China range between -0.497 and -0.196 and the income elasticity is between 1.01 and 1.05. They highlight that these results indicate that increases in disposable income induce a soar in gasoline consumption and traffic volume, which is mainly due to the increasing ownership of cars and energy efficiency gains. In particular, they have quantified these results and show that given the current income increase rate of 6–8%, an increase of gasoline price by 18%–23% is needed to counteract income effects for one year.

2.2.2 Mobility-control measures as complementary policies to carbon pricing

A direct implication from the above review is that, under a "carbon-price-only policy", substantial mitigation in the transportation sector can be reached only through very high carbon prices. This diagnosis is confirmed by the last IPCC assessment report (IPCC, 2014a) which continues the reflection by suggesting the recourse to a suite of policy instruments to gain large emissions reductions. Indeed, the concerns raised by the political acceptability and the economic consequences of such high carbon prices lead to consider the role of complementary measures that aim at controlling transport-related carbon emissions through specific actions on their determinants.

A number of measures can be envisaged to decrease the carbon intensity and/or the energy intensity determinants of carbon emissions, but all of them are submitted to constraints limiting their efficiency (see section 2.1.1, and Yan and Crookes, 2009 for the specific case of China). For instance, the development of electric or hydrogen vehicles to reduce the carbon intensity of vehicles would need dedicated and coordinated policies to encourage their diffusion and override the technological barriers (Hao et al., 2014b, Han et al., 2014, Yuan et al., 2015). Such policies can consist of basic research and R&D (to foster the batteries' improvements in terms of autonomy and safety), infrastructure deployment (e.g., able to provide the necessary density of charging stations) or pricing incentives (which can bring forward the date at which such

alternative types of vehicles would become cost-effective on a large scale)[3]. Furthermore, note that energy intensity standards[4] (like fuel efficiency or carbon emissions standards) have proven to be an effective way of reducing transportation emissions (IPCC, 2014a) and help to overcome private agent's partial information and imperfect foresight when making vehicle purchase decisions. However, even if standards have proven efficient to foster the diffusion of more carbon and energy efficient vehicles, their potential effect may be limited when facing a stringent climate constraint. In the absence of clear price-signals, saturation of efficiency potentials in mature fleet and the slow renewal of vehicle fleet, particularly in developing countries, may be obstacles to reaching the long-term benefits of energy savings (Waisman et al., 2013).

The obstacles faced by the technological solutions lead naturally to consider specific measures on the "behavioral" determinants of transport-related emissions, i.e. on the volume and structure of mobility. These latter are highly dependent upon the spatial organization of the economy, so that without specific measures, economies and China in particular face the risk of lock-ins in very carbonized transportation pathways (IPCC, 2014, a, b). To reduce the overall demand for transportation, some degree of reorganization of firm's production/distribution process and households' patterns of consumption and lifestyles is necessary (McKinnon, 2010; Piecyk and McKinnon, 2010; Bristow et al., 2008). Concentration of production units and their location with respect to consumption areas are decisive determinants of the volume and modes of freight transport (Pan et al., 2013, Tian et al., 2014). Moreover, the necessity to access to essential activities, particularly to commute for work purpose represents a strong constraint on household's mobility demand. These points are strongly correlated with the spatial organization of human settlements, and particularly with the development patterns of urban areas. In China, the expansion of the urban area in major cities has doubled during the period from 1997 to 2009 (Shen and Zhou, 2014), the urban population ratio has increased from 26% in 1990 to 50% in 2010 and is expected to continue increasing over the next decades (Chen and Song, 2014)[5].

[3] This also depends, in the electric case, on the rhythm of decarbonization of electricity generation.

[4] The fuel economy standards adopted by China since 2005 have induced a significant reduction in the fuel consumption of the new automobile fleet (the rate has decreased by 15% between 2005 and 2009) (He et al., 2013).

[5] Many econometric studies have demonstrated that energy consumption and CO_2 emissions from transport are correlated with population density or other more precise city morphological indicators (city shape, accessibility to public transport, etc) (Mindali et al., 2004; Bento et al., 2005; Grazi et al., 2008; Le Néchet, 2011). Several case studies discuss the hypothesis of the compact city as a sustainable urban form (Holden and Norland, 2005; Muniz and Galindo, 2005) and the association between automobile dependence (or emissions) and land use planning and regulations (Newman and Kenworthy, 1996; Glaeser and Kahn, 2010).

Related to this, the "China Ministry of Housing and Urban–Rural Development" has published in 2010 a document called ''Urban Comprehensive Transportation System Planning Procedure" that will serve as a legal requirement for the development of urban and transportation planning. It requires in particular that both transportation system planning and urban general planning be coordinated (Su et al., 2014). For instance, transit-oriented development strategies that pay attention to the localization of residential, employment, and shopping facilities can encourage a recourse to low carbon transportation modes, and thereby provide the double benefit of reducing car dependence and preventing urban sprawl (Newman and Kenworthy, 1996; Cervero, 2004; Olaru et al., 2011). A reduction of the use of LDVs (light duty vehicles) however represents a major challenge, particularly in China (IEA, 2009). A large and diverse mix of policy measures would be necessary to restrain their deployment, by focusing on land use patterns, public transport options as well as pricing policies (IPCC, 2014,a, b). For instance, parking managements, dedicated bus lanes, possibly in combination with a vehicle access charge for LDVs, can strongly help shifts towards public transport (Creutzig and He, 2009). The implementation of such policies in China has already proven their effectiveness. For example, when comparing Shanghai and Beijing, two similar cities (in terms of affluence level, culture and population (Hao et al., 2011), it is observed that Shanghai is three times less dependent on LDVs than Beijing (IPCC, 2014a). Shanghai has implemented a number of measures to restrain the use of LDVs (setting expensive license auctions, building few new roads and investing massively in public transport network), whereas Beijing has built an extensive network of high capacity expressways and until recently, didn't do much to restrain vehicles use or ownership[6]. Beyond this, many other policy strategies can help reducing the volume of energy intensive mobility like for instance improving traffic managements (Barth and Boriboonsomsin, 2008), better truck routing systems (Suzuki, 2011) or weather high-speed rail to substitute for short-distance air travel (e.g. the Beijing to Shanghai line). More generally, complementary policies can focus on infrastructure, fiscal incentives, land-use, building regulations and other policies affecting how buildings are designed, but also industrial policies and other regulations that affect how firms locate. In addition to policies dealing with physical infrastructure elements, other soft policies can also be considered, for example those using

[6] Beijing has recently put in place measures to restrain the use of vehicles: forbidding the car use one day per week since 2008 and limiting the number of new license plates issued each year since 2011 (Santos et al., 2010; Hao et al., 2011). Such measures have proven to substantially reduce C02 emissions (Zhang et al., 2014a). Furthermore, Beijing Municipal Government has released in 2013 a "Clean Air Action Plan 2013-1017" document to control on-road vehicles emissions. (Zhang et al., 2014b) demonstrate that such traffic control policies play a significant role in mitigating urban vehicle emissions.

information and communication technologies such as dynamic ride sharing, smart real-time information to find parking space, demand-responsive para-transit services or replacing physical mobility by telecommunications (Cairns et al. 2004; Anable et al., 2005; Cairns et al., 2008; Santos et al., 2010)[7].Thus to gain large emissions reductions, a mix of policy instruments is required, including investments and greater support for innovation.

3 Modeling framework

Although the transport sector is not absent from Energy-Economy-Environment (E3) models that are used to assess the cost of climate change mitigation, they mostly focus on energy and lack a joint framework combining energy, transportation and urban planning dimensions. A detailed representation of infrastructural and behavioral changes, or the link between urban forms and mitigation is also rare. Furthermore, most models have a limited ability to assess behavioral changes such as modal shift or journey avoidance resulting from structural development[8] (IPCC, 2014a). These limitations may impact model results and make their estimates for transport conservative (Pietzcker et al., 2013). In addition, models mostly only consider an increased carbon price as the driver of decarbonized economies (Waisman et al., 2013). Recent efforts to incorporate non-price drivers and lifestyles in transport modelling have been made by Anable et al. (2012) and Brand et al. (2012).

An overview of the way the transportation sector is represented in E3 models is provided by, Schafer (2012), who suggests that the gap between bottom-up technology-rich and top-down macroeconomic models can be bridged by introducing behavioral dimensions. Currently bottom-up models rely on exogenous transportation demand trends i.e do not provide an endogenous evolution of modal choices or mobility volumes, while the endogenous demand of mobility in top-down models is exclusively induced by prices[9]. Moreover, the "rebound effect" induced by technology improvement and the "induced demand effect" triggered by infrastructure development are not considered in either of these two types of models.

[7] For what concerns the more efficient use of vehicles, recent programs have estimated the contribution of eco-driving behaviors (International Transport Forum, 2007) and find that they can contribute to a 10% reduction of fuel demand (Barkenbus, 2010).

[8] Note that this concerns exclusively E3 models, and that sectoral transportation models deal explicitly with these issues (at the expense of measuring transport emissions reductions with respect to the amounts that other sectors could contribute (IPCC, 2014a)).

[9] This is due to the fact that top-down macroeconomic models represent the transport sector in nested CES (constant elasticity of substitution) production functions.

In order to provide an assessment of the macroeconomic cost of mitigation policies in China with a particular focus on the role and potentials offered by the transportation sector, the work described in this paper uses IMACLIM-R, a hybrid E3 model that precisely *(i)* tries to bridge the gap between bottom-up and top-down models and *(ii)* take into account non-energy and non-price drivers of transportation dynamics.

3.1 Imaclim-R model and the transport sector

The hybrid Imaclim-R E3 model is a global and multi-sector[10] general equilibrium model. It describes dynamic trajectories in one year steps over the whole 21st century through the recursive succession of top-down annual static equilibria and bottom-up dynamic modules (Figure 1).

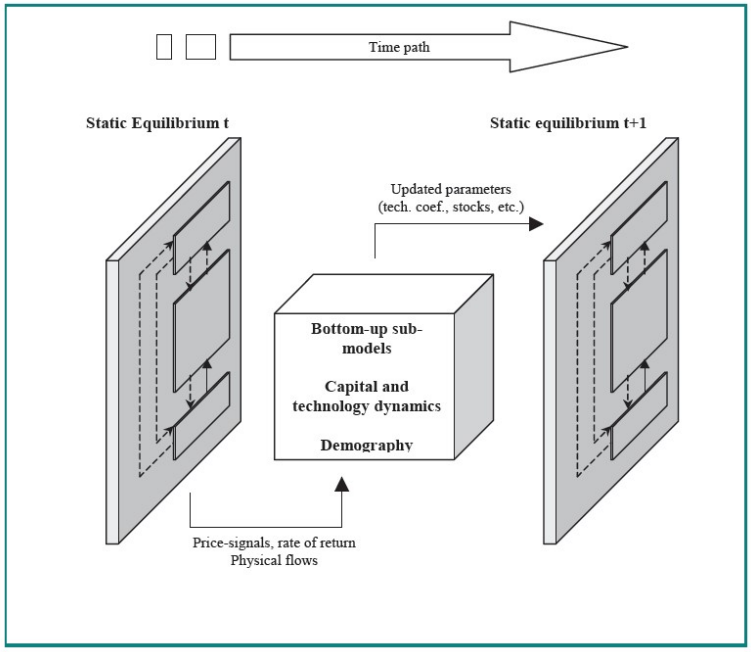

Figure 1 : Recursive and modular architecture of the IMACLIM.

[10] The global version of the IMACLIM-R model that used in this thesis divides the economy in 12 regions—USA, Canada, Europe, OECD Pacific, Former Soviet Union, **China**, India, Brazil, Middle East, Africa, Rest of Asia, Rest of Latin America—, and 12 productive sectors—Coal, Crude Oil, Natural Gas, Refined products, Electricity, Construction, Agriculture and related industries, Energy-intensive Industries, Air Transport, Sea Transport, Other Transports, Other industries and Services. In addition IMACLIM-R includes transportation with personal vehicles and non-motorized transport.

Although a detailed description of the IMACLIM-R model is provided in Hamdi-Cherif and Waisman, (2016), Waisman et al., (2012) and in Waisman et al.,(2013), a very short description of its transport sector dynamics are provided again here.

Passenger services are available for four modes: air, automobile, public, and non-motorized; and the level of their demand is subject to a twofold constraint on household utility maximization: a standard income budget and a time budget[11]. These two constraints allow Imaclim-R to capture four stylized features about passenger transportation: *(1)* a rebound effect on mobility of energy efficiency improvements, *(2)* an induction effect on mobility demand by infrastructure deployment, *(3)* the specific modal breakdown between transport modes, and *(4)* the constraints imposed on mobility needs by the locations of firms and households. The model includes an infrastructure for the three motorized modes; roads, public transport infrastructure, and airports. The infrastructure has an evolving but at the same time limited capacity, meaning that as demand for a mode increases, congestion also increases. When this occurs the time taken to travel an extra *pkm* increases, and this reduces the utility of transport. This is because the utility of a mode increases the further you can go in it within the time budget. Furthermore, efficiency of passenger vehicles improves with rising income through the purchase of more efficient makes[12].

For freight transport, three modes are modelled: air, water, and terrestrial[13]. The freight intensity of production is measured by input-outputs coefficients which describe a linear dependence of freight mobility in a given mode to production volumes of a specific sector. This Leontief approach allows us to capture two important features that drive the modal breakdown and the intensity of freight mobility needs, namely (*1)* the spatial organization of production and distribution processes and *(2)* the energy efficiency of freight vehicles which itself increases when prices increase according to an exogenous trend.

[11] The time budget constraint represents the regularity in travel time budget across time and space. Number of studies demonstrates indeed that at an aggregate and average level, households allocate a fixed amount of time to transportation, regardless of transportation costs (see for example Zahavi and Talvitie, 1980; Bieber et al., 1994; Vilhelmson, 1999; Schafer and Victor, 2000). In particular Zahavi (1979, 1980) and later van Wee et al. (2006), using samples of cities in developed and developing countries observed that a traveler spend between 1.1 and 1.3 hours per day in transports. Here, we follow Zhang et al. (2007) who studied the concept of travel time budget stability for China. We consider that a Chinese traveler assigns a constant amount of its time equal to 1.1h per day to transport.

[12] China moves through all the steps' revenue (low, middle, and high) along with the whole century. Each step revenue period depends on the scenario considered. For example, in the reference scenario of this study, China has low per capita income from 2010 to 2020, then a middle per capita income from 2020 to 2085 and finally, it has a high per capita income from 2085 to 2100.

[13] Terrestrial transport includes both heavy duty vehicles and rail.

3.2 Two contrasting scenarios

In the context of assessing the role of the transportation sector in the Chinese transformation towards a low carbon society, we consider two illustrative climate policy scenarios. Their comparison will highlight and allow assessment of the role of a number of targeted policies for the transportation sector. Both scenarios have the same global stabilization objective, namely a total radiative forcing of 3.4W/m^2 in 2100[14] which is thought to limit the increase of the temperature to 2.5°C with respect to the pre-industrial area. The scenarios are constrained by the same global CO_2 emission trajectory[15], which correspond to a carbon emission reduction with respect to the business-as-usual (BAU or baseline) scenario of 24%, 43% and 85% in 2025, 2050 and 2100 respectively. Figure 2 shows the emission trajectories of both the baseline and the climate scenarios.

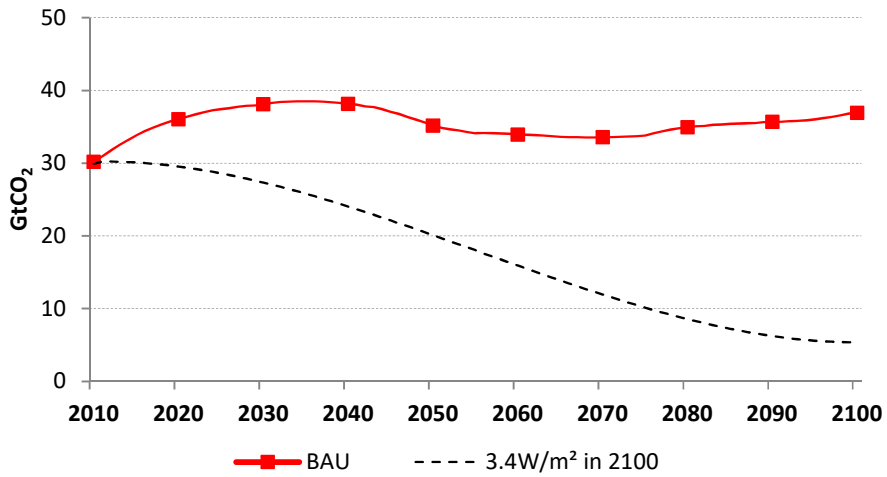

Figure 2 : Global CO_2 emissions (energy only).

[14] This objective is intermediate between 2.6 W/m^2 and 4.5 W/m^2 that are the two more constrained objectives considered in the last IPCC assessment report (IPCC, 2013) and more broadly in the RCP literature (Meinshausen et al., 2011). This target corresponds to the radiative forcing in 2100 from the pathway developed by IMAGE model in the Energy Modeling Forum 24 study.

[15] The emission trajectory is elaborated by using a three-reservoir (atmosphere, biosphere + ocean mixed layer, and deep ocean) linear carbon cycle model calibrated on the IMAGE model (Ambrosi at al., 2003) and translates the level of radiative forcing that is considered.

In order to satisfy this climate objective (the dotted trajectory in Figure 2), the necessary CO_2 price is endogenously calculated by the model in each of the two scenarios. Each year, the model calculates endogenously the level of carbon tax that would restrict emissions to the exogenous target given for that period, and at the same time carbon tax revenues are recycled in a lump-sum manner within each region (and thus in China in particular). Although the carbon prices obtained are different in the two scenarios (see section 4.3), the reductions that they generate in China - when compared to the baseline- are roughly the same: on average 39%, 49% and 88% in 2025, 2050 and 2100 respectively.

In keeping with Waisman et al (2013) two stabilization scenarios are distinguished from each other by the nature of transport-related policies that are considered or introduced in parallel with the carbon tax.

In the first scenario ((hereafter referred to as 'CarbonPriceOnly'), no changes with respect to the baseline scenario are implemented in terms of investment choices that can drive mobility demand. In particular, it is assumed that demand for basic mobility services (commuting, shopping and access to services) evolves proportionally to total passenger transport demand, i.e. we assume an increase attributable to continuing urban sprawl as households gain better access to more efficient transport modes. In addition, investments in transportation infrastructures are driven by the objective of avoiding congestion and. the freight transport intensity of production stays constant. In the second scenario (hereafter referred to as 'ClimInfraPol'), the carbon pricing policy is complemented by measures that serve to control the "behavioral" determinants of transport in the course of the low-carbon transition. We explicitly include spatial planning policies and changes in investment decisions for long-lived transport-related infrastructures. These representations are done in a very stylized way but encapsulate rich policy packages that are implemented at different spatial scales. In contrast to 'CarbonPriceOnly', this scenario assumes a progressive reduction of households' basic mobility so as to represent a spatial reorganization at the urban level (more dense cities) and soft measures towards less mobility-dependent conglomerations. More precisely, we assume that the ratio of the constrained mobility over the total households' mobility demand decreases from 50% in 2020 to 30% from 2050 on. In addition investments in transportation infrastructures for vehicles and air travel are restricted thus favoring public modes instead of private vehicles. This is done by assuming a maximum threshold to the mobility offered by vehicle and air travel in China of 3500 pkm/capita and 80pkm/capita respectively. Thirdly a 1% yearly decrease in the freight transportation intensity of production is assumed to represent

reorganization in production/distribution logistics inducing a decrease of transportation needs (e.g. improved backloading, more space-efficient packaging, shorter or more transport-efficient ordering cycles…etc.).

4 Results

In all of the scenarios considered, CO_2 emissions from the Chinese transportation sector peak around 2045 then decrease continuously thereafter until 2090 and then plateau over the last 10 years of the century (Figure 3, left-hand panel). This trajectory is related to UN population projections for the country which follow a similar trajectory. Despite a decrease from 2045, CO_2 emissions from the transportation sector in the climate stabilization scenarios represent an important share of total remaining emissions, particularly at the end of the century where they can reach 60% in CarbonPriceOnly (Figure 3, right-hand panel).

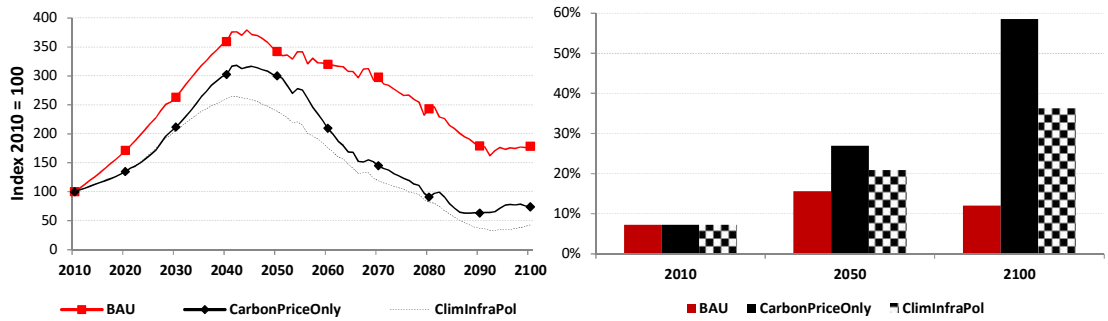

Figure 3 : Chinese CO_2 emissions from transportation sector as an index of 2010 level [right-hand panel]; Share of CO_2 emissions from the transportation sector in the total Chinese CO_2 emissions [right-hand panel].

As is standard in climate policy analysis for the transport sector, we decompose the results into emissions from passenger transport and those from freight transport to understand the mechanisms at play when facing the challenge of decarbonization in this sector.

4.1 The dynamics of Passenger transport

Figure 4 shows that Chinese CO_2 emissions from passengers' transport increase significantly during the first half of the 21st century regardless of the transportation mode and scenario considered. However, while the level of these emissions remain above their 2010 level in 2100 in the absence of climate mitigation policy, they become significantly lower in the stabilization

scenarios, particularly when early transport-specific policy measures are taken (37% lower in CarbonPriceOnly and 72% lower in ClimInfraPol). This last point illustrates the importance of transport related complementary measures in the decarboniszation processes (even when optimistic assumption on technology potentials are taken, e.g. on electric vehicles).

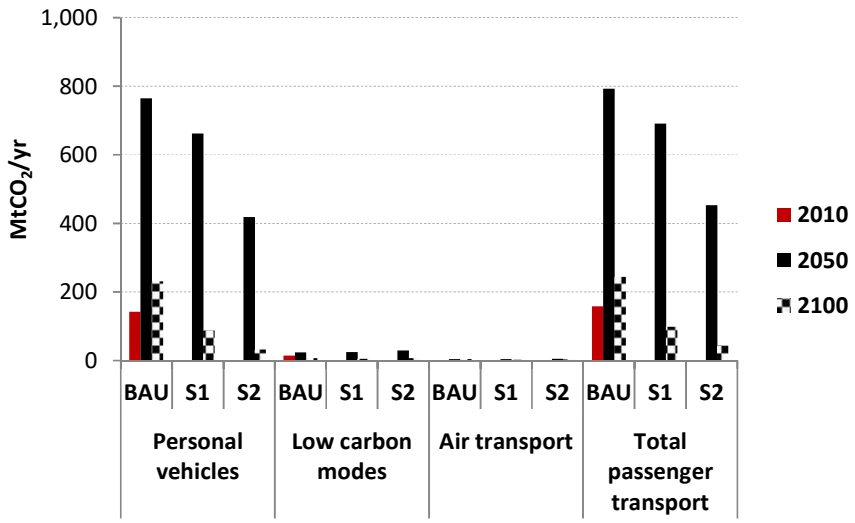

Figure 4 : Chinese CO_2 emissions (in $MtCO_2$) from passengers transport.

It can be observed that these passenger transport emissions come mainly from personal vehicles. However to delve deeper into this finding, and in order to understand what the mechanisms at play are and the dynamics of these emissions among the modes, the mechanisms are disaggregated into *(i)* the evolution of the total passenger mobility per capita, *(ii)* modal structure evolution and *(iii)* vehicle fleet efficiency improvements and/or electrification; (Volume, Structure and Intensity effects, see section 2.1).

(i) The rapid increase of mobility in the baseline scenario is only moderately affected by the mitigation policy when the carbon price is used as the sole instrument. Figure 5 shows that the Chinese passenger mobility per capita is found to be only 7% lower in 2050 and 13% lower in 2100 in CarbonPriceOnly than in the baseline. This small effect is due to the lowering of international oil and coal prices (thanks to lower oil and coal demand induced by the climate policy), which limits the increase of fuel costs, and thus restricts the price-effect on demand. This result is also due to urban spatial patterns that are characterized by strong inertia. Despite a carbon pricing policy, they are locked-in over the long-term and cannot be changed overnight, limiting thus the decrease of passenger mobility demand. The

fundamental role of infrastructure is highlighted by the results obtained under the ClimInfraPol scenario. As shown in Figure 5, passenger mobility is significantly lower when the 'early action' specific measures limiting the development of urban sprawl are implemented (29% in 2050 and 48% in 2100 than in the baseline).

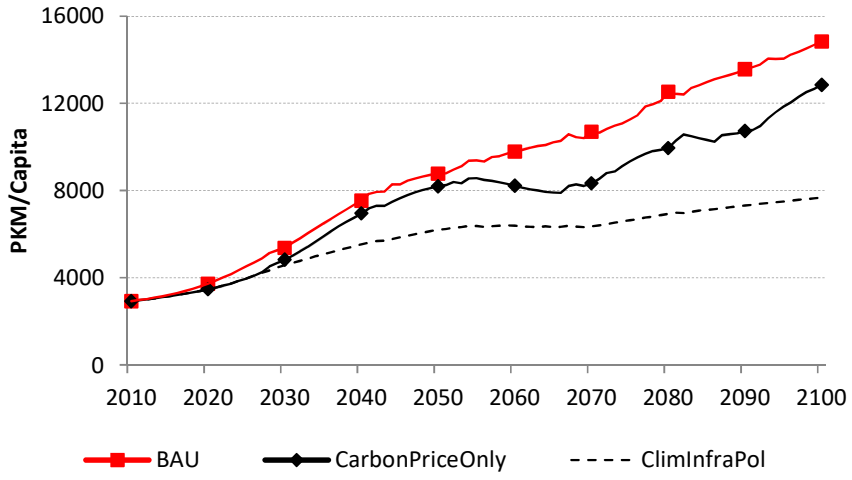

Figure 5 : Total Chinese mobility, in passenger.kilometers per capita.

(ii) Table 1 shows that the modal structure of the CarbonPriceOnly scenario is similar to that of the baseline case. The lowering of international oil and coal prices, which partially offset the increase of fuel costs due to the carbon price, makes motorized modes more accessible. This is then associated with investments in road infrastructures, which decreases road congestion and in turn favors the attractiveness of private cars at the expense of other transportation modes. But if specific measures triggering an early redirection of investments in favor of low-carbon transportation infrastructures are implemented (ClimInfraPol scenario), the modal structure becomes very different. We indeed observe a significant shift from personal vehicles to public and non-motorized transport. One can note that the ClimInfraPol scenario is also characterized by a higher share of air transport, even if it remains very small (1.5% in 2100). This is because in ClimInfraPol mobility needs are decreased due to the changed urban structure and can then be satisfied by low-carbon modes, which releases time and budget for the passenger to travel by plane.

	2010	2050			2100		
		BAU	CarbonPriceOnly	ClimInfraPol	BAU	CarbonPriceOnly	ClimInfraPol
Pesonal vehicles	28%	78%	74%	60%	92%	88%	67%
Low carbon modes	72%	22%	25%	39%	7%	11%	31%
Air transport	0.2%	0.3%	0.4%	0.6%	0.6%	0.7%	1.5%

Table 1: Transportation modes shares in total Chinese passenger mobility
Low carbon modes include public transport and non-motorized modes.

(iii) Finally, we consider the liquid fuel consumption of the Chinese personal vehicle fleet per passenger.kilometer to capture both the increased efficiency of internal combustion engines (ICE) and the electrification of the fleet through the diffusion of hybrid and electric vehicles (Figure 6). In the CarbonPriceOnly scenario, the carbon price ensures significantly better vehicle efficiency than in the baseline case, while this efficiency effect is reduced in the ClimInfraPol scenario. This is because carbon prices are lower in ClimInfraPol than in CarbonPriceOnly case (see section 4.3) and the fleet turn-over is slower due to lower vehicle use. Both of these effects affect the diffusion of efficient ICE and electrified vehicles.

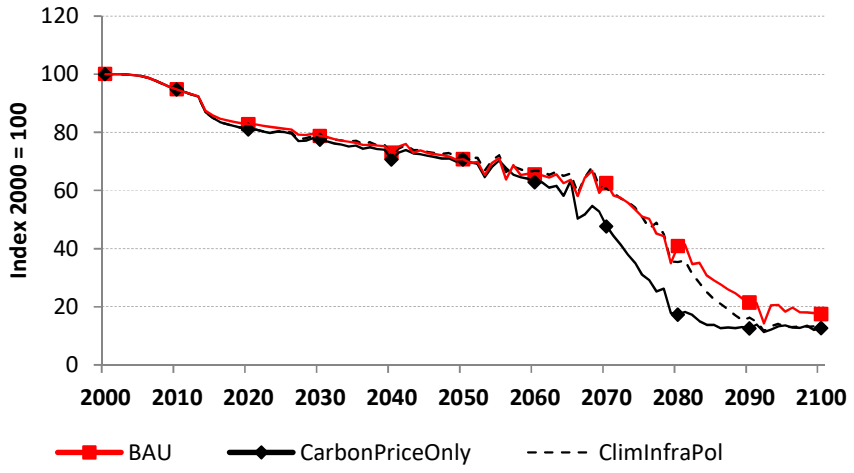

Figure 6 : Liquid fuel consumption of the Chinese personal vehicle fleet per passenger.kilometer (As an index of 2000 level).

This analysis illustrate that depending on the measures that are adopted, the determinants of CO_2 emissions reductions trends can be very different. We find indeed that under a "carbon price only" policy (CarbonPriceOnly), the major effect is due to the diffusion of energy efficiency in vehicles, whereas modal shifts towards low-carbon modes coupled with mobility reduction measures play a dominant role in ClimInfraPol.

4.2 The dynamics of freight transportation

Even when a climate policy is implemented, total emissions from freight transport increase significantly in the first half of the century: they increase as fast as in the baseline case but are on average 20% lower (Figure 7, left-hand panel). The two emission trajectories (CarbonPriceOnly and ClimInfraPol) then decrease continuously over the long-term and start to be really distinguished from 2060. Under carbon-price-only policy (CarbonPriceOnly), emissions are 58% lower than their baseline level in 2100, while they are 75% lower when transport focused policies are implemented.

Maritime and air freight transport emissions are only moderately affected by the climate policy in the first half of the century (13% and 11% lower than the baseline emissions respectively in CarbonPriceOnly and ClimInfraPol, Figure 7, right-hand panel). They are much more affected in the second period (respectively 59% and 63% lower than the baseline emissions in 2100) due to lower freight mobility needs in parallel with less overall economic activity and less trade (because of higher international transport prices induced by the carbon price).

However, one can note that emissions from freight transport come mainly from inland freight that represent on average 85% of freight emissions (Figure 7, right-hand panel). The reduction of emissions from inland freight is faster under the ClimInfraPol scenario and leads to a level of emissions that is 50% lower than their level in CarbonPriceOnly. Note that the difference is primarily due to the reduction in freight transportation intensity of production between CarbonPriceOnly and ClimInfraPol.

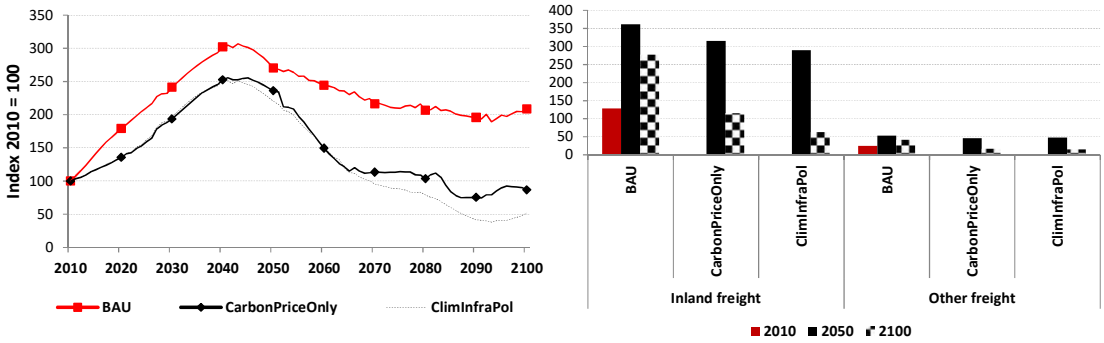

Figure 7 : Total Chinese CO_2 emissions from freight transportation (as an index of 2010 level) [right-hand panel]; CO_2 emissions from Inland freight and Other freight ($MtCO^2$) [right-hand panel] (Inland freight includes heavy-duty-vehicles and rail freight; Other freight aggregates maritime and air freight transportation)

To go further with these observations, and to better understand what are the different determinants of emissions reduction in the freight transportation sector, let us proceed in a similar manner as for emissions from passenger transport: we disaggregate the mechanisms into ***(i)*** Volume, ***(ii)*** Structure and ***(iii)*** Intensity effects.

(i) Under constant freight transportation input per unit of production (CarbonPriceOnly), freight transport activity is significantly reduced with respect to the baseline case (Figure 8), particularly for the long-term (29% lower in 2100). Indeed, the carbon pricing policy induces a contraction of the economic activity (Waisman et al., 2012) and the Chinese energy intensive industrial production in particular, as well as structural change towards less transport-intensive activities.

In the ClimInfraPol scenario, the economic activity is less reduced due to lower levels of carbon prices (see section 4.3). Despite this, the freight transport activity is nevertheless significantly lower, particularly over the long-run (52% lower than the baseline case in 2100). This is due to the constraint imposed on firm's freight mobility needs in the production/distribution process. Indeed, implementing early action towards adjustments on logistic organization and optimization of vehicles' use, decrease the transport intensity of these processes and hence induce a significant lower volume of freight mobility needs.

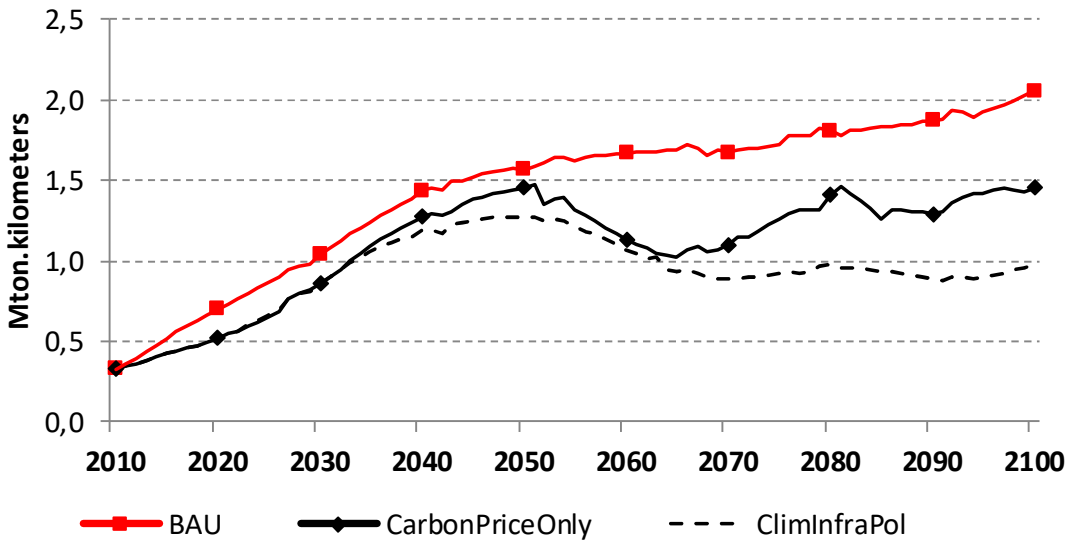

Figure 8 : Chinese freight transportation activity

(ii) The modal structure of the freight transportation is the same in all the scenarios considered. Obviously, as we could expect from the modal distribution of emissions, the freight transportation activities are almost entirely ensured by the inland freight over the whole century (Table 2).

	2010	2050			2100		
		BAU	CarbonPriceOnly	ClimInfraPol	BAU	CarbonPriceOnly	ClimInfraPol
Inland freight	94%	97%	97%	97%	98%	98%	98%
Other freight	6%	3%	3%	3%	2%	2%	2%

Table 2: Transportation modes shares in total Chinese passenger mobility
Low carbon modes include public transport and non-motorized modes.

(iii) Similarly to the case of passenger transport, we consider liquid fuel consumption per ton.kilometer in order to examine the increased efficiency of Chinese heavy-duty-vehicles (HDV). Since inland freight transportation is responsible for more than 85% of emissions from freight and account for almost all the freight activity, we indeed focus on the energy efficiency

gains of this "sector" (i.e. we will not look at energy efficiency gains of the maritime and air transportation).

Energy efficiency gains are similar in the three scenarios, with an average of 0.7% annual increase over the period 2010-2100 (Figure 9). This means that the climate policy doesn't induce significant improvements in terms of energy efficiency of the inland freight transportation. However, we observe that these gains are a little bit more important in the CarbonPriceOnly scenario than in ClimInfraPol, particularly during the last twenty years (e.g. liquid fuel consumption of HDV are 8% lower in CarbonPriceOnly than in ClimInfraPol), due to the lower carbon prices of the ClimInfraPol scenario.

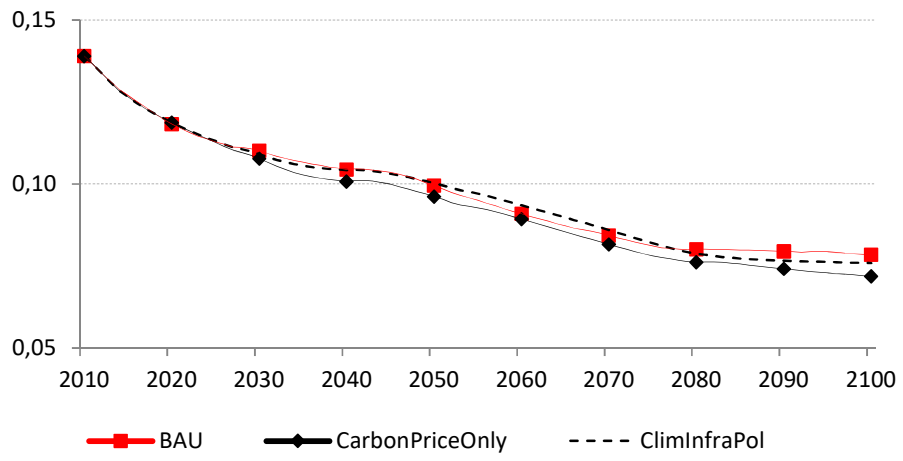

Figure 9 : Inland freight transportation liquid fuel consumption per ton.kilometer.

This analysis illustrates that the major determinant of CO_2 emissions reduction in the Chinese freight transportation sector is the volume of inland freight mobility needs. Hence, implementing early actions towards a reorganization of production/distribution processes (e.g. a concentration of production units as well as their location with respect to consumption areas) plays a major role for mitigation policies.

4.3 Beyond carbon pricing: macroeconomic implications of infrastructure policies in China

We finally analyze in this section how the implementation of complementary policies to carbon pricing, namely specific measures to control mobility, affects the Chinese economy in its transition to a low-carbon future.

When we look at emissions reductions in the three main Chinese emitting sectors (Transport, Electricity and Industry, see Table 3), we find significantly different pictures under the two mitigation scenarios. In the CarbonPriceOnly scenario, the transportation sector has the lowest decarbonization rate, with even continued increasing emissions during the first half of the century despite the mitigation policy. This means that without specific measures towards reducing mobility, decarbonization efforts bear mainly on non-transportation sectors (electricity and industry). This is because mitigation efforts are easier in these two sectors than in the transport sector . Under the ClimInfraPol scenario, Table 3 shows lower values of emissions variations for transport and higher for electricity and industry. This illustrates that the "transportation policies" increase the contribution of the transportation sector to mitigation efforts and allow the other main emitting sectors to slow their decarbonization effort.

		2010-2050	2050-2100
Transports	**CarbonPriceOnly**	2.2%	-2.8%
	ClimInfraPol	1.8%	-3.4%
Electricity	**CarbonPriceOnly**	-2.7%	-3.0%
	ClimInfraPol	-2.3%	-2.3%
Industry	**CarbonPriceOnly**	-0.3%	-6.5%
	ClimInfraPol	-0.1%	-6.2%

Table 3: Mean annual emissions variations compared to the baseline (negative for reductions and positive for increases)

Furthermore, one can note that the carbon intensity of the Chinese liquid fuels is significantly lower in the ClimInfraPol scenario than in the CarbonPriceOnly case (15% lower in 2050 and 30% lower in 2100, as captured by Figure 10). This is explained by the penetration of the Coal-to-Liquid (CTL) fuels in the CarbonPriceOnly scenario and their absence in the ClimInfraPol case due to lower mobility needs.

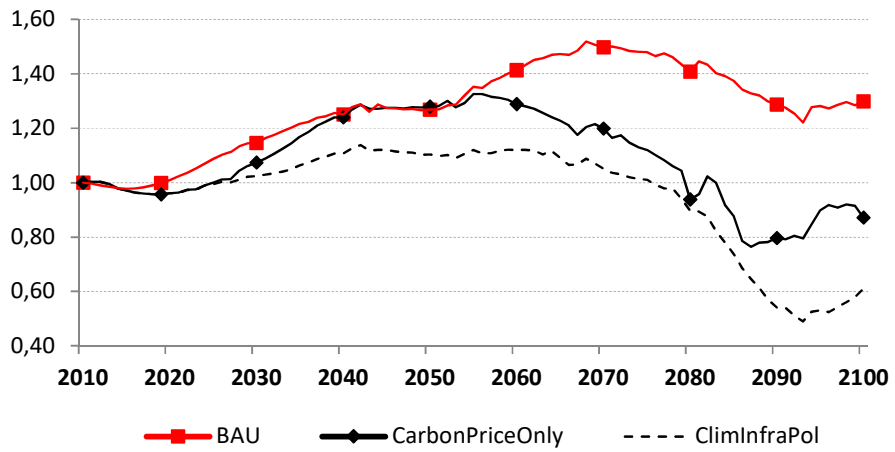

Figure 10 : Carbon intensity of the Chinese liquid fuels (tCO2/toe) as an index of 2010 level.

As a consequence, the carbon price path necessary to respect the global emissions trajectory is lower in ClimInfraPol than in CarbonPriceOnly (Figure 11, left-hand panel), which induces reductions of the macroeconomic mitigation costs (Figure 11, right-hand panel).

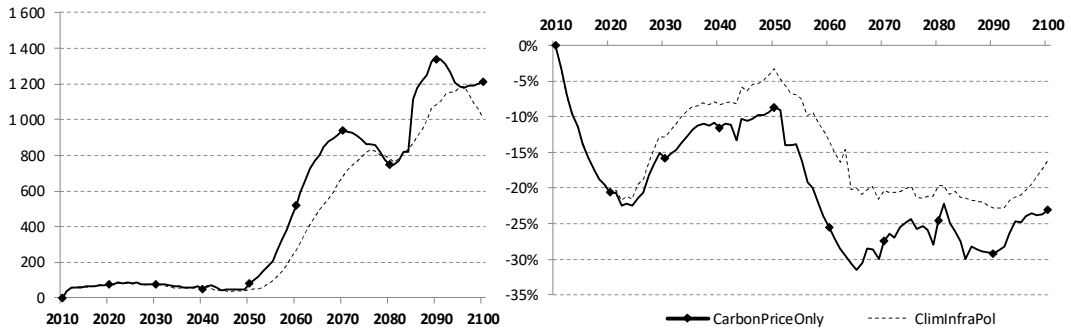

Figure 11 : Path of carbon prices (in [constant 2001] U.S. dollars/tCO2) [left-hand panel]; GDP variations between stabilization and reference scenario [right-hand panel].

In CarbonPriceOnly, when no specific measure to accompany the carbon pricing policy is implemented, very high CO_2 prices are necessary in the second half of the century to comply with the stringent emission constraint (e.g. 1400\$/tCO_2 in 2085). As explained in (Hamdi-Cherif and Waisman, 2016), these very high prices are mainly linked to the transportation sector

since *(i)* all the other sectors have already made substantive cuts in their emissions, *(ii)* an important fraction of the Chinese population gains access to fossil fuels intensive road-based mobility and *(iii)* because this sector is particularly weakly sensitive to price signals. Furthermore, the recourse to such high price levels can be explained by *(i)* the inertia of infrastructures, location choices, and urban forms embedded in the model, and *(ii)* by the important rebound effect of mobility (Waisman et al., 2013). These very high carbon prices allow reaching significant emissions reductions –we indeed observe a reduction of total Chinese emissions by 50% in 2050 and by 86% in 2100 with respect to the baseline emissions- but they lead to important macroeconomic costs (Figure 11, right-hand panel). The lack of change in infrastructure and associated demand dominate the mitigation costs that can exceed 30% of the baseline GDP.

In ClimInfraPol, when the carbon pricing policy is complemented by transport-specific measures that favor low-carbon modes and lower mobility needs, carbon prices are on average 18% lower until 2050 and 25% lower over 2050-2100. The higher decarbonization of the transportation sector allows indeed CO_2 prices to be significantly lower and thus the associated macroeconomic costs to be significantly reduced too (Figure 11): long-term mitigation costs are reduced by 5 points in 2050 and by 10 points in 2100 when compared to CarbonPriceOnly scenario's costs. Indeed, lower carbon prices and less passenger mobility needs induce a decrease of households' energy expenditures dedicated to transport (Table 4). The reduction of households' transport spending releases budget for other goods and services thus enhancing purchasing power and production. This contributes to lowering unemployment and increasing real wages which further enhances purchasing power and production thus boosting the Chinese economy.

	2020	2050	2070	2100
BAU	2%	6%	7%	2%
CarbonPriceOnly	2%	6%	6%	3%
ClimInfraPol	2%	3%	4%	1%

Table 4: Share of energy expenditures dedicated to transport (fuels for cars) in the total households' budget

5 Discussion and Conclusion

This paper investigates the role of passenger and freight transportation activities in the transition to a low carbon Chinese society. A particular attention is given to specific measures designed to control the growth of mobility. It is an attempt to quantify the impact of urban voluntary policies on Chinese mitigation costs. This research is carried out by adopting the Energy-Economy-Environment model IMACLIM-R, which represents explicitly the transportation sector, including its non-price determinants (infrastructures and spatial organization), and captures its interactions with the rest of the economy through a general equilibrium framework.

Since the transport sector has proven to be the most difficult in which to reduce carbon emissions, it represents a dominant share of remaining emissions in the long-term when ambitious mitigation objectives are set (See Figure 3). Because of its weak reactivity to price increases, very high levels of carbon prices are needed in the second half of the century to reach low mitigation targets. We find in fact that they can reach 1400\$/tCO_2 by the end of the century.

However we find that controlling mobility growth allows limiting these effects by offering mitigation potentials independent of carbon prices. This study considers three potential sources of mobility moderation: *(i)* urban reorganization lowering the constrained mobility (i.e. mobility for commuting and shopping), *(ii)* infrastructure deployment favoring low-carbon modes (essentially public transports) and *(iii)* changes in logistics organization driving lower freight mobility intensity of production/distribution processes. These measures allow significant reductions of carbon price levels (on average 25% lower over 2050-2100) and hence help limiting the macroeconomic costs of the mitigation policies (*e.g.* long-term mitigation costs are reduced by 5 percentage points in 2050 and by 10 percentage points in 2100).

At the same time, one has to keep in mind that these conclusions are based on modelling that uses aggregate level descriptions of the transportation sector and the economy in general. Ó Broin and Guivarch (2016) have recently published work that attempts to improve the representation of transport infrastructure in IMACLIM-R. Furthermore, the modelling framework used does not explicitly represent the underlying policy measures adopted at different scales to trigger these evolutions, like for example land planning, explicit transportation policies or fiscal policies (e.g. De Vos and Witlox, 2013, Su et al., 2014). This means that this study does not enter into discussion about the detailed policy instruments to be combined. Although a general equilibrium framework allows capturing interactions between transportation and other important sectors of the economy, this means also that we ignore some

potentially important indirect effects of these policies beyond the transportation sector, like for instance those affecting real estate markets.

Despite these limitations, our results seem to be robust since they are consistent with findings of a large literature that highlight the importance of transportation infrastructure policies and urban planning in the mitigation processes (IPCC, 2014 a, b, for the aggregate level; e.g. Han and Hayashi, 2008; Loo and Li 2012; He et al., 2013; Yuan et al., 2015 for the specific Chinese case). Our results allow us to conclude that further investigations on the synergies between carbon pricing schemes and a wide set of spatial and housing policies aimed at controlling mobility needs are critical to set in place efficient energy policies, especially when considering ambitious climate mitigation strategies. Nonetheless we have shown that a package made up of both price and non-price policies and measures for the transport sector can make a significant contribution to mitigation cost reduction in China.

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