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Investigating Transport Emissions in Beijing, China: A Scenario Planning Approach

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Abstract

The aim of this paper is to explore and analyse how to reduce smog-related air pollutants and carbon dioxide (CO2) emissions generated by passenger transport systems, using a case study of the city of Beijing. The analysis uses in-depth surveys with experts and practitioners in China to examine the current business as usual (BAU) projection for emissions in Beijing, the drivers and trends affecting current projections, and to develop alternative scenarios that might help reduce projected emissions to a significant degree. These are based around different variants of population and migration growth and environmental stewardship. Respondent views are also used to test the validity of the scenarios. The current levels of smog caused by transport emissions are much higher in Beijing than the internationally accepted safety standards, due, in part, to the high levels of motorised traffic. CO2 emissions always tend to be overlooked because economic growth is prioritised. The sustainable model represents one of the best models for Beijing to follow; however, Beijing faces great challenges in becoming more sustainable in environmental terms over the next few years, mainly due to population growth and increased migration, even if there is powerful top-down government environmental stewardship. The aspiration to reduce smog-related air pollutants and CO2 emissions in Beijing by implementing sustainable transport mitigation measures seems to be very ambitious; however, it is perhaps from this type of context that the real innovations in transport planning will emerge.

Keywords

Transport emissions; sustainable transport; scenario matrix; Beijing.

1. Introduction

Ever since the days of Buchanan (1963) there have been concerns over the impacts of the ‘traffic problem’ on the city. In Beijing, the scale of projected population growth equates to a huge projected vehicle fleet – with attendant problems of global and local air pollution, congestion, casualties, inactive lifestyles, and impacts on the built fabric. As Buchanan would say: “It is impossible to spend any time on the study of the future of traffic in towns […] without being at once appalled by the magnitude of the emergency that is coming upon us […] we are nourishing at great cost a monster of great potential destructiveness." (Buchanan, 1963, Recommendations, p.8). To date, the global energy consumption in the transport sector has accounted for more than 30% of the world's total energy consumption; in China the proportion is approximately 20% (Wang et al., 2014). Over the past few decades, with the rapid development of its economy, China has had to face the dual challenges of reducing smog-related local air pollutants and contributing to reduced greenhouse gas emissions (GHGs) (Wu et al., 2011). This is different to the Western industrialised countries, where the local air quality problems are usually less stark. Beijing is a useful case study city to consider due to the severity of the problems being faced, in terms of high levels of motorised traffic, associated smog-related local air pollution and transport CO2 emissions, together with rapid urbanisation, in-migration and economic growth (Feng et al., 2013). This paper aims to explore how to reduce transport smog-related local air pollutants and CO2 emissions in Beijing, developing scenarios that might lead to much greater environmental sustainability in travel – and plausibility testing these against the likely problems in implementation.

On-road vehicle emissions in Beijing have recently attracted attention from some scholars and policy-makers. However, so far, only a few studies on transport emission issues in Beijing have been conducted: for example, Wu et al. (2010) and Hao et al. (2011) discuss on-road vehicle emission control strategies and policy implementation; Zhang et al. (2014) estimate future trends regarding vehicle emissions; Wang et al. (2014) examine how changing urban forms affect CO2 transport emissions; whilst Ma et al. (2015) evaluate CO2 transport emissions resulting from daily passenger travel. Some general control strategies and mitigation measures have been implemented by the Beijing Municipal Government (BMG) (2013a), i.e. The Clean Air Action Plan, 2013-2017. However, Beijing is still facing significant pressure to reduce air pollution and CO2 emissions. The analysis in this paper uses in-depth surveys with experts and practitioners in China to examine the current BAU projection for emissions in Beijing, the drivers and trends affecting current projections, and develops alternative scenarios that might help reduce projected emissions to a significant degree. It focuses in particular on two key drivers (migration/population growth and governmental stewardship), as ranked by experts independently, using these to develop future scenarios.

Though there have been many studies on reducing transport CO2 emissions in the Western industrialised context (Geurs and Van Wee, 2004; Åkerman and Höjer, 2006; Sperling and Gordon, 2009; Gilbert and Perl, 2010; Hickman and Banister, 2014; and many others), there have been few studies considering the potential policy responses in China – and, in particular, the special requirements of the Beijing context.

2. Research Methodology

The research uses a participatory scenario approach consisting of four main steps (Figure 1). Firstly, mixed qualitative and quantitative methods were employed in an in-depth expert survey (Round 1) to analyse the trends affecting passenger travel in Beijing and determine the key drivers of change. Secondly, a quantitative survey (Round 2) was used to help rank the two most important parameters which were then applied as dimensions in the scenario matrix. Next, a forward-looking scenario approach (based on Schwartz, 1998; Van der Heijden, 2005; IIS, 2006) was applied (Round 3) to develop alternative scenarios, and to explore and discuss how the experts' preferred scenarios could be implemented. Finally, the surveys were tested for plausibility (Round 4). The participatory survey approach was used to help shape the different development scenarios, and ultimately develop potential effective control strategies and mitigation measures.

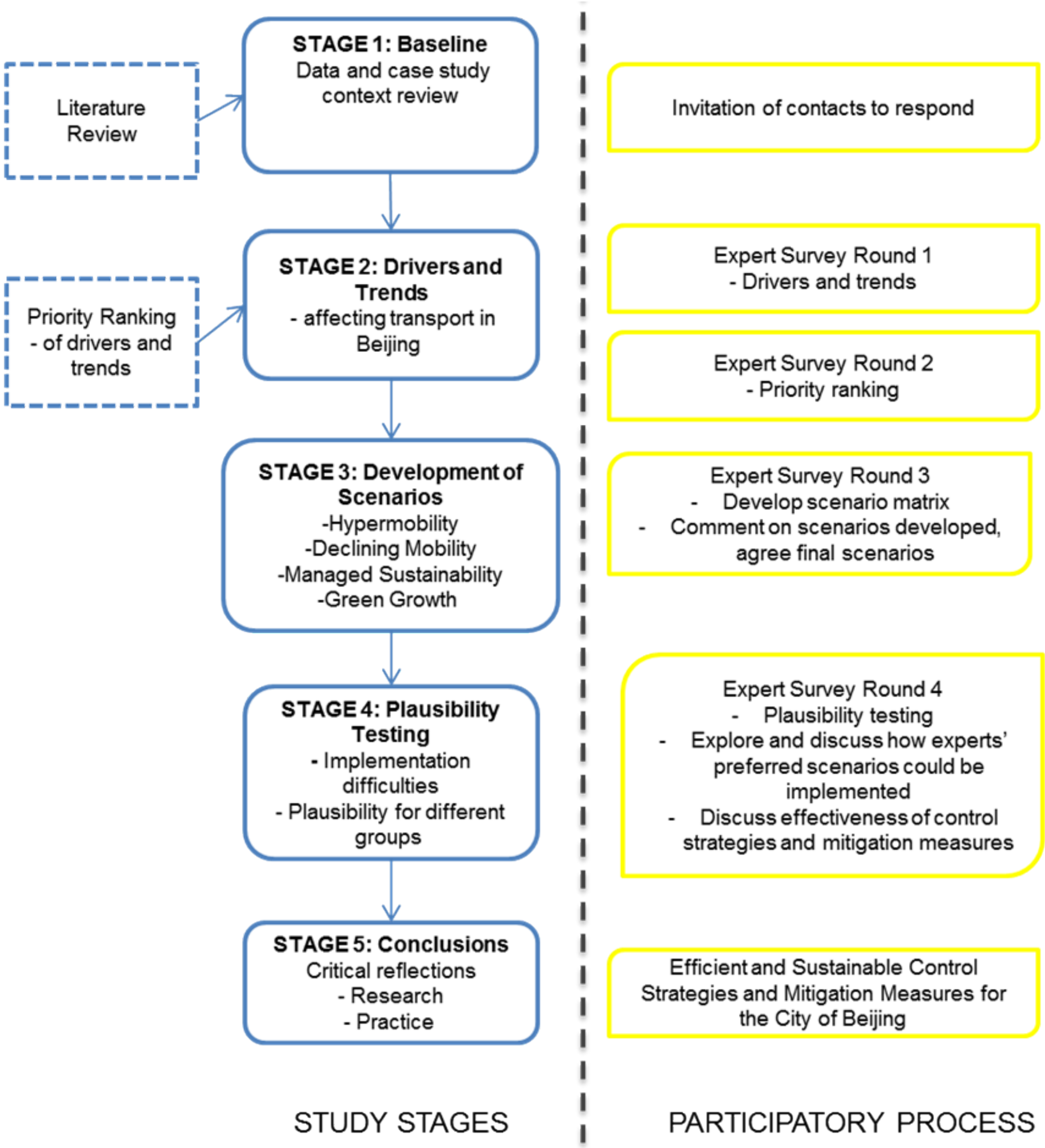

Figure 1: The Participatory Scenario Approach

The surveys took the form of interviews in which experts were asked to explain their rankings and judgments regarding the feasibility of the problems described. Hence the objective was to gain views and, ultimately, agreement among experts on particular issues. There were several rounds of questions, which gradually built on the knowledge gained in order to reach the final scenarios.

3. Developing Scenarios for Beijing

This section first analyses and discusses the results collected from the primary data and the findings of the existing literature review. Next, the survey findings from the three rounds of questions are presented. Current BAU issues, and efficient control strategies and mitigation measures are then developed and evaluated under different scenarios for Beijing.

3.1. Analysing Trends and Uncertainties

Experts were asked to identify trends and uncertainties (the key drivers of change) affecting passenger transport in Beijing, and key elements were determined as illustrated. These were then placed in a priority matrix where participants ranked issues from 1 to 3 (lowest to highest impact, see Appendix 1 for calculations). Next, the final results were ranked as set out below to produce the top ten drivers of change:

1) Population growth and migration
2) City planning and addressing transport issues
3) Technical change
4) Government environmental stewardship
5) Economic growth rate
6) Energy and power supply
7) Other drivers of change
8) Age profile
9) Income levels
10) Urban transport structure

3.2. Priority Ranking

Experts were asked to identify the two most significant factors from the list of critical trends and uncertainties affecting transport in Beijing. These were then used to generate the axes on the scenario matrix (following Hickman and Banister, 2014; and based on the Shell scenario matrix approach, Waverley Management Consultants, 2006). Most experts (36%) identified ‘population growth and migration’ as having the greatest likely impact on the transport sector in Beijing, followed by ‘government environmental stewardship’ (20%).

3.3. Developing the Scenario Matrix

Four scenarios are developed to help identify different potential futures for Beijing: “Hypermobility”; “Declining Mobility”; “Managed Sustainability”; and “Green Growth” (Figure 2), and are discussed in more detail below. The time frame of the BAU projection and strategic target covers the period from 2014 to 2050.

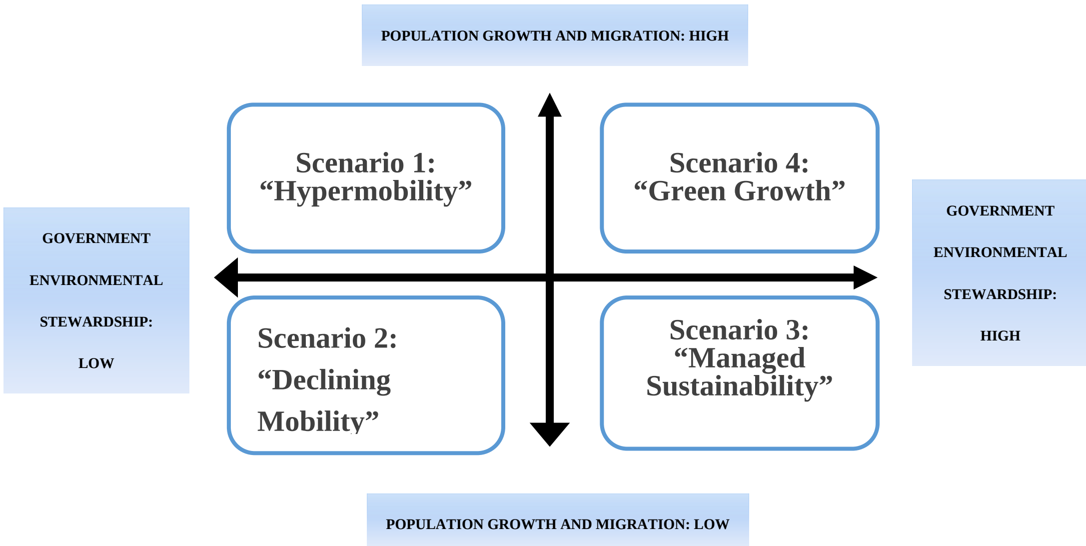

Figure 2: Scenario Matrix for Beijing

Scenario 1: "Hypermobility"

This represents a very mobile future, and one based on an increased use of the petrol-based private motor car. It is similar to a BAU projection. There is high population growth and little real interest in environmental stewardship at the city and national governmental levels.

- There are some extensions to the Beijing Subway system, but they are limited, extensive surface bus rapid transit systems are seen as unaffordable;
- A 7th Ringway is built across the city-region; with much highway widening in the city – however highway congestion remains as a major feature in the city;
- Urban planning remains weak and there is little success in steering development in a polycentric manner around a high quality public transport system;
- Many city functions (employment and administrative) remain heavily centralised, public transport networks are very heavily crowded, and there is little public interest in sustainability issues;
- 'Sleeping' satellite towns are developed, but radial public transport networks into the city are very overloaded;
- There is little interest in improving cycling, walking and the public realm;

- Low emission vehicles generate much interest, yet fail to realise much market share in the vehicle fleet;
- There is a general lack of environmental awareness among politicians and residents – the focus is on economic (GDP) growth rather than improvements to quality of life.

Scenario 2: "Declining Mobility"[i]

This represents a very difficult future for Beijing, where the congestion of the city, and the poor urban planning, means it has become very unattractive to residents and visitors. It is the Detroit-style collapse scenario, where people leave for better planned cities and higher qualities of life elsewhere. There is little increase in population from current levels, and potentially a major reduction, hence traffic levels remain similar or lower than today. There is no interest in environmental stewardship at the governmental levels – again the focus is on re-starting the economy, but with little success.

- There is some limited ring road widening and highway extensions, yet little funding is available for extensive highway investments;
- There is little funding to extend and even maintain the Beijing Subway system or other public transport modes, and the current network falls into some disrepair;
- Urban planning remains weak, and is even seen as a 'brake' on economic growth aspirations. Many central areas are in need of redevelopment and there is a move of population outside of the city to the suburbs in the city-region. The previous rural-urban migration trend now becomes urban-suburb and rural-suburb;
- Many city functions (employment and administrative) move to other neighbouring cities. There is little public interest in sustainability issues;
- There is little interest in improving cycling, walking and the public realm;
- Low emission vehicles still do not gain any significant market share.

Scenario 3: "Managed Sustainability"

This represents a positive future for Beijing, where urban planning and investment in public transport, walking and cycling and the public realm creates a very attractive city. There is limited population growth as the overall Chinese and global economy is not growing as rapidly as previous years. There is great interest in environmental and city stewardship at the governmental levels – with a focus on improving the well-being and quality of life of all residents in the city, including existing residents and in-migrants.

- There is no more road widening and highway extensions – the transport budget goes to improvements to the public transport system, cycling and walking and the public realm;
- The Beijing Subway system is extended to cover more suburban areas and a large bus rapid transit system is developed;
- Urban planning is seen as central to the management of the city, with strategic plans developed to steer new development, regeneration and the integration of urban planning and transport planning. The city becomes much more polycentric, with a growth boundary to limit further sprawl. There are less long distance trips made across the city – the suburban city centres become self-contained.
- There is huge public interest in sustainability issues, and cycling and walking become very important modes of travel. Use of the private car is managed, with road pricing against vehicle emissions, higher costs for car parking, and a much greater use of car sharing and hiring rather than direct ownership. All of the vehicle fleet is clean – with electric cars and hybrids very popular.

Scenario 4: "Green Growth"

This scenario represents a very positive future for Beijing, where the city extends as part of the wider Bohai Rim city region, under conditions of strong economic growth, high levels of in-migration and strong environmental stewardship. Strong urban planning and very large investment in public transport, walking and cycling and the public realm creates a very attractive city.

- There are some road widening and highway extensions – but the vast majority of a very large transport budget goes to improvements to the public transport system. There is investment in an extensive multimodal public transport system (including High Speed Rail, Subway, light rapid transit, bus rapid transit and bus-based systems), large efforts to improve the integration between modes, and large investment in cycling and walking and the public realm;

- Urban planning is very well resourced, and is seen as central to the management of the city. Again, strategic plans are developed to steer new development, regeneration and the integration of urban planning and transport planning. The city becomes much more polycentric, with excellent connection between cities in the Bohai Rim region. There are high levels of mobility, but it is mostly public transport and cycling-based. A range of satellite towns are developed, with an emphasis on self-containment as employment, residential development and other facilities are all provided;
- Use of the private car is again heavily managed, with a range of traffic demand management measures, including road pricing and restraints on car parking (higher prices and space constraints). All of the vehicle fleet is clean – with electric cars and hybrids very popular.

4. Exploring Scenario 1 (Hypermobility): Plausibility Testing and Implementability

4.1. Increased Population Growth and Migration

Approximately 70% of the interviewees pointed out that the key reason for the increase in private vehicles and traffic congestion is Beijing's population growth and uncontrolled migration. Originally, the Beijing Municipality Government (BMG) expected to restrict population growth and migration to 18 million by 2020; however, official statistics show that Beijing's population had already reached 21.14 million in 2013. According to BMBS (2014), Beijing's population will reach 30 million by the end of 2030, and not including 3 million people who have not registered for temporary residence permits, but live and work in Beijing. In addition, in 2013, approximately 86% of Beijing's permanent population were living in urban areas while the remaining 14% were living in suburban areas. The urban population rose by 8.5% between 2012 and 2013 – there are rapid urbanisation levels in Beijing. The speed and scale of the population growth is difficult to accommodate in terms of the transportation system. On one hand, increased population growth and migration cause the public transport network (e.g. Subway and buses) to become overloaded; thus, in order to avoid using uncomfortable and crowded public transport, people tend to buy private vehicles for travel (i.e. for going to work, school, shops, etc.). This results in very heavy congestion and high levels of smog-related air pollutants and CO2 emissions. On the other hand, due to the already high density of urban areas in Beijing, some residents have to live in suburban areas. Most of them work in the central urban areas, and this separation between work and home results in a high level of car-based commuting. The continued population growth can only be accommodated by a careful planning of new development and new transport investments.

4.2. Dormitory Satellite Towns

To help alleviate the traffic pressure within Beijing, the BMG wanted to develop several new satellite towns with good-quality links to the existing city, with the purpose of dispersing traffic and reducing population overcrowding (Kong et al., 2005, see details on ‘Beijing Master Plan 1991-2010’). However, some experts have argued that most of these new satellite towns have become dormitory towns, resulting in a growing separation between their homes and workplaces for many citizens, and encouraging more people to buy private vehicles for their daily commute. The intention was that each satellite town should be relatively self-sufficient, self-resourcing, and self-supporting, as well as having a good balance between housing and jobs. However, in practice, this aspiration has proved difficult to achieve, particularly as there has been little incentive to not own and use the private car. The debate about Tongzhou was emphasised by some experts as an example which illustrates this phenomenon, with large numbers of people commuting to the CBD, resulting in a high ‘tidal traffic flow’ at peak time on weekdays and general traffic congestion.

4.3. Insufficient Instruments of Governmental Intervention

A few of the experts stated that certain policy instruments currently used are very effective. For example, drivers can check the Beijing real-time traffic information system (BRTIS), which updates every two minutes, before they leave their origin and then choose clear roadways to drive on in order to avoid congestion. Second, license-plate restriction was implemented before the Beijing 2008 Olympic Games in order to alleviate vehicle exhaust emissions caused by traffic congestion. This has helped to reduce rapid vehicle growth in the city (BTMB, 2014). When the policy was implemented on 10th April, 2009, around 60,000 private vehicles were restricted every working day, which was intended to reduce CO2 emissions by 310 tons.

Furthermore, the average vehicle speed at peak time has been improved by 17%, since the policy took effect (Guo, 2009). Third, the BMG released a revised license-plate lottery scheme, following the earlier vehicle lottery system which has been in place since 2011. This was aimed at further reducing private vehicle growth (BMG, 2013). Under the new plan, the license-plate quota will be reduced from 240,000 to 150,000 new licenses per year. New energy vehicles (e.g. Battery Electric Vehicles, BEVs) will be increased from 20,000 in 2014 to 60,000 in 2017 (Arnd, 2013; Table 1). However, most of the representatives maintained that the policy measures, alongside driving restrictions limiting the number of cars from other cities, can only temporarily moderate the rapid increase in private vehicles and alleviate the current traffic congestion in Beijing, as they constitute ‘passive’ approaches rather than ‘active’ measures (Paterson, 2007).

Increasing highway capacity through new ring roads and highways is of limited use where there is a high latent demand for traffic. If there are no effective control strategies limiting the use of private vehicles, the roads will again reach saturation point in only a few years; this has been the lesson from the UK and international experience (SACTRA, 1994). Other policy measures, such as the license-plate lottery and license-plate restrictions, are of limited effectiveness, as people can still buy more cars to avoid them – there are always routes around the legislation. Many of these approaches designed to restrict traffic might actually encourage people to buy more vehicles – there are often unintended effects of policy. Driving restrictions can only prevent cars with non-Beijing license plates driving within the fifth ring road, but not outside of that area. Clearly the demand for car ownership and use is immense in Beijing, and a very innovative and wide-ranging strategy will be required to even partially offset the projected increases in traffic.

Table 1: A Revised License-plate Quota (2014 to 2017)

	2014	2015	2016	2017	Total
Standard Gasoline Vehicles	130,000	120,000	90,000	90,000	430,000
Battery Electric Vehicles	20,000	30,000	60,000	60,000	170,000
Total	150,000	150,000	150,000	150,000	600,000

(Source: adapted by authors, from Arnd, 2013; BMG, 2013b)

4.4. Public Transport Subsidies and Low Fares

Some governmental politicians among the survey respondents suggested that a transit oriented development (TOD) model could help restrict demand for private vehicles, and reduce air pollution and CO2 emissions caused by vehicles. However, there are problems with applying this planning approach to Chinese cities. Beijing is built at a high density already, and to an extent almost the entire city is developed at TOD densities. The main difficulty is in developing extensive networks of different types of public transport, with good integration between, which can then serve the development. Applying a low fares model for public transport is also difficult. The purpose of persuading more residents to take public transport and encouraging sustainable travel may be laudable, but, a lower cost of public transport would generate larger passenger volumes, and this would mean that the public transport system would become even more overloaded. This might prove counterproductive and encourage people to buy private vehicles for commuting or travel instead of taking public transport. For example, currently the price of a single Subway ticket is 2 RMB[ii] and a single bus ticket just 1 RMB. The experts commented that the current low fare policy is useful as it allows much of the urban population to access public transport, but it may not be sustainable in the long term, certainly not if reduced fares were used, as it would cause an unnecessary increase in travel demand. Some respondents also mentioned that the BMG will not be able to subsidise public transport after 2014 due to financial constraints. Ground traffic operating income dropped from 3.087 billion RMB in 2007 to 2.593 billion RMB in 2013 (BTMB, 2014); and according to the 2013 official metro statistics, the average single cost per passenger was

7.9 RMB, but the actual cost of a single ticket was 2 RMB, equating to a loss of 5.9 RMB per person (cited in BMG, 2013). Furthermore, the utilisation of 13 out of 17 underground lines was over 100% at peak time in 2013. The current public transport system in Beijing is heavily subsidised – however, this is the case for many, if not all, metropolitan public transportation systems, and indeed is the case for all highway systems, which are usually built with the public purse. A small number of the respondents argued that the negative effects of encouraging people to take public transport more should not be attributed to insufficient BMG subsidies or unreasonably low fares, as the Subway, buses, and other forms of public transport, have drawbacks inherent in their own structures and characteristics. This is because most public transport is based on fixed transport routes that cannot fulfil people's door-to-door requirements. Thus, most passengers have to use other modes of transport (i.e. private vehicles, walking, cycling, and taxis) to reach their final destinations, and even to access the public transport services.

4.5. Other Overlooked Enabling Mechanisms

The increase in smog-related air pollutants and CO2 emissions generated from the transport sector are associated with an increase in private vehicles, traffic congestion, and an overloaded public transport network. Many of the survey respondents cited increased motorisation as the main cause of thick haze in Beijing, particularly in terms of its contribution to PM2.5. Some, however, pointed out that vehicle tailpipe gas emissions account for less than 20% of smog-related air pollutants, while the rest are released by industrial pollution emissions, burning coal and other factors (Song et al., 2013) – there are multiple causes for the poor air quality in Beijing.

However, traffic related emissions need to be reduced. With over 5.2 million private vehicles in Beijing, 95% of which are fossil-fuel powered vehicles (85% petro-powered vehicles and 10% diesel-powered vehicles) (BTMB, 2013), the ICE causes severe air pollution and CO2 emissions. Vehicle braking also contributes to PM2.5, as vehicle brake pads contain nanosized particles of dust which are major sources of smog-related air pollutants (Schallabock and Petersen, 1999). Clearly, increased friction between roads and car tyres and the use of brake pads also produces more PM emissions from traffic congestion (ibid.). The majority of private cars in Beijing are petrol-fuelled, which generally have a less significant effect on primary PM2.5 emissions compared to diesel-powered vehicles. Exhaust gases from gasoline such as NOx and SO2 contribute greatly to the formation of secondary particles such as SO4 and NO3 in the air (Weinmann, 2014). Increased automobile usage, burning coal, industrial production emissions and dust are four main sources of PM2.5 in Beijing (ibid). Thus, it is necessary to control air pollution resulting from increased mobility – any future growth in traffic is likely to exacerbate an already problematic emission issue.

5. Exploring Scenario 3 (Managed Sustainability) and Scenario 4 (Green Growth): Plausibility Testing and Implementability

5.1. Limitations of Population Growth and Migration

Over 75% of the survey respondents stated that the development gap between urban and rural areas in Beijing is very problematic and should be reduced, while improving economic growth in the suburbs and other Tier Two and Tier Three cities. The BMG has applied property regulations designed to curb migration, which require people to register for a permanent residence certificate (‘hukou’) or provide evidence of at least five years’ tax payments, before they can buy housing in Beijing. However, there are no other effective strategies in place to stop migrants renting or buying housing in other cities near Beijing, which might contribute to the problem of dormitory towns or ‘tidal traffic flow’. Neither the national nor local governments currently offer any instruments that can be effectively applied to limit population growth and migration in Beijing. However, if a coordinated land-use policy could be implemented, it might help to indirectly limit population growth in Beijing (Huang et al., 2009). This is a major problem for the national and city governments in China, and it is difficult to provide a solution without some rebalancing of the quality of life in urban and rural areas.

5.2. Government Intervention and Public Awareness

Some respondents claimed that most of the current instruments of government intervention can only temporarily restrict transport smog-related air pollutants and CO2 emissions, which echoes Paterson (2007) who argues that long-term strategic sustainable development has been inadequate. An example is the environmental legislation published by the National

People's Congress (NPC), in May 2014, proposing that if vehicles are stopped for more than three minutes, drivers should switch off their engines. This means that petrol and energy consumption is reduced, while also raising awareness of environmental protection, so that citizens can actively engage in environmental protection. Legislation and instruments of government intervention are important methods for mitigating smog-related air pollutants and CO2 emissions; but the most significant measure in this respect is enhancing citizens' environmental awareness (e.g. long-term educational policy) in order to resolve environmental degradation. This has to be a key element of any future strategy.

5.3. Technical Change and Innovation Development

The majority of the experts suggested that technical innovation could significantly reduce smog-related air pollutants and CO2 emissions in Beijing, particularly by developing BEVs, implementing renewable energy and applying intelligent transportation systems (Gilbert and Perl, 2008; Van Wee et al., 2013), although ICE-powered vehicles will still continue to play a role in ground transport over the next few decades (OLEV, 2013). Most representatives (especially academics and transport planners) particularly emphasised the technological development and wider use of different types of BEVs in terms of their future potential benefits (NAIGT, 2009; OLEV, 2013; Zhang, 2015), a strategy for which they cited two main reasons. First, and foremost, BEVs can reduce oil dependence while also cutting vehicle exhaust (i.e. air pollution and CO2 emissions) (Gilbert and Perl, 2008); second, China's vehicle fleet lags far behind most developed countries in terms of technical development. However, BEVs and conventional vehicles are totally different entities: a BEV constitutes a battery pack and electric engine; while a conventional car is based on an ICE and gearbox (OLEV, 2013; Zhang, 2015). Therefore, BEV development can be seen as part of a transport revolution to transform China's motor industry, while reducing smog-related air pollutants and CO2 emissions (Gilbert and Perl, 2008).

Smog and CO2 emissions should not only be considered in terms of the direct impact of vehicle exhausts, but the indirect effects (e.g. the energy source) also need to be taken into account. Energy sources vary between countries and China's energy consumption is derived mainly from burning coal (Jiang, 2011; Greenpeace, 2014). In the northeast of China, where Beijing is located, over 90% of electricity is generated from coal-fired power plants which, in themselves, cause high levels of PM2.5 and CO2 emissions (Greenpeace, 2014). In circumstances where electricity is generated mainly by coal-fired power, indirect air pollution and CO2 emissions from BEVs may be even higher than from standard gasoline vehicles in Beijing. This view is also supported by Archer (2011b) and Zhang (2015), who analysed the whole life-cycle energy consumption and CO2 emissions of ICE vehicles (oil drilling-store-fuel burning generated power per 100 km [well-tank-wheel]) and EVs (coal mining-coal transportation-coal burning generated power per 100 km) rather than only calculating CO2 emissions produced directly from vehicle exhaust. The results showed that the estimated whole life-cycle of total CO2 emissions for a BEV is higher than for a standard gasoline vehicle, mainly due to the coal-based energy structure in Beijing (Zhang, 2015; Archer, 2011a). If plug-in hybrid vehicles are developed and promoted as an efficient solution to reducing CO2 emissions in the forthcoming years in Beijing (NAIGT, 2009), the power source is critical. In the future, if clean coal technology can be introduced or the dominant coal-fired power structure can be changed by using other clean energy sources (e.g. hydro energy or renewables), BEVs could replace ICE vehicles as part of a transport revolution reducing not only smog-related air pollutants and CO2 emissions, but also car-based fossil-fuel dependence (Gilbert and Perl, 2008; NAIGT, 2009; Zhang, 2015; Figure 3).

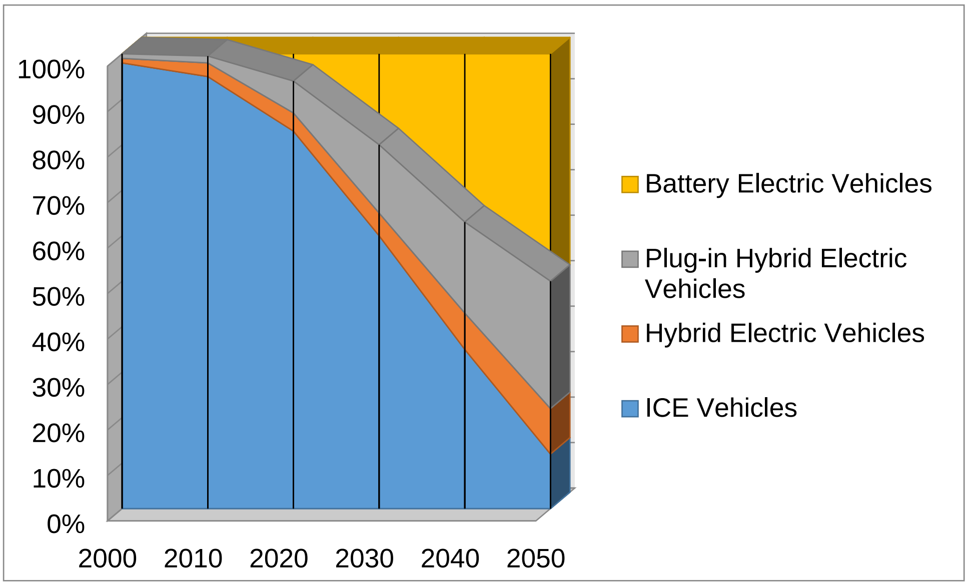

Figure 3: Development Strategy and Trend Forecasting for Each Vehicle Technology in Scenario 3

(Source: adapted by authors, from Zhang, 2015)

6. Conclusions

Beijing is a large, complex and unique city, and perhaps one of the most difficult in the world to seek to reduce the reliance on the private car, the high levels of smog-related air pollutants and CO2 emissions. Three pressing problems need to be resolved.First, the level of investment required in public transport, walking and cycling is not enough to offset the rise in traffic volumes. Second, the development of low emission vehicles (e.g. BEVs) is likely to play an important role in a wide-ranging strategy targeted at reducing smog and CO2 emissions. However, Beijing's current energy supply (i.e. coal-based energy) is not helpful here – and this needs to change if BEVs are to play a significant role. Finally, a key problem for cities in China is uncontrolled population and migration growth. There are currently few effective instruments offered by national or city governments that can be applied. Urban planning in Beijing, and across the Bohai Rim city region, needs to be much strengthened, reducing urban sprawl, over-centralised functions, and dormitory satellite towns, which are associated with a high level of car-based commuting. A polycentric built form, within Beijing and across the city region, linked by extensive multimodal public transport networks – and including a growth boundary for the inaccessible areas – is the model to pursue. Effective city planning is critical to enable greater sustainability in travel – developed at the multilevel scales of the metropolis, the city and the neighbourhood – and perhaps it is in Beijing, and China, that the leading practice and innovations can emerge.

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Figure Captions

Figure 1: The Participatory Scenario Approach

Figure 2: Scenario Matrix for Beijing

Figure 3: Development Strategy and Trend Forecasting for Each Vehicle Technology

Table 1: A Revised License-plate Quota (2014 to 2017)

Appendices

Appendix 1: Important Trends and Uncertainties in Beijing

Number	Important Trends and Uncertainties	Future Trends and Uncertainties			Current Drivers of Change			Overall Ratio	Ranking
		Ranking Scale1	Experts1	Total Score1	Ranking Scale2	Experts2	Total Score2		
1	Economic growth rate (GDP)	3	3	9	3	2	6	0.0797	5
		2	3	6	2	6	12		
		1	5	5	1	6	6		
2	Government environmental stewardship	3	1	3	3	4	12	0.0851	4
		2	6	12	2	6	12		
		1	4	4	1	4	4		
3	Population growth and migration	3	20	60	3	26	78	0.3297	1
		2	6	12	2	8	16		
		1	12	12	1	4	4		
4	Technical change	3	9	27	3	2	6	0.1232	3
		2	8	16	2	4	8		
		1	8	8	1	3	3		
5	City planning and addressing transport issues	3	10	30	3	10	30	0.2192	2
		2	10	20	2	10	20		
		1	9	9	1	12	12		
6	Globalisation (international trade)	3	0	0	3	0	0	0.0000	N/A
		2	0	0	2	0	0		
		1	0	0	1	0	0		
7	Social equity (inclusion of minority	3	0	0	3	0	0	0.0000	N/A

	groups)	2	0	0	2	0	0		
		1	0	0	1	0	0		
8	Energy and power supply (clean fuel)	3	0	0	3	2	6	0.0435	6
		2	3	6	2	2	4		
		1	4	4	1	4	4		
9	Climate change (major environmental shocks)	3	2	6	3	0	0	0.0109	N/A
		2	0	0	2	0	0		
		1	0	0	1	0	0		
10	Age profile (ageing population)	3	0	0	3	0	0	0.0308	8
		2	4	8	2	2	4		
		1	0	0	1	5	5		
11	Aspirations and culture (continued 'eastern consumption')	3	0	0	3	0	0	0.0000	N/A
		2	0	0	2	0	0		
		1	0	0	1	0	0		
12	Income levels (income inequality)	3	1	3	3	0	0	0.0254	9
		2	1	2	2	4	8		
		1	1	1	1	0	0		
13	Urban transport structure	3	0	0	3	0	0	0.0181	10
		2	2	4	2	2	4		
		1	2	2	1	0	0		
14	Other drivers of change	3	0	0	3	0	0	0.0344	7
		2	3	6	2	2	4		
		1	1	1	1	8	8		

Notes:

1) *Overall Ratio = [Ranking Score × Number of Experts) ÷ Sum of Each Total Score] × 100%*

$$Or(x) = \frac{\sum_{n=1}^{n}(RS_{F(x)n} \times E_{F(x)n}) + \sum_{n=1}^{n}(RS_{C(x)n} \times E_{C(x)n})}{\sum TS_F + \sum TS_C} \times 100\%$$

O_r *is the overall ratio*

$RS_{F(x)}$ *is the ranking scale of future trends and uncertainties*

$E_{F(x)}$ *is the number of experts' vote for future trends and uncertainties*

$RS_{C(x)}$ *is the ranking scale of current drivers of change*

$E_{C(x)}$ *is the number of experts' vote for current drivers of change*

n *is the scale which is* $1 \le n \le 3$, $n \in Z$

TS_F *is the total score of future trends and uncertainties*

TS_C *is the total score of current drivers of change*

x *is the economic growth rate; government environmental stewardship; or population growth and migration, etc.*

2) *Scale: 3 has the highest impact and 1 has the lowest impact*

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[i] Scenario 2 – 'Declining Mobility' will not be further explored and discussed in detail in this research because it is unlikely to happen by 2050 in Beijing.

[ii] 1 RMB ≈ 0.1 GBP; hence a single Subway ticket is 20 pence.