Assessment of integrated "Transport – Land Use" policies potential to reduce long term energy consumption of urban transportation. A prospective simulation in Bangalore, India

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Keywords

urban model, integrated transport and land use policies, Bangalore

Abstract

The current trends of urban dynamics in the Third World are alarming with regard to climate change, because they are giving an increasingly important role to cars—to the detriment of public and non-motorized transportation. Yet this is the type of energy consumption that is expected to grow the fastest, in business-as-usual scenarios. How can these market-based urban trends be influenced? What level of emissions reduction can be achieved? This article shows that first, there is a relevant and urgent need to tackle the urban dynamics of cities in developing countries focusing on the "transport – land uses" couple, and second, that existing transport technologies and decision-helping tools are already available to take up the climate change challenge. Through the application of an integrated "transport – land uses" model, TRANUS, this study demonstrates that transit technologies affordable to an emerging city like Bangalore can significantly curb the trajectories of energy consumption and the ensuing carbon dioxide emissions, if and only if they are implemented in the framework of appropriate urban planning. Furthermore, this study establishes that there are tools which are available to facilitate the necessary policymaking processes. These tools allow stakeholders to discuss different political alternatives integrating energy issues, based on quantitative assessments

Introduction

Sustainable development has become widely recognized, but the challenge is now to translate the concept into action in the field, and especially in cities. The current trends of urban dynamics in the Third World are alarming with regard to climate change, because they are giving an increasingly important role to cars—to the detriment of public and non-motorized transportation. Yet this is the type of energy consumption that is expected to grow the fastest, in business-as-usual scenarios. Considering the life span of urban structures, the type of urban growth that cities of the South will experience in the next three decades will determine the level of their energy consumption and greenhouse gas emissions in the second half of the century.

The article shows that first, there is a relevant and urgent need to tackle the urban dynamics of cities in developing countries focusing on the relation between transportation and urbanism, and second, that the existing transport technologies and decision-helping tools are already adequate to take up the climate change challenges. This study demonstrates that the transportation technologies affordable to an emerging city like Bangalore can significantly curb the trajectories of energy consumption and of the ensuing carbon dioxide emissions, if, and only if they are implemented in the framework of appropriate urban planning. Furthermore, it establishes that there are tools which are available to ease policy making processes. These tools allow stakeholders to discuss different political alternatives integrating energy issues, based on quantitative assessments. The article addresses these issues through a case study of Bangalore, India.

Bangalore (India): Challenges to the sustainability of the economic boom

Over the past fifteen years, Bangalore has experienced profound economic, social and spatial mutations linked to the boom in information technology (IT). But these transformations and their speed jeopardize the city's urban management capacity. The sustainability of urban development, especially its environmental component, is particularly at risk. The city with its dense and radial-concentric structure is confronted by high-speed demographic growth and urban sprawl (See Textbox 1), and risks becoming congested, leading to an unmanageable situation.

Though the dynamics of Bangalore's urban development underwent an abrupt change during the 1990s linked to the boom of IT activities, the realities that urban planners must work with do not exactly fit with the idyllic image of an "Indian Silicon Valley". The IT sector has become an essential motor of urban prosperity (See box 1), but even so, it has not dramatically changed the distribution of employment in the city, or improved living conditions for the population as a whole. The IT dynamic contributed to the demographic explosion and the exacerbation of social inequalities. Alongside the glittering image of the "IT City", it would be wise to consider the risks of fragmentation incurred by urban society because of the digital revolution: the disparity ratio of incomes between the first and the last quintile has changed in ten years from 4.9 in 1991 to 13.6 in 2001, a significant jump that implies a profound change in the equilibrium of the city. While inequalities were until recently moderate, the city is now about to pass to a new form of society, marked by inequality tensions: the richest 20% of the city's inhabitants benefit from over half the city's income, whereas the poorest 20% only see a negligible amount – 3.8% of the total (SCE-CREOCEAN, 2004; 2005).

The demographic and economic booms of the 1990s led to fundamental changes in the dynamics structuring the urban space and a dislocation of the traditionally dense and concentric urban structure. As shown in map 1 (figure 1), in absence of geographical constraints, Bangalore is now spreading in all directions, especially along major roads. These roads attract industries and commercial activities far from the city center, and the residential development is following. The passage from urban growth in concentric circles, which produced the dense fabric of the earlier city, to this linear and divergent expansion, has led to an imbalance between the different zones of the urban area. As one can see in map 1 (figure 1), the intensity of urban development is not identical in all directions. It continues to sprawl massively to the northeast and to the south, whereas along Whitefield Road to the east and Hosur Road to the southeast, it is resolutely linear.

The new pattern of mobility and the increasing congestion reinforce the unsustainable urban trends that Bangalore is facing. Today, Bangalore and Delhi share the highest motorization ratio in India: 32 vehicles for every 100 persons (SCE-CREOCEAN, 2004; 2005). Though there is more and more congestion at rush hour, travel time remained on average around 33 minutes per trip in 2001 (BCIP, 2001). But this situation is not likely to last. In 2005, 12.3% of the households owned a car and 44.5% a motorcycle. These modes represent, respectively, 4.5% and 30.4% of the modal share. On the other hand, 38.4% of the households do not own any vehicle, and walking and bus constitute, respectively, 16.2% and 41.3% of the distribution of trips by mode. Between 1991 and 2005, the number of vehicles registered in Bangalore increased by over 200% (from 680,000 to 2,200,000), which corresponds to an annual growth of the number of cars and motorcycles that is three times greater than that of the population (10.8% for car and 9.5% for two-wheelers, compared to 3.25% for the population) (RITES, 2001; SCE-CREOCEAN, 2004; 2005). In view of the fact that rising household income leads to increasing private motor vehicle ownership, and considering also the imminent entry into the market of the world cheapest Tata company's car, the Nano, one can anticipate a dramatic growth in vehicle traffic and extensive gridlock to appear within the next few years. Moreover, Bangalore is in danger of entering into a vicious cycle in which the present dynamics of dispersion of housing schemes in peripheral areas leads to increase the use of private car. Increasing motorization will in return push for more dispersion of housing schemes. Traffic congestion, increasing transportation times, and the deterioration of the quality of life can all have a direct impact on the economic dynamism of the city.

TRANUS, an integrated "Transport-Land Use" model

There are around twenty integrated models (EPA, 2000). There are significant variations among the models as concerns overall structure, comprehensiveness, theoretical foundations, modeling techniques, data requirements and model calibration process. TRANUS is the one which offers the appropriate balance between theoretical relevance and operational requirements for my research project (Lefevre, 2007). TRANUS is an integrated Transport-Land Use model, which de la Barra and Perez have been developing since 1982 (de la Barra, Perez, 1984; de la Barra, 1989, 1998). It is the most widely applied integrated model (EPA, 2000). It has been implemented both in Northern cities (Baltimore, Sacramento, Osaka, Brussels, etc.) and in Southern cities (Sao Paulo, Mexico, Caracas, Bogota, etc.). Moreover, as reported in Miller et al (Miller et al., 1998), de la Barra showed through an application on Baltimore that TRANUS is able to simulate urban dynamics already observed, in a retrospective way. This success in an ex-post simulation - which is considered as the most significant test for a prospective model's relevance (Masson, 2000) – proves its operationality. In addition to that, theoretical and practical arguments achieved to convince me that TRANUS was the most appropriate model for the objectives and the context of my research.

TRANUS adopts the main concepts of spatial economics, location, land use, and the generation of land rent, developed by Von Thünen in 1826, and refined by Wingo and Alonso in 1964. The works on gravity and entropy models developed by Hansen (1959) and Lowry (1964), and completed by Wilson (1970) are also an important component of TRANUS. Finally, TRANUS uses the input-output accounting framework developed by Leontief (1936), since it includes a complete input-output model to represent the economy of a spatial system and the formation of prices. In TRANUS the original input-output model has been generalized to all sectors participating in urban dynamics, like land, activities, population and transport operators. Thus the spatial dimension has also been added and

The population of Bangalore has tripled in thirty years. It increased from 4.13 to 5.68 million inhabitants between 1991 and 2001, growing the fastest of all Indian cities, apart from Delhi. Bangalore is now the fifth biggest city in the country. Though its growth rate has decreased slightly (from 3.52% between 1981 and 1991, down to 3.25% between 1991 and 2001), it could reach 10 million inhabitants by 2020.

From 1997 to 2001, overall job growth amounted to approximately 500,000 jobs; 94,000 companies were also created, of which 93,845 were small businesses (less than 10 employees), mostly informal (SCE-CREOCEAN, 2004; 2005). This growth partially corresponds to the many cases of production off shoring that Bangalore benefited from in recent years. They also led to significant increases in induced employment in more traditional sectors of activity, especially services. However, though the turnover of IT companies increased rapidly, the rate of this exceptional growth slowed significantly year by year, from 70% (2000-2001) to 33% (2001-2002), then to 25% (2002-2003) (SCE-CREOCEAN, 2004; 2005).

Out of a total working population of 2.4 million, only 360.000 are employed by IT companies. It is estimated that the non-organized sector employs about 1 million persons in Bangalore, which is over 40% of all jobs! Some experts even claim that the correct proportion is around 75%. (SCE-CREOCEAN, 2004; 2005)

The urban sprawl of Bangalore is even more impressive: the annual growth rate of its urban area is 5.4% (which corresponds to 2,200 extra hectares, or nearly 8.5 square miles every year). In 2005, the city's surface area was 540 square kilometres (nearly 208.5 square miles), up from 284 square kilometres in 1990, and 202 in 1983. (SCE-CREOCEAN, 2004; 2005)

Textbox 1. Population growth, employment vitality and urban Sprawl of Bangalore

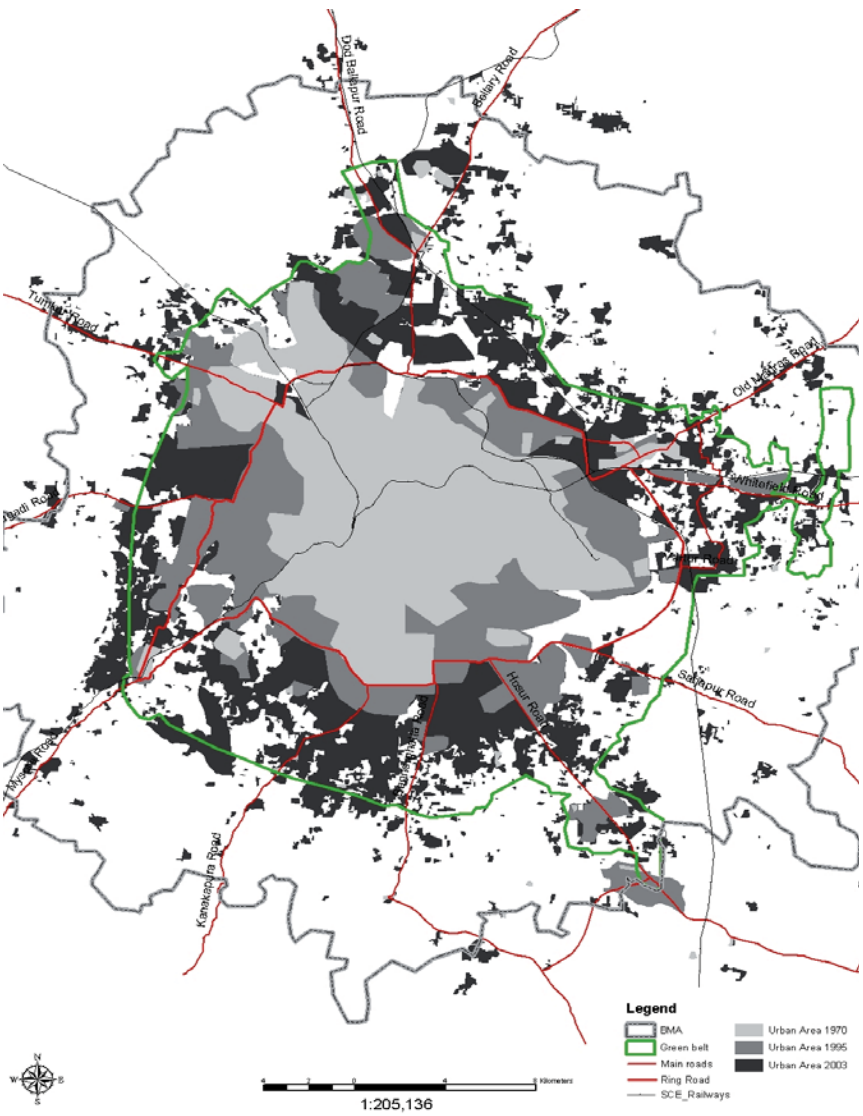

Figure 1. Urban Sprawl of Bangalore 1970-2003. Source: SCE-CREOCEAN, 2005

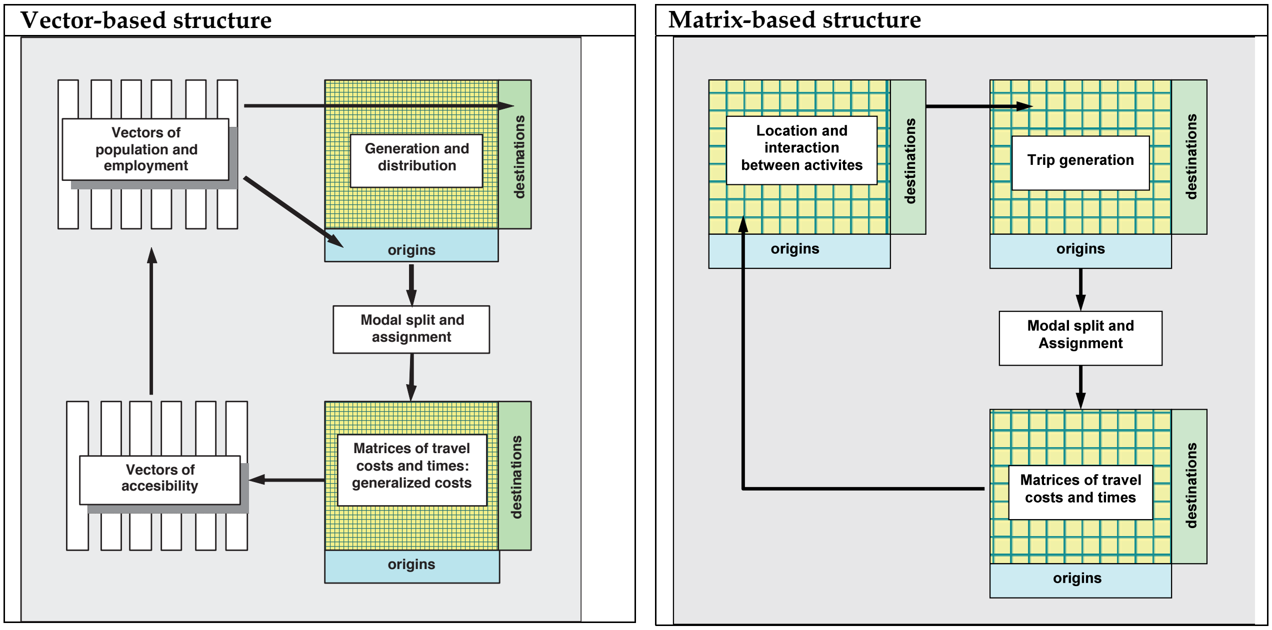

Figure 2. Structures in integrated land use and transport models. Source: de la Barra, 2004.

integrated with the transport system. TRANUS is also rooted in the discrete choice models and random utility theory (McFadden, 1975). In TRANUS the discrete choice approach is applied to all components of the land use and transport system, from trip generation to mode choice, path choice, location choice and land use choice. De la Barra (2004) presents TRANUS as "a long chain of linked discrete choice models". Finally TRANUS has drawn heavily from conventional four steps transport models, such as graph theory, queuing theory, minimum path search as originally proposed by Dijkstra in the 1950s (de la Barra, 1989).

Among different theoretical features, the original matrix-to-matrix structure deserves to be presented here because it improves significantly the consistency of TRANUS. De la Barra (2004) explains that the first integrated transport – land use models (LUTM) that attempted to feed back the results of the transport model into the land use calculations preserved the vector structure of the data. The resulting structure is shown in figure 2 (left). The vectors of activities estimated by the land use model are fed into the transport model, from which trip flows are calculated. The trip distribution model calculates trip matrices from such trip ends, and from this point the calculations become matrix-based. Each cell in the trips matrix is split by mode and then assigned to the corresponding networks. After capacity constraint procedures, the model estimates for each cell travel cost and time contributing to generalized cost, and the resulting matrices are fed back into the land use model. Because the land use model is based on a vector structure, the matrices of generalized cost must be aggregated from matrix to vectors, becoming vectors of accessibility, affecting the location of activities. A transformation in the transport system at some points changes the corresponding cells in the matrices of generalized cost, and eventually the vectors of accessibility, thus affecting the location of activities.

De la Barra (2004) suggests that there are two important problems in this scheme. The first come up from the matrix-to-vector transformation when generalized cost is fed back into the land use model because there is no satisfactory method to aggregate matrices of generalized cost into vectors of accessibility[1]. A transport change that, for example, improves a specific origin-destination link but not others, might get completely diluted in the aggregation process, perhaps becoming worthless and producing similar results in terms of population and employment in the with and without-project scenarios. The second problems identified by de la Barra (2004) occurs in the vector-to-matrix transformation when the results of the land use model are fed into the transport model, because there is no guarantee of consistency between how the relationships between activities are simulated in the trip distribution model and in the land use model (through accessibility vectors). They may have contradictory results. In the previous example a gain in accessibility between two specific zones may not show in the vectors of population and employment used by the land use model, but the distribution model, because it is matrix-based, will reflect the change, resulting in an increase in the number of trips.

To solve these problems, de la Barra adopted in TRANUS a matrix-based structure, as shown in figure 2 (right). The land use model estimates both the location of and interaction between activities, generating matrices of flows. On a cell-by-cell basis, trip generation functions transform the matrices of flows into trip matrices, divided by mode, and are assigned to the network. After capacity restriction the process ends with transportation cost and time matrices, which are fed back into the land use model. The entire process is carried out on matrices, without the need for aggregations. Also, if there is a local transport improvement affecting only a couple of cells, as in the previous example, it is followed throughout the process without loss due to aggregation.

1. Current methods use weighted averages or other simple formulas, resulting in a loss of richness in the information.

Table 1. Application of TRANUS: Sub-division of each urban sector and collect of data.

Sector	Category	Data	Sources of data
Activities	Traditional heavy industries	Minimum and Maximum input demand by output unit, production, price By population's categories: % of total employment By zone: employment	- SCE-CREOCEAN - Reports form the local, state and national authorities - literature on Bangalore - interviews of experts
	Information Technologies industries		
	Administrative services		
	Retail		
	Educational services		
Land	Mixed-use land	By zone: superficies, prices	- SCE-CREOCEAN
	Residential land		
	Industrial land		
Population	Quintile 1	Average income, value of travel time, value of waiting time	- SCE-CREOCEAN - Census 2001 Reports form the local, state and national authorities
	Quintile 2		
	Quintile 3		
	Quintile 4		
	Quintile 5		
Public transportation modes	Bus	Equivalent PCU, frequency minimum and maximum, average waiting time, capacity, average occupancy, unit boarding and alight time, tariff, operation costs, free flow speed, flow at peak hours for major roads	- SCE-CREOCEAN - BMTC (local public bus company) - RITES - interviews of experts
	Metro		
	Rickshaw		
Private Transportation modes	Car		
	Motorcycle		
	Bicycle		
	Walking		
Road network	Arterial	Name, length, authorized modes, carrying capacity, free-flow speed, % speed reduction at Volume/Capacity = 1, V/C at Max speed reduction, etc.	- SCE-CREOCEAN - RITES - Reports form the local, state and national authorities
	Sub-arterial		
	Main road		
	Ring road		
	Connect Road		
	Walking		

On the practical point of view, TRANUS presents key advantages. The TRANUS system is programmed to run on standard PCs operating under Windows. All programs and documentation may be downloaded freely[2]. Finally, the TRANUS user's interface provides useful flexibility and ease of use for setting up a database, importing/exporting data to and from other applications, running the models and presenting results.

In accord with de Palma et al. (2005), I agree that the most promising technique for transport-land uses modeling is certainly micro-simulation[3] which makes it possible to reproduce the complex spatial behavior of individuals. These models aim a more detailed representation of urban activities' diversity and of the trip decisions process. Up to now, this approach consists of associating a very detailed land-use model with a very detailed transport model[4]. However, first, these models still do not have a sufficient record of application and, second, they require a large amount of data that are not available nowadays in Bangalore.

Therefore, I selected TRANUS as the most appropriate model to satisfy my theoretical and operational requirements. As presented in the next section, I also added to TRANUS a module to translate urban structure's evolution in terms of energy consumption, according to specific characteristics of the vehicle park in Bangalore. I applied TRANUS to Bangalore and test a set of transport and land-uses policies, based on the current, voted or under-discussion urban policies in Bangalore.

2. From www.modelistica.com or www.tranus.com.

3. Like IRPUD (Wegener, 1982), URBANSIM (Waddell, 1994), MASTER (Mackett, 1990), DELTA (Simmonds, 1998).

4. For example, de Palma works on the connection between URBANSIM and METROPOLIS.

Table 2. Characteristics of the three scenarios tested with TRANUS

Scenario Name	Transport Policies and Investment	Land Uses Policies	Economic Policies
Business As Usual	- Construction of the Central Ring Road (CRR); - Construction of the Peripheral Ring Road (PRR); - Extension of bus lines as far as the PRR; - Intervention at highly congested intersections (quality of road service equal or under G*);	No new policies (Only zoning rules);	No policies;
Metro -	- Construction of two lines of metro, crossing at the city center;	No new policies (Only zoning rules);	No policies;
Metro +	- Construction of two lines of metro, crossing at the city center (similar as "Metro-");	- City center: all the vacant lands are open to urbanization + Progressive conversion of industrial lands to mixed lands (5% per year); - First belt: all the vacant land are open to urbanization; - Second belt: No lands are open to new urbanization + Progressive conversion of residential lands to industrial lands (equivalent to the superficial changes in the city center);	- Increase of the operation costs of car: tax on fuel (100%); - Parking costs in the city center (equivalent to 30 minutes of the time value of quintile 5) and in the first belt (equivalent to 15 minutes of the time value of quintile 5);

* Quality of road service is evaluated according to "Transport Research Board (TRB), 2000, Highway Capacity Manual, National Research Council, Washington, DC".

The application of TRANUS to Bangalore

The required data were gathered through five main sources: SCE-CREOCEAN, the consulting office in charge of the elaboration of the master plan "Bangalore 2020" who welcome me during six months; RITES, the consulting office in charge of the development of the metro project; existing reports in the different local, state and national administrations; and interviews with experts. The existing transport data sets were completed with traffic surveys carried on at the key intersection of the road network by seven surveyors during the month of April 2004.

The urban area of Bangalore was divided into forty-seven zones. Then I entered for each zone the set of data describing the different sectors, taking 2003 as the base year to calibrate the simulation. Each sector was divided into several categories as presented in table 1. Table 1 also indicates the required data for each categories and the source where these data were found.

TRANUS adopts a negative function in order to take into account the increase of energy consumption due to congestion. As TRANUS does not quest after taking into account the increase of energy consumption due to an excessive speed, it doesn't consider that the energy consumption raise beyond an optimal[5] speed (specific to each vehicle). Therefore, I preferred to adopt U shaped curves that allow me to take into account both congestion and excessive speed. Thus I calculated the energy consumption based on the functions provided by the Indian Road Congress (IRC, 1995) for each type of vehicle.

5. The optimality is considered here in terms of energy consumption per unit of distance.

Testing three urban policies scenarios

Next, I assessed the capacity and the better combinations of the three levers – investment in transport infrastructure, land-uses regulation and pricing policy – available to the municipality to reduce long-term energy consumption. I therefore compared a business-as-usual scenario with a "metro-" scenario and a "metro+" scenario articulated to the metro project which is under construction in Bangalore. The three scenarios main characteristics are presented in table 2. It should be noted that this is not a fictional urban planning scenario: the policies involved in the three scenarios are being implemented or planned in Bangalore or in other developing cities[6].

In all scenarios, the investment capacity of the municipality is capped by the budget currently devoted to the construction of the two metro lines today (US$ 1,089 billion over 20 years). Moreover, these simulations were carried out *ceteris paribus.*

Findings: A policy integrating transportation and urban planning can significantly lower the trajectories of energy consumption associated with urban transportation

Two main conclusions can be drawn from these results. First, the answer to the initial question is "yes": with realistic policies (building a subway network, encouraging higher density

6. A metro is currently under construction; transport oriented land use policies regulating the type of usages authorized, the level of mixed usages, etc. were implemented in Curitiba (Brazil), but also partially in Mumbai (India); density fuel tax and parking pricing were implemented in Bogota (Colombia) at the end of the 1990s.

Table 3. Projected mobility indicators and energy consumption

Scenario	Inter-zone trips	Average Distance (Km)	Share of private mode (car + moto)	Average Time (decimal hour)	Energy consumption (L)
Base year	664,553	12.66	45%	1.13	853,151
BAU	+65%	13.66	43%	1.27	+70%
METRO-	+61%	13.08	36%	1.63	+51%
METRO+	+59%	12.19	23%	1.23	+9%

and mix of land-uses in zones of improved accessibility, and implementing economic instruments, like fuel taxes or parking pricing schemes), a stabilization of energy consumption and carbon dioxide emissions is possible. Second, the energy savings obtained from the integration of transport policies and land-use policies are significantly larger than those obtained from a transport investment alone.

What are the underlying processes shaping these results? Why and how is the integration of "transport – land uses" policies so successful? I analyzed the evolution of the spatial distribution of homes and jobs, as well as the growth in land consumption using GIS maps. These maps allow us to understand how the policies tested impact the location decisions. Then, I examined the impact of this urban structuring process on inter-zone mobility, characterized by number, distance, average duration and modal distribution of trips.

In the business-as-usual scenario, phenomena of peri-urbanization and de-densification can be observed in the city center, whereas the localization of jobs remains stable. The localization of new jobs is homogenous throughout the territory of Bangalore. In the "metro-" scenario, this centrifugal process is similarly observed, although in a less intensive way. Moreover, the peri-urbanization of the residences is in this case mostly oriented toward the first-ring suburbs. Meanwhile the new employments are more concentrated in the catchment area of the metro, notably in the city center. On the contrary, in the "metro+" scenario, the spatial distribution of new homes and jobs is concentrated in the inner-ring suburbs and in the South of the second-ring suburbs. The city center, at the intersection of the two subway lines, is still losing residents, but this time, it is clearly because the population is being driven out by jobs. The trend of job concentration in the city center increases real-estate prices, and the population that cannot pay leaves the center to find housing in peripheral areas that are accessible by metro.

To represent the phenomena of urban sprawl, or conversely, urban condensation, I choose the proxy of the evolution of land consumption—that is, the evolution of square meters occupied by residences and activities. The evolution of land consumption[7] is very dissimilar in these three scenarios. In the "metro+" scenario, new real-estate consumption is concentrated in central zones and in the first-ring and second-ring suburbs accessible by metro. We observed that the amount of this real-estate consumption is relatively low, which indicates a process of densification of these zones. Real-estate consumption decreases in the other zones, especially the more peripheral ones; this suggests a phenomenon of urban condensation. The evolution of land prices reflects these trends: residential and industrial land prices increase significantly in the city center and in the first belt. In these areas, the growth is more moderate for mixed-uses land. The decision to limit the amount of land open to urbanization in the peripheries, in order to fight against urban sprawl, generates a strong valorization of the peripheral lands. In contrast, in the business-as-usual scenario, the peripherization of homes and jobs, and the de-densification of the city center, induces high land consumption in the periphery and abandonment of land in certain central urban areas.

Again, the "metro-" scenario presents an intermediate situation characterized by less peripheral land consumption than in the business-as-usual one. The metro limits the urban sprawl and increase the attractiveness of the city centre, but alone it doesn't generate a process of urban condensation. That explains why the increase in land prices – for residential, mixed, and industrial usages – is rather similar to the one observed for the BAU scenario, and lesser than the one observed for the "metro+" scenario. Thus, the subway alone channels urban development toward certain areas, but it needs to be integrated into appropriate urban planning in order to counter urban sprawl.

How are these evolutions of the urban structure translated in terms of mobility? How do the differences between the evolutions of the urban structure under these three scenarios explain that the integration of land uses and transport policies (the scenario "metro+") allows larger transport-energy savings? The least increase both in inter-zonal mobility and particularly in average distance of inter-zone trips can be observed in the "metro+" scenario. These two results reflect both the greater densification and the greater diversification of land usages in the "metro +" scenario than in the two other scenarios. Densification and mixed land usages lead to both fewer and shorter trips because it becomes easier to find a job or a shop near where one lives. Likewise, I observed a decrease of the modal share of private transport modes: 43% for the "BAU" scenario, 36% for the "metro –" scenario and 23% for the "metro +" one. This is again due to the densification and the diversification of land usages, and, for the "metro +" scenario, to the pricing policies discouraging people from using their cars and motocycles. Densification, mixed land usages and pricing policies lead to fewer and shorter trips, and discourage the use of the car for these trips. Finally, I observed the strongest congestion in the "metro-" scenario. This can be explained by the relatively high modal share of private vehicles and the little investment in road infrastructures characterizing this scenario. This stronger congestion in the "metro-" scenario generates a longer average duration of trips than in the "metro+" and even than the "BAU" scenario.

7. This was the parameter chosen to represent the phenomena of urban sprawl or condensation.

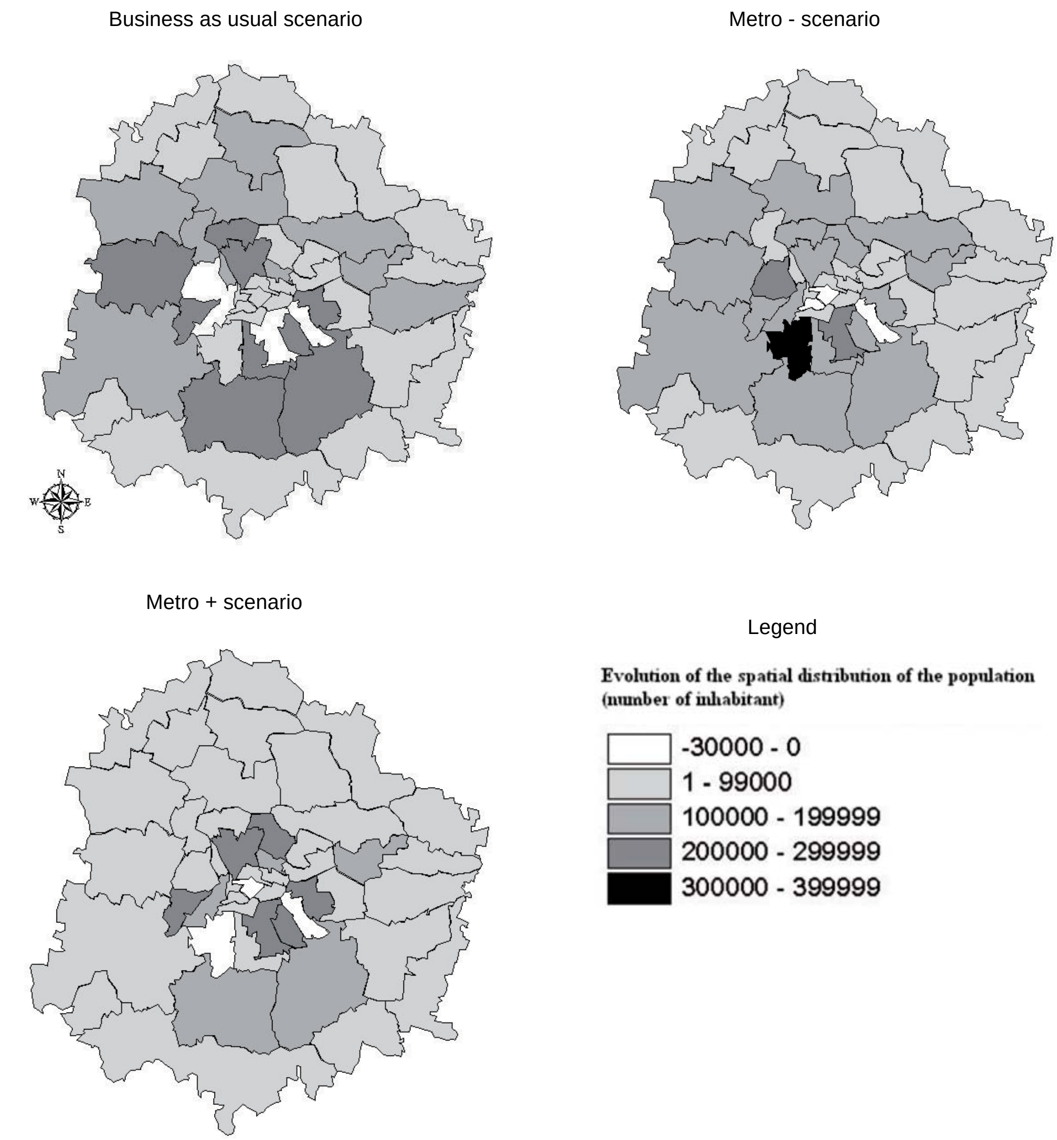

Figure 3. Projected population distribution

Conclusions

Beyond the case of Bangalore, this research shows the significant influence of urban policies on transportation energy consumption drivers. Returning to the ASIF framework presented in the introduction of this article, this analysis shows that actions on total activity (A) and mode share (S) can significantly reduce transportation energy consumption. It shows that the effects of the "metro-" scenario on the total inter-zone trips – a parameter participating in the activity (A) component - are close to the effects generated in the "metro+" scenario: the growth of total inter-zone trips in the "metro-" scenario and the "metro+" scenario are, respectively, 61% and 59%. On the contrary, there are significant differences between these two scenarios in terms of average distance (respectively, 13.08 km and 12.19 km), which is also part of the activity (A) component. There are also significant differences in terms of modal share, the (S) component of ASIF, and in terms of average time. This last parameter influences not only the (F) component (more fuel consumed for the same distance) but also indirectly the (S) component by changing the relative performance of each mode.

Moreover, these results demonstrate the relevance of focusing the urban governance of transportation energy planning on the interactions between transport system and land uses system: the savings obtained from the integration of transport and land use policies are much more important than the savings obtained from a transport investment alone. The transportation technologies affordable to an emerging city like Bangalore can significantly curb the trajectories of energy consumption, as well as the ensuing carbon dioxide emissions, if and only if they are implemented in the framework of appropriate urban planning.

This study also demonstrates that the existing transport technologies and decision-helping tools are already available to take up the challenges of climate change. The study establishes that there are tools which are available to facilitate the policy making processes. These tools allow stakeholders to discuss different political alternatives integrating energy issues, based on quantitative assessments. TRANUS allows one to test different combinations of the three main policies available to urban planners: regulation of urban and peri-urban land uses, investment in transport infrastructure, and pricing policies.

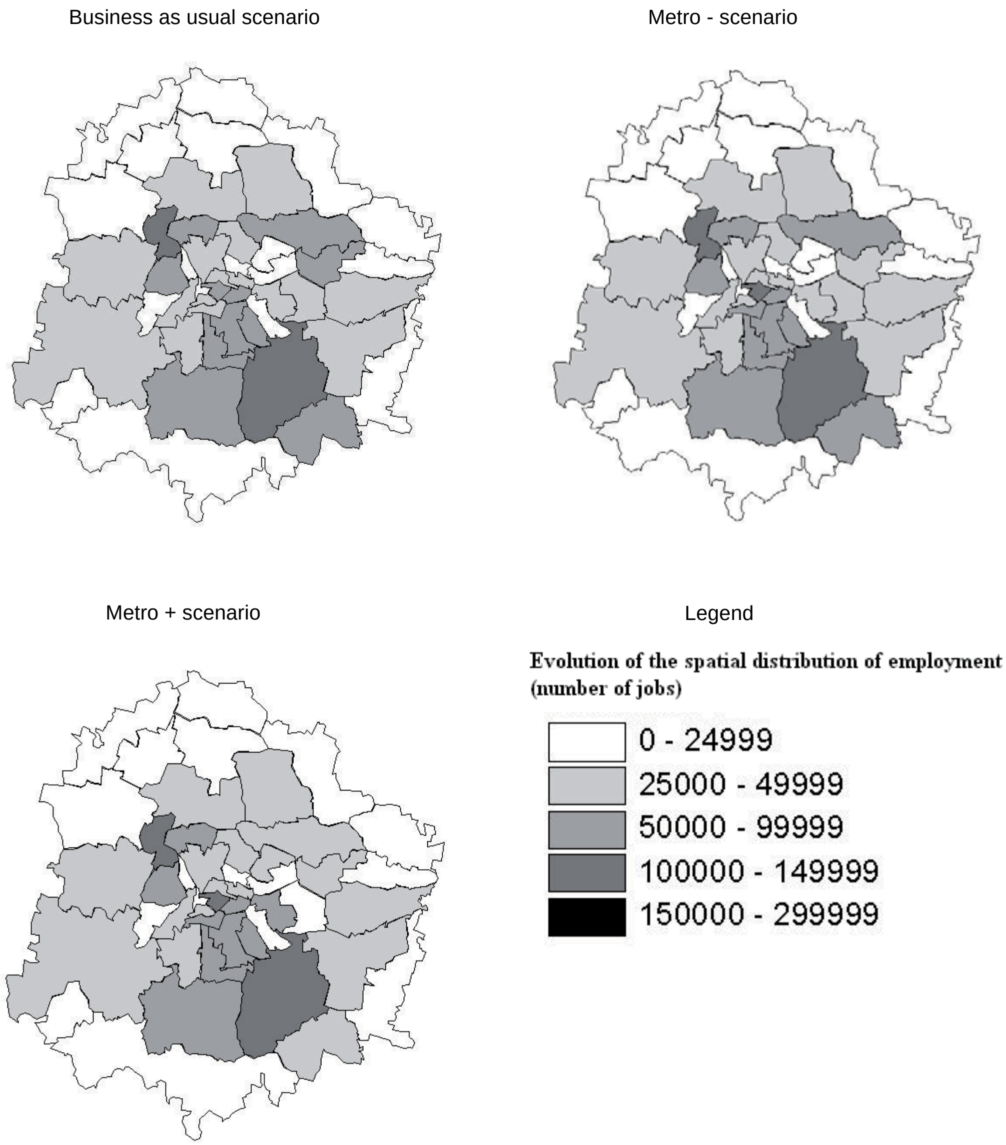

Figure 4. Projected employment distribution

In conclusion, this article shows that the urban developers, private and public, have effective levers of action in their hands. The main task is to first anticipate and secondly frame the market dynamics within an urban planning approach focusing on the "Transport – Land uses" couple. However, the land-uses policies and the transport policies are only means for achieving amore global objective. They need to be framed by a more general vision of "the city that citizens want".

References

Alonso, W.,1964. Location and Land use. Harvard University Press. Cambridge Press.

Peter, C., Fulton, W., 2001. The Regional City: Planning for the End of Sprawl. Washington, DC: Island Press

de la Barra, T., Pérez, B. Vera, N., 1984. TRANUS-J: Putting large models into small computers. Environment and Planning B: Planning and Design. 11.

de la Barra, T., 1989. Integrated land use and transport modelling - Decision chains and hierarchies. Cambridge Urban and Architectural Studies. Cambridge University Press, Geat Britain.

EPA, 2000. Projecting Land-Use Change : a summary of models for assessing the effects of community growth and change on land-use patterns. EPA/600/R-00/098.

Heitzman, J., 2004. Network city: Planning the information society in Bangalore. Oxford University Press, Oxford.

PNUH, 2004. State of the World's Cities Report 2004/5

Rao, A., 2005. Bangalore: whither the future, in India Together.

RITES Ltd., Delhi Metro Rail Corporation Ltd., 2003. Detailed project report. Bangalore Metro (phase-I). For the Government of Karnataka.

SCE-CREOCEAN, 2004 and 2005. Metropolitan Spatial Data Infrastructure for Bangalore.

Solomon, B., 2004. Emerging globalized city forms in the South - some implications for planning. Workshop Energy and transport in Peri-urban Indian communities, Bangalore.

UN Population Division 2000. World urbanization prospects: the 1999 revision

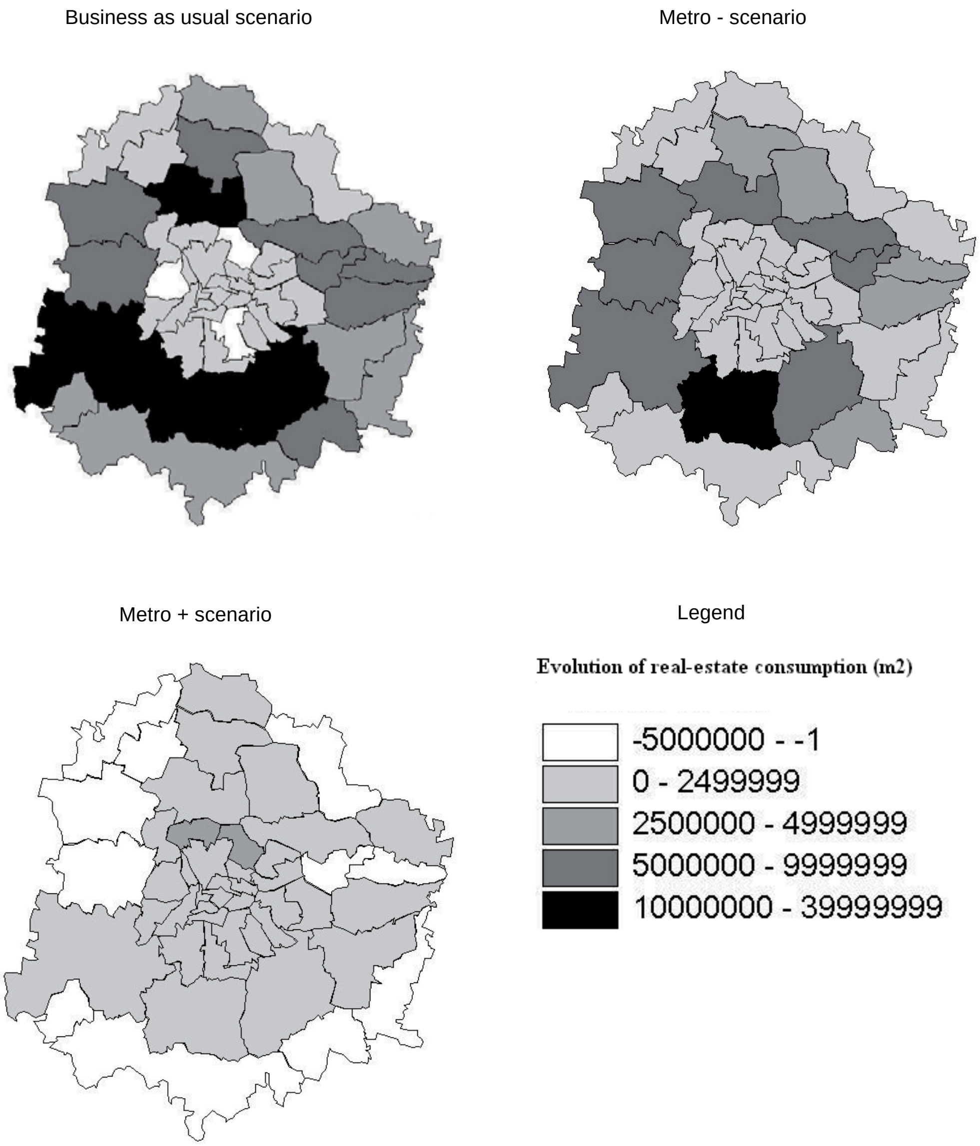

Figure 5. Projected evolution of land consumption

Table 4. Projected land prices

	BAU	METRO-	METRO+
Residential Land			
City center	+89%	+76%	+103%
First belt	+84%	+70%	+99%
Second belt	+3%	0%	+122%
Mixed usages land			
City center	+81%	+81%	+84%
First belt	+38%	+36%	+10%
Second belt	0%	0%	+134%
Industrial Land			
City center	+26%	+81%	+125%
First belt	+62%	+36%	+223%
Second belt	0%	0%	+314%