THE INFLUENCE OF BUILT ENVIRONMENT AND SOCIO-ECONOMIC FACTORS ON COMMUTING ENERGY DEMAND: A PATH ANALYSIS-BASED APPROACH

Soufiane Boukarta [1,3], Ewa Berezowska-Azzag [2,3]

[1] Institute of Architecture and Urban Planning, University of Blida, Algeria
[2] Ecole Polytechnique d'Architecture et d'Urbanisme (EPAU), Algeria
[3] Laboratoire, Ville, Urbanisme et développement durable (VUDD), Algeria

Manuscript received: September 24, 2021
Revised version: October 14, 2022

Boukarta S., Berezowska-Azzag E., 2022. The influence of built environment and socio-economic factors on commuting energy demand. A path analysis-based approach. *Quaestiones Geographicae* 41(4), Bogucki Wydawnictwo Naukowe, Poznań, pp. 19–39. 7 figs, 7 tables.

Abstract: Transport is the second energy consumer sector after housing in Algeria. In this article, we explore the energy implication of commuting by considering a panel of socio-economic (SE) and built environment (BE) driving factors. The method is based on four steps: (i) The first step is to identify the main and potential drivers from the literature review and to propose a model that summarises the main assumptions that could explain the volume of commuting and the resulting energy consumption. (ii) In the second step, we designed and distributed 700 questionnaires in the municipality of Djelfa and retained 184 valid questionnaires in the final study sample. (iii) In the third step, we developed a method adapted to urban areas to quantify energy consumption as a function of the distance travelled, the type and density of occupation by means of transport and the type of fuel. (iv) The fourth step is to check the fit of the hypothetical model with a path analysis-based approach. The model developed identifies 15 factors, of which five have a direct impact and 10 have an indirect impact on the energy consumption of commuting. The model shows that building density and the age of the respondent can reduce the energy consumption of commuting by up to −15% and −12% respectively; whereas the number of cars by housing and the round-trip frequency could increase the energy consumption up to 38% and 27% respectively. Our results suggest a structuring role of the socio-economic characteristics of households in explaining the energy consumption of commuting.

Keywords: Djelfa (Algeria), energy consumption, path analysis, sensitivity analysis, commuting

Corresponding author: Soufiane Boukarta, Institute of Architecture and Urban Planning, University of Blida, route de soumâa, Blida, Algeria 9000; e-mail: sofiansasse@gmail.com

Abbreviations: ALGERAC – the Algerian Accreditation Body (*L'Organisme Algérien d'Accréditation*), APRUE – National Agency for the Promotion and Rationalisation of Energy Use (*Agence Nationale pour la Promotion et la Rationalisation de l'Utilisation de l'Énergie*), CFI – Comparative Fit Index, Da – Algerian dinar, GHG – greenhouse gas, LPG – liquefied petroleum gas, NFI – normal fit index, PNME – National Energy Management Plan (*Plan national de maitrise de l'énergie*), SEM – Structural Equation Modelling, SNAT – National Spatial Planning Scheme (*Schéma national d'Aménagement du territoire*), Toe – tonne of oil equivalent, VKT – vehicle kilometre travelled

https://doi.org/10.14746/quageo-2022-0039
ISSN 2082-2103, eISSN 2081-6383

Introduction

Energy is one of the main concerns in this century because of its scarcity and also due to its greenhouse gas (GHG) emissions. Cities are responsible for more than three-quarters of global pollution (Rogers, Gumuchdjian 2008). As a direct consequence of the increasing use of fossil fuels, climate change and its impact have already been observed since the past century with global warming, the melting of the ice pack and the disappearance of several plant and animal species. And if no action is taken, the impact of climate change will continue to be a disaster for the Earth and for humanity. According to the IPCC (2007), even if measures against climate change are taken into consideration by countries, there will be an increase of 0.1°C for each decade, which means that we expect a minimum temperature increase of around 1° by 2100. Sustainable development is introduced in international law to be the purpose around which all countries across the world have to act to reduce the impact of climate change (Boutaud 2005). The main orientation of sustainable development is to assess the countries' development based on indicators (Idem). This approach helps the decision makers to take necessary actions to reorient the development of their regions so as to be more sustainable. Several summits were organised to gather countries around a set of actions aimed at reducing fossil energy consumption. Algeria, as a signatory of the Kyoto protocol, has launched several actions to reduce its consumption of fossil energy, such as inventories of energy consumption (MEAT, IPCC 2001, MATEC 2010) and the enactment of law 99-09. These set out several actions, among which we found PNME, the national plan of energy mastering, which has as its main goal reducing energy consumption in the four main sectors consuming fossil energy: residential buildings, transport, industry and the agricultural sector (APRUE 2007, 2014, 2015, 2017). For the residential sector, several actions were proposed like constructing 600 housing with high energy performance (HPE) in different climate zones of the country (Boukarta 2019).

In Algeria, the transport sector alone could account for >30% of the final energy consumption, which means that this sector represents a real potential for reducing fossil energy consumption and the resulting GHGs (APRUE 2014). To address this objective, it is necessary to identify the driving factors behind the need for motorised travel. This paper seeks to explain energy consumption resulting from commuting in relation to the built environment (BE) and the socio-economic (SE) characteristics of households. In developing countries, studies aimed at identifying effective factors that could explain the energy consumption caused by commuting are rare; in Algeria, this study is the first. Commuting is the only type considered for this study, as it is characterised by its regularity and large share of total transport volume. According to our literature review, the other modes of travel such as shopping or leisure require different methods for their characterisation (Boukarta 2019). This paper also proposes a comparison of the impact of the driving factors identified between developing countries and the developed ones.

In Algeria, as in many countries around the world, new urban areas are emerging every year with less built density and less functional diversity. It is therefore to be expected that the use of private cars for commuting and energy consumption will increase in the future. An assessment of the energy consumption generated by commuting would help policymakers and planners to design more energy-efficient neighbourhoods. This paper proposes a method to quantify energy consumption in urban areas and investigates the main factors explaining energy consumption due to commuting.

The second section presents a review of the scientific literature with the objective of identifying the research gap and the main factors that have an impact on commuting. In the third section, the developed method is presented and in the following section, an application of the method in the urban area of the city of Djelfa is demonstrated and discussed in the light of other studies.

Literature review and research gap

The literature review aims at identifying the conceptual model, the scale of the study, the type of transport, the data sources and sampling, the method of analysis adopted in several articles and the results of each study.

The literature review is based on original papers indexed in the Scopus and Web of Science databases. A total of 27 articles are reviewed and summarised in Table A1 in Appendix. The literature review allowed us to identify the following findings:

1. In contrast to developing countries where transport studies are rare, Western countries, led by the United States and the Nordic countries are the forerunners in the field of transport studies.
2. The scale of the studies remains variable and can be at the level of a neighbourhood (Cervero, Radlsch 1995), a city (Newman, Kenworthy 1989; Van Acker, Witlox 2010), a region (Holden, Norland 2005), a metropolis (Nguyen 2014; Ding et al. 2017) or a country (national). The most common studies are those that focus on a metropolitan area, to assess the impact of metropolisation on the phenomenon of socio-spatial segregation.
3. Commuting is the most studied type of transport, as it is time-constrained and almost permanently repeated. Similarly, school mobility is not dealt with in our review because studies on school mobility are less widespread and are generally considered in rural and schoolless municipalities (Marique 2013).
4. Depending on the source of the data, the analyses use: (a) data from travel surveys already carried out at regional, metropolitan or national levels (Breheny 1995; Dieleman et al. 2002; Dargay 2004; Brownstone, Golob 2008); (b) data from household consumption surveys (Dargay 2004); (c) usually, data are often compiled on the basis of surveys carried out by public bodies or authors by distributing questionnaires (Boukarta, Berezowska-Azzag 2020) in the most common case, or by sending questionnaires by mail (Holden, Norland 2005) or by e-mail (Handy et al. 2005). Travel distances are often estimated through the use of geographic information systems (GIS) by calculating the distance between origin and destination. For the most accurate and innovative data source, some authors use the mobile phone signal (Calabrese et al. 2012).
5. The sample size used for the studies varies greatly and depends mainly on the scale of a study. The representativeness of the sample in some studies is not always close to the census data, because the survey methodology is often linked to the survey area. In this case, some authors introduce qualitative interviews (Naess 2010). The sample size varies significantly from one study to another, from a hundred respondents (or households) to several thousands.
6. The explanatory factors for commuting presented in the studies reviewed are related to either the SE characteristics of households, the BE, or both. The use of factors varies considerably from study to study. The environmental data was classified by Cervero and Kockelman (1997) into 3D (density, diversity and design). In a more recent meta-analysis, Ewing and Cervero (2010) extended this list to 5D, introducing distance to public transport and destination access.
7. The results of the studies are often presented in the form of models and their explanatory power is expressed in terms of the type of statistical analysis used. The coefficient of determination (R^2) for regression analyses, the pseudo R^2 for logistic regression analyses. Manaugh et al. (2009) and Van Acker and Witlox (2010) have found that it is necessary to consider SE factors and factors related to the BE in the same model because several factors have only an indirect effect and the interaction between the variables explains vehicle kilometre travelled (VKTs) better than a model that considers BE and SE factors separately.

It appears that both BE and SE factors are important for explaining modal share, but some researchers have emphasised the importance of one over the other. In the United Kingdom, Stead (2001) emphasises the importance of SE factors in explaining car modal share over BE factors. In the United States, Ewing and Cervero (2002) found a greater impact of BE factors in explaining car modal share.

As observed in this literature review, few studies attempt to answer the question of how the results from developed to developing countries can be transferred. This paper aims to shed light on this aspect by identifying the impact of household SE parameters and those of the BE in explaining commuting and related energy use. In addition, this paper seeks to test the hypothesis that household SE characteristics play a structuring role in shaping commuting energy consumption in the same way as factors in the BE. A comparison between the impact of SE factors and the BE would help explain the importance of both in explaining energy consumption.

Material and method

City presentation and data collection

We chose the commune of Djelfa as a case study because the SNAT (2030) guidelines (Official Gazette, 2010) aim at the urbanisation of the highlands through the planning of new cities, and the city of Djelfa is a representative city in terms of city size that can serve as a reference for future studies in the same geographical area. Also, the scale of our study area covers the main urban agglomeration area as shown in Figure 1.

In Algeria, surveys relative to transport are not made by government institutions and the unique way to obtain this kind of data is to organise a new survey. We have organised a household survey for the period of March to April 2015. A questionnaire was administrated by a hand-to-hand approach via a network of interviewers trained for this purpose. In all, 700 questionnaires were distributed but only 184 questionnaires from 300 collected were considered as appropriate for this study and 116 were not considered because of the lack of information provided by households relative to their housing or working location. We also sought spatial representativeness so that the households in our sample were randomly distributed over almost the entire urban area of the municipality, and in our sample, as shown in Figure 5, the households are well distributed spatially. The city of Djelfa has nearly 50,000 households. If we consider the urban agglomeration area (our focus area), we will have barely 40,000 households (census data). According to the formula of Leslie et al. (1965), our sample represents

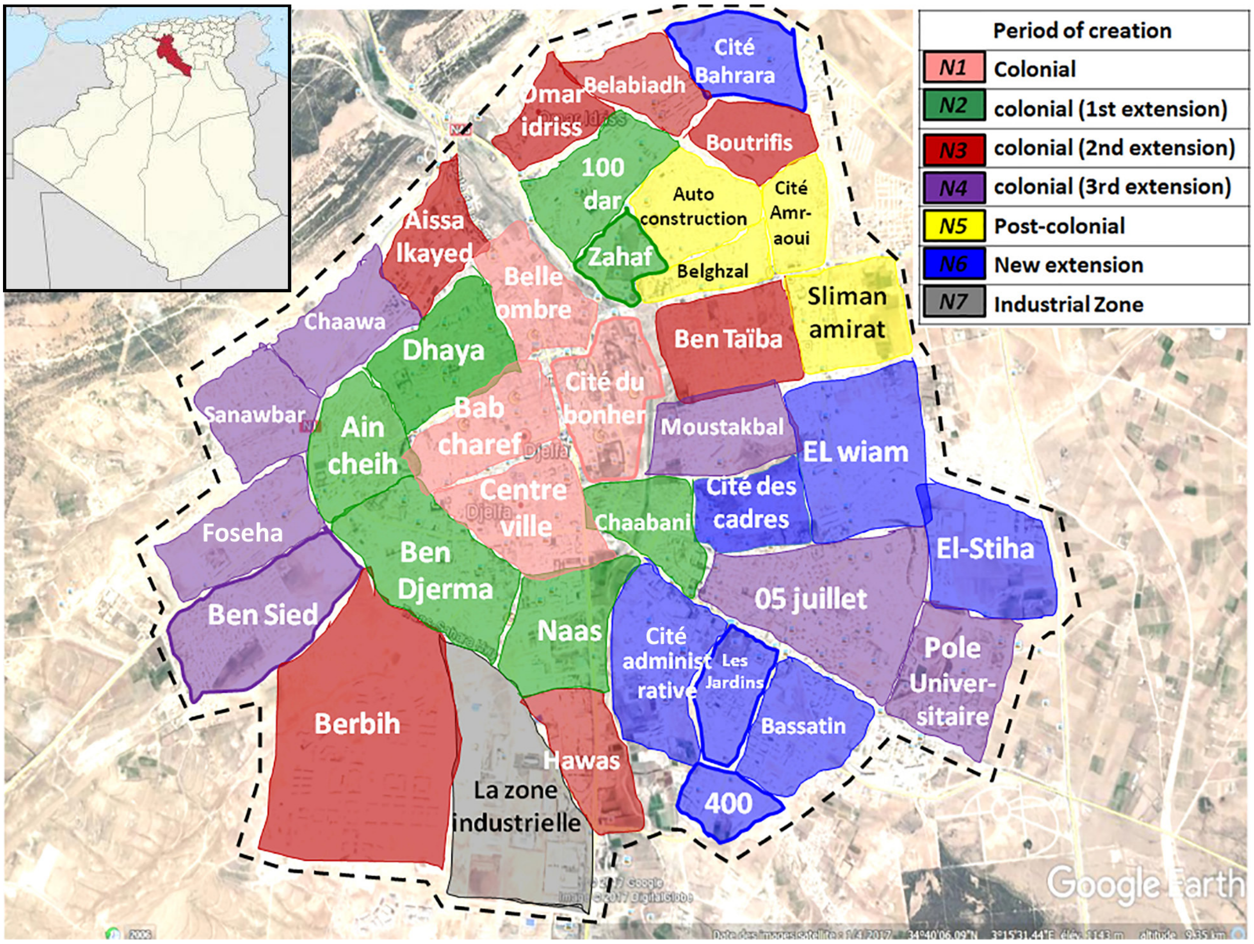

Fig. 1. Study area and the neighbourhoods of the city according to their period of creation.
Source: own composition based on Bouzidi et Boukhari 2013.

the city of Djelfa with a confidence level of 95% and a margin of error of about 7%. Moreover, the comparison of our survey data with the census shows a similar trend, which means that our sample is representative. The data requested by our questionnaire aimed at obtaining the volume of commuting, modal share, SE characteristics of households and characteristics of the BE.

Analysis method

There are several methods that could be used to carry out the importance of each factor, and all of them are statistical methods. Based on their flexibility in terms of the number of variables introduced, the robustness of the results and the scope of the methods (confirmatory, exploratory), we can identify mainly two approaches: (a) an exploratory approach conducted usually with bivariate correlation or principal component analysis, which aims to explore whether a variable does or does not have an impact on the phenomenon studied without giving a value to this impact (Boukarta, Berezowska-Azzag 2018) and (b) a confirmatory approach which is usually carried out based on multivariate analysis. It consists of identifying the impact or importance of a variable while considering the interactions between the different variables. Several papers have used linear regression analysis (Calabrese et al. 2012), logistic regression (Cervero, Radisch 1995; Dargay 2004) and structural equation analysis (SEM) (Brownstone, Golob 2008; Van Acker, Witlox 2010). The most commonly used approach is regression analysis, but this approach does not take into account the indirect effect, which may be important in some cases. Using SEMs, models can give both the direct and indirect effect for each factor. The path analysis model is a specific case of SEM. It considers, unlike SEM, only the observed variables. Path analysis is a graphical approach that makes it possible to test, confirm or refute hypotheses that could explain the observed phenomenon. It is based on two statistical techniques: factor and regression analyses. It gives for each determining factor its direct effect and possibly its indirect effect. The minimum sample size required to carry out a SEM is 10 times the number of variables considered in the model (Kline 1998).

The energy consumption generated by commuting is a relevant indicator because it helps to understand the difference between the centre of the city and its peripheral extension. In fact, energy consumption for commuting depends on kilometres travelled, modal choice, round-trip frequency and fuel type (Muñiz, Galindo 2005; Marique, Reiter 2012). In the next section, we will draw a set of hypotheses based on the literature review.

Research hypotheses and framework

For our study and based on the theoretical core, we have adopted the conceptual framework presented in Figure 2 to explain the energy consumption of commuting in Djelfa. The latter explains the need for commuting through the two following registers: (a) SE characteristics of households (the education level, age, income, profession, car ownership and household size) and the (b) characteristics of the BE presented within the 5D nomenclature of Ewing and Cervero (2010). The first step in drawing the hypothetical path analysis is to carry out the impact of each factor as presented below. The second step is to hypothesise the interaction between the factors based on an exploratory analysis.

Bivariate correlation as an exploratory analysis

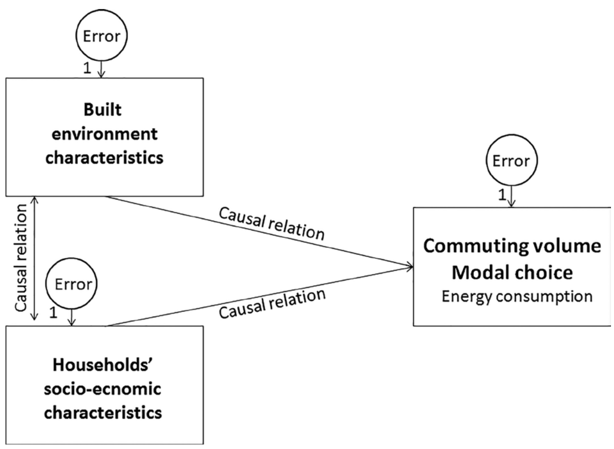

Fig. 2. Conceptual model explaining the need for commuting.

Knowing the expected impact of the factors on VKTs allows us to identify the importance of each factor. To determine whether the variables have a direct or indirect effect, we performed bivariate correlation between the energy consumption of commuting and the variables. As

Table 1. Pearson's bivariate correlation.

	Commuting energy consumption (KWh × person^{-1} × year^{-1})		
	Correlation	Sig	No.
Home-work distance (m)	0.561*	0.000	162
Outward journey time (min)	0.035	0.661	163
Number of bus rotations	0.247*	0.004	136
Built density	−0.135	0.133	125
Plot ratio	−0.120	0.184	125
Housing type (1: collective, 2: individual)	−0.153	0.051	164
Distance from national road (m)	0.256*	0.003	136
Distance to centre (m)	0.280*	0.001	133
Block's area (m^2)	0.224*	0.012	125
Average number of floors	0.143	0.112	125
Mixed use index	−0.049	0.545	156
Distance to public transport (housing zone)	−0.152	0.059	154
Distance to public transport (work zone)	−0.145	0.064	164
Round trip frequency	0.118	0.141	156
Profession (1: public, 2: liberal)	0.169*	0.031	163
Respondent age	−0.265*	0.005	109
Respondent's education level	0.107	0.183	156
Household's education level	0.102	0.541	38
Income	0.136	0.082	163
Household's average age	−0.307	0.064	37
Number of cars owned	0.379*	0.000	163
Occupancy rate per housing	−0.073	0.418	126

*Significant at 0.05 level.
Source: own compilation.

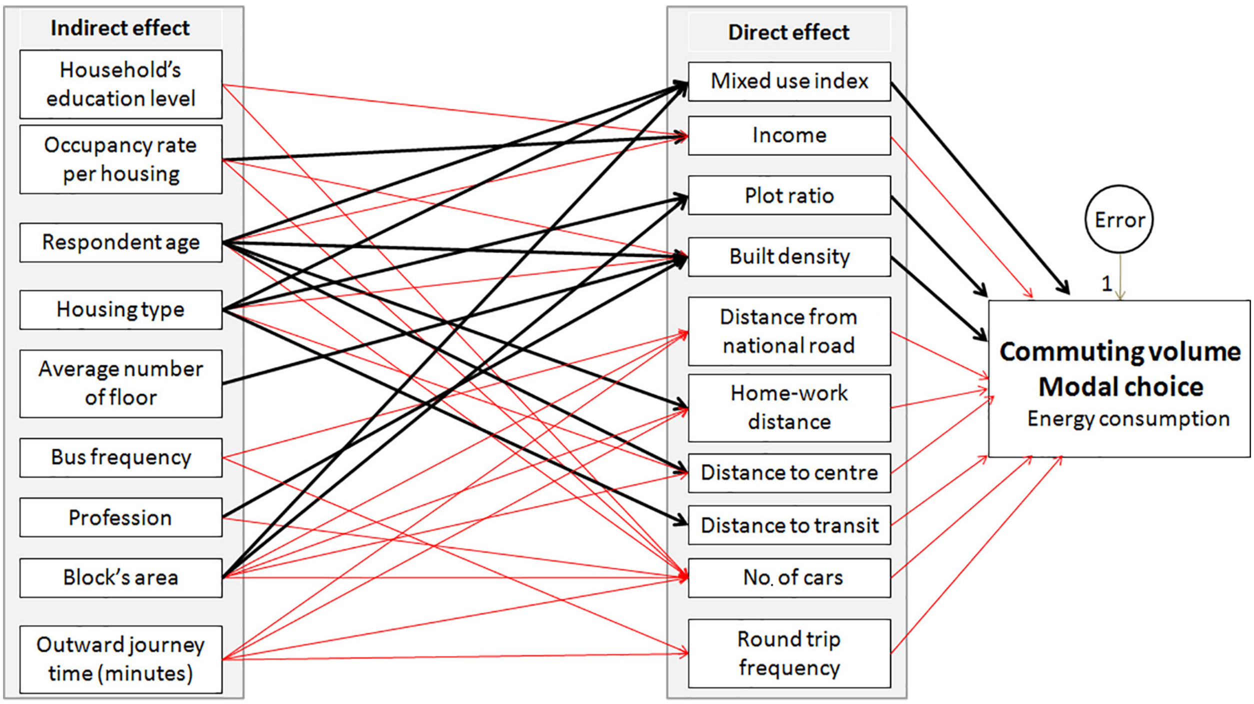

Fig. 3. The hypothesised model.
In red: positive causal relation; in black: negative causal relation
Source: own study.

a first assumption, all factors with a significant correlation with energy consumption are considered to have a direct effect, while the other factors are considered to have an indirect effect (see Table 1).

Based on the theoretical core and bivariate analysis, we identified the nature of the expected impact (direct or indirect effect) and the significance (negative or positive correlation) of each variable. Figure 4 presents the hypothetical paths that we need to check for validity with an approach based on the path analysis presented in the 'Results' section of the article.

Several assumptions were made in the initial model, as shown in Figure 3. Each factor must satisfy a *P*-value greater than 5% to be considered in the model. The theoretical model must be adjusted step by step until the fit indices match the thresholds as shown below (Boukarta, Berezowska-Azzag 2018).

1. The Root Mean Square Error (RMSE) of approximation must be <0.06 and 0.08 (Schreiber et al. 2006; Hooper et al. 2008);
2. The Normal Fit Index (NFI) has to be larger than 0.95 (Hu, Bentler 1999);
3. The Comparative Fit Index (CFI) has to be higher or close to 0.95 (Schreiber et al. 2006; Iacobucci 2010).

If the fit indices of the model satisfied all conditions, it can be considered as a good model for estimating the effect of each driving factor considered in the model. Furthermore, the main purpose of using a path analysis approach is to identify the interaction between factors rather than to predict outcomes for which regression modelling is preferred.

Results and discussion

Data description

Comparison between the data obtained from our questionnaire and the census data indicates that our data are closer to the 2008 census data, which means that our data are representative (Fig. 4). The questionnaire distributed has as its main target the SE characterisation of households in the urban area of Djelfa and also the BE according to the 5Ds (Ewing, Cervero 2010). A descriptive statistic of the data obtained is presented in Table 2.

Figure 5 shows the distribution of jobs and housing according to our survey. It is clear that the city centre and its close surroundings are the main employment areas, while the new extensions are oriented towards housing with a low density of jobs. This distribution also indicates that the main road and the city centre could play a pivotal role between the east and west of the city. We can already suggest an important role for the city centre and the national road in shaping mobility in the city of Djelfa in general and commuting in particular.

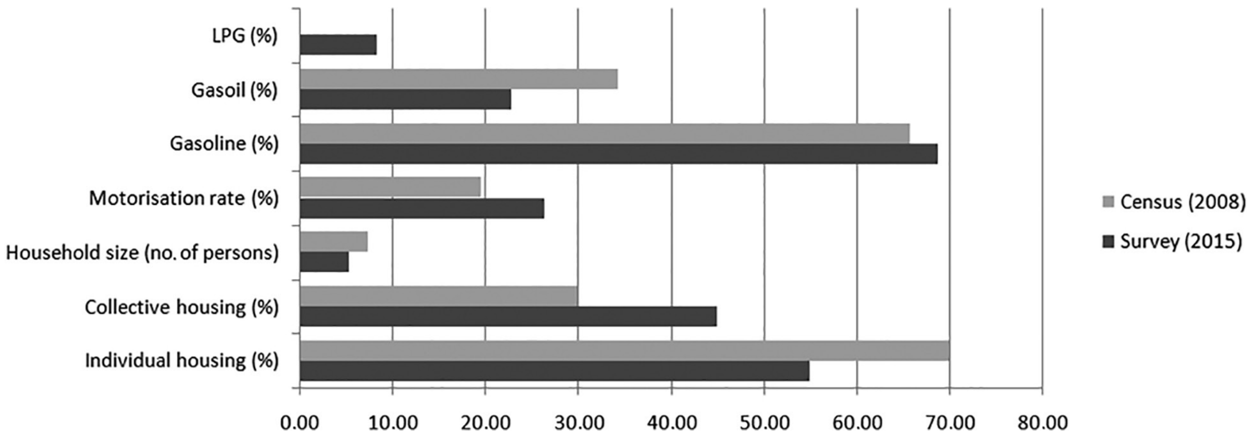

Fig. 4. Comparison between the survey and census data.
LPG – liquefied petroleum gas
Source: own study.

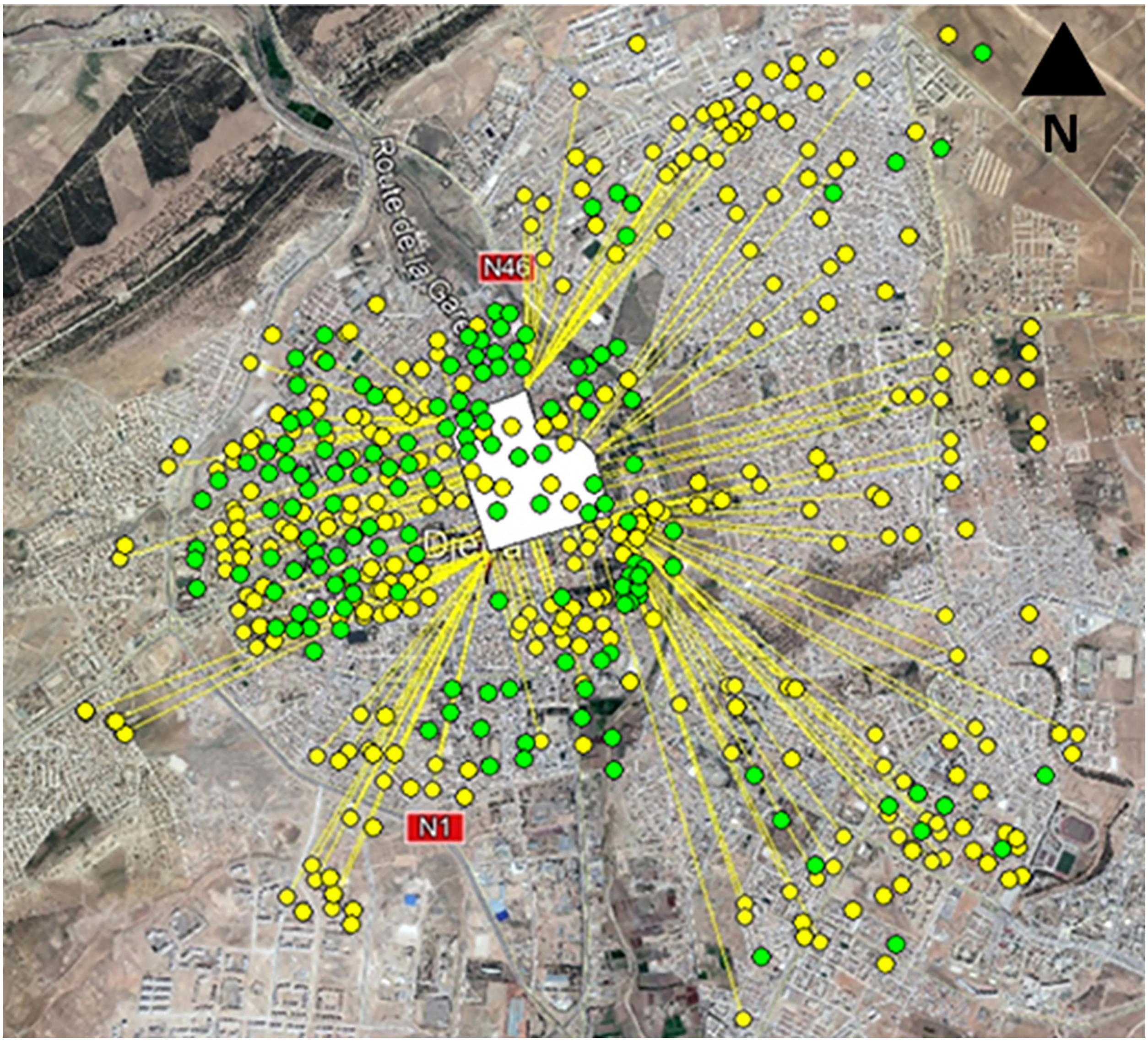

Fig. 5. Employment and housing locations.
green: workplace, yellow: housing, white: centre of the city
Source: authors' compilation based on Google Earth (2015).

Table 2. Descriptive statistics.

Variables	N	Variable type	Minimum	Maximum	Average	SD
Accessibility						
Outward journey time (min)	175	Continuous	2	200	20.59	18.26
Home–work distance (m)	162	Continuous	50	18,000	2,206.91	1,966.96
Number of bus rotations	150	Continuous	0	3	1.20	0.556
Density						
Plot ratio*	139	Continuous	0.17	1.00	0.59	0.32
Built density*	139	Continuous	0.60	3.20	2.02	0.74
Design						
Distance to centre (m)*	148	Continuous	17.59	2,659.18	1,219.54	696.57
Distance from national road (m)*	151	Continuous	25.62	2,569.23	1,163.83	629.94
Average number of floors. (n)*	139	Continuous	2.00	6.00	3.79	1.08
Block's area (m^2)*	139	Continuous	770	36.061	7,398.83	9,150.32
Housing type (1: collective, 2: individual)	184	Nominal	1	2	1.54	0.50

Variables	N	Variable type	Minimum	Maximum	Average	SD
Distance to public transport						
Distance to public transport (housing zone) (0: <300, 4: >1 km)	173	Ordinal	1.00	4.00	2.3237	0.98
Distance to public transport (work zone) (0: <300, 4: >1 km)	172	Ordinal	0.00	4.00	1.6919	0.97
Bus frequency	184	Continuous	0.00	5.00	2.4620	1.56
Diversity						
Mixed use index (from 5 to 40)*	175	Continuous	12	36	24.23	5.38
Households' SE characteristics						
Household's average age*	42	Continuous	16.33	43.80	27.1681	8.44
Respondent age	120	Continuous	27	70	43.95	10.82
Round-trip frequency	172	Continuous	1	4	1.66	0.51
Household's education level	46	Continuous	2.00	5.00	3.5230	0.77
Respondent's education level	174	Ordinal	0	4	3.26	1.06
Number of cars owned	184	Continuous	0	2	0.60	0.57
Profession (1: public, 2: liberal)	181	Nominal	1	3	1.19	0.52
Income (from 15,000 to + 60,000 Da)	181	Ordinal	1	4	2.15	0.95
Occupancy rate per housing.	139	Continuous	2	12	5.34	1.87
Modal share						
Public transport (TC (1: TC, 0: other)	184	Nominal	0.00	1.00	0.31	0.46
Car (1: Voiture, 0: other)	184	Nominal	0.00	1.00	0.26	0.44
Walking (1: MAP, 0: other)	184	Nominal	0.00	1.00	0.42	0.49

SD – standard deviation, SE – socio-economic
Source: Boukarta and Berezowska-Azzag (2020).

Modelling of energy consumption induced by commuting

Conversion of fuel consumption to single unit of consumption (kWh × km^{-1} × person^{-1})

To model the energy consumption generated by home-to-work mobility, we had to convert fuel consumption to kWh per person in order to identify the most important factors and to make a comparison between the impact of the factors of the BE and those of SE characteristics.

Based on Muniz and Galindo (2005) and Marique and Reiter (2012), who developed a method for converting fuel into kWh per person in the suburbs of the Walloon region, we have developed a method to convert fuel into kWh per km per person for urban areas. The developed method considers the fuel consumption and its density. For calculation of the energy consumption of commuting, we have applied formula 1 as below:

$$Ec\left(\frac{kWh}{km.pers}\right) = \left[Fc\left(\frac{L}{km}\right) \times Df\left(\frac{Tf}{L}\right)\right] \times F1\left(\frac{Toe}{Tf}\right) \times F2\left(\frac{kWh}{Toe}\right)\Big] \,/\, Ro(pers) \qquad (1)$$

where: Ec – energy consumption of commuting; Fc – fuel consumption; Df – fuel density; F1 – tonne fuel to tonne oil equivalent conversion factor; F2 – Toe to kWh conversion factor; Ro – rate occupancy per vehicle, Tf – tonne of fuel, Toe – tonne of oil equivalent.

To apply Formula 1, we collected the following data: (i) the average consumption per car per 100 km obtained from the questionnaires; (ii) identification of the main fuel sources in Algeria (liquefied petroleum gas (LPG), diesel and petrol) and their characteristics. As the APRUE only provides conversion in terms of mass of fuel per Toe, we had to look for the density of each fuel. For diesel vehicles, the density is obtained from *L'Organisme Algérien d'Accréditation* (ALGERAC), and the density of petrol and LPG from Abouri and Siagh (2016); (iii) the occupancy rate per vehicle is obtained from our survey and (iv) finally, the conversion factors are all obtained from APRUE (2017). For the average consumption of buses, we tried to get the average consumption of representative buses, but the bus drivers only gave us the cost of the trip for 2 days, which amounts to 1,300–1,900 Da. It is difficult to estimate the number of kilometres travelled on this basis, which led us to turn to the manufacturers

Table 3. Fuel conversion to kWh per km per person.

	Means of commuting			
	Car			Bus
Fuel type	Diesel	Petrol	LPG	Diesel
Consumption (L × km^{-1})	0.063*	0.075*	0.075*	0.2**
Rate of occupation per vehicle	1.27*	1.27*	1.27*	28**
Density (Tonne/m^3)	0.825****	0.735*****	0.55	0.825
Conversion factor 1 (T fuel – >Toe)***	1,015	1,054	1,084	1,015
Conversion factor 2 (Toe – >KWh)	11,630***			
Consumption KWh × km^{-1}	0.61	0.68	0.52	1.95
Consumption KWh per person per Km per one-way trip	0.48	0.53	0.41	0.07
Consumption KWh per person per Km per year (225 day)	108	119.25	92.25	15.75

*Obtained from survey
**Obtained from manufacturer web site (Toyota et ISUZU)
***APRUE (2017)
****The Algerian accreditation body
*****Abouri and Siagh (2016)
LPG – liquefied petroleum gas
Source: own study.

Table 4. Descriptive statistics of the energy consumption generated by commuting to work.

	Minimum	Maximum	Average	SD
Home-to-work distance	50	18,000	2,206.91	1,966.96
Daily consumption (kWh × person^{-1})	0.00	3.60	0.4853	0.788
Annual consumption (kWh × person^{-1} × an)	0.00	810.00	109.1854	177.31

SD – standard deviation.
Source: own study.

(Isuzu and Toyota) to find out the average consumption per 100 km and the occupancy rate per vehicle (Coaster and Isuzu buses).

Once the data were obtained, we calculated the energy consumption of commuting. It appears that the bus has the lowest consumption per person (0.1 kWh per person per one-way trip). LPG consumes on average almost the same volume as petrol, but its low price makes it cheaper than petrol and it is also less polluting. For calculation of the annual consumption, we estimated the annual working days to be about 225 days. Days other than working days are annual holidays (30), public holidays (10 days which are: 1 January, Yennayer, El Mawlid Ennabawi, Ashoura, 1 May, 5 July, Aid el Fitr, Moharrem, Aid el Kbir, 1 November[1]) and weekends (100 days). Public holidays may occur during weekends or annual leave. We estimate working days when public holidays, annual leave and weekends do not coincide (Table 3).

Based on the calculations presented in Table 3, we estimated the energy consumption generated by commuting according to home-to-work distances, modal share, rate occupancy per vehicle and fuel type. The results are presented in Table 4.

Running the path analysis model

Before having the model shown in Figure 6, we tested the model presented in Figure 3 in Section 3, but only one model responds positively to the fit indices as shown in Table 5.

Tables 6 and 7 show the direct effects and significance levels, as well as the direct, indirect and total effects, respectively.

Discussion

The path analysis-based approach allowed us to identify 15 variables explaining the energy consumption generated by commuting in the urban area of the municipality of Djelfa. Ten driving factors have an increasing effect on energy

[1] Yennayer is the Berber New Year's Day; El Mawlid Ennabawi, Ashoura, Aid el Fitr, Moharrem and Aid el Kbir are religious feast; 1 May is the workers' day, 5 July is the Independence Day; 1 November: National Revolution Day.

Table 5. Fit indices of the energy consumption of commuting model.

	df	c^2	Probability level	RMSEA	NFI	CFI
Commuting energy consumption model	53	47.785	0.677	0.000	0.948	1.000

CFI – Comparative Fit Index, NFI – Normal Fit Index, RMSE – Root Mean Square Error
Source: own study.

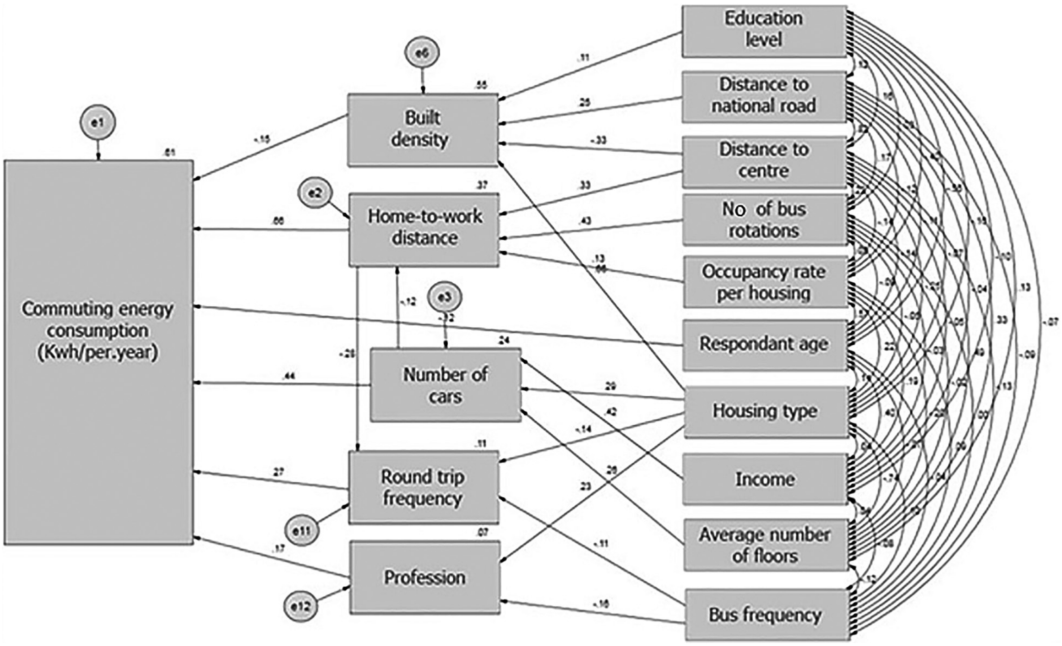

Fig. 6. Direct effects of driving factors explaining the energy consumption generated by commuting. R^2 = 0.61.
Source: own compilation.

Table 6. Direct effects between driving factors.

			Effect	P
Number of cars	< – –	Income	0.425	***
Number of cars	< – –	Number of floors	0.255	0.019**
Number of cars	< – –	Housing type	0.295	0.004**
Home-to-work distance	< – –	Distance to centre	0.330	***
Home-to-work distance	< – –	Number of bus rotation	0.427	***
Home-to-work distance	< – –	Occupancy rate per housing	0.130	0.070*
Home-to-work distance	< – –	Number of cars	−0.117	0.071*
Built density	< – –	Distance to national road	0.252	0.014**
Profession	< – –	Bus frequency	−0.155	0.032**
Built density	< – –	Distance to centre	−0.331	0.002**
Built density	< – –	Education level	0.111	0.061*
Profession	< – –	Housing type	0.227	0.002**
Round trip frequency	< – –	Housing type	−0.139	0.057*
Built density	< – –	Housing type	0.664	***
Round trip frequency	< – –	Bus frequency	−0.105	0.149
Round trip frequency	< – –	Home-to-work distance	−0.285	***
Energy consumption (kWh × person^{-1} × year^{-1})	< – –	Home-to-work distance	0.661	***
Energy consumption (kWh × person^{-1} × year^{-1})	< – –	Profession	0.165	***
Energy consumption (kWh × person^{-1} × year^{-1})	< – –	Round trip frequency	0.271	***
Energy consumption (kWh × person^{-1} × year^{-1})	< – –	Number of cars	0.448	***
Energy consumption (kWh × person^{-1} × year^{-1})	< – –	Built density	−0.145	0.007**
Energy consumption (kWh × person^{-1} × year^{-1})	< – –	Respondent age	−0.119	0.032**

***Significant at 0.001 level
**Significant at 0.05 level
*Significant at 0.1 level
Source: own study.

Table 7. Direct and indirect effects of the driving factors of energy consumption generated by commuting.

	Effect	Number of cars	Home-to-work distance	Round trip frequency	Profes-sion	Built density	Energy consumption (kWh person^{-1} × year^{-1})
Number of floors	Direct	0.255	0.000	0.000	0.000	0.000	0.000
	Indirect	0.000	−0.030	0.009	0.000	0.000	0.097
	Total	0.255	**−0.030**	0.009	0.000	0.000	0.097
Housing type	Direct	0.295	0.000	−0.139	0.227	0.664	0.000
	Indirect	0.000	−0.035	0.010	0.000	0.000	0.016
	Total	**0.295**	**−0.035**	**−0.129**	**0.227**	**0.664**	**0.016**
Income	Direct	0.425	0.000	0.000	0.000	0.000	0.000
	Indirect	0.000	−0.050	0.014	0.000	0.000	0.161
	Total	0.425	**−0.050**	0.014	0.000	0.000	0.161
Occupancy rate per housing	Direct	0.000	0.130	0.000	0.000	0.000	0.000
	Indirect	0.000	0.000	−0.037	0.000	0.000	0.076
	Total	0.000	0.130	**−0.037**	0.000	0.000	0.076
Bus rotation	Direct	0.000	0.427	0.000	0.000	0.000	0.000
	Indirect	0.000	0.000	−0.122	0.000	0.000	0.249
	Total	0.000	0.427	**−0.122**	0.000	0.000	0.249
Distance to centre	Direct	0.000	0.330	0.000	0.000	−0.331	0.000
	Indirect	0.000	0.000	−0.094	0.000	0.000	0.241
	Total	0.000	0.330	**−0.094**	0.000	**−0.331**	0.241
Number of cars	Direct	0.000	−0.117	0.000	0.000	0.000	0.448
	Indirect	0.000	0.000	0.033	0.000	0.000	−0.068
	Total	0.000	**−0.117**	0.033	0.000	0.000	0.379
Education level	Direct	0.000	0.000	0.000	0.000	0.111	0.000
	Indirect	0.000	0.000	0.000	0.000	0.000	−0.016
	Total	0.000	0.000	0.000	0.000	0.111	**−0.016**
Bus frequency	Direct	0.000	0.000	−0.105	−0.155	0.000	0.000
	Indirect	0.000	0.000	0.000	0.000	0.000	−0.054
	Total	0.000	0.000	**−0.105**	**−0.155**	0.000	**−0.054**
Distance to national road	Direct	0.000	0.000	0.000	0.000	0.252	0.000
	Indirect	0.000	0.000	0.000	0.000	0.000	−0.037
	Total	0.000	0.000	0.000	0.000	0.252	**−0.037**
Home-to-work distance	Direct	0.000	0.000	−0.285	0.000	0.000	0.661
	Indirect	0.000	0.000	0.000	0.000	0.000	−0.077
	Total	0.000	0.000	**−0.285**	0.000	0.000	0.584
Respondent age	Direct	0.000	0.000	0.000	0.000	0.000	−0.119
	Indirect	0.000	0.000	0.000	0.000	0.000	0.000
	Total	0.000	0.000	0.000	0.000	0.000	**−0.119**
Round−trip frequency	Direct	0.000	0.000	0.000	0.000	0.000	0.271
	Indirect	0.000	0.000	0.000	0.000	0.000	0.000
	Total	0.000	0.000	0.000	0.000	0.000	0.271
Profession	Direct	0.000	0.000	0.000	0.000	0.000	0.165
	Indirect	0.000	0.000	0.000	0.000	0.000	0.000
	Total	0.000	0.000	0.000	0.000	0.000	0.165
Built density	Direct	0.000	0.000	0.000	0.000	0.000	−0.145
	Indirect	0.000	0.000	0.000	0.000	0.000	0.000
	Total	0.000	0.000	0.000	0.000	0.000	**−0.145**

consumption and five variables tend to reduce it (Fig. 7).

We found in the first position the factors increasing the commuting energy consumption. The home-to-work distance has a direct effect of 0.66 and an indirect effect mediated through the round-trip frequency −0.076 (−0.28 × 0.27). The total effect is 0.584 per standard deviation (SD), that is, for each additional kilometre, energy consumption increases at 52.64 kWh annually.

Fig. 7. Effect of SE and BE driving factors per unit of measurement on energy consumption of commuting to work.
BE – built environment, SE – socio-economic
Source: own compilation.

Almost the same results have been obtained by other authors. In Belgium, Van Acker and Witlox (2010) have found that distances travelled by car increase by 2.6% for every 15 minutes more in the time spent travelling to work. In the same country, Marique (2013) has found that job diversity within a 10-km radius is associated with a −0.421 decrease in energy consumption per person per trip (kWh per person). Calabrese et al. (2012) have observed in Massachusetts that car travel distances to work decreased by −0.3917 for every additional 10 km of distance to work.

The number of cars comes second, with a direct effect of 0.45 and an indirect effect via home-to-work distance of −0.079 (−0.12 × 0.66). The total effect is 0.379 per SD (177.31 kWh), that is, for each additional car per household, energy consumption increases by 116.87 kWh × person^{-1} × year^{-1}. A similar effect was identified by Cervero and Radisch (1995), Kitamura et al. (1997) and Pan et al. (2009), who have found that the number of cars per adult reduces the modal share of non-motorised travel by −0.7798, −0.387 and −3.652 times, respectively.

The third most important effect is the round-trip frequency, with a direct effect of 0.27 per SD, that is, for each additional round-trip frequency, energy consumption increases by 93.87 kWh × person^{-1} × year^{-1}. The model also shows that the frequency of trips is a mediator of the effect of the type of housing (individual or collective) and the frequency of buses. This means that the frequency of trips increases in single-family dwellings where the bus frequency is lower. The number of bus rotations has an indirect effect mediated by commuting distance of 0.284 (0.43 × 0.66) and commuting frequency of −0.0325 (0.43 × −0.28 × 0.27). The total effect is 0.249, that is, for each bus rotation, energy consumption increases by 79.40 kWh × person^{-1} × year^{-1}. Indeed, increasing the number of bus stops would increase the travel time. Pan et al. (2009) have found that the choice of car as a travel mode increases by 1.03 times for each additional minute and Chen et al. (2007) have observed that the number of bus stops per trip increases car use for travel by 7.1%.

Distance to the centre comes fifth with an indirect effect mediated by built-up density 0.05 (−0.33 × −0.15), by home-to-work distance 0.218 (0.33 × 0.66) and by round-trip frequency −0.025 (0.33 × −0.28 × 0.27). The total effect is 0.241 per SD, that is, for each additional kilometre of distance to the centre, energy consumption will increase by 61.35 kWh × person^{-1} × year^{-1}. Distance to the centre is positively correlated with distance travelled by the private car. Holden and Norland

(2005) have obtained almost the same result in Oslo. For each additional kilometre of distance to the centre, the energy consumption generated by motorised travel increases by 108 kWh × person^{-1} × year^{-1}. Similarly, Naess (2010) has shown a positive association between distance to the centre and energy consumption generated by car travel.

Profession comes sixth with a direct effect of 0.165 per SD. In other words, liberals tend to consume 55.726 kWh × person^{-1} × year^{-1} more than public-sector employees. Occupation could be considered as a proxy for income; in Algeria liberal employees have a higher income than public-sector employees. Income is the most common determinant in mobility studies. Several studies have found a positive correlation between income and VKT; a higher income leads to more motorised mobility. In our study, the income effect acts indirectly through the number of cars by 0.193 (0.43 × 0.45) and through the home to work distance by −0.034 (0.43 × −0.12 × 0.66). The total effect is 0.161 per SD, that is, for every additional 15,000 Da (≈103€), energy consumption increases by 30 kWh × person^{-1} × year^{-1}. Van Acker and Witlox (2010) have found that income is positively associated with car travel in Belgium. Households with an income above €3,100 travel 13% more by car than households with a lower income. Khan et al. (2014) have observed that income could explain up to 6.21% of car trips in Seattle, while Dieleman et al. (2002) have found a smaller impact in the Netherlands (2.9%).

Holden and Norland (2005) in Oslo, Norway, have noted an increase in energy consumption due to motorised mobility of 2 kWh/persons for every 1,000 Norwegian Kroner or 100€ × person^{-1}. And Næss (2010) found that income is positively correlated with VKTs and explains an additional 1.41 km (Beta = 0.07) for every 1,000 Yuan (127€). While for the same income, and for trips to the centre, Naess (2014) has observed a weak positive correlation between VKTs and income in Copenhagen, 0.0045 km more for every additional 1,000 Danish kroner (134€). The author explains this weak correlation by the location of housing. Households with higher incomes tend to live in the centre, while households with lower incomes tend to live on the outskirts near public transport.

In the eighth place comes the number of floors per urban block with an indirect effect through the number of cars per household of 0.117 (0.26 × 0.45) and through the home-to-work distance of −0.0206 (0.26 × −0.12 × 0.66). The total effect is 0.097, that is, for each additional storey per urban block, energy consumption increases by 16 kWh × person^{-1} × year^{-1}. The number of floors per urban block is a proxy for the distance-to-centre factor. Indeed, the highest buildings are located in the periphery of the municipality of Djelfa.

In the ninth place is the occupancy rate per dwelling, which has an indirect effect mediated by home-to-work distance of 0.0858 (0.13 × −0.66) and by round-trip frequency of −0.0098 (0.13 × −0.28 × 0.27). The total effect is 0.076, that is, for each additional household member, energy consumption for mobility increases by 7.187 kWh × person^{-1} × year^{-1}. The occupancy rate per dwelling or the size of a household in most studies is negatively correlated with motorised mobility. Ding et al. (2017) have found that household size reduces car travel by up to −0.56 in Baltimore and Cervero and Radisch (1995) have shown positive associations between household size and increasing use of public transport modes, cycling and walking rather than driving in the United States.

Similarly, Ma et al. (2014) in China have observed that household size has a negative impact on chain travel. While in Seattle, Khan et al. (2014) have found that household size has a positive impact (by 25%) on distances travelled by car. The researchers explain this positive correlation by the presence of young children dependent on their parents' mobility. Other researchers have found that household size has no impact on the volume of car travel (Chen et al. 2007; Manaugh et al. 2009). Chen et al. (2007) have observed that the effect of household size is more pronounced for households with children under the age of six.

In the last position and with the smallest effect on energy consumption generated by commuting is the type of housing which has an indirect effect mediated: by built density of −0.099 (0.66 × −0.15), by number of cars of 0.135 (0.3 × 0.45), by home-to-work distance of −0.024 (0.3 × −0.12 × 0.66), by round-trip frequency of −0.0378 (−0.14 × 0.27) and finally by profession of 0.391 (0.23 × 0.17). The total effect amounts to 0.016 per SD only, that is, an occupant residing in an individual housing tends to consume 5.67 kWh × person^{-1} × year^{-1} more than a person living in a collective housing. The type of housing can also be considered as a proxy of the income, as living in a single-family house is often possible for households with a higher income.

In the cluster of driving factors with a reducing impact on energy consumption, we find built density at the top of the ranking with a direct effect of −0.15 per SD, that is, for each additional +1 value of built density, energy consumption decreases by −35.46 kWh × person^{-1} × year^{-1}. The same conclusions have been found by Brownstone and Golob (2008) in California. A reduction in built density for the same household composition could increase vehicle miles travelled by up to 1,171 miles. Researchers explain these results by the fact that car ownership is less frequent at higher built density. Van Acker and Witlox (2010) have also found that the car modal share tends to decrease in areas with high built density. They also found that car ownership is also negatively correlated with car modal share. In contrast, in Norway, Holden and Norland (2005) have found that built density is not significantly correlated with VKTs.

The age of the respondent comes second, with a direct effect of −0.12 per SD, that is, for every 10 years increase in the age of the respondent, the energy consumption for commuting decreases by −19.66 kWh × person^{-1} × year^{-1}. Our results are in line with several studies. In much of the scientific literature, age is considered to be a factor that reduces the energy generated by car travel (Handy et al. 2005; Pan et al. 2009; Van Acker, Witlox 2010). Similarly, in Montreal, age was found to be positively correlated with proximity to work (Manaugh et al. 2009). While in Hangzhou, age only explains −0.013 km × day^{-1} of VKT (Naess 2014) and +0.088 km × day^{-1} in Copenhagen (Idem). The author explains this opposition of the age effect by the lifestyle effect. Educated young people in Copenhagen tend to live in the centre, while the opposite is true in Hangzhou. In New York, Chen et al. (2007) have also found a positive correlation with VKTs (0.01). The authors explain this correlation by the fact that older people tend to use cars more than younger people, as car ownership is higher among older people. Holden and Norland (2005) have found that age in Oslo has no statistically significant effect on VKTs.

Bus frequency in the residential environment comes third, reducing energy consumption by an effect of −0.054, mediated by round-trip frequency −0.027 (−0.10 × 0.27) and by profession −0.027 (−0.16 × 0.17). In other words, for each additional bus frequency in the residential area, energy consumption for mobility decreases by −6.13 kWh × person^{-1} × year^{-1}. The distance to the national road comes second to last with a small effect of −0.037 mediated by built density. For each additional kilometre of distance from the station road, energy consumption decreases by −9.41 kWh × person^{-1} × year^{-1}.

Indeed, the national road runs along the city from north to south and divides it into two parts: east and west. A large volume of transport passes along the national road, which is characterised by the large width of its carriageway and the presence of several bus stops, which gives it a structuring role in the city of Djelfa. The distance to the national road in the city of Djelfa is a proxy for the distance to public transport. Indeed, the greater the distance to public transport, the greater the use of the car for travel. Van Acker and Witlox (2010) and Calabrese et al. (2012), Khan et al. (2014) and Ding et al. (2017) state that doubling the distance to public transport increases the distance travelled by car by 3.4%, 3.04%, 13.2% and 4.7%, respectively. Ding et al. (2017) have also found that public transport use drops by −11.4% if the distance to public transport is doubled.

Education level comes last, with a small effect of −0.016 per SD, mediated by built density. In other words, for each additional level of education, energy consumption decreases by −2.67 kWh × person^{-1} × year^{-1}. The impact of education level on VKTs is variable in the scientific literature, ranging from a positive, negative and non-significant correlation. Feng et al. (2013) in China and the Netherlands, Marique (2013) in Belgium have found that each additional SD of the level of education generates 23.4%, 18.1% and 16.8% more distance travelled by car respectively. Calabrese et al. (2012) have found a negative correlation between the education level and car travel distances (Beta = -0.0817). In the Netherlands, Dieleman et al. (2002) have observed that people with a higher level of education tend to prefer car travel to public transport by 4.3% and that the level of education explains only 0.2% of the distances travelled by car. Other research has shown that education level has no statistically significant effect on the energy generated by car travel in Oslo (Holden, Norland 2005) and China (Naess 2010). In general, the impact of education level has a small or insignificant impact in explaining VKTs.

To draw a general conclusion, we have observed that SE factors explain 281 kWh × person^{-1} × year^{-1}, while BE factors explain 164 kWh × person^{-1} × year^{-1}. The BE has an impact that appears to be lower than SE factors in explaining commuting energy. This finding is similar to that of Stead (2001), who has found that variation in travel patterns is often due more to SE reasons than to characteristics of the BE.

Conclusion

The environmental impact caused by fossil fuel consumption and the resulting GHGs is increasingly being taken into account by developed countries, and recently by developing ones. The comparison of our findings with those obtained by the authors who considered other cities in developed countries showed almost similar effects. This would lead us to the conclusion that the current knowledge developed through studies in developed countries is potentially transferable to developing ones, subject to seeing what further research in developing countries would yield. The impact of driving factors on the energy consumption of commuting allows us to draw some interesting conclusions. Increased built density, proximity to workplaces, more bus stops and functional diversity in new urban extensions would reduce commuting energy consumption. Similarly, car use for home-to-work trips, round-trip frequency and car ownership would decrease with a reduction in home-to-work distance. Our results suggest a structuring role for the SE characteristics of households in explaining the energy consumption of commuting. The SE characteristics of households are directly related to the quality of the BE, and there appear to be disparities in the distribution of working area density. The new urban areas are less dense and almost totally residential. This implies a greater distance to reach the working areas which are concentrated in the centre. Urban development policy should take into account functional diversity when designing new urban extensions to reduce the modal share of the car, GHG emissions and energy consumption.

Other mobility modes such as shopping, leisure and home-to-school mobility could be considered for future research. Our results could be used in a parameterised tool that could help policymakers and urban planners to design less energy consuming neighbourhoods and could also raise awareness among commuters to be more environmentally friendly.

References

Abouri R., Siagh H., 2016. *Production de l'essence sans plomb par amélioration du procédé de reforming catalytique*. Master Thesis, Kasdi Merbah University, Algeria.

Algerian accreditation body, 2016, Certificate of Accreditation N 1-2-016, Technical Annex, Algerac, Algeria.

APRUE, 2007. The National Agency for the Promotion and Rationalisation of Energy Use, Final consumption, key figures for 2005.

APRUE, 2014. The National Agency for the Promotion and Rationalisation of Energy Use, Final consumption, key figure for the year 2012.

APRUE, 2015. The National Agency for the Promotion and Rationalisation of Energy Use, The National Energy Situation, 2013 figures, 2015 edition.

APRUE, 2017. The National Agency for the Promotion and Rationalisation of Energy Use, The National Energy Situation, 2015 figures, 2017 edition.

Bakour M., 2016. *La mobilité urbaine et la planification des réseaux de transport dans une logique de renouvellement urbain, le cas d'Alger*. PHD thesis, EPAU, Algeria.

Boukarta S., 2019. *Déterminants de la forme urbaine générant le potentiel de maîtrise de l'énergie en zone semi-aride. Application sur le cas de Djelfa en Algérie*. PhD Dissertation, Ecole polytechnique d'architecture et d'urbanisme d'Alger, Algeria.

Boukarta S., Berezowska-Azzag E., 2018. Assessing household gas and electricity consumption, case study of Djelfa, Algeria. *Quaestiones Geographicae* 37(4): 111–129. DOI 10.2478/quageo-2018-0034.

Boukarta S., Berezowska-Azzag E., 2020. Exploring the role of socio-economic and built environment driving factors in shaping the commuting modal share: A path-analysis-based approach. *Quaestiones Geographicae* 39(4): 87–107.

Boutaud Aurélien, *Penser le changement ou changer le pansement*. Dissertation thesis, 2005, Rochelle University, France.

Breheny M., 1995. The compact city and transport energy consumption. *Transactions of the Institute of British Geographers*: 20(1): 81–101.

Brownstone D., Golob T.F., 2008. The impact of residential density on vehicle usage and energy consumption. *Journal of Urban Economics* 65(1): 91–98.

Calabrese F., Diao M., Di Lorenzo G., Ferreira J. Jr., Ratti C., 2012. Understanding individual mobility patterns from urban sensing data: A mobile phone trace example. *Transportation Research Part C: Emerging Technologies* 26: 301–313.

Cervero R., Kockelman K., 1997. Travel demand and the 3Ds: Density, diversity, and design. *Transportation Research Part D: Transport and Environment* 2: 199–219.

Cervero R., Murakami J., 2010. Effects of built environments on vehicle miles traveled: Evidence from 370 US urbanized areas. *Environment and Planning A* 42(2): 400–418.

Cervero R., Radisch C., 1995. Travel choices in pedestrian versus automobile oriented neighborhoods. *Transport Policy* 3(3): 127–141.

Chen C., Gong H., Paaswell R., 2007. Role of the built environment on mode choice decisions: Additional evidence on the impact of density. *Transportation* 35(3): 285–299.

Dargay J., 2004. The effect of prices and income on car travel in the UK. *Transportation Research Part A: Policy and Practice* 41(10): 949–960.

Dieleman F.M., Dijst M., Burghouwt G., 2002. Urban form and travel behaviour: Micro-level household attributes and residential context. *Urban Studies* 39(3): 507–527.

Ding C., Wang D., Liu C., Zhang Y., Yang J., 2017. Exploring the influence of built environment on travel mode choice considering the mediating effects of car ownership and travel distance. *Transportation Research Part A: Policy and Practice* 100: 65–80.

Ewing R., Cervero R., 2002. Travel and the built environment: A synthesis. *Transportation Research Record: Journal of the Transportation Research Board* 1780: 87–114.

Ewing R., Cervero R., 2010. Travel and the built environment: A meta-analysis. *Journal of the American Planning Association* 76(3): 265–294.

Feng J., Dijst M., Prillwitz J., Wissink B., 2013. Travel time and distance in international perspective: A comparison between Nanjing (China) and the Randstad (The Netherlands). *Urban Studies* 50(14): 2993–3010.

Handy S., Cao X., Mokhtarian P., 2005. Correlation or causality between the built environment and travel behavior? Evidence from Northern California. *Transportation Research Part D: Transport and Environment* 10(6): 427–444.

Holden E., Norland I.T., 2005. Three challenges for the compact city as a sustainable urban form: Household consumption of energy and transport in eight residential areas in the greater Oslo region. *Urban Studies* 42(12): 2145–2166.

Hooper D., Coughlan J., Mullen M.R., 2008. Structural equation modelling: Guidelines for determining model fit. *Electronic Journal of Business research methods* 6(1): 53–60.

Hu L.T., Bentler P.M., 1999. Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal* 6(1): 1–55.

Iacobucci D., 2010. Structural equations modeling: Fit indices, sample size, and advanced topics. *Journal of Consumer Psychology* 20(1): 90–98.

Official Gazette (61), 2010. Law No. 10-02 approving the National Spatial Planning Scheme (SNAT 2030).

Karathodorou N., Graham D.J., Noland R.B., 2010. Estimating the effect of urban density on fuel demand. *Energy Economics* 32(1): 86–92.

Khan M., Kockelman K.M., Xiong X., 2014. Models for anticipating non-motorized travel choices, and the role of the built environment. *Transport Policy* 35: 117–126.

Kitamura R., Mokhtarian P.L., Laidet L., 1997. A micro-analysis of land use and travel in five neighborhoods in the San Francisco Bay Area. *Transportation* 24(2): 125–158.

Kline R., 1998. *Principles and practice of structural equation modeling*. The Guilford Press, New York, NY.

Leslie K., Bolstein R., Crow M., 1965. Statistical formulas and citations for sample size and result analyzer. *American Statistical* 52(2): 41.

Limtanakool N., Dijst M., Schwanen T., 2006. The influence of socioeconomic characteristics, land use and travel time considerations on mode choice for medium-and longer-distance trips. *Journal of Transport Geography* 14(5): 327–341.

Ma J., Mitchell G., Heppenstall A., 2014. Daily travel behaviour in Beijing, China: An analysis of workers' trip chains, and the role of socio-demographics and urban form. *Habitat International* 43: 263–273.

Manaugh K., Miranda-Moreno L.F., El-Geneidy A.M., 2009. The effect of neighbourhood characteristics, accessibility, home–work location, and demographics on commuting distances. *Transportation* 37(4): 627–646.

Manaugh K., Kreider T., 2013. What is mixed use? Presenting an interaction method for measuring land use mix. *Journal of Transport and Land Use* 6(1): 63–72.

Marique A.F., 2013. *Méthodologie d'évaluation énergétique des quartiers périurbains. Perspectives pour le renouvellement périurbain wallon* (Doctoral dissertation, Liège university, Belgique)

Marique A.F., Reiter S., 2012. A method for evaluating transport energy consumption in suburban areas. *Environmental Impact Assessment Review* 33(1): 1–6.

Matec, 2010. National Inventory of Greenhouse Gas Emissions for the year 2000.

MEAT, 2001. Development of the National Climate Change Strategy and Action Plan.

Muñiz I., Galindo A., 2005. Urban form and the ecological footprint of commuting. The case of Barcelona. *Ecological Economics* 55(4): 499–514.

Næss P., 2010. Residential location, travel, and energy use in the Hangzhou metropolitan area. *Journal of Transport and Land Use* 3(3): 27–59.

Naess P., 2014. Tempest in a teapot: The exaggerated problem of transport-related residential self-selection as a source of error in empirical studies. *Journal of Transport and Land Use* 7(3): 57–79.

Newman P.W.G., Kenworthy J.R., 1989. *Cities and automobile dependence: An international sourcebook.* Gower, Aldershot, UK.

Nguyen Q.S., 2014. *Mobilités spatiales et ségrégation dans un contexte de métropolisation: Le cas de Hanoi*. Phd Dissertation. Lyon 2 university.

Pan H., Shen Q., Zhang M., 2009. Influence of urban form on travel behaviour in four neighbourhoods of Shanghai. *Urban Studies* 46(2): 275–294.

Rogers R.G., Gumuchdjian P., 2008. *Des Villes durables pour une petite planète*. Ed Moniteur, France.

Schreiber J.B., Nora A., Stage F.K., Barlow E.A., King J., 2006. Reporting structural equation modeling and confirmatory factor analysis results: A review. *The Journal of Educational Research* 99(6): 323–338.

Stead D., 2001. Relationships between land use, socioeconomic factors, and travel patterns in Britain. *Environment and Planning B: Planning and Design* 28(4): 499–528.

Van Acker V., Witlox F., 2010. Car ownership as a mediating variable in car travel behaviour research using a struc-

tural equation modelling approach to identify its dual relationship. *Journal of Transport Geography* 18(1): 65–74.
Zhang Y., Wu W., Li Y., Liu Q., Li C., 2014. Does the built environment make a difference? An investigation of household vehicle use in Zhongshan metropolitan area, China. *Sustainability* 6(8): 4910–4930.

Appendix

Table A1. Description of the papers chosen for the literature review.

Authors	Country	Period	Data sources	Study scale	Sensitivity analysis method	Sample size	Mobility type C	Mobility type S	Mobility type L	drivers SE	drivers BE	explanatory power of the modal
Van Acker and Witlox (2010)	Belgium	2000–2001	Survey on behaviour of travellers in Ghent on people aged 18 and over.	City	SEM	2,500 households	×	×	×	×	×	R^2 = 20.1%
Breheny (1995)	UK – Wales	1961–1991	Aggregated data from Ecotec project (1993).	National	Interpolation from data from Ecotec project (1993).	Ecotec project sample (1993)	×	×	×		×	–
Brownstone and Golob (2008)	California	2001	National Household Transportation Survey. Aggregate data.	National	SEM	2,079 households	×	×	×	×	×	R^2 = 0.37 and 0.42
Calabrese et al. (2012)	Massachusetts, USA	2011	Deducted by detecting signal of mobile phones carried out by AirSag.	Metropolitan area	Multiple linear regression	1,101 households	×	×	×	×	×	R^2 = 49.40% and 56.48%
Newman et al. (1989)	32 cities of different countries	1980	Collection of fuel consumption data and calculation of density excluding rural areas. Urban planning agency of different countries. Aggregate data.	City	Bivariate correlation analysis	32 cities	×	×	×	×	×	/
Cervero and Murakami (2010)	USA	2003	Data collected from Highway Statistics. Department of Commerce.	National	SEM	370 urban areas	×	×	×		×	CFI (>0: 900) 0.969 NFI (>0: 950) 0.961 NNFI (>0: 900) 0.942
Cervero and Radisch (1995)	USA	1990–1991	Bay Area Travel questionnaire survey.	Neighbourhood	Binary logistic regression	2 Neighbourhoods: 620 households for non commuting. And 840 households for commuting	×	×	×	×	×	Pseudo R^2 = 0.29, Predicted cases = 88.6%.
Chen et al. (2007)	NY, USA	1997/1998	Household survey	Metropolitan area	SEM	2,089 trips	×			×	×	R^2 = 0.45 and 0.58
Dargay (2004)	UK	1970–1995	Surveys of family spending.	National	Semi-logistic regression	256 pseudo panels	×	×	×	×	×	R^2 = 0.989
Dieleman et al. (2002)	Netherlands	1996	National Mobility Survey in the Netherlands	National	Multinomial logistic regression	70,000 households	×	×	×	×	×	R^2 = 0.31

Authors	Country	Period	Data sources	Study scale	Sensitivity analysis method	Sample size	Mobility type			drivers		explanatory power of the modal
							C	S	L	SE	BE	
Ding et al. (2017)	Baltimore USA	2001	Household survey	Metropolitan area	SEM	3,519 households	×			×	×	/
Feng et al. (2013)	China and Netherlands	2008	Household survey on mobility in both countries.	City	Multiple linear regression	2,989 respondents for 10 districts in China and 1,322 respondents for Randstad.	×	×	×	×	×	China: $R^2 = 0.115$ Randstad $R^2 = 0.124$
Handy et al. (2005)	California (US)	2003	E-mail questionnaire carried out on eight neighbourhoods.	District in metropolitan area	Linear regression	1,466 respondents				×	×	$R^2 = 0.16$ R^2 adjusted = 154
Holden and Norland (2005)	Oslo, Borway	2003	Questionnaire distributed by mail.	Regional	linear regression	650 for daily trips, 778 for leisure travel, <100 respondents per zone (eight zones selected for the study).	×		×	×	×	$R^2 = 0.231$ for commuting
Karathodorou et al. (2010)	42 countries	1995	Millennium Cities Database for Sustainable Transport (1999) for 100 countries. And car occupancy from Mobility in Cities database (2006).	Cities	Linear regression	84 cities	×		×	×	×	$R^2 = 0.61$
Khan et al. (2014)	Seatle, USA	2006	Questionnaires/Puget Sound Regional Council	Metropolitan area	Regression modelling	10,510 respondents of 4,741 households.	×		×	×	×	/
Kitamura et al. (1997)	San Francisco, USA	1994	Questionnaire, And land use information is obtained from the Metropolitan Transportation Commission.	Neighbourhood	Multiple linear regression	5 Neighbourhoods, 640 respondents,	×		×	×	×	$R^2 = 0.2125$
Limtanakool et al. (2006)	Netherlands	1996	National Mobility Survey conducted by telephone interview and questionnaire	Regional	Binary logistic regression	Commuting: 2,326 Shopping: 932 Leisure: 3,072	×	×	×	×	×	
Ma et al. (2014)	China	2007	Questionnaires	Neighbourhoods	Logistic regression	60 households, 699 trips of 10 neighbourhoods.	×	×	×	×	×	Pseudo $R^2 = 0.16$
Manaugh et al. (2009)	Montréal, Canada	2003	Origin-destination survey,	Neighbourhoods	Linear regression	17,000 trips	×			×	×	SE: $R^2 = 0.06$. SE+BE modal: $R^2 = 0.40$

Authors	Country	Period	Data sources	Study scale	Sensitivity analysis method	Sample size	Mobility type			drivers		explanatory power of the modal
							C	S	L	SE	BE	
Marique (2013)	Belgium	2001	2001 SE survey	National	Multiple linear regression	966.247 respondents.	×			×	×	$R^2 = 0.457$
Næss (2010)	Hangzhou, China	2005	Qualitative interview and questionnaire in 40 urban areas.	Urban zone	Multiple linear regression	28 interviews 3,150 questionnaire respondents.	×			×	×	$R^2 = 0.189$
Naess (2014)	Hangzhou, China and Copenhague, Danemark	2005	Interview and questionnaire	Regional	Linear regression	1932 et 3150 questionnaire	×			×	×	Copenhague $R^2 = 0.233$ Hangzhou $R^2 = 0.095$
Pan et al. (2009)	Shanghai, China	2001	Questionnaires	Neighbourhood	Multiple logistic regression	1,709 respondents in 4 Neighbourhoods	×		×	×	×	Pseudo R^2 = 0.2714
Zhang et al. (2014)	Zhongshan, China	2010	Questionnaires	Neighbourhoods	Linear regression	25,618 respondents	×	×	×	×	×	Pseudo R^2 = 0.2823
Bakour (2016)	Algiers, Algeria	2004	Household survey conducted by an organisation	City	Linear regression	1,200 respondents	×					R^2 = 0.5 à 0.9

BE – built environment, C – commuting, CFI – Comparative Fit Index, L – leisure, NFI – Normal Fit Index, S – shopping, SE – socio-economic, SEM – structural equation modelling

Source: own compilation.