The uptake of electrification and its transport and land use impacts; The case of Southampton (UK)

Victoria Gouge[1], Paraskevi Sarri [2*], Ioannis Kaparias [2]

[1] WSP, Southampton, UK

[2] University of Southampton, Transportation Research Group, Southampton, UK

SHORT SUMMARY

Electric vehicles (EVs) are heralded as a promising green alternative to conventional fossil-fuel-powered vehicles. The introduction of EVs is likely to impact the urban structure, but the magnitude of these impacts remains largely unexplored. The aim of this study is, hence, to shed light on this aspect by utilising the TRANUS Land-Use and Transportation Interaction (LUTI) model and by formulating a methodological framework to model electrification. Southampton (UK) is used as a case study and varying uptakes of EVs are modelled for a set of future scenarios. Based on census data and government projections, the model provides a quantitative outcome of the potential effects. The results indicate that employment might grow substantially in suburban areas. These changes are related to transport changes associated with private car use, such as growth in trips, distance travelled and journey times. Therefore, congestion increases and more interventions need to be implemented alongside electrification.

Keywords: LUTI, Electrification, Southampton

1. INTRODUCTION

In 2020 the UK government announced that there will be an end of the sale of conventional cars by 2030, with all new vehicles being fully zero emission at the tailpipe by 2035 (1). EVs, are expected to require infrastructure that occupies space (2), have lower vehicle operating costs to conventional cars (3), which increases accessibility (4) and as a result favours density suburban areas and increase urban sprawl (5). This phenomenon is likely to bring other consequences, such as loss of land, increased household energy use and lower land use stability in a community.

However, the exact impacts of EVs in different case studies have been rather underexplored (Orsi, 2021), as urban areas have different characteristics around the world. This paper aims to contribute to this aspect, as the potential impacts of EVs on land use and transport should be researched at a higher level of detail (6,7) and for different case studies.

To examine these impacts, LUTI models are an appropriate tool in this respect, as they forecast land use impacts based on transportation interventions and vice versa (8). LUTI models are methodologically grouped in three types:

1. aggregate spatial interaction models
2. utility-maximising models
3. activity-based, microsimulation models (9)

Spatial interaction models are considered insufficient in terms of behavioural realism, because of their initial random procedure of allocation of activities (10) . A model that belongs in either the second or the third category is suitable for this analysis. Here, TRANUS is chosen, because it simulates effects of different interventions and assists in economic, environmental and social analyses (9).

2. CREATING AN APPLICATION MODEL IN TRANUS LUTI MODEL

2.1 Structure of TRANUS

TRANUS has advantages, that were considered for selecting it for this application. First of all, it is dynamic and works on multi-level scales of analysis (11). It is also flexible in terms of the structure of the land use model. It incorporates methodological characteristics of other LUTI models, while at the same time utilises an advanced mathematical framework (12). Practically, TRANUS utilises discrete choice models to all components, making it a chain of linked choice models (13). Based on these characteristics TRANUS has been classified as Random Utility-Based Multi-Region Input–Output (RUBMRIO) model (14) and these models are appropriate tools for incorporating electrification, as conducted in (15), where a new RUMBRIO model was created especially for modelling EVs.

Land-use and transport are fully integrated in TRANUS, creating a holistic system. Initially, land use demand is estimated for each zone and subsequently activities are spatially distributed. If supply is not equal to the estimated demand, prices are adjusted to reach equilibrium through an iterative process. This procedure is based on an input output model that, with relationships of consumption and production among the model sectors. Sectors in TRANUS are more generic that the classic interpretation, as they do represent classical economy sectors, but they also represent other aspects of the system, such as population and land. Outputs of this procedure is an estimation of the location of the activities, the space that these activities consume and the final land prices. Moreover, an OD matrix is outputted for use in the transport module (11).

The transportation module evaluates different variables, namely operating costs, network characteristics, transport supply, fares, values of time and others, to estimate paths for each origin-destination pair as well as the cost of each path. This procedure in TRANUS is called multipath search. The output from multipath search is a combination of among transport links in the network, transport routes and modes. Following, for each path the transport costs are estimated and the number of trips is generated, as an elastic function of disutilites and a function of flows, and finally are assigned to the paths. Travel times are then adjusted based on network capacities. If vehicle numbers are increased, the speeds are reduced, increasing subsequently travel time. Congestion and waiting times determine the transport costs. It is important to mention that congestion affects all modes that are sharing the same network link. This procedure is an iterative process, with multimodal assignment as well as trip generation being repeated until the system reaches equilibrium (11).

2.2 Case Study

The case study is the city of Southampton (UK). Southampton is the largest city of Hampshire county and has one of the most important ports in the UK (16). Its transport strategy includes the improvement of air quality (17), by encouraging EV ownership and creating more Electric Vehicle Charging Points (EVCPs) (18). Hence, because of the financial importance of the case study and the aims of its transport plan, results from this analysis will be useful to local planners and the conclusions will be transferable to other urban cores of similar urban structure across Europe.

2.3 Land use model calibration

A Lowry structure was followed and the sectors are population, basic employment, service employment and land. The sectors are separated to those that generate flows and those that do not (13). The sectors of population and service employment are inducted and transportable, as they generate flows, while land is a non-transportable and does not generate flows. Finally, basic employment is defined as an exogenous sector (export-oriented employment), which includes processes of production of which products are exported out of the modelling area. As a result, the location of basic employment is not dependent on other activities in modelling area and this sector also does not generate flows (19).

The relationships between these sectors are:

- Population consumes service employment and land
- Basic employment consumes population and land
- Service employment consumes population and land
- Land does not consume anything

These relationships are shown in Figure 1. The logit dispersion parameter for the distribution of production defines whether these sectors generate flows or not. This parameter is equal to 0 for basic employment and land and equal to 1 for population and service employment (20).

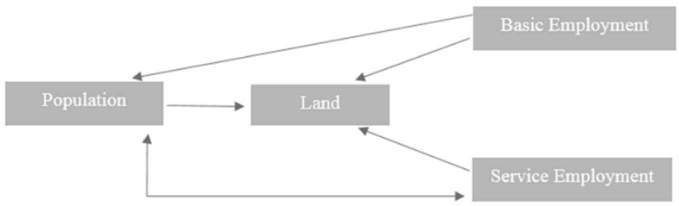

Figure 1: Relationships of the land use sectors

Population was obtained from (21), population projections for future scenarios from (22), house price statistics from (23) and finally the employment data from (24).

The input-output table connects land use and transport in TRANUS. The ratios of employment to population and vice versa were calculated and the rest of the required parameters are equivalent to coefficients of the input-output table. The function which is used to obtain the coefficients is:

$$\alpha_{ij} = minXi - (maxXi - minXi) * e^{-\delta_{ij} * U} \quad (1)$$

"α_{ij}: production of sector n demanded by sector m in zone i
$minXi$: minimum amount of *n* required production of *m*
$minXi$: maximum amount of *n* required production of *m*
δ_{ij}: elasticity of *m* with respect to cost of input *n*
U: consumption disutility of *n* in *i*" (25)

2.4 Transportation model calibration

The required parameters, in order to calibrate the TRANUS transport model and for it to conduct the initial multipath search procedure, are:

- Values of time and vehicle availability for trip purposes modelled, retrieved from (20).
- A list of the modes and their transport and cost characteristics. Sources for the data were (20,26).
- The highway network, obtained from (27) and data of the public transport network from (28).
- PCU values from (29).
- Capacity of the network links, which was determined by the number of lanes. Capacity estimates from (30) were applied to each lane for each road link.

Finally, the basis of the multipath search of the TRANUS transportation model is the transfer matrix, which was created and presented in Table 1. the definition of this matrix is essential for simulating multimodality within the application. If a cell is empty, then a modal shift is forbidden and if there is a value, then this represents the cost for switching modes.

Table 1: Transfer Matrix

Mode	*Private Car*	*Bus*	*Walk*	*Bicycle*	*Taxi*	*Rail*
Private Car	£0		-	-	-	-
Bus	-	£1.50	£0	£0	£4	£5
Walk	-	£1.50	-	-	£4	£5
Bicycle	-	£1.50	£0	£0	-	£5
Taxi	-	£1.50	£0	-	£4	£5
Rail	-	£1.50	£0	£0	£4	£5

Having completed this procedure, as already mentioned, an iterative process begins until the system reaches equilibrium with congestion, travel time, transport costs and network capacities (11).

3. SCENARIOS AND METHODOLOGY

3.1 Definition of Scenarios

In total, four scenarios were modelled: the Business As Usual (BAU) scenario for 2021, and three future scenarios: 2026, 2031 and 2036. The main reason that future scenarios were modelled was because of the different levels of adoption of EVs in the fleet the following years and the examination of the different land use and transport effects that these proportion may have (3). The way that these proportions will be incorporated in the methodology, is analysed in the following section. Moreover, the specific years were selected, as in 2030 the sale of EVs in the UK will be banned to reach an zero-emissions in 2035 (1). As a result, an intermediate year was chosen from 2021 to 2030, namely 2026, and the selection of the other two years, was based on the fact that it would be useful to model one year after the goals mentioned by the UK government, thus 2031 and 2036.

Table 2: Proportion of EVs in the fleet per scenario (3)

Scenario	Proportion of EVs in the fleet
Business As Usual Scenario	2%
Scenario 2026	7%
Scenario 2031	16%
Scenario 2036	26%

3.2 Principles of proposed methodology

The methodology is based on the framework presented by (31), where automation and ride-hailing were incorporated to the four-stage model. Since advanced technologies are modelled in the four-stage framework, researching how this framework can adopt electrification is essential. The framework is adapted for introducing the adoption of EVs as follows:

- ***Trip Generation*:** According to (32) land use characteristics determine trip generation. In TRANUS an attractor factor is used in every zone, based on its characteristics (11), thus including the location of EVCPs in the attractor factor, trip generation is affected. Indeed, EVCPs attract EVs (33), assuming however full availability.

The location of EVCPs within Southampton in 2021 is presented in Figure 2. Figure 3 presents the estimated forecasts for EVCPs within the UK (34), the percentage increases were then applied to the current Southampton EVCPs. Following, the values generated for Southampton were extrapolated and distributed in the future scenarios. Figure 4, shows EVCPs for the 2036 scenario.

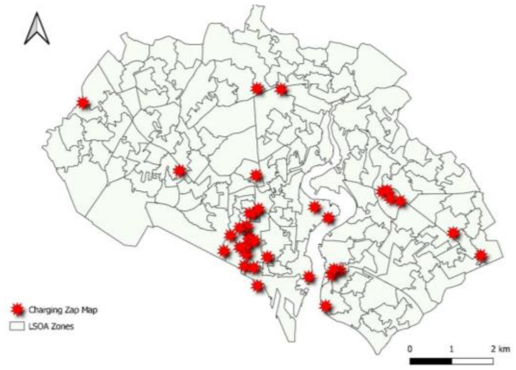

Figure 2: EVCPs in Southampton (35)

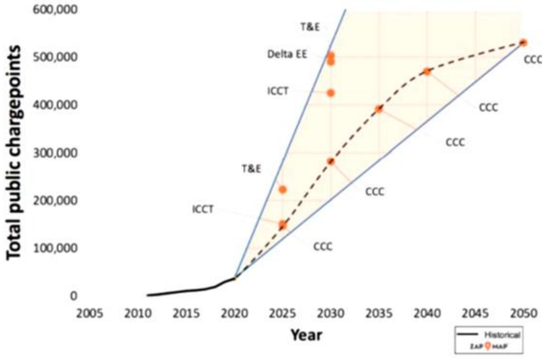

Figure 3: EVCPs Projections - UK (34)

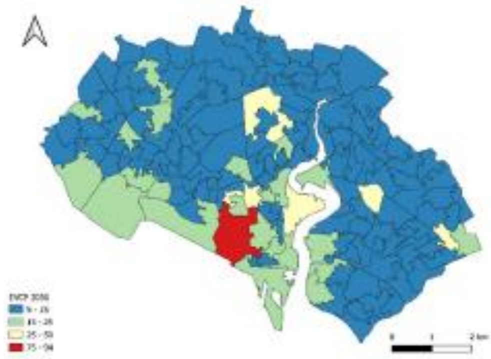

Figure 4: EVCPs in Southampton in 2036

Attractors of zones in TRANUS ($W_i^{n,t}$) are determined by the modeller before the interactive process for reaching equilibrium. As a result, the potential location of EVCPs is incorporated in $W_i^{n,t}$, in order to affect the attraction function. presented in (2):

$$A_i^{n,t} = \left(\sum_k b_n^k \left(\tilde{X}_i^{k,t-1}\right)\right) * W_i^{n,t} \tag{2}$$

- $A_i^{n,t}$: Attractor of sector n in zone i for period t.
- b_n^k: Relative weight of sector k as an attractor to sector n
- $\tilde{X}_i^{k,t-1}$: Total production of k in i at period t-1.
- $W_i^{n,t}$: Initial attractor of zone i that takes into account elements that attract the location of n (25)

- ***Trip Distribution:*** Changes in the impedance function will be implemented by incorporating the changes in generalised cost, as fuel cost of EVs is lower (3). The procedure for calculating the generalised cost is conducted according to (3).
- ***Modal Split and Assignment*:** In TRANUS modal split and assignment are combined in one algorithm, as the model utilises a probabilistic logit model for multimodal assignment (11). Thus, including the EVs in the choice set is important, for estimating modal split, which will affect assignment. However, since EVs are not widely adopted, EVs are included in a generalised private car mode by utilising projections of proportions of EVs in the fleet, presented in Table 2. The generalised cost that was calculated for each technology, is multiplied with each proportion and finally, after adding the values, the result is the generalised cost of the generalised car mode. A similar procedure was introduced in (36). This procedure is presented in (3).

$$GC_Y = PT_{EV_Y} * GC_{EV_Y} + PT_{Petrol_Y} * GC_{Petrol_Y} + PT_{Diesel_Y} * GC_{Diesel_Y} \quad (3)$$

- GC_Y: Total generalised cost for each simulation year (Y)
- PT_Y: Proportion of travel for each Y
- GC_{EV_Y}: Generalised cost for each vehicle type for each Y.

4. RESULTS

Based on Figure 5, bus and walking trips increase slightly which is related to population increase within the future scenarios. The bicycle becomes a less attractive mode, whilst the car shows an increase. This is expected, as the generalised cost of the private car becomes lower with EVs, which increases accessibility by this mode. Results in (37) is in line with the results, as it is suggested that increase in EVs could lead to a substantial reduction in cycling. Figure 6 shows that vehicle distance increases for private car, which supports research in (2) who suggests that lower vehicle operating costs lead to increase in total mileage. These results are also evident through the investigation of travel time. Figure 7 and show travel time by various modes for both modelled trip purposes. Travel time for bus and walking increase slightly. Cycling for both trip purposes indicate a substantial decrease in travel time, which is due to the reduction in cycle trips overall. Car trips show large increases in travel time, with 'Home to Services' trips having a greater increase than 'Home to Work'. This is due to the increase in car trips and the increase in vehicle distance for private car use causing congestion on the roads which leads to the increase in travel time. Figure 9 indicates energy consumption increases, while the cost for private car use decreases, which makes long journeys by car more attractive

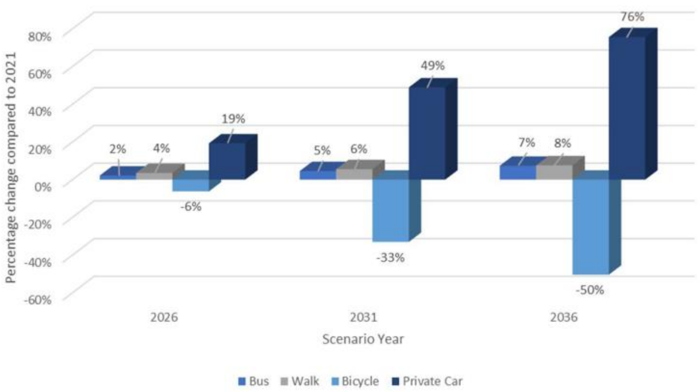

Figure 5: Boardings per mode

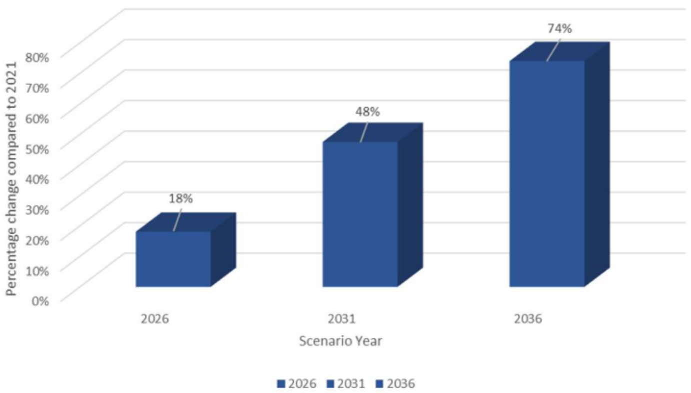

Figure 6: Vehicle distance of private car

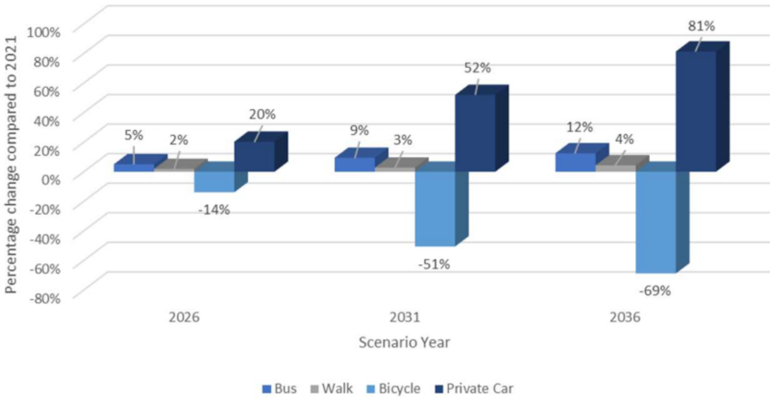

Figure 7:Travel time by mode for Home to Work Trips

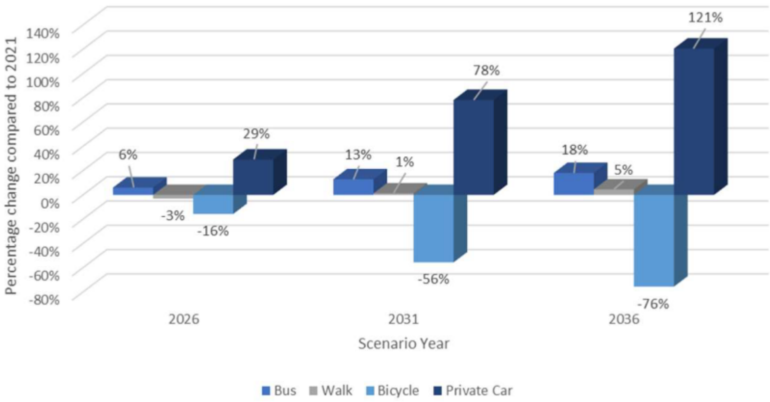

Figure 8:Travel time by mode for Home to Services Trips

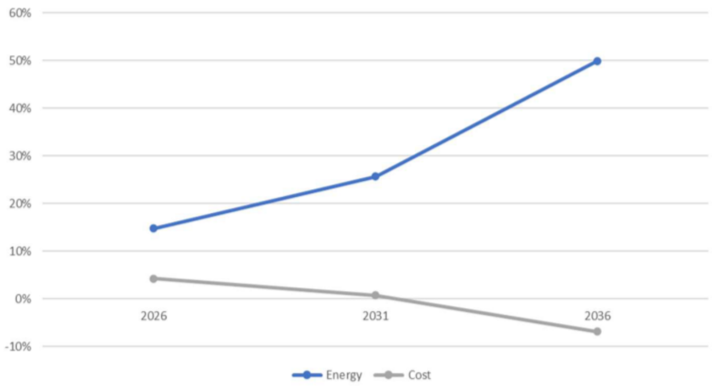

Figure 9: Energy Consumed and Cost of private car

Regarding the land use results, maps of the percentage changes of the results from the future scenarios to the 2021 scenario were created. The predicted percentage change in Service Employment for the three future scenarios are presented in Figure 10, Figure 11 and Figure 12. Population and Service employment results indicated similar patterns in all scenarios, thus only the maps of service employment are presented, which are also indicative for population. Service employment in the 2026 scenario did not present any percentage changes. However, this phenomenon changes in the scenarios of 2031 and 2036. The highest predicted percentage change in service employment jobs in 2031 are within most of the zones, with the exception of two zones in the outskirts of the city, in which no change was predicted. In the final scenario however, this phenomenon changes, as it is clear that employment is increased in all zones of the city resulting to a uniform distribution of employment increase across the city. Similar conclusions for a general increase of population and service employment were also found in (15), in their experiment of modelling EVs in Kofu urban area of Yamanashi Prefecture in Japan.

Basic employment results from scenarios 2026 and 2036 in comparison with 2021 are presented in Figure 13 and Figure 14. The spatial distribution of basic employment is different from and the other sectors. The results indicate the highest increase is distributed in zones in the suburbs, which had low numbers of basic jobs in the base scenario. The results of some of the zones regarding this sector is presented in Table 3. Basic employment increases in suburban areas as the percentage of EVs increases. The distribution of the increases in basic employment correlates with the zones with more EVCPs, with the exception of the city centre.

Table 3: Percentage changes of Basic Employment

Zone	Basic Employment 2021	Basic Employment 2026	% Change from 2026 to 2021	Basic Employment 2031	% Change from 2031 to 2021	Basic Employment 2036	% Change from 2026 to 2021
Shirley	45	633	1307%	1347	2893%	2061	4480%
Coxford	5	32	540%	65	1200%	98	1860%
Millbrook	35	86	146%	148	323%	210	500%
Woolston	10	24	140%	41	310%	58	480%
Bargate	10	23	130%	38	280%	53	430%
Redbridge	5	11	120%	19	280%	27	440%
Bitterne	15	33	120%	55	267%	77	413%

As car use increases, increase in journey times is causing congestion, whereas routes in the suburbs have better journey times which attracts more employment. These results are in agreement with the results of (38), where in suburban areas of their case study travel times and distances increased.

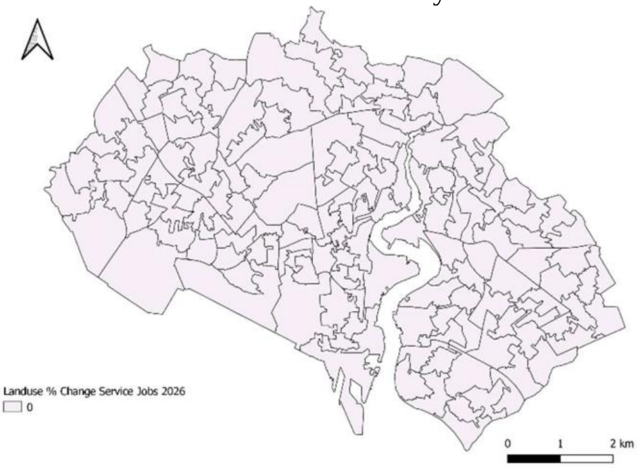

Figure 10: Service employment and population 2026

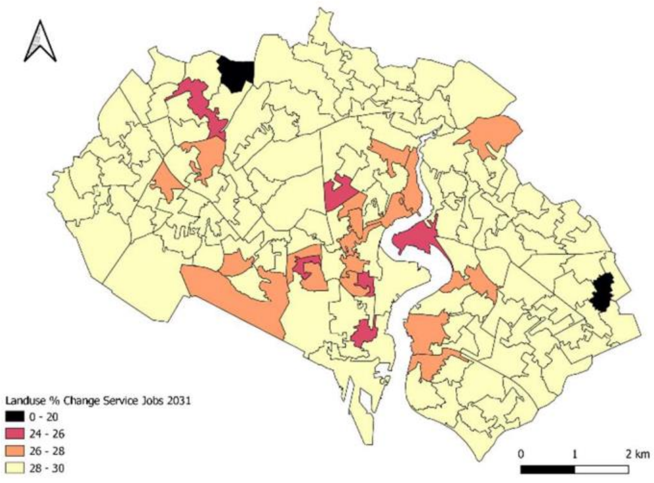

Figure 11: Service employment and population 2031

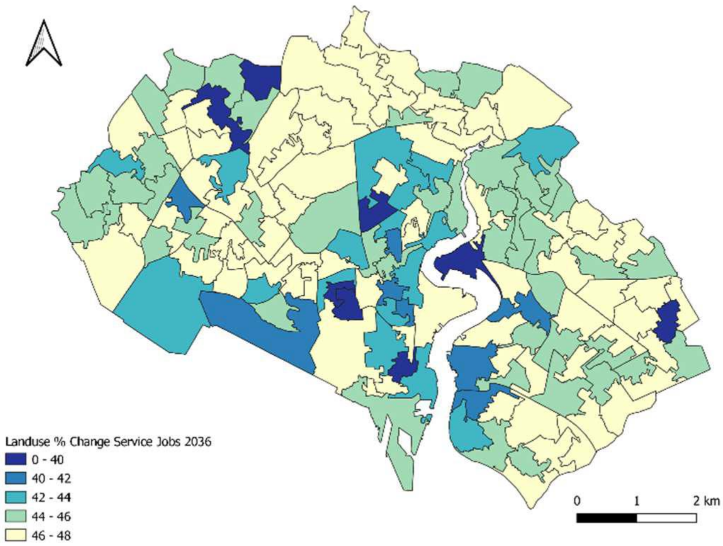

Figure 12: Service employment and population 2036

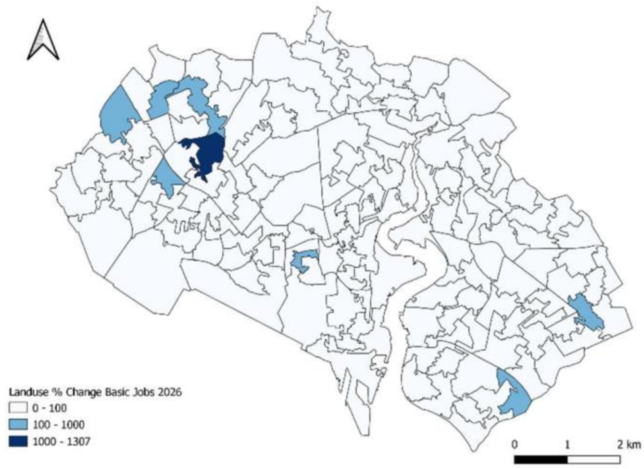

Figure 13: Basic Employment in2021

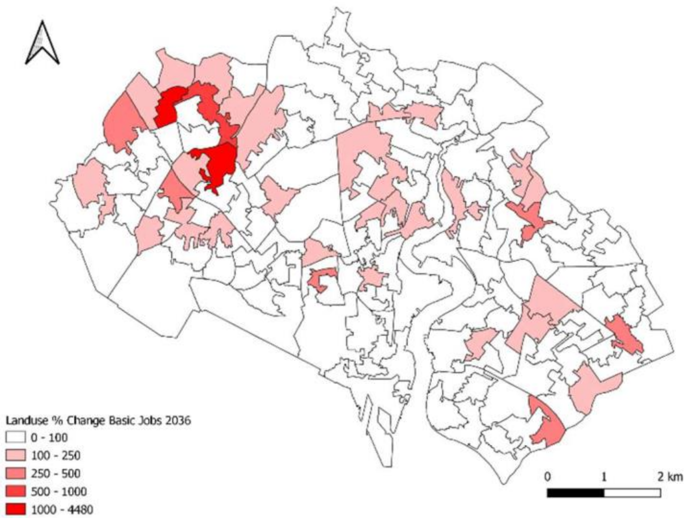

Figure 14: Basic Employment in 2036

Considering these results holistically, the increase of accessibility by car has led employment sectors to the suburbs, as the land prices are lower while the city centre of the urban core not losing financial power. This indicates the financial growth in areas with higher accessibility and the attraction of basic employment from exogenous zones of the model, as in the suburban zones the existence of EVCPs and lower land prices and rents has made them more attractive.

5. CONCLUSIONS

In conclusion, in this analysis a methodology for incorporating EVs in the transportation module of a LUTI model is proposed based on the transport characteristics of this innovation, as well as the structure of the transportation model. Overall, the modelling procedure provided reasonable results. In the case of Southampton, which was simulated using the TRANUS LUTI model, the land-use results indicate that higher adoption of EVs leads to higher employment growth in the suburbs, particularly if EVCPs are allocated in these zones. The transport results indicate that lower generalised cost of EVs makes longer trips more attractive, increases travel times and increases energy consumption. Bicycle use was negatively affected with the adoption of EVs. As a result, implementing a number of interventions that promotes active travel as well as adoption EVs is essential for sustainability in transport.

Limitations of this analysis are related to the uncertainty regarding the proportions of EVs adoption rates, the assumption of full availability in EVCPs, the modelling of only EV adoption and not including other policies, such as Southampton Cycling Network (39). Further research could explore differing EV uptake scenarios, along with modelling of sustainable urban mobility plans or road pricing, in order to explore further land-use and transport impacts.

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