Identifying the land use effects of new transportation technologies. The case of West Midlands

Paraskevi Sarri [1], Ioannis Kaparias [1], John Preston [1], David Simmonds[2]

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

[2] David Simmonds Consultancy Ltd, Cambridge, UK and Heriot-Watt University, Edinburgh, UK

Abstract

Emerging technologies in transportation, such as autonomous (AVs) and electric vehicles (EVs), are expected to change the evolution of land use characteristics at both the regional and urban level. Due to its socioeconomic characteristics, the West Midlands is expected to adopt these technologies and is deemed an appropriate example to test technological scenarios. The aim of the study is to examine different scenarios for the uptake of AVs and EVs in order to appraise the possible land use effects. Three situations are examined, with the first being related to the existence of EVs by the year 2021, the second to both level 2 AVs and EVs by 2021 the third to Level 2 and Level 3 AVs as well as EVs by 2031. These are examined at both the regional and urban level, using the DELTA Land Use and Transportation Interaction (LUTI) model. Having modelled the scenarios by estimating differences in generalised cost and modal splits, the regional and urban effects are appraised with cartographic representations and graphs, in order to draw conclusions. Differing results are found at the regional and urban levels, whilst the biggest changes occur when all the technologies exist simultaneously.

Introduction

The field of transportation is currently experiencing radical changes with the introduction of new disruptive technologies, such as Automated Vehicles (AVs) and Electric Vehicles (EVs). Such innovations are expected to change every day travel and to significantly impact people's lives to the extent that some researchers have argued that the step-change will mark the start of a new era. The last time that such innovative interventions in transport were implemented, was when the first car was launched [1] as it created financial opportunities and contributed to the radical re-distribution of land uses in cities. The literature on new transportation technologies and on how their implementation and take-up may be achieved is extensive. However, their impacts on the urban structure remains largely under-explored [2], with some researchers concluding towards increased urban sprawl of activities [3] and others towards densified core scenarios [4].

To examine these impacts, mathematical modelling and simulations are essential. Land Use and Transport Interaction (LUTI) models are an appropriate tool in this respect. LUTI models are simulations that forecast the evolution of space based on change in transportation and vice versa, they include a set of extensive procedures of spatial analysis and finally allow for the evaluation of policies through their results [5]. There is a variety of methodologies of LUTI models with the most distinctive three being:

- Aggregate spatial interaction-based models.
- Utility-maximizing multinomial logit based models.
- Activity-based, microsimulation models [6].

Aggregate spatial interaction-based models use the maximum entropy approach in which initially the choices made are considered completely random and later cost in included to make decisions more rational [7]. Even though they have been shown to be consistent with the utility maximisation models [8], other researchers claim that because of the initial decision making procedure they lack sufficient behavioural realism [9].

Given that a rational decision-making process is needed in order to explore the adoption of new technologies, a LUTI model that is based on either utility-maximisation or behavioural rules-based microsimulation models is required. As such, the DELTA model is selected as most suitable, as it has the ability of using both methodologies, thus providing flexibility in modelling.

The DELTA LUTI model

DELTA links to separate transport and land use models and it is accessibility-based, meaning that it considers the accessibility from each spatial unit of analysis to different destinations, including work and non-work trips. The land use in DELTA is represented by the demographic change, which is modelled based on household formation, construction and demolition rates, but also the employment change. Following the economic growth model, DELTA then uses growth or decrease rates for each employment sector in every spatial unit of analysis, which are fed to the location model, that predicts the location of activities [6] over a one-year period. The transport part, on the other hand, is updated less frequently and is usually inserted largely unchanged over a number of years. For example, in Figure 1 the transport component stays the same for the first five years and then is updated in 2016 [10].

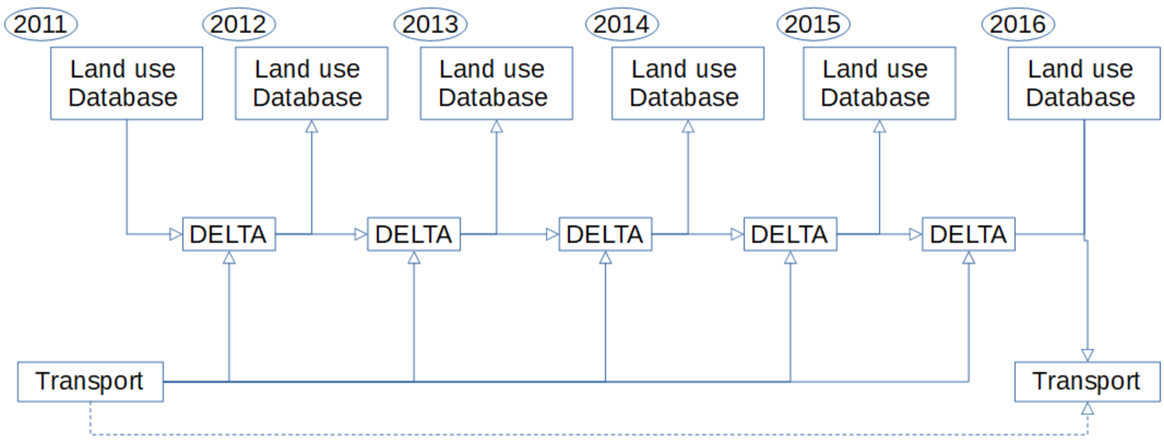

Figure 1: Operation of DELTA over time periods [10]

Study area and datasets

Because DELTA works in multi-level zones, it is feasible to analyse scenarios at both regional and urban level. Before analysing the methodology, it is important to give an overview of the study areas and examine their suitability for the examination of these technologies.

For the regional level of analysis, the West Midlands is selected, which is the third smallest region of England by area equal to 13,000 km^2. The most important urban areas in the region are Birmingham, Coventry, and Wolverhampton [11]. The region is one of the most accessible regions in the UK, because it is linked with the areas of the country by road and rail networks [11]. The region and its metropolitan and urban areas are the most growing areas in England excluding London [12].

Coventry is a city used as a case study for the scenarios, analysed on at the urban level. The city is also a metropolitan borough in West Midlands with a population approximately of 350,000 [13]. In terms of transportation, the city is close to four motorways and served by train, bus services, as well as by Birmingham's International Airport (BHX) [14]. In Figure 2, the West Midlands and Coventry are presented.

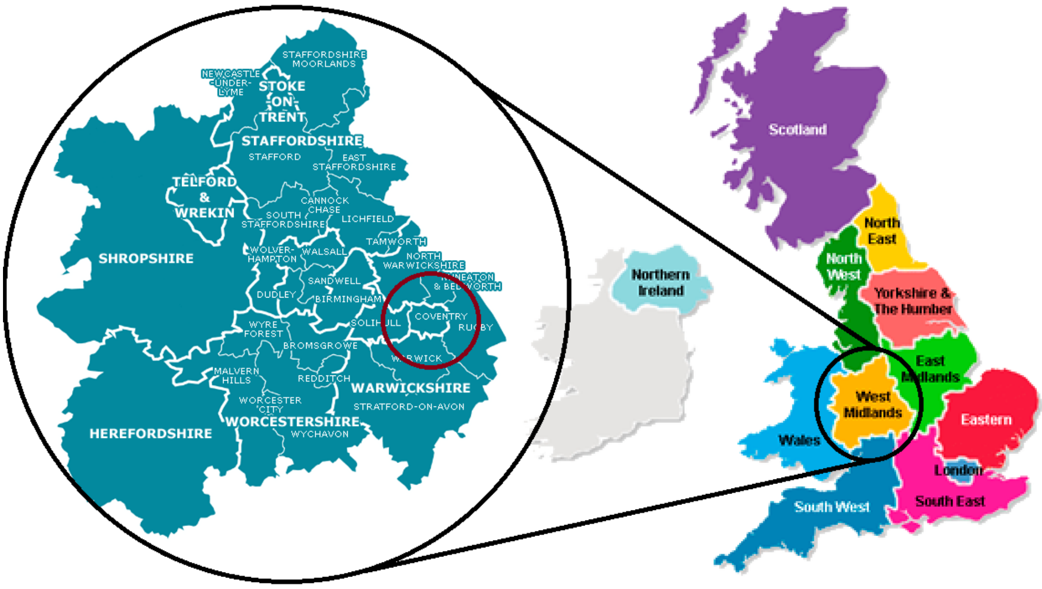

Figure 2: Location of West Midlands and Coventry, UK. Edited from [15]

Because of the importance and financial growth of these areas and their historic links with the automotive industry, the region will be one of the first to adopt AVs, thus it is deemed an adequate example to test the simulation for this technology. In this project the application model, namely the base scenario, was provided from the David Simmonds Consultancy Ltd, who provided access to:

- The DELTA software and the Highly Strategic Transport Model (HSTM).
- The application model of West Midlands [16].

Methodology

Six scenarios will be tested in this simulation. The first three are relevant to the existence of new transport technologies in the city of Coventry (urban scenarios) and the following three to the existence of the same technologies in region of the West Midlands (regional scenarios). A description is presented in Table 1.

Table 1: Description of Scenarios

Scenario	Scenario Name
Business As Usual Scenario	BAU
EVs – year 2021 (Coventry)	U1
EVs and Level 2 AVs – year 2021 (Coventry)	U2
EVs, Level 2 and Level 3 AV – year 2031 (Coventry)	U3
EVs – year 2021 (West Midlands)	R1
EVs and Level 2 AVs – year 2021 (West Midlands)	R2
EVs, Level 2 and Level 3 AVs – year 2031 (West Midlands)	R3

It is expected that EVs and AVs will have different generalised cost from conventional vehicles. EVs will use a different energy source and thus have different vehicle operating costs. AVs are expected to allow productive time while travelling, thus reducing this way the value of time [23-24]. The procedure for calculating the generalised cost (GC) is conducted according to [18], as follows:

1. Estimation of the Non- Fuel Costs in (£/km) for each vehicle type (NFC)
2. Estimation of the Fuel Costs in (£/km) for each vehicle type (FC)
3. Estimation of the Value of Time (£/h) for each vehicle type (VoT)
4. Estimation of the distance in (km) for each trip (D)
5. Estimation of the journey time in (h) for each trip (JT)
6. Usage of equation (1) to estimate the generalised cost per trip for every vehicle type.

$$GC = (NFC + FC) * D + VoT * JT \tag{1}$$

The generalised cost in DELTA (GC_D), presented in equation 2, is used to calculate measures of accessibility in minutes [19]. To change the units from monetary costs to minutes, generalised cost (GC) is divided by the average value of time per purpose ($VoT_{purpose}$), for which values are taken from[20].

$$GC_D = \frac{GC}{VoT_{purpose}} \tag{2}$$

This procedure is completed for both work and non-work trips, for every year and for every zone pair.

There are some important assumptions that have been deemed appropriate to make these calculations feasible, as these technologies do not exist yet and some essential variables have not been estimated. These are:

- Average speed for trips within urban areas is 40 km/h and within regional areas is 50 km/h [21].
- The non-fuel and the fuel costs of AVs are equal to those of and conventional vehicles.
- The value of time of EVs is equal to the value of time of conventional vehicles.
- The value of time of Level 2 AVs is 5% lower than for conventional vehicles for both work and non-work trips, because a portion of travel time is spent productively [22].
- The value of time of Level 3 AVs is 50% lower than for conventional vehicles for work trips and 80% smaller for non-work trips [22].

After the adoption of EVs and AVs, a portion of travel (PT) is expected to switch to these technologies, gradually [10-24-27]. This essentially means that in every year the amount of EVs and AV s is not expected to be the same in the network. Since the transportation simulation year period in this application of DELTA ten years, starting from 2011, these proportions are presented for the years 2021 and 2031 and the values used, come from a number of sources [24-27]. Table 2 contains the exact proportions.

Table 2: Forecasted Portions of Travel. (PT) Edited from: [24-27],

	EV	**AV level 2**	**AV level 3**
2021	1.71%	4%	0%
2031	16.36%	12%	30%

The portions of travel in Table 2 are multiplied with the percentage difference of generalised cost of EVs and AVs from conventional cars, to find the total change of generalised cost per vehicle type. Knowing that there is a mixture of vehicle types in one year, the total changes per vehicle type are added, to find the total change in generalised cost for each transportation simulation year. This procedure is mathematically presented as equation 3.

$$\Delta GC_y^S = PT_{EV_Y}^{\ S} * \Delta GC_{EV_Y} + PT_{AVL2_Y}^{\ S} * \Delta GC_{AVL2_Y} + PT_{AVL3_Y}^{\ S} * \Delta GC_{AVL3_Y} \qquad (3)$$

Where:

- ΔGC_y^S: Total change in generalised cost for each transportation simulation year and for each scenario
- PT_Y^S: Portion of travel for each transportation simulation year and for each scenario
- ΔGC_Y: Generalised cost proportional change for each vehicle type for the specific simulation year.

Subscripts EV, AVL2 and AVL3, refer to electric vehicles, autonomous vehicles level 2 and autonomous vehicles level 3 respectively.

It is essential to mention that ΔGC_y^S is calculated for both work and non-work purpose trips but also for every zone pair of each level of analysis. Each purpose of travel has different generalised costs based on the differences of value of time and each zone pair has a different generalised cost, based on the distance between the centroids of these zones.

An example of ΔGC_y^S results, for the year 2031 for work trips in a zone pair (406-424) in Coventry is presented in Table 3.

Table 3: Final reductions of generalised cost for urban zone pair

	ΔGC_{2031}^{U1}	**Scenario Name**	ΔGC_{2031}^{U2}	**Scenario Name**	ΔGC_{2031}^{U3}	**Scenario Name**
Zone pair in Coventry	-7.2%	U1	-19%	U2	-34%	U3

As expected the reduction in the final scenario is the highest, knowing that there are higher PTs with vehicles that have a smaller generalised cost from conventional vehicles.

Results

To analyse whether the differences of the generalised cost of travel have an effect on the urban and regional structure, two factors need to be examined in depth: population growth and employment growth. Both have a decisive influence on important areas, such as the advancement of human knowledge and technological power, as well as the elaboration of cultural modes and social institutions. Also, both have implications for the natural world, political order and human well-being.

Graphical representations for the two variables over the modelling period, which is 20 years, are provided for both the urban and regional scenarios. Moreover, cartographical representations are provided, in order to visualise the spatial distribution of activities based on the results for the key years after the incorporation of technologies, namely 2022, 2032 and 2042.

- Urban Scenarios (U1, U2 & U3)

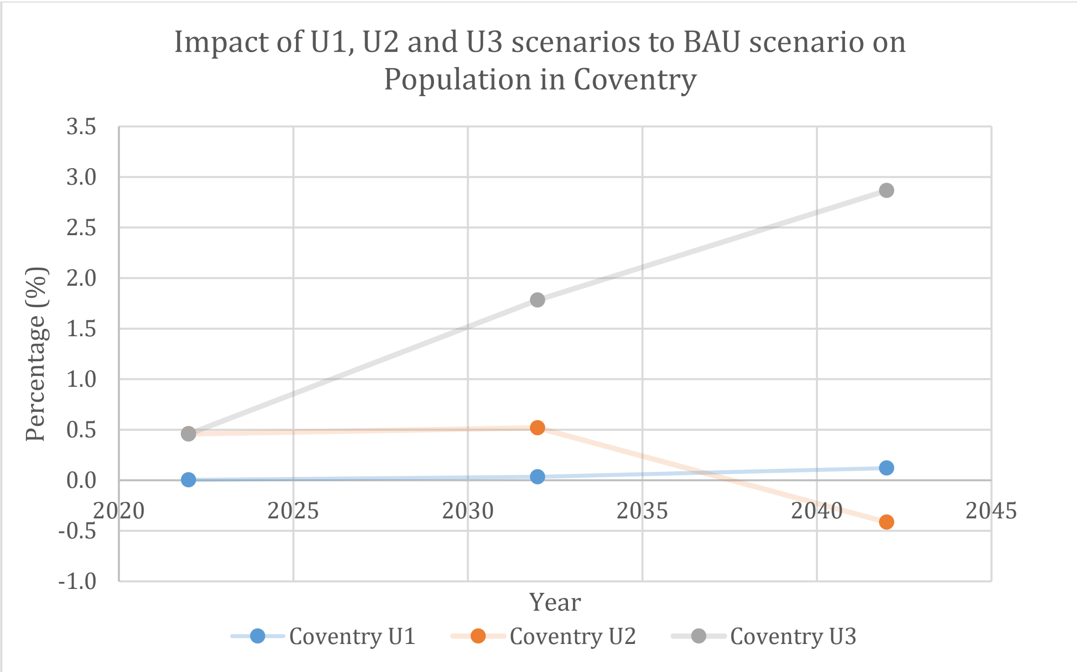

Figure 3: Population Change of Coventry for Each Scenario

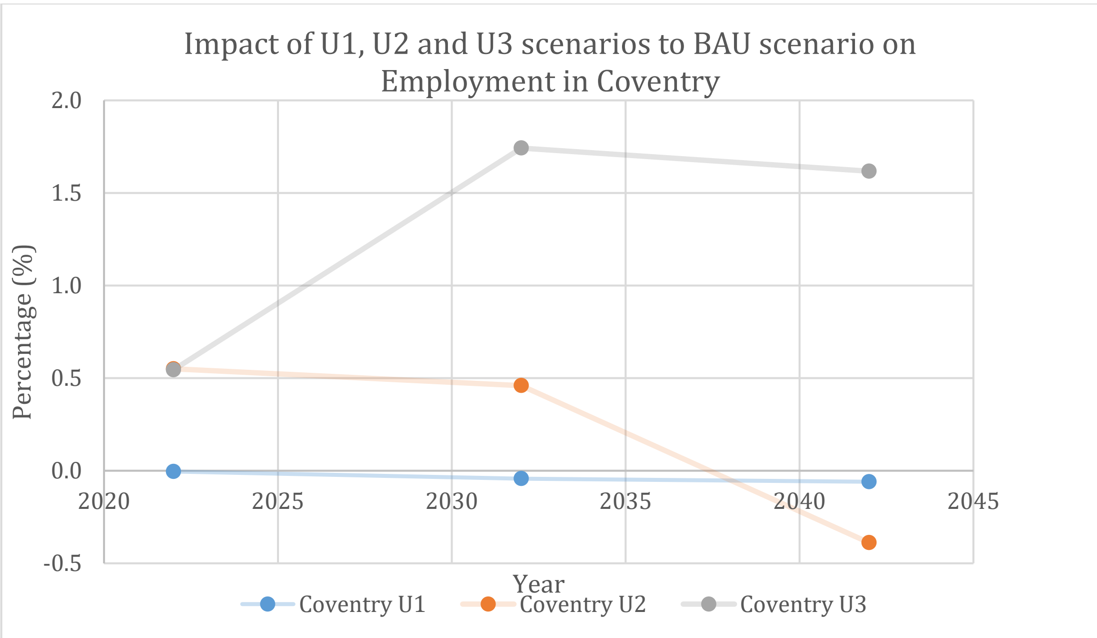

Figure 4: Employment Change of Coventry for Each Scenario

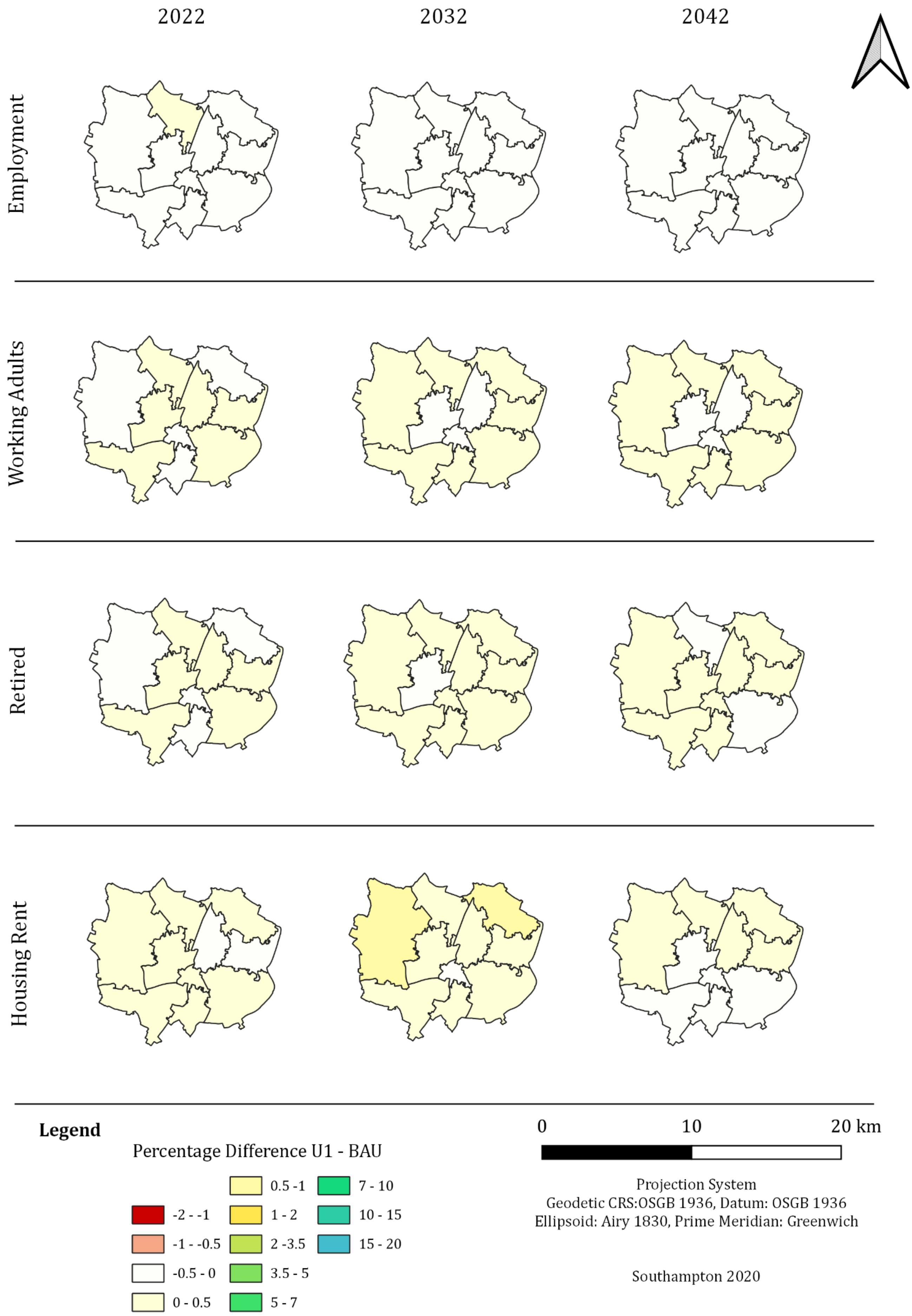

Figure 5: Results of EV Urban Scenario (U1) (Edited from: [25] *&* [16]*)*

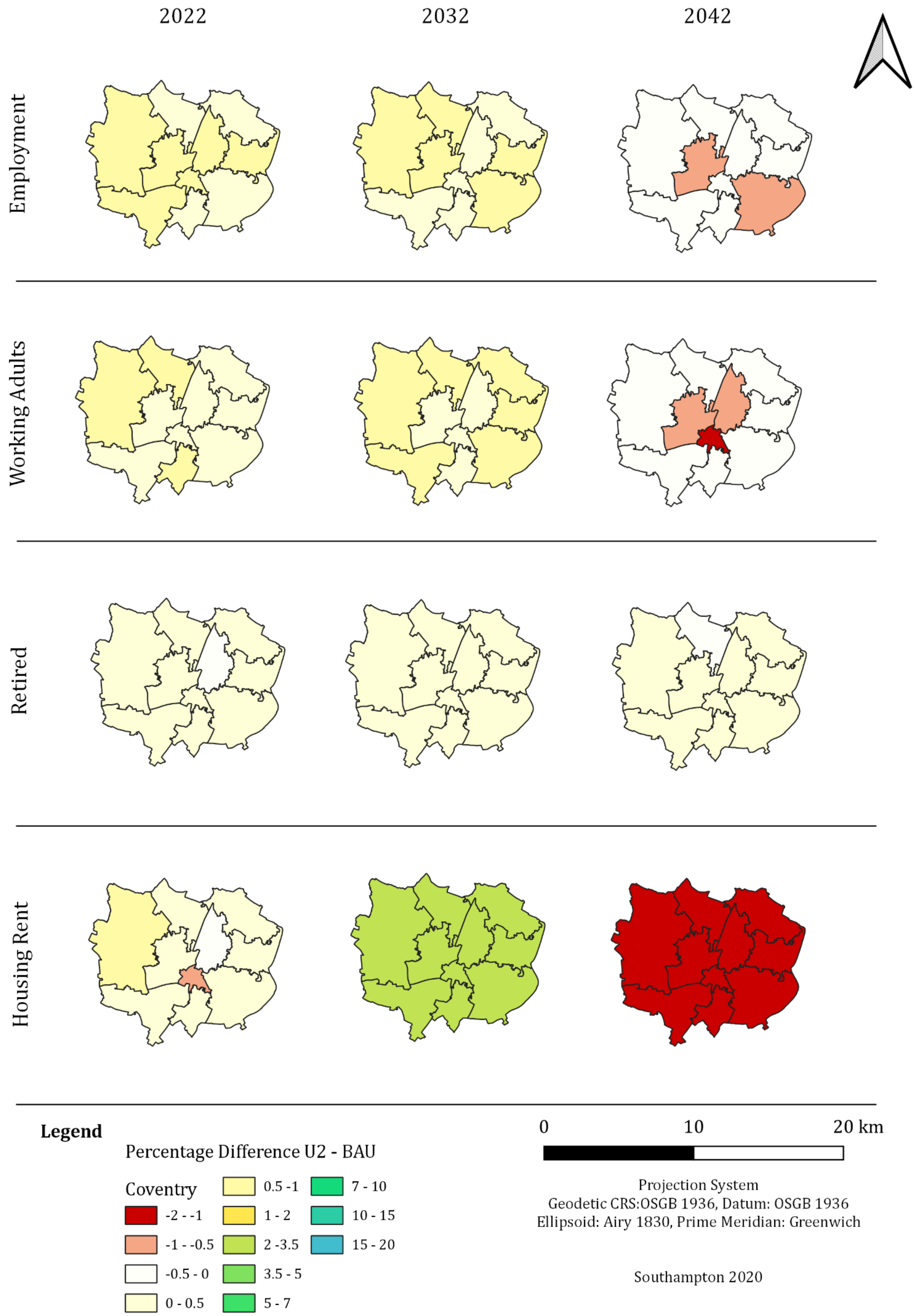

Figure 6: Results of EV and AV Level 2 Urban Scenario (U2) (Edited from: [25] & [16]*)*

Figure 7: Results of EV, AV Level 2 and AV Level 3 Urban Scenario (U3) (Edited from: [25] & [16]*)*

Urban Results Interpretation

U1:

The two variables presented chronologically in Figure 3 and Figure 4 are population and employment respectively. With the introduction of EVs, both variables seem to have very low change that does not even surpass 0.5%. These results are expected as the generalised cost was only reduced slightly and also are in accordance with [26], where even though the population was increased up to 14.93%, based on policy goals of the region, the usage of EVs did not surpass 1%. Of course the simulation in [26] was the opposite as the one the present study, but both studies converge to the conclusion that the existence of EVs have a small potential of affecting land use. It is interesting that the population and employment, have opposite trends, even though it is expected they should alter with similar trends and simultaneously. However, in the cartographical representation the population is separated between working adults and retired, as those tend to have opposite trends. In the long run, there are more zones where the number of working adults decreases hence the distribution of working adults follows the pattern of employment. Regarding the spatial distribution of activities, the urban centre seems to lose its financial power gradually in a very slow rate

U2:

After the incorporation of EVs and Level 2 AVs, both population and employment increase, meaning that unlike U1, the two variables now have the same trends. However, it essential to mention that percentages range from -0.5% to 0.5%. These numbers are in accordance with the results of [27], which again belong in the same range for the correspondent scenario of the paper, for all levels of analysis. The most interesting element is that in the 2022- 2032 period there are positive values in both employment and population change and this is not the case in the 2032-2042 modelling period. This means that initially the existence of lower cost private mobility increased accessibility and both variables increased, as a result the housing rent also increased (see Figure 6) which resulted in a decrease of the population of working adults, especially in the urban core. As a result, since population was distributed in other zones, new job opportunities arose in those areas.

U3:

With the existence all three technologies, both employment and population increase gradually with higher percentages from the two previous scenarios. The results range in the same percentage limits as in the corresponding scenario of [27]. Thus, in total it is evident that the total financial activity of the city is increased. However, it is vital to examine the spatial distribution of these within the study area. From the cartographical representations, it is clear that gradually population and employment are attracted to the periphery of the city, rather than the centre, leading to an urban sprawl scenario, as stated in [3]. In [3] after an extensive literature review, it was concluded that cities will face urban sprawl of financial activity after the existence of automated vehicles. Because of the evident urban sprawl, it is expected that with the existence of even more innovative technologies, smaller urban centres can be formed to the peripheral area of the city. As a result, the current Burgess monocentric model, that the city follows, will be transformed to a polycentric model.

- Regional Scenarios (R1, R2 & R3)

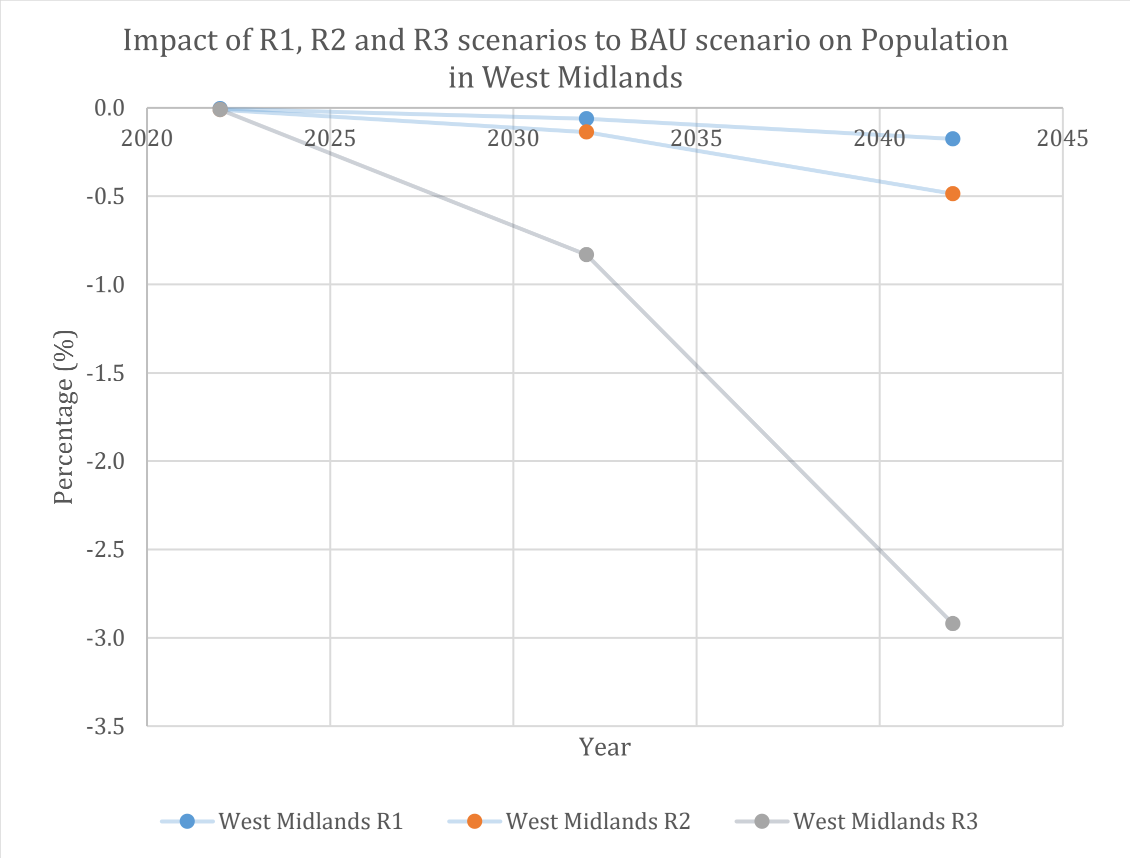

Figure 8: Population Change of West Midlands for Each Scenario

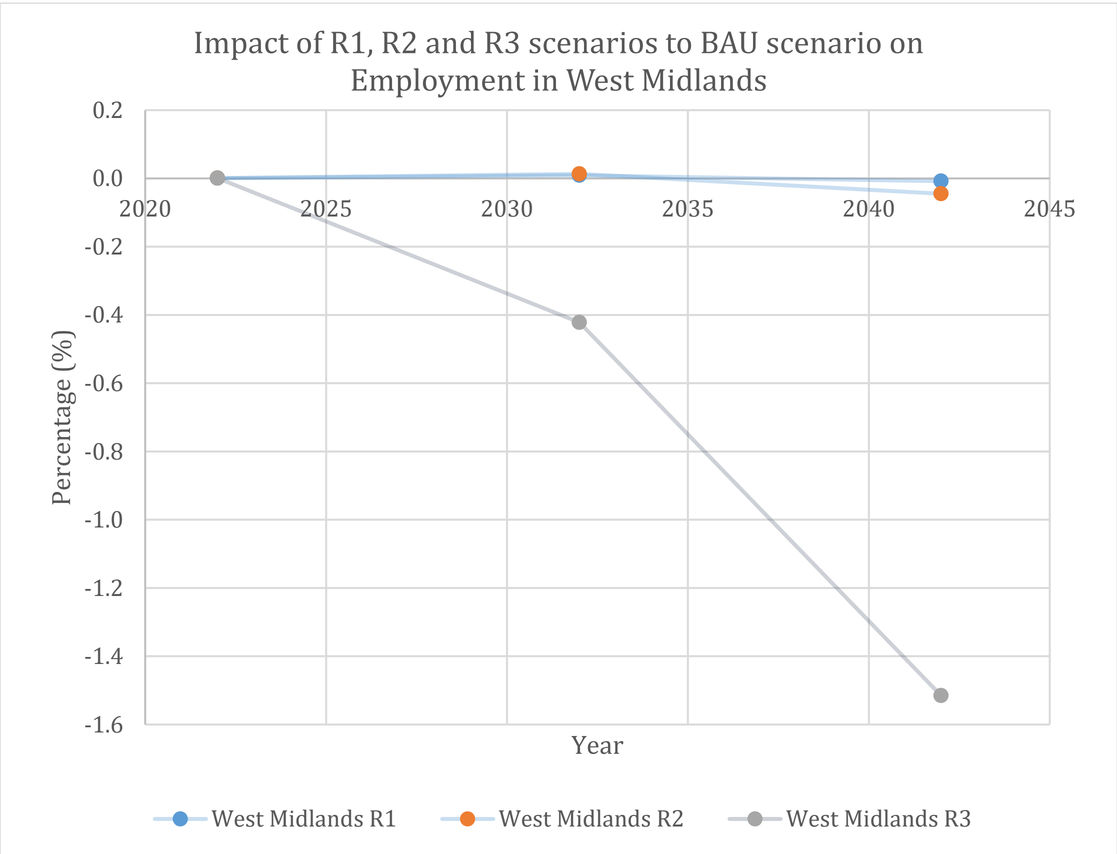

Figure 9: Employment Change of West Midlands for Each Scenario

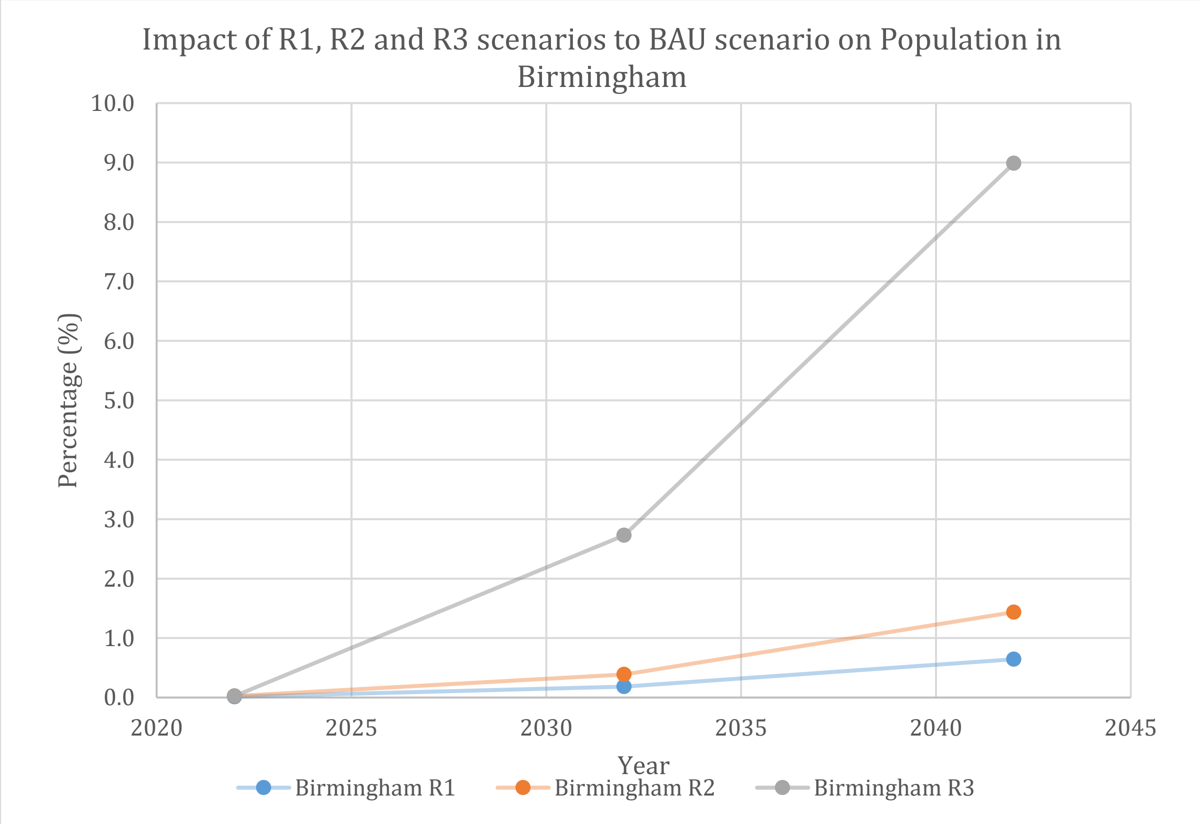

Figure 10: Population Change of Birmingham for Each Scenario

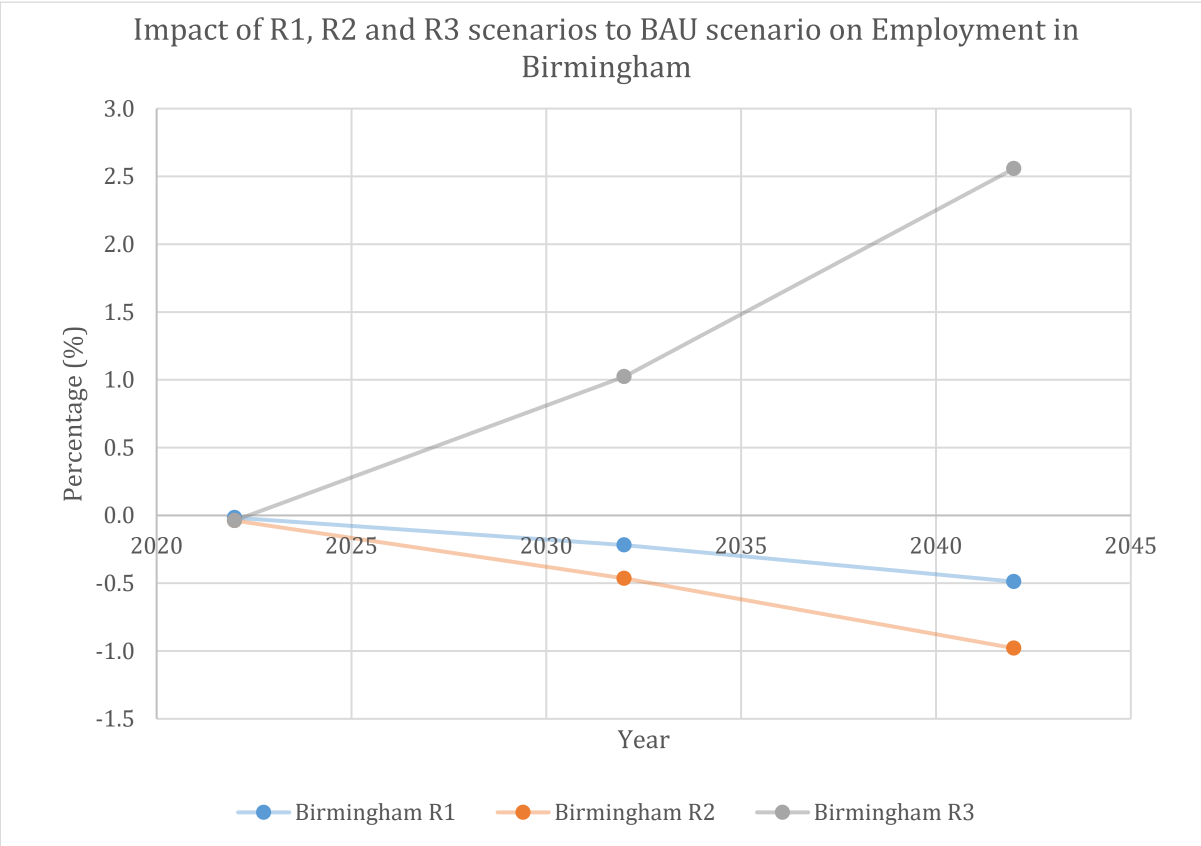

Figure 11: Employment Change of Birmingham for Each Scenario

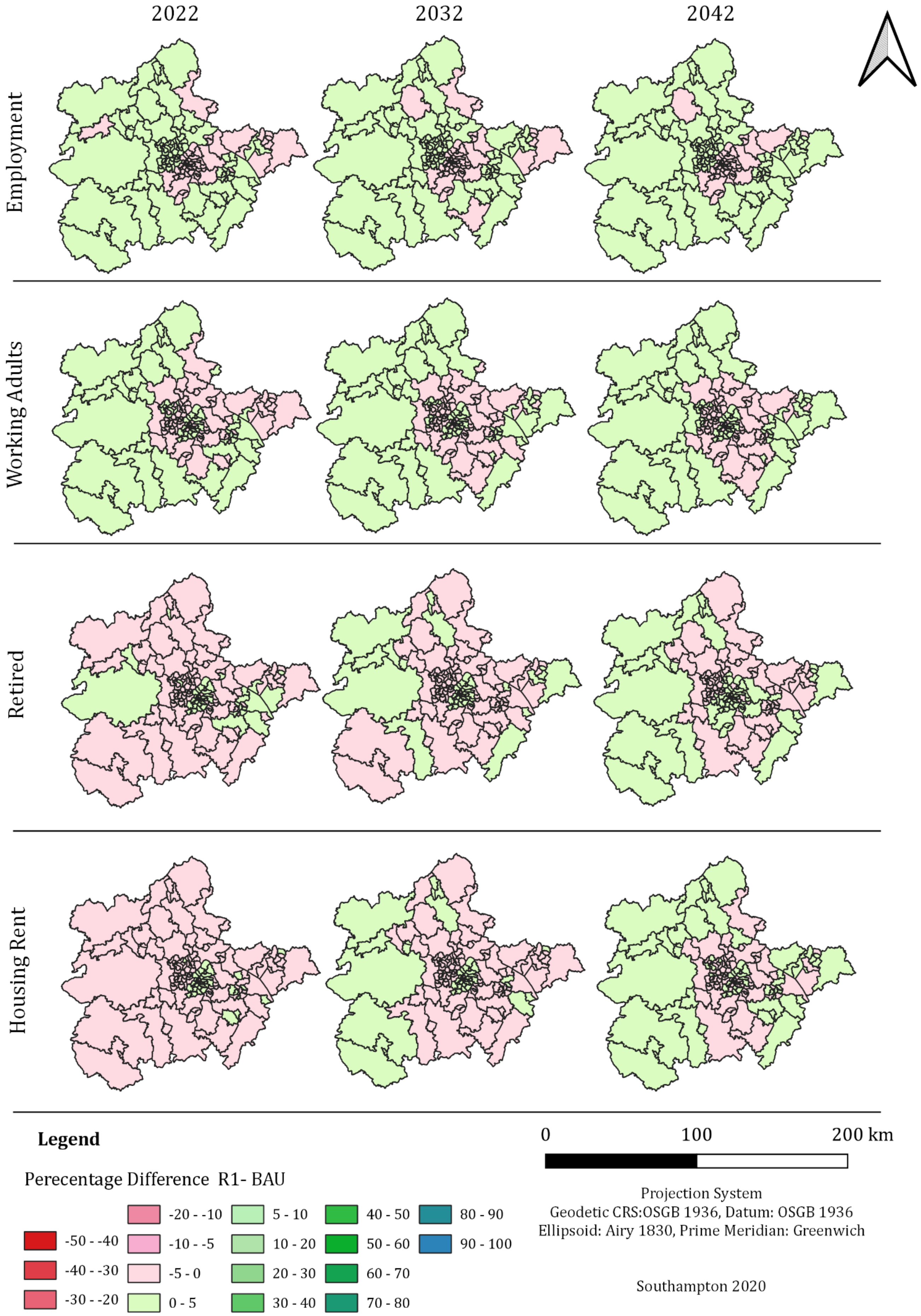

Figure 12: Results of EV Regional Scenario (R1) (Edited from: [25] & [16]*)*

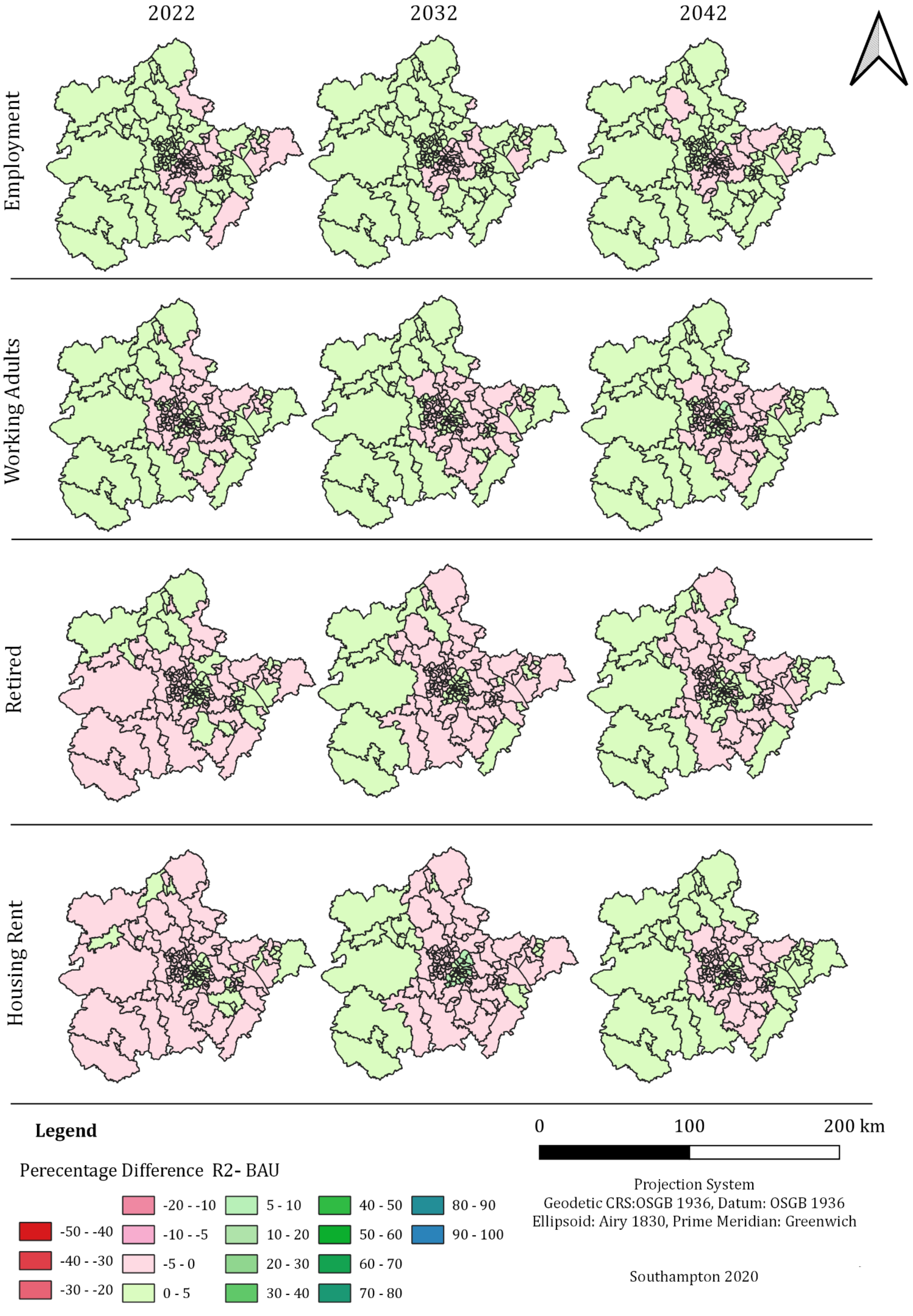

Figure 13: Results of EV and AV Level 2 Regional Scenario (R2) (Edited from: [25] & [16]*)*

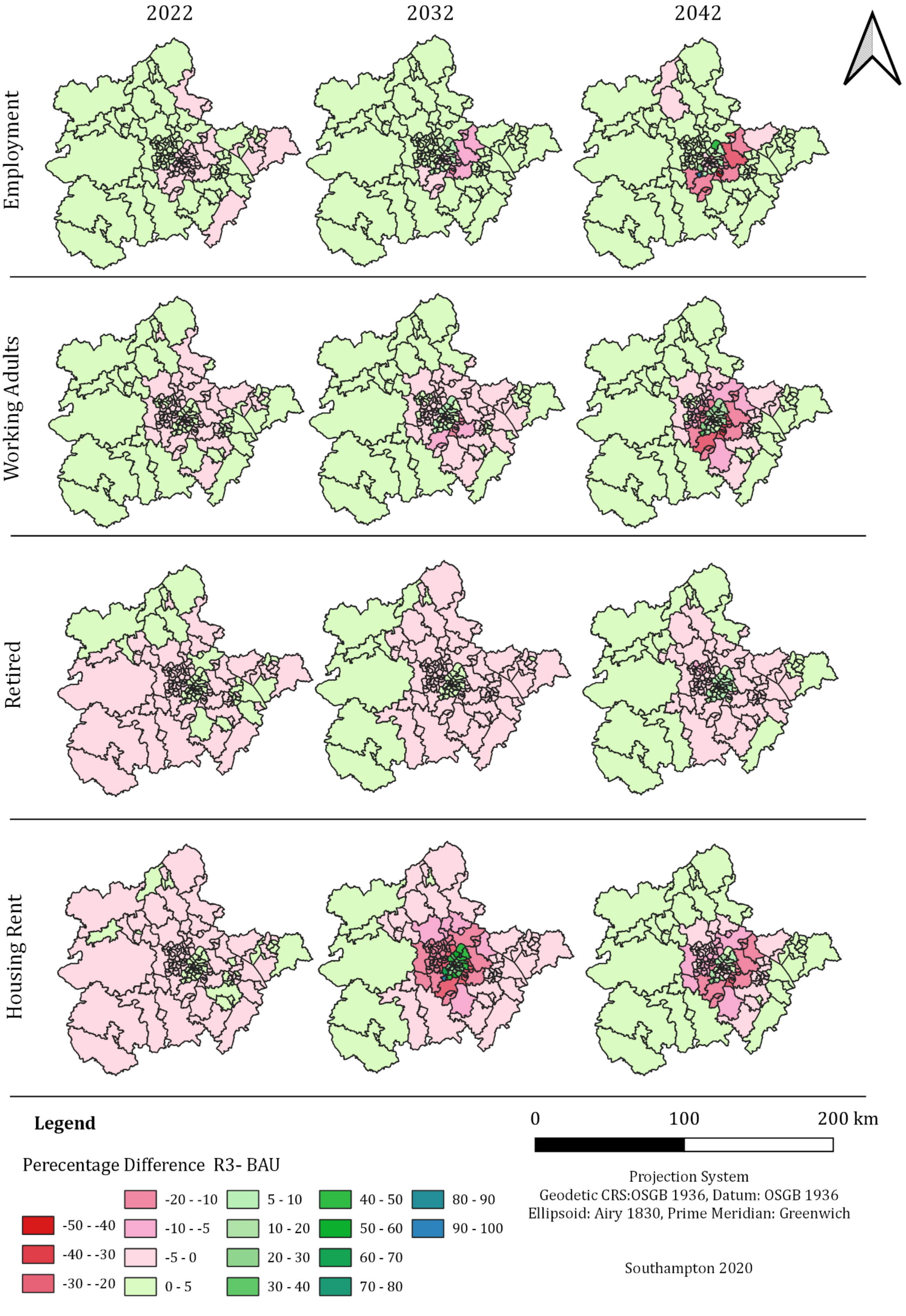

Figure 14: Results of EV, AV Level 2and AV Level 3 Regional Scenario (R3) (Edited from: [25] *&* [16]*)*

Regional Results Interpretation

R1:

In this scenario population and employment face a decrease, but as also concluded in U1 scenario and in [26], the change do not surpass 0.5% in absolute terms. The city of Birmingham does not follow the general results of the region as the trend of population is increasing and as shown in Figure 12 the same result is also found for working adults and the retired. In conclusion, it is clear from the results that EVs do not change the distribution of activities in high percentages, which is to be expected, as the generalised costs were not reduced by high percentages.

R2:

This scenario follows the same trends as R1 and the percentages indicate a higher reduction in comparison with R1. Spatially, it is essential to mention that working adults in the region seem to be attracted in the periphery and Birmingham, forming essentially three concentric circular zones. The first being Birmingham, where working adults increase, the second is a group of zones around Birmingham where working population is decreasing and the final is a ring around these zones in the peripheral area of the region where working adults increased in comparison with the BAU scenario. Because longer commutes now are more acceptable as the generalised cost is reduced, it not unexpected that people were attracted to the periphery. The fact that Birmingham is gaining power is because the existence of the already developed public transportation system and the lower cost of private transport makes the area more attractive for housing and employment, as the city now is more accessible. In [27] the conclusions of the corresponding scenario are the same as here, namely that the periphery of the region seems to attract population. However, in this case the four largest financial centres of the region(Amsterdam, Rotterdam, Hague and Utrecht) face a population decrease [27], which is the exact opposite as the case of Birmingham.

R3:

The highest change in population and employment is in this scenario. It is essential to note that unlike R1 and R2, the two variables here follow the same trends throughout all the analysis period, not just regionally, but also in the city of Birmingham. Overall, the results are higher in absolute values, which is expected as in this scenario the biggest cost changes were modelled. The results in this scenario are in agreement with [28], where in the private autonomous scenario the far outer areas of the study area developed in terms of population. The trends here indicate that densification in the main regional financial core (in this case Birmingham) is to be expected as well as increase in the periphery, as also concluded in R2 scenario. Figure 8 and Figure 9 show an average decrease in the region, because the decrease in the adjacent zones of Birmingham is higher in absolute value than the increase in the zones of Birmingham and the periphery, as also represented in Figure 14. Overall, both employment and population are decreased and regionally it is evident that financial cores as well as the peripheral areas attract those two variables, thus it is expected that if other cities, in adjacent regions adopt these technologies, their financial cores will gain power and new smaller financial centres will be formed in the borders of these regions.

Analysis in the periphery of the region

The periphery of the region appears to attract population and employment, especially in the R3 scenario. This means that it is essential to examine the effects in a set of buffer zones around the region as shown in Figure 15.

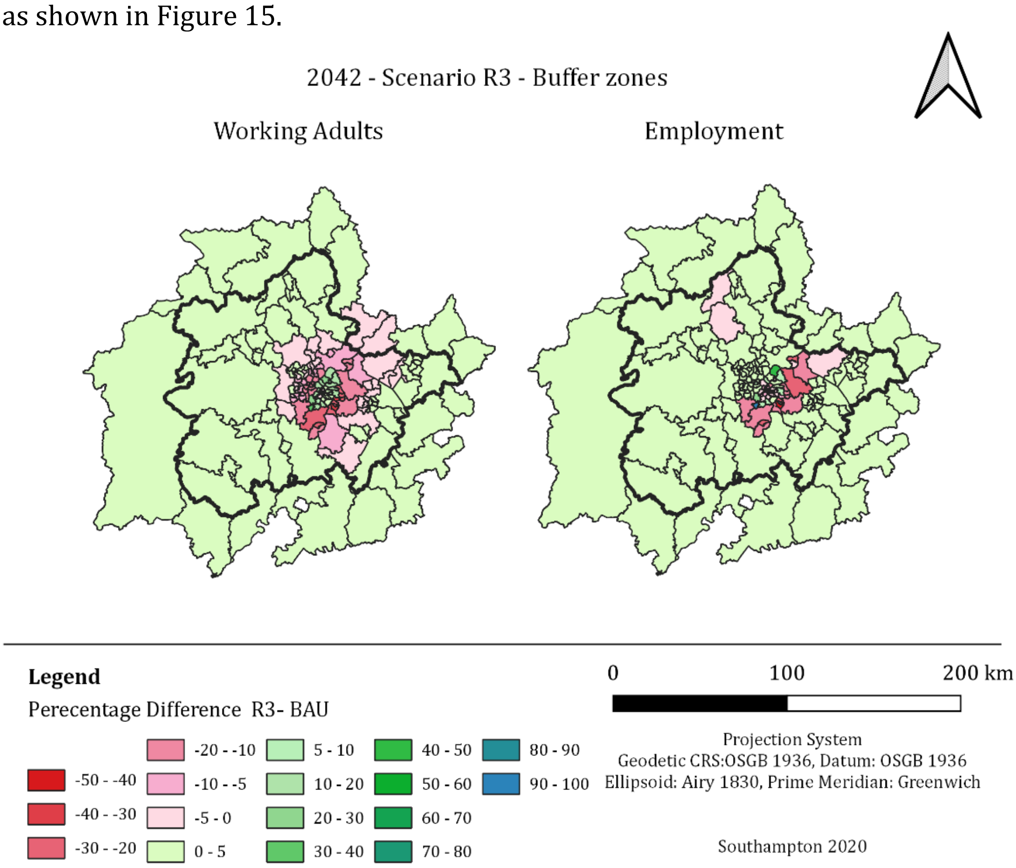

Figure 15: Buffer Zone Examination(Edited from: [25] *&* [16]*)*

It is clear that both working adults and employment are increased even in zones outside of the boundaries of the study area after 20 years. The co-existence of the new technologies provided higher freedom in mobility and acceptance of longer distance trips. Hence, this phenomenon lead to a spatial redistribution of activities, which did not only affect the region, but the adjoint regions and their financial opportunities as well.

Conclusions and Discussion

In conclusion, modelling new transportation technologies can produce valuable results regarding the evolution of an area in both the urban and the regional scale of analysis. The conclusions from the results of the urban level of analysis cannot be scaled to the regional level of analysis or vice versa, as according to the above analysis, the two levels of analysis seem to follow different trends. The adoption of all three technologies would lead for example to urban population and employment sprawl, regionally three rings of financial activity are formed, meaning that both the main financial core, and the periphery are developed. Moreover, the adoption of different technologies has different land use effects. Being able to predict the economic and activity change in an area, as well as its spatial distribution, is a vital factor for decision makers. These results could be used for creating policies, which could be more beneficial, in accordance with the contextual strategic goals and finally more sustainable.

Acknowledgements

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