Dynamic Microsimulation Modelling for National Infrastructure Demand in an Uncertain Future

Chengchao Zuo[1], Mark Birkin[1*], Nicolas Malleson[1]

[1]School of Geography, University of Leeds
Leeds, West Yorkshire, LS2 9JT, UK
Telephone: +44 (0) 113 34 36838
Email: geocz|m.h.birkin|N.Malleson06@leeds.ac.uk

1. Introduction

National infrastructure (NI, including energy, transport, water, waste and ICT) is a foundation for economic productivity and human wellbeing. However, the NI of the UK and other advanced economies face serious challenges which include: significant vulnerabilities, capacity limitations, and a number of NI components nearing the end of their useful life and etc. (CST, 2009). The UK Infrastructure Transition Research Consortium (ITRC) has been established, funded by EPSRC, to provide theoretical research, models and practical decision support tools to enable strategic analysis and planning of NI system; to respond to future demographic, social and lifestyle changes; and to build resilience to intensifying impacts of climate change. The research is divided into five Work Steams (WS) structured as indicated in Figure 1:

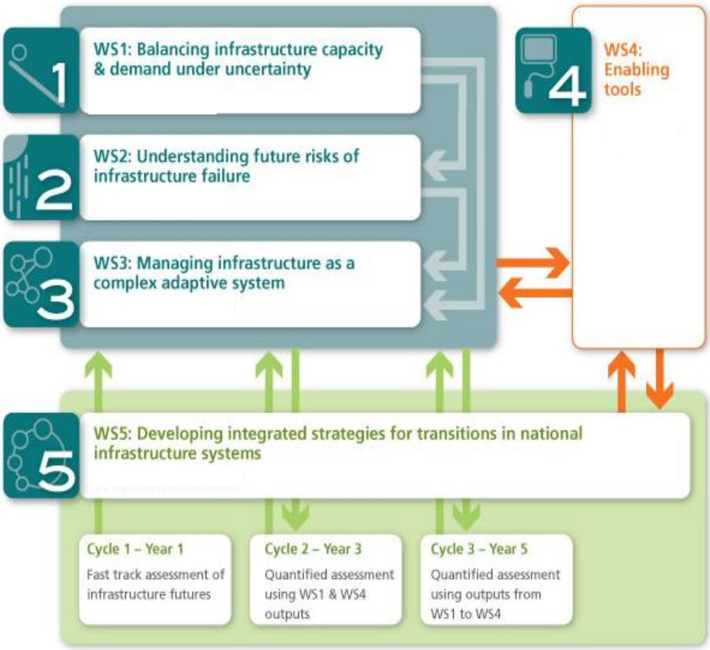

Figure 1 Overview of the ITRC Work Stream Structure (Source: Hall etc., 2012)

In WS1, a generic modelling framework for analysis of long term change in capacity and demand under uncertainty will be developed. In this paper, a framework will be provided for the projection of population change into the medium-term future. The disaggregation of these projections to individual household types will be demonstrated using a demographic microsimulation model (MSM). The energy sector will be used to demonstrate the deployment of the MSM as a means to estimate the infrastructure demand in response to demographic change.

2. Methodology and Dataset

2.1 Introduction

MSM approaches for energy demand analysis have attracted growing interest in recent years (e.g. Chingcuanco and Miller, 2011). In this research, a dynamic MSM is built to estimate domestic energy consumption for the whole country and for a long time period (to 2100). The modelling process is made up of three steps as illustrated in Figure 2: firstly, a series of population projection scenarios was built to create year specified aggregated population statistics at local authority level under different scenarios; secondly, the microsimulation model (PRM) was used to generate both individual and household micro-data; and at last, the detailed energy demand can be calculated based on the characteristics and behaviour of each household.

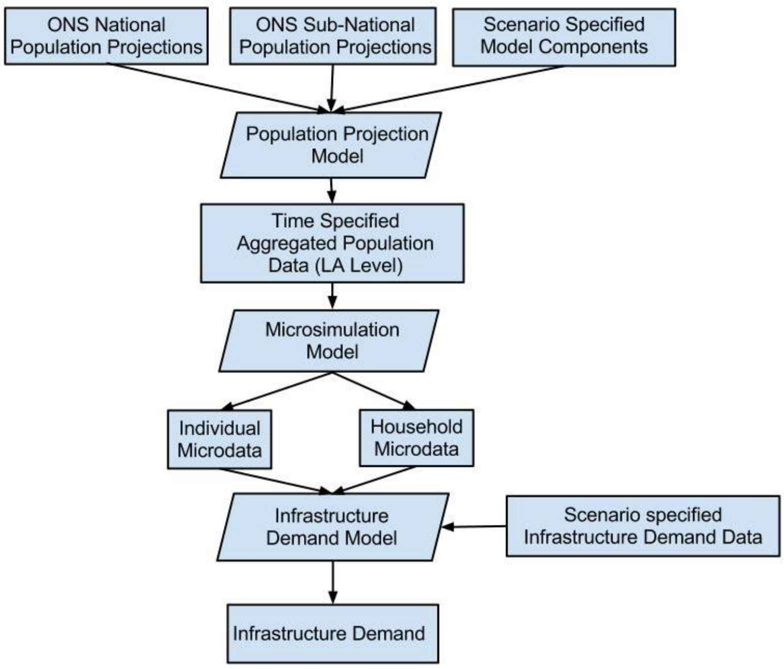

Figure 2 Modelling Process

2.2 Population Projection Under Different Scenarios

The aim of this process is to follow the methodology employed by ONS, and extends their national population projections (up to 2083) and sub-national population (up to 2033) to generate a local authority[1] (LA) specified aggregated population projection up to 2100. The population projection model is driven by three components: fertility, mortality and migration. For the fertility components, the dynamics are driven by the age specific fertility rate (ASFR). The current local ASFR is calculated by applying the regional fertility differential to the ASFR of ONS national projection. The same method was used to calculate the local age-specific mortality rate (ASMR). Since detailed migration forecasts and data are unpublished, migration is estimated based on the residual difference between the projection here and the ONS sub-national projection after constraining for the number of births and deaths in each region. The projections discussed here have been used to execute three different scenarios. The changes reflect ONS scenarios (Table 1)

Table 1 Projection components with different scenarios (ONS, 2008)

Scenario	Description	Fertility	Mortality	Migration
baseline	The typical baseline projection under normal conditions.	-	Assumes a 1% annual improvement (mortality drops by 1% per year in each age group)	-
high	High population: increased fertility and immigration, decreased mortality.	Increased by 10%	2% improvement rate	Additional 33% immigration.
low	Low population: decreased fertility and immigration, increased mortality.	Decreased by 10%.	No improvement rate	Less 33% immigration.

The figures below (Figure 3) summarize the projection results under the three different scenarios.

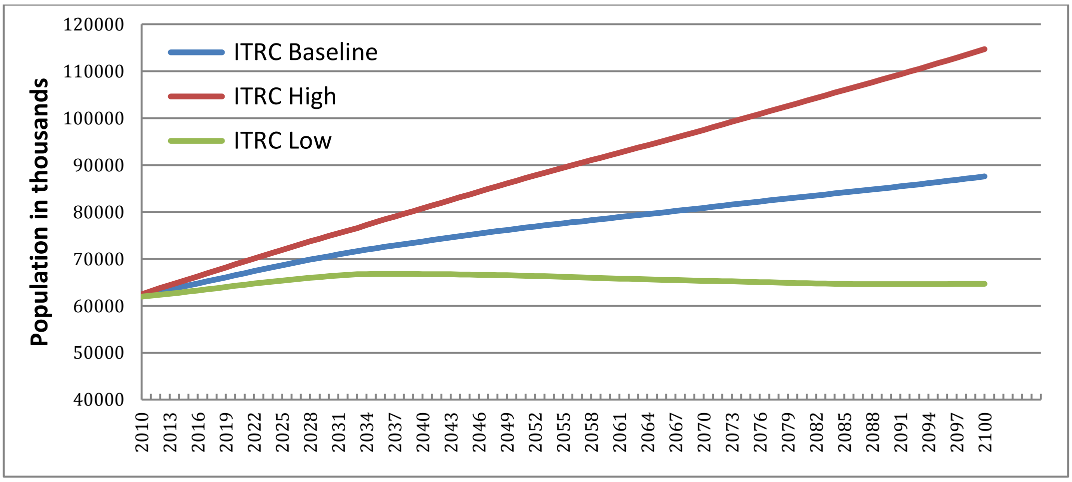

Figure 3 Population projection under different scenarios

[1] LA is an administrative geography with 480 spatial units in England and Wales, having an average population in the order of 40,000 households and 100,000 individuals.

In the baseline scenario, the population of Great Britain increases from 61 million to 84 million by 2083 and to 89 million by 2100. Figure 4 indicated the change of the age structure between 2010 and 2100 under three different scenarios. According to the projection results, the population will become progressively more elderly, which will have a profound impact on the provision of health and social services such as housing for which utilisation trends to increase with age.

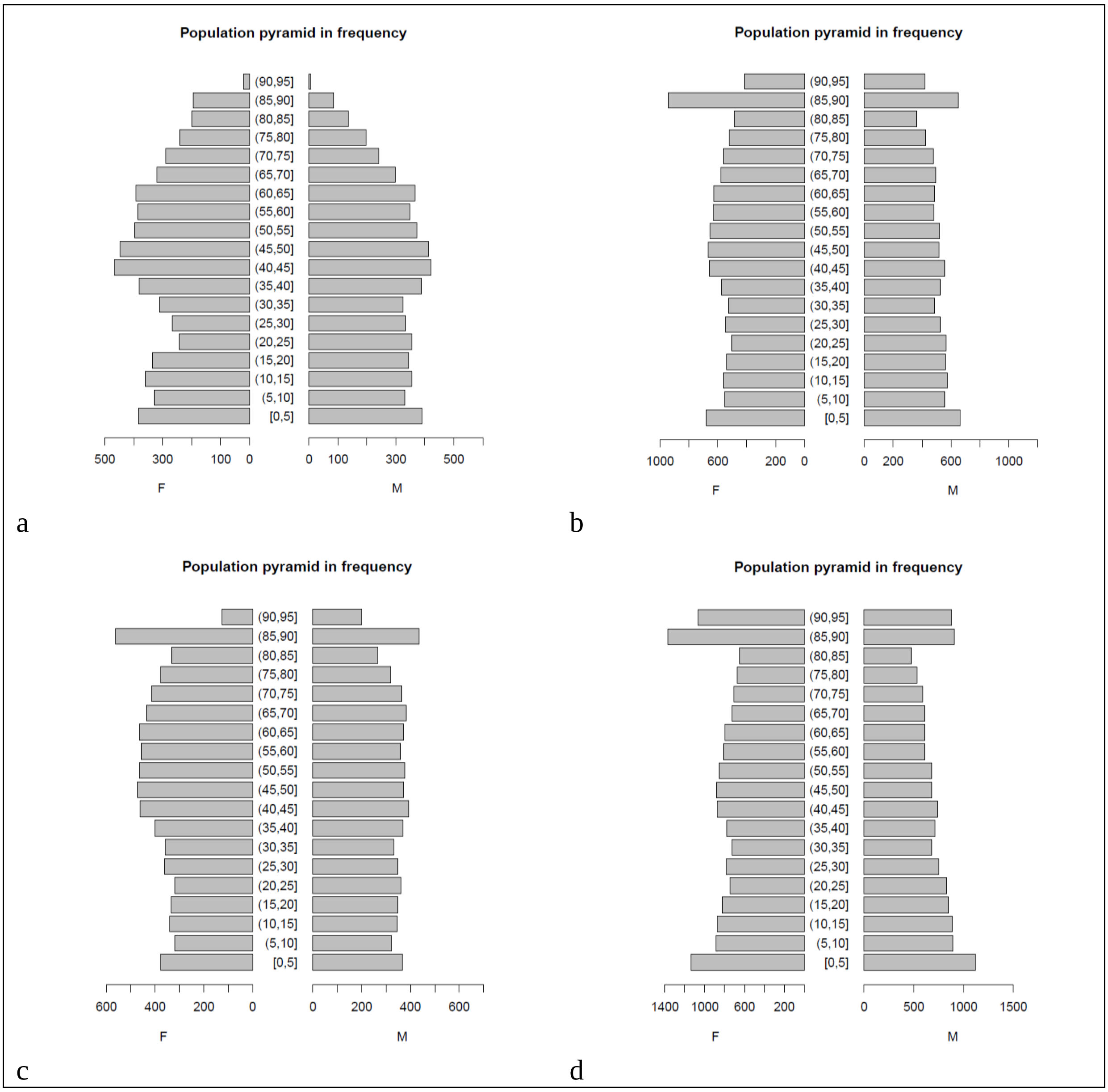

Figure 4 Population Pyramid for a) 2010, b) Baseline Scenario 2100, c) Low Scenario 2100, d) High Scenario 2100

2.3 Microsimulation

In this research, the Population Reconstruction Model (PRM) (Birkin, 2013) was used to recreate population data at individual level for each LA using a combination of two inputs: 1) the sample of anonymised records (SARs) data from census and 2) the small area statistics generated from the population projection model. The model creates a complete representation of the national population on an LA-by-LA basis. For each household and their component individuals, a wide variety of key socio-economic and demographic attributes comprising age, gender , marital status, occupation, ethnicity and health status, as well as housing variables including tenure, household size and composition will be represented. Figure 5 shows the growth of one-personed household from 2010 to 2100 under baseline scenario. As the figure suggests there will be a significant increase of one-person households in metropolitan areas.

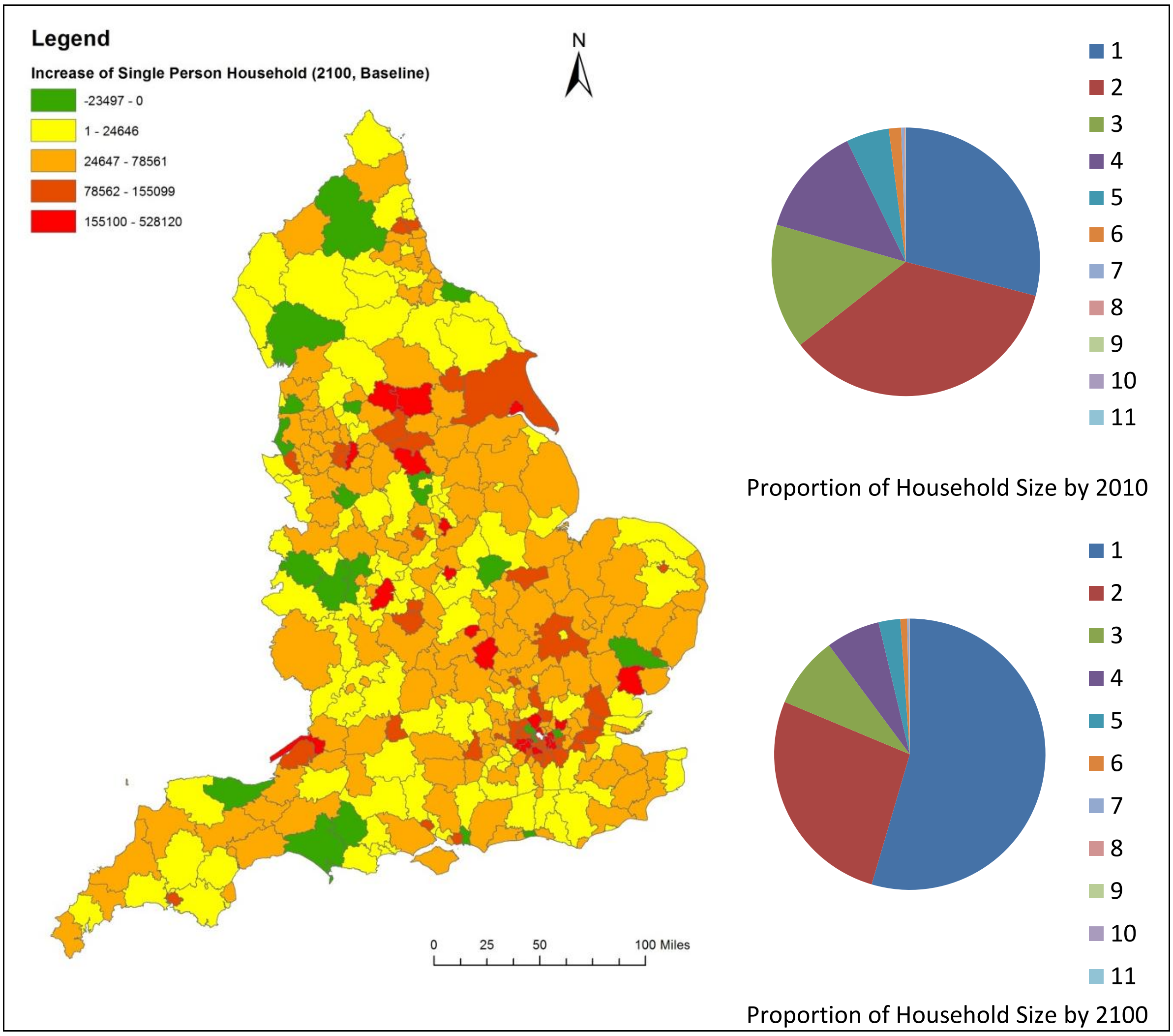

Figure 5 Increase of One-Person Households (2010-2100)

2.4 Infrastructure Demand Modelling

The infrastructure demand model is still under development. Recent studies (e.g. Duckman and Jackson, 2008) have demonstrated the feasibility of integrating the disaggregated household/demographic data into the infrastructure demand analysis.

For ITRC research, the household data has firstly been classified into six classes based on the size the number of retired people (age>65 for male and age>60 for female) and whether have children (age<18) as Table 2 indicated. At this stage in the ITRC research project household composition and location are taken as the major drivers of infrastructure demand. Households are classified in six types as shown in Table 2. Figure 6 shows the variation of the six categories of households during 2010 and 2100 in a rural area (Herefordshire), a metropolitan district (Leeds), an aged mid-sized town (Brighton) and in the urban fringe (Mid Bedfordshire).

Table 2 Classification of Household

Retired Household		Non-Retired Household			
1 person	2 or more persons	without children	1 adults with children	2 adults with children	3 or more adults with Children
1	2	3	4	5	6

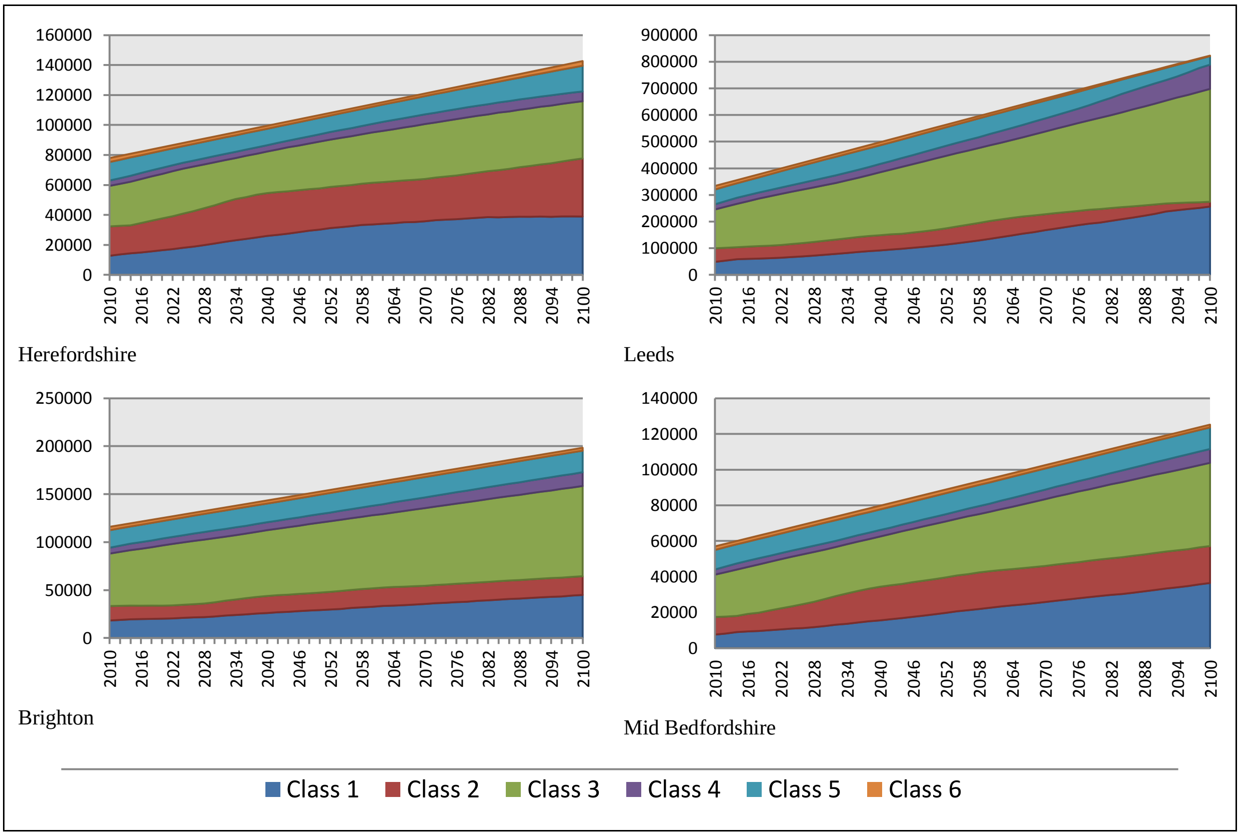

Figure 6 Variation of 6 classes during 2010 and 2100 at 4 local authorities

According to the simulation results, the increase in retired households (Class 1 and 2) is much greater in rural Herefordshire than urban Leeds; while in the urban area smaller households (Class 1, 3 and 4) have a significant increase. In this abstract, a straightforward estimation of energy consumption is presented based on the disaggregated household data and National Energy Efficiency Data Framework (NEED) published by DECC (2012) which considers household size and its location:

$$D_{total} = \sum D_{HH}(size) * ee_{region}/ee_{country} \quad [1]$$

where D_{total} represent the demand for energy of the whole country, $D_{HH}(size)$ represent the size specified household demand for energy which can be obtained from NEED dataset $ee_{region}/ee_{country}$ represents the regional differential in energy efficiency with ee_{region} and $ee_{country}$ represent the mean energy efficiency for the each specific region and for the whole country respectively. Figure 7 below shows the increasing of energy consumption by 2100 under the baseline scenario.

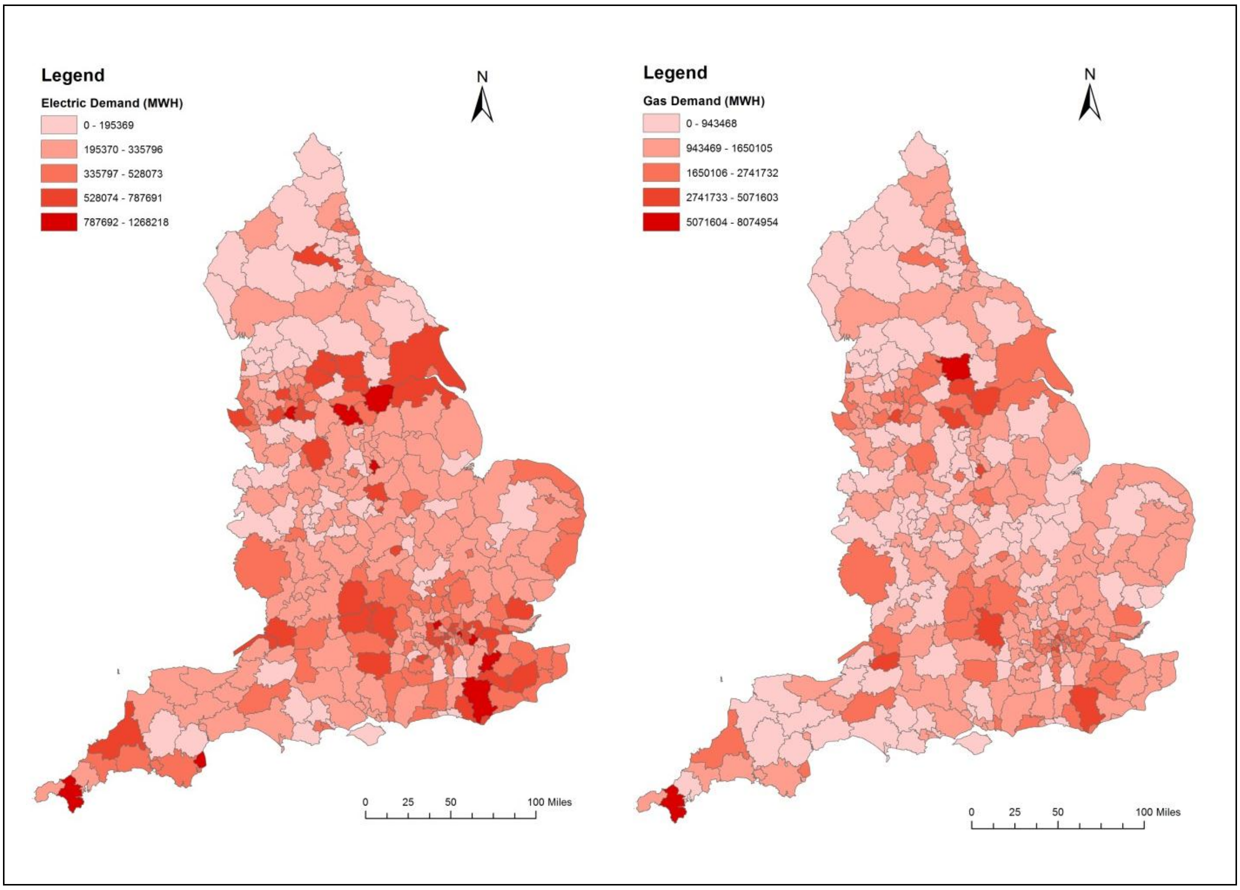

Figure 7 Demands for Electricity and Gas by 2100

3. Results and Discussion

According to the modelling results, total electricity and gas consumption will increase from 89TWh and 295TWh at 2010 to 156TWh and 477TWh at 2100 respectively under the baseline scenario, 112TWh and 351TWh under ONS Low Scenario, and 214TWh and 621TWh under ONS High scenario. Figure 8 shows the variation of the demand for energy for the 4 local authorities under different scenarios. In the future, the following research are proposed: 1) building different models for all of the four sectors (excluding ICT), 2) expanding the population projection scenarios to represent a more diverse range of population futures; 3) refining the demand model by considering more household characteristics; 4) taking household behaviour into account to create demand model with a higher temporal resolution; 5) integrating UKCP data into the simulation work to assess the demand change in the context of changing climate.

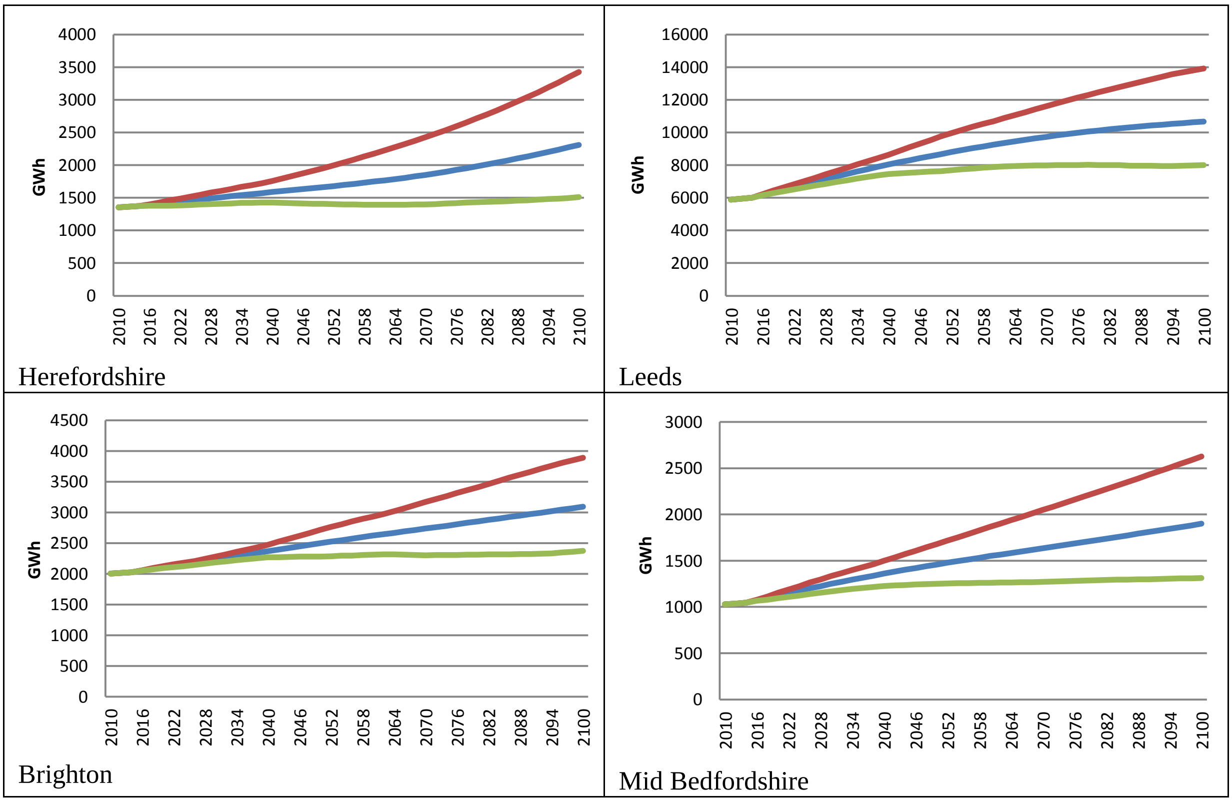

Figure 8 Demands for energy during 2010 to 2100 at 4 local authorities

Acknowledgement

The authors would like to gratefully acknowledge the support of EPSRC for the ITRC project.

References:

Birkin, M., (2013). Challenges for Spatial Dynamic Microsimulation Modelling, in Tanton, R., Edwards, K.L. (eds.) Spatial Microsimulation: A Reference Guide for Users, Springer, London

Chingcuanco, F.,and Miller, E. (2011), A microsimulation model of urban energy use: Modelling residential space heating demand in ILUTE, Computers, Environment and Urban System, 36(2), 186-194

Council for Science and Technology, (2009), A National Infrastructure for the 21st Century, London

Department for Environment and Climate Change (2012) National Energy Efficiency Data Framework

Duckman, A., and Jackson, T., (2008), Household energy consumption in the UK: A highly geographically and socio-economically disaggregated model, Energy Policy, 31(8), 3177-3192

Hall, J., Henriques, J., Hickford, A and Nicholls R. (eds.), (2012), A Fast Track Analysis of strategies for infrastructure provision in Great Britain: Full Report. Environmental Change Institute, University of Oxford.

Office for National Statistics, (2008), Reports on the 2008-based National Population Projections http://www.ons.gov.uk/ons/rel/npp/national-population-projections/2008-based-projections/national-population-projections.pdf