Energy modelling of regions using stakeholder generated visions as scenarios

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Abstract

To achieve the UK Government Carbon Emissions targets, large scale retrofitting of the built environment is required. This paper will explore the changes required to achieve the retrofitting targets for dwellings based on visions of the character of the Cardiff City region in 2050. The three visions of a utopian future: i) Connected Cardiff; ii) Compact Cardiff–Wilderness Valleys; iii) Orchard Cardiff City-Region represent scenarios with different societal and land use changes. They all achieve the 80% reductions required, but have different pathways to this goal.

Building on earlier work based on "Bottom Up" urban scale model EEP, this paper will outline the modelling of large areas using extensive data sources that describe the existing stock. Together with the scenario work, this research models societal changes represented by population and household size change and the associated energy use. The paper discusses data sources required and methods to model population and household changes.

The results generated from the model show the retrofit pathways required to achieve the targets set. In addition the outcomes of the research are visualised through mapping of the pathways across the Cardiff City region.

Introduction

The UK government has set an ambitious target of 80% reduction of carbon emissions by the year 2050. As the vast majority of buildings that will exist in 2050 have already been built, and the interactions of the carbon emission reduction methods, such as fabric improvements, occupant behaviour and renewable technologies in the urban retrofit design process need to be researched further.

The Welsh Government have committed to achieving annual emissions reductions of 3% carbon equivalents in areas within their competence (WAG, 2010a). In addition, power generation emissions are also included in the 3% target, by assigning them to the end-users. This is in recognition of the importance of reducing electricity consumption as part of achieving sustainability goals. Taking the above into account, the residential sector becomes a key target area for reductions as it represent 30% of the emissions within Welsh Government competence (WAG, 2008) and the aspiration has been expressed to make all new buildings "zero carbon" in future. Other goals include reducing the use of carbon-based energy by 80-90%, and at least matching electricity consumption in Wales with power generated from renewable sources by 2025 (WAG, 2009) which would translate to more than 30TWh of renewable electricity and 3TWh of renewable heat per year.

More ambitious views have also been expressed, which involve generating twice as much renewable electricity in 2025 as presently consumed in Wales, and covering all local energy needs by low carbon electricity by 2050 (WAG, 2010b). In this context, local authorities in Wales share the responsibility of improving and maintaining building stock condition to certain levels of sustainability (NAW, 2001), and promoting the deployment of renewable energy schemes in their area (WAG, 2010c). The Welsh residential sector has a larger share of hard to treat properties compared to the rest of the UK. This could mean higher potential for energy efficiency improvements but also higher

associated marginal costs (Baker and Preston, 2006). There is currently no representative residential stock model for Wales, and studies quoted in literature model the region based on data from other parts of the UK (Hinnels et al, 2007). In view of the policy targets and stakeholder responsibilities at the local authority level, it is necessary to obtain a more accurate portrayal of the sector in order to address stock-specific constraints and opportunities in Wales. Recent research has used a top-down model to derive insights on the impact of retrofit measures at local authority level (Gandhi et al. 2012). Focusing within the local authority at a lower level, this bottom-up approach goes one step further to demonstrate the possibility of providing policy makers and stakeholders at the local level with valuable information on the potential for retrofit based on area specific data.

Cardiff City Region

The concept of a Cardiff or South East Wales city region was a rather vague one without a clear geographic or administrative boundary, or governance structure. . For the purposes of this paper a broad view of the city-region was taken including the local authorities of Neath Port Talbot and Swansea to the west. This was intended to capture the strong economic connections between the three urban regions along the south coast (Newport, Cardiff and Swansea) which differ significantly from the neighbouring rural regions of West and Mid Wales. More recently the Welsh government has announced the creation of separate City Region Boards for Cardiff South East Wales and Swansea Bay.

The Cardiff City Region, as defined for the purposes of this paper, is home to some 1.86 million people. That is 60% of Wales' population despite spanning only 17% of its area. Indeed, the three urban centres of Swansea, Cardiff and Newport account for 24% of the Welsh population. Population density varies across the project area, with Cardiff by far the most concentrated.

The region has been divided by Welsh Government into four zones which cross the local authority boundaries, Head of the Valleys, Connections Corridor, Cardiff Coastal Zone, and Swansea Coastal Zone (figure 1). These zones have been used in the visioning to express the population movement of the City region from 2014 to 2050.

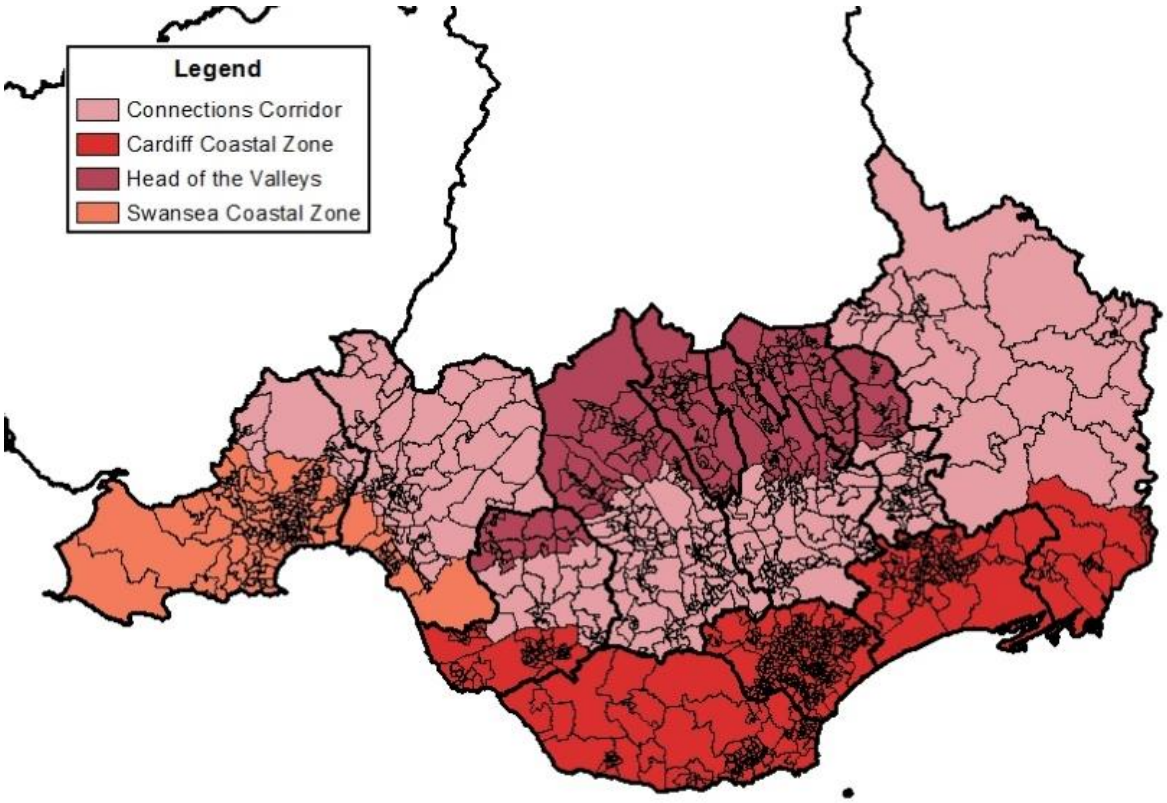

Figure 1 Regional zones (Welsh Government 2008)

Visioning process

The Retrofit 2050 project created three contrasting long term (2050) visions for retrofit city-regional futures, developed through an extensive research process that spanned 2011-2013, including: a series of workshops that brought together national experts in the fields of water, waste, energy and transport. These contextual scenarios were intended as a tool which can be adapted and used by a wide variety of stakeholders and organisations to stimulate discussion and inform future policy and long-term planning (Eames 2014).

The three visions each describe distinctive long-term visions of what a sustainable future might look like for core UK city regions in 2050. The three visions are:

- Smart-Networked City: envisages the city as a hub within a highly mobile and competitive globally networked society.
- Compact City: envisages the city as a site of intensive and efficient urban living.
- Self Reliant-Green City: envisages the city as a self-reliant bio-region, living in harmony with nature.

Each of these futures is described by two key dimensions of change for systemic urban retrofitting: change in land-use and urban form; social values and institutions.

Regional visions

The national visions were then grounded in the Cardiff city region by the Retrofit 2050 project team using workshops incorporating regional stakeholders from local government, industry and civil

society groups, semi-structured interviews with regional stakeholders and a desk-based review of relevant policy documents and grey literature.

The Cardiff 2050 City Regional Scenarios therefore represent an exploration of how these different articulations of urban sustainability can be manifest and grounded in the economic, political, social, technological and ecological transformation processes shaping the development of Cardiff and South East Wales. The narrative for each of the Cardiff scenarios is built upon a 'pitch' developed by the participants during the regional workshop, intended to summarise Cardiff's bid for the prize of 'best retrofit city' in a fictional future 'European Sustainable Cities of 2050' competition. The very different assumptions about future population and settlement patterns embodied in the scenarios also reflect the divergent views of the expert participants in the regional workshop.

The modelling of these visions explores the change in population and household size to develop a stock profile of the Cardiff City region in 2050 (Table 1). This profile has been modelled to guide policy makers to the extent of the retrofitting required to achieve the UK Government 2050 emission reduction targets.

	Connected Cardiff	Compact Cardiff - Wilderness Valleys	Orchard Cardiff
Indicative population and population changes (2050)	2.75 million High population growth Inward migration	2.25 million Moderate population growth Internal re-distribution	1.75 million Moderate population decline Outward migration
Household size (2050) persons per house	1.95 Business as usual trend	2.32 City centre living	2.60 Return to 1970 household sizes
Change in building stock composition (2014-2050)	640,000 New build 770,000 Retrofitted 30,000 Demolished	310,000 New build 660,000 Retrofitted 140,000 Demolished	60,000 New build 610,000 Retrofitted 190,000 Demolished

Table 1 Scenarios Summary and Indicative Indicators

Cardiff city Regions stock

The Cardiff City Region, as defined for the purpose of this chapter, consists of 12 Welsh Local Authorities. Within this region, nestled along the south coast, are Wales' 3 major urban areas (Newport, Cardiff and Swansea) which account for 24% of the Welsh population. Inland from these urban areas is the South Wales coal field and the communities that evolved due to the industrial revolution. The region therefore consists of densely populated valleys and coastal cities as well sparser areas such as those found in the Vale of Glamorgan and Monmouthshire which have remained largely rural in nature. The Office for National Statistics' hierarchical system builds up from clusters of adjacent postcodes into areas of a similar number of households (Output areas) forming a logical geographical base for analysing the housing stock.

A region's housing stock is a consequence of its past: of the techniques used when built and the major and minor modifications made through the years. Subtle and dramatic variations can be observed both between and within areas. Understanding and representing these variations is key to modelling the energy consumption of dwellings at a regional scale.

When compared to the UK housing stock, Cardiff City Region's stock contains a substantially larger proportion of pre 1919 terraced houses with a relatively low proportion of new builds (Figure 2). In order to model future visions, the region's stock must be analysed on smaller geographical levels, allowing the representation of current and potential economic and social situations.

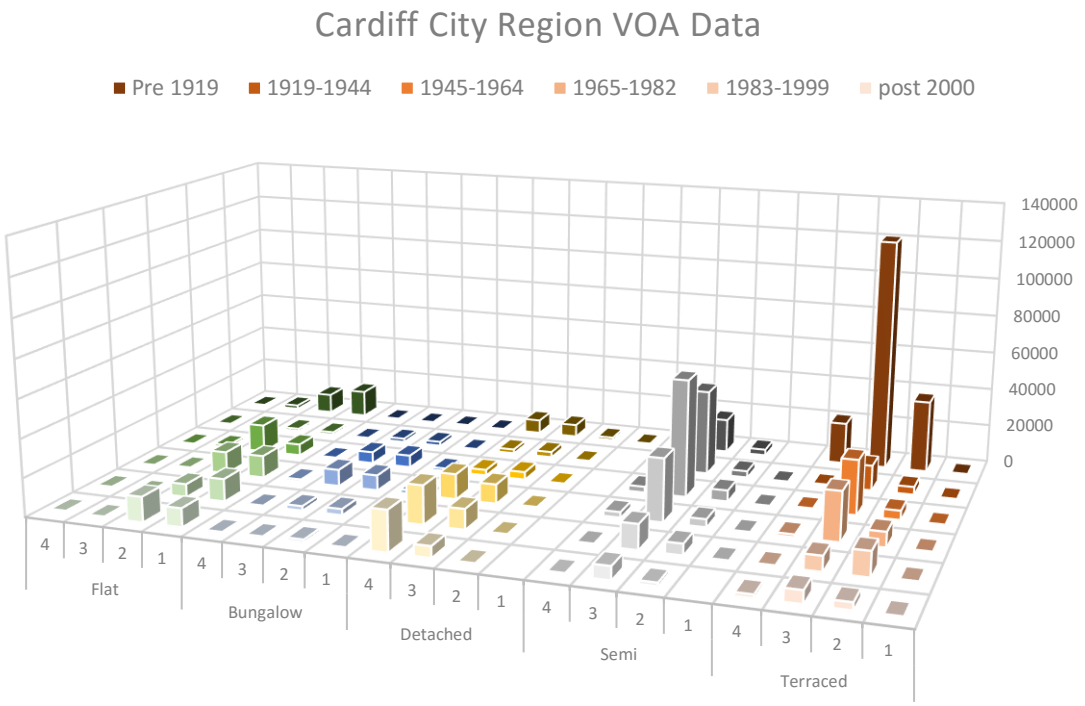

Figure 2 Cardiff City Region building stock breakdown (VOA data)

Modelling at an urban scale

Modelling the energy consumption of domestic buildings at an urban or regional scale has traditionally been undertaken in a top-down policy orientated way, where the gross energy consumption data provided by the energy suppliers is used as a starting point (Swan and Ugursal 2009). This data is then analysed using stock surveys to give average composite buildings that can be analysed (Gouldson et al. 2012) using building modelling techniques. This top-down approach is reliant on historical data to produce predictions, rather than based on building physics modelling. This method has inherent difficultly in dealing with new technologies and changes in occupant behaviour and their likely impact on future energy consumption.

Alternatively bottom-up approaches have the potential to model buildings in great detail to take into account complex interactions of building occupants, passive design and active systems. Initial attempts to model at the urban scale through a bottom-up modelling approach such as the Energy and Environment Prediction model (EEP) (Jones, et al. 2007) are based on steady state models, such as the Standard Assessment Procedure (SAP) (BRE 1998). They predict the energy consumption for archetypes of buildings that represent the considered building stock. In a recent review (Sanaieian et al. 2014), EEP was still considered one of the primary methods for modelling energy performance of buildings at an urban scale. Kavgic et al. (2010) described the model as an exemplar and base their work firmly on its achievements.

EEP model

The EEP model simplifies the simulation of the urban environment by using simple standard energy prediction tools, and ways of grouping houses together. The grouping of houses usually follows the type of house e.g. terraced, semi-detached or detached, which is reasonable for simple problems, but when trying to predict the energy use of a detached house it could be two ends of a very large scale, from a labourers cottage to a mansion. The logical way to further group houses is by their size and when they were built. To do this a number of common house types are surveyed, and the results of these surveys are clustered together to give groups of houses with similar energy predictions.

The EEP model uses the UK government's Standard Assessment Procedure (SAP) (BRE, 1998) as the method for measuring the carbon emissions related to residential building stock. The model within EEP has been adapted to allow the modelling of fabric retrofit, building integrated renewable technologies and occupant behaviour. The EEP model allows for "what if" functions to target different retrofit options, and this capability has been developed further using the population and household size predictions from the ONS and stakeholder derived visions for 2050 allowing the domestic energy demand for a small census area to be tracked through time.

Data sources

As large numbers of dwellings are considered when studying a city or region, it is important that the information about each dwelling is easily collected and modelled. A number of datasets were investigated including Valuation Office Agency data which has a complete breakdown of property types down to LSOA level, and the UK Map dataset which is a GIS based classification of building blocks – age, typology, floor area and building heights. These building based datasets were compared to the Census which has a wide range of single or bivariate data on LSOA or OA level. Finally, energy efficiency measure installation data is required to predict the energy performance of buildings. The Energy Saving Trust's Home Energy Efficiency Database (HEED) which contains records of energy efficiency installations grouped by local authority, age and typology and DECC's NEED database which is a weighted sample of properties on a regional level were used.

From these datasets a procedure was developed for use within the model that groups together dwellings with similar energy performance characteristics creating 'house types'. This needs fewer calculations when the whole or large sectors of the local authority are investigated. For example, if all houses within an area can be reduced to 240 types based on built age, typology and size, then subsequent calculations only have to deal with 240 house types and not every house in the area. This allows real time calculations to be carried out, such as estimating the consequences of applying specific energy saving measures.

A cluster analysis technique, similar to the EEP model, was used to identify dwellings with similar energy consumption and carbon dioxide emissions. The characteristics chosen for the clustering are considered to have the greatest influence on domestic energy performance (Table 2).

City region scenario modelling

Three visions of urban sustainability: a 'smart' city future, a 'compact' and a self-reliant green' city regional future, have been used as the basis for a regional building stock model. The order of modelling does not follow chronologically but rather follows the order described by the numbering in figure 3: (1) 2014/15 -> (2) 1990 -> (3a, 3b, 3c) 2050-> (4ai, 4bi, 4ci …) 2015 to 2050. This stock model starts from the baseline of 2014/15 and moves backwards to 1990. The 1990 model is to be used to measure the visions' ability to reach the 80% reduction in carbon emissions by 2050 compared to 1990. The

model will then attempt to represent the region in 2050 according to the three visions. Pathways to reach the 2050 visions will then be modelled in steps of five years from 2015 to 2050.

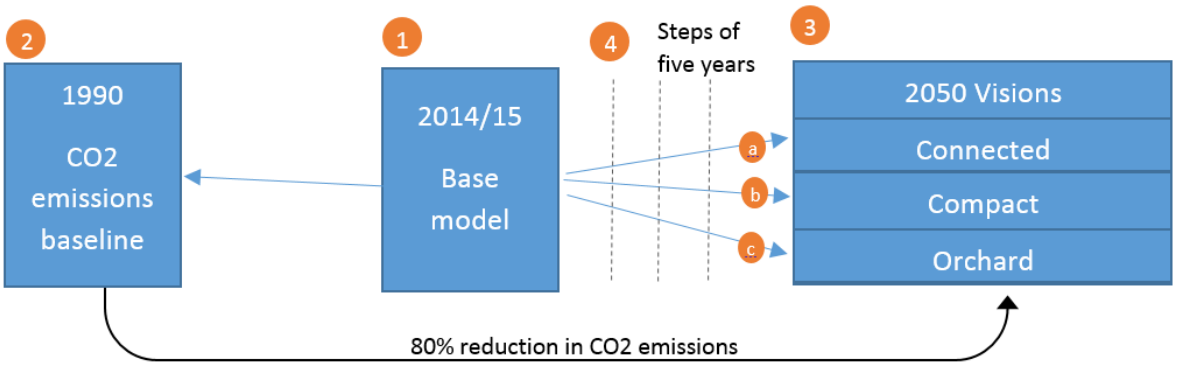

Figure 3 Order of modelling of the city region models.

Number of dwellings – 2014/15

The baseline model is based on the Valuation Office Agency's (VOA) 2014 database of the UK's current housing stock per LSOA. The data gives the number of each property type in each LSOA and distinguishes properties as shown in Table 2.

Age	one of 12 built periods	Pre 1900, 1900-1918, 1919- 1929, 1930-1939, 1945-1954, 1955-1964, 1965-1972, 1983-1992, 1993-1999, 2000-2009, 2010-2014, Post 2014
Typology	one of 5 typologies	Bungalow, Detached, Flat/maisonette, Terraced, Semi,
Size	number of bedrooms	1, 2, 3, 4+,

Table 2 Property Types – Age, Typology and Size

This give 240 types of property types allowing detailed modelling of the building stock to be undertaken.

Number of dwellings - 1990

The number of dwellings in the 1990 model per LSOA was based on the number of dwellings built before 1993 in the VOA database.

Number of dwellings – 2050 Scenarios

The 2050 scenarios developed for the region outlines the approximate number of dwellings built and demolished by the year 2050. Within the narratives of these visions, conditions for the demolition and building of new dwellings were derived:

Connected Cardiff

- New build in peri-urban – Large Increase
- New build in less dense urban – Large Increase
- Expanding housing supply
- 30,000 dwellings demolished (4%)
- 640,000 new build

Compact Cardiff - Wilderness Valleys

- New build in less dense urban – Moderate Increase
- A lot of the valleys towns uninhabited, uplands demolished, more wild sparse hinterland
- Growth of medium to high density urban conurbations
- High density neighbourhood centres within/around Swansea, Bridgend, Cardiff, Newport
- 140,000 dwellings demolished (17%)
- 310,000 new build

Orchard Cardiff

- Demolition of poor dense stock – Moderate decrease
- Demolition urban/peri-urban
- 190,000 demolished (24%)
- 60,000 new build

These conditions can be modelled on LSOA levels using the four geographical indicators rurality (figure 4), flood risk (figure 5), regional zone (figure 1) and density as a percentage of built upon land. Some of the vision data cannot be modelled as it would be required to identify geographical areas within LSOAs. As the model is based on LSOA level data, these conditions are not modelled for the demolition and new build in the compact vision. In spite of this, it is hoped that the modelled scenarios using the above indicators can represent the three visions of urban sustainability reasonably accurately.

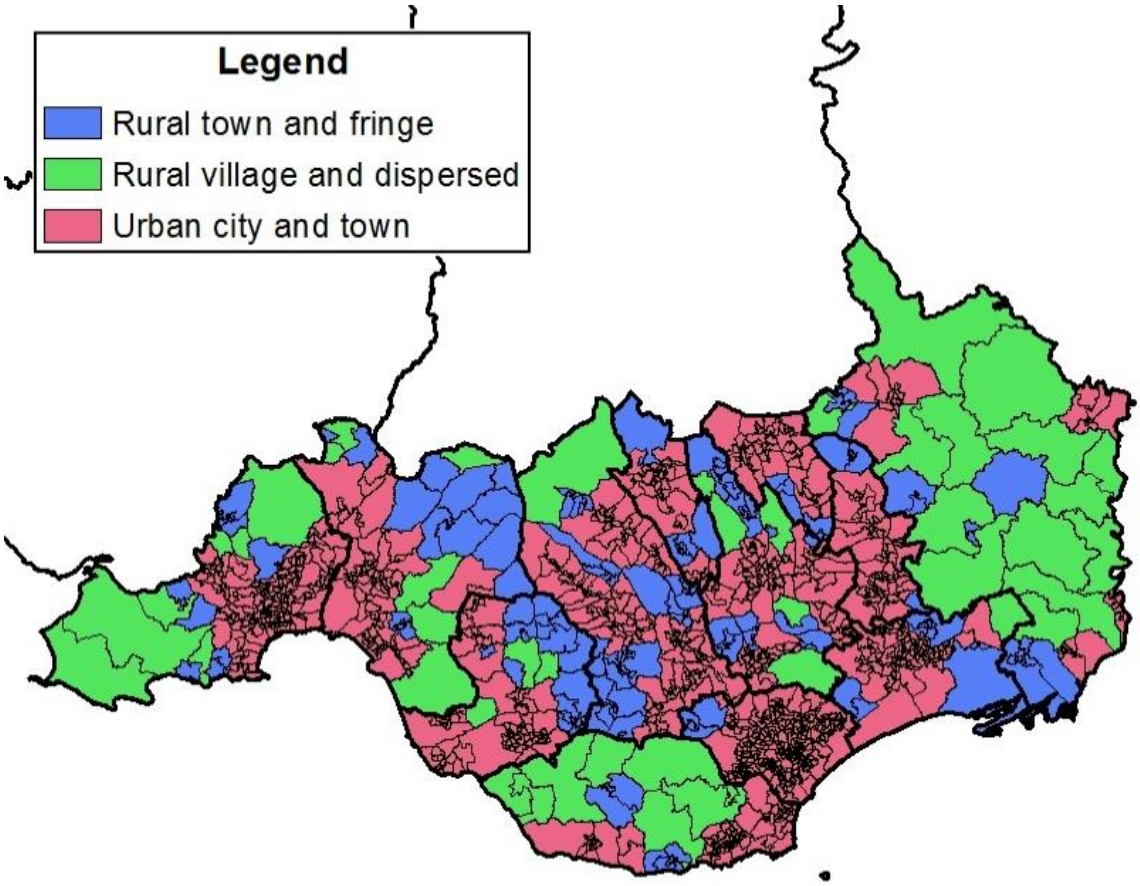

Figure 4 LSOA rurality (Office for National Statistics 2011)

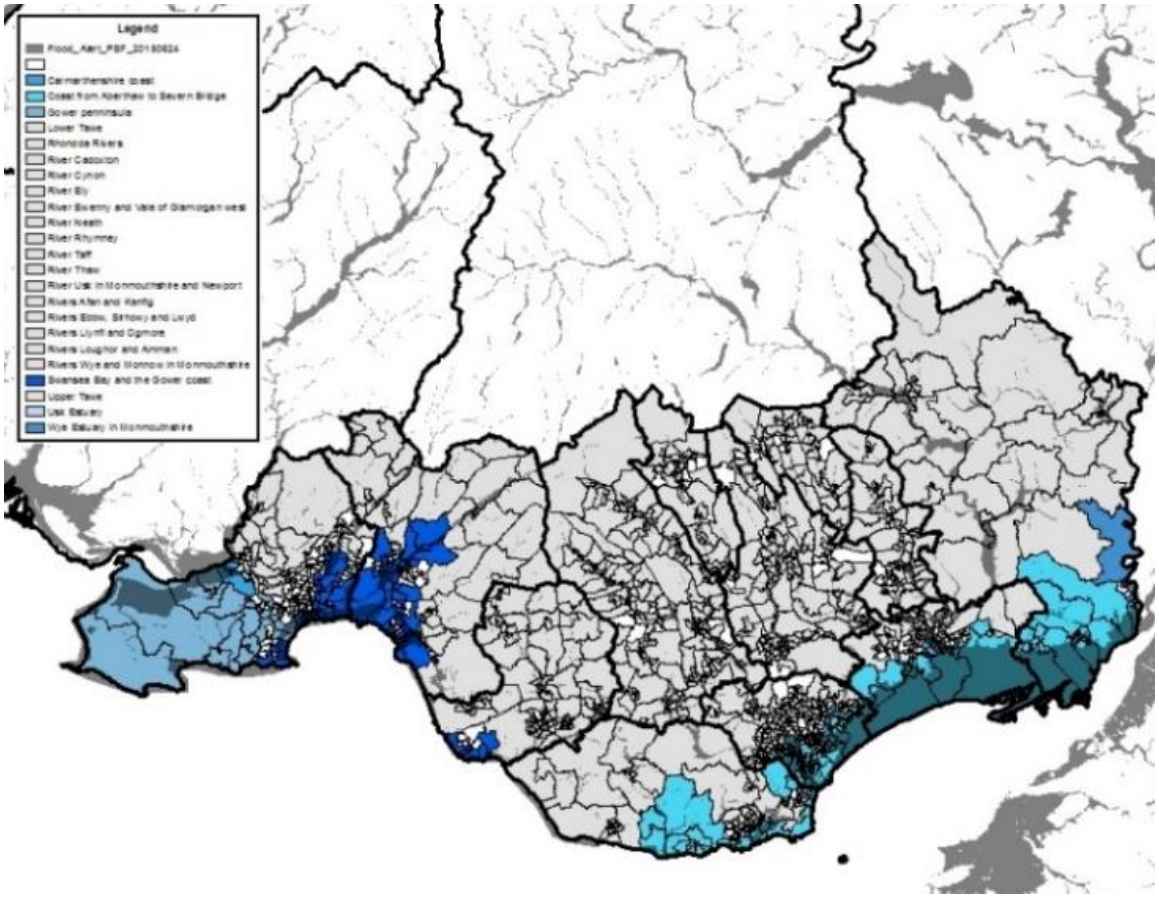

Figure 5 Flood risk map for City region (NRW 2015)

Results from modelling

The outcome of the modelling process allows the Cardiff city region to be modelled from 1990 to 2050. The population and household size projections for the three visions are very different and the modelling of these considering the data at a LSOA level shows the different pathways to the visions in 2050. In the maps of number of households (figures 6 to 9) the existing levels show a reasonable consistent level of building density throughout the region (Figure 6). The Connected Cardiff vision takes advantage of the lower valleys' connected corridor as a resource for increasing housing, building on the proposed Metro and a shift towards the use of public transport to deliver future development of the economy. This is shown with an increased urbanisation of the corridor highlighted by the dark red LSOAs on the map (Figure 7). The Compact Cardiff vision deals with flood risks through flood defences based upon tidal lagoons and barrages and shows massive densification of housing (darker southern LSOAs) in the coastal zone of the city region. In addition the re-wilderness of the upper valleys lead by the demolition of hard to treat housing is shown by the lighter shades towards the north and the Heads of the Valleys zone (Figure 8). The Orchard Cardiff vision expresses the greening of the city centres (lighter shades) and the increase use of a Metro system to provide access to land throughout the city region (Figure 9).

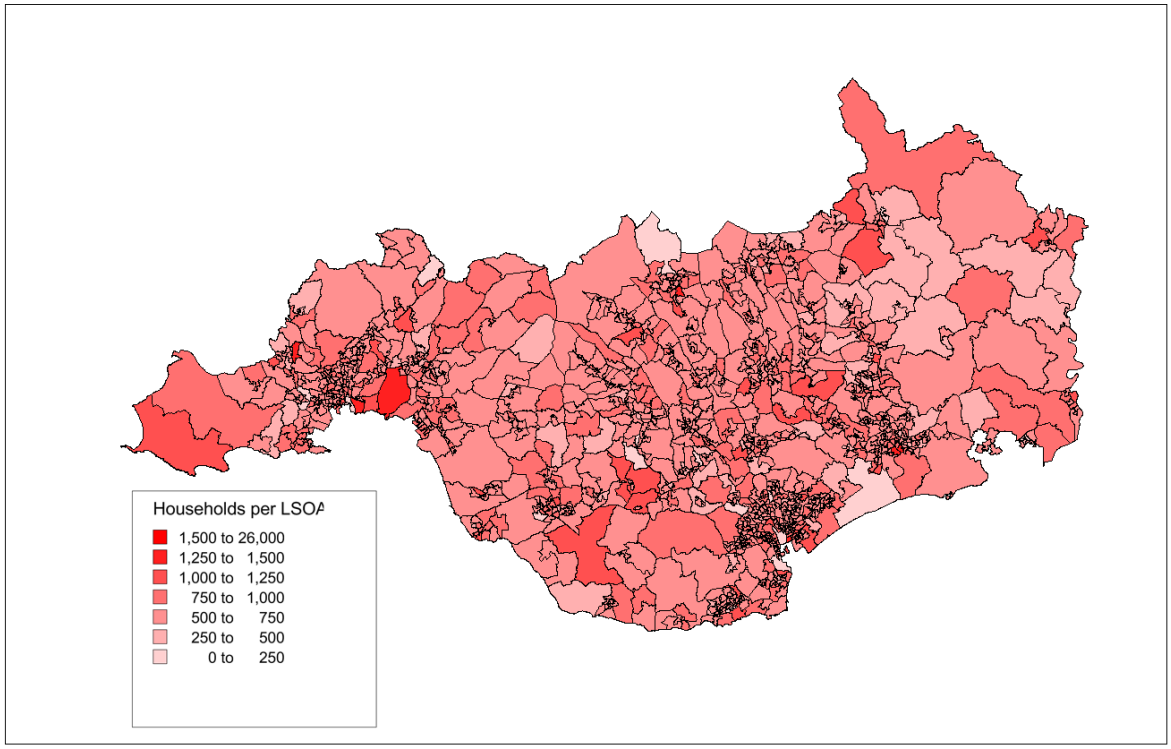

Figure 6 Existing households per LSOA

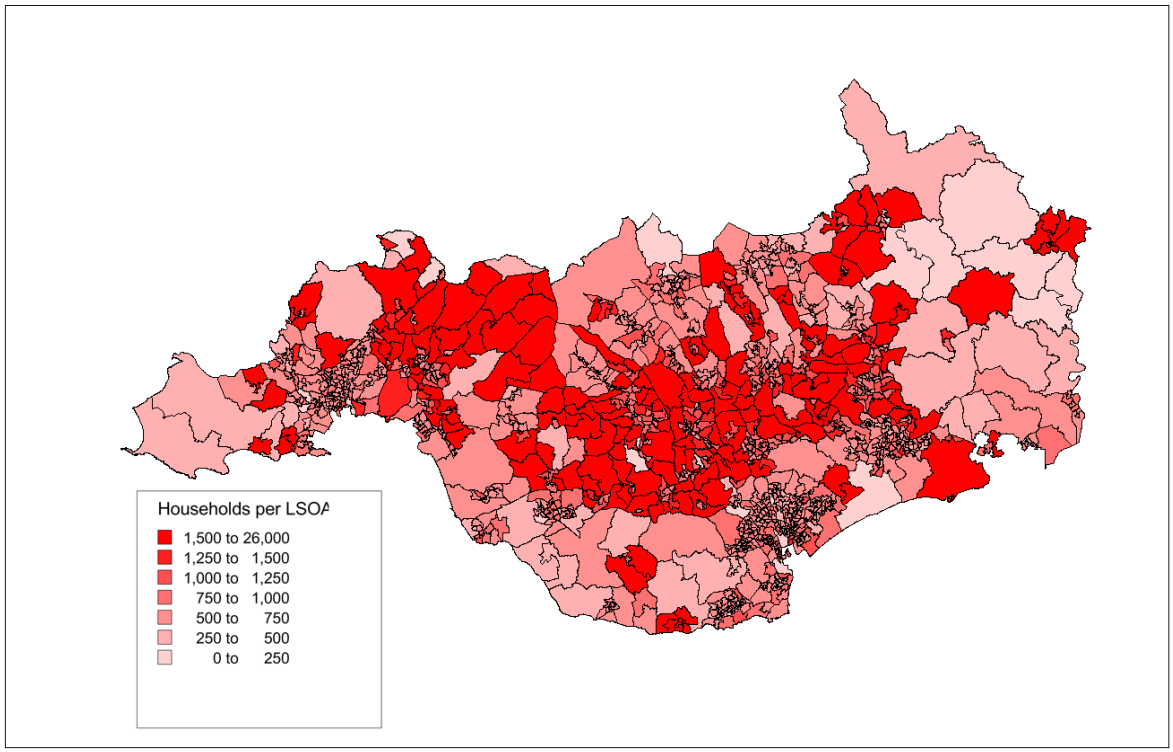

Figure 7 Households per LSOA for Retrofit 2050 Connected Cardiff Vision

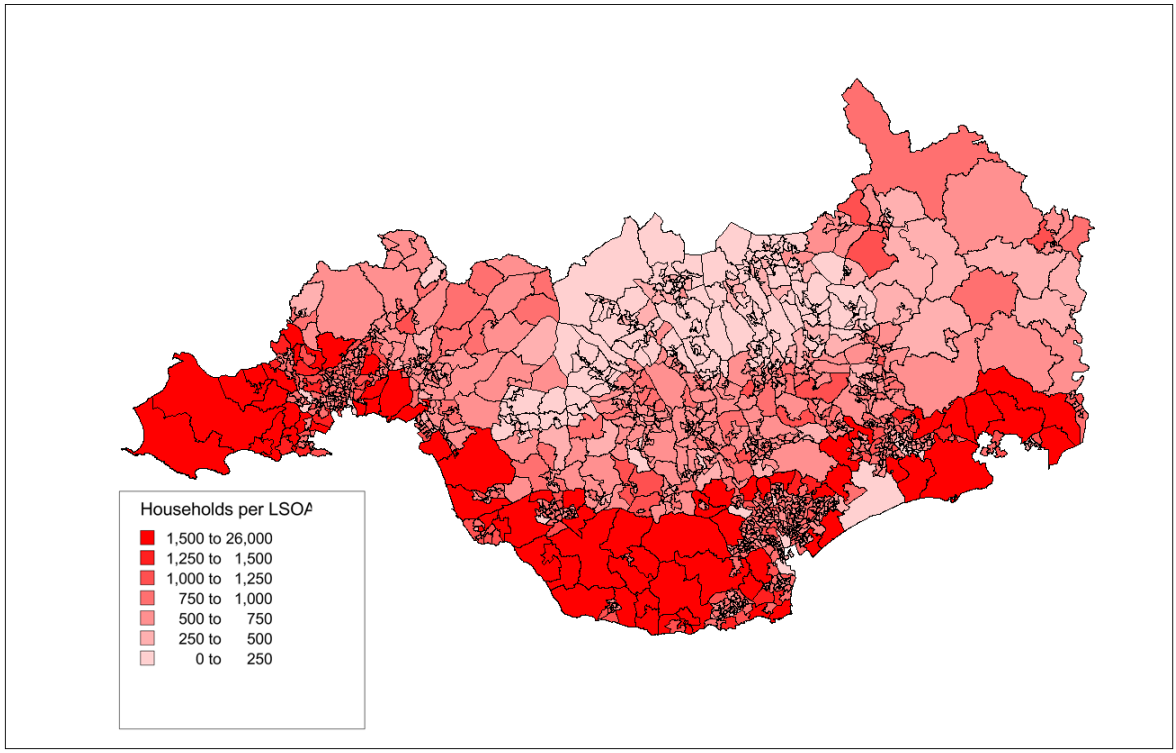

Figure 8 Households per LSOA for Retrofit 2050 Compact Cardiff Vision

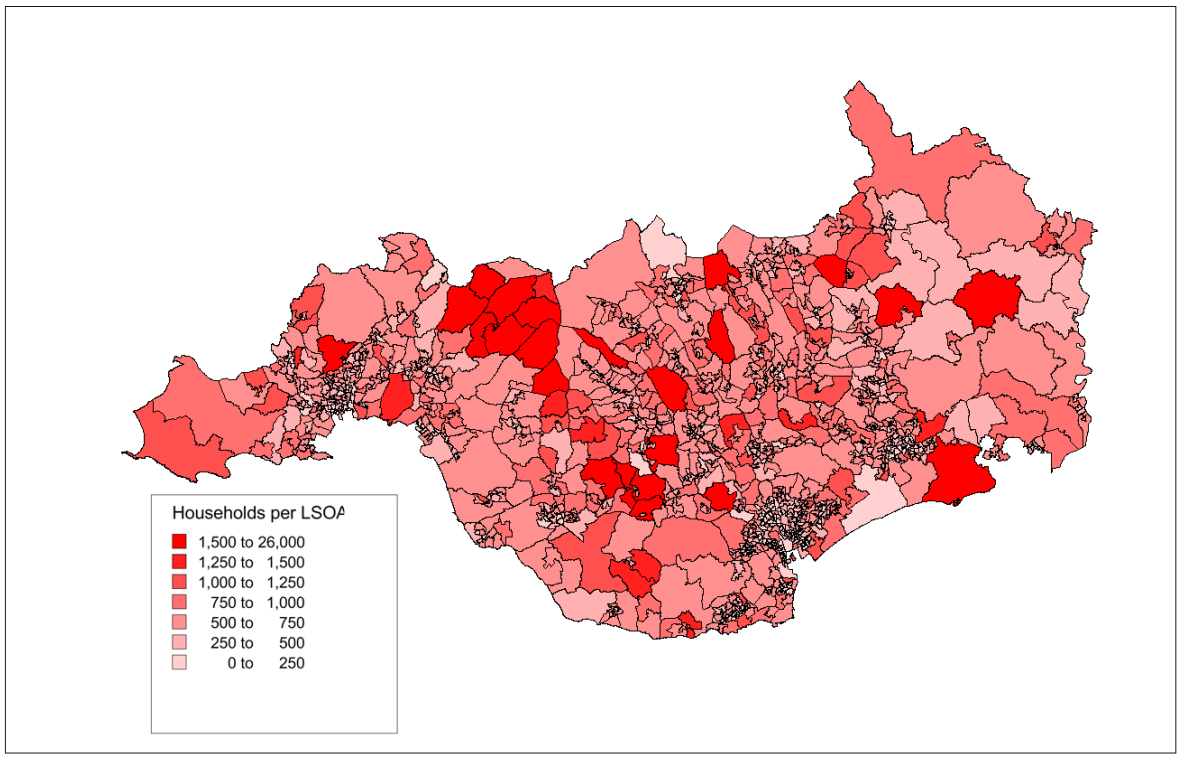

Figure 9 Households per LSOA for Retrofit 2050 Orchard Cardiff Vision

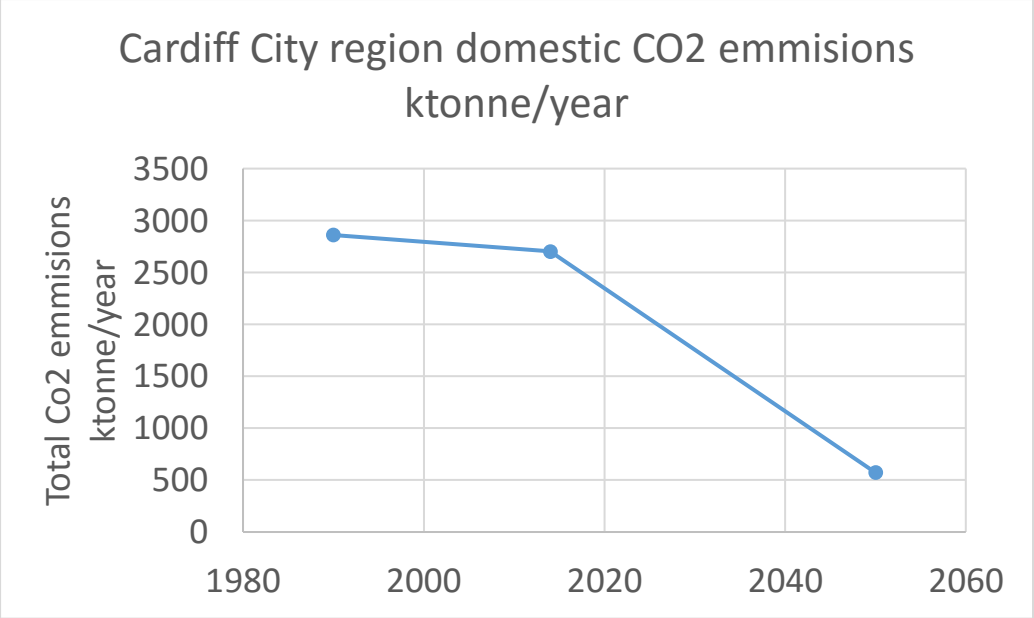

Figure 10 Overall progress to the 80% target reduction in Carbon emissions

When the region is considered as a whole the vision process is based on the premise that carbon emissions will be reduced by 80%. Using the modelling that has been undertaken it can be seen that there has been a 5.5% reduction in emissions in the 24 years from 1990 to 2014 (Figure 10). This leaves the remaining 74.5% reduction to take place over the next 36 years. In terms of annual reduction from 1990 to 2014 there has been a 0.2% annual reduction, the next 36 years will need an annual reduction of 2%.

Conclusions

The paper has shown that it is possible to build a "Bottom Up" urban scale model to describe the modelling of large areas using extensive data sources of the existing stock. This model has been merged with a scenario work based on City Regional visions of a future that achieves the 80% target. The model includes societal changes represented by population and household size change together with geographical indicators such as rurality (figure 4), flood risk (figure 5), regional zone (figure 1) and density as a percentage of built upon land. The sources of the data required are becoming more available and complete and as such give more confidence in model outcomes. The methods of modelling population and household changes are generally applied at a Local Authority level, in this model these are combined with housing data (VOA data) and the migration and stock levels gained from the visions.

The results generated from the model show the retrofit pathways required to achieve the targets set. In addition the outcomes of the research are visualised through mapping of the pathways across the Cardiff City region.

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