CASA0009 - Spatial Data Capture, Storage and Analysis

Wales Housing Energy Efficiency

The Energetic Mappers:
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1. Introduction

In the context of Climate Change, nations around the world established their commitment to act on its causes and adapt to its consequences (FCCC, 2015). By 2025, Wales plans to achieve its energy efficiency potential and become a model in implementing energy efficiency technology (Welsh Government, 2019a). To accomplish this goal, the Welsh Government is aligned with the EU and UK's obligations to reduce carbon emissions and achieve net-zero carbon goals. Through the Environment Bill, Wales has set the goal to decrease emissions by at least 80% by 2050 (Welsh Government, 2019a).

This study explores one of the contributing sectors to Climate Change: residential housing. It verifies if the strategy planned for Wales to achieve the net-zero carbon goals changes the overall energy efficiency of its properties. Likewise, if such an impact exists, it explores how this would impact the housing market. Therefore, this study aims to answer two questions:

1. How will housing prices change based on improvements in Energy Performance Certificate (EPC) ratings?
2. How will an increase in energy efficiency impact emissions?

This analysis utilises a recently created dataset that enhances the UK Land Registry dataset by georeferencing and linking it with domestic Energy Performance Certificates (Chi *et al.*, 2019). A representative sample of homes sold in Wales during the years 2011 and 2019 was analysed. The results of this study are also shared on the following website and aim to inform energy policy making about the potential benefits of increasing the energy efficiency of residential housing.

2. Background

Business and housing in Wales account for nearly one-third of all greenhouse gases emissions, with the residential sector specifically responsible for 9.5% of the total emissions (Welsh Government, 2019a) (Figure 1). Another sector with a significant impact is energy supply, which emits 29.5% of the gases; figure 1 shows that 27% of its production is consumed by domestic buildings (Welsh Government, 2019a). The age of the buildings has influenced this high energy consumption. Wales has an estimated 1.4 million residential dwellings (Welsh Government, 2019), of which a significant number corresponds to older buildings dependent on inefficient energy features. This has caused Wales to have the least thermally efficient building stock in Europe (Welsh Government, 2019a).

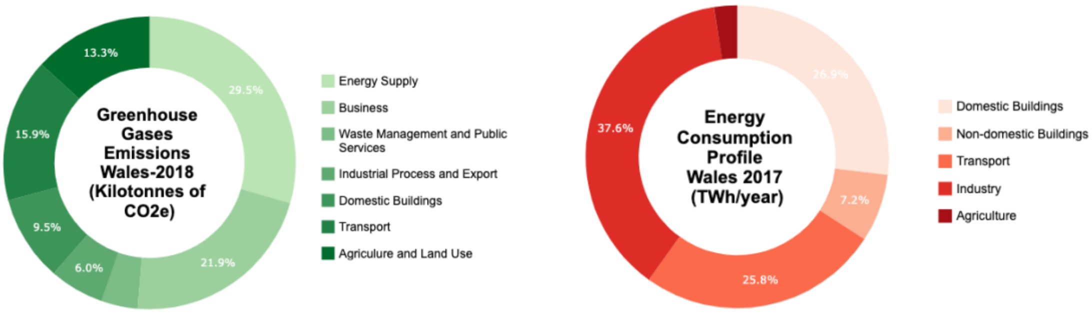

Figure 1. *Greenhouse gases emissions during 2018 (left) and energy consumption by sector during 2017 in Wales (right) (Welsh Government, 2020a). Domestic buildings emit almost 10% of the total emissions and consume almost 27% of the energy production in Wales (Regen for the Welsh Government, 2020).*

An UK average home emits 8.1 CO_2 equivalent tonnes/year (CCC, 2015). From the sample of Wales housing stock, some properties exceeded these numbers, reaching figures of up to 9.4 tonnes/year. This was not the case for all regions; emissions below the UK average were also identified, for example, 5.5 CO_2 tonnes/year in the Cardiff region in southern Wales (Figure 2). It is in this area where the highest housing prices are recorded (£450,000). According to studies, housing prices are considerably related to the energy efficiency of the dwellings (Fuerst *et al.*, 2016).

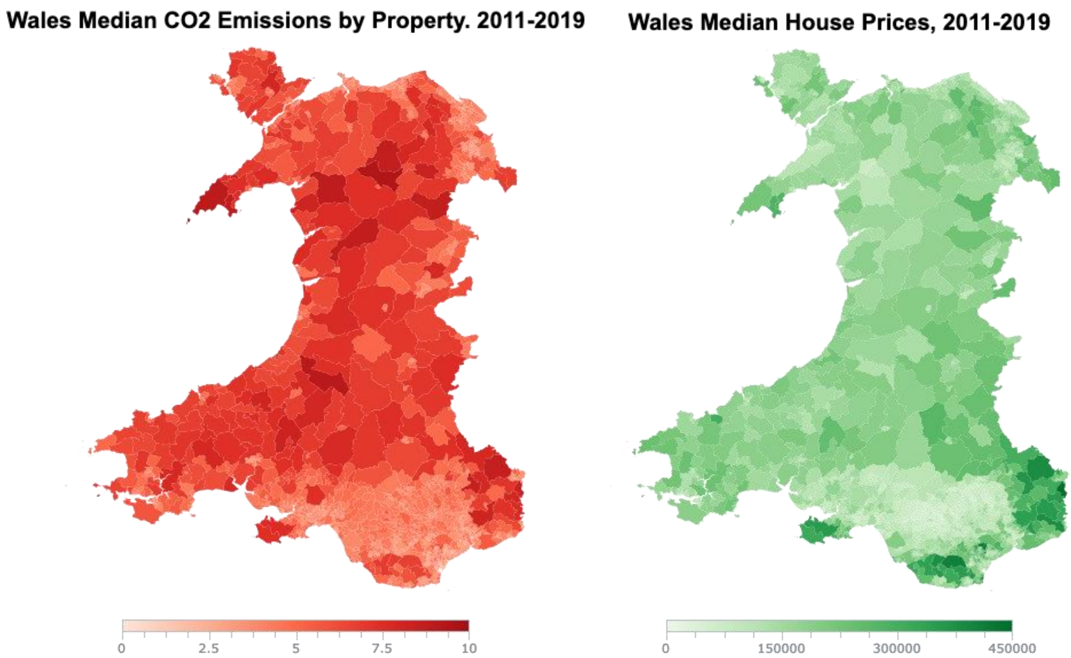

***Figure 2**. Choropleth maps of Wales median CO2 tonnes/year emissions by properties during 2011-2019 (left) and Wales median house prices for the same period (right).*

In 2008, the measurement of energy use in new and existing buildings in the UK became obligatory following the European Union's Energy Performance of Buildings Directive (Fuerst *et al.*, 2016). In this sense, the Energy Performance Certificates (EPC) were established to indicate a building's efficiency on a scale of bands from A to G, with A being the highest rating assigned to the most energy-efficient properties with low running costs (Fuerst *et al.*, 2016). This measure assesses two metrics: fuel cost-based energy performance rating and CO_2 emissions. The EPC is accompanied by detailed suggestions of the actions required to reduce carbon emissions and thus reduce fuel bills (DCLG, 2007).

From the dataset analysed, between 2011 to 2019 the Wales housing market showed a notable change in the improvement of EPC ratings. Approximately 25% of its properties in the lower scales (E, F, G) for 2011, it reduced them to almost 20% by 2019, and 15% by 2020. Most homes fell into the D band (Figure 3), a trend that remained stable over the years, mostly in central and south-eastern Wales. The most critical EPC ratings remained in the northern regions, as in Snowdonia, specifically in LSOAs as Conwy and Gwynedd. This highlights the need for more significant efforts to encourage domestic energy efficiency improvements.

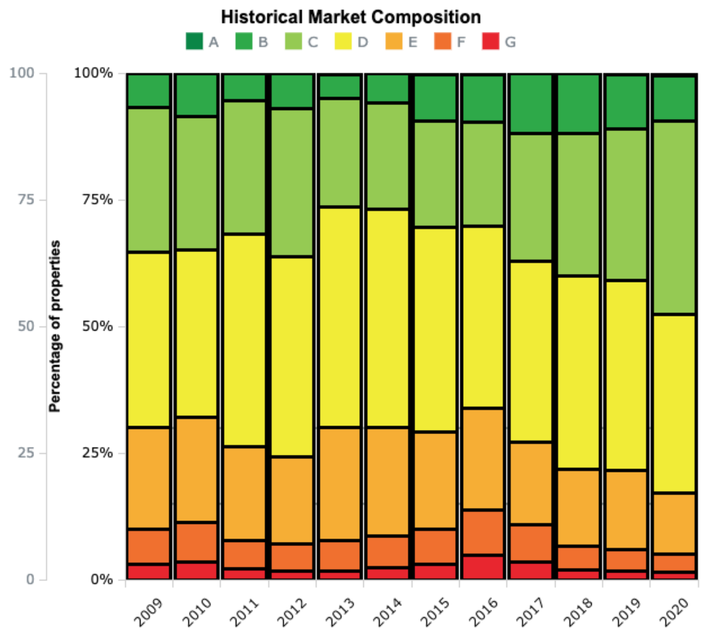

Figure 3. *Distribution of EPC ratings in Wales from 2009-2020. Band D predominates throughout the entire period.*

The Welsh Government is aligned with the UK's Climate Change Bill that sets out the target to reduce emissions by 80% by 2050 (Welsh Government, 2019a). To meet this goal, it aims to reduce emissions by 3.0% annually. Likewise, it estimates that improving the energy efficiency of homes with EPC ratings of E, F or G to D will improve the average annual fuel bill by £600 (Welsh Government, 2019a). In that sense, the EPC has been a measure to encourage energy savings and investment into home upgrades. However, the Climate Change Committee (CCC) has indicated that retrofitting towards the D rating will not put the UK on track to meet its goal. Instead, the CCC recommends transitioning all homes to EPC band C by 2035 (UK Parliament, 2021). This new target will bring Wales closer to achieving its net-zero carbon goals.

Figure 4 shows that according to the studied sample, if all residential properties in Wales were retrofitted to meet their potential energy rating, nearly 15% of dwellings would remain with an EPC rating lower than the C band. This implies a potential to retrofit most of the existing properties to become more energy efficient towards the environmental challenges.

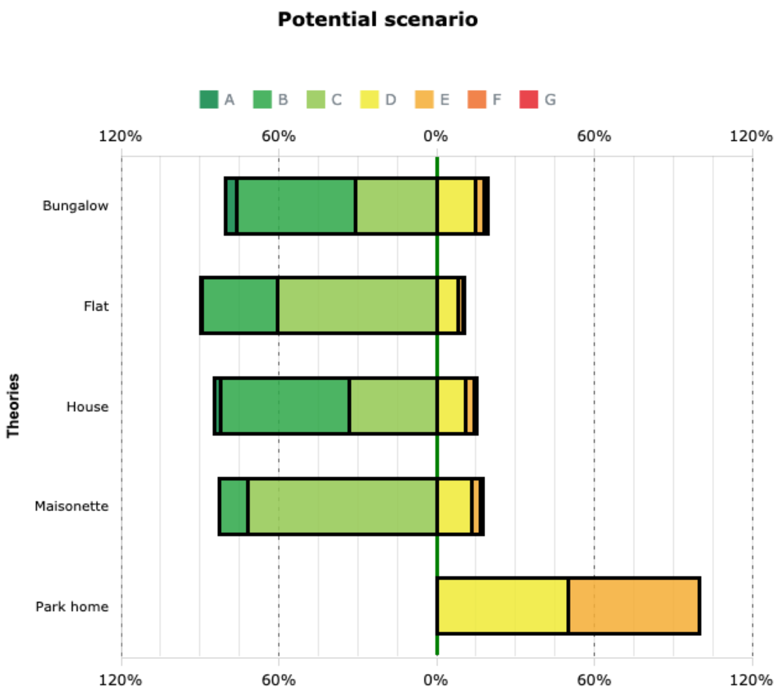

Figure 4. *Potential scenario if properties would reach their potential EPC rating. Park home category accounts for a minimal number of the overall count of the sample.*

In terms of funding, the UK government is investing £10 billion across schemes, including Green Homes Grant, Home Upgrade Grant, and Social Housing Decarbonisation Fund

(BEIS, 2020; UK Parliament, 2021). These schemes can lift 1.5 million homes across the UK to the band C by 2030 (BEIS, 2020). The UK Government anticipates a potential of private investment three times greater than what the government is committing (BEIS, 2020). Furthermore, Wales recently announced the Optimised Retrofit Programme to decarbonise Welsh homes. It has a budget of £19.5 million to update at least 1,000 homes (Welsh Government, 2020b). However, despite these commitments, the CCC indicates that estimates to retrofit all homes in the UK that require an upgrade could entail an investment ranging from £35 Billion to £73 Billion (UK Parliament, 2021). These estimates are much greater than what is already invested by the government, implying that the new commitment may already be at risk if not adequately funded by the private sector.

While it is expected that improving energy efficiency can reduce fuel bills by £600 annually (Welsh Government, 2019a), the cost to retrofit has a much wider range. The BEIS estimates retrofitting homes could be as low as £1,800 depending on the upgrades required (UK Parliament, 2021). However, current retrofit programmes in Leeds estimated a cost of £17,700 to £ 24,900 (UK Parliament, 2021). Furthermore, full home retrofits from a low EPC band F could cost up to £70,000 if no government support is provided (Early, 2020).

Retrofitting homes to achieve greater energy efficiency can also improve their value in the property market. In 2016, Fuerst et al. (2016) studied the influence of the EPC on the property market value in Wales. The study utilised property transaction data collected between 2003 and 2014 and buildings' attributes such as the number of bedrooms, the age of the building, location, and size. The constructed regression model by the authors has shown that there is a positive price increase for properties with EPC ratings A, B (12.8%), and C (3.5%) compared to houses with a D rating (Fuerst *et al.*, 2016). Moreover, properties with rating E and F have their prices discounted by 3.6% and 6.5%, respectively (Fuerst *et al.*, 2016).

Although there appears to be a benefit on reaching higher energy efficiency ratings, the range of costs to retrofit a home along with limited Government support places significant risks on homeowners who decide to meet the UK Government's zero-carbon goals. Therefore, it warrants an analysis to understand the potential return on investment to incentivise private funding of energy efficiency. Likewise, it is important to understand to what extent such improvements contribute to the overall action against Climate Change.

The following sections will provide details on the data used to carry out this study, the analysis process, and the findings. Likewise, it will explore how this information could be displayed on a website for policymakers to interact with.

3. Data

3.1.Data sources

3.1.1. Residential property price linked with EPCs dataset for England and Wales 2011-2019.

Data of the EPC rating of a home and its housing price is required to conduct the analysis. Currently, there is no existing comprehensive database of a home's sale price and its property characteristics (Chi *et al.*, 2020). Therefore, this analysis makes use of the dataset created by Chi et al. (2019). Residential transactions data from Land Registry Price Paid Data (PPD), representing 79% of the whole market sales between 2011-2019 have been linked to Domestic Energy Performance Certificates (Chi *et al*., 2020). It is valuable to note that this data is representative of homes sold during the years 2011 and 2019. Therefore, it must be considered as a sample of the Wales housing market.

The housing stock is quite diverse, and after this linkage, it is possible to explore house price per square meters or normalised. Likewise, data includes fields from 286,632 sale transactions in Wales such as: date, price paid, type of property, area, and energy ratings. Data is presented at the property level, which provides a localised and potential perspective of the issues to address environmental impact.

3.1.2. Welsh Index of Multiple Deprivation (IMD) 2019.

The Welsh Index of Multiple Deprivation assesses living conditions inequality at LSOAs level; higher values represent most deprived areas. Education, health, crime, employment, environment, housing, and income are weighted and make up the IMD. IMD enables addressing socio-economic dimensions in the analysis.

3.1.3. Wales LSOAS (shapefile and geojson format).

Administrative boundaries of Lower Super Output Areas (LSOAs) are presented in the Geo-Portal for Wales developed between Welsh Government and Natural Resources Wales. The geographic information containing 1,909 LSOAs has been explored in their Shapefile and geojson formats. LSOAs codes are used as identifiers to match other relevant datasets.

3.2.Data handling, cleaning, and management.

The properties corresponding to Wales were extracted from the dataset created by Chi et al. (2019). The data was filtered through a field that specified all regions for Wales specifically. A total of 286,565 records were obtained. Similarly, based on the similar analysis conducted by Fuerst et al., 2016, the fields selected for analysis included: the price, type, number of rooms, transaction date of the properties, current and potential EPC ratings, and CO_2 emissions of the properties. As part of the analysis, data from the Wales IMD, was also merged with the base dataset. This dataset included duplicate records since, over the years, the properties could be on the market repeatedly, so they were considered for the analysis. However, to describe the housing market and its overall energy efficiency, duplicates were excluded, resulting in 253,965 units based on the last year of the transaction.
To create the descriptive and interactive maps, the dataset was merged with the geojson of the Wales LSOA. For the analysis, other data transformations were considered, which are explained in the next section of the report. All the data processing and analysis were conducted in Python.

4. Data analysis

The following section of the report will explain the process of estimating the influence of the EPC ratings on the price and emission of CO_2 per square metre of the sold properties in Wales during the studied period. Secondly, it will introduce techniques used to simulate the potential increase and decrease of housing stock prices and CO_2 emission for three scenarios. These scenarios were defined based on existing housing retrofit policy targets and recommendations.

Table 1. *Different scenarios to be analysed.*

Scenario A	**Scenario B**	**Scenario C**
Transition of all residential buildings to the max EPC rating that they can potentially reach (determined during the EPC rating process).	Transition of all residential buildings from bands D, E, F, G to rating C, as recommended by the CCC.	Transition of all residential buildings from bands E, F, G to the Wales' average rating, D.

4.1. Modelling the effect of the EPC on the price of the sold properties.

Using a similar hedonic model as Fuerst *et al* (2016)., the study introduces the following regression equation.

$$(1) \qquad P_{it} = \alpha_i + \sum_{i=1}^{J} \beta_j X_{jit} + \sum_{t=1}^{T} \gamma_t D_t + \sum_{l=1}^{L} \delta_l S_l$$

Where P_{it} represents the natural logarithm of the transaction price for the property i sold during time t, X_{jit} is the vector of the property attributes such as floor area, the number of bedrooms, information if the property is newly built, dummy variables reflecting property type, dummy variables reflecting EPC rating, and the natural logarithm of Welsh IMD measure in 2019 on the LSOA level. Additionally, the model included fixed effect variables, which control the fact that the transactions took place in different periods and dissimilar LSOAs. D_t represents the year and the quarter in which the property has been sold, whereas S_l reflects LSOA in which such a transaction took place.

Before the regression could be conducted, some variables had to be log-transformed to meet the regression requirements of normal distribution. Moreover, the linear relations between independent and dependent variables have been validated before the regression analysis.

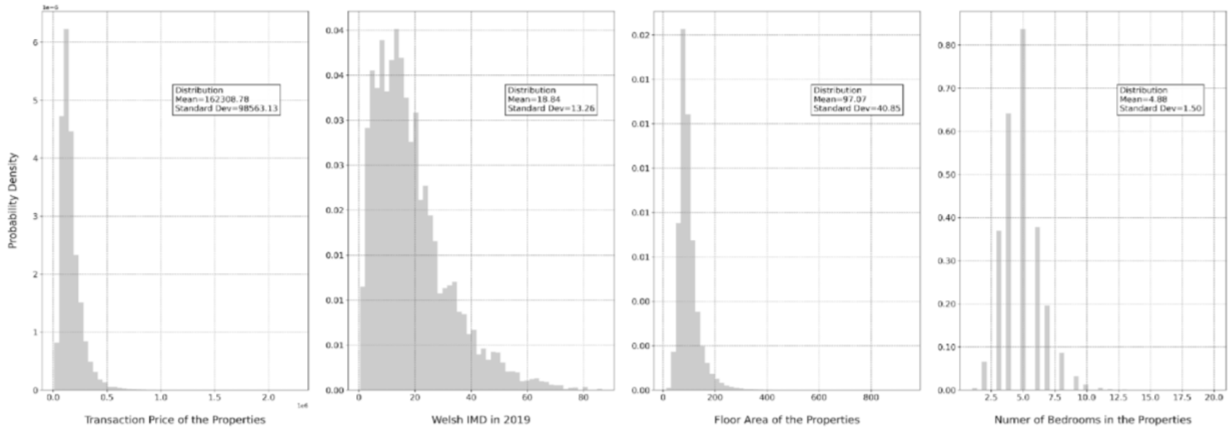

Figure 5. *Distribution of variables prior to the log transformation.*

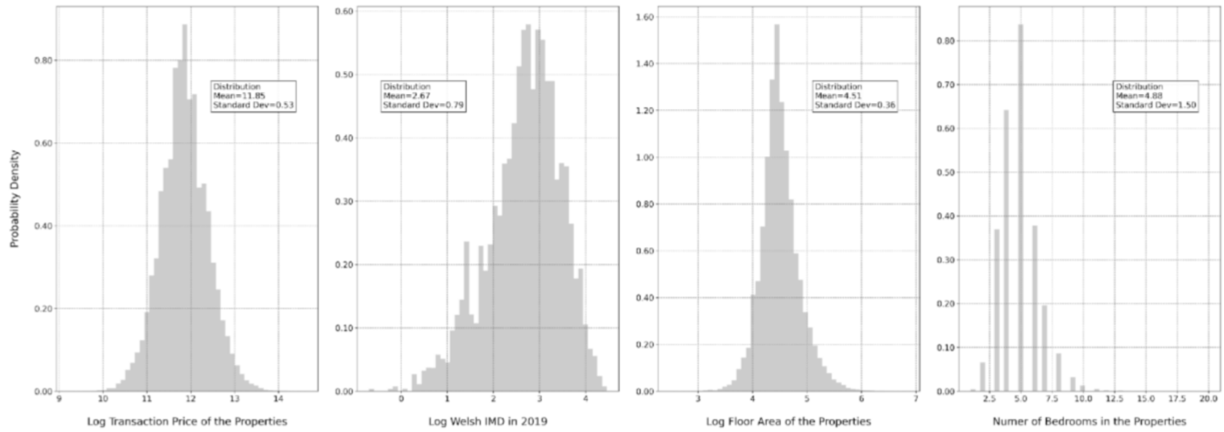

Figure 6. *Distribution of variables after the log transformation.*

The model proved to be statistically significant with a P-value less than 0.05 and the model explained a high amount of variance in transaction price with an R^2 of 0.8. The coefficient of EPC ratings is referenced against the band G which has been removed from the model. The coefficients depict the average percentage premiums of property price relative to band G as follows: B (25.6%), C (21.9%), D (17.5%), E (13.4%) and F (25.6%).

Table 2. *Result of the hedonic regression model.*

	Coefficient	***Standard error***	***t***	***P>|t|***
Intercept	11.826	0.006	2030.352	0.000
Log (Floor area)	0.004	0.000	207.897	0.000
Number of Bedrooms	0.038	0.001	74.930	0.000
Log (WIMD)	-0.186	0.006	-31.785	0.000
Band B	0.256	0.005	48.064	0.000
Band C	0.219	0.003	66.594	0.000
Band D	0.175	0.003	55.407	0.000
Band E	0.134	0.003	41.855	0.000
Band F	0.089	0.003	25.795	0.000
Old or New	0.076	0.008	9.348	0.000
Type (Flat)	-0.597	0.003	-225.572	0.000
Type (Semi-detached)	-0.246	0.001	-181.672	0.000
Type (Terraced)	-0.396	0.001	-264.842	0.000

Quarterly fixed effects	Y	Y	Y	Y
LSOA fixed effects	Y	Y	Y	Y
R-squared:	***0.799***		*F-statistic:*	*578.500*
Adj. R-squared: *0.797*			*Prob (F-statistic):*	*0.000*

4.2.Simulating the potential price increase for three different scenarios.

Given the coefficient of each EPC band from the regression model, interpreted as average percentage premiums, and the variable on the potential EPC ratings of each property, it is possible to simulate the hypothetical transaction price across various scenarios. The following equation has been deployed to calculate the potential property price:

$$PP_i = P_i * (\beta_{EPC_{potencial}} - \beta_{EPC_{current}} + 1) \quad (2)$$

Where P_i is the actual price at which the property was sold, betas reflect the coefficient of the EPC rating calculated in the hedonic regression model. Such a method produces the hypothetical price if every other independent variable stays the same.

4.3.Modelling the effect of the EPC ratings of the CO_2 emission per square metre.

Moreover, this analysis introduced a second regression model to quantify the relation between the EPC bands and the CO_2 emission per square metre. The following equation had been used:

$$CQ_i = \alpha_i + \sum_{i=1}^{J} \beta_j R_{ji} \quad (3)$$

Where CQ_i is the current CO_2 emission per square metre of the property, R_{ji} is a set of dummy variables that takes the value of 1 for the corresponding current EPC rating of the property i and the value of 0 for every other. Moreover, the beta is the vector of the estimated coefficient for every EPC band. Again, some variables had to be log-transformed to meet the regression requirements of normal distribution.

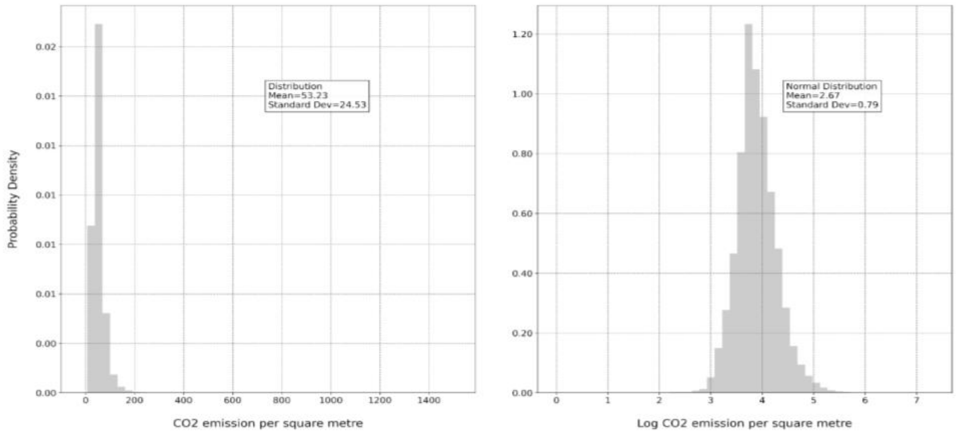

Figure 7. *Distribution of the dependent variable prior to the log transformation on the left and after on the right.*

The regression model estimated the coefficient of EPC ratings on CO_2 emission per square metre has proven to be statistically significant with a P-value less than 0.05 and the model explained a high amount of variance in CO_2 emission per square metre with an R^2 of around 0.7. Again, the coefficient of EPC ratings refers to the band G which has been removed from the model. The coefficients depict the average percentage drop of the CO_2 emission per square metre in the properties and go as follows: B (-159.9%), C (-129.8%), D (-93.7%), E (-58.6%) and F (-29.0%).

Table 3. *Results of the second regression model.*

	Coefficient	***Standard error***	***t***	***P>|t|***
Intercept	4.769	0.003	1794.033	0.000
Band B	-1.599	0.005	-355.078	0.000
Band C	-1.298	0.003	-463.195	0.000
Band D	-0.937	0.003	-344.001	0.000
Band E	-0.586	0.003	-209.951	0.000
Band F	-0.290	0.003	-94.470	0.000
R-squared:	**0.694**		F-statistic:	129700
Adj. R-squared:	0.694		Prob (F-statistic):	0.000

4.4. Simulating the potential CO_2 emission decreases for three different scenarios.

Similarly, as with estimating potential home prices, the following equation has been used to simulate the hypothetical decrease of the CO_2 emission per square metre for each property:

$$(4) \qquad PCQ_i = CQ_i * (\beta_{EPC_{potencial}} - \beta_{EPC_{current}} + 1)$$

Where PCQ_i is the potential CO_2 emission per square metre of property i, CQ_i is the current CO_2 emission per square metre whereas betas reflect the coefficient of the EPC rating calculated in the second regression model.

5. Results

5.1.Research Aims & Additional Findings

The analysis set out to understand two primary research questions.

a) How will house prices change based on improvements in Energy Performance Certificate Ratings?

Figure 8 below details the percentage increase in home value depending on the EPC Rating it achieves after an upgrade. If a home is upgraded to an EPC rating of D (Scenario C), the model predicts a 1.1% increase in value, whereas upgrading the EPC rating to the maximum potential for all homes (Scenario A) yields an increase of 6%. This is an impact six times greater than the Welsh Government's current commitment of upgrading homes to an EPC rating of D (Welsh Government, 2019a).

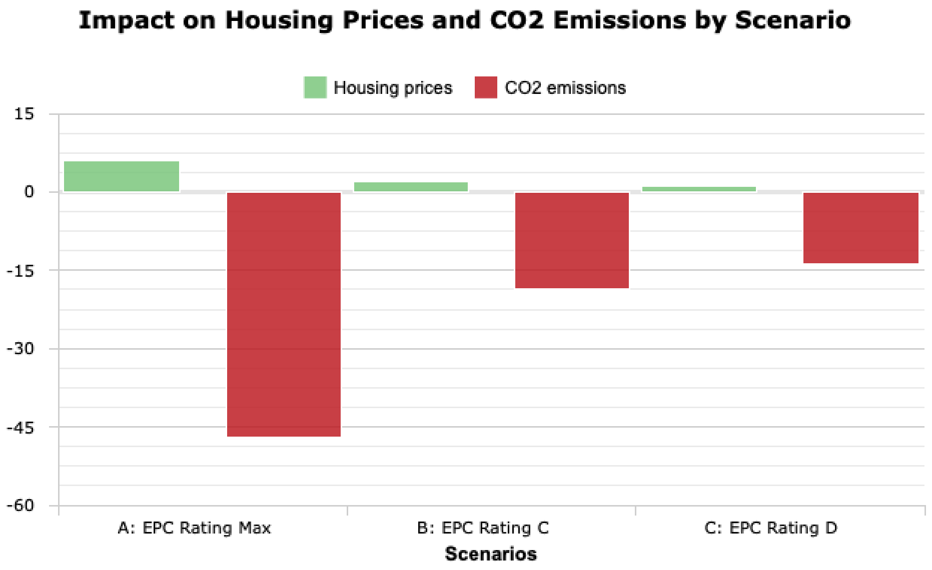

Figure 8. *Percentage increase in home prices and decrease on CO_2 emissions*

b) How will an increase in energy efficiency impact emissions?

Figure 8 also details the percentage decrease in emissions for homes based on the upgraded EPC rating. If a home is upgraded to an EPC rating of D, the model predicts a 13.7% decrease in CO_2 emissions (Scenario C), whereas upgrading the EPC rating to the maximum potential for all homes (Scenario A) yields a 46.9% decrease in emissions. This range demonstrates the substantial difference between the Welsh government's commitment to upgrade all homes to EPC rating D versus their maximum potential.

The findings of the analytical models are essential in two ways. First, an upgrade of homes to the maximum EPC rating changes CO_2 emissions by a higher percentage than housing prices. Secondly, the modelling implies that renovating all homes to the maximum potential EPC rating will still not meet the UK government's goal of an 80% reduction by 2050.

Furthermore, Figure 9 summarises the percentage of homes that will require renovation of all units analysed. For all homes to meet an EPC rating of D, 31.7% of homes will need to be upgraded. However, to meet the maximum potential EPC rating, it will require upgrading 83.9% of all homes – more than 200,000 dwellings.

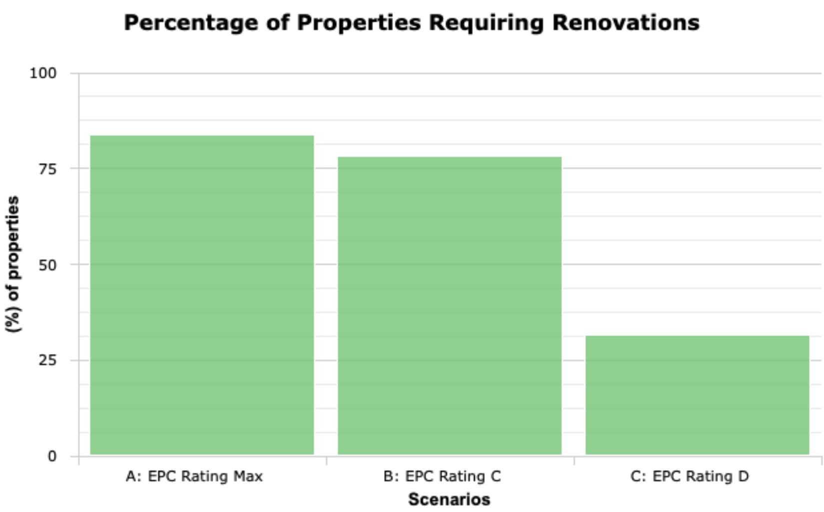

Figure 9*. Percentage of homes to renovate.*

These findings highlight the magnitude of the challenge Wales faces in decarbonising its housing sector. Importantly, this analysis calls into question the Climate Change Committee's recommendation that the UK government should renovate all homes to meet an EPC rating of C. The modelling here suggests that an EPC rating of C will only reduce emissions by 18.6%.

It is important to recognise that renovating all eligible homes will still fall short of the UK Government's goals.

5.2.Policy Context

To place the number of dwellings in a policy context, the Welsh government has recently committed £19.5 million to upgrade 1,000 homes as part of its Optimised Retrofit Programme (Welsh Government, 2020b). This will provide approximately £19,500 per home for renovation, which aligns with data from the Leeds retrofit programme ranging in costs between £17,700 to £24,900 (UK Parliament, 2021). If the Welsh government expanded its budget to cover all eligible homes within this dataset, it would need to invest approximately £4.69 billion -- significantly higher than the Optimised Retrofit Programme of £19.5 million. Based on the analytical model produced, the renovation would result in a net increase in home values of £2.78 billion, thereby yielding a gap between the investment and home value return of £1.91 billion.

The estimation of a loss in return on investment and still falling short of the CO_2 emissions target may incentivise a more targeted approach by policymakers. What follows is three possible policy responses that may be considered:

a) *Limit the government's investment to the potential value recovered in the home.* In the maximum potential scenario, the government can expect a home's value to increase by 6%. Therefore, this model provides an opportunity for the government to design incentive programmes relative to the expected increase in the value of the home. In this case, it could offer 6% of the home's value to renovate, minimising losses on investment. Furthermore, the UK government estimates that the private industry is likely to invest three times as much as the government in home renovations (BEIS, 2020). If this occurs, then it should be feasible to achieve the required £4.69 billion investment.

b) *Prioritise investment for homes that need the most support.* Figure 10 estimates the median percentage increase of home values based on the Wales Index of Multiple Deprivation groups. From this perspective, it is possible to observe that homes that account for the 10% most deprived benefit the most from renovations. These homes amount to only 0.10% of total homes that require an upgrade and therefore could be prioritised.

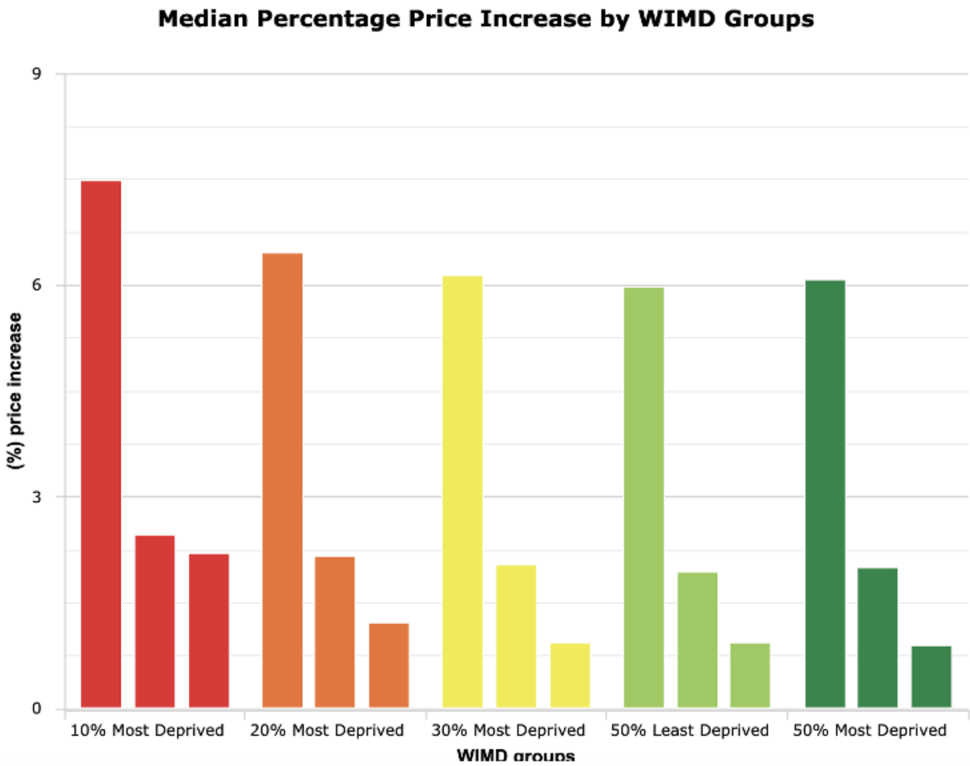

Figure 10. *Percentage price increase by WIMD groups.*

c) *Prioritise investment amongst LSOAs with the greatest price increase or greatest decrease in emissions.* The website additionally provides a spatial perspective on the analytical models produced. Figure 11 contains screenshots of the interactive map that allows policymakers to see which LSOAs can have the greatest impact. In the short-term, these are the LSOAs that could receive initial rounds of investment to drive the greatest improvements.

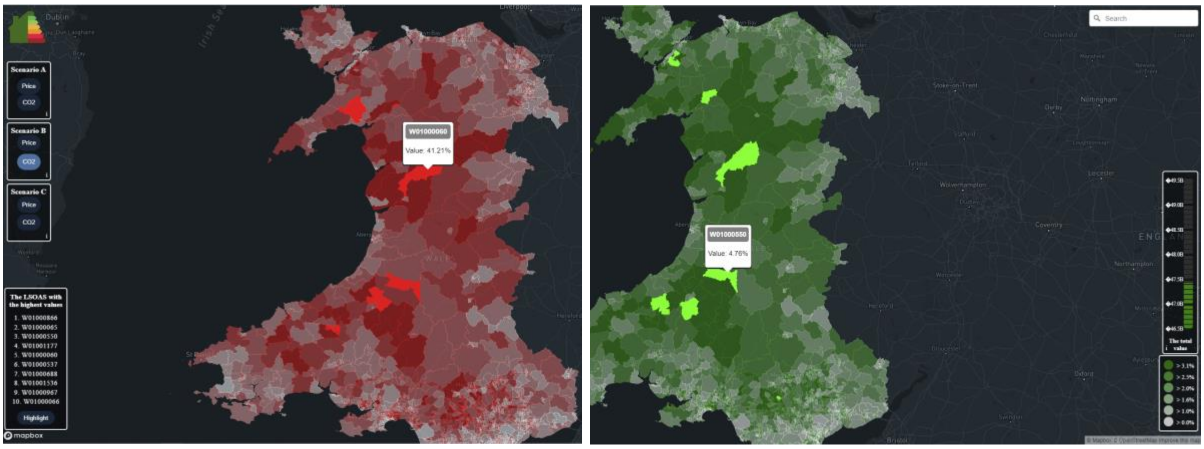

Figure 11. *Screenshots of the website*

6. Website and data visualisation

6.1.Front end

The website was structured to be accessible to users, and the ease of data exploration was the motivating theme behind the interface. The website provides the option of individual exploration based on the technical skill level of the users.

The theme of the website revolves around interactivity and strong visual content. The colour patterns were derived from the EEC logo. Media Query and Flexbox (Mapbox, 2021) were used for the responsive elements and to reach a wide variety of users. In some aspects, it was found to be an efficient way to add flexibility to the interface without the use of more complicated techniques like CSS grids.

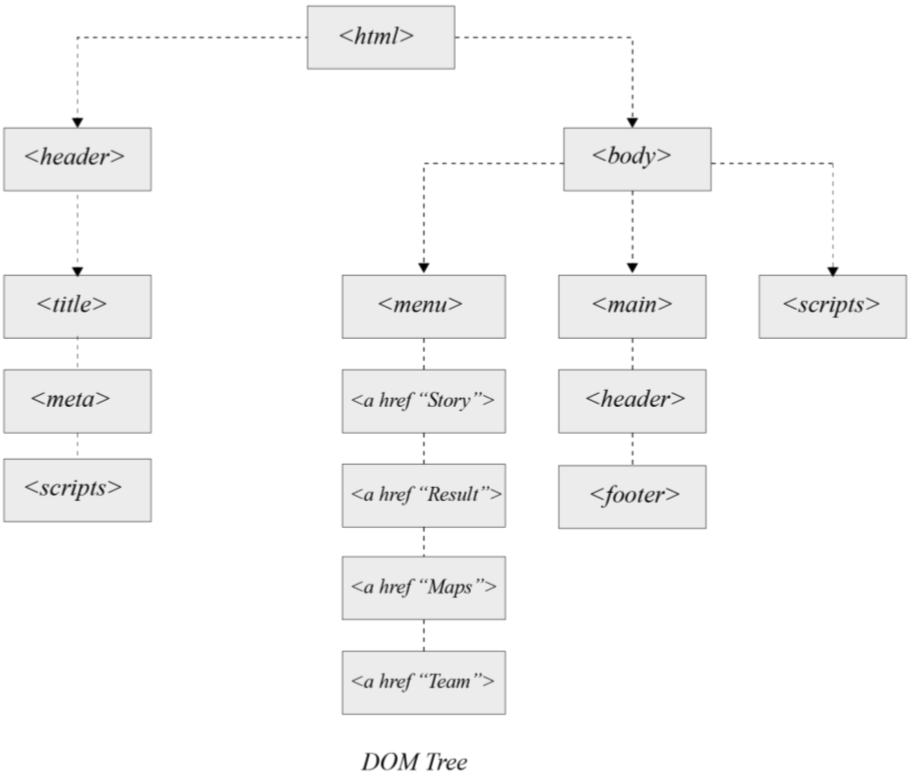

Figure 12. *DOM tree shows the structure of the main page of the website*

The website consists of five individual HTML pages: Landing, Story, Results, Map and Team. The user can navigate to each page using the menu on the right of the landing page or click through the EPC logo buttons guiding from one page to another. All elements and pages were designed and animated using styling techniques in CSS or JavaScript. Furthermore, online exploratory tools such as Miro and sketched wireframes were used to design the entire hierarchical structure to support the user experience. Figure 13 shows the overall structure of the front end of the website.

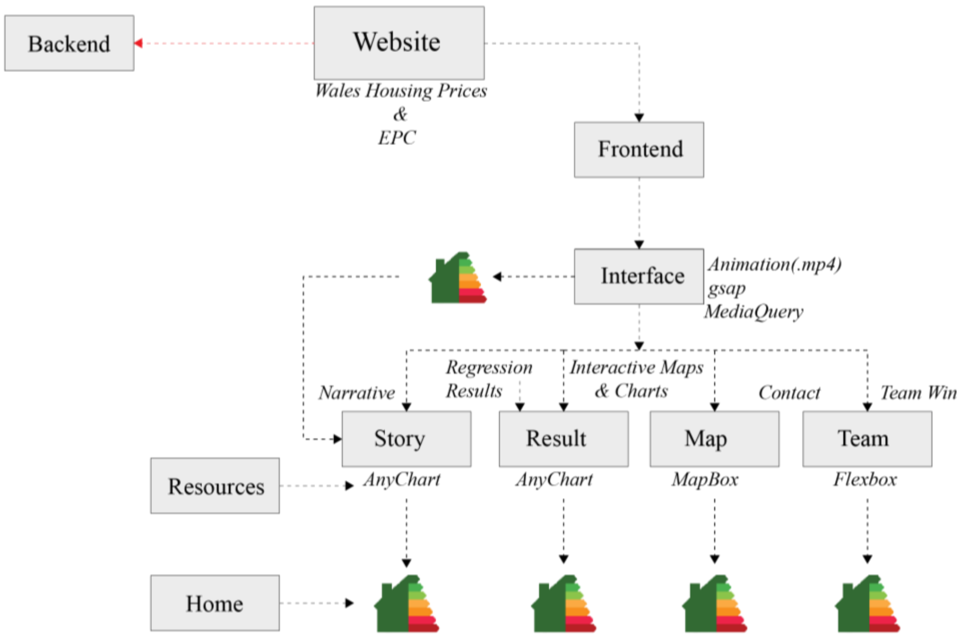

Figure 13. *Front end flow chart.*

6.1.1. Landing page

The landing page follows a basic user-friendly layout giving a preview of the corresponding subject. The background mainly comprises a looped video[1] (mp4). The EPC inspired icon at the bottom allows navigation to the next page on the main menu. Additionally, there is a tab at the right top of the page that opens a sliding hidden menu leading to other pages of the website. Most of the texts and elements space out evenly, positions were either kept absolute or changed relative to the screen size (w3schools, n.d.). Other libraries such as GSAP were consulted to integrate animations. Platforms such as Stack Overflow and W3schools were particularly helpful in integrating the different components of this page. It is pertinent to thank Jan-Philipp Richtmann's[2] work as the inspiration behind the landing page.

6.1.2. Story and results pages

Research and background information of the study is presented on these pages which can be accessed via the hidden sliding menu on the main page. Users can simply access all the information by scrolling down. The page is bifurcated into different sections consisting of paragraphs, pictures and charts introducing all the descriptive analysis of the data and background research in the form of a narrative. For the visual appearance of this section and

[1] The background video was downloaded from this source: https://www.pexels.com/video/drone-shot-of-residential-area-in-the-philippines-6709657/.

[2] Links to access this website: https://jprichtmann.github.io

some functionalities, inspirations were taken from The Los Angeles 100% Renewable Energy Study and Citu Group websites[3], screenshots in Figure 14. The workflow during the construction of this section is summarised in Figure 15.

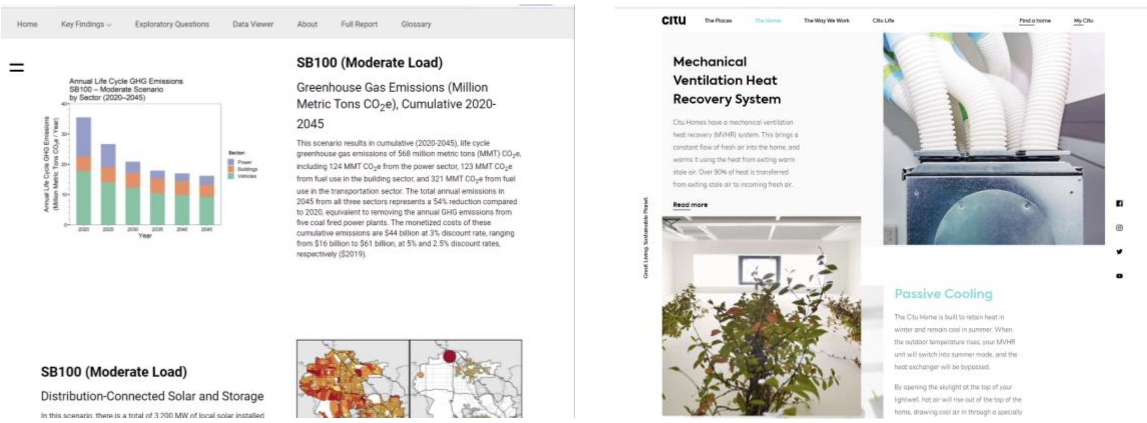

***Figure 14**. Los Angeles 100% Renewable Energy Study (Left) and Citu Group Websites (Right)*

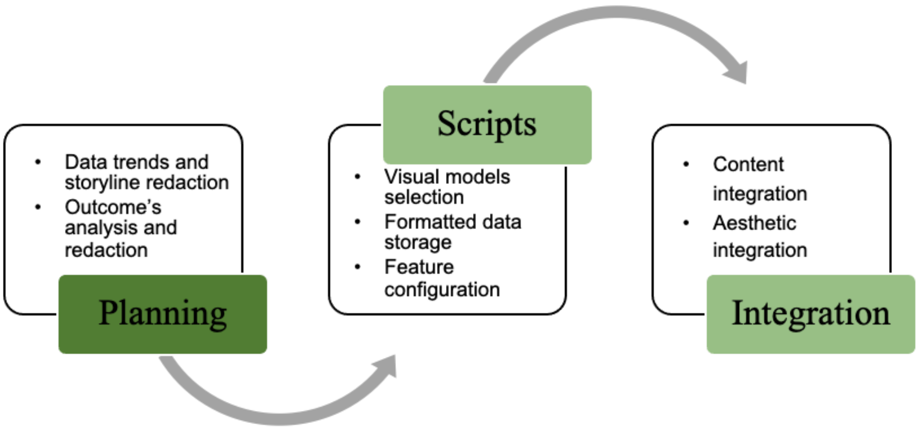

***Figure 15**. Workflow to elaborate the Story and Results page.*

6.1.2.1.Graphics and maps

To communicate outcomes, several JavaScript libraries were evaluated. Graphs and maps shown in the Story and Results tab were elaborated with Anychart libraries; some of the methods used were pie(), bar(), column(), and choropleth(), for maps. These are interactive JavaScript charts designed for the web and other apps (Anychart, 2021). Usually, web pages built around the narrative comprise stagnant information, but the library assisted in presenting all details in an interactive format and created continuity in the overall experience between

[3] Links to access these websites: https://maps.nrel.gov/la100/ and https://citu.co.uk/citu-home.

various elements on the story page. The documentation from the Anycharts website guided the process of creating datasets using Python to export to external files in JSON and geojson format.

The visualisation of each graph and map was created independently in its JavaScript format to adjust its properties better. Once the data was loaded on the scripts, the personalised features such as labels, axis, grids, and display information were configured. The storyline of the research guided the content integration through pages of Story and Results.

Content division elements were structured to integrate and position text and graphs consistently. Therefore, similar structures such as text-only, left-hand, and right-hand text were used repeatedly according to the story plot. At the final stage of design, each page was formatted for consistent aesthetics that are visually appealing and effectively informative.

6.1.3. Interactive map

The map page comprises the housing price analysis based on different scenarios. While creating the map, the Mapbox API was selected, which, like Google maps, displays information on a map and allows for interactivity (Mapbox, 2021). After specifying the starting coordinates and the zoom level to show the country of Wales, the Mapbox plugin called Mapbox-choropleth to add choropleth map layers. This package requires geojson and CSV files; both files were stored in the Spatial Data Capture web server and linked via the path in JavaScript.

The hover and click functions have been added to each layer to allow for more clarity and accuracy in reading the exact values for a selected LSOA. Next, six toggle buttons are introduced to enable users to turn on and off layers on the map. Additionally, legends are added that were automatically created during the layers' generation.

Moreover, two essential elements have been created to understand the results better:

1. A list of the LSOAs with the highest values on each layer of the map are included with a button highlighting those LSOAs on the map.
2. A total value indicator is on the right side of the screen, displaying either the collective value of the whole studied housing stock or the total amount of CO2 emitted by all the properties annually.

Finally, an if statement that elements such as "legends", "top 10 list" and "total value" should be visible only if the layer, which they are referring to, is currently turned on by the toggles.

6.1.4. Team page

The flexbox design was utilised to demonstrate the team page of the website. The cards are auto arranged on the screen depending on the available space. Additionally, the page has also been configured for use on a mobile phone or tablet. When the screen space is limited, the cards will arrange vertically, enabling them to scroll through them more conveniently.

7. Technical integration

Figure 16 provides a diagram of how data is processed, analysed, and uploaded to the website.

Data Inputs: The “EPC-PPD TRXN" is a .csv file that is the combined EPC Rating, and Price Paid transaction dataset created by Chi et al. (2019). The WIMD dataset is a shapefile that contains the Welsh Index of Multiple Deprivation (Welsh Government, 2019b).

- Data Processing & Analysis: The datasets are processed in Python for descriptive statistics and the multivariate regression models.
- Data Outputs: Datasets that only contain descriptive statistics are converted into either JSON or GEOJSON format. These datasets support the charts on the “Story” page of the website. The analytical output of the multivariate regression model is split into multiple dimensions: GEOJSON that contains geometric data, LSOA level that supports the interactive map, and Global level that supports the results presented on the website.
- Database & API: To display data on the website, data is either uploaded directly to the UCL server or is called from SQL using an API. The SQL database exclusively contains the output of the multivariate regression models.

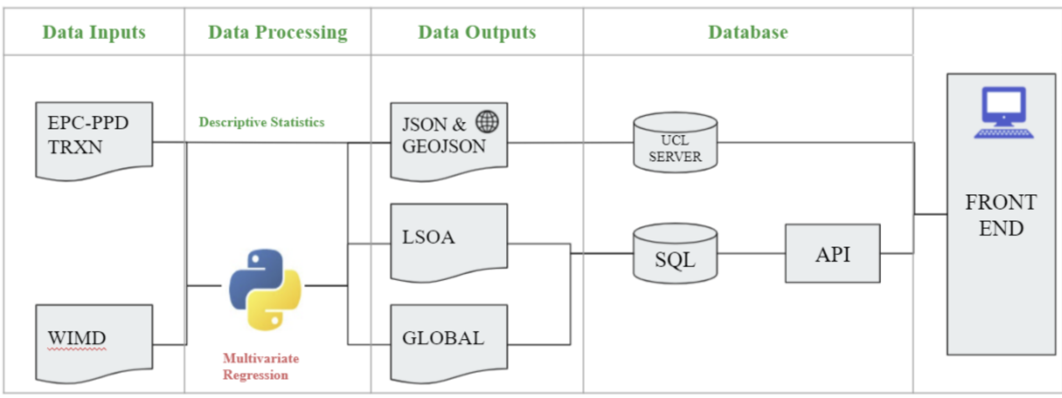

Figure 16. *Diagram of data flow to website*

Members worked on individual aspects of the website, but consistent integrated coding sessions ensured that compatibility issues didn't significantly impact performance. The console.log function was utilised extensively to troubleshoot errors in the codes.

8. Conclusion

This study selected Wales to analyse the potential impact of improvements in household energy efficiency regarding CO_2 emissions and housing prices. The impact was analysed according to three scenarios where different improvement of Energy Performance Certificates bands was evaluated. A website has been built to display the results; users can access the information through an interactive map and charts accompanied by a brief description of the study.

It is necessary to indicate several considerations related to the results and limitations faced during the process of this study. Regarding the methodology, given the close relationship between EPC ratings and the age of the buildings, the coefficient estimates might have either overstated or understated the actual effect. On the other hand, the analysis does not consider the costs of improving properties' EPC ratings, which will vary significantly and depend on the age and type of property. Another limitation of the methodology is the effect of the hedonic characteristics in the dwelling's price, which might have impacted it in a non-linear fashion.

A proper valuation of benefits due to EPC upgrades would also consider industries and jobs created and reduced health costs of Welsh residents. Furthermore, more accurate results would have been achieved with a complete dataset as the one used for the analysis represents a sample of Wales housing market and tracks latest metrics only if the property has been sold. Concerning the building of the website, limitations were faced while using the libraries for the interactive charts and maps. Since the library used for these components required a specific data format, this influenced the processing time of the dataset. Regarding the integration of the website, as all members worked on different components, integrating the scripts was complex as, on some occasions, the directories were pointing to different folders. Similar issues emerged because of the VPN connection and varying server paths on different machines.

If given more time, it would be valuable to comply with web accessibility standards and guidelines, thus eliminating barriers that may arise for people with disabilities while using the website. Furthermore, all pages could be optimised to be used in different browsers and devices. Optimising the code would address compatibility issues and improve, for example, the loading time of the maps. Future improvement could also be made in the displaying of the results in the interactive maps. Instead of scenarios, it would be convenient to provide policymakers with more functionality to determine which LSOAs require investment given their own set of constraints: WIMD score, percentage of improvement in house price or emissions. This would require adding the possibility to input information to query the SQL database versus the Top 10 provided at this moment.

Link to the website: http://dev.spatialdatacapture.org/~ucfnsha/energeticMappers/index.html

Link to the GitHub repository: https://github.com/divyasharma-git/energeticmappers

Word count: 5,078

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