University of Strathclyde Engineering

Department of Mechanical and Aerospace Engineering

APPROACH TO ENERGY RELATED CITY MAPPING FOR UTILITIES AND LOCAL AUTHORITIES

Author: Patrícia Vidal Gea

Supervisor: Dr. Joe Clarke

A thesis submitted in partial fulfilment for the requirement of the degree

Master of Science

Sustainable Engineering: Renewable Energy Systems and the Environment

2012

Copyright Declaration

This thesis is the result of the author's original research. It has been composed by the author and has not been previously submitted for examination which has led to the award of a degree.

The copyright of this thesis belongs to the author under the terms of the United Kingdom Copyright Acts as qualified by University of Strathclyde Regulation 3.50. Due acknowledgement must always be made of the use of any material contained in, or derived from, this thesis.

Signed: Date: 7th September 2012

Abstract

At present, society is becoming more self conscious about the fact that carbon emissions should be reduced to minimize the impact of a climate change with hypothetical anthropogenic origins. This belief has lead countries all over the world to establish ambitious carbon restrictive targets. Moreover, buildings energy consumption is responsible for roughly a 40% of the total European greenhouse gas emissions [1], thus, it seems that this sector has a key role to play in helping achieve the government targets.

On the other hand, we are moving fast towards smarter cities, which will be based on information systems. Smart metering systems are meant to be installed in the majority of households by 2019 [2], one of their roles being to provide real time high resolution consumption data to utilities. The benefits of modelling this information in order to obtain a better knowledge of the current system seem evident. Therefore, the aim of this project will be to perform an approach to carbon mapping in urban areas by means of GIS software in order to show, in first instance, its potential for accomplishing the government targets and further to explore the range of possibilities that this software can offer to utilities and local authorities.

The steps in this project are: detection of the options that GIS software can offer in the energy field, determination of the information that is considered relevant for the previous purposes and is going to be included in the maps; identification of the information sources; definition of the data treatment prior to representation, exploration of the different viable representation techniques and consultation to energy experts.

The results include a list of functionalities that GIS offers to utilities and local authorities and an extensive research on the best ways to represent energy related data in urban areas.

Acknowledgments

I want to express my sincere thanks to my supervisor, Dr. Joe Clarke, for his support and good advice throughout the project realisation. Also special thanks to Dr. Jae-Min Kim, of the ESRU department, for his time and dedication.

I would also like to thank Derek Drummond and Ciaran Higgins from Scottish Power, for their time and help.

My gratitude to Dr. Michael Grant, who listened to my queries at the initial stage of my project and helped me to move forward.

Special thanks to all the anonymous energy experts who contributed to this project.

I would also like to extend my thanks to my family, partner and friends for their unique unconditional support.

Finally, my most sincere thanks to the ‘Iberdrola Foundation’, which gave me the opportunity to study this Master’s degree and have a unique life experience.

Table of contents

List of figures

List of tables

1. Introduction

We live in an era where society is becoming more self-conscious about the existence of a climate change with hypothetical anthropogenic origins. Many measures are being put in place at all levels to reduce carbon emissions, such as 'the 20-20-20 targets' at European level, where Europe is committed by 2020 to reduce the carbon emissions at least by 20% compared to 1990 levels, to produce 20% of the energy consumed in the EU with renewable resources and to reduce the energy consumption by 20% compared to the projected levels by improving energy efficiency, which became law on June 2009 [3]; or at smaller level, the 'Climate Change (Scotland) Act 2009', committing Scotland to a legally-binding 42% reduction in carbon emissions by 2020 against 1990 levels, and an 80% by 2050 [4].

Moreover buildings energy consumption (households + services) accounts for roughly a 40-45% of the total energy use in Europe, generating significant amounts of CO_2 [1]. Thus, it is important to have a deeper knowledge of the sector emissions generation, so that higher emitting sources can be detected, analysed, and action can be taken in order to reduce them and get closer to the carbon commitments.

At the same time, big changes are being imposed to utilities as we move towards smarter cities, entailing larger renewable energy deployment, smart metering and deployment of technology information systems. Thus, huge amounts of data will be generated by the electric network that, if well processed, can be a major source of information on societies' current energy consumption behaviour. Geographic Information Systems (GIS) are an adequate tool for displaying information on maps, such as consumed energy, energy price or equivalent carbon emissions[1].

Although historically GIS tools have been used for several purposes, there is no information available which reports on the handling of this issue. Therefore, the aim of this project will be to perform an approach to carbon mapping in urban areas by means of GIS software in order to show, in first instance, its potential for accomplishing the government targets and further on explore the range of possibilities that this software can offer to utilities and local authorities.

[1] **Equivalent carbon emissions of a dwelling:** The total emissions generated by energy consumption, calculated depending on the type of fuel, and in the case of electricity, depending on the balance of generating sources.

1.1. Objectives

The main purpose of this project is to prototype an approach to carbon city mapping in order to increase the understanding of its potential for utilities and local authorities. To do so, special attention will be put in detecting the possibilities that this tool can offer to the described users as well as the data treatment, representation processes and maps interpretation.

An artificial scenario will be created for representation purposes; however, it is only intended to be illustrative of the possibilities that GIS software offers for utilities and local authorities when using real, confidential data.

1.2. Method

To perform this approach, different main aspects will be studied in depth:

- **Functionalities detection** *(section 3)***:** It is the core of the project. An extensive analysis on the range of options that GIS offers to utilities and local authorities in relation to energy consumption will be detailed.
- **Data treatment** (*section 4.1*): All the processes that occur once the desired data is detected until the moment when it is ready for representation, including data filtering, combination, transformation, etc.
- **Data representation** (*section 4.2*)**:** There is not only one single way to represent energy data in maps; therefore, an approach to different representation techniques will be done, using the conjecture & test method.
- **Maps interpretation** (*section 4.3*): The opinion of several energy experts will be taken into consideration to conclude which techniques are more effective for the energy data representation purposes.

Finally, limitations of the current approach will be identified and further work suggested.

2. Key concepts

2.1. Previous work

Previous studies have been carried out using GIS in relation to carbon emissions:

- Representation of total carbon emissions of a city (data from regional energy statistics).

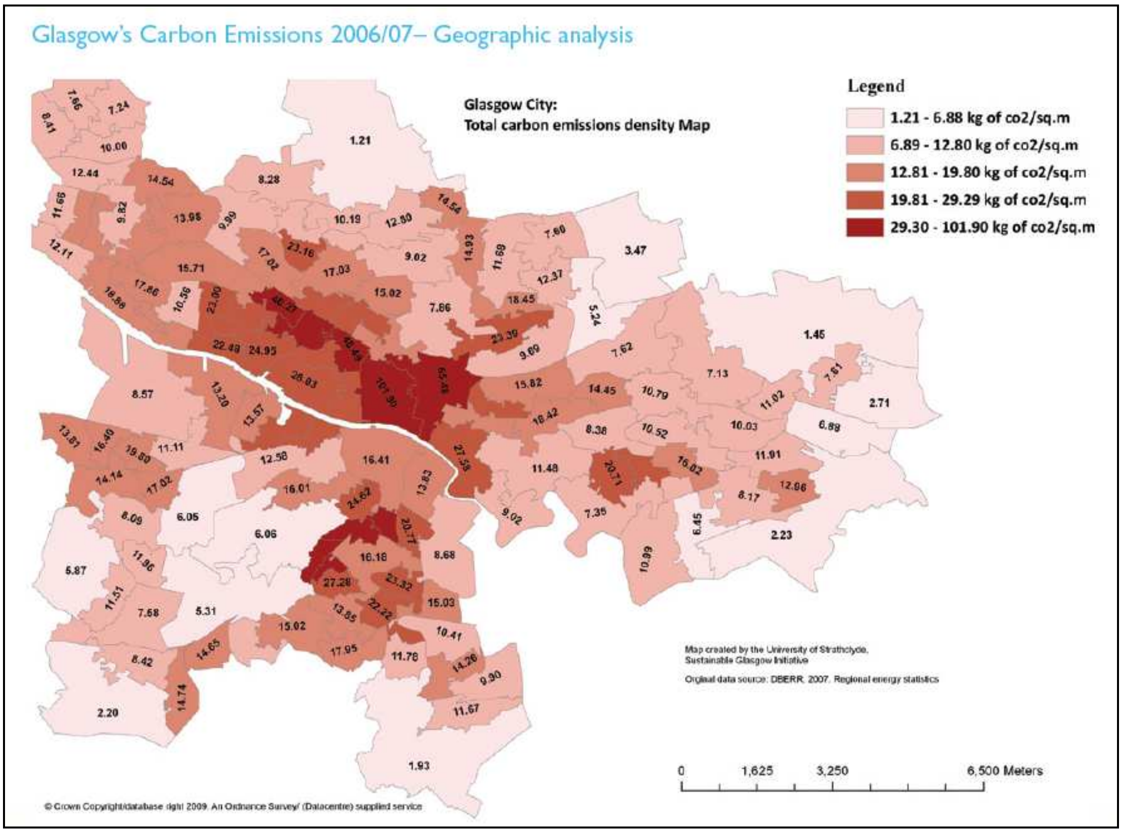


Fig. 1 – Representation of Glasgow carbon emissions. Source: [5].

Also, previous work has been done in relation to energy consumption representation in maps:

- Maps showing domestic, industrial and commercial electricity consumption at local authority level:

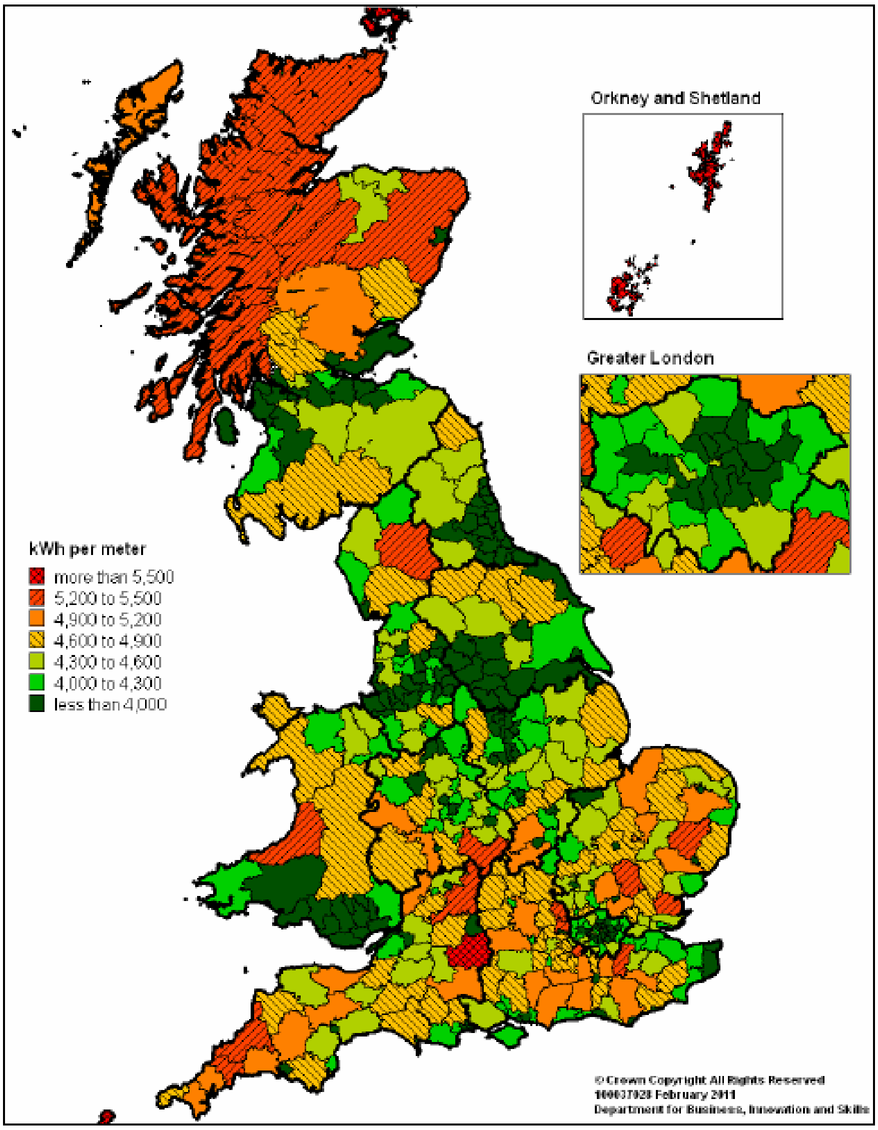


Fig. 2 – Representation of United Kingdom (UK) domestic energy consumption (2009) using GIS. Source: [6].

- Observation of the relationship between energy consumption and the building final purpose.

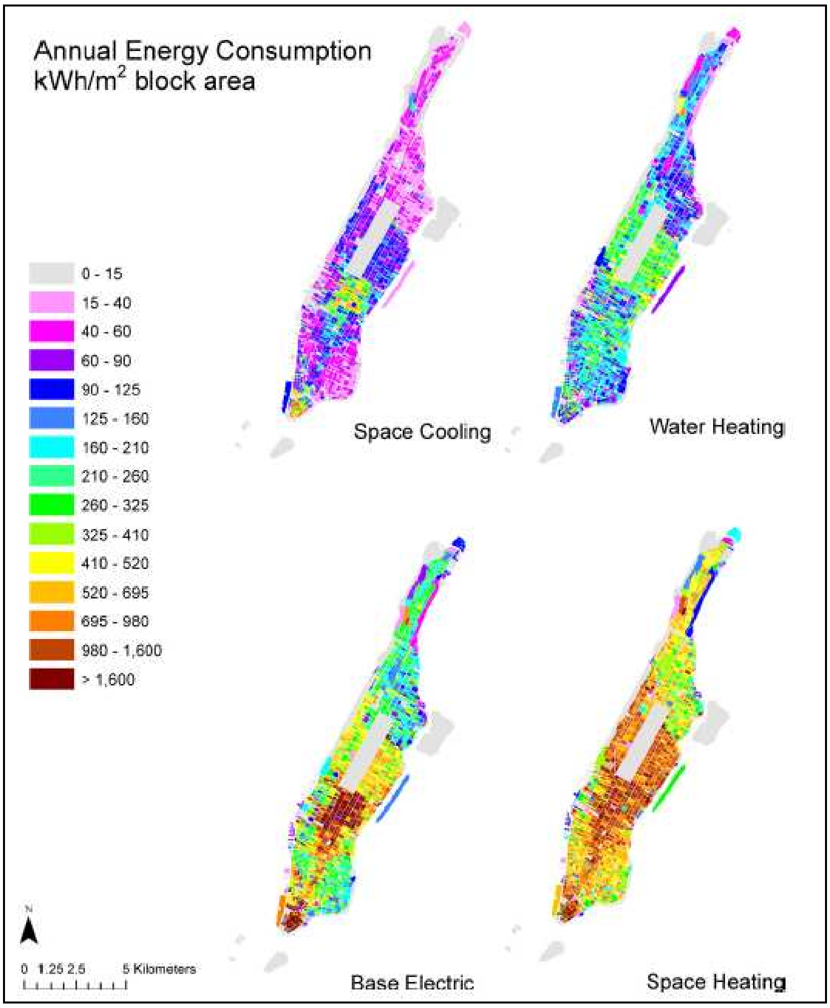


Fig. 3 – Representation of the energy consumed for different purposes in a city area. Source: [7].

- Study of the effect of changes in energy consumption patterns in relation to different dwelling types and ownership.

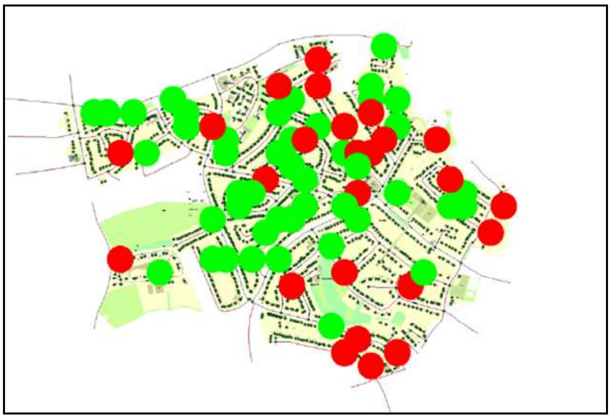


Fig. 4 – Clusters of high and low energy consumers. Source: [8].

Finally, GIS mapping has also already been used for displaying characteristics of the <u>building energy stock</u>:

- Representation of energy performance certificate of buildings (EPC) to suggest a 'Zone Energy Indicator':

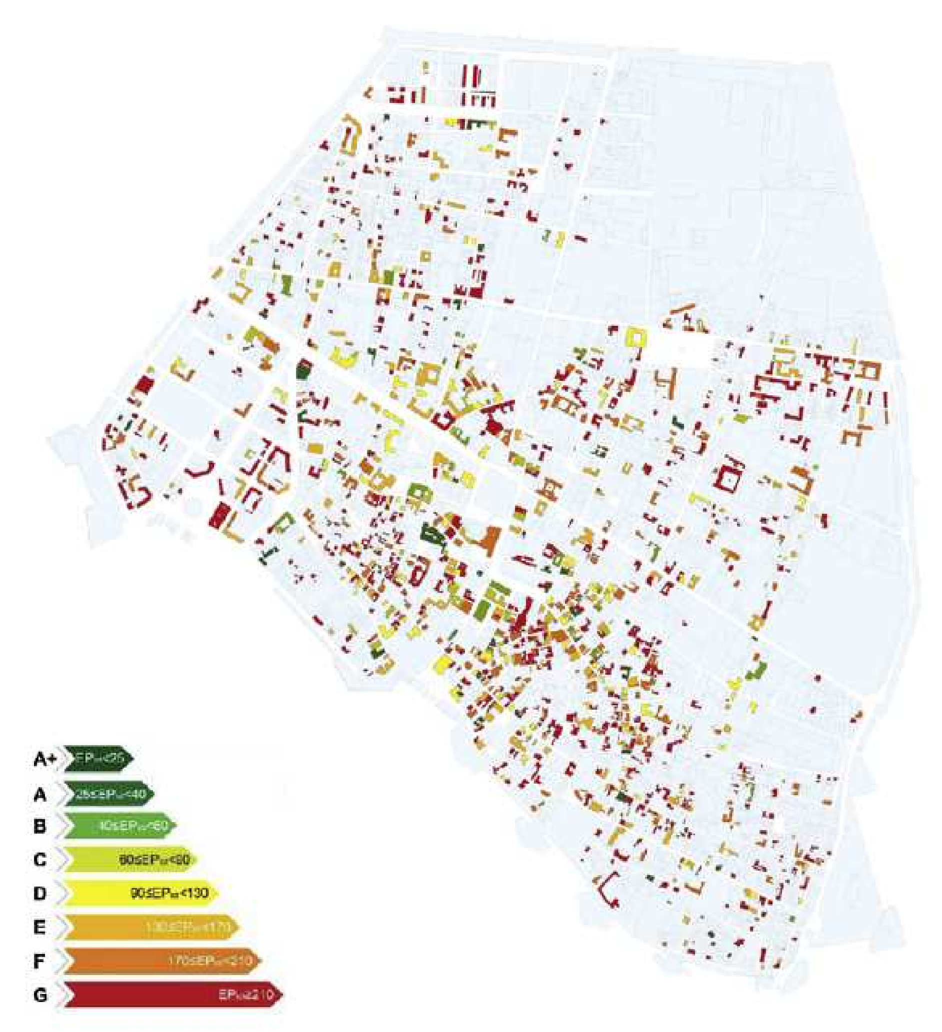


Fig. 5 – Representation of the buildings EPC rating. Source: [9].

However, the approach that is going to be presented in this project has two main innovative aspects: the energy data origin comes from direct metering-lectures and it considers the inclusion of different information attributes in a single map.

2.2. Introduction to geographic information systems (GIS)

GIS are a very powerful tool that allows mapping data that previously could only be displayed on a table, which allows trends and patterns to be detected. These systems work by loading some georeferenced data as well as the maps of the area of interest. This data is treated and presented in a suitable way (the information output can be presented in many different ways, but what is important is that it must be consistent with human capacity for perception). This generates an output, which consists of information, a valuable resource that needs to be interpreted. Moreover, having the appropriate knowledge can be a crucial factor in order to have a good understanding of the situation and therefore extract the right conclusions.

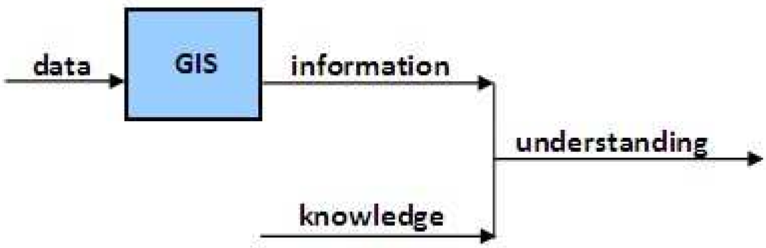


Fig. 6 – GIS systems functionality.

GIS have been used since the late 1960s at different scales and with several different purposes, e. g. analysing the factors causing a situation; assisting in decision making processes, assessing risks or displaying forecasting. The main initial barrier of this technology was the accessibility to digital data; however, soon after several countries set up coordinating bodies in order to formulate and regulate national geographic information strategies.

There are different GIS software packages available in the market at present, such as ArcGis, Clark Labs IDRISI Selva, etc. However, the development of GIS open source[2] programs has been notable in recent years (different websites can be found in internet listing open source and commercial GIS software). Some of the most common open source GIS packages are: Quantum GIS (QGIS), GeoServer, GRASS GIS, OpenMap, etc. Chen, D. et al (2010) looked over 30 open source packages to identify a list of the most suitable to be used for a specific purpose (entailing particular needs). The study

[2] **Open source**: Means that the source code is easily accessible, and it can be modified, and distributed for non-commercial purposes.

highlighted that although QGIS cannot be installed in Windows Vista, it can run in different operating systems, such as Windows or Linux. Moreover, tests showed that its startup time is significantly faster than others, it works satisfactorily with large size images and it has low demand for computing resources [10]. For the aforementioned reasons, the software package selected for this project has been: Quantum GIS 1.7.4. [11].

QGIS program interface can be roughly divided into the following main areas:

1- Menu and tool bars
2- Map legend
3- Map view
4- Map overview

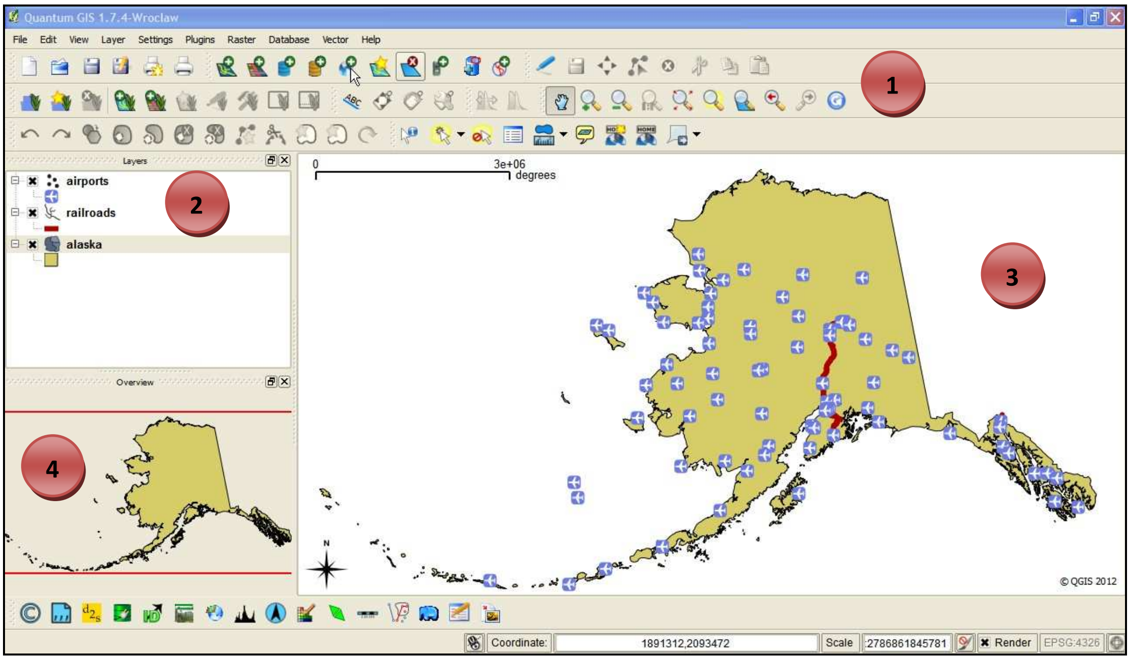


Fig. 7 – QGIS 1.7.4. interface. Source: [11].

Information is stored in GIS in layers, which can be hidden or displayed in the map view when desired. Hence, a map output is the result of overlaying different information layers.

There are two different ways to represent the same information, using vector layers or raster layers:

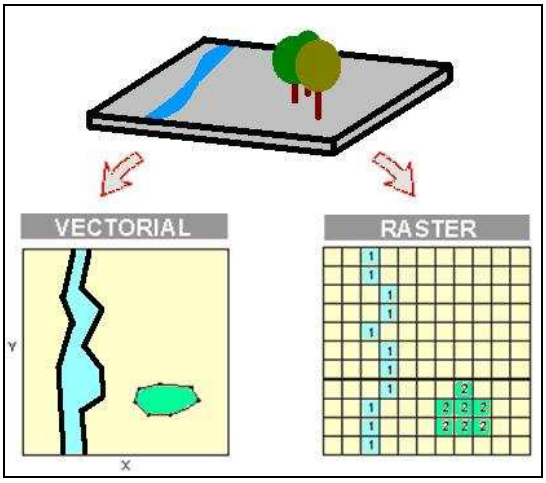


Fig. 8 – Representation of the same reality using two different methods: vector and raster layers. Source: [12].

- **Vector layers:** Are represented by means of <u>discrete points</u>, e.g. airports location; <u>lines</u>, e.g. pipelines or roads; or <u>polygons</u>, e.g. the regions of the country.
- **Raster layers:** Are images made up of grids of rectangles or squares, each having a different colour.

Each entity in the map is defined in terms of its geographical location (spatial coordinates) and their attributes or properties. This information can be requested when desired for a single entity, as shown below:

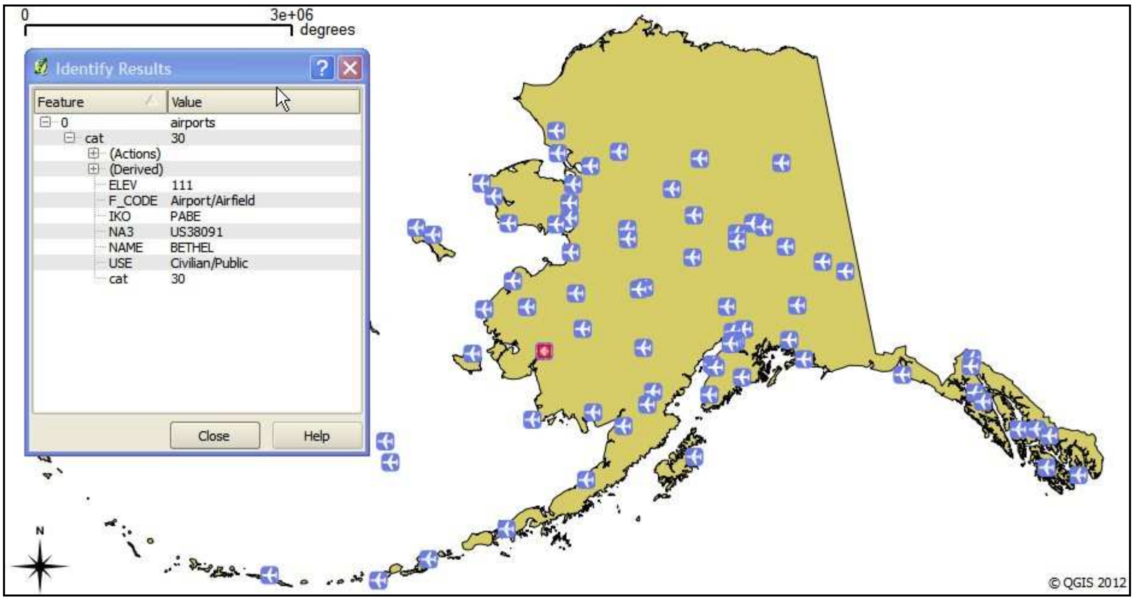
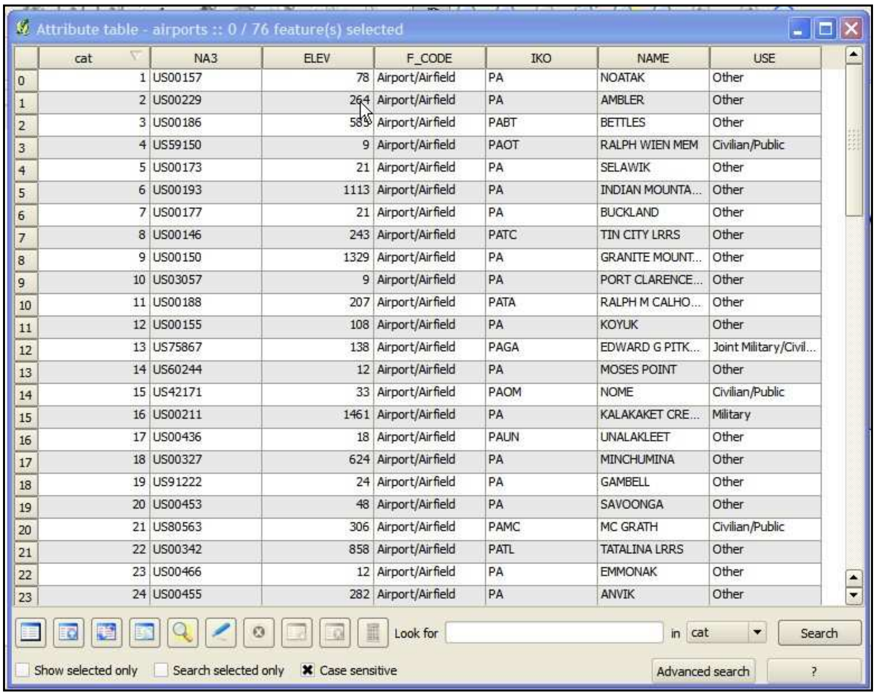


Fig. 9 – Information display of one point. Source: [11].

All this information is stored in an 'Attribute table', which contains the information associated to all the entities of one layer:



	cat	NA3	ELEV	F_CODE	IKO	NAME	USE
0	1	US00157	78	Airport/Airfield	PA	NOATAK	Other
1	2	US00229	264	Airport/Airfield	PA	AMBLER	Other
2	3	US00186	585	Airport/Airfield	PABT	BETTLES	Other
3	4	US59150	9	Airport/Airfield	PAOT	RALPH WIEN MEM	Civilian/Public
4	5	US00173	21	Airport/Airfield	PA	SELAWIK	Other
5	6	US00193	1113	Airport/Airfield	PA	INDIAN MOUNTA...	Other
6	7	US00177	21	Airport/Airfield	PA	BUCKLAND	Other
7	8	US00146	243	Airport/Airfield	PATC	TIN CITY LRRS	Other
8	9	US00150	1329	Airport/Airfield	PA	GRANITE MOUNT...	Other
9	10	US03057	9	Airport/Airfield	PA	PORT CLARENCE...	Other
10	11	US00188	207	Airport/Airfield	PATA	RALPH M CALHO...	Other
11	12	US00155	108	Airport/Airfield	PA	KOYUK	Other
12	13	US75867	138	Airport/Airfield	PAGA	EDWARD G PITK...	Joint Military/Civil...
13	14	US60244	12	Airport/Airfield	PA	MOSES POINT	Other
14	15	US42171	33	Airport/Airfield	PAOM	NOME	Civilian/Public
15	16	US00211	1461	Airport/Airfield	PA	KALAKAKET CRE...	Military
16	17	US00436	18	Airport/Airfield	PAUN	UNALAKLEET	Other
17	18	US00327	624	Airport/Airfield	PA	MINCHUMINA	Other
18	19	US91222	24	Airport/Airfield	PA	GAMBELL	Other
19	20	US00453	48	Airport/Airfield	PA	SAVOONGA	Other
20	21	US80563	306	Airport/Airfield	PAMC	MC GRATH	Civilian/Public
21	22	US00342	858	Airport/Airfield	PATL	TATALINA LRRS	Other
22	23	US00466	12	Airport/Airfield	PA	EMMONAK	Other
23	24	US00455	282	Airport/Airfield	PA	ANVIK	Other

Fig. 10 – Attribute table. Source: [11].

GIS software allow the production of four main types of maps: objects in space (Fig. 11), continuous variation over space (Fig. 12), choropleth maps (Fig. 13) and isoline maps (Fig. 14):

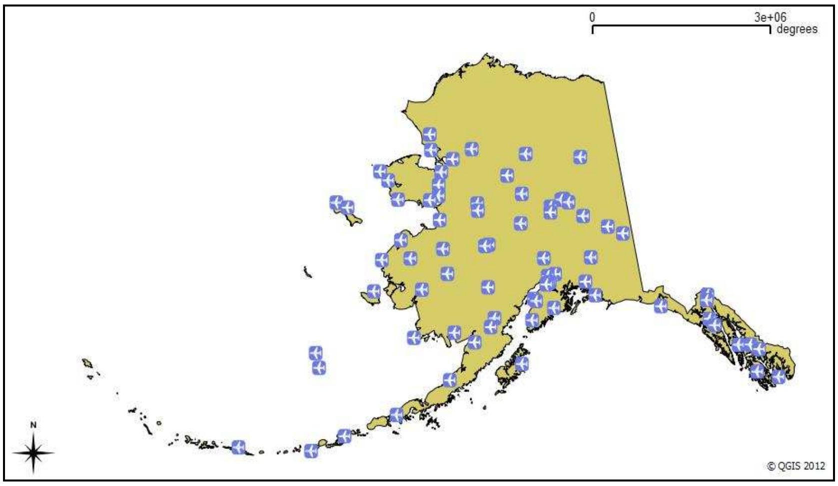


Fig. 11 – Objects in space. Source: [11].

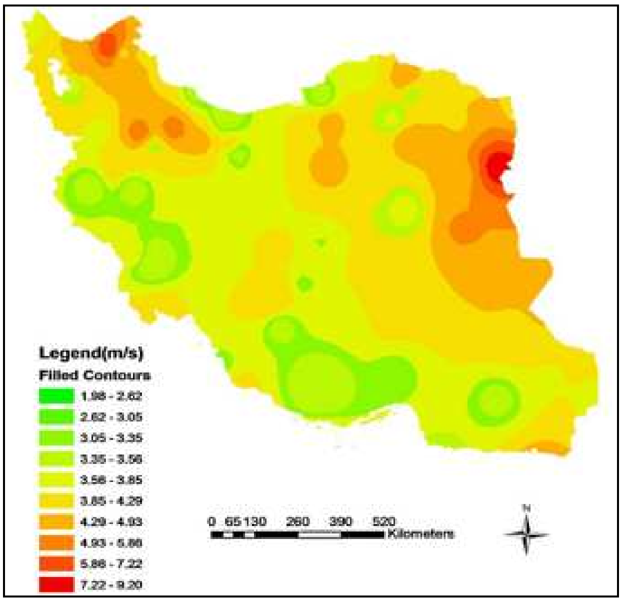


Fig. 12 – Continuous variation over space. Source: [13].

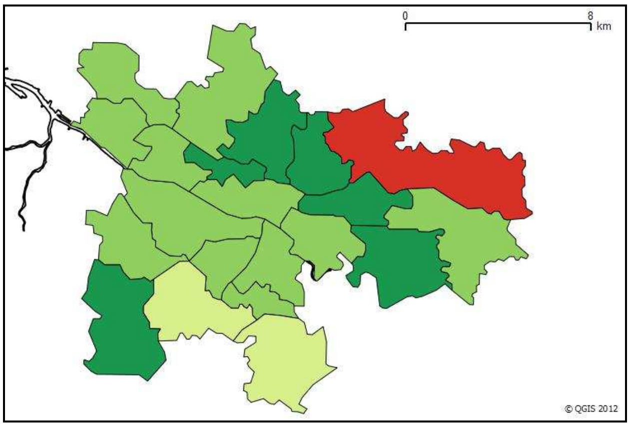


Fig. 13 – Choropleth map[3].

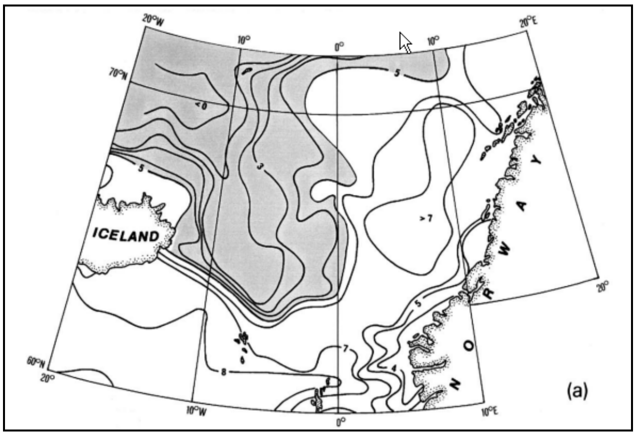


Fig. 14 - Isoline map[4]. Source: [14].

[3] **Choropleth map:** A thematic map in which areas are carefully coloured or shaded to distinguish the classed values of a specific attribute [16].

[4] **Isoline map:** A map with lines connecting points with equal values.

Heywood *et al.* (1995) proved that the slight differences in the way different GIS implement similar methods, can entail different results. Thus, it is crucial to understand the way GIS software works, enabling any results to be understood and explained correctly [15].

2.3. Data sources, management and analysis

The different stages of data processing (Fig. 15), entailing the identification of data sources, data management processes and the final maps analysis and interpretation will be developed in this section.

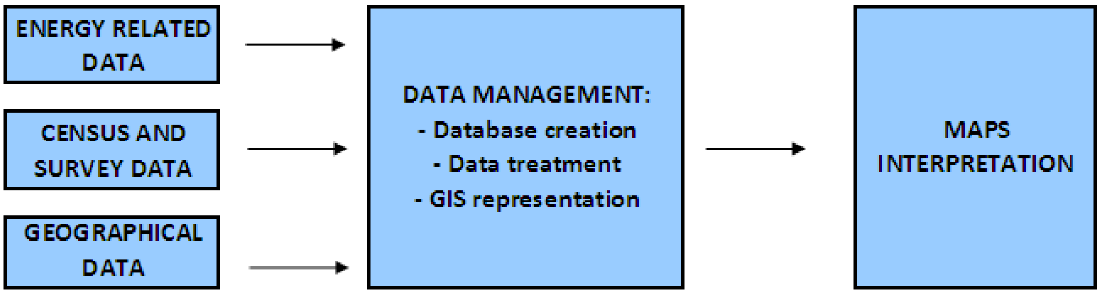


Fig. 15 – Data processing.

2.3.1. Data sources

Defining the problem of study and selecting the appropriate data are crucial steps in the design of any GIS project. Hence, a good project design is indispensable for an appropriate output. Once the data needed in each case is determined, the identification of the possible data sources can be completed.

Data representation in the built environment has a huge potential, since it can provide very valuable information to companies and local authorities. However, it also contains several significant concerns:

- The first one is how ethical it is to associate private population-related data with discrete geographical locations. To solve this, different masking techniques can be used to make the results anonymous so that the minimum entity can be a single house.
- Also, there is a common technical problem: there are many sources of population data, but these are usually not associated to any geographical location, so a spatial referencing process is needed.
- Data quality is also crucial to have reliable results. Geographic data has three components: spatial, temporal and thematic. Data has a good quality when it is accurate, precise, has good resolution, is complete and consistent in the three aforementioned aspects [17].

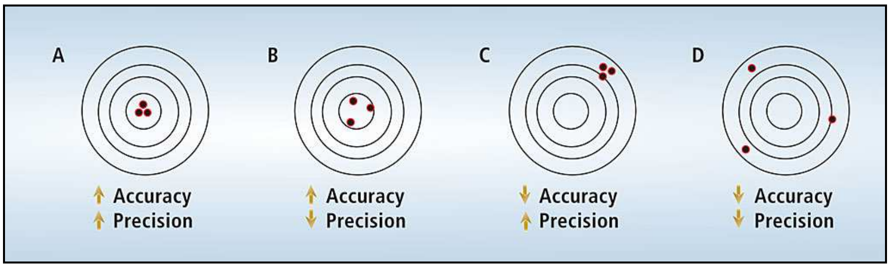


Fig. 16 – Explanation of the Concepts accuracy and precision. Source: [18].

2.3.1.1. Energy related data

There are two main sources of energy related data: measured data and data coming from simulations.

2.3.1.1.1. Measured data

Utilities have the consumption register of all their clients, which has been obtained by a metering lecture. At present, in many cases this lecture is done manually by a worker of the company, with an approximate frequency of one visit per month; however, we are moving towards a metering system providing continuous lectures, with intervals between 15 and 30 minutes, so the availability of electrical and gas consumption data for all the households within the area of study will be an assumption of this project.

2.3.1.1.2. Data coming from simulations

Data can also come from simulations. Different specific software can be used to obtain energy consumption values, for example: a software where the inputs are the house area, number of rooms, etc., and the output: average electrical consumption.

Data from simulations is very useful particularly for future scenarios predictions.

2.3.1.2. Census and survey data

- <u>Building stock information:</u> Local authorities are in possession of buildings features information: year of construction, dwelling cadastral value, EPC rating, etc.
- <u>Census information:</u> Local authorities also have information about its citizens: age, sex, social insurance number, profession, income, etc. (This government trend of defining each citizen by a series of numbers was defined in 1996 by Mark Poster as 'digital citizens' [19]).

2.3.1.3. Geographical data

Most of the developed countries have agencies coordinating geographical data, which is often downloadable free of charge.

'Ordnance survey' is the national mapping agency of Great Britain, and geographical data of the country can be accessed free of charge [20]. This organization offers vector, raster and point data files covering different scales and applications. For the approach presented, the following file has been downloaded:

- District_borough_unitary_ward_region

'The Scottish Government' also offers free of charge geographic files compatible with GIS software [21]. The following file has been downloaded from this source:

- 2009-2010 Urban Rural Classification Shapefiles

The 'Scottish Neighbourhood Statistics' offers free of charge geographic information Shapefiles too [22]. The following files have been downloaded and used in this approach:

- Datazones_2001
- IntGeography_2001

'Digimap' is a collection of EDINA services, a service from the University of Edinburgh that offers free access to maps and geospatial data of Great Britain for staff and students in higher and further education [23]. The following file has been used for this approach:

- Topo_Area

2.3.2. Data management

Data management process is composed of the following stages:

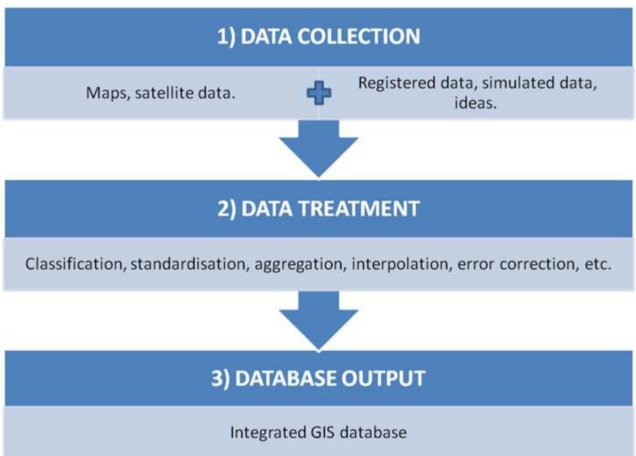


Fig. 17 – The data management process.

1) Data collection: Once the required data has been defined according to the project requirements, it will be collected. At present, technology provides automatic data collection devices that allow a large amount of data to be otained, in order to better know the reality. However, this data needs to be dealt with in an easy manner that allows storing and treating it, so that it can be converted into a suitable output that provides the information needed. Databases are the management method most commonly used, which consist of a set of structured data, being usually accessed by means of a database management systems (DBMS), a set of computer programmes that will allow users to deal with data without needing to know how it is physically structured and stored in the computer. DBMS offer different options to present the data in a suitable manner for the user's purpose, allowing the data to be ordered under specific criteria, filtered, summarised or combined to provide specific information. However, databases also have limitations. Oxborrow [24] summarises the main databases problems as:

- Complexity: Its utilisation may require users training.
- Cost: The overall cost includes software development and design stages, maintenance and data storage.
- Inefficiencies in processing: When happening, will require time to get fixed up.
- Rigidity: Some databases do not accept long text strings, or other types of data.

Moreover, special attention needs to be put on data backup, recovery, auditing and security.

The definition and filling of the database with real data (data encoding process) is often a very time-consuming process (data input and updating can represent approximately an 80% of the duration of many large-scale GIS projects [25]) and its importance cannot be underestimated. The different data input methods are: manual entry (keycoding), digital data transfer, digitalisation or scanning processes.

At present, the incorporation of GIS systems by multinational companies, local authorities, etc. is growing; being the software compatibility with the existing internal databases a crucial aspect for its success. These multi-user applications have specific needs, such as security, reliability, integrity, performance and current access by different users often using intranet systems. In most cases there is a specific department working with GIS, controlling the data and the access to it, and dealing with all the issues described in this chapter.

Some of the most commonly used DBMS packages are:

- Open source: mySQL, PostgreSQL, etc.
- Proprietary software: Oracle, Microsoft SQL server, etc.

2) Data treatment: Once data has been collected, it undertakes different transformation processes, depending on the final purposes, which can include data classification, standardisation, aggregation, interpolation, error correction, etc. Errors are inevitable along these processes (stages 1 and 2), and its minimisation is crucial, as the reliability of the results will depend on the data quality. Linking databases to GIS provides a further level of data value.

3) Database output: Once the necessary data has been collected from different sources, a common 'Coordinates reference system' to work with needs to be chosen (a commonly used system is WGS84, which is a global projection system). Also, when combining data from datasets collected by different entities, knowing the metadata[5] is necessary in order to know whether it is sensible or not to represent the different data together in a single map [26].

The data output format will depend on the map's purpose, the audience to whom the results are directed and the cost constraints. The huge amount of possibilities offered by GIS software can make the maps design a very time consuming process, but at the same time very effective.

2.3.3. Data analysis

Once the data has been collected, treated and represented, the analysis of the results takes place, which most of the times consists in identifying spatial patterns, and where answers to some questions can be given and decisions be made. To do so, GIS provides some functions such as: measurement of lengths, perimeters and areas, distance calculations, point in polygon queries (e.g. is there an entity with a specific attribute in a given area?), shape analysis, etc.

[5] **Metadata**: By definition it is 'data about data'. It is a file normally attached to data files, which indicates the origins, quality and applicability of the data.

3. System's functionality

This is a time of major changes for electrical utilities, which will have to adapt to new government regulations in a small period of time. The adoption of GIS can be a useful tool helping this purpose, as will be detailed in this section.

For the specific purpose of this project, which is meant to be useful to utilities supplying gas and electricity to a specific urban area, as well as the competent local authorities the specific functionalities have been categorised as follows:

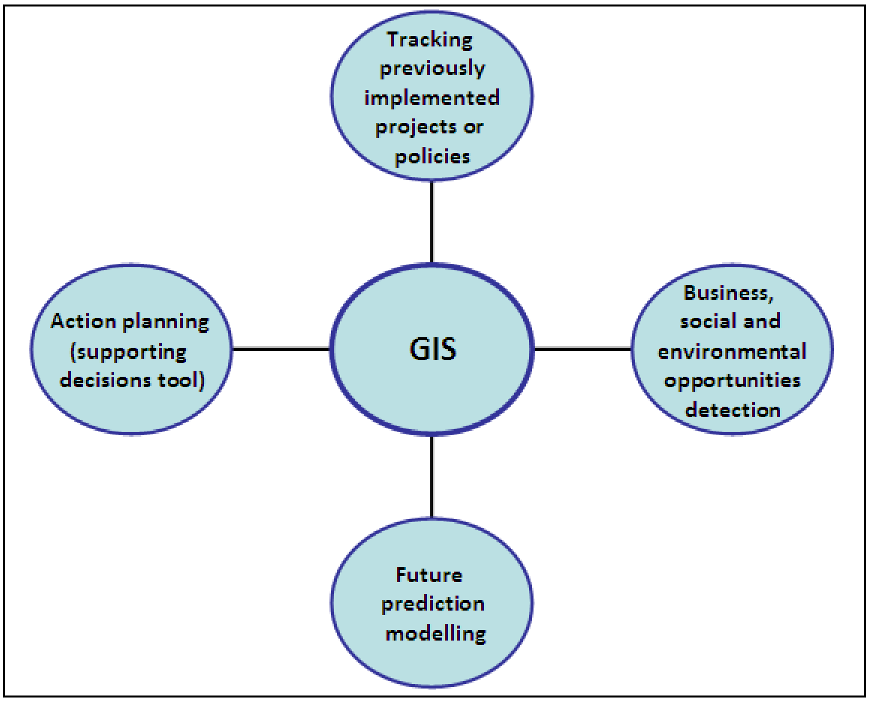


Fig. 18 – GIS functionalities.

- <u>Tracking previously implemented projects or policies:</u> Previously implemented policies can be tracked along the time to detect if they are accomplishing their original purposes, and if they are not, analyse the current present situation and the causes that have led to it. This can be done by representing the variables change in a single map, which can be become relatively complex to perceive, or by displaying a series of single maps, each one representing a moment in time and comparing them, which tends to be easier to interpret, as it gives the user an idea of change in time. Finally, performing an animation with the maps just mentioned is believed to be an excellent way to introduce the temporal component to spatial data. Some examples of this kind of functionality in the energy field would be the implementation of distributed generation technologies (e.g. district heating) or the tracking of buildings energy consumption after efficiency improvement actions have taken place.

- Action planning (supporting decision tool): Different strategic actions are continuously being implemented in urban areas. Having access to information directly or indirectly related to the decision topic will allow a decision making process that takes into account a higher number of factors, ending up with overall better results. Most of the time, choropleth maps are the most appropriate for decision making, as they transmit information in a very clear and understandable manner. An example of action planning would be the measures implemented in order to achieve the climate change targets of a specific urban area. The representation of the policy limitations on a map is also very useful for action planning.
- Business, social and environmental opportunities detection: the overlap of different layers can highlight some causality relations leading to undesirable situations. Hence, once they are detected, action can be taken in order to be improved. Also specific needs can be detected, creating business opportunities. Some examples can be the detection of an area with overall higher carbon emissions, where action should be taken in order to decrease it, the identification of where and when infrastructure upgrades are appropriate (e.g. transmission lines) or the feasibility of a new project depending on the surrounding area.
- Future prediction modelling: The representation on a map of the prediction of a future situation can pinpoint specific needs and generate actions in order to progress and take actions in advance, in order to avoid or minimise future problems. For example, the needs of substations modifications can be studied in a scenario with high deployment of small scale renewable and feed in tariffs.

For all the purposes exposed above, an example of the kind of information that has been considered relevant to be included in a GIS system within the energy sector is as follows:

ATTRIBUTE	UNITS
Electrical consumption	[kWh/year] [kWh/year/person] [kWh/year/m^2]
Gas consumption	[kWh/year] [kWh/year/person] [kWh/year/m^2]
Equivalent carbon emissions coming from electric consumption	[kg CO_2/year] [kg CO_2/year/person] [kg CO_2/ year/m^2]
Equivalent carbon emissions coming from gas consumption	[kg CO_2/year] [kg CO_2/year/person] [kg CO_2/ year/m^2]
Fuel poverty[6] $\left(\frac{fuel\ \cos ts}{income}\right)$	[%]
Heat to power ratio[7]	(X:Y)

Table 1 – Energy related data.

ATTRIBUTE	UNITS (QUANTITATIVE VARIABLE) / CLASSING (QUALITATIVE VARIABLE)
Floor area	[m^2]
Building type	Detached house (DH) Semi-detached house (SD) Flat (FL).
EPC building rating	[A to G]
Heating type	Electric heaters (EH) Gas fired heaters (GH) HVAC (HV)

[6] **Fuel poverty:** A household suffers from fuel poverty if more than 10% of its economic income is used to pay heating in order to maintain a satisfactory temperature [28].

[7] **Heat to power ratio:** It is a ratio used to evaluate the suitability of a CHP system in a specific site. The value represents the amount of usable heat generated per each unit of electricity generated [29].

Sky availability	[m^2]
Number of inhabitants per dwelling	-
Average inhabitants age	Years old

Table 2 – Census and survey data.

ATTRIBUTE	UNITS
Geographic information	Mountains, rivers, oceans, lakes, landform…
Administration information	City boundaries, districts…
Roads	Motorways, major roads, minor roads…
Generic urban information	Postcodes, street names…
Soil type	Residential, commercial, parks, industrial…

Table 3 – Geographical data.

Organizations such as multinational companies, local governments or utilities are using GIS more and more for a whole range of applications, like marketing, facilities location and engineering applications following two main objectives: driving down costs and improving customer service [27]. However, the decision of whether to install a GIS system, which includes justifying the investment cost, can be complicated. Clear objectives need to be defined prior to software acquisition; moreover, costs and benefits need to be listed and assessed. Some of the more common are compiled in the following table:

Direct costs		Direct benefits	
1 Hardware / software	■ Hardware ■ Fewer staff required ■ Software ■ Software development ■ Customization ■ Consumables (printer supplies, etc.) ■ Software upgrades ■ Maintenance and support contracts ■ Communications networks	1 Savings	■ Reduced cost of information production and provision ■ Fewer staff required ■ Less space required for, e.g., map storage ■ Time savings for routine and repetitive tasks
2 Data	■ Database creation ■ Data conversion ■ Database maintenance ■ Data updating	2 Increased effectiveness	■ Faster provision of information ■ Greater range of information services provided ■ Information more readily available ■ Up-to-date information available
3 Human/admin.	■ Insurance ■ Administration ■ Security ■ Training ■ Rent	3 New products	■ New range of output – maps, tables, etc. ■ Better-quality output
4 Method for choosing system	■ Pilot project ■ Benchmarking ■ Cost–benefit analysis ■ Consultancy		

Indirect costs	Indirect benefits
■ Increased reliance on computers – vulnerability to failures, changes in software/hardware, etc. ■ Poorer working environment – noise, heat, tedious tasks for users ■ Higher-skilled workforce required	■ Improved information sharing and flows ■ Better-informed decision making ■ Stronger competitive ability ■ Better-motivated workforce – more career options, less tedious tasks ■ Greater analysis and understanding of problems ■ Justification for decisions made ■ Improved visualization of data

Table 4 – Costs and benefits of using GIS. Source: [15]

A cost-benefit analysis may be a good exercise to help taking this decision; however some of the costs and benefits of GIS may not be easy to quantify, especially the indirect ones.

4. Mapping process stages: data treatment, representation and interpretation

A complete approach to energy related information mapping, which includes data treatment, representation and interpretation, is going to be developed in this section.

4.1. Data treatment

Before being displayed on a map, data must be analysed and many times treated, which includes filtering it, combining it, transforming it, etc. It is very important that data quality is assured along this process, as map reliability will depend on it.

One of the most important processes in the representation of energy related data is the data calculation processes. There are two main calculations that will be completed for the purpose of this project: to obtain a electricity usage value (kWh/year) from a continuous energy metering lecture (kWh), and to transform the units of the consumed fuel or electricity (kWh/year) into carbon emissions (Kg CO_2/year).

4.1.1. Obtaining a power consumption value from continuous energy metering lectures

One of the assumptions of this project is that in few years time, continuous metering systems will be installed around Scotland, so utilities will have 15 min. resolution consumption data at their disposal, which represented daily will be:

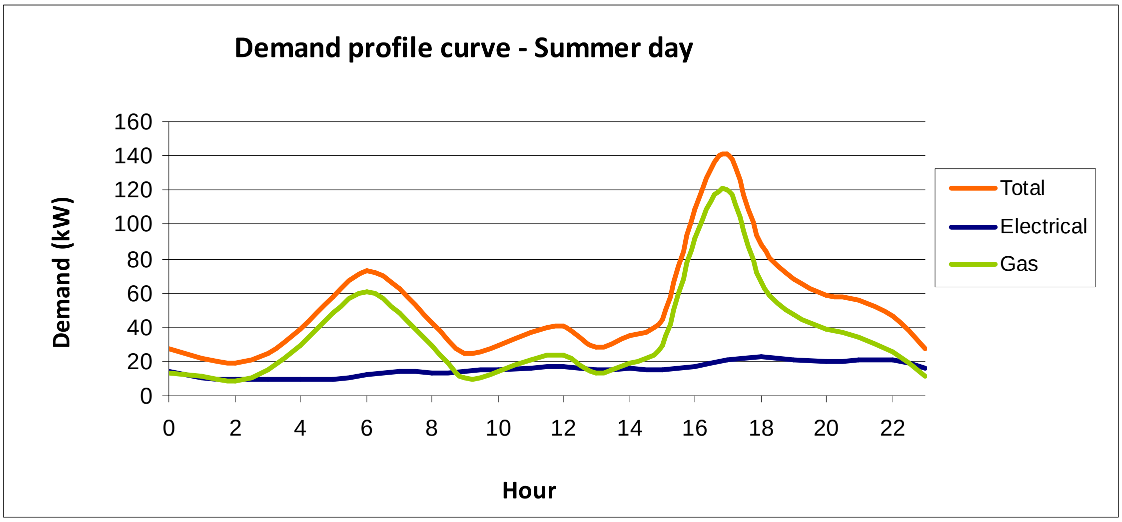


Fig. 19 – Example of a summer demand profile curve. Source: [30].

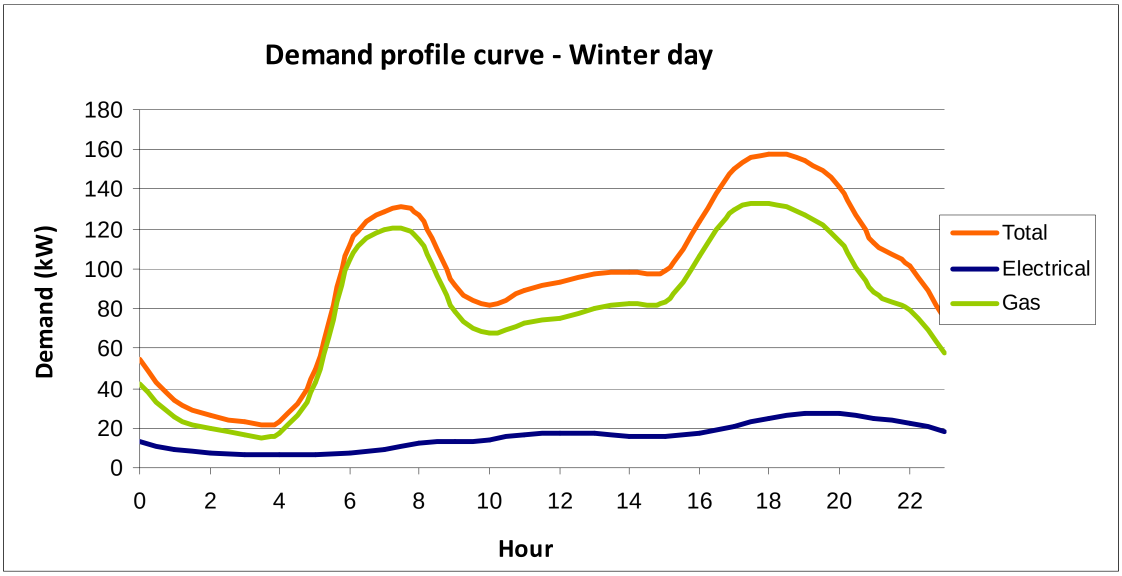


Fig. 20 – Example of a winter demand profile curve. Source: [30].

The consumed power[8] is going to be expressed, for the project purposes, in kWh/year. The suggested method to calculate this power value is the 'trapezoidal rule', which consists in discretizing the curve into several intervals (in this case of 15 minutes), and approximating the area under it by:

$$\int_a^b f(x)dx \approx (b-a)\cdot\frac{f(a)+f(b)}{2} \qquad \text{(Equation 1)}$$

being 'a' and 'b' the first and last hour value of each interval.

The values obtained for each of the 15 minutes intervals are added up for a whole year, and the resulting number is the annual energy consumption for a specific dwelling. These values have been found to be roughly 10000 kWh/year of gas consumption and 3000 kWh/year of electrical consumption, for a domestic building in Glasgow city.

4.1.2. Obtaining carbon equivalent emissions from energy consumption

Once the annual consumed energy is known, it can be converted into carbon emissions by means of the spreadsheet 'emissions' [31], which allows the conversion of different types of fuels consumption (kWh/year) into carbon emissions (g of CO_2/year).

The following equations for both gas and electricity have been obtained from this spreadsheet and have been used to obtain the carbon emission values that are displayed in the maps.

[8] **Consumed power:** rate at which energy is consumed.

4.1.2.1. Conversion of gas consumption into carbon emissions

The equation obtained from the spreadsheet is the following:

$$y = 244.3716 \cdot x \qquad \text{(Equation 2)}$$

where ‘x’ represents the amount of gas consumed in a period of time (in kWh/time period) and ‘y’ the carbon emissions released from this consumption (in grams/time period).

4.1.2.2. Conversion of electrical consumption into carbon emissions

The amount of emissions released per unit of energy consumed depends on the fuel mix that has been used to obtain the electricity. For the period 1 April 2010 to 31 March 2011, the UK fuel mix was as follows [32]:

ENERGY SOURCE	%
Coal	28.9
Natural gas	44.2
Nuclear	17.3
Renewables	7.9
Other	1.7

Table 5 – UK fuel mix breakdown. Source: [32].

Thus, the values presented in Table 5 have been introduced into the ‘emissions’ spreadsheet to obtain the following equation:

$$y = 3254.03 \cdot x - 2.01 \qquad \text{(Equation 3)}$$

where ‘x’ represents the amount of gas consumed in a period of time (in kWh/time period) and ‘y’ represents the carbon emissions released from this consumption (in grams/time period).

4.2. Data representation

There exist multiple ways to represent data on a map, some are better than others, some are valid and some not; however there is not one single answer to this question. Therefore, an extensive study has been carried out to determine which the most suitable techniques for displaying energy related information are.

The method that has been used for this purpose is conjecture & test. Hence, some initial representation techniques have been presented, which have been subsequently evaluated by several energy experts in order to determine their effectiveness.

4.2.1. Data display introduction

In *section 3 System's functionality*, the different information attributes that are considered to be of interest for this project are listed. This information cannot be displayed all at once, as the resulting maps would be overcrowded. Therefore, the first step is to study which combination of attributes could be represented at the same time in a single map.

It is sensible to represent just one parameter of energy data per map except for the case when the proportion of electrical and gas consumption wants to be compared. Different census attributes can be represented in a single map, as well as dwelling characteristics. Moreover, both census and dwelling characteristics attributes can be represented together to provide a higher level of information. These possible combinations are represented in Fig. 21:

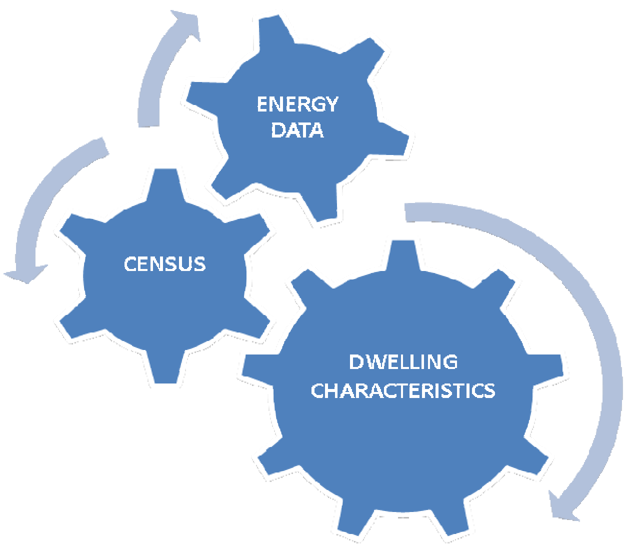


Fig. 21 – Interaction between the variables that can be represented in the maps.

4.2.2. Scenario creation

In order to show the capabilities of the GIS techniques for the aforementioned purposes, data is needed. Certainly, real data would be subjected to confidentiality issues, as has been previously explained in *section 2.3.1 Data sources*, therefore, an artificial scenario will be created. The area selected for this study has been Glasgow city, due to real building geographical data availability provided by the ESRU department of the University of Strathclyde. Nevertheless, the conclusions of this approach to representation methods will be valid for any urban area.

For displaying the data, an attribute table must be created, which shows some of the selected attributes:

ATTRIBUTE	MEANING	UNITS OF MEASURE	DESCRIPTION	ORIGIN
X	x geographic coordinate	-	Numeric value	Geographic data base
Y	y geographic coordinate	-	Numeric value	Geographic data base
Ref	dwelling reference code	-	Alphanumeric chain	Created
Heating_ty	Heating type	-	1 – Electric heating 2 – Gas heating 3 – HVAC[9]	Local authorities
EPC_rating	Energy Performance Certificate rating	-	1 – Energy efficient to 7 – Not energy efficient)	Local authorities
Area	Dwelling area	m^2	Numeric value	Local authorities

[9] **HVAC:** Heating, ventilation and air conditioning.

Cad_value	Cadastral value	£	Numeric value	Local authorities
Hh_ty	Household type	-	1 – Household with children 2 – Single parent households 3 – Single person household	Local authorities
Aver_age	Dwelling inhabitants average age	Years old	Numeric value	Local authorities
N_inhabitants	Number of inhabitants	-	Numeric value	Local authorities
HP_ratio	Heat to power ratio	-	Numeric value : Numeric value	*See Table 7*
F_pov	Fuel poverty	-	Percentage	Local authorities
Elec_cons	Electrical consumption	$\frac{kWh}{year}$	Numeric value	*See Table 7*
Gas_cons	Gas consumption	$\frac{kWh}{year}$	Numeric value	*See Table 7*
Elec_em	Carbon emissions from the electrical consumption	$\frac{kg\ CO_2}{year}$	Numeric value	*See Table 7*
Gas_em	Carbon emissions from the gas consumption	$\frac{kg\ CO_2}{year}$	Numeric value	*See Table 7*
Total_em	Total carbon emissions	$\frac{kg\ CO_2}{year}$	Numeric value	*See Table 7*

Table 6 – Attribute table.

The following table shows the data origins and calculations that are carried out in an external database and imported into the ‘Attribute table’:

ATTRIBUTE	MEANING	UNIT OF MEASURE	COLLECTION METHOD	VALUE ORIGIN
Date	Date of lecture collection	-	dd/mm/yy	Utilities automatic collection
Time	Time of lecture collection	-	hh:mm:ss	Utilities automatic collection
Elect_lect	Meter electric lecture	kWh	Numeric value	Utilities automatic collection
Gas_lect	Meter gas lecture	kWh	Numeric value	Utilities automatic collection
Elec_cons	Electrical consumption	$\frac{kWh}{year}$	Numeric value	$35040 \cdot \left(Elect\_lect_n - Elect\_lect_{(n-1)}\right)$
Gas_cons	Gas consumption	$\frac{kWh}{year}$	Numeric value	$35040 \cdot \left(Gas\_lect_n - Gas\_lect_{(n-1)}\right)$
Elec_em	Carbon emissions from the electrical consumption	$\frac{kg\ CO_2}{year}$	Numeric value	$Elec\_em = \frac{3254.03 \cdot \sum_{n=1}^{365} Elec\_cons - 2.01}{1000}$
Gas_em	Carbon emissions from the gas consumption	$\frac{kg\ CO_2}{year}$	Numeric value	$Gas\_em = \frac{244.3716 \cdot \sum_{n=1}^{365} Gas\_cons}{1000}$
Total_em	Total carbon emissions	$\frac{kg\ CO_2}{year}$	Alphanumeric chain	$Total\_em = Elec\_em + Gas\_em$
HP_ratio	Heat to power ratio	-	Numeric value : Numeric value	$HP\_ratio = \frac{Gas\_cons}{Elec\_cons}$

Table 7 – Generation of ‘Atribute table’ contents.

An artificial scenario has been created with some of the data detailed in Table 6.

The following data has been used for the scenario creation:

- Wards population by age (2010) [33]
- Household types (2010) [33]
- Wards average household size (2010) [33]
- Average ordinary domestic electrical consumption (2010) [34]
- Average ordinary domestic gas consumption (2010) [34]
- Number of dwellings of each band per ward [35]
- Percentage of each dwelling type per ward [35]
- Conversion data table from postcodes to data zones [36]

A screenshot of the scenario generated attribute table is shown below:

	X	Y	EPC_rating	Hh_ty	Aver_age	Elec_cons	Gas_cons	Elec_em	Gas_em	Total_em
0	260004	668680	2	1	40.06	3645	14343	11861	3505	15366
1	260042	668426	2	1	26.577	2898	10607	9430	2592	12022
2	260050	668315	3	1	47.275	3073	11480	10000	2805	12805
3	260067	668316	3	1	40.879	2481	8521	8073	2082	10155
4	260081	668379	2	1	40.735	5126	21747	16680	5314	21994
5	260085	668426	2	1	45.032	2683	9528	8731	2328	11059
6	260088	668319	3	1	41.046	2826	10248	9196	2504	11700

Fig. 22 – Part of the scenario created attribute table.

4.2.3. General rules for one variable information displaying

The results yield both qualitative (e.g. the company which supplies the fuel to each household) and quantitative (e.g. the amount carbon emissions released in a period of time) types of information, and it is important to be able to represent these appropriately. Generally, colour hue and symbol shape are appropriate for showing categorical differences, while quantities are better represented by colour lightness and symbol size [37]. However, many different representations of the same data can be made, depending e.g. on the map scale, the symbol selection, the data classing or the way of combining multiple variables.

4.2.3.1. Map scale issues

The geographical maps characteristic of this approach consist of urban areas. Around the world there are urban areas of many different sizes, which at the same time can be divided in various ways. For the case study of this project, it has been considered appropriate to work with three different zoom levels of the city (Table 8). The possible divisions of the displayed area are also mentioned in the table:

ZOOM	LEVEL OF DETAIL	POSSIBLE DIVISIONS	IMAGE
Zoom 1	Streets view	-	Fig. 23
Zoom 2	Wards view	District Zones[10] (DZ)	Fig. 24
		Intermediate Geography[11] (IG)	Fig. 25
Zoom 3	City view	Intermediate Geography (IG)	Fig. 26
		Wards[12]	Fig. 27

Table 8 – Zoom levels and divisions.

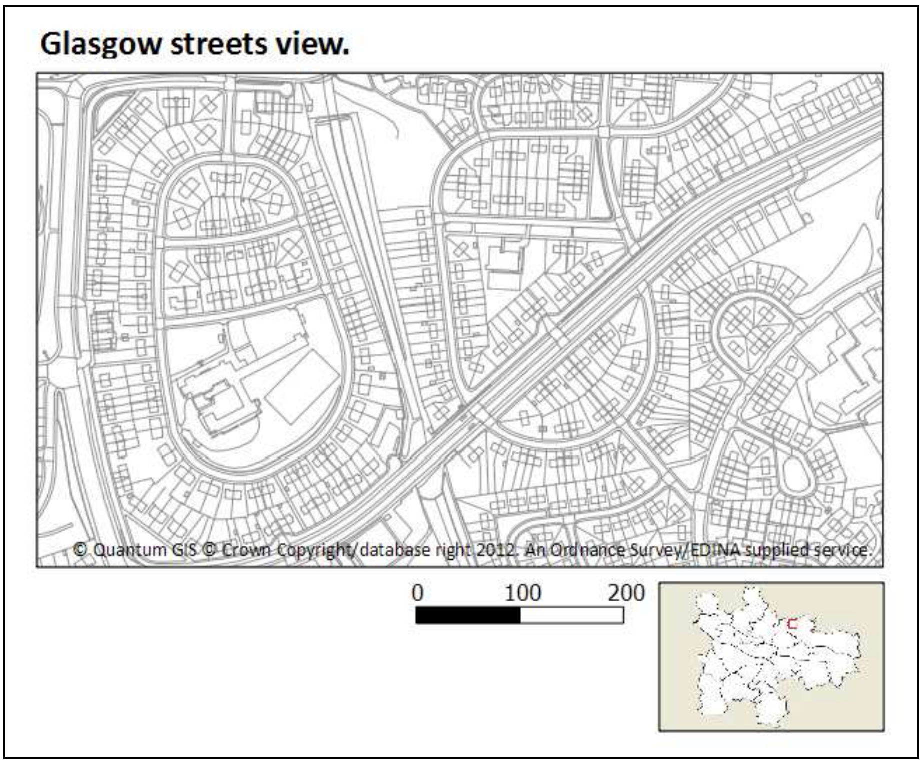


Fig. 23 – Zoom 1 view.

[10] **Data zones:** Small areas in which Scotland is divided, each containing at least 500 residents, which were created from 2001 Census Output Areas. Source: [16].

[11] **Intermediate Geography:** A geography division used in Scotland, which areas are built from grouping data zones and fit into council area boundaries. They contain at least 2500 inhabitants. Source: [16].

[12] **Wards**: Electoral wards or divisions are the base of UK administrative geography (all other higher units are built up from them). Source: [16].

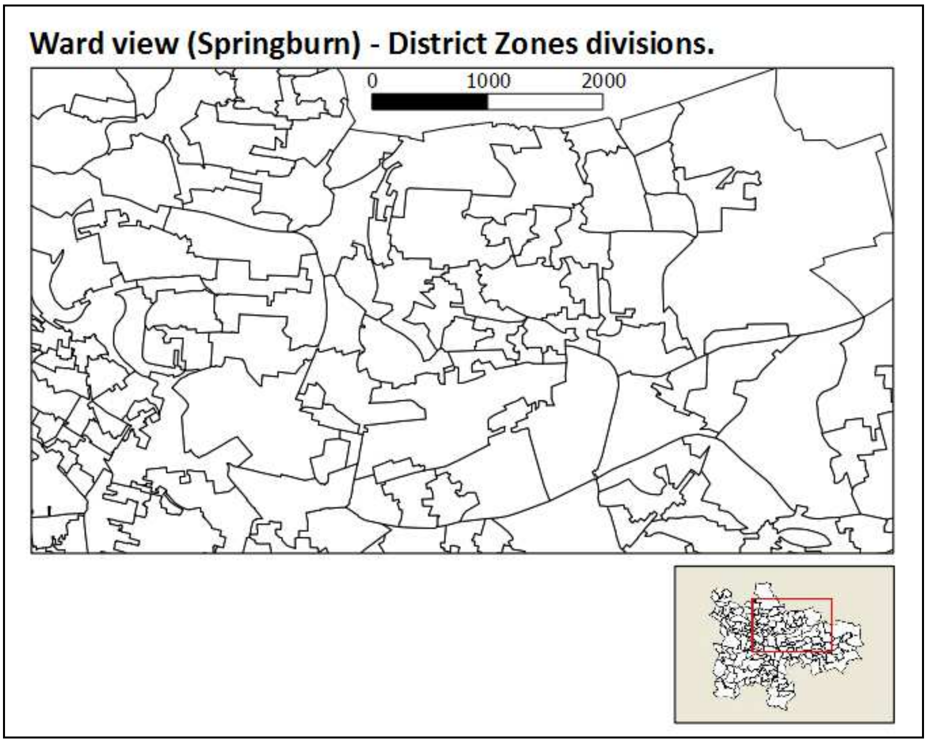


Fig. 24 – Zoom 2 view: small areas division.

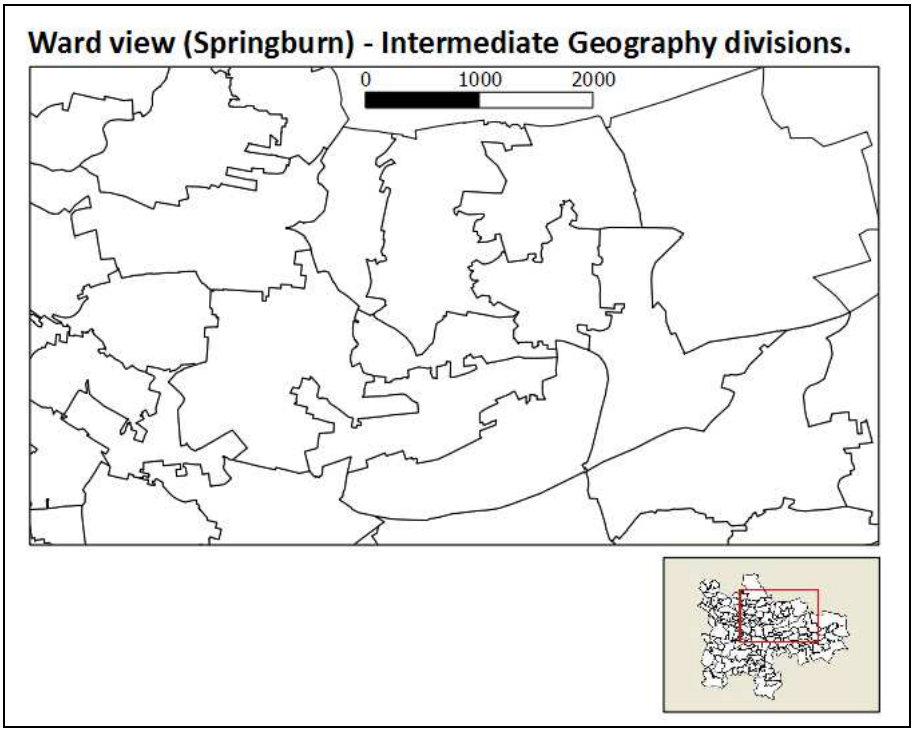


Fig. 25 – Zoom 2 view: big areas division.

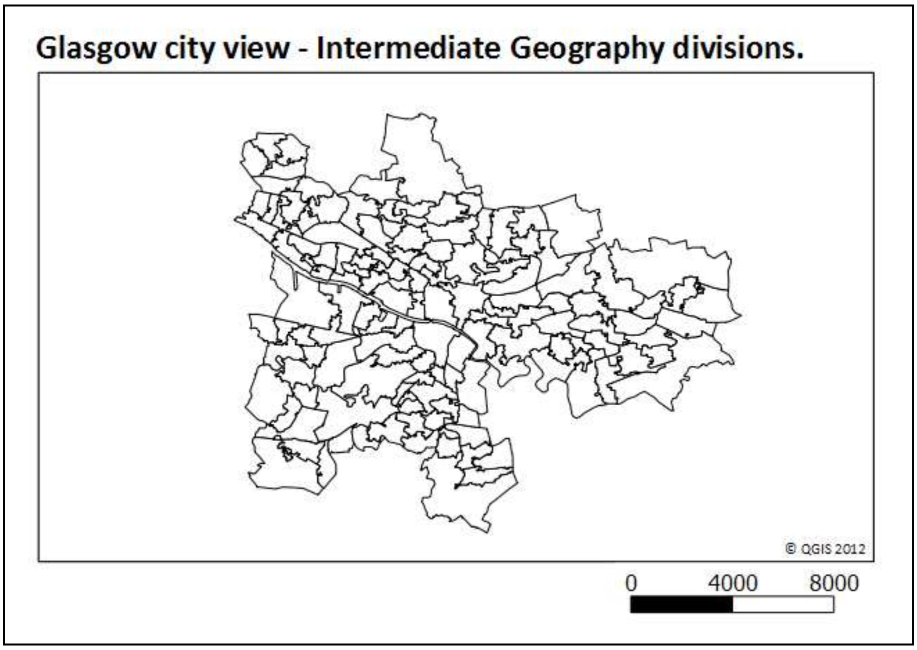


Fig. 26 – Zoom 3 view: small areas division.

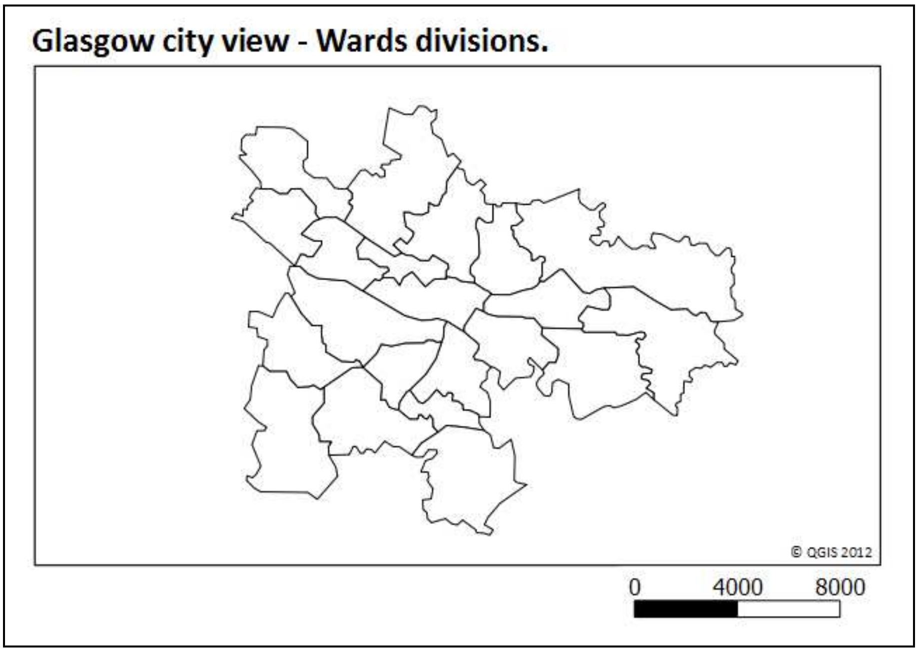


Fig. 27 – Zoom 4 view: big areas division.

In general terms, data must always be legible, and overcrowded maps, as well as difficult to read maps, must be avoided. Different zoom levels may need different representation techniques for displaying the same data, e.g. representing carbon emissions data in Zoom 1 (Fig. 28) or in Zoom 2 (Fig. 29) using the same technique does not result in appropriate results.

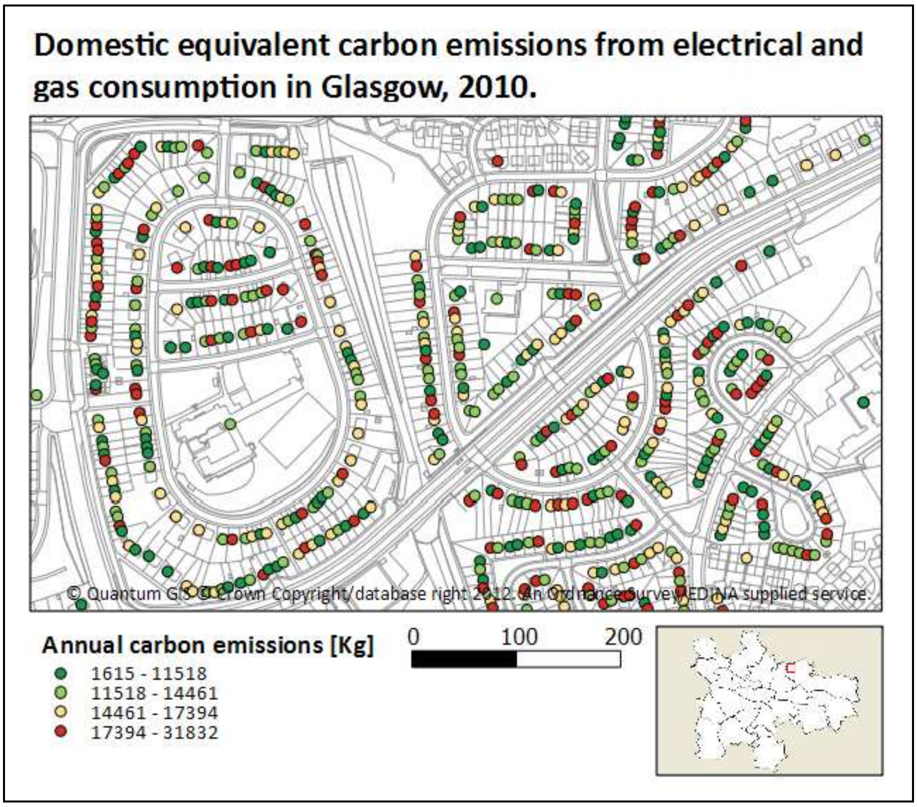


Fig. 28 – Information display using points in 'Streets view' (zoom 1).

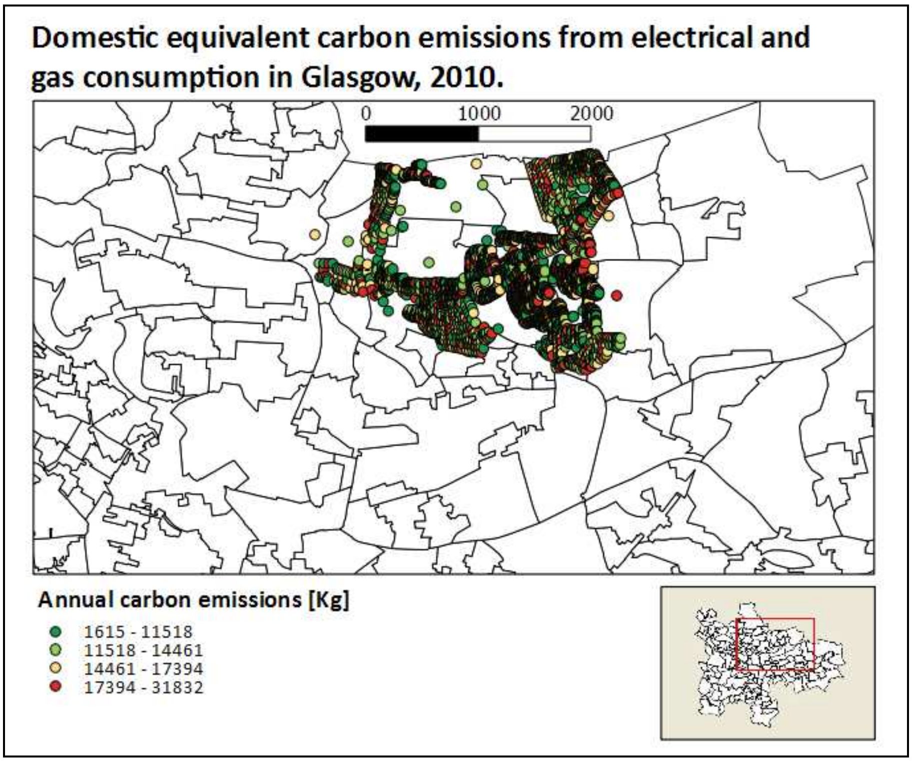


Fig. 29 – Data representation using points in 'Wards view' (zoom 2).

Thus, it is necessary to aggregate the information using polygons (Fig. 30):

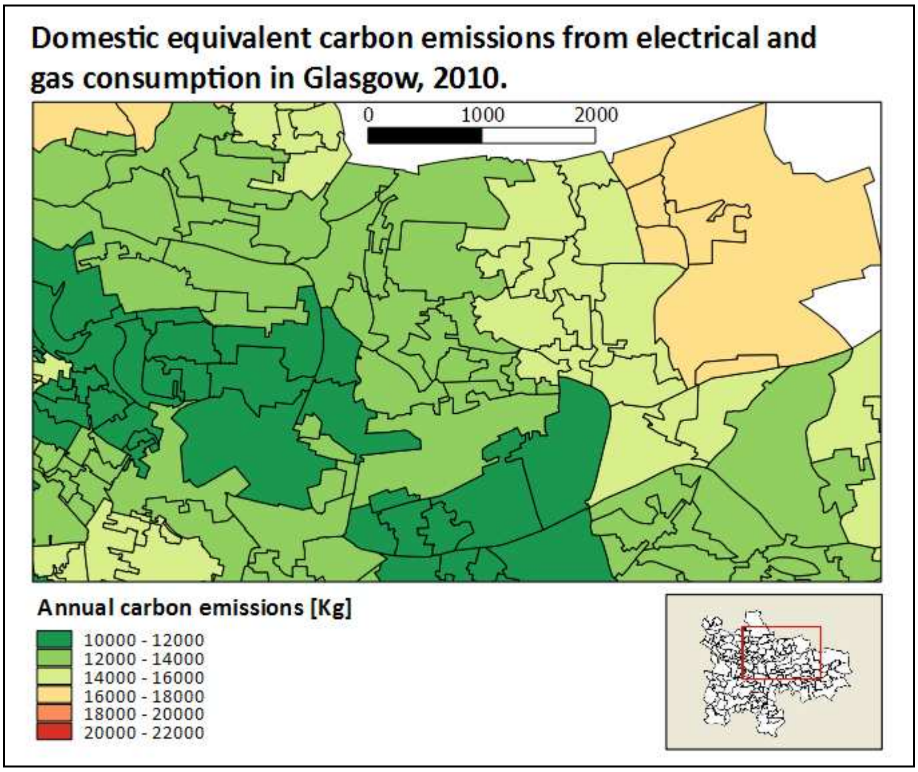


Fig. 30 – Data representation using polygons in 'Wards view' (zoom 2).

Therefore, the purpose of this project will be to explore the representation techniques for the data of interest in order to achieve clear and concise maps.

4.2.3.2. Symbol selection

The appropriate choice of the symbols for representing the information is crucial for a good understanding. Symbols can have different sizes, textures, colours, orientations and shapes, and the combination of these characteristics can lead to a clear map, or a confusing or non-understandable map. How to select the most appropriate characteristics is going to be explained in detail in the following sections.

4.2.3.2.1. Symbol size

The symbol size is often used to represent the magnitude of the represented variables; therefore it is mainly used for representing quantitative variables.

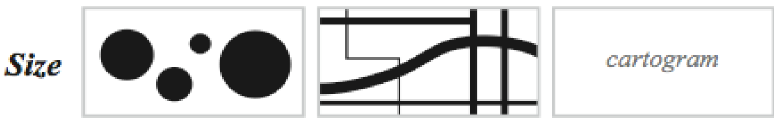


Fig. 31 – Points, lines and areas different sizes. Source: [38].

Commonly squares or circles (Fig. 32), but also representative shapes (Fig. 33), can be scaled at wish. It is important that smaller symbols are displayed above larger ones, so that they are always visible. For this purpose, different degrees of transparency can also be used.

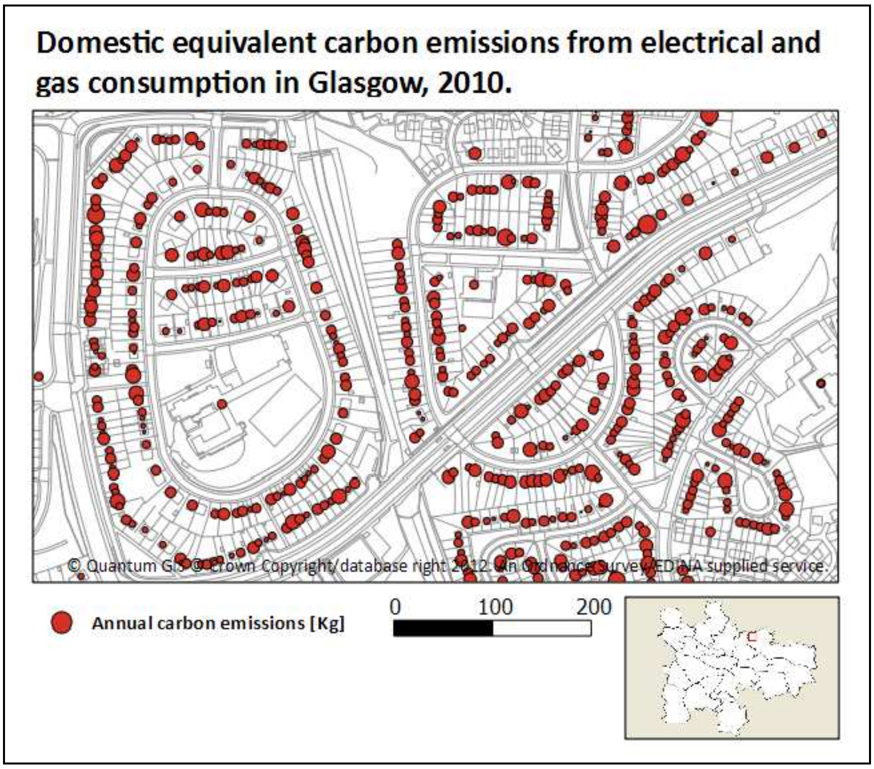


Fig. 32 – Symbol variable size for data representation.

.

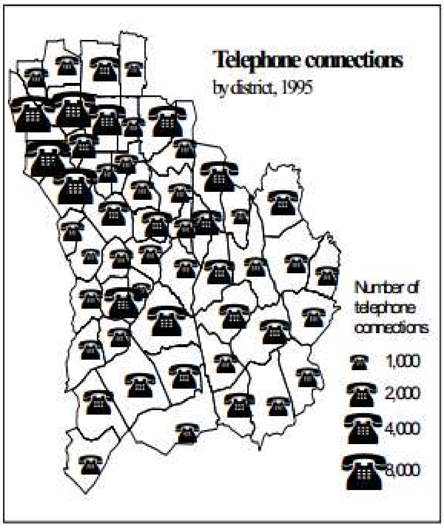


Fig. 33 – Pictogram variable size for data representation. Source: [39].

Cartograms are abstract maps that have the geographical areas modified depending on the value they are representing. Fig. 34 shows a cartogram example:

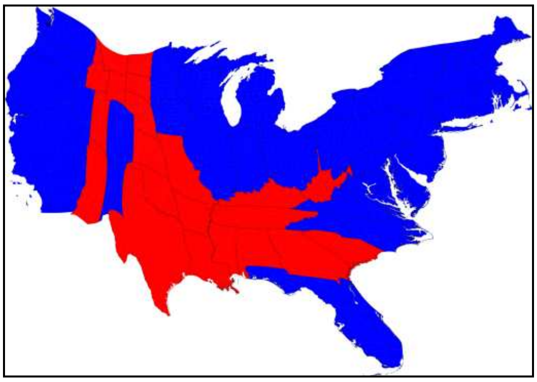


Fig. 34 – Cartogram scaling the size of the United States of America (USA) to be proportional to the number of electoral votes. Source: [40].

4.2.3.2.2. Symbol colour

The colours that are selected are a key issue in maps representation, as the appropriate option can simplify and increase understanding, while a poor colour choice, can confuse the reader. Different colour hues, values and intensities can be used for different purposes. The following figure summarises the different colour options, and the purpose for which are most appropriate, whether to show quantitative or qualitative differences:

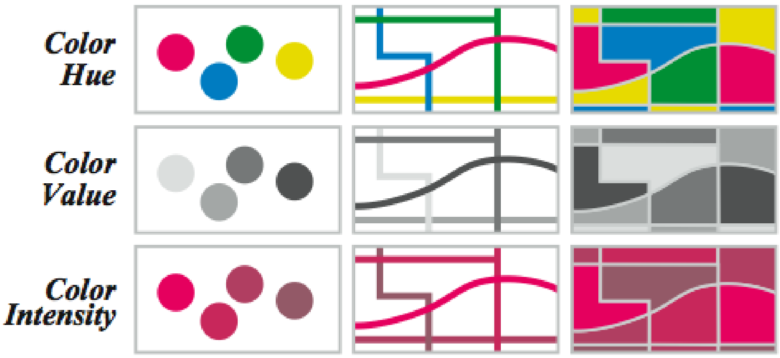


Fig. 35 – Variation in colour hue, value and intensity for points, lines and polygons. Source: [38].

Variations of colour hue can be found very often, particularly if they are adjacent in the spectrum, such as ‘yellow-orange-red’ (Fig. 36). There are some other hub combinations commonly used, such as the traffic-light signalling, with green standing for ‘yes’ or ‘good’ and red standing for ‘no’ or ‘bad’ and yellow representing an intermediate state (Fig. 37), or spectral (rainbow) schemes, which are commonly used as they are found to be easy to read by many users (shown in Fig. 38). Moreover, there exist some typical combinations like ‘light-to-dark’ colours for low-to-high values (red is used in Fig. 39).

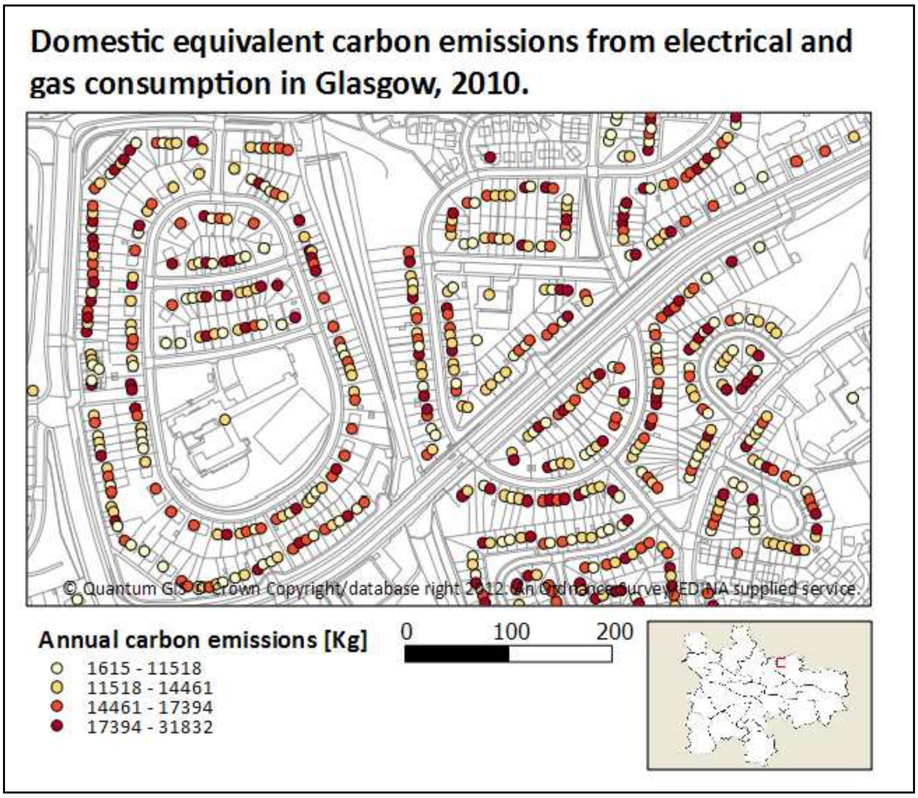


Fig. 36 - Sequential scale with colours transition: yellow-orange-red

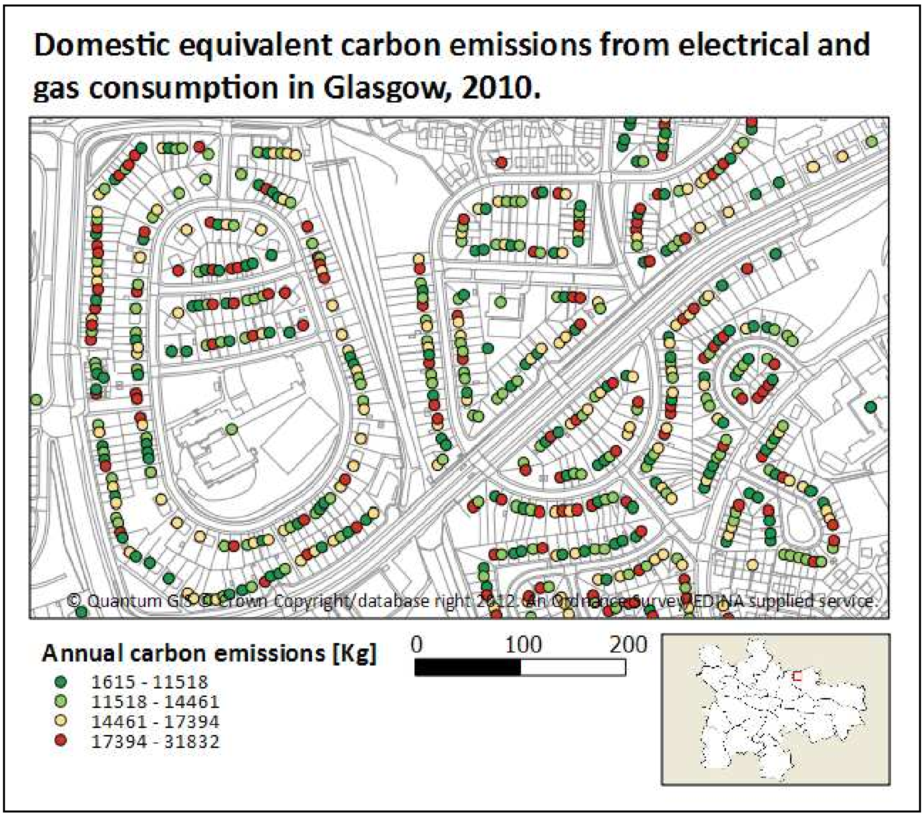


Fig. 37 – Traffic light colour scale.

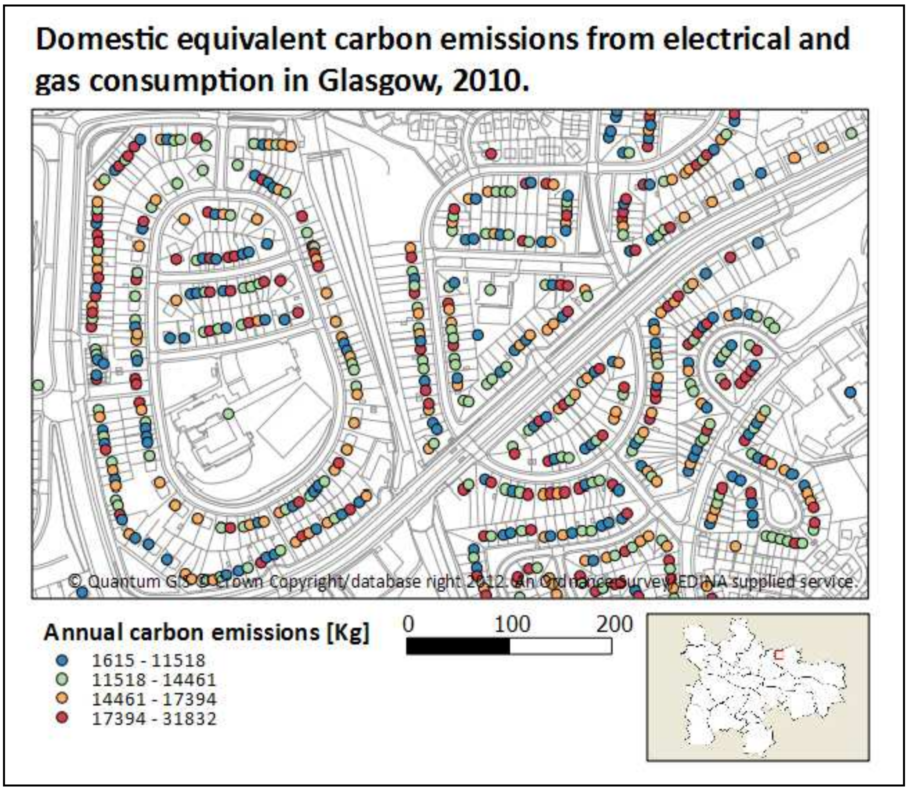


Fig. 38 – Spectral colour scale.

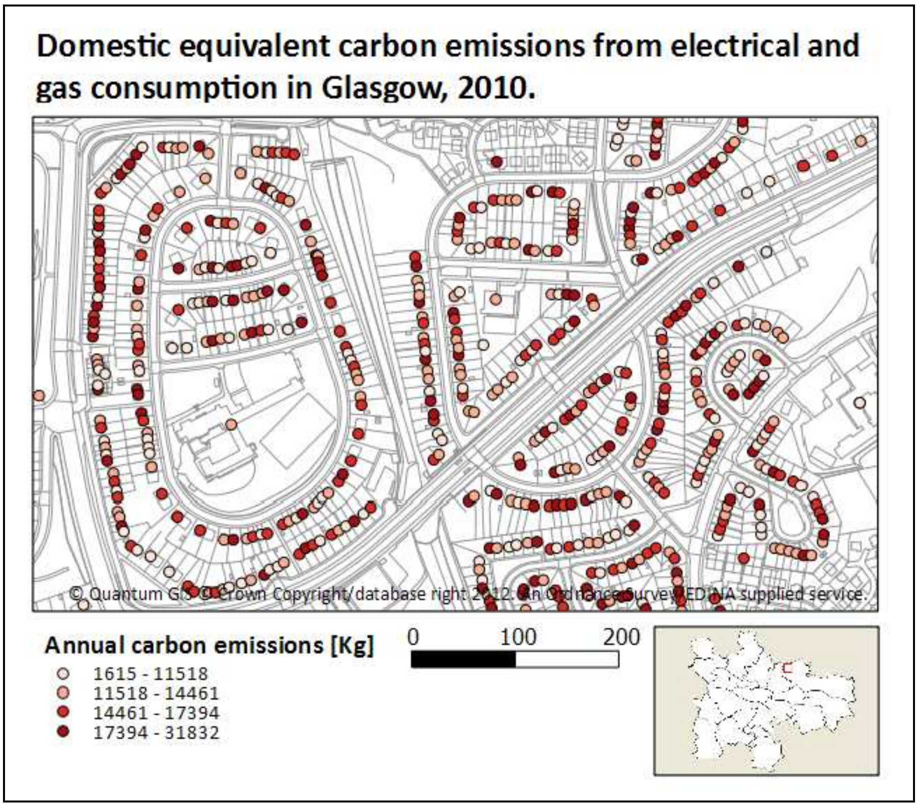


Fig. 39 – Sequential simple one colour scale: Red.

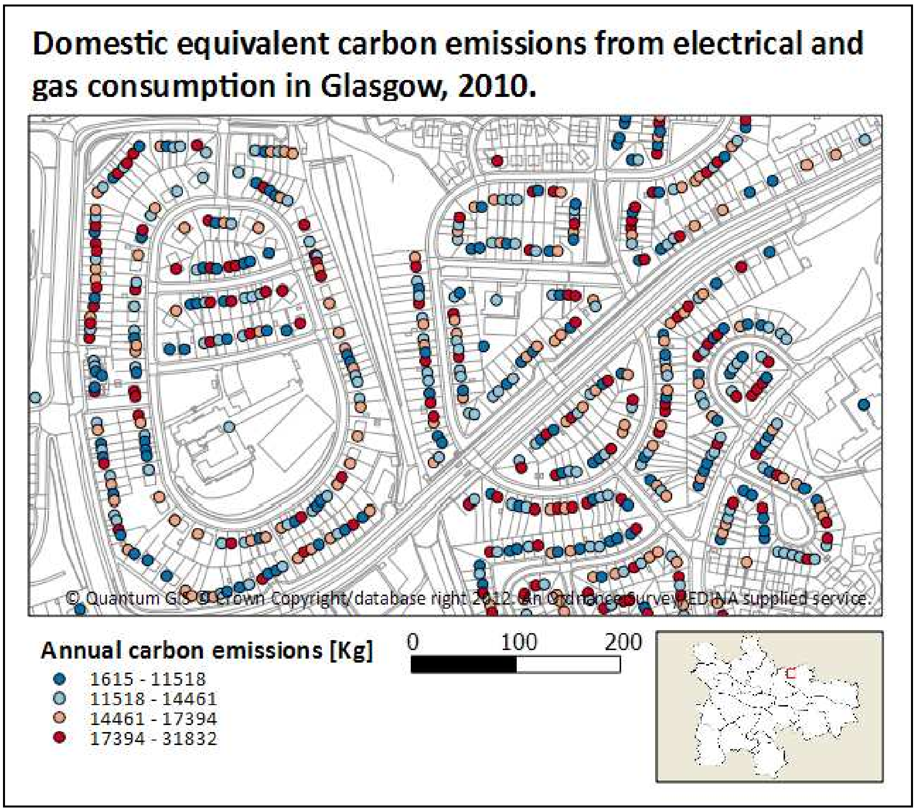


Fig. 40 – Cold to hot colour scale.

4.2.3.2.3. Symbol shape

GIS software offers many options as for the symbols, which can be ‘simple markers’ (Fig. 41), ‘font markers’ (Fig. 42) or ‘scalable vector graphics’ (SVG) (Fig. 43).

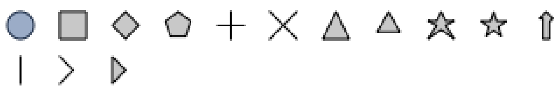


Fig. 41 – Simple markers. Source: [11].

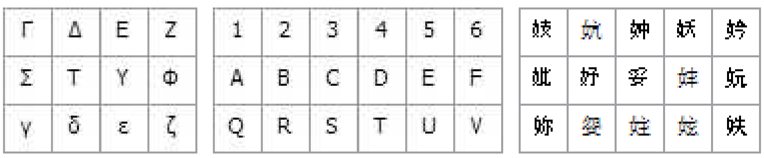


Fig. 42 – Font markers. Source: [11].

Fig. 43 – SVG . Source: [11].

Although lines and polygons can also be composed by different symbols, it is not frequently used.

4.2.3.2.4. Symbol texture

The use of different textures can be applied to points, lines and polygons (Fig. 44); nevertheless it is more often used in data represented by polygons. Changes in texture can both represent quantitative and qualitative variables.

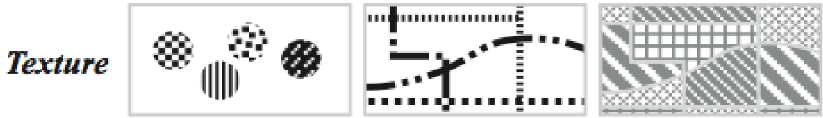


Fig. 44 – Different textures for points, lines and polygons. Source: [38].

Fig. 45 shows an example of data represented by areas with different textures. However, colours are more often used for the representation of a single variable in a map, and texture variations are frequently used when combining two or more variables displayed in the same map.

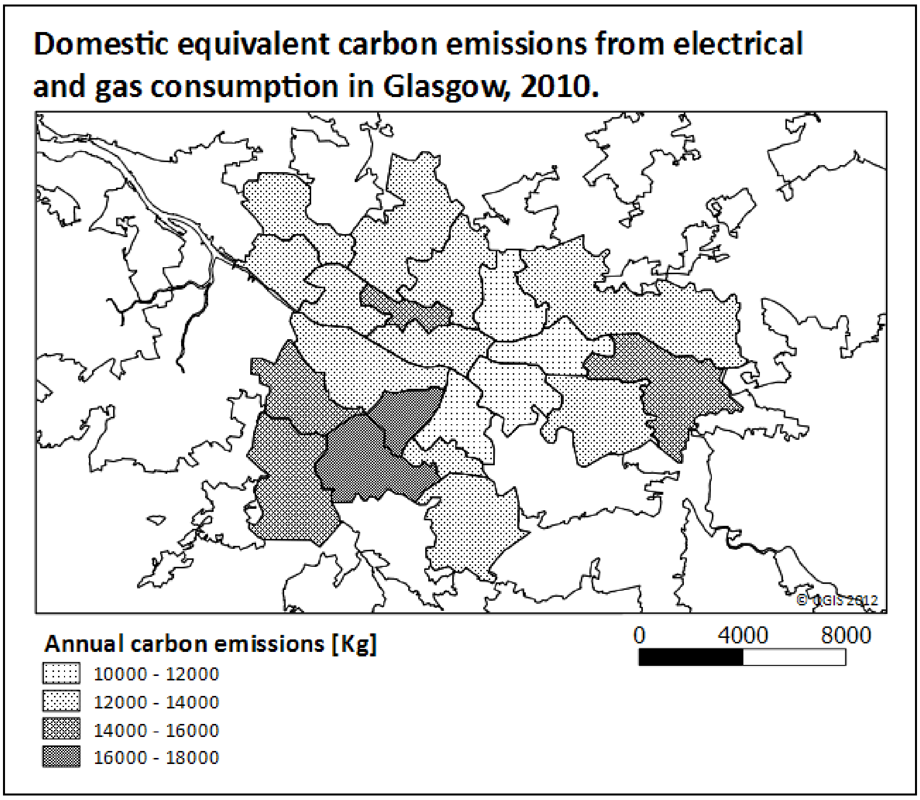


Fig. 45 – Use of different densities to represent one variable values.

4.2.3.3. Data classing

How to break the intervals when representing data with different colours is also a very important issue. Most of the GIS software offers different intervals options such as:

- Equal intervals (Fig. 46): Splits data into the number of intervals indicated by the user, of equal with.
- Quantiles (Fig. 47): Data is divided so that each interval has the same number of entries [41].
- Jenks natural breaks (Fig. 48): Splits data into classes based on minimizing the variance within groups and maximizing it between them [41].
- Standard deviation (Fig. 49): The mean data value is found and class breaks are placed above and below the mean at intervals of 0.25, 0.5 or 1 standard deviations until all the data values are contained within the classes [41].
- Pretty breaks (Fig. 50): The breaks are made so that the intervals width is the same, but they are rounded. Only some number of classes can be represented using pretty breaks.

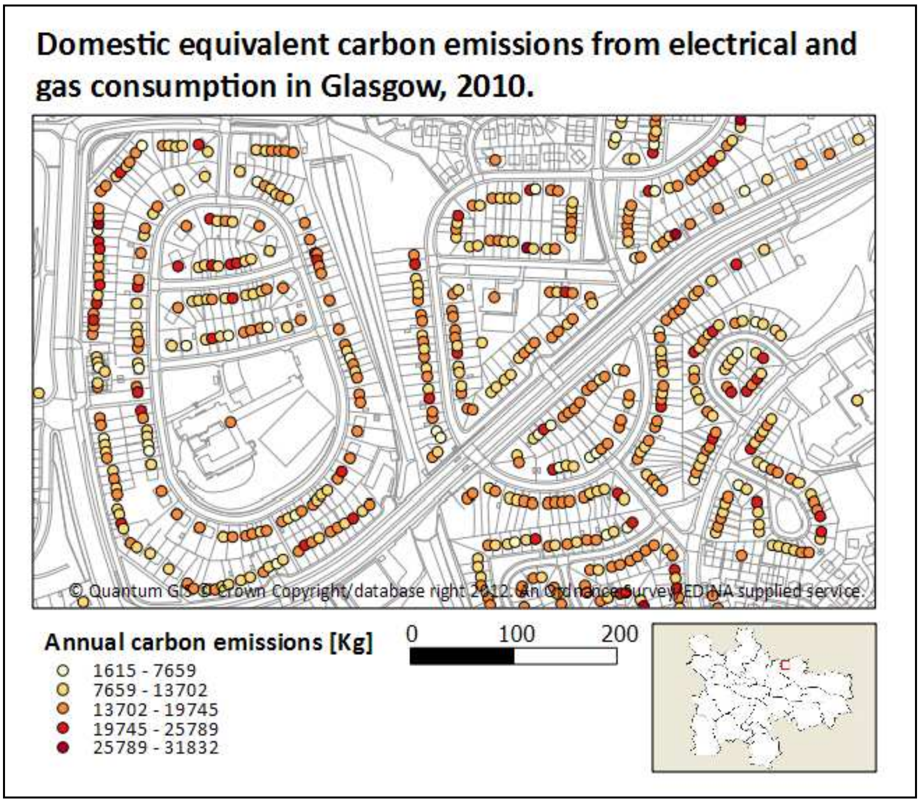


Fig. 46 – Equal intervals breaks.

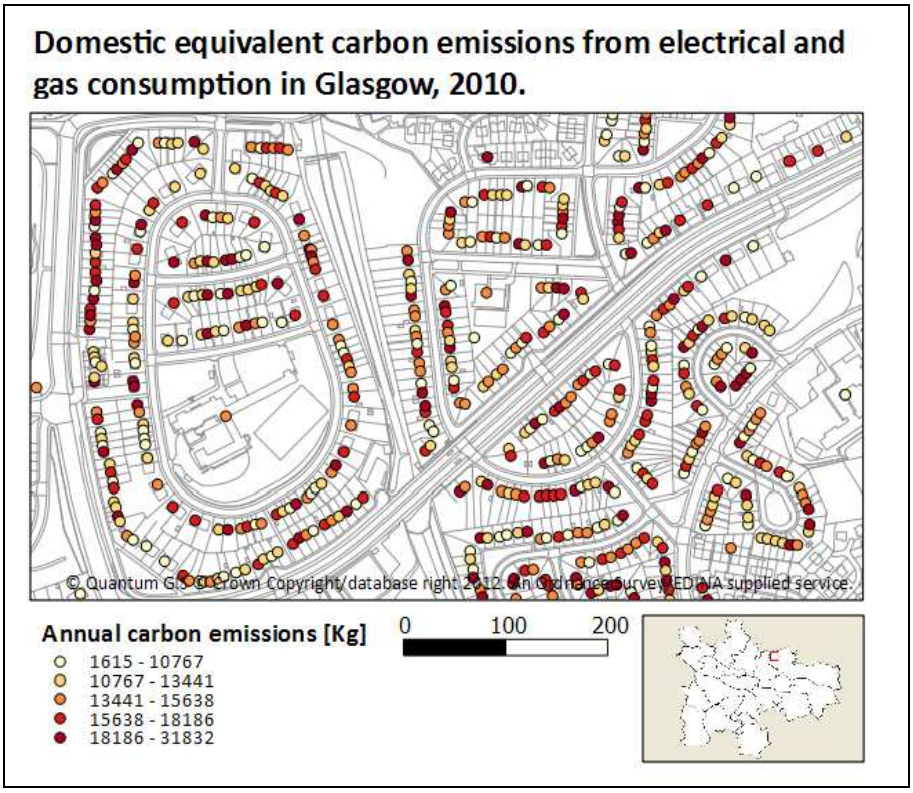


Fig. 47 – Quantiles.

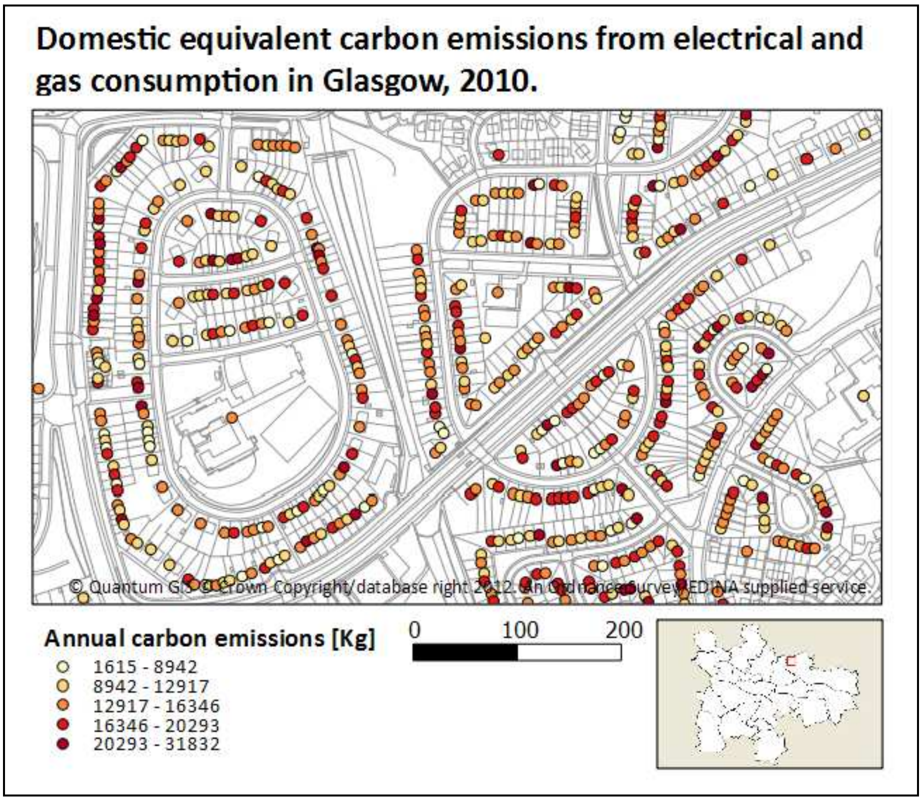


Fig. 48 – Natural breaks.

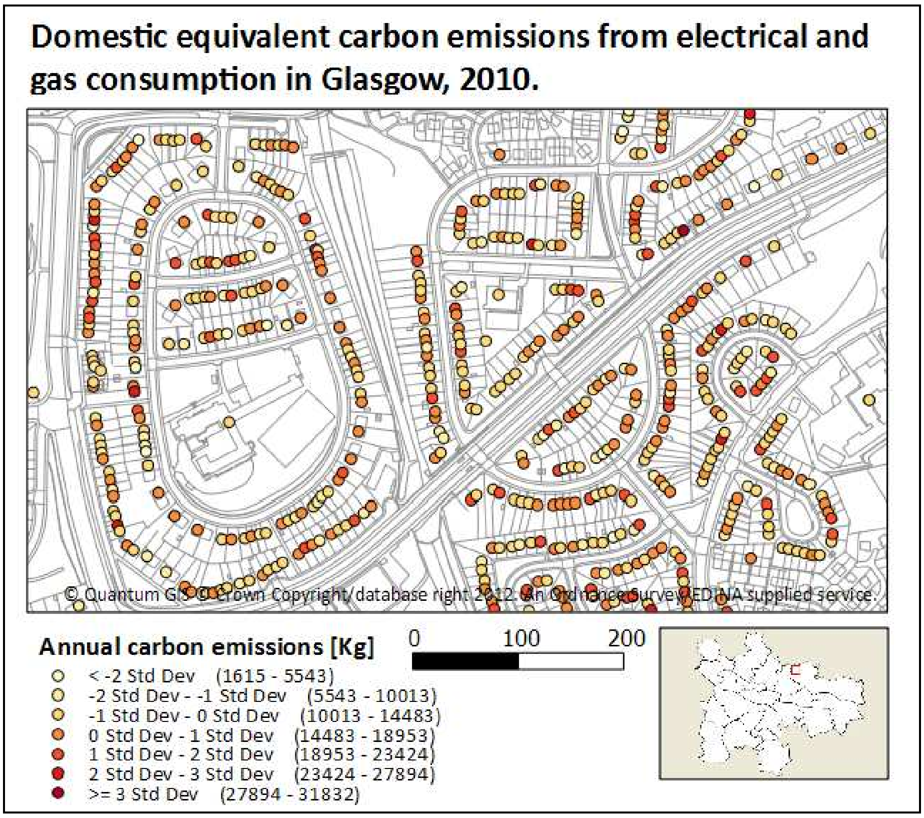


Fig. 49 – Standard deviation breaks.

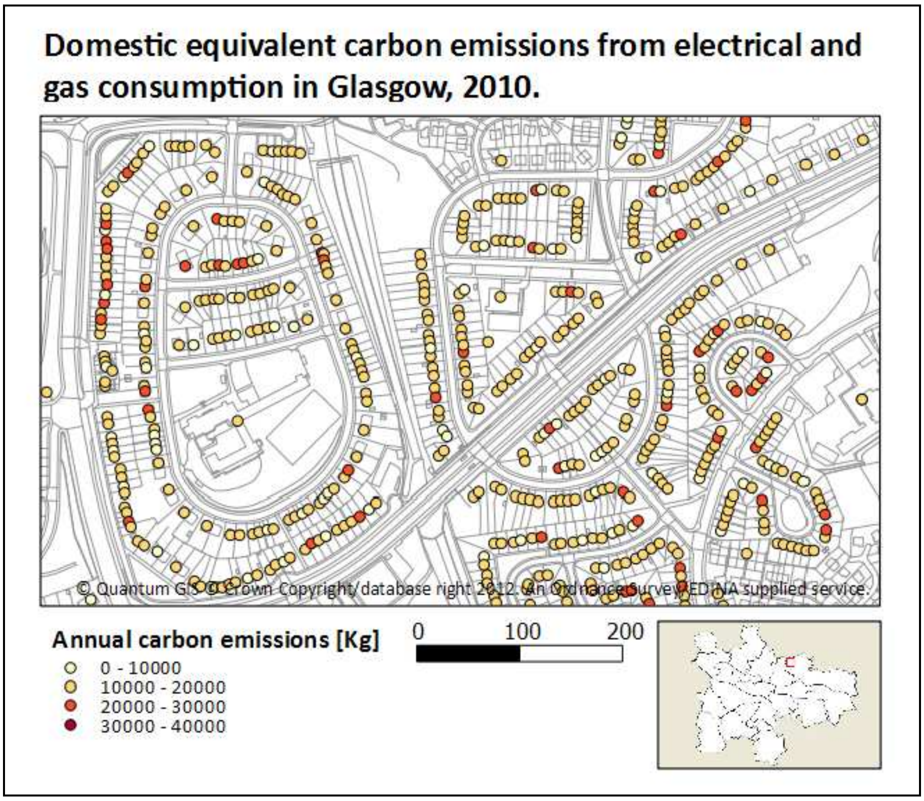


Fig. 50 – Pretty breaks.

Cartographers suggest representing the data of interest in a histogram, such as the one shown in Fig. 51, in order to help decide how to break down the data in to intervals. Representing the extreme data in their own groups and the other using a standard method is in general a good technique. The final breakdowns will depend on whether there is any particular issue that needs to be emphasized in the map.

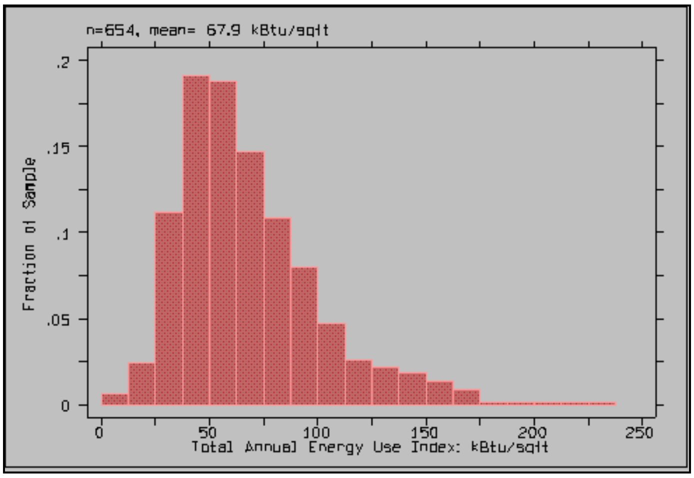


Fig. 51 – Data represented in a histogram. Source: [42].

Generally, having a higher number of intervals means that more detailed information is provided, but the maps become more confusing, as the identification of one colour in the legend becomes tougher. Some authors like Brewer (2006) [37] claim that seven classes is often the maximum for a choropleth map to be readable, however, other authors make more conservative statements, such as Heywood et al. [25] who specify that in most cases a maximum of five classes are sufficient for most mapping purposes.

4.2.4. Simultaneous representation of multiple variables

Until this point, information representation techniques have been reviewed, but only the representation of a single information attribute has been considered. Nevertheless, one of the interesting aspects about GIS systems is that different layers of information can be displayed at the same time, so patterns can be detected.

There are two main ways to represent more than one information attribute at the same time; the first one is to express the different data using different symbol attributes and combining them on the map, while the second method consists of mathematically combining different information attributes to represent one single variable on the map.

4.2.4.1. Graphical multivariable representation

The representation of 'two' and 'three or more' attributes will be analysed separately.

4.2.4.1.1. Representation of two attributes using GIS tools

GIS tools allow representing different information attributes by means of combining shapes, colours, sizes, densities, textures and orientations. To create the maps, some of the data introduced in *section 4.2.1 Data display introduction* will be represented on the three zoom levels that where presented in *section 4.2.3.1 Map scale issues.*

Many different two variables combinations could be displayed at the same time. For example:

- Domestic equivalent carbon emissions from electrical and gas consumption & dwelling type (flat, terraced house, detached house, etc.).
- Domestic equivalent carbon emissions from electrical and gas consumption & dwelling inhabitants age.
- Domestic equivalent carbon emissions from electrical and gas consumption & dwelling EPC rating.
- …

The representation techniques of two variables will depend of the type of variables (quantitative or qualitative), thus the three possible combinations between qualitative and quantitative variables will be exemplified:

1.	**HOUSEHOLD EQUIVALENT EMISSIONS** quantitative variable	&	**HOUSEHOLD TYPE** qualitative variable (3 possible values)

ZOOM 1: City view

In the city view zoom the entities are represented by polygons, therefore, the following ways to display the variables are considered appropriate:

- Colour-coded quantitative variable & shape-coded qualitative variable (Fig. 52).
- Colour-coded quantitative variable & colour-coded qualitative variable (Fig. 53).

- Colour-coded quantitative variable & qualitative variable represented using pie charts (Fig. 54).
- Colour-coded qualitative variable & quantitative variable represented using bar charts (Fig. 55).

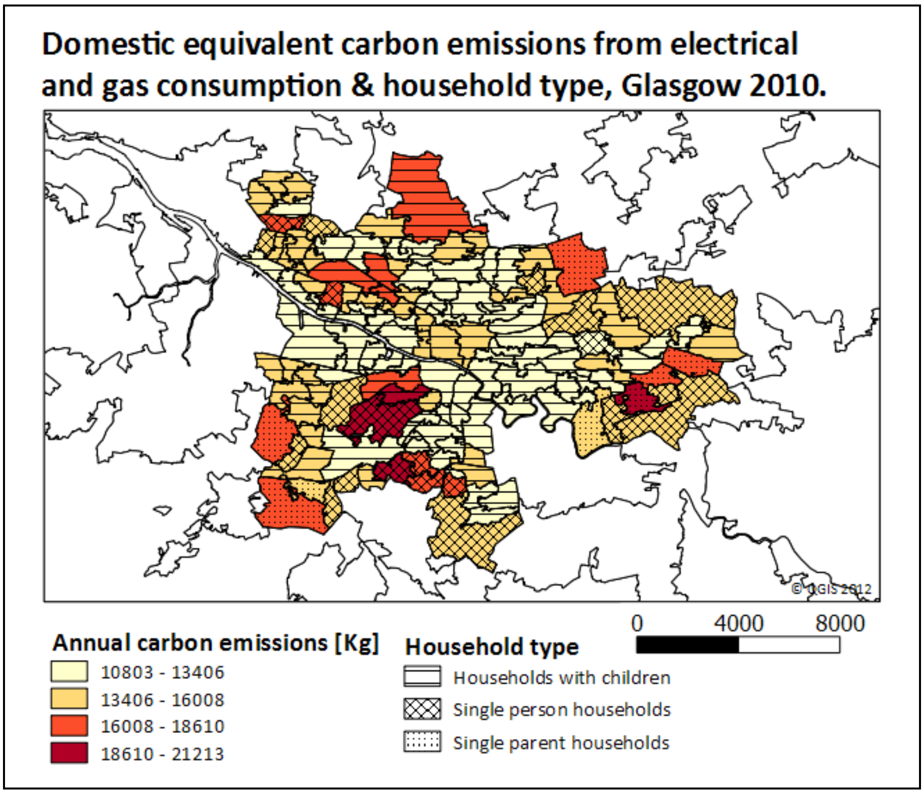


Fig. 52 – Two variables city view (IG's divisions): colour-coded quantitative variable & texture-coded qualitative variable (3 possible values).

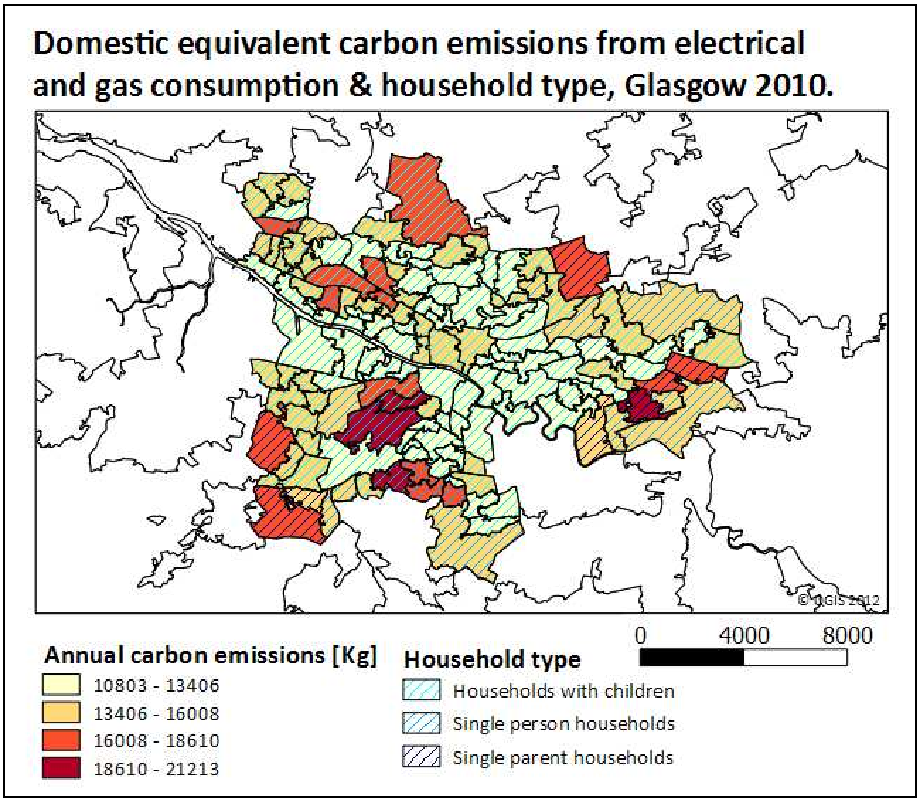


Fig. 53 - Two variables city view (IG's divisions): colour-coded quantitative variable & colour-coded qualitative variable (3 possible values).

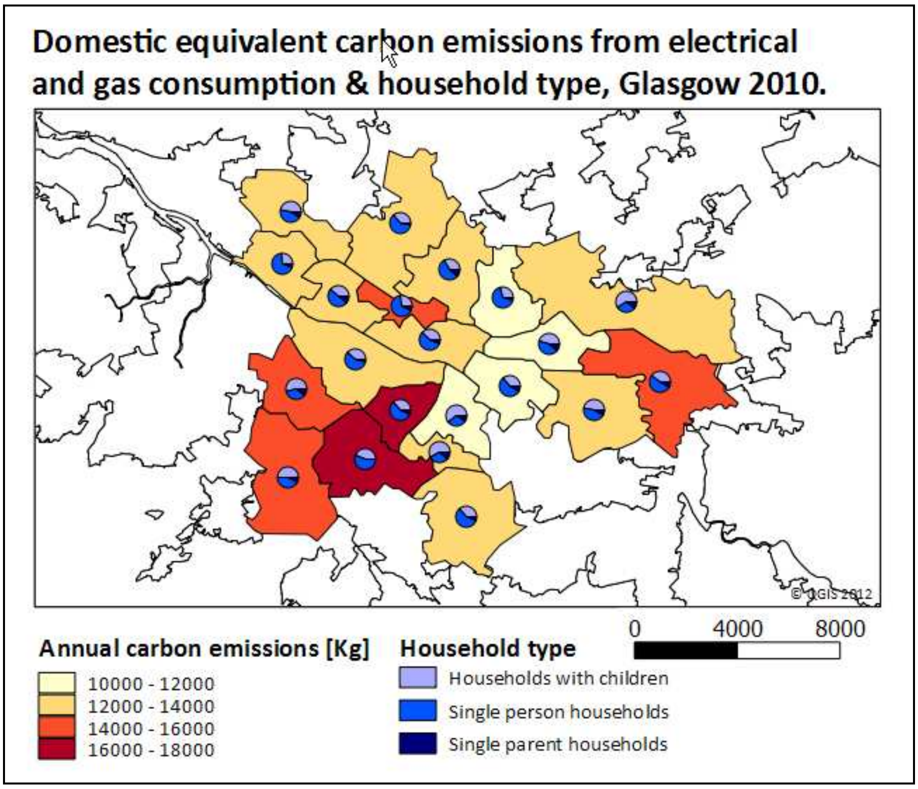


Fig. 54 – Two variables city view (wards divisions): Colour-coded quantitative variable & qualitative variable represented using pie charts (3 possible values).

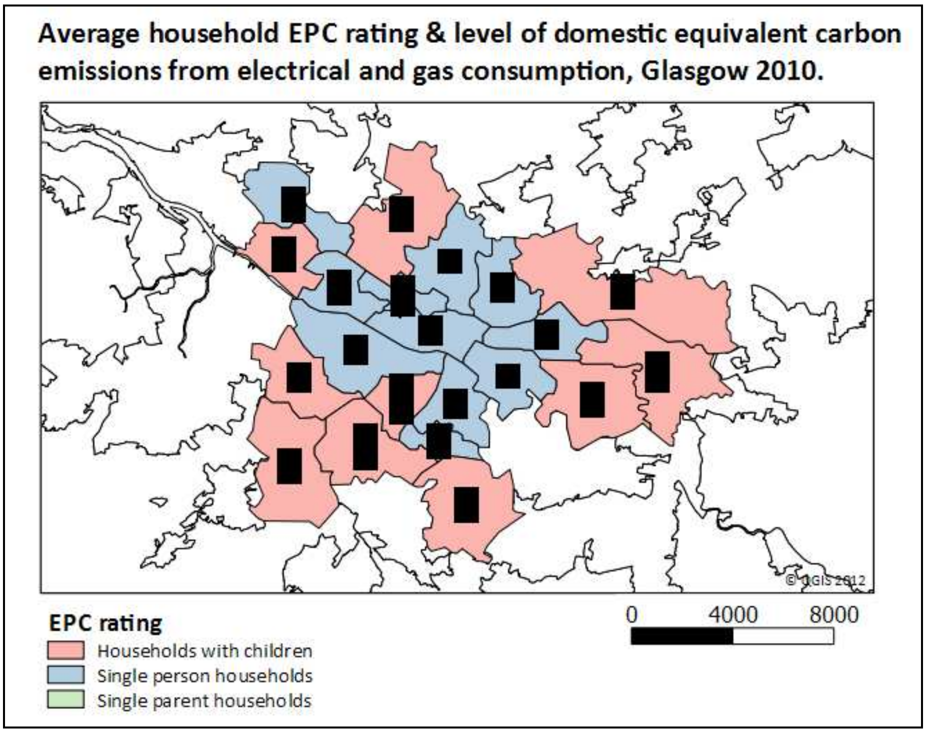


Fig. 55 – Two variables city view (wards divisions): Colour-coded qualitative variable (3 possible values) & quantitative variable represented using bar charts.

The selected division areas of the city for Fig. 52 and Fig. 53 has been IG's, as the information transmitted by the map when the divisions are smaller is higher, and in these cases the results can be clearly read. However, for Fig. 54 and Fig. 55, the selected division has been wards and not GI's; the reason is the presence of diagrams (pie and bar charts), which tend to occupy a large space.

<u>ZOOM 2: Ward view</u>

In the ward zoom view, the variables are also represented by polygons, and two zones' divisions are suitable: DZ's and GI's, as a division into wards would not provide enough information. In this case, the possible representations are:

- Colour-coded quantitative variable & shape-coded qualitative variable (Fig. 56).
- Colour-coded quantitative variable & colour-coded qualitative variable (Fig. 57).
- Colour-coded quantitative variable & qualitative variable represented alphabetically (Fig. 58).
- Colour-coded qualitative variable & quantitative variable represented using bar charts (Fig. 59).

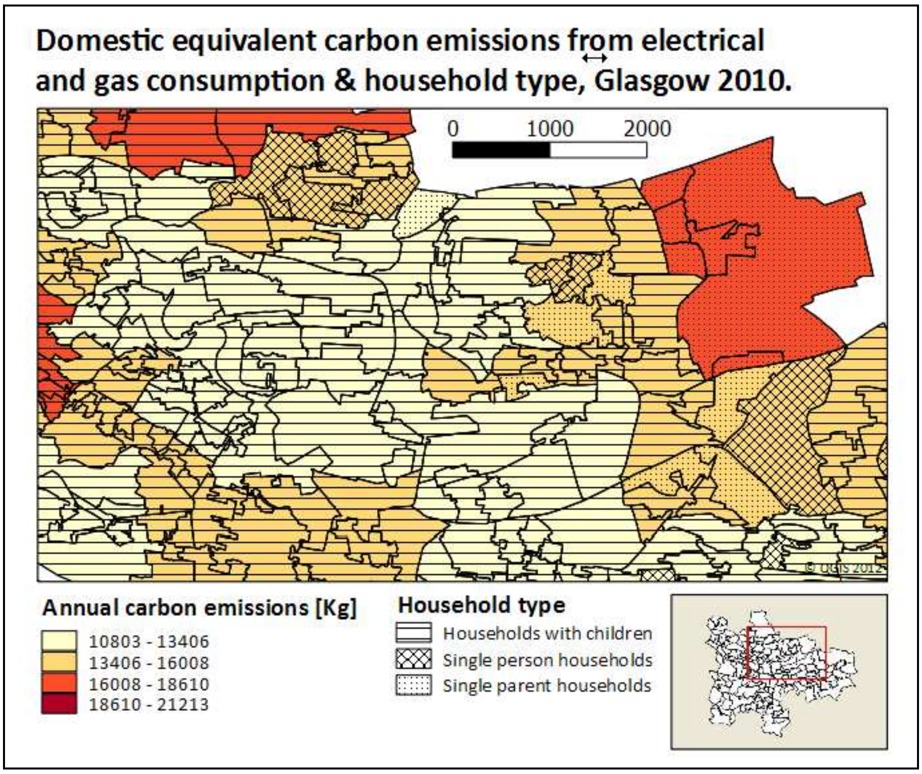


Fig. 56 – Two variables ward view (DZ's divisions): colour-coded quantitative variable & texture-coded qualitative variable (3 possible values).

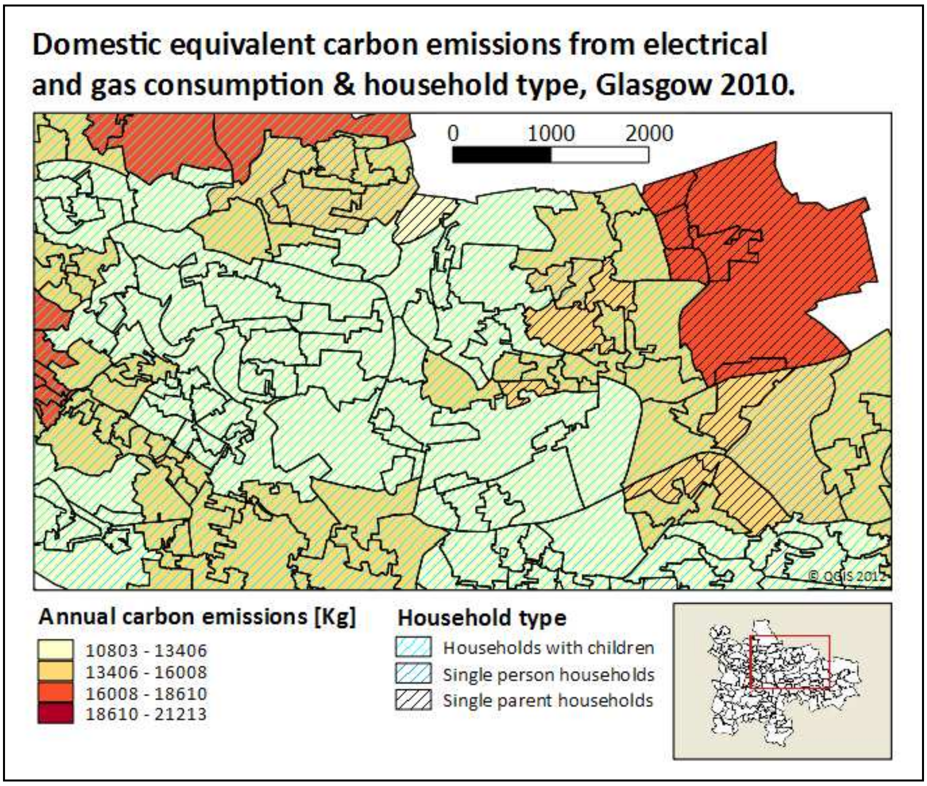


Fig. 57 – Two variables ward view (DZ's divisions): colour-coded quantitative variable & colour-coded qualitative variable (3 possible values).

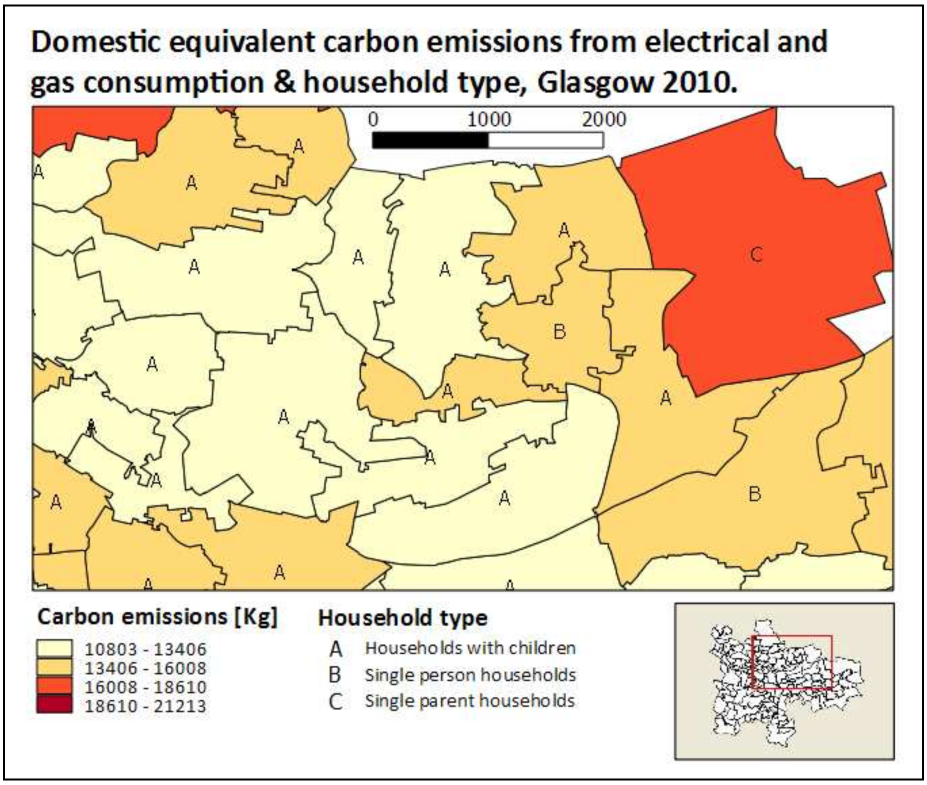


Fig. 58 – Two variables ward view (IG's divisions): Colour-coded quantitative variable & qualitative variable represented alphabetically (3 possible values).

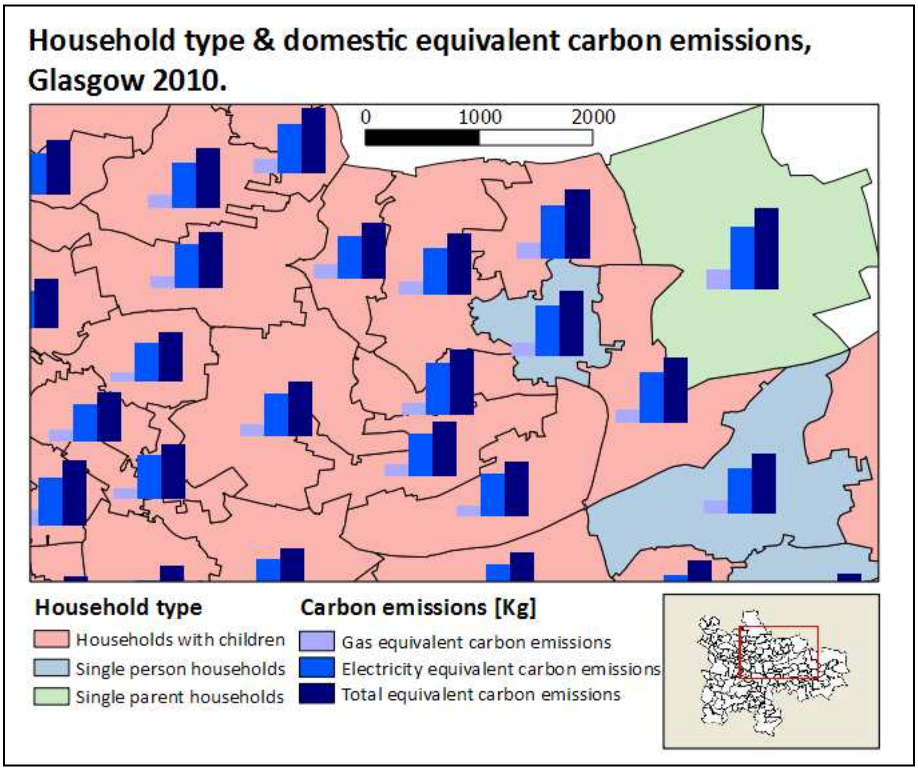


Fig. 59 – Two variables ward view (IG's divisions): colour-coded qualitative variable (3 possible values) & quantitative variable represented using bar charts.

In this case, the maps combining different colours and textures (Fig. 56 and Fig. 57) have been divided into DZ's, as they can be read easily and provide a higher level of information. On the other hand, maps displaying symbols, or charts (Fig. 58 and Fig. 59) have been divided into IG's, as a way to facilitate the map lecture.

ZOOM 3: Streets view

The 'streets view' zoom allows the representation of the data using points, instead of areas. Up to two variables can therefore be displayed combining:

- Colour-coded quantitative variable and shape-coded qualitative variable (Fig. 60).
- Colour-coded qualitative variable and size-coded quantitative variable (Fig. 61).

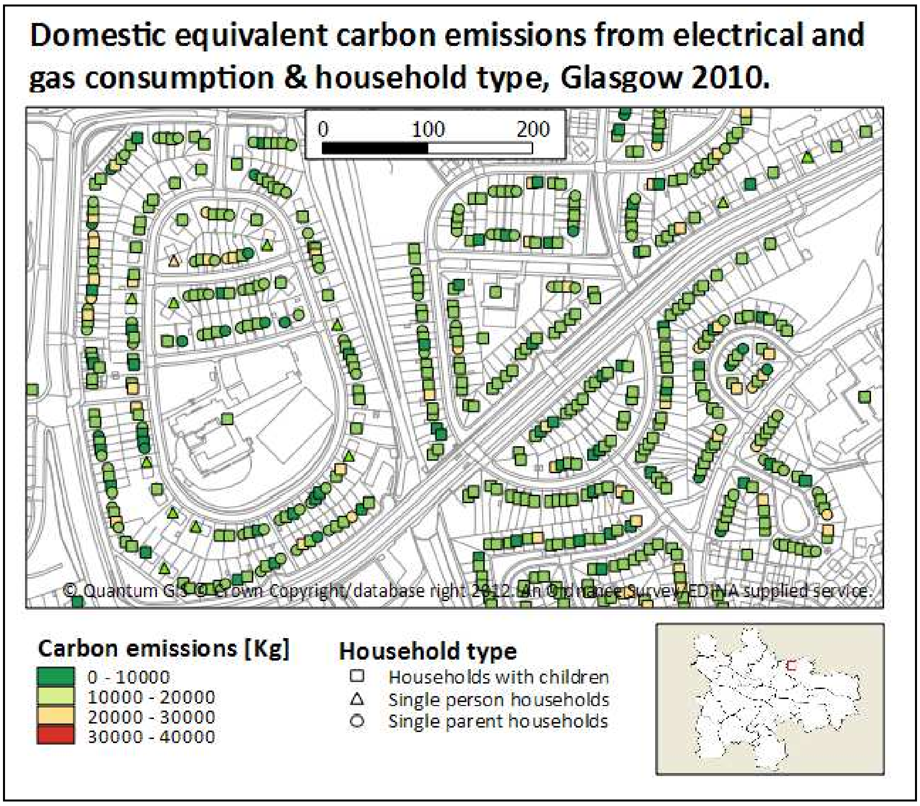


Fig. 60 – Two variables streets view: colour-coded quantitative variable & shape-coded qualitative variable (3 possible values).

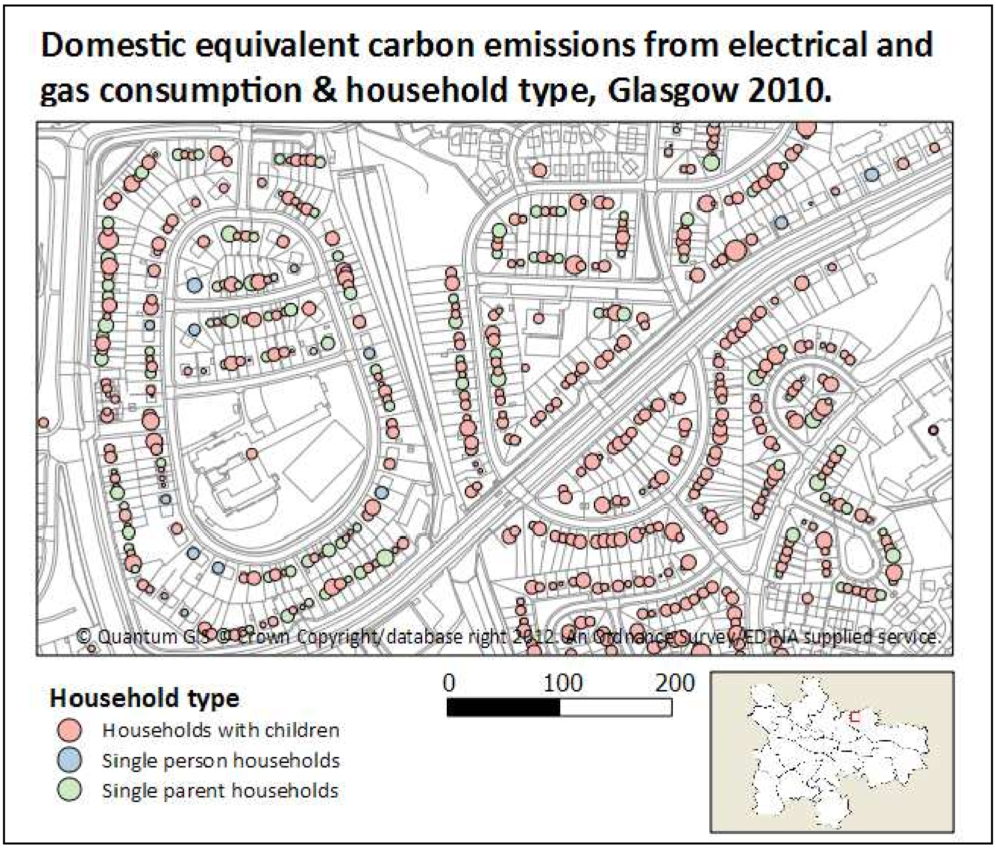


Fig. 61 - Two variables streets view: size-coded quantitative variable & colour-coded qualitative variable (3 possible values).

However, there are some special cases where a variable is commonly associated to one specific representation, e.g. a colour or a shape; in those cases it is sensible to represent it following the established criterion. A clear example is dwellings EPC rating, which is a qualitative variable that can take 7 different values (from A to G), which is strongly associated to a colour scale (Fig. 62). Thus, it would seem sensible for maps with variables represented by polygons (zooms one and two) to display the emissions size-based (using bars), and use a colour scale to represent the EPC rating grade (Fig. 63), and for dot represented maps, to display colour-coded EPC rating and size-coded emissions (Fig. 65).

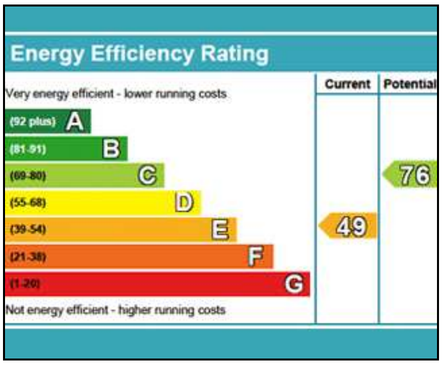


Fig. 62 – Energy efficiency rating graph for homes. Source: [44].

ZOOM 1: City view

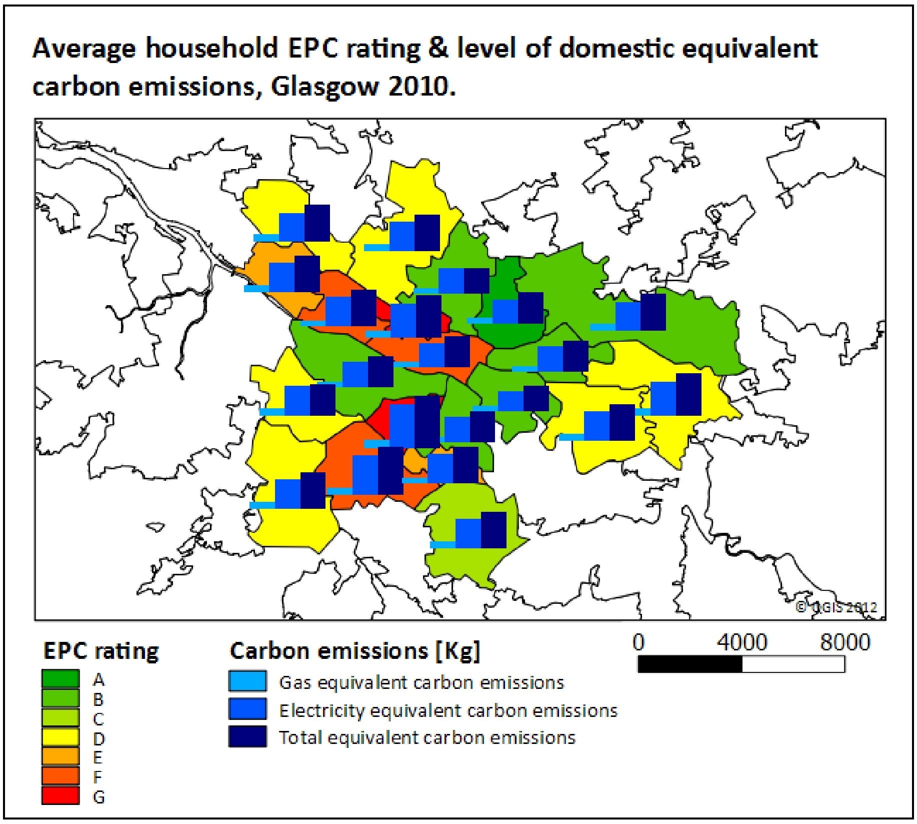


Fig. 63 – Two variables city view (wards divisions): colour-coded qualitative variable (7 possible values) & quantitative variable represented by bars.

Another possibility to represent these two variables is to classify the emissions colour-coded and to add a pie chart with the proportion of dwellings of each rating (Fig. 64). Most of the time, including a second level of information using pie charts is only possible for maps in which the information is displayed using polygons (zooms one and two), as if pie charts where exposed above the points, those would be covered and the first information level would be lost. The polygons must have a considerable size so that the pie charts can be easily identified and read, and the colour of the area under them can be still visible.

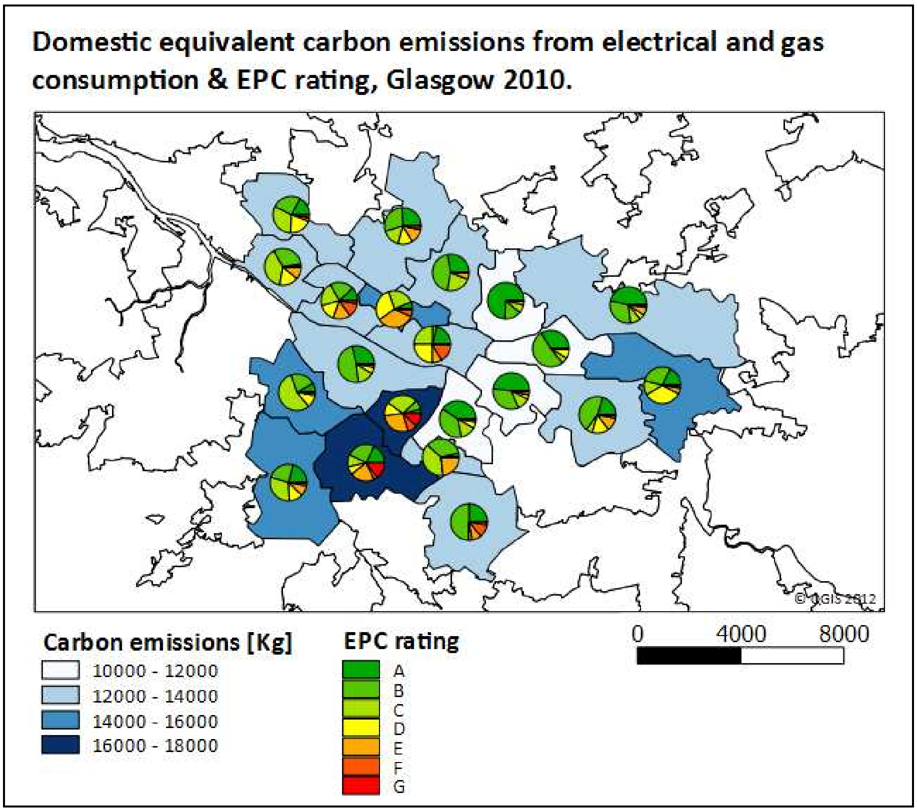


Fig. 64 – Two variables city view (wards divisions): Colour-coded quantitative variable & qualitative variable (7 possible values) represented using pie charts.

In this case, a scale of blues has been used to represent the equivalent carbon emissions, to avoid colour confusions with the EPC rating. The resulting figure (Fig. 64) provides a higher level of information than Fig. 63 respectively. Thus, it can be concluded that the representation of quantitative variables colour-coded instead of size-coded gives more information. The use of bars is more suitable when the represented values are notably different; the fact that not all bars start at the same height (due to its representation on a map) can cause visual confusion with similar values.

ZOOM 2: Ward view

As zoom 2 is also represented using polygons, the methods of representation and conclusions are the same as for zoom 1.

ZOOM 3: Streets view

In this case the variables are represented using points. The most logical displaying option for zoom 3 is to represent the average dwellings EPC rating colour-coded and the emissions size-coded. The use of pie charts only makes sense for areas that are composed by different points, but not for the representation of single dot entities.

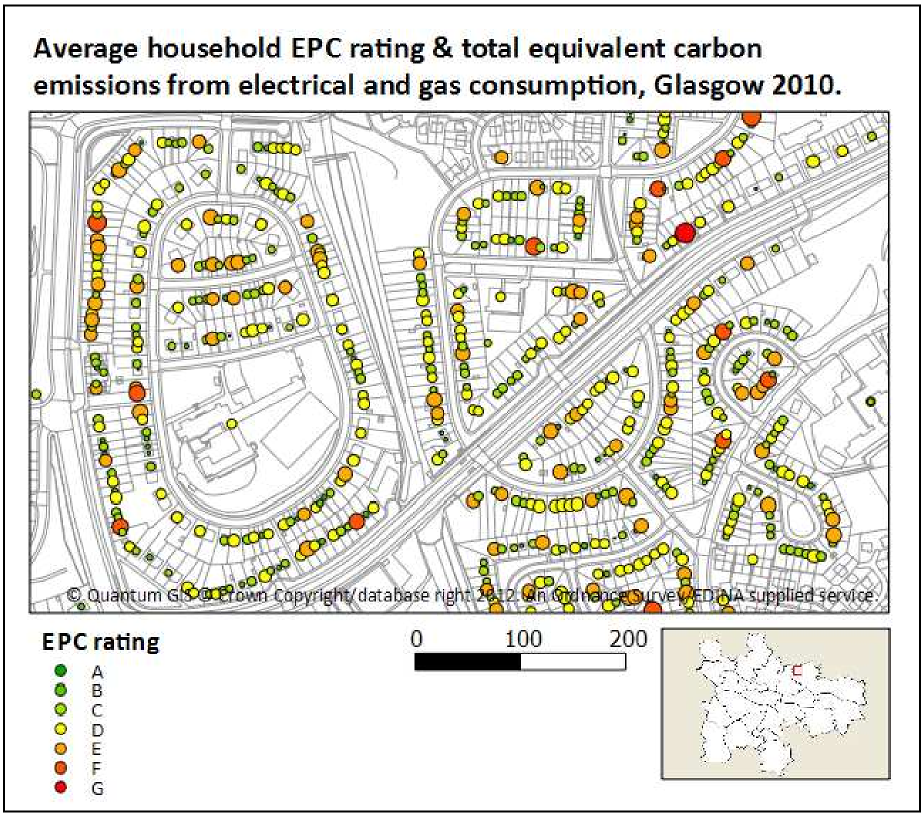


Fig. 65 – Two variables streets view: Colour-coded qualitative variable (7 possible values) & size-coded quantitative variable.

2.	**LEVEL OF HOUSEHOLD EQUIVALENT CARBON EMISSIONS** qualitative variable (3 possible values)	&	**DWELLINGS EPC RATING** qualitative variable (7 possible values)

ZOOM 1: City view

For the representation of two qualitative variables using polygons, it will be distinguished between the variable with higher number of possible values (variable A – in this case EPC rating) and the one with lower number of possible values (variable B – in this case the level of carbon emissions). The following options are suitable for polygons display:

- Colour-coded variable A, texture-coded variable B (Fig. 66).
- Colour-coded variable B, texture-coded variable A → not considered as in this case variable A is strongly associated to a scale colour.
- Colour-coded variable A, variable B represented using pie charts (Fig. 67).
- Colour-coded variable B, variable A represented using pie charts, (Fig. 68).
- Colour-coded variable A, colour-coded variable B (Fig. 69).
- Colour-coded variable B, colour-coded variable A (Fig. 70).
- Colour-coded variable A, symbol-size-coded variable B (Fig. 71).
- Colour-coded variable B, symbol-alphabetical-coded variable A (Fig. 72).

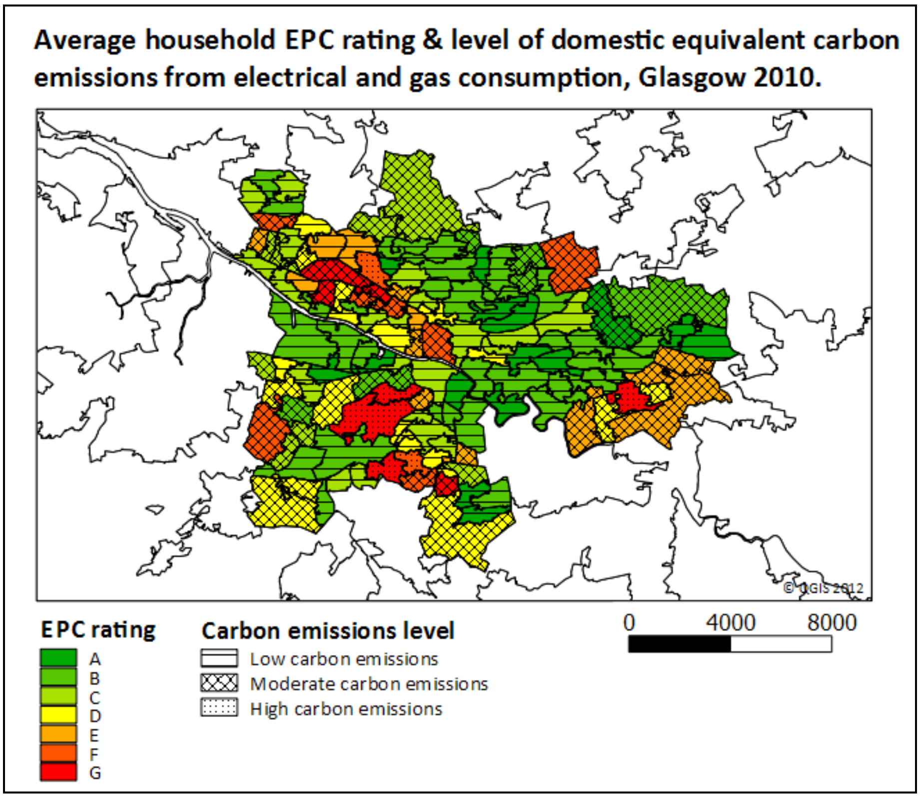


Fig. 66 – Two variables city view (IG's division): Colour-coded variable A (7 possible values) & texture-coded variable B (3 possible values).

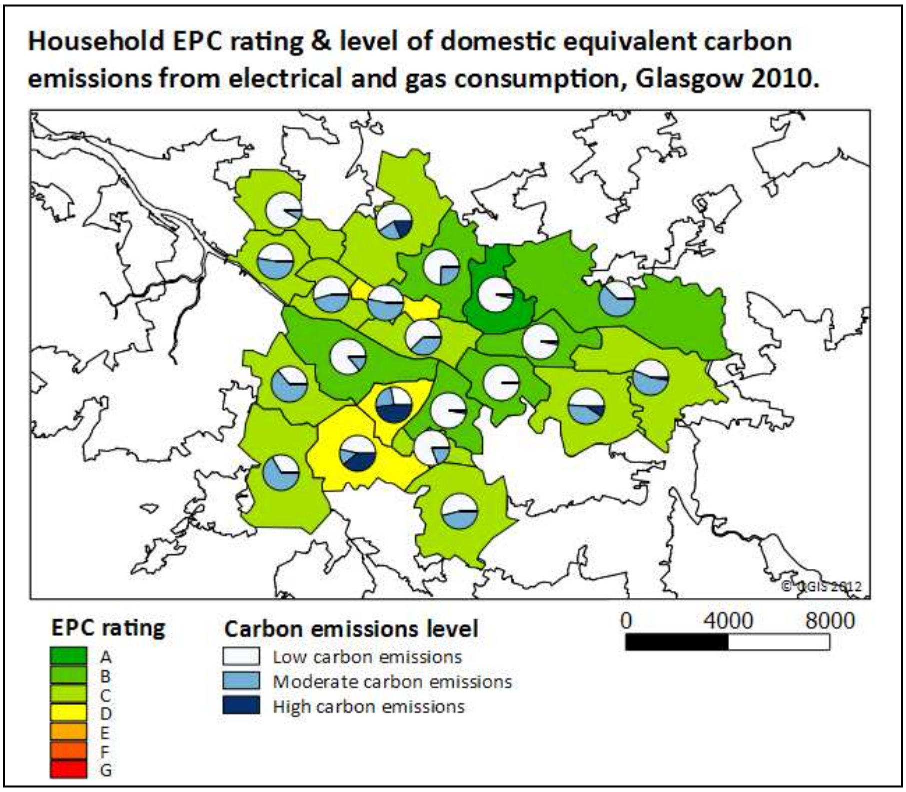


Fig. 67 - Two variables city view (wards division): Colour-coded variable A (7 possible values) & variable B (3 possible values) represented using pie charts.

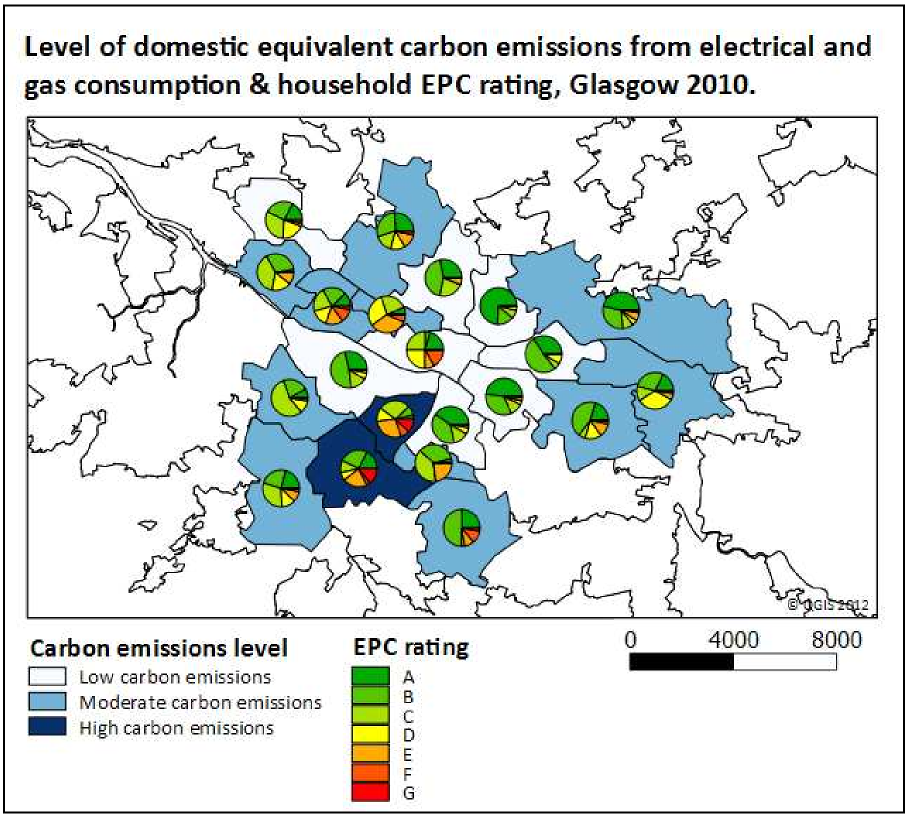


Fig. 68 – Two variables city view (wards division): Colour-coded variable B (3 possible values) & variable A (7 possible values) represented using pie charts.

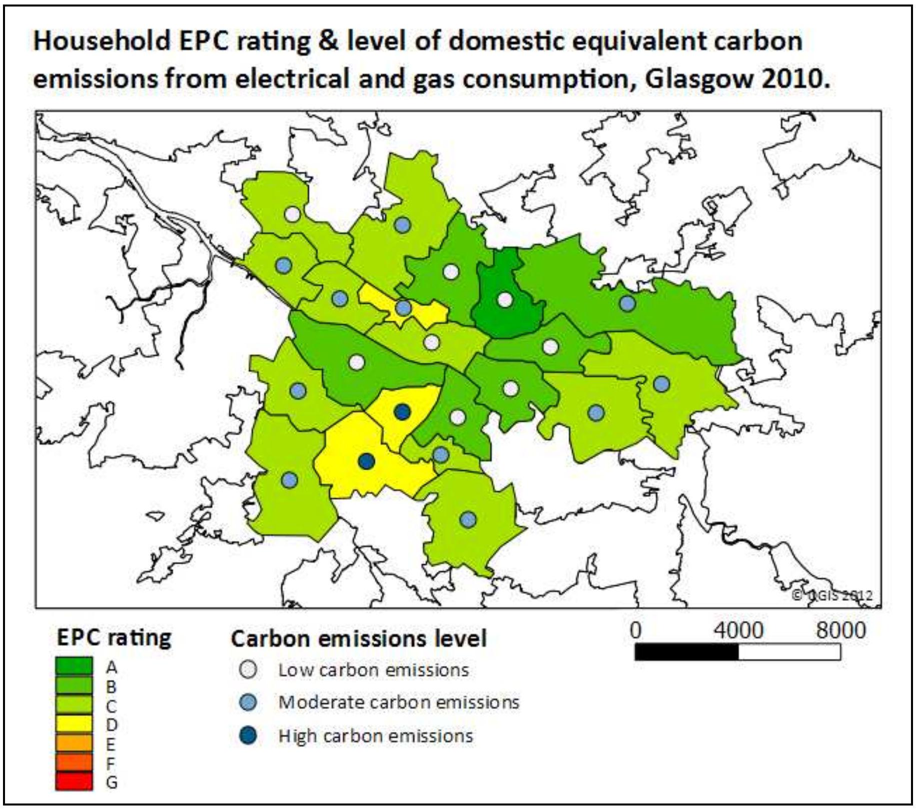


Fig. 69 – Two variables city view (wards division): Colour-coded variable A (7 possible values) & colour-coded variable B (3 possible values).

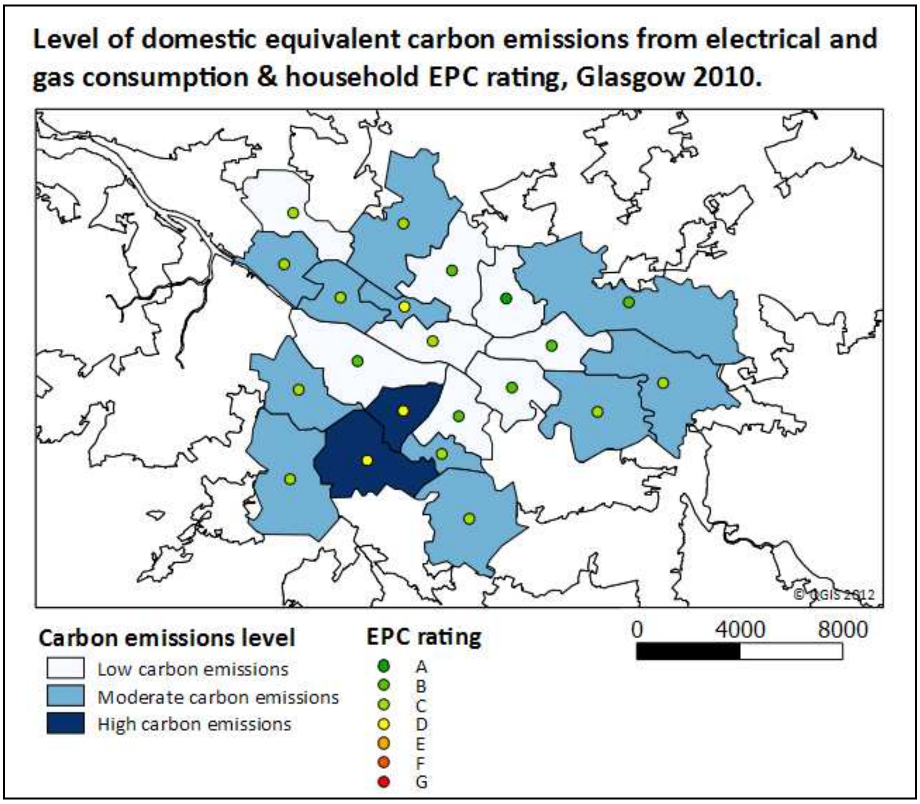


Fig. 70 – Two variables city view (wards division): Colour-coded variable B (3 possible values) & colour-coded variable A (7 possible values).

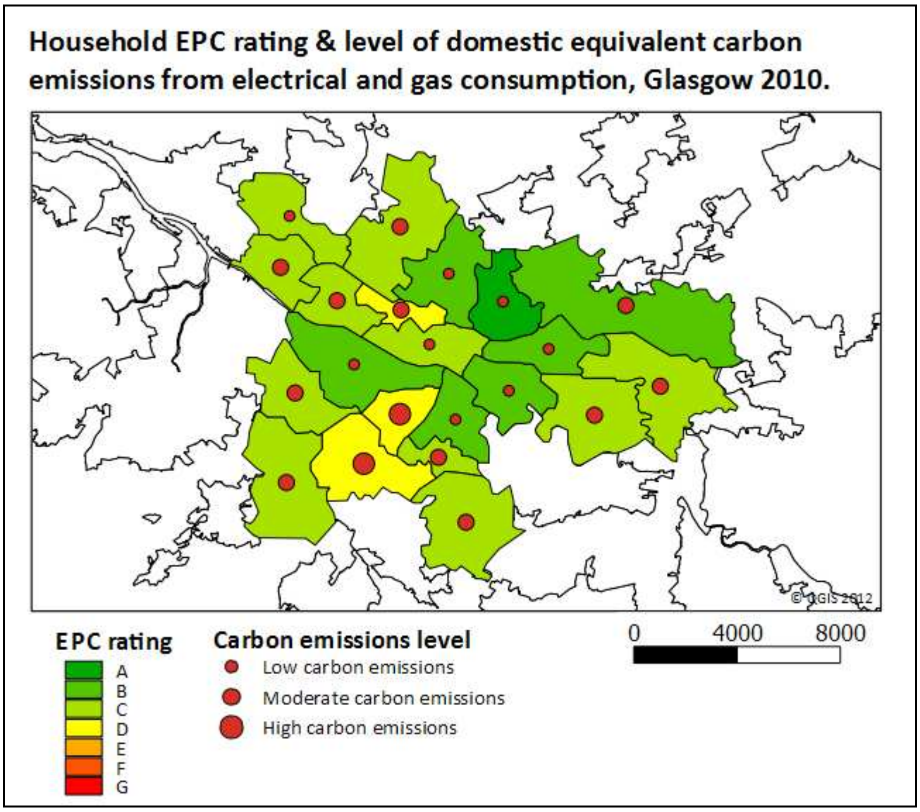


Fig. 71 – Two variables city view (wards division): Colour-coded variable A (7 possible values) & size-coded variable B (3 possible values).

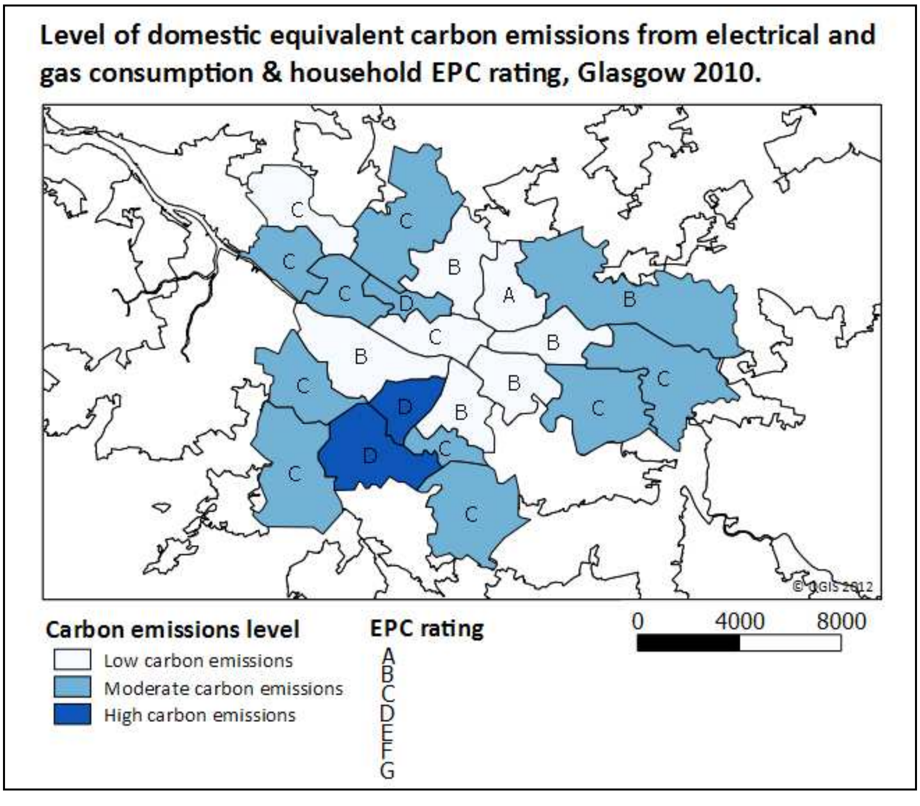


Fig. 72 – Two variables city view (wards division): Colour-coded variable B (3 possible values) & alphabetical-coded variable A (7 possible values).

In general, maps with colours are more visual than the ones with alphabetical symbols. Also, if there is one variable more relevant than the other it is recommended to display it under the secondary variable, occupying a bigger area. Also it is recommended when combining two colours to use pale ones for the background, and use shiny ones for the second attribute, usually displayed in a smaller area above the first one. It is also advisable to use pie charts whenever it is possible, as they provide more information and can be easily read.

ZOOM 2: Ward view

The representation techniques and conclusions are the same than for zoom 1.

ZOOM 3: Streets view

The logical representation for the selected variables in a street view zoom level is to represent EPC rating colour-coded and level of carbon emissions size-coded (Fig. 73). Other representation techniques could also be used, particularly for the second variable, such as shape-coded, texture-coded or even orientation-coded. However the logic will determine the selected representation technique every time.

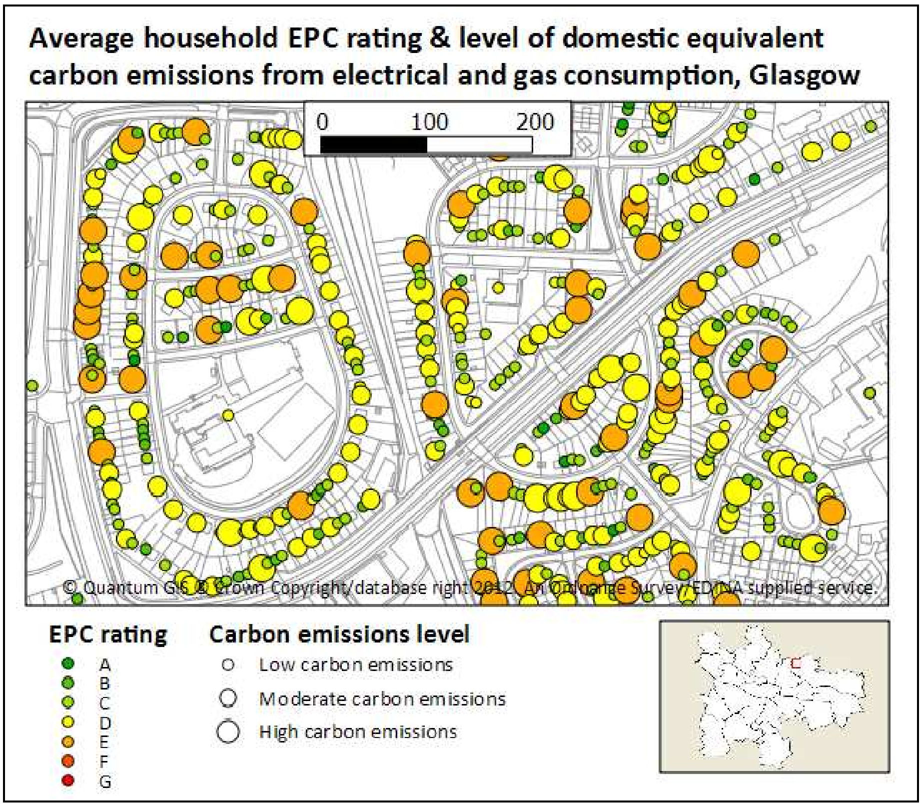


Fig. 73 – Two variables streets view: Colour-coded variable A (7 possible values) & size-coded variable B (3 possible values).

3. HOUSEHOLD EQUIVALENT CARBON EMISSIONS	&	**INHABITANTS AVERAGE AGE**
quantitative variable		quantitative variable

For the representation of two quantitative variables, the proposed options are the following ones:

- Colour-coded variable 1 and colour-coded variable 2 (Fig. 74).
- Colour-coded variable 2 and colour-coded variable 1 (Fig. 75).
- Colour-coded variable 1 and variable 2 represented in a bar diagram (Fig. 76).
- Colour-coded variable 2 and variable 1 represented in a bar diagram (Fig. 77).
- Colour-coded variable 1 and texture-coded variable 2 (Fig. 78).
- Colour-coded variable 2 and texture-coded variable 1 (Fig. 79).

ZOOM 1: City view

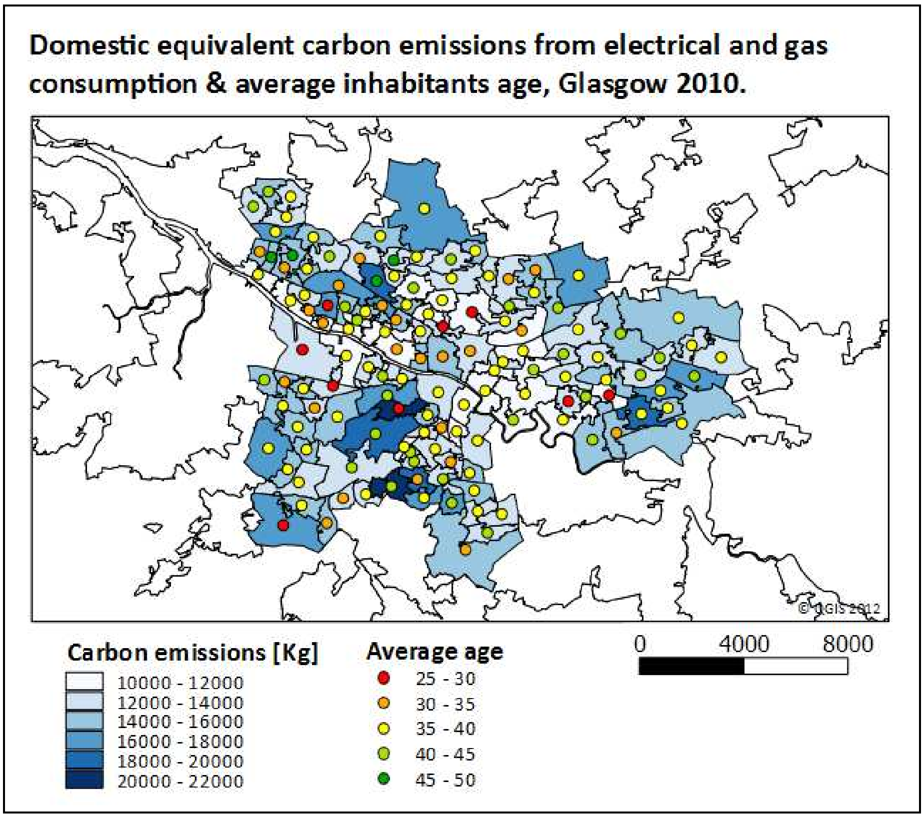


Fig. 74 – Two variables city view (IG's division): Colour-coded variable 1 & colour-coded variable 2.

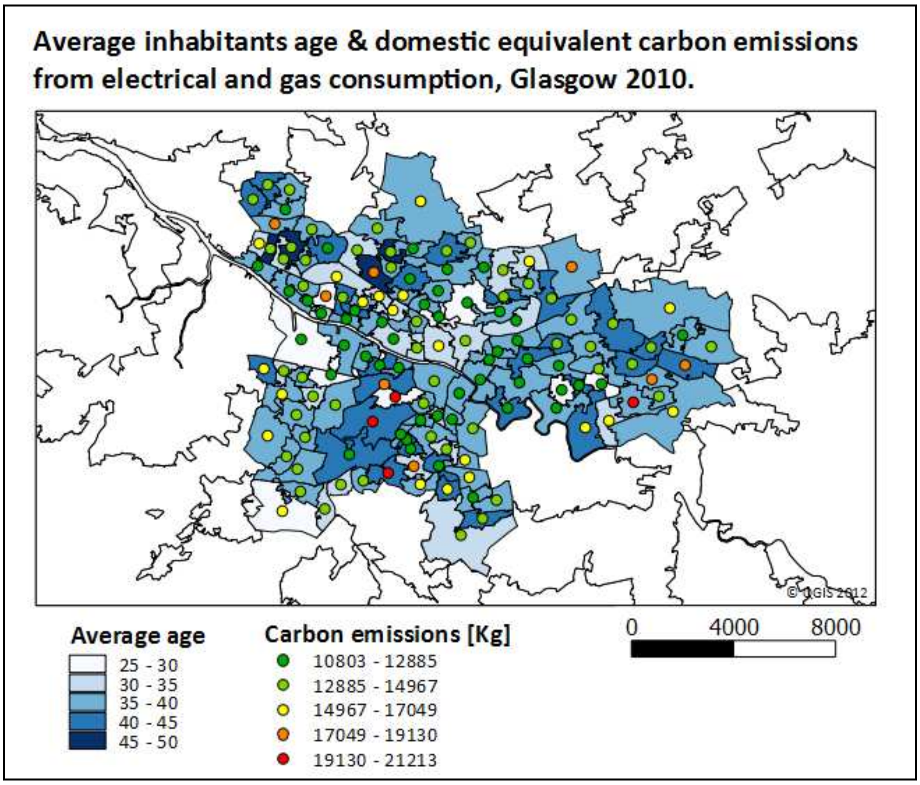


Fig. 75 – Two variables city view (IG's division): Colour-coded variable 2 & colour-coded variable 1.

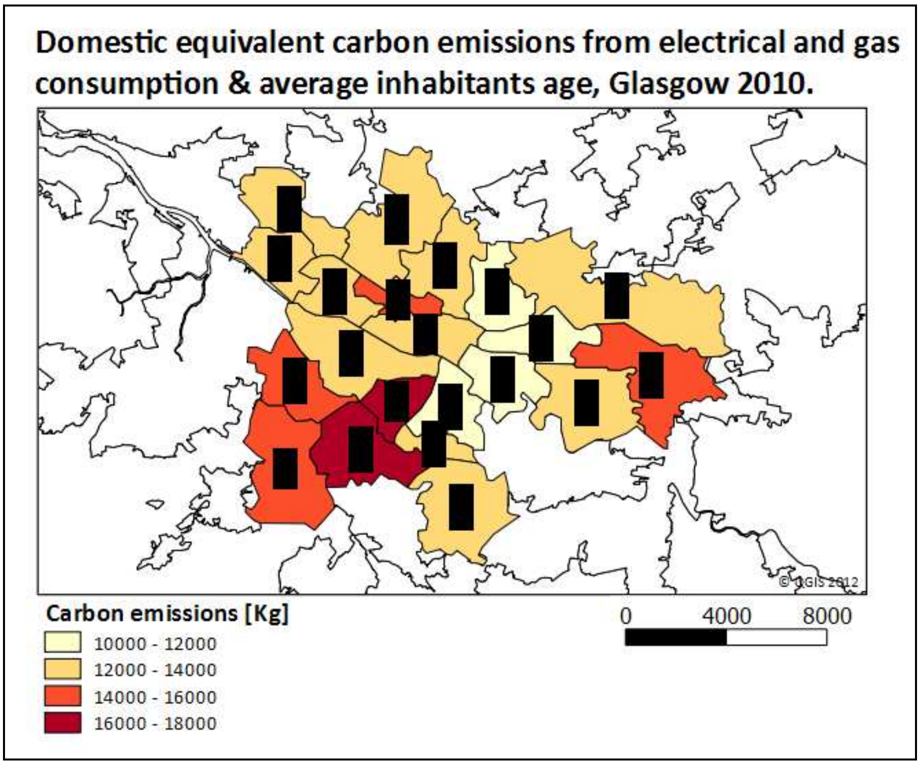


Fig. 76 – Two variables city view (wards division): Colour-coded variable 1 & variable 2 represented using bar charts.

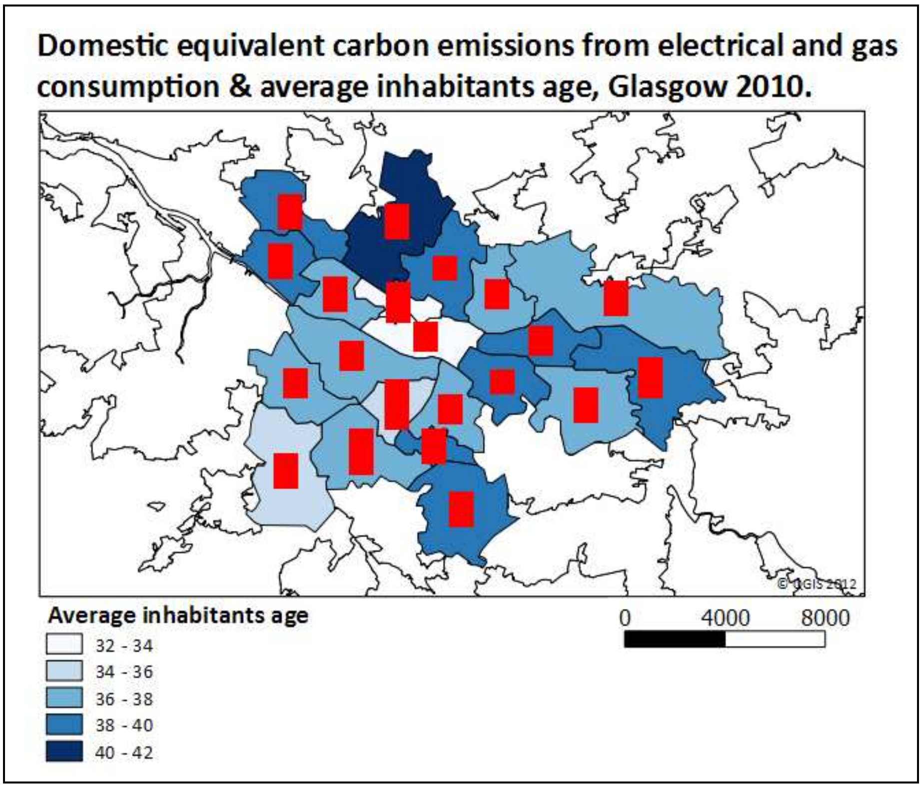


Fig. 77 – Two variables city view (wards division): Colour-coded variable 2 & variable 1 represented using bar charts.

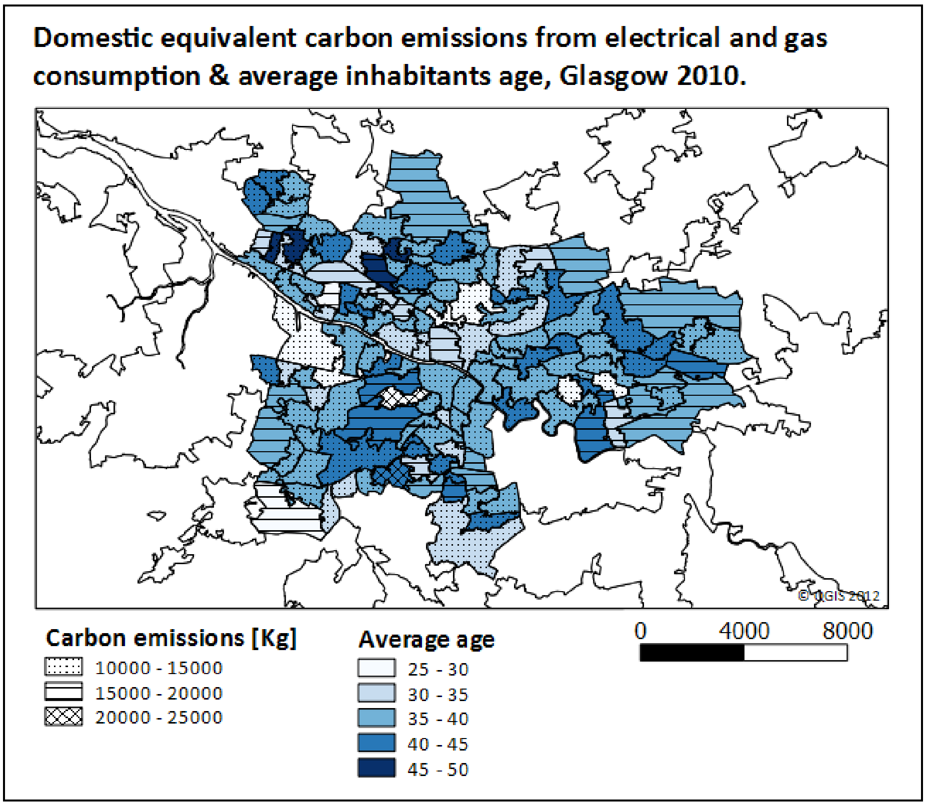


Fig. 78 – Two variables city view (IG's division): Colour-coded variable 1 & texture-coded variable 2.

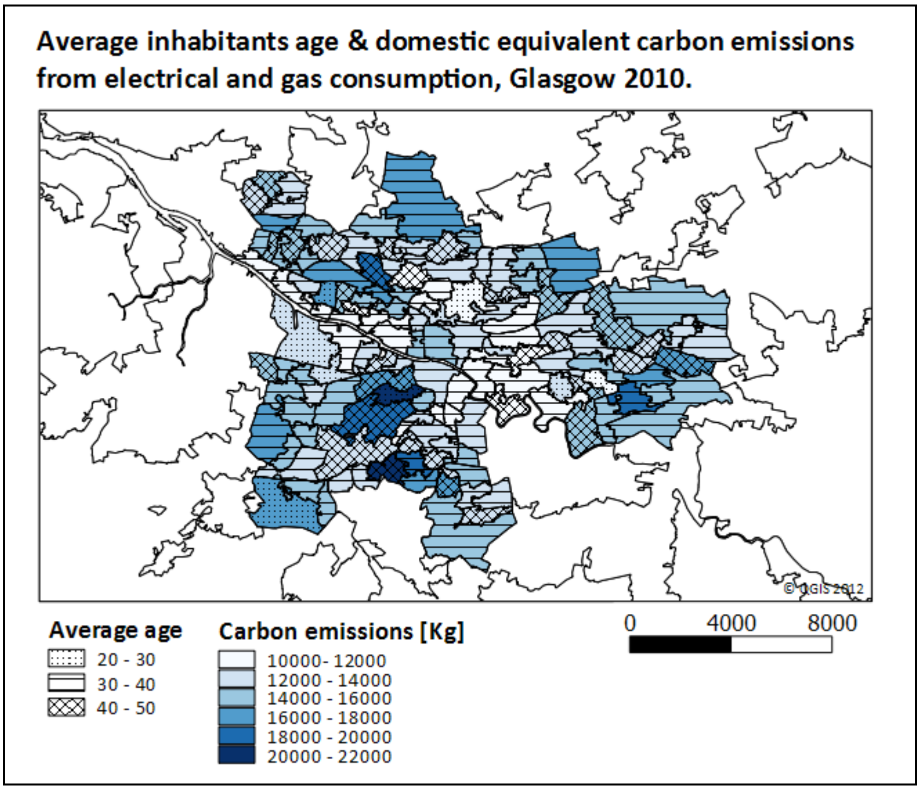


Fig. 79 – Two variables city view (IG's division): Colour-coded variable 2 & texture-coded variable 1.

It is more sensible to represent the quantitative variable that has more differentiated numbers using bars, and the other one colour-coded, in this case Fig. 76 and Fig. 77 represent the same information; however the second one is easier to understand.

When combining a colour-coded variable with a texture-coded variable it is important that the colours used are light while ensuring that the quantitative texture-coded variable are not divided into many divisions, as both things will make the map more difficult to read.

ZOOM 2: Ward view

Zoom 2 has the same representation options as shown for zoom 1, therefore the conclusions are the same.

ZOOM 3: Streets view

For the streets view representation, it is recommended to combine both quantitative variables one colour-coded and the other one size-coded and vice versa.

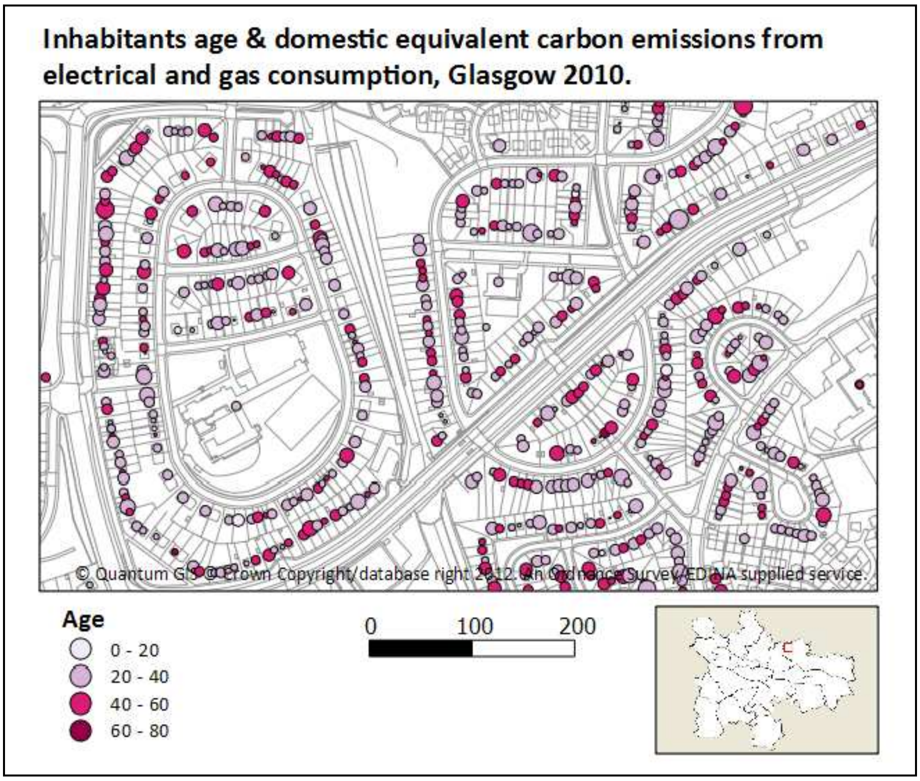


Fig. 80 – Two variables streets view: Colour-coded variable 1 & size-coded variable 2.

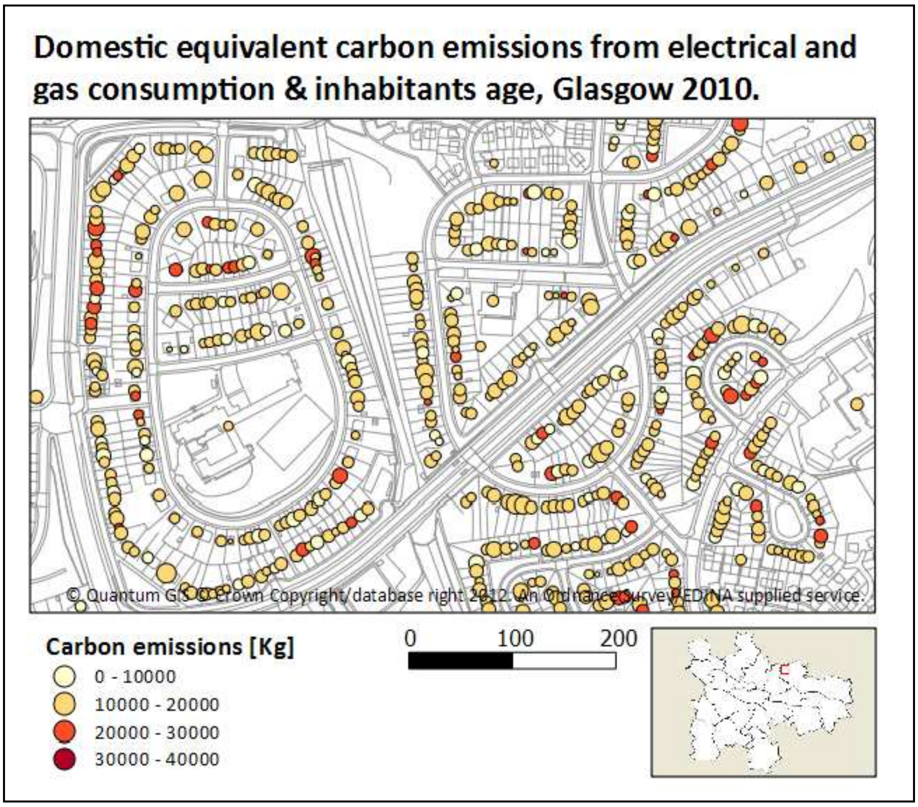


Fig. 81 – Two variables streets view: Colour-coded variable 2 & size-coded variable 1.

4.2.4.1.2. Representation of three or more attributes using GIS tools

Representing three variables in the same map can only be done on a few occasions. As we have seen in *section 4.2.4.1 Graphical multivariable representation*, most of the maps already combine different coding systems to display two variables; therefore, representing a third would result in an overcrowded map. Only in a few cases, with maps divided into big areas, would it be feasible to include a third variable. One example of this is e.g. Fig. 71, in which another variable could be represented, e.g. the number of household inhabitants:

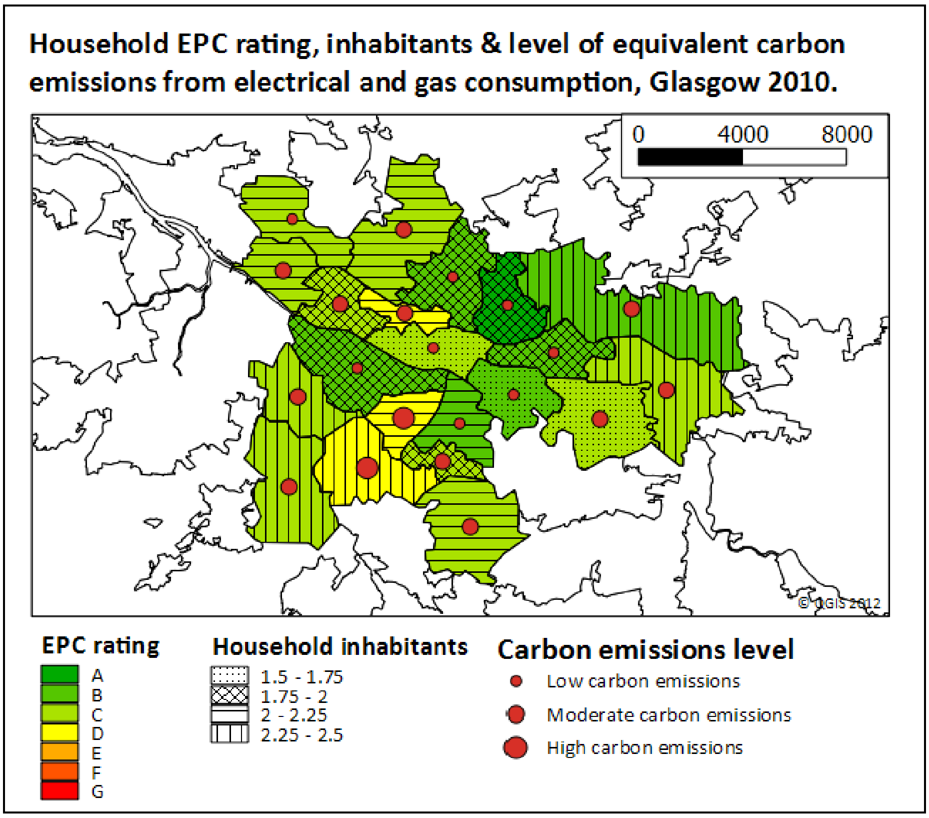


Fig. 82 – Three variables city view (wards division): Colour-coded qualitative variable (7 possible values), texture-coded quantitative variable and size-coded qualitative variable (3 possible values).

Therefore, to add a third variable in polygon represented maps, it is recommended that they are divided into big areas and the colours used are significantly different.

On the other hand 'queries' can be a suitable solution for displaying further information. A 'query' consists on displaying only the variables that fulfil a specific requirement, e.g. Fig. 66 does not seem to be able to include any other variable; however, somebody could be interested in knowing if there is any pattern between the two displayed variables (EPC rating and carbon emissions level) and the number of inhabitants. Therefore a query like: 'show only the data of the IG areas in which the average inhabitants' age is under 30 years old' (Fig. 83).

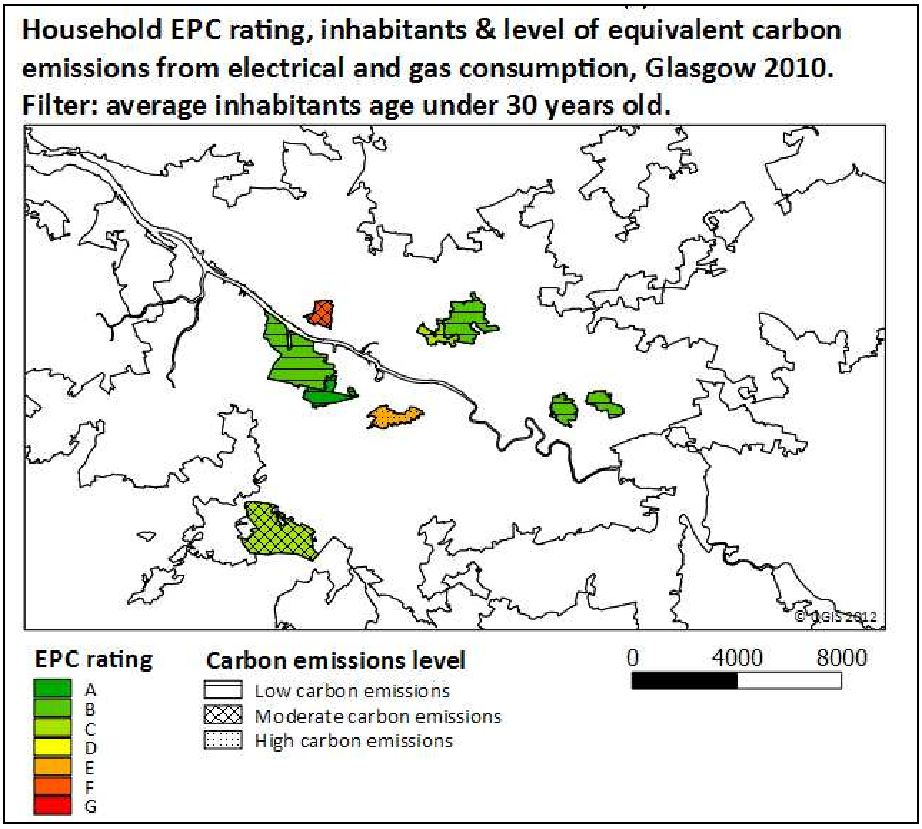


Fig. 83 – Two variables city view (IG's division). Information filtered by average inhabitants' age under 30 years.

Queries can be more complex, e.g.:

- 'Or' condition: Show only areas with average age under 30 years or above 40.
- 'And' condition: Show areas which suffer from fuel poverty and are not located in a specific ward.
- Different variables combination: Show areas with age under 30 years and suffering from fuel poverty.
- …

The same queries can be done when the data is represented using dots instead of polygons.

4.2.4.2. Mathematical combination of variables

Different information attributes can be mathematically combined in order to be represented in one single GIS attribute. The main purpose of combining more than one variable is usually to support decisions for spatial location, which will be based on measurable attributes of the alternatives being considered (this process is known as *multi-criteria evaluation (MCE)*). One decision example would be: 'which areas of the city are more suitable for the installation of small scale solar thermal panels?' A possible combination of variables would be the following:

HOUSEHOLD EQUIVALENT CARBON EMISSIONS FROM GAS CONSUMPTION quantitative variable	&	**SKY ACCESS** quantitative variable

To express the suitability of installing small scale renewables (SSR), different scores are given to each of the attributes (criteria) by means of weighing factors, depending on its relevance. The procedure to combine two or more variables (x_i) is the following:

1. Weights (w_i) must be assigned to each of the variables as a percentage, representing their relevance. The sum of all the weights must add to 100%.

$$\sum_{i=0}^{n} w_i = 1 \qquad \text{(Equation 4)}$$

2. The data must be standardized, so that it continuously varies from e.g. 0-1, 0-100, 0-250, etc. representing in all cases the worst and the best situation, or vice versa. The most commonly used way of standardization is:

$$X_i = \frac{x_i - \min_x}{\max_x - \min_x} \qquad \text{(Equation 5)}$$

Where X_i = standarized value of the variable
x_i = original value of the variable
$\min_x$ = minimum value of the variable series
$\max_x$ = maximum value of the variable series

3. The procedure for combining them is: for each entity, the result of multiplying each of the standardised variables by its corresponding weight is added, as shown in the following expression:

$$\{X = w_1 * X_1 + w_2 * X_2 + ... + w_n * X_n\} \qquad \text{(Equation 6)}$$

Where X = suitability index for location of a spatial entity
w_i = weighing factor
X_i = standardised variable value

The distinction between factors and constraints is important. They are both criteria, but while a constraint is a Boolean criteria (it can be yes or no), being the legislation a typical example, the factors are criteria that define a degree of suitability, usually represented by scores.

Therefore, a one variable map like Fig. 84, showing just the household equivalent carbon emissions, becomes Fig. 85, which is represented using the same colour scale, but represents the conjunction of both variables, household equivalent carbon emissions and sky access, in this case equally averaged:

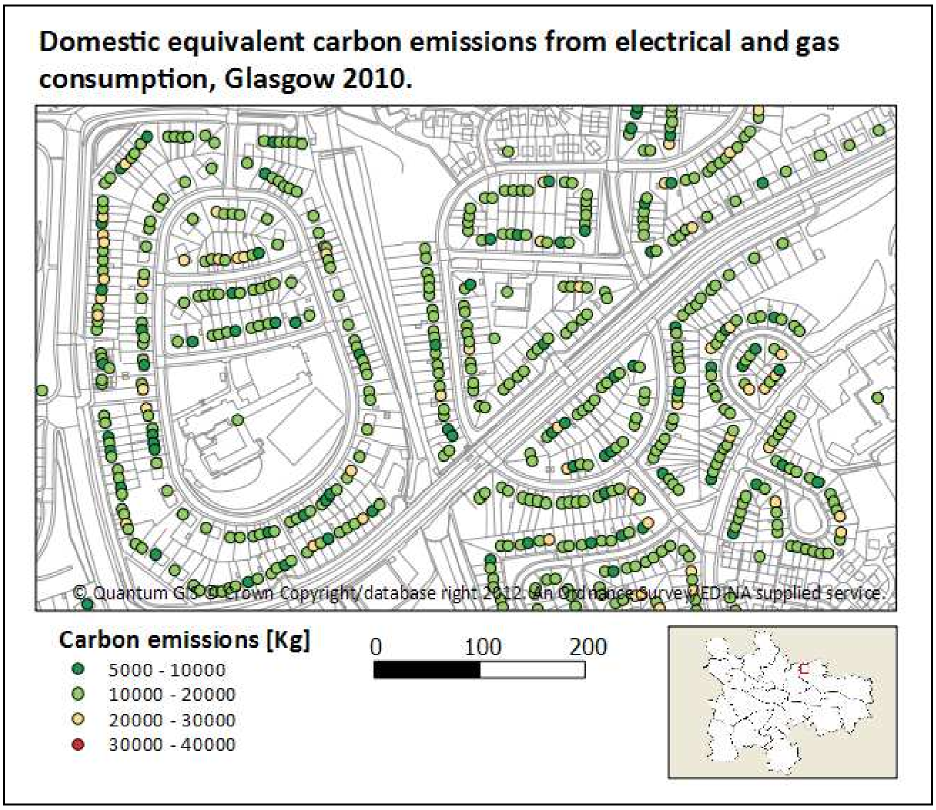


Fig. 84 – Monovariable layer.

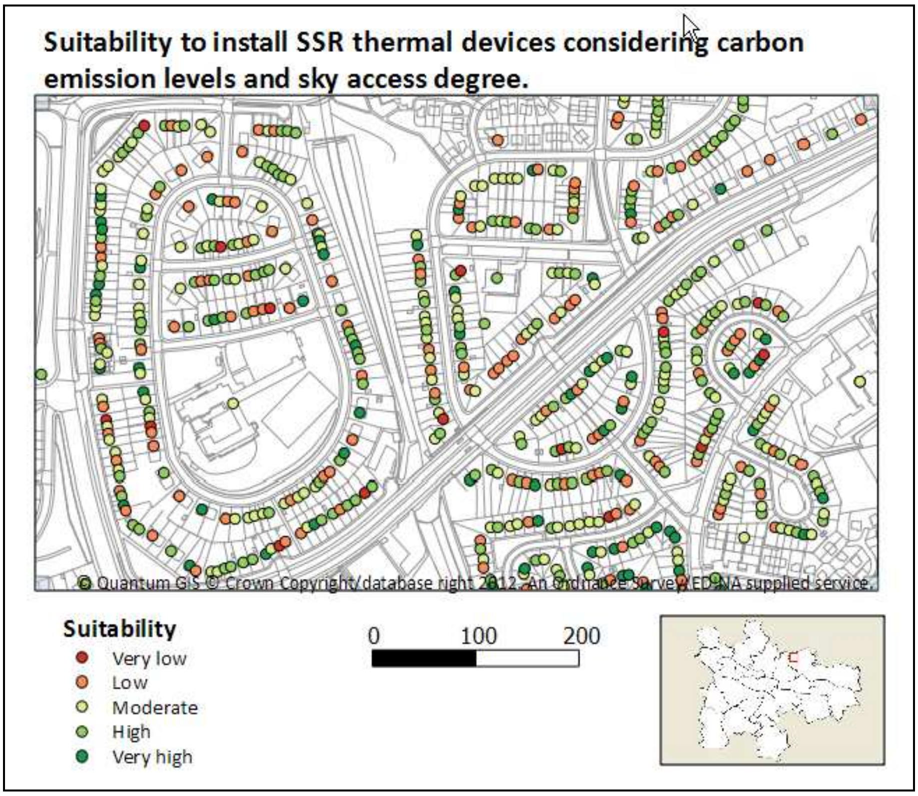


Fig. 85 – Multivariable layer.

More than two variables with different weighs can be combined. The chosen factors can be highly relevant on the results output, e.g. if a utility wants to install SSR thermal devices, the factors that it may be interested to know are:

- Dwelling equivalent carbon emissions
- Sky access
- Average age of the dwelling inhabitants
- Property cadastral value

These factors must be analysed by an expert's committee and a relevance degree must be assigned to each of the variables. Table 9 reflects two possible weighing options.

FACTOR	RELEVANCE	OPTION 1	OPTION 2
Sky access	Yes/No	>60%	>60%
Equivalent carbon emissions	High	50%	60%
Property cadastral value	Moderate	25%	30%
Average age of the dwelling inhabitants	Moderate	25%	10%
Σ		100%	100%

Table 9 – Selected variables, given relevance, and three possible weighing factor percentages.

All the data has been standardized so it goes from 0 to 1. The obtained values do not have any units, but their representation by means of a colour scale allows making a qualitative judgement for the suitability of the devices installation, for that purpose a breakdown of 5 equal intervals has been selected (see *section 4.2.3.3 Data classing*), dividing the suitability into the following categories: 'very low', 'low', 'moderate', 'high', 'very high'. The results of representing the two options described in Table 9 are shown below:

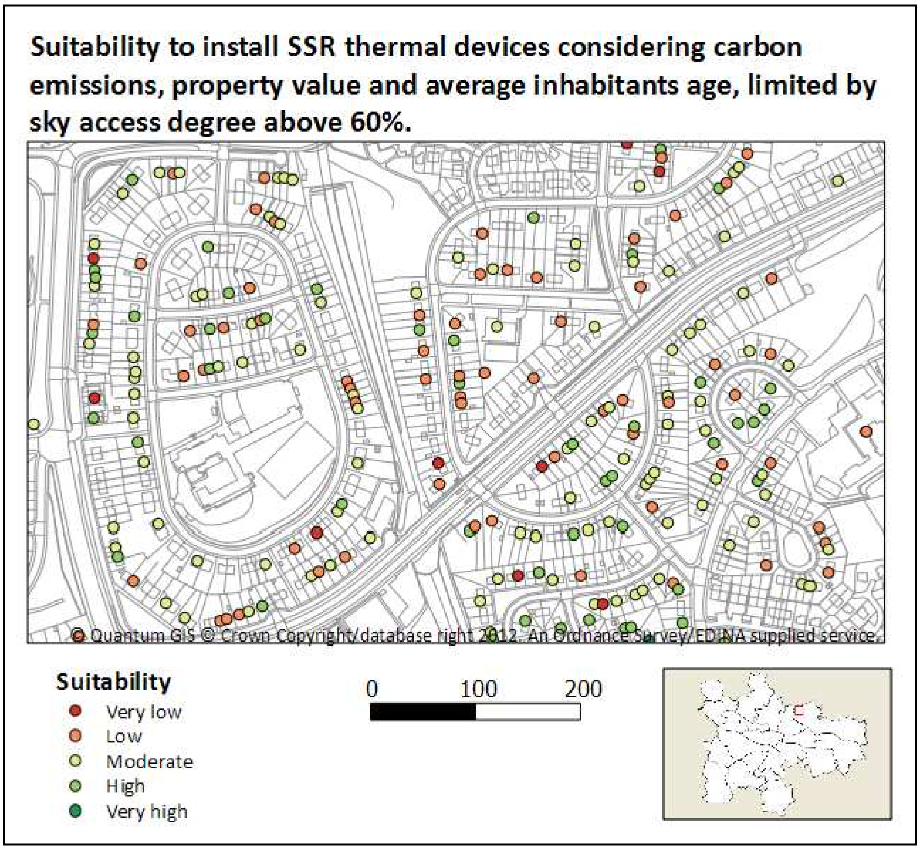


Fig. 86 – Weighing factors option 1.

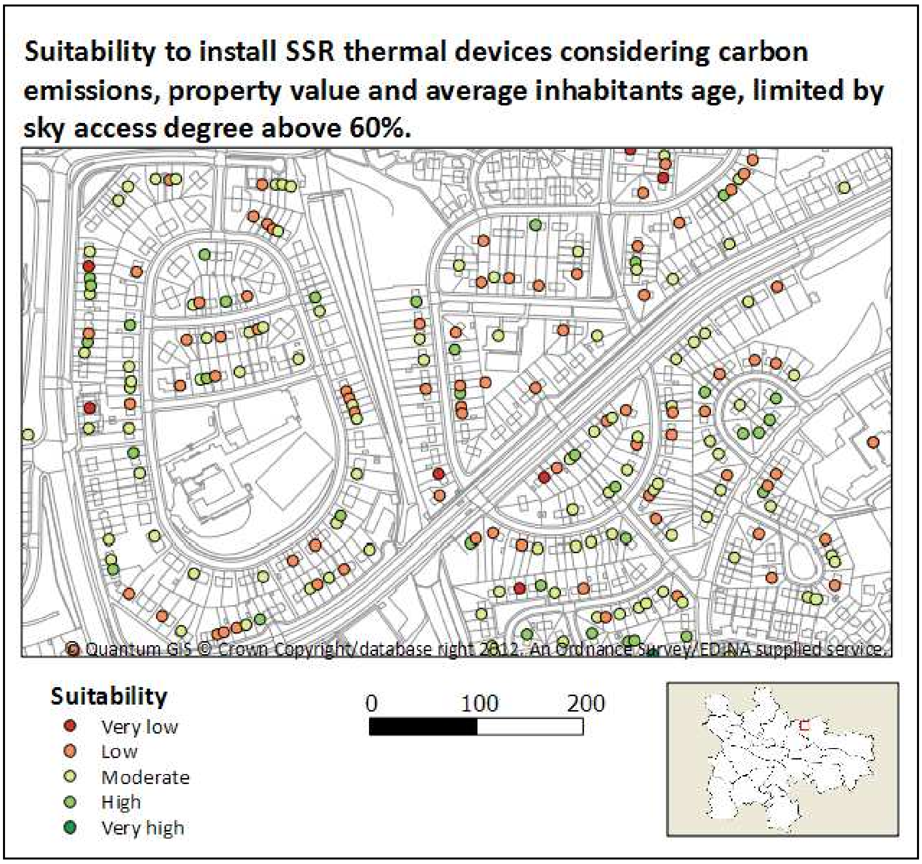


Fig. 87 – Weighing factors option 2.

As it can be seen, in this case, the difference between Fig. 86 and Fig. 87 is not very significant, although some slight variations can be detected. This fact will depend on the case of study and the number of variables considered. The same process can be used on a choropleth map, where the difference between the maps is more evident to the naked eye.

Thus, the final result will depend on who did the MCE, the data quality and the selection of the criteria and weighing factors. Moreover, Kristin Shrader-Frechette (2000) illustrates the potential for models[13] to be differently interpreted depending on the motivations of policy makers [44].

Even though MCE is often used, it has some limitations: e.g. the linearly factors standardisation it doubtingly the most appropriate way of doing it. Moreover, even though the chosen weights are usually established by experts, there is not a single answer, and the results output can be highly dependant on the chosen values.

[13] **Models:** Simplification of the reality.

4.3. Maps interpretation: Energy experts judgement

To complete the identification of the most appropriate representation techniques for energy related information displayed on maps, the consultation to different energy experts has been considered appropriate. Therefore the opinion of a group of 17 energy experts has been consulted by means of a questionnaire creation, the complete version of which can be found in Appendix 1.

- QUESTION 1:

Objective: Determine which method of representing data on a map is more suitable.

Options:

A: Results displayed using a small squared grid on the map.

B: Choropleth map indicating the sources origin.

C: Results displayed using a bigger slightly transparent squared grid.

D: Choropleth map.

Results distribution:

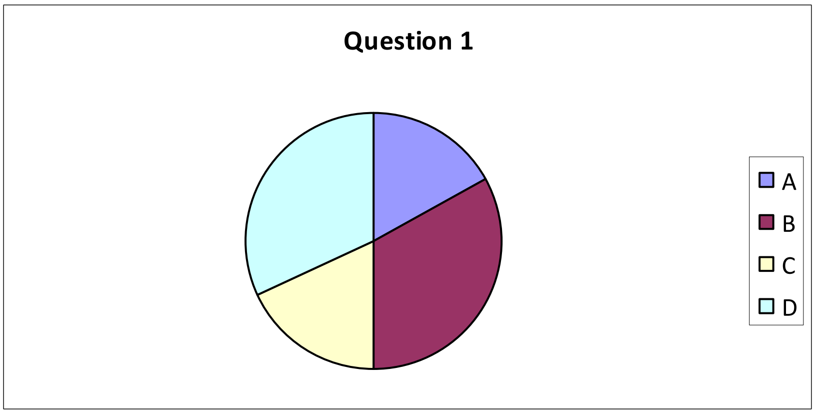


Fig. 88 – Answers to question 1 presented in a pie chart.

Conclusions:

- In general, figures with coloured areas (choropleth maps) are found to be clearer than the ones with results presented on a discretized grid.
- From the two preferred maps (A and D), there is not a clear fancied option; essentially A provides more information; however D is found to be clearer at a glance.

- <u>QUESTION 2</u>:

Objective: Determine which colour scale is better to represent carbon emissions.

Options:

A: Change in colour hue: yellow to red.

B: Traffic light colour scale: green to yellow to red.

C: Spectral (rainbow) scale.

D: Light to dark (reds).

E: Cold to hot: Blue to red.

Results distribution:

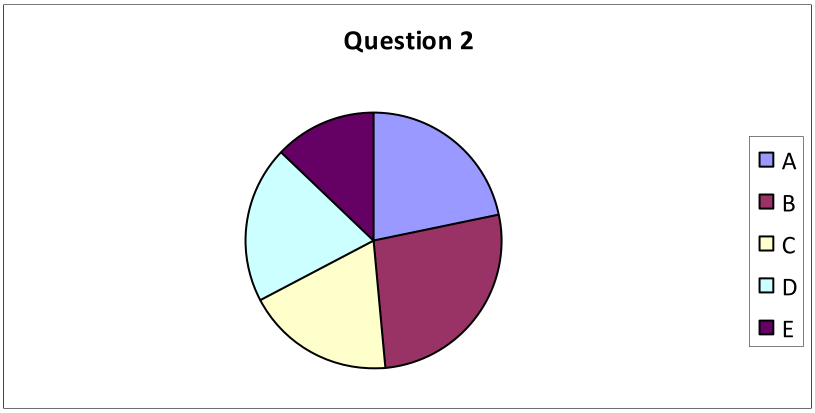


Fig. 89 – Answers to question 2 presented in a pie chart.

Conclusions:

- To represent equivalent carbon emissions 'the traffic light colour scale' (green to yellow to red) is the most liked opition.
- The options: 'change in colour hue': yellow_to_red, 'light to dark' (reds) and 'spectral (rainbow) scale' are also found appropriate for carbon emissions representation.
- In general, the option 'cold to hot' (blue to red) is the less liked to represent carbon emissions.

- QUESTION 3:

Objective: The purpose was to see which classing was better if we wanted detect the buildings with higher carbon emissions.

Options:

A: Natural breaks.

B: Quantiles.

C: Equal interval breaks.

D: Standard deviation.

E: Pretty breaks.

Results distribution:

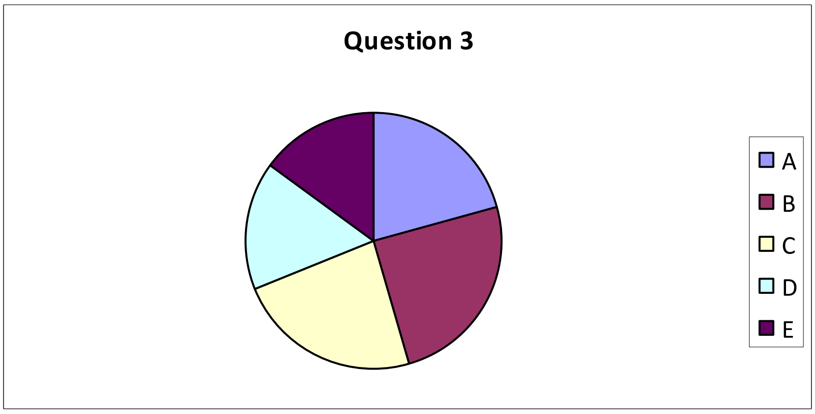


Fig. 90 – Answers to question 3 presented in a pie chart.

Conclusions:

- Even though the classing with pretty breaks did not allow the detection of any point in the higher rank, the map with 3 useful breaks (considerably less information than the other maps) was often chose by some of the experts as a first preference, highlighting the importance of this kind of breaks for a better understanding.
- Even though the information provided with the standard deviation division was higher (as the number of intervals was bigger) probably the fact that the picture did not show any point in the higher rank dissuaded its choice.
- The preferred options as chosen by the energy experts were as follows: quantiles, natural breaks and equal interval breaks, showing that in general higher number of darker points in the figure were preferred.

- The personal conclusion extracted from the experts' response is that in most cases none of the classing methods offered by the software were adequate for presenting the data. The values classing will logically vary depending on the map's purpose, but an appropriate classing will be made based on the data histogram, moreover the interval limits should not be any number, but they should be made at least slightly 'pretty'.

- QUESTION 4:

Objective: In this case the preferred way of combining two variables in a small zoom map was questioned.

Options:

A: Colour-coded variable 1, texture-coded variable 2.

B: Colour-coded variable 1, texture colour-coded variable 2.

C: Colour-coded variable 1, variable 2 presented in pie charts.

D: Colour-coded variable 1, variable 2 presented in bar charts.

Results distribution:

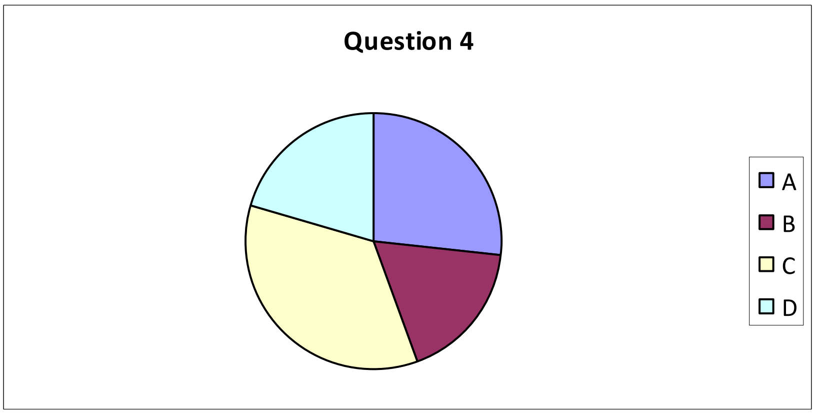


Fig. 91 – Answers to question 4 presented in a pie chart.

Conclusions:

- The clearly preferred option, was the one displaying pie charts, followed by the combination of colours and textures.
- Bars were found to be slightly confusing; however, the concept of representing gas, electrical and total emissions in three different bars was liked.

- The representation of colour-coded texture was the least liked, as it was found to be confusing.

- QUESTION 5:

Objective: The objective was the same as in question 4, but with a larger zoom detail.

Options:

A: Colour-coded variable 1, texture-coded variable 2.

B: Colour-coded variable 1, texture colour-coded variable 2.

C: Colour-coded variable 1, alphabetically represented variable 2.

D: Colour-coded variable 1, variable 2 represented in bar charts.

Results distribution:

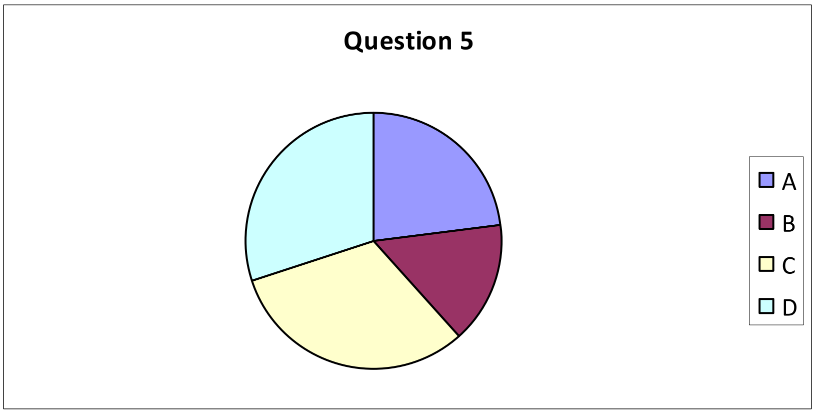


Fig. 92 – Answers to question 5 presented in a pie chart.

Conclusions:

- The representation using letters is found clear enough.
- In general, the three options: mixing colours and textures, colours and letters and colours and bars are found useful in general.

- <u>QUESTION 6</u>:

Objective: Determine which combination is better to represent two attributes using discrete points.

Options:

A: Colour-coded variable 1, shape-coded variable 2.

B: Size-coded variable 1, colour-coded variable 2.

Results distribution:

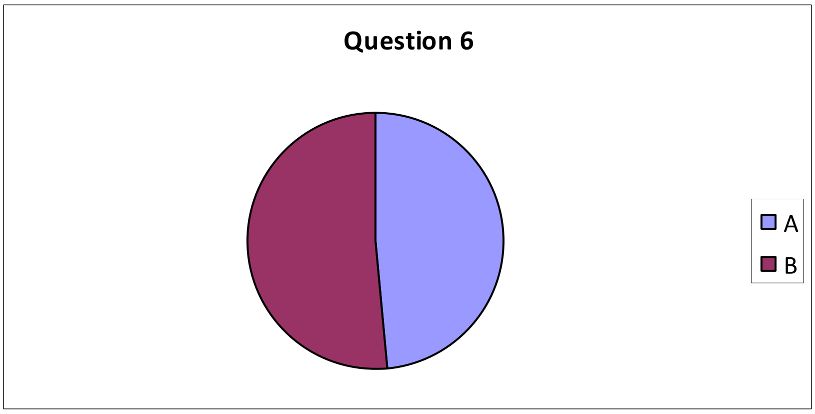


Fig. 93 – Answers to question 6 presented in a pie chart.

Conclusions:

- In this case, none of the options are clearly more liked than the other one. The general impression is that none of the figures are good enough, as the different shapes in option A are found to be difficult to decipher, while picture B is found to be overcrowded.
- Both representations with a larger zoom level would probably be more liked. Therefore, when combining different shapes or colours a relatively low number of points are needed. It is important that the shape difference can be easily identified.
- For the current zoom level aggregating data in areas would probably turn out to be a better solution.

- **QUESTION 7**:

Objectives: To find the most appropriate representation technique to detect patterns between two qualitative variables and detect the preference in the variable's displaying order.

Options:

A: Colour-coded variable 1, texture-coded variable 2.

B: Colour-coded variable 1, variable 2 represented using pie charts.

C: Colour-coded variable 2, variable 1 represented using pie charts.

D: Colour-coded variable 1, colour-coded variable 2.

E: Colour-coded variable 2, colour-coded variable 1.

F: Colour-coded variable 1, size-coded variable 2.

G: Colour-coded variable 2, alphabetically represented variable 2.

Results distribution:

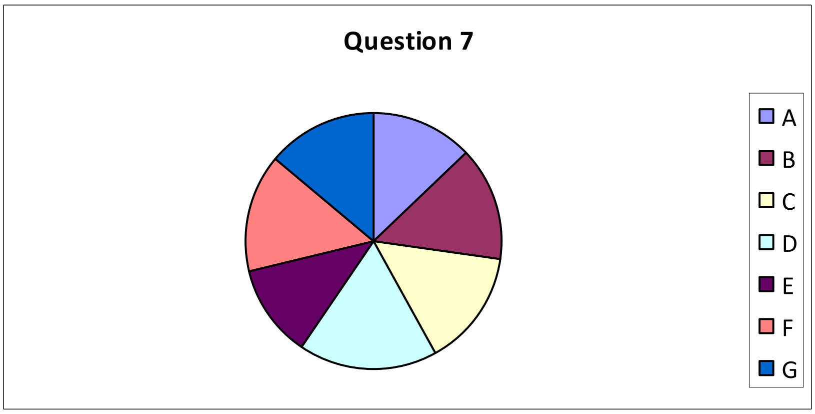


Fig. 94 – Answers to question 7 presented in a pie chart.

Comments: This question was found to be difficult to reply to by some of the experts, maybe that is why answers are so uneven. Option E has been more penalised, but this is probably because the size of the dots is not big enough, and this makes the map reading more difficult.

Conclusions:

- One of the question purposes was to detect the preference in the variable's displaying order, but the results do not show a clear preference.

- It can be seen that when the carbon emissions are displayed below, the preferred option for displaying EPC rating is pie charts, followed by letters and the least preferred option is colours.
- When the emissions are presented on coloured-EPC rating, the preferred options are: colour-coded, size-coded, pie chart and texture-coded.
- Even though the combination of colours and textures would seem a good way for detecting patterns, this is the least liked option. Probably a lower number of divisions and an intensity graduate pattern would be found more useful.

- QUESTION 8:

Objectives: To detect the preference in the variable's displaying order and also which representation technique was better for detecting patterns between two variables (one quantitative and one qualitative).

Options:

A: Colour-coded variable 1, colour-coded variable 2 (smaller size).

B: Colour-coded variable 2, colour-coded variable 1 (smaller size).

C: Colour-coded variable 1, variable 2 represented in a bar chart.

D: Colour-coded variable 2, variable 1 represented in a bar chart.

E: Texture-coded variable 1, colour-coded variable 2.

F: Texture-coded variable 2, colour-coded variable 1.

Results distribution:

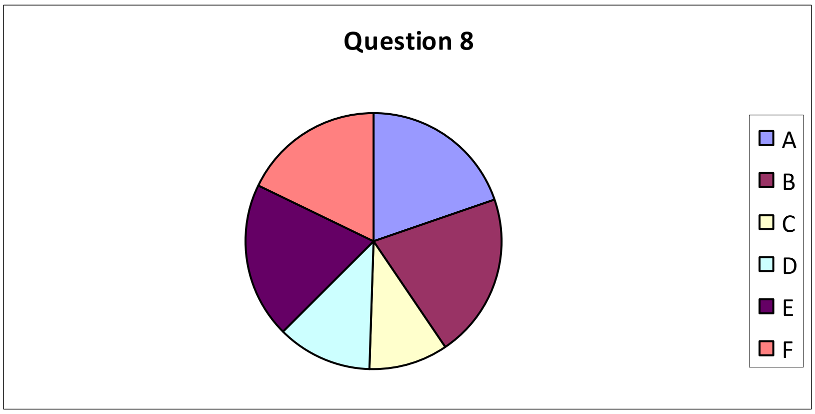


Fig. 95 – Answers to question 8 presented in a pie chart.

Conclusions:

- To detect the relationship degree between two variables, three possible combinations where presented: colour-coded & colour-coded, colour-coded & bar coded and colour-coded & texture-coded. The experts coincide that the bars are the less favourite option, as they find its reading confusing, followed by texture-coded, while the preferred option is to combine two different colour-coded variables, although they agreed that both colour scales should not have many divisions and its representation should be big enough to allow the map to be read easily.

5. Conclusions

GIS is a very powerful tool that is going to be used more and more often in the future. In this thesis, different functionalities, data treatment and representation techniques have been explored to display energy related information in maps. This is thought to be a useful tool for utilities and local authorities in many ways, as they can:

- Have a support decision tool for action planning.
- Detect business and environmental opportunities.
- Track the effect of previously implemented action plans.
- Model future predictions.

As for the representation techniques, different conclusions on how data should be displayed have been made:

- In general, maps classed into higher number of intervals provide more detailed information; however, they become more confusing as the colours identification in the legend becomes tougher.
- In a two variables map, the addition of further information layers is subject to maps with big area divisions, which at the same time entails lower resolution.
- The representation of quantitative variables size-coded does allow the comparison between entities, but does not provide as much information as colour-coded represented quantitative variables.
- The use of bars to express quantitative variables in choropleth maps can become confusing if the represented values are not significantly different.
- The use of pie charts only makes sense for areas that are composed by different points, but not for the representation of single dot entities.
- If one variable is more relevant than another, it is recommended that it is displayed under the less important one.
- When combining two colours, it is good practice to use pale colours for the variable underneath and shine ones for the secondary attribute, usually displayed in a smaller area above the first one.
- The use of pie charts it highly recommended, as they provide a further level of information and are very visual.

- When using the MCE method, the result will depend on who did the MCE, the data quality and the selection of the criteria and weighing factors.
- Queries can be a suitable solution for filtering the information shown in maps that already have two attributes.
- If a third level of information needs to be added in a map, it is necessary that the main area be divided into big divisions (more data aggregated, lower information level) allowing a proper reading.
- The display of more than three attributes in a single map is not recommended.

Also, the experts' consultation has lead to the following conclusions:

- Choropleth maps are found to be very clear and useful for transmitting information.
- The preferred colours for representing carbon emissions are the 'traffic light colour scale' (green, yellow, red), followed by the change in colour hue (yellow to red) and then 'light to dark' (red).
- The classing needs to be done case-specific (based on the data histogram and the map's purpose). Moreover it is very important to make the interval limits as pretty as possible to make the comprehension easier.
- In general, when combining two variables, when presenting the first one colour-coded, the preferred ways of presenting the second variable are: pie charts, colour-coded, size-coded and by means of letters, while the ones less preferred are bar charts and texture-coded.

6. Further work

As for the presented functionality of the system, it could be improved with:

- Representation of other none-metered types of heating, e.g. wood/biomass, oil, liquefied petroleum gas (LPG) or bottled gas, coal/other processed solid fuel, etc.

Other functionalities of GIS:

- Once a GIS system has been installed in a utility, it can be used for many other purposes, such as presentation of information, internal objectives tracking, etc.

Better conversion from metering lectures to carbon emissions:

- The equations used to convert energy metering into carbon emissions does not include the equivalent emissions of the transmission process (losses).

Further work for better conclusions:

- The comparison of the same urban area maps with energy consumption information for summer and winter seasons would provide a deeper level of knowledge of the current situation, which would lead to more accurate conclusions.
- Representation in the maps and further comparison of carbon emissions per m^2, carbon emissions/person, etc.
- Create different maps for electrical and thermal demands and the associated carbon emissions.

References

[1] UNEP (2007) *BUILDINGS AND CLIMATE CHANGE. Status, Challenges and Opportunities.* [online; accessed 24.05.12] **http://www.unep.fr/shared/publications/pdf/DTIx0916xPA-BuildingsClimate.pdf**

[2] Department of Energy & Climate Change (2012) *Smart meters* [online; accessed 30.05.2012] **http://www.decc.gov.uk/en/content/cms/tackling/smart_meters/smart_meters.aspx**

[3] European Commission. Climate Action. (2010) *The 20-20-20 targets* [online; accessed 10.06.2012] **http://ec.europa.eu/clima/policies/package/index_en.htm**

[4] The Scottish Government (2020) *Climate Change (Scotland) Act 2009* [online; accessed 10.06.2012] **http://www.scotland.gov.uk/Topics/Environment/climatechange/scotlands-action/climatechangeact/**

[5] Sustainable Glasgow (2010) *Sustainable Glasgow Report 2010* [online; accessed 10.08.2012] **http://www.glasgow.gov.uk/NR/rdonlyres/E4E3CBEB-51FA-42BF-9C0A-112E49C95C71/0/SustainableGlasgowReport.pdf**

[6] Department of Energy & Climate Change (2010) *Maps showing domestic, industrial and commercial electricity consumption at local authority level. PUBLICATION URN 10D/1028.* **http://www.decc.gov.uk/assets/decc/statistics/regional/file41499.pdf**

[7] Howard, B.; Parshall, L.; Thompson, J.; Hammer, S.; Dickinson J. & Modi, V. (2012) 'Spatial distribution of urban building energy consumption by end use' *Energy and Buildings*, vol. 45, pp. 141-151.

[8] Keith J. Baker, R. Mark Rylatt (2008) 'Improving the prediction of UK domestic energy-demand using annual consumption-data'. *Applied Energy*, vol. 85, pp. 475-482.

[9] Fabbri, K.; Zuppiroli, M. & Ambrogio, K. (2012) ‘Heritage buildings and energy performance: Mapping with GIS tools’ *Energy and Buildings*, vol. 48, pp. 137-145.

[10] Chen, D.; Shams, S.; Carmona-Moreno, C. & Leone, A. (2010) ‘Assessment of open source GIS software for water resources management in developing countries’ *Journal of Hydro-environment Research*, vol. 4, pp. 253-254.

[11] QGIS Development Team (2012) *Version 1.7.4. disponible* [online; accessed 22.05.2012]

http://www.qgis.org/

[12] Ph.D. Pau Fonseca i Casas (2012) *GEOSim* [online; accessed 31.07.2012]

http://www-eio.upc.edu/~pau/?q=node/18

[13] Alamdari, P.; Nematollahi, O. and Mirhosseini, M. (2012) ‘Assessment of wind energy in Iran: A review’ *Renewable and Sustainable Energy Reviews*, vol. 16, pp. 836-860.

[14] Bjørklund, K.R.; Cortese, G.; Swanberg, N. and Schrader, H.J. (1998) ‘Radiolarian faunal provinces in surface sediments of the Greenland, Iceland and Norwegian (GIN) Seas’ *Marine Micropaleontology*, vol. 35, pp. 105-140.

[15] Heywood, D. I.; Oliver. J & Tomlinson, S. (1995) ‘Building an exploratory multi-criteria modelling environment for spatial decision support’. In: Heywood, I.; Cornelius, S. and Carver, S. (2006) ‘An introduction to geographical information systems’. Pearson education limited, Harlow (UK).

[16] Office for National Statistics (2012) A Beginner’s Guide to UK Geography. Glossary [online; accessed 27.05.12]

http://www.ons.gov.uk/ons/guide-method/geography/beginner-s-guide/glossary/index.html

[17] Longley, P. A.; Goodchild, M. F.; Maguire, D. J. & Rhind D. W. (2010) *Geographical Information Systems. Volume 1. Principles and Technical Issues.* John Wiley & Sons, Inc, New York (USA).

[18] esri (2007) Geodatabases That Are Easier to Set Up and Manage. [online; accessed 12.08.2012]

http://www.esri.com/news/arcuser/0807/gdb_precision.html

[19] Poster, M. (1996) 'Databases as Discourse, or Electronic Interpellations.' In *Computers, Surveillance and Privacy*, ed. By D. Lyon and E. Zureik. Minneapolis: University of Minnestoa Press.

[20] Ordnance Survey (2012) *OS Open Data* [online; accessed 12.05.2012] **https://www.ordnancesurvey.co.uk/opendatadownload/products.html**

[21] The Scottish Government (2010) *2009-2010 Urban Rural Classificaiton associated shapefiles* [online; accessed 28.05.2012] **http://www.scotland.gov.uk/Topics/Statistics/About/Methodology/2010URShape**

[22] Scottish Neighbourhood Statistics (2012) *Geography* [online; accessed 13.06.2012] **http://www.sns.gov.uk/Downloads/DownloadGeography.aspx**

[23] EDINA (2012) *Digimap* [online; accessed 22.05.2012] **http://edina.ac.uk/digimap/**

[24] Oxborrow E P (1989) *Databases and Database Systems: Concepts and Issues*, 2nd edn. Chartwell Bratt, Sweden. In: Heywood, I.; Cornelius, S. and Carver, S. (2006) *An introduction to geographical information* systems. Pearson education limited, Harlow (UK).

[25] Heywood, I.; Cornelius, S. and Carver, S. (2006) *An introduction to geographical information* systems. Pearson education limited, Harlow (UK).

[26] Nadine Schuurman (2004) *GIS: a short introduction*. UK: Blackwell Publishing

[27] Longley, P. A.; Goodchild, M. F.; Maguire, D. J. & Rhind D. W. (2010) *Geographical Information Systems. Volume 2. Management Issues and Applications.* John Wiley & Sons, Inc, New York (USA).

[28] Department of Energy & Climate Change (2012) *Fuel poverty statistics* [online; accessed 25.07.2012] **http://www.decc.gov.uk/en/content/cms/statistics/fuelpov_stats/fuelpov_stats.aspx**

[29] Carbon trust (2012) *Introducing combined heat and power* [online; accessed 25.07.2012] **www.carbontrust.com/media/19529/ctv044_introducing_combined_heat_and_power.pdf**

[30] The future of Small Scale Renewables (2012) *Demand profiles* [online; accessed 10.08.2012] **http://www.esru.strath.ac.uk/EandE/Web_sites/11-12/Small_scale_renewables/demand.html**

[31] Spreadsheet 'emissions', handed over by the ESRU department in Strathclyde University.

[32] Department of Energy & Climate Change (2012) *Fuel mix disclosure data table* [online; accessed 03.06.2012] **http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/fuel_mix/fuel_mix.aspx**

[33] Glasgow city council (2012) *Ward Factsheets* [online; accessed 18.07.2012] **http://www.glasgow.gov.uk/en/AboutGlasgow/Factsheets/Wards/**

[34] Department of Energy & Climate Change (2010) *MLSOA electricity and gas: 2010* [online; accessed 18.07.2012] **http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/regional/mlsoa_llsoa/mlsoa_2010/mlsoa_2010.aspx**

[35] Scottish Neighbourhood Statistics (2011) Report: Glasgow dwellings information [online; accessed 18.07.2012] **http://www.sns.gov.uk/Reports/Table.aspx?ReportId=7&SessionKey={fd53f922-8482-451b-b4d3-fb333359d340}&ReportType=Indicator&LatestData=False**

[36] The Scottish Government (2012) *0090481- Glasgow City* [online; accessed 18.07.2012] **www.scotland.gov.uk/Resource/Doc/933/0090481.xls**

[37] Cynthia, A. Brewer (2006) 'Basic Mapping Principles for Visualizing Cancer Data Using Geographic Information Systems (GIS)' Am J Prev Med 2006; 30 (2S):S25-S36).

[38] Making Maps: DIY CARTOGRAPHY (2008) *Map Symbols: Showing Multivariate Data with Texture* [online; accessed 01.07.2012] **http://makingmaps.net/2008/02/13/map-symbols-showing-multivariate-data-with-texture/**

[39] United Nations (2009) *Handbook on Geospatial Infrastructure in Support of Census Activities.* United Nations: New York.

[40] Newman M. E. J. (2008) *Maps of the 2008 US presidential election results* [online; accessed 07.08.2012]
http://www-personal.umich.edu/~mejn/election/2008/

[41] esri (2002) *GIS Dictionary* [online; accessed 01.08.2012]
http://support.esri.com/en/knowledgebase/Gisdictionary/browse

[42] Florida solar energy center (2007) *Energy Efficient Schools: 1996 Energy Survey* [online; accessed 08.08.2012]
http://www.fsec.ucf.edu/en/research/buildings/schools/energysurvey.htm

[43] Directgov (2012) *Energy performance certificates – what they are* [online; accessed 12.07.2012]
http://www.direct.gov.uk/en/homeandcommunity/buyingandsellingyourhome/energyperformancecertificates/dg_177026

[44] Shrader-Frechette, K. (2000). 'Reading the Riddle of Nuclear Waste: Idealized Geological Models and Positivist Epistemology'. In *Earth Matters: The Earth Sciences, Philosophy, and the Claims of Community*, ed. By R. Frodeman. Upper Saddle River, NJ: Prentice Hall.

Additional references

Quantum GIS User guide. Version 1.7.0 "Wroclaw" [online; accessed 22.05.2012]
http://download.osgeo.org/qgis/doc/manual/qgis-1.7.0_user_guide_en.pdf

Appendix 1 – Energy experts questionnaire

Slide 1

PLEASE, READ CAREFULLY

This questionnaire is composed of 8 questions. Its answer will take you max 15 minutes.

You can answer it in the attached word document.

To answer this questionnaire please order the presented maps from first (the map that serves the purpose explained in the question best) to last (the map that serves the purpose least).
If you feel that some of the maps serve equally for the purpose that can be your answer.
If you feel that some of the maps do not serve for the purpose please indicate it too.
Also, feel free to express any suggestions or ideas that may occur to you regarding the representation of energy related information using maps.

Slide 2

APPROACH TO CO_2 CITY MAPPING FOR UTILITIES AND LOCAL AUTHORITIES

PROJECT PURPOSE: To make an approach to prove how maps can help understanding the reality of the carbon emissions from the domestic sector, and to support decisions in order to reduce these emissions.

OBJECTIVE OF THIS QUESTIONNAIRE: to determine what are the best representation techniques for displaying energy-related information.

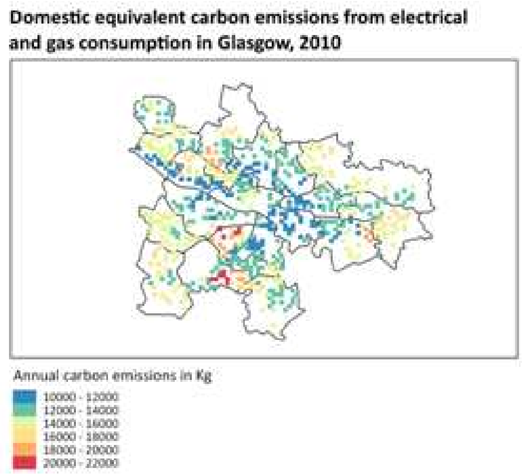
Note: *The carbon emissions represented in the maps are called 'equivalent carbon emissions' and represent the amount of CO_2 released for the consumption of a certain amount of gas or electricity in a dwelling. Even if in many occasions the emissions are not physically released in the same dwelling, it is represented as such, so that this data can be compared with other relevant information, helping the detection of patterns and relationships.*

Question 1

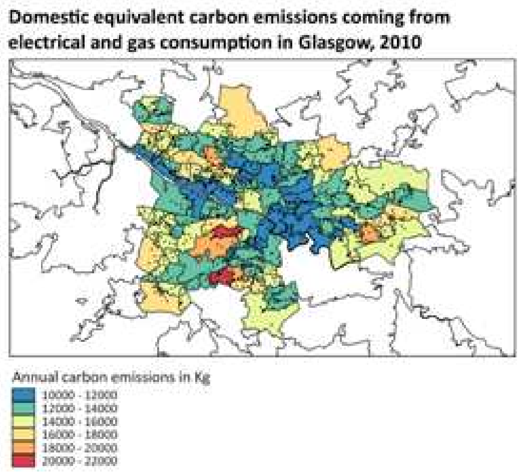
1) Imagine you would like to know the current carbon emissions from the domestic sector in Glasgow. Which of the following representation techniques helps you to better understand it?

Black dots represent the data origin

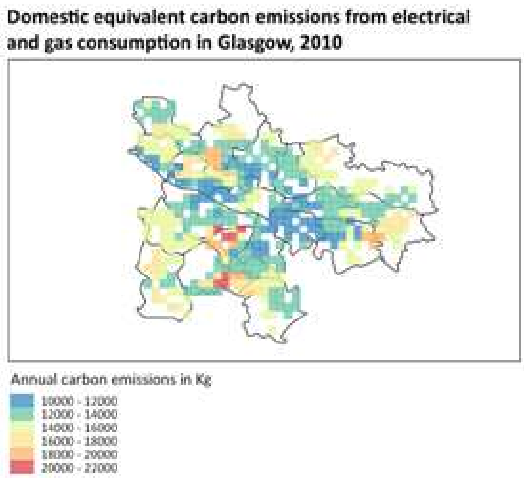
a.



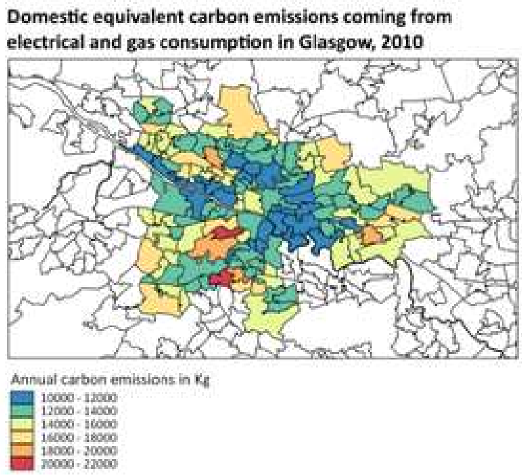
b.



c.

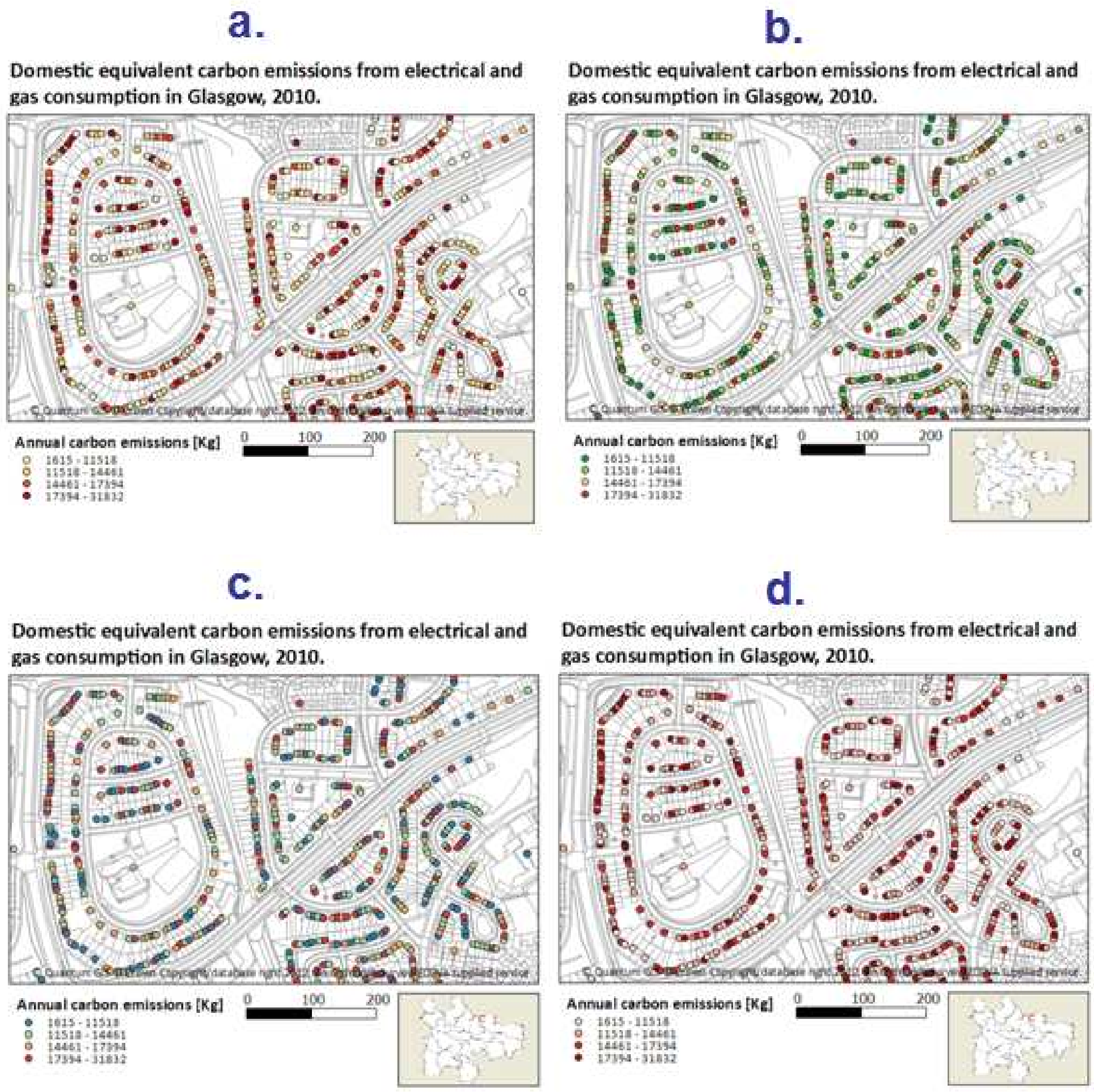


d.

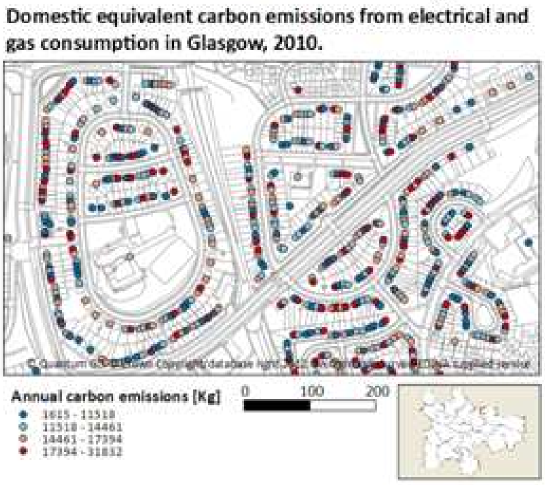


Question 2

2) Imagine we want to represent equivalent carbon emissions on a map. Which colors help you to better understand it?



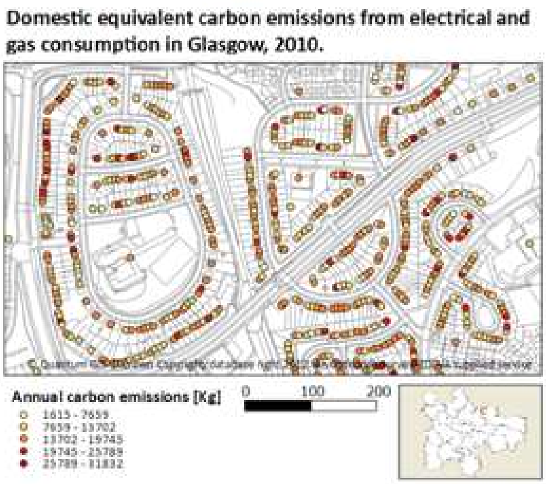
e.



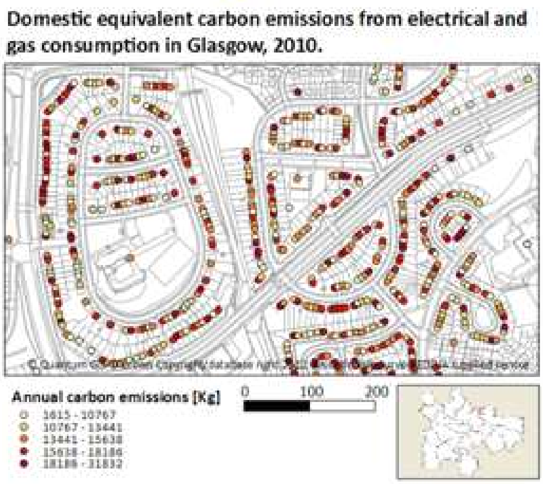
Question 3

3) Suppose that you would like to identify which dwellings have higher equivalent emissions in the area displayed in the map, because you want to take some action to reduce them. Which map/s do you find more useful for that purpose and why?

a.

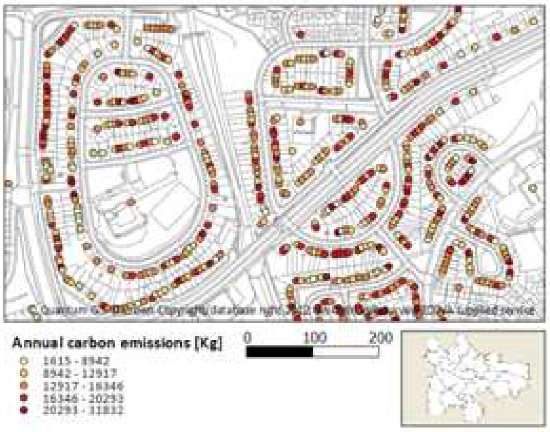


b.



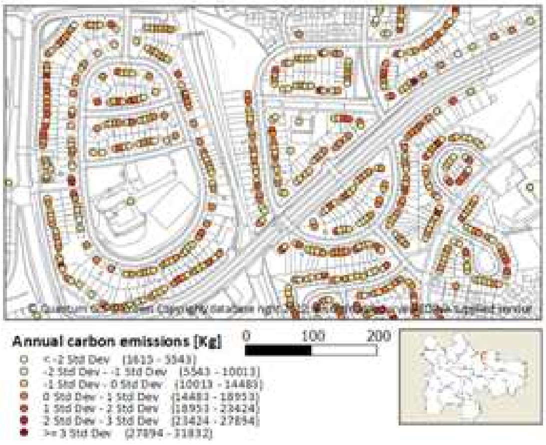
c.

Domestic equivalent carbon emissions from electrical and gas consumption in Glasgow, 2010.



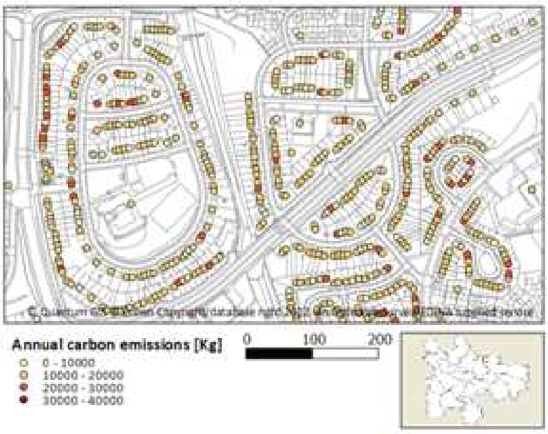
d.

Domestic equivalent carbon emissions from electrical and gas consumption in Glasgow, 2010.



e.

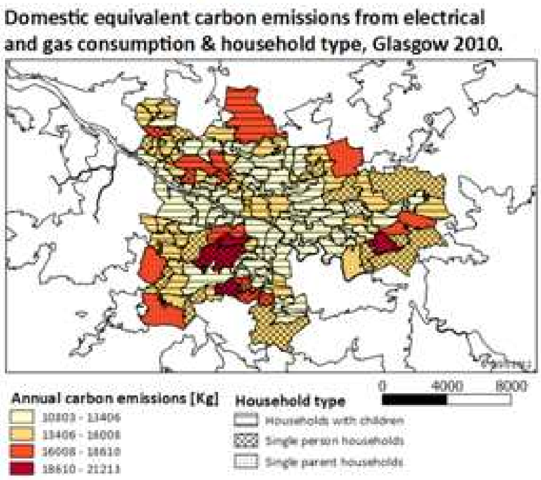
Domestic equivalent carbon emissions from electrical and gas consumption in Glasgow, 2010.



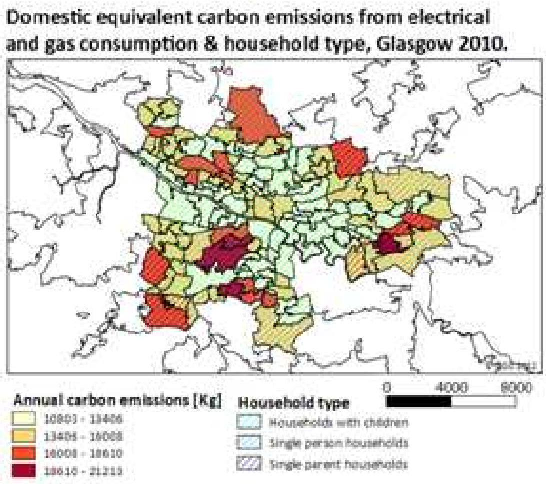
Question 4

4) Suppose that you would like to know if the equivalent carbon emissions and the household type are somehow related. Which of the presented maps help you to better answer that question?

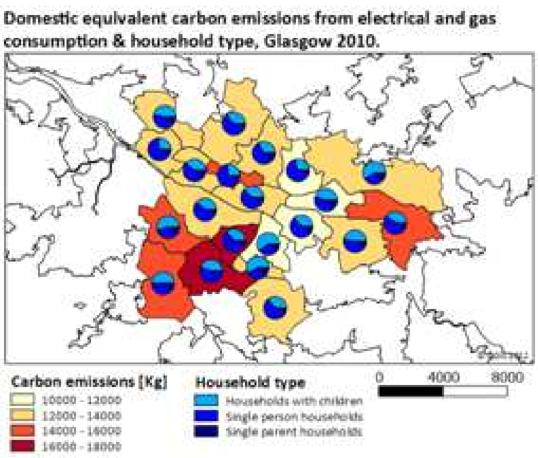
a.



b.

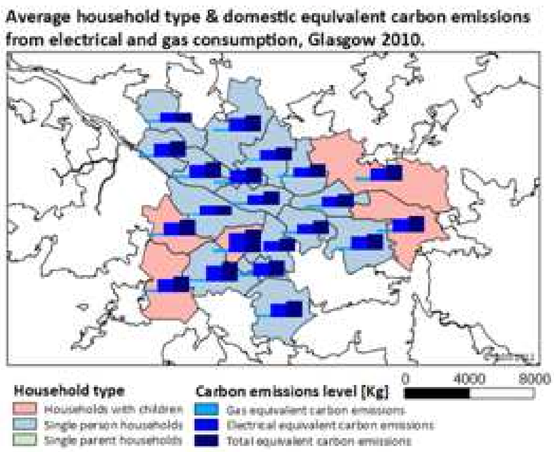


c.



The bars height represents the area equivalent carbon emissions

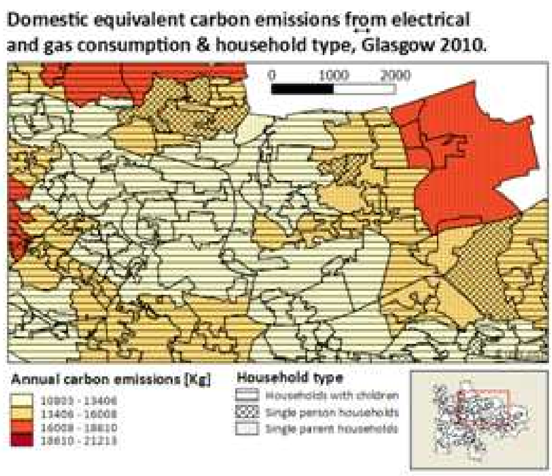
d.



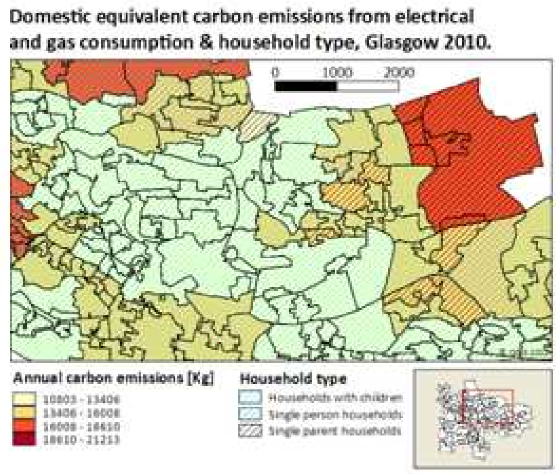
Question 5

5) Suppose that you would like to know if the equivalent carbon emissions and the household type are somehow related. In this case, which of the presented maps help you to better answer that question?

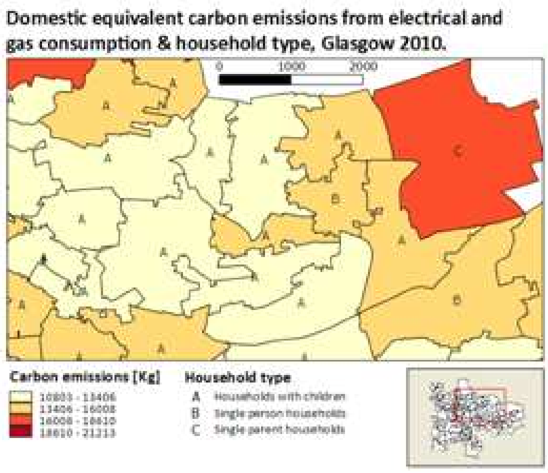
a.



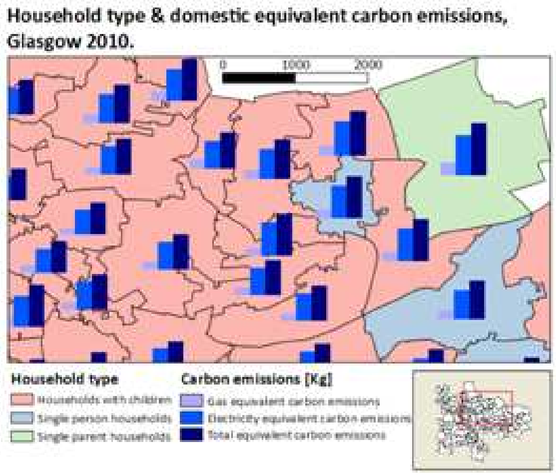
b.



c.



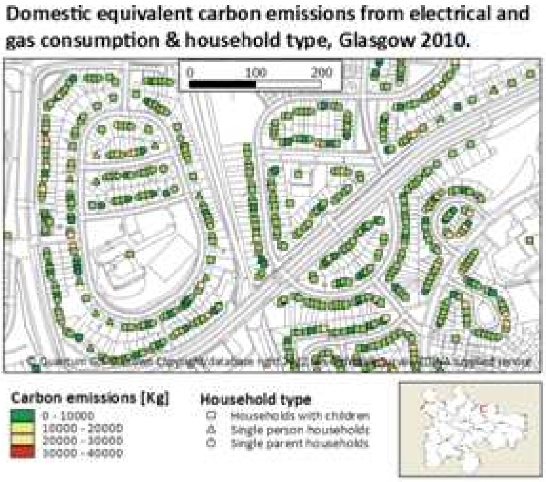
d.



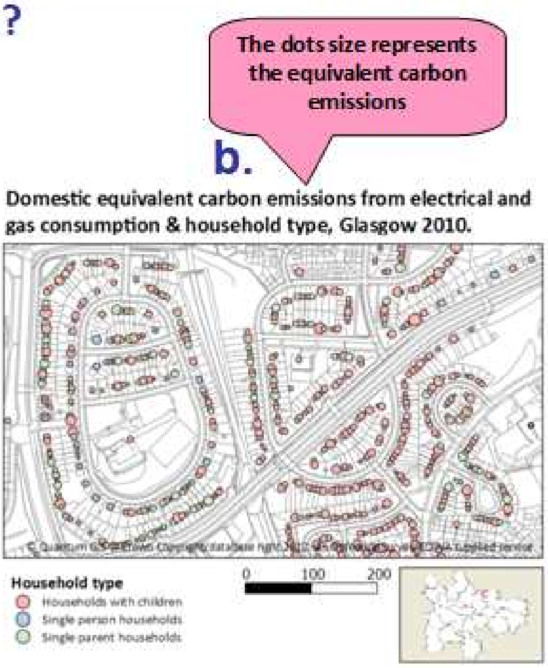
Question 6

6) Suppose that you would like to know if the equivalent carbon emissions and the household type are somehow related. In this case, which of the presented maps help you to better answer that question?

a.



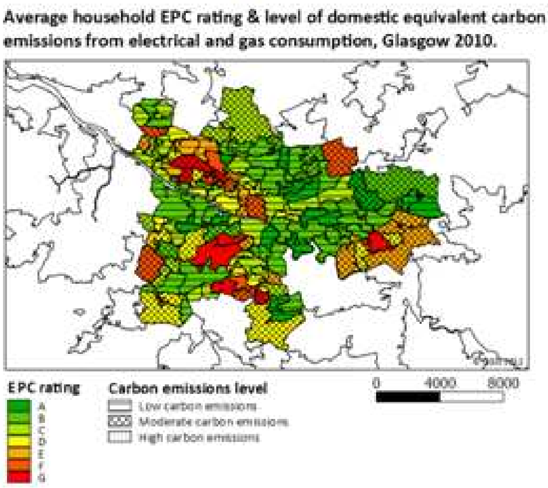
b.



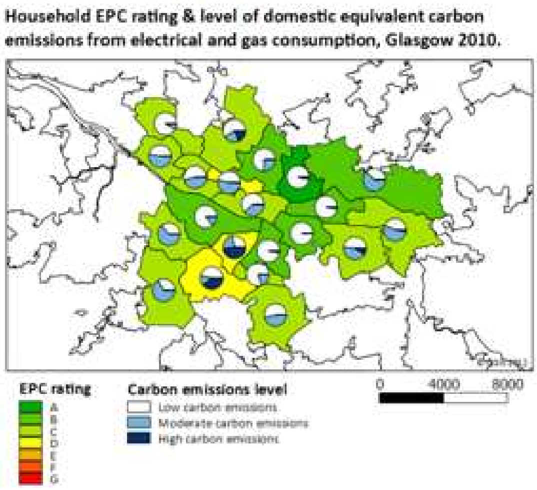
Question 7

7) Imagine you would like to know if the equivalent carbon emissions and the dwellings EPC rating are somehow related. Which of the presented maps help you to better answer that question?

a.

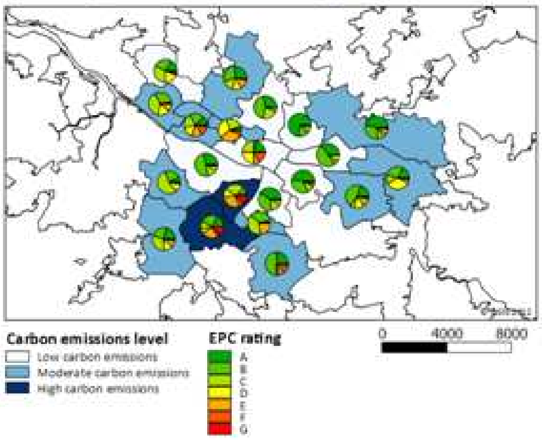


b.



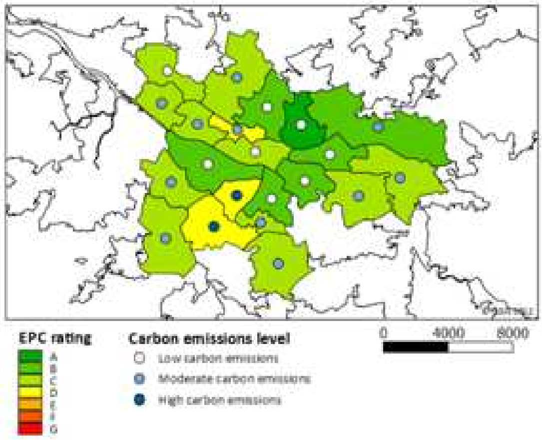
c.

Level of domestic equivalent carbon emissions from electrical and gas consumption & household EPC rating, Glasgow 2010.



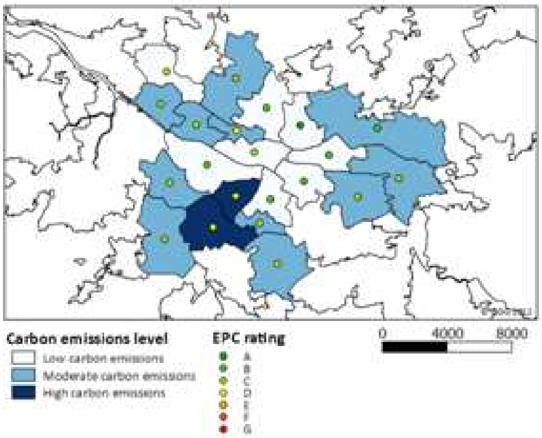
d.

Household EPC rating & level of domestic equivalent carbon emissions from electrical and gas consumption, Glasgow 2010.



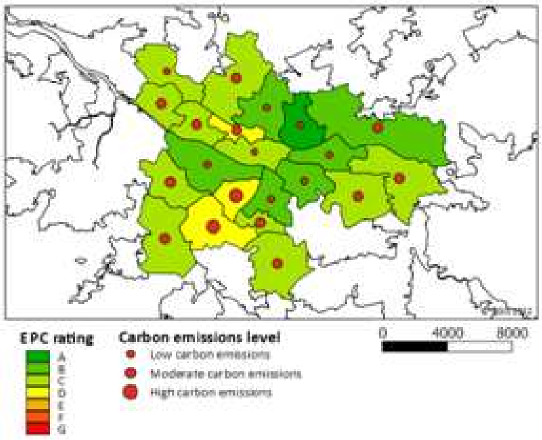
e.

Level of domestic equivalent carbon emissions from electrical and gas consumption & household EPC rating, Glasgow 2010.



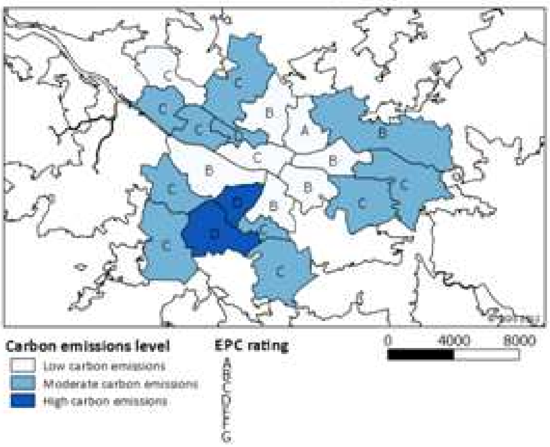
f.

Household EPC rating & level of domestic equivalent carbon emissions from electrical and gas consumption, Glasgow 2010.



g.

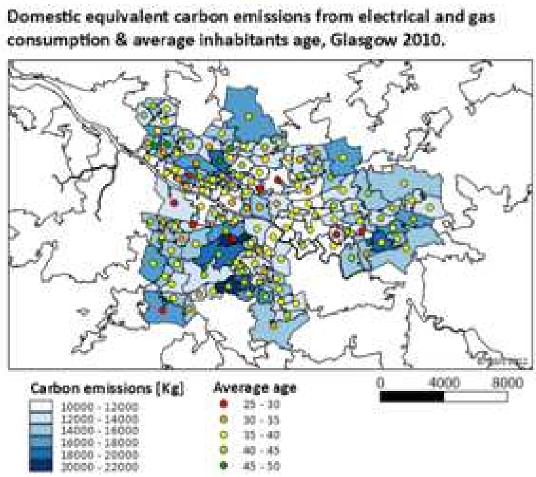
Level of domestic equivalent carbon emissions from electrical and gas consumption & household EPC rating, Glasgow 2010.



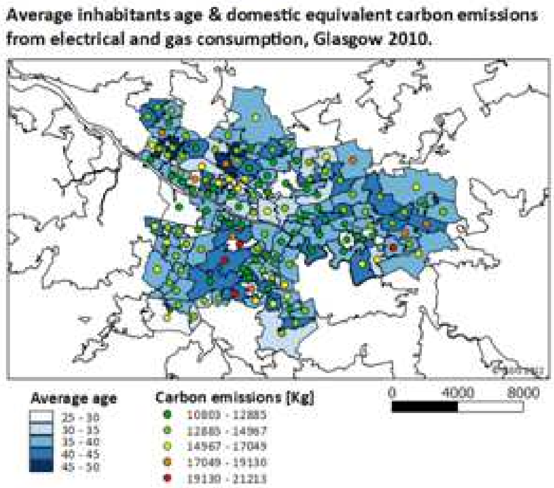
Question 8

8) Imagine you would like to know if the equivalent carbon emissions and the inhabitants age are somehow related. Which of the presented maps helps you to better answer that question?

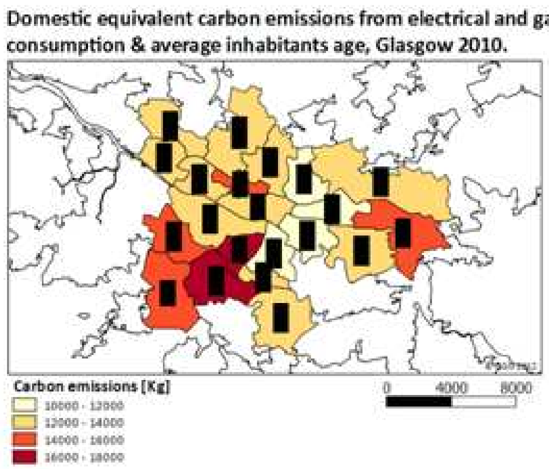
a.



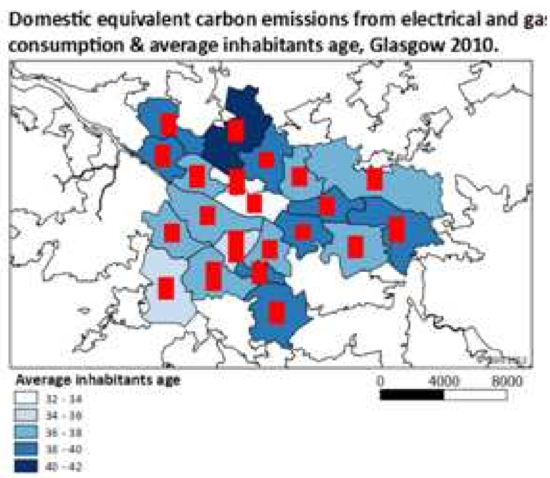
b.



c.

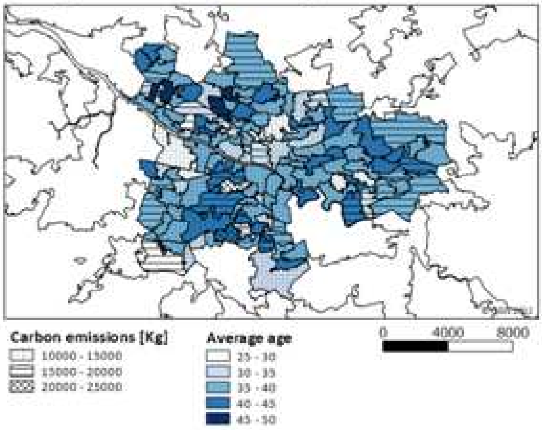


d.



e.

Domestic equivalent carbon emissions from electrical and gas consumption & average inhabitants age, Glasgow 2010.



f.

Average inhabitants age & domestic equivalent carbon emissions from electrical and gas consumption, Glasgow 2010.