Department of Mechanical and Aerospace Engineering

Policy Barriers to Clean Energy Deployment in Cities

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Copyright Declaration

Abstract

In order to combat climate change, a transition to clean energy sources from fossil fuels is required. However, the potential for this in urban areas can be limited due to land use restrictions. The effect that planning policy has on land use in cities, and therefore on potential clean energy yields was investigated using Glasgow as a case study. Research into how national and local planning policies affect land use was undertaken, with city planners consulted during an interview process. In order to determine the effect that relaxing certain types of policies would have on available land in Glasgow, a GIS tool called GoMap was used, which provided an output of available land in m^2 from relaxing policies. In order to calculate the annual energy yields and carbon reductions that using this land for clean energy developments would entail mathematical models were created on excel. Probabilistic models to generate synthetic climate data in order to determine energy yields were used for wind and solar energy, and a simpler model was generated to estimate potential thermal energy yields from minewater heat recovery schemes.

It was found that under current planning policy land use restrictions, if half of the available land was used for wind and solar power then enough energy could be produced to power the equivalent of 90,000 homes, reducing Glasgow's carbon footprint by around 90,000 tonnes. Relaxing social policies concerning visual impact was determined to be the most feasible policy relaxation scenario and yielded the highest amount of available land, compared to biodiversity, environmental, developmental or visual intrusion policies. If social and visual intrusion policies are relaxed together, then there is the potential to provide electricity for around half of the cities homes. It was determined that the implementation of six minewater heat recovery schemes could provide heat for between 300 and 700 homes, however this number could increase if other suitable sites were identified. It was identified that solar energy represents a more efficiency renewable energy source than wind in Glasgow, with an energy density of around 150kWh/m^2, compared to just 30kWh/m^2 for wind energy. This is due to multiple wind turbines requiring a large area of land. Therefore, a combination of solar power and minewater heat recovery could provide clean energy for a significant portion of the city, contributing to meet the councils carbon reduction targets.

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1. Introduction

1.1 Problem Background

Levels of urbanisation are increasing worldwide, which in turn is increasing the energy demand of cities. This trend combined with the drive for a transition towards clean energy sources means that urban energy systems are going to have to adapt to meet a higher demand while also reducing their carbon emissions. The UN estimates that over half of the world's population currently live in urban environments, and this is expected to increase to 70% by 2050 [1]. It is estimated that currently around two thirds of global energy consumption can be attributed to urban areas and this results in 71% of global energy related carbon emissions [2], this figure will increase as the percentage of the population living in cities increases. To reduce emissions whilst also meeting an increasing demand, urban energy systems will have to increase their deployment of renewables and clean energy technologies. There will be several challenges and barriers to this transition, particularly for countries like the UK where the national energy system is traditionally highly centralized, with a relatively small number of large power generation plants meeting most of the energy demand, mostly situated away from high population areas.

The IEA have identified that local government policy can be a key driver for implementing sustainable energy solutions in towns and cities [3]. They argue that well implemented policy can greatly increase renewable energy deployment, for both villages and large cities, regardless of the size of the urban area. However, national and local planning policy can also provide barriers to clean energy deployment. In many cities, there are a multitude of land use restrictions that can block developments such as renewable energy sites. Jones [4] argues that most developed countries need to redo their land use and energy policies in order to maximise private sector investment into clean energy, and thus meet climate change mitigation targets. Using Glasgow as a case study, this project will investigate how different types of planning policy can affect land use in a city and estimate the potential energy yield and resultant carbon savings that freeing up land for different clean energy sources could entail.

1.2 Objectives

The effect on land availability and the knock-on effect on potential renewable energy yields of various types of planning and land use policy were investigated using Glasgow as a case study. The following objectives were required in order to meet this aim:

- A review of land use and planning policy affecting Glasgow in order to determine the most feasible policy relaxations

- The determination of potential land availability in the city, both currently and after the relaxation of various policy factors

- Calculations of the potential energy yield and carbon emission reductions that could be achieved in the city, if areas of land freed up from policy relaxations were used for the deployment of renewables

1.3 Project Outline

In order to meet the objectives of the project, the following methods were used. How planning policy affects land use in the city was determined by researching national government guidelines and the Glasgow City Development Plan which outlines all key policies and considerations for future developments in the city. In order to determine that all information contained within the development plan had been understood correctly, and to gauge which of its policies were most likely to be relaxed, or strictly enforced, city planners from Glasgow City Council were consulted during an interview process. This allowed a high level of clarity to be obtained on how national and local level policies affect land use and potential developments in the city. To assess land availability in the city from policy relaxations, a GIS tool developed by the University of Strathclyde called 'GoMap' was used. GoMap contains built in information on all key policies affecting land use in the city, arranging them into groups of policy factors, and using a scoring system to determine land availability. The tool provides a map of the city showing which areas are heavily restricted and which are available for potential developments. The weighting of different policies can be altered to change the land availability this process was carried out to determine the areas of land made available from various policy relaxations. Mathematical models were then developed on Excel in order to calculate the potential energy yield if this freed up land was to be used for renewable sites. Two probabilistic models were created for solar PV and wind energy which generate synthetic climate data for Glasgow and use that to calculate the energy yield in kWh/m^2 if these technologies were to be implemented in the available land. Another model was generated that calculates the potential energy output for using ground source heat pumps in abandoned mine shafts across the city, which has been identified as a potential method of providing clean heat to homes through district heating networks. The process above allowed the potential energy yield and resultant carbon reduction for various policy relaxation scenarios to be determined.

1.4 Scope

The project focused solely on the area of the City of Glasgow. Similar results would be likely to be obtained for most cities in Scotland, as planning policies will be similar across the country due to sharing the same national guidelines, and energy outputs (for wind and solar) should be roughly similar as they are dependent upon the climate. Energy output for ground source heat, either in a mineshaft scheme or not, is dependent upon several different local geological factors so will vary across the country. GoMap can also be altered for any city in the world, provided an accurate map and planning policy information is available. Therefore, the methods outlined in this project could be applied anywhere in the world to determine potential energy yields from policy relaxations.

Models were created to assess the potential energy output of solar PV, wind and GSHP from available land in the city. Other clean energy technologies such as biocrops, anaerobic digestion, fuel cells and energy storage were not considered, but would have also been viable for the purposes of the project. Due to time constraints, the probabilistic mathematical models used to determine wind speeds and solar energy throughout the year did not consider urban microclimate effects such as shading, heat transfer between buildings and longwave radiation. This has been identified as a key influencing factor behind the performance gap in urban energy systems modelling [5] so may affect the accuracy of the results. The potential energy yield from minewater GSHPs in the city was calculated using limited information on the determining variables from preliminary analysis from borehole data conducted by the BGS. Once borehole data from more sites in the city has been obtained and made publicly available, the potential energy yield for each individual site will be easier to accurately calculate.

No environmental impact assessment was undertaken for any of the identified potential sites for PV, wind turbines or GSHP within the city. If any of these developments was to be taken forward, then a full EIA analysis would have to be undertaken.

2. The development control process

2.1 Land Use and Planning Policy

Land use and planning in Glasgow is determined by multiple factors. Overall guidelines and strategic aims are provided by the Scottish Government in the form of the National Planning Framework and Scottish Planning Policy documents. These are then translated into policies for Glasgow, specifically in the council's City Development Plan which highlights key policy areas and how they affect land use and developments in the city. Each policy in the development plan also has detailed supplementary guidance to help inform decision making processes in that area. To gauge that all information from these documents had been understood fully, and to gain an insight into how the information presented within them is applied when assessing plans and developments affecting the city's land use, interviews with city planners were undertaken. The key information from these policy documents and interviews on how planning policy affects potential developments within the city is summarised in this chapter subsection.

National Government Guidelines

The National Planning Framework [6] provides the Scottish government's long-term strategy for driving and enhancing development, the economy and key infrastructure. It provides four key aims for the future of Scotland, that all development proposals should be looking to help achieve. These are to make Scotland:

"1. A successful, sustainable place; 2. A low carbon place; 3. A natural resilient place; 4. A connected place."

The first aim is concerned with encouraging economic and development growth in a low-carbon economy, in which there are reduced inequalities and ample opportunities. The second aim looks to continue the work done so far on reducing the carbon footprint of Scotland through energy efficiency measures and clean energy technologies. Both these aims look to promote developments in clean energy and renewables. The third aim is concerned with protecting natural and cultural assets through environmental protections on green spaces, habitats, historic environments etc. Policies to achieve this aim can provide barriers to clean energy developments by placing restrictions on protected areas of land. The fourth aim looks to improve Scotland's digital, and public transport networks, so have little bearing on potential clean energy deployment.

Instructions on how land use and planning policy are to help achieve these aims are provided in the 'Scottish Planning Policy' document [7]. Here, details are provided for local authorities on how various planning policies can be implemented in a development plan in order to encourage sustainable economic growth, climate change mitigation and protecting cultural assets. These guidelines encouraged the creation of Glasgow City Council's City Development Plan, which outlines the key planning policies to allow the city to meet the aims stated above, these policies can act as both an incentive or a hinderance to the deployment of renewables in the city.

Local Planning Policy

The Glasgow City Development Plan [8] highlights the key policies which must be considered when approving developments within the city in order to meet the aims outlined by the national government. The plan consists of 12 policy areas, each with supplementary guidance documents, which all developments must adhere to. The overall structure of the development plan is shown below in Figure 1.

As can be seen in Figure 1, the key aims and strategic outcomes of the plan are very similar to the aims outlined in the national guidelines. The policies listed in the plan outline the required considerations for any development in the city, and also provide information on the various protections on different land within the city, and how that can hinder potential developments such as renewable energy technologies. CDP 1 and CDP 2, 'the placemaking principle' and the 'sustainable spatial strategy' are overarching policies that should be considered for all proposals in order to meet the strategic outcomes of the plan. They do not provide any specific land restrictions but give practical instructions for planners on how to meet the aims of the plan. CDP 5 – Resource Management provides the city's plan for energy management and reducing carbon emissions, providing guidelines for encouraging renewable technologies in the city. CDP 6 – Green Belt and Green Network, CDP 7 – Natural Environment and CDP 9 – Historic Environment present the largest barriers to clean energy deployment in the city, each of these policies containing various land use restrictions on different areas of the city which can potentially block clean energy deployments. The remaining policies do not

Figure 1: *The structure and content of the development plan. [8]*

have a major influence on the potential of clean energy deployment in Glasgow, but still provide some land restrictions, for example, land dedicated to retail to promote town centres for CDP4 – Network of Centres, or land reserved for housing developments too aid with CDP 10 – Meeting Housing Needs. The key policies within the development plan that affect the potential of renewables deployment in the city, and information obtained during the interviews with city planners is given below.

CDP 5 – Resource Management

Policy 5 in the City Development Plan provides guidance on how the city can help in meeting the government's climate change mitigation targets by supporting energy generation from low-carbon sources, electrifying transport, promoting energy efficiency measures, sustainably dealing with waste and setting up district heating networks. The supplementary guidance for this policy [9] is closely linked with the city's 'Energy and Carbon Masterplan', [10] with both giving details on how clean energy should be promoted within the city, but also providing lists of assessment criteria that any potential development would have to meet. Included in this list are effects on aspects such as net economic impact, natural heritage, public access, proximity to buildings, hydrology etc. (for full list see SG: 5 [9]). Thus, despite the encouragement for renewable developments in CDP 5, there are also several potential obstacles implicated here as well.

The supplementary guidance for CDP 5 also includes a spatial framework for wind energy in the city, identifying the areas suitable for potential wind turbine sites. The conclusions of the spatial framework are that there are very few sites suitable for wind development in the city, due to the high proportion of urban area, and the 1 km buffer zone around any housing. However, in the interview it was made clear that the spatial framework was intended to identify any sites that were optimal for wind generation and that wind developments could still take place on areas disregarded in the framework. It was confirmed that wind turbines could be positioned within the 1 km urban buffer zone, however in the past there had been visual impact issues from houses experiencing a flickering effect from the turbines. Glasgow airport also will raise objections to any potential wind farm site within a certain radius from their control tower due to previous problems with the turbines affecting radar readings. Wind turbines can now be constructed to not interfere with radar, but the city planner said that any proposed site would still likely face objections from the airport.

The supplementary guidance also promotes the development of heat networks and district heating zones, in order to de-carbonise heating in the city and help reduce fuel poverty. The guidance recommends implementing a variety of heat sources and thermal storage in large connected networks to help meet these aims. The city planners confirmed that this is something the council are keen to implement and that using GSHPs in abandoned mine shafts could play a key role in this. However, they also highlighted the many potential issues in the form of mine stability, chemical changes in water, and unclear subterranean land ownership laws. The energy and carbon masterplan [10] provides further information on developing district heating networks in the city, estimating potential yields and carbon savings, and identifying potential areas for district heating schemes as shown below in Figure 2.

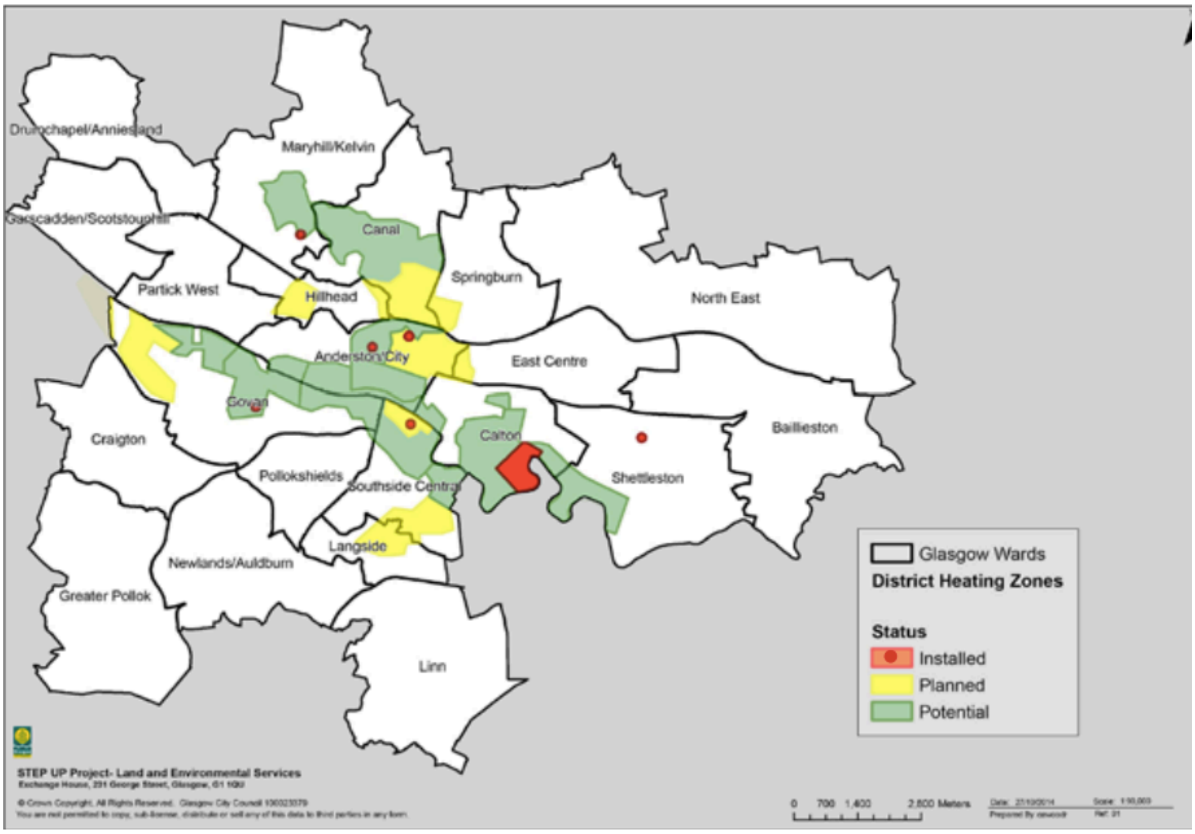

Figure 2: *Potential district heating zones within the city boundaries, from the energy and carbon masterplan [10]*

CDP 6 – Green Belt and Green Network

CDP 6 in the development plan outlines protections on green and open space within the city. This provides a potential barrier to energy deployment as it restricts open land that can be ideal for technologies such as wind turbines or PV panels. The functions of various green space in the city, such as habitat networks, climate change mitigation, growing spaces, sport and recreation and water management to name a few, are highlighted by this policy. The supplementary guidance [11] lists all types of areas that have various protections from developments through this policy. They include: parks and gardens, amenity green space, playparks, green corridors, natural and semi-natural green space, grassland, churchyards and cemeteries, sports grounds and playing fields and multifunctional green spaces. The supplementary guidance makes it clear that there should not be developments on any of these areas if the development is to have a negative impact on the areas' use. This was further confirmed during the interviews, where it was stressed that not impacting the functionality of the green space is the key factor when deciding upon potential developments. The city planners made it clear that ground source heat sites would be preferred to technologies such as PV and wind turbines on green space within the city, as they are underground and so have fewer impacts on the land's use and also less visual impact. An example was given of a solar array that was to be constructed on the green belt near Baillieston that had to be dropped due to nearby residents' concerns over the visual impact of the site. It was also made clear, however, that the council are open to proposals such as wind and solar on green networks spaces, so long as the functionality of the land is not affected. They said that a development will have a much higher chance of success if it also helps to bring improvements to biodiversity, increasing green networks or drainage systems. Positioning raised solar panels on green space, so that the area underneath could potentially retain its functionality, is not seen as a desirable option to the planners, as this could prevent grass from growing. They did however say that raised solar panels could be applied over sports pitches or sheltered children's play parks. The planners then gave information on how the council is currently undertaking work for writing its open space strategy, which will provide a detailed understanding of how each area of open space in the city is currently used. Once this work is complete the council will have a better idea of which green space areas do not fulfil a large role, so can be developed on, and which have important roles and must therefore be strictly protected.

CDP 7 – Natural Environment

CDP 7 in the development plan aims to protect the natural environments in Glasgow, including their ecosystems and protected species. There is some overlap with CDP 6, as CDP 7 involves legislation protecting green spaces such as woodland and green corridors within the city. As well as protecting sensitive areas, the policy also aims to help develop linkages between habitats, restore older destroyed habitats and increase the resilience of habitats and green spaces in the city to climate change. This policy can act as a hindrance to potential clean energy developments as it protects large areas of undeveloped land within the city which could be used for renewable sites. The full list of areas protected by this policy is given in the supplementary guidance [12] and includes all sites of special scientific interest (SSSIs), local nature reserves (LNRs), sites of importance for nature conservation (SINCs) and any other habitats of protected species such as birds, bats, otters, voles, owls and badgers.

Information on how the protections on these areas of land are implemented was given during the interview. The planners stated that the hierarchy for restrictions on these sites is provided by the Scottish government, with internationally designated sites at the top, SSSIs with significant levels of protection, and LNRs and SINCs with the least amount of formal legislative protection. Glasgow does not have any internationally designated conservation sites, so they can be disregarded for the purposes of this project. SSSIs have a high level of protection, with any developments unlikely to be given the go ahead on these, unless there were direct clear benefits on a national scale. To develop on SSSIs, the local council, Scottish government and Scottish National Heritage all have to agree that the work is absolutely necessary, so clean energy technologies are likely to be green lighted. LNRs and SINCs have similar amounts of protection, but fulfil different roles: LNRs are intended to get people to get involved and interact with nature, and SINCs are specific areas dedicated to conservation so they may not want people entering them. The planners said that energy development could take place on either of these sites, but all checklists in the supplementary guidance would have to be met, and there would have to be no impact on the site's functionality as an LNR or SINC.

CDP 9 – Historic Environment

CDP 9 looks to preserve and develop the appearance of parts of the city to support economic development and regeneration, tourism and leisure and encourage a sense of identity and heritage within the city. This can provide a barrier to clean energy in the city, as technologies such as wind turbines and PV panels can stand out distinctly against historical buildings. The policy involves the protection of several areas within the city including a world heritage site, listed buildings, historical conservation areas and designed landscapes. Full details for how protections on these areas are legislatively enforced are given in the supplementary guidance [13]. The main priorities for listed buildings and historical conservation areas are to protect their appearance and character of building and areas of special historical or architectural interest. Any developments which drastically alter the appearance of listed buildings or conservation areas will not be allowed. There are also five gardens and designed landscapes in the city, which do not have any primary protective legislation, but still have guidelines in the planning process to protect their appearance and character. Any potential developments on these sites would also have to be given the green light from Historic Environment Scotland. Glasgow also has a UNESCO world heritage site, the Antonine wall, on which no development can take place that may change the site's archaeological character or setting, by international law. Other sites in Glasgow protected by this policy are historic battlefields, ancient monuments and sites of archaeological importance.

During the interview, it was made clear that clean energy developments can still take place in historical conservation areas, and even designed landscapes, with each being decided on a case-by-case basis rather than a blanket approach being taken. The planners said that technologies such as PV panels can be placed on listed buildings or in conservation areas, but that this would usually have to take place on the side of the building that is not ‘public facing’. One of the planners referenced technologies such as newly emerging PV panels that look just like slate as an example of innovation which can allow energy developments on historically protected sites. The planners said that developments can also take place in designed landscapes, but that this would usually only go ahead if it improved the site’s self-sufficiency or running costs (i.e. not to power the city) and without ruining the visual character of the area. The less visually obtrusive a development is, the more likely it is to be green lighted. An example was given of a water source heat pump being installed in in the River Kelvin, next to Kelvingrove museum. This area is one of the city’s designed landscapes, but the project was allowed as it is visually unobtrusive and will help to reduce the running costs of the museum. This is an example of a clean energy development in a highly protected area, as it is a designed landscape, next to a listed building and in a key green corridor protected by CDP 7.

The four policies listed above provide the main direct restrictions on land use that could be barriers to clean energy deployment in the city, however other policies within the development plan can also act as a hindrance to potential renewable sites. CDP 3 – Economic Development, CDP – 4 Network of Centres, and CDP 12 – Delivering Development are all concerned with delivering sustainable growth in all areas of the city through retail, education, industry etc. They do not provide any direct barriers to clean energy deployment but do have areas of land marked down as sites for various types of developments, thus limiting the land that could be used for renewables. CDP 10 – Delivering Housing Needs, which provides the council’s strategy for providing affordable housing, is similar in that it does not provide a legislative barrier to energy deployments but does restrict areas of land in the city that have been identified as potential housing sites. CDP 8 – Water Environment does not provide any land restrictions, but can still be a barrier to projects such as ground source heat pumps, which can affect the quality of water beneath the city. CDP 11 – Sustainable Transport is concerned with improving transport networks in the city, so does not provide any barriers to energy deployment; the policy does however mention the airport’s objections to wind turbines, as mentioned previously.

The key policies affecting land use in the city that could provide barriers to clean energy projects have been summarised above. How these policies are incorporated into the GIS software 'GoMap' and how this tool was used to determine land availability from various policy relaxations is outlined in the next subsection.

2.2 GoMap

In order to determine the potential land availability from policy relaxations a GIS (graphical information systems) tool called GoMap was used. GoMap was developed by ESRU at the University of Strathclyde and is used for identifying potential areas for clean energy developments in cities, using built-in policy information to score areas of land in the city on how restrictive they are to potential developments [14]. A colour-coded map of the city is presented as an output. Individual policies can be turned on or off, or the scoring and weightings of policies altered, in order to create a new map showing the total area of land available for development. This chapter subsection will cover how GoMap functions, how it was used to determine available land from policy relaxations and how the policies referenced in Section 2.1 are incorporated into the software.

GoMap Details

GoMap incorporates policy information into various factors which are split between two main categories: policy and technical. Policy factors contain the policy information described in Section 2.1, splitting individual policy aspects (such as SSSIs, consented housing, listed buildings etc.) between five policy factors: biodiversity, developmental, environmental, social and visual intrusion. The technical factors incorporate issues such as over-shading, substation congestion and substation distance. These were discounted for the purposes of this project, as explained in the next paragraph. Each policy aspect is assigned a score between 1 and 4 on how restrictive that policy is to land use, with 1 meaning it is unlikely to prevent developments, and 4 being that no developments will take place under any circumstances. GoMap breaks up the city intro a grid of 100 m by 100 m squares; the score for each square is then calculated based on the scores of the policy factors in each square. It is possible to use higher resolutions (i.e. 50 m by 50 m) to improve the accuracy of the software, however this greatly increases computational time so was not undertaken in this project. The score is calculated using either a 'lenient' or a 'stringent' method. The lenient method calculates the average score for all aspects present for a particular policy factor, then the score for that square is the average of all factor scores, rounded to the nearest integer. The stringent method uses the highest policy aspect score to determine the factor score, then takes the highest policy factor score as the score for that grid cell. For this project, the lenient method was used, as the stringent method is unavailable when using user-defined weightings on policy factors or aspects. GoMap automatically has all policy factors weighted equally, however user-defined weightings can be used – where the grid cell score is determined by the policy factor that has the highest weighting. This was how the effect of relaxing policies was simulated using GoMap. The software calculates the score for each cell, then presents the results as a colour coded map of the city, where cells with a score of 1 are green, 2 orange, 3 red and 4 black – an example of this is shown below in Figure 3. The total area for each score is also given as an output.

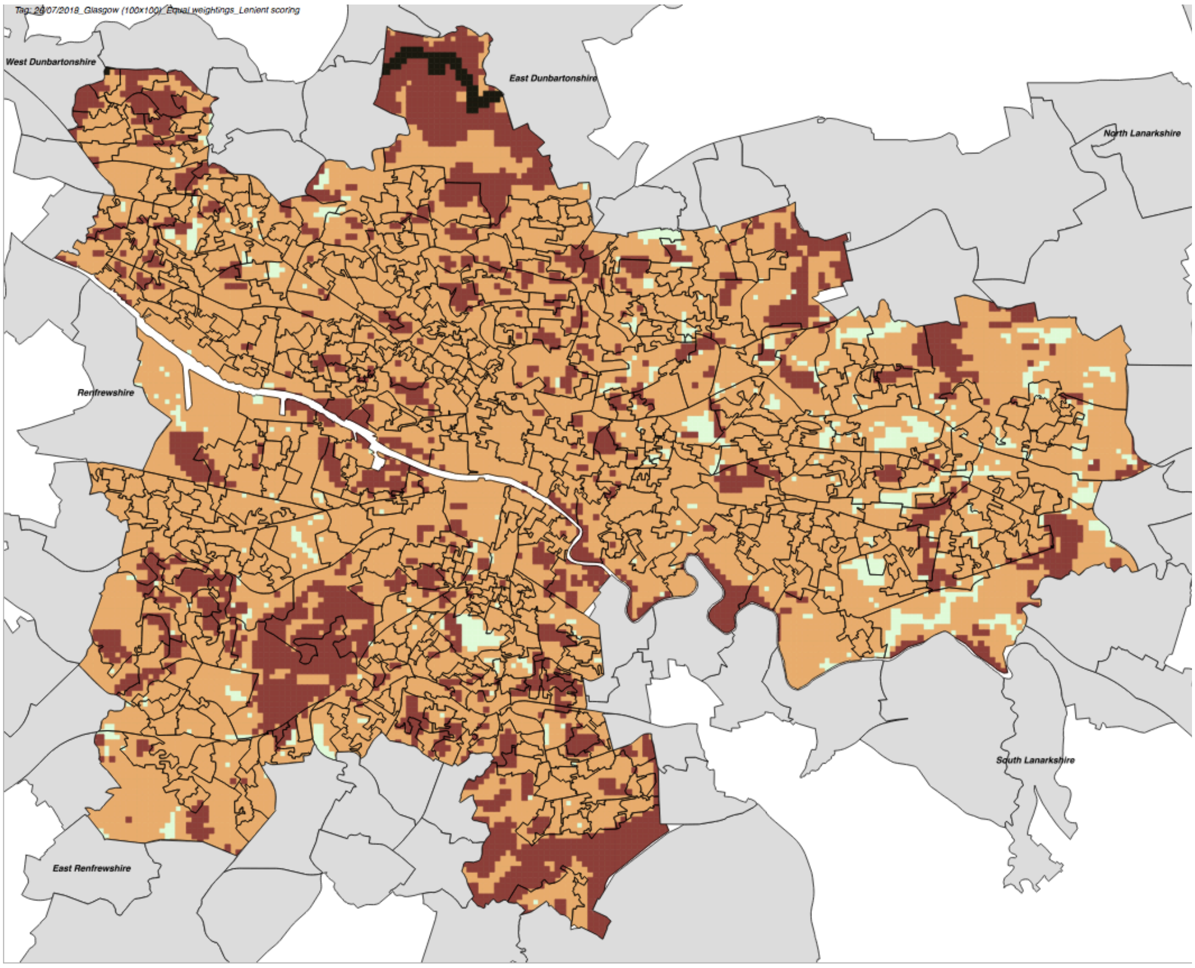

Figure 3: *The default map provided by GoMap, with equal weightings for all technical and policy factors using a lenient scoring method*

Determining Land Availability Using GoMap

In order to establish the potential land availability from policy relaxations, user defined weightings were applied to the policy factors. The weightings of 1 or more policy factors were reduced by half, or to zero, with all other policy factor weightings being kept equal to zero, giving each policy factor a weighting of equal, half or zero results in 125 possible permutations. GoMap could have been scripted to run through all of these permutations and give the land availability for each, however, due to time constraints this option was not taken forward. Instead, the biodiversity and environmental policy factors were combined into one (i.e. they would be changed in weighting together) and then the most feasible policy relaxation scenarios out of the remaining potential permutations were processed. Full information on the scenarios identified and their resultant land availability is in Section 3.1. Technical factors were discounted for this project, as the objectives are concerned with policy constraints, so having technical factors switched off allows the effect of different policy factors on land use to be observed more clearly. Furthermore, when using user-defined weightings, the technical factors were more dominant than the policy factors when determining land restrictions, meaning that the outputted map and land availability barely changed when altering policy factors. Individual policy aspects could also have had their scores altered, or been switched on and off, however this would have created a very high number of potential permutations so only policy factors were altered for this project. Each of the five policy factors whose weightings were adjusted to obtain the land availability results and how they incorporate the policy information in Section 2.1 are discussed in the following paragraphs.

Biodiversity Policy Factor

The biodiversity factor incorporates all land use restrictions on protected creatures' habitats within the city boundaries. As can be seen in Figure 4, this does not cover a large area, with only a few small sections of the city having protected land for creature habitats. Figure 4 was generated by setting the weighting of all other factors to zero, and having biodiversity at 100%. The other figures in this subsection were created using the same method as described here for each policy factor.

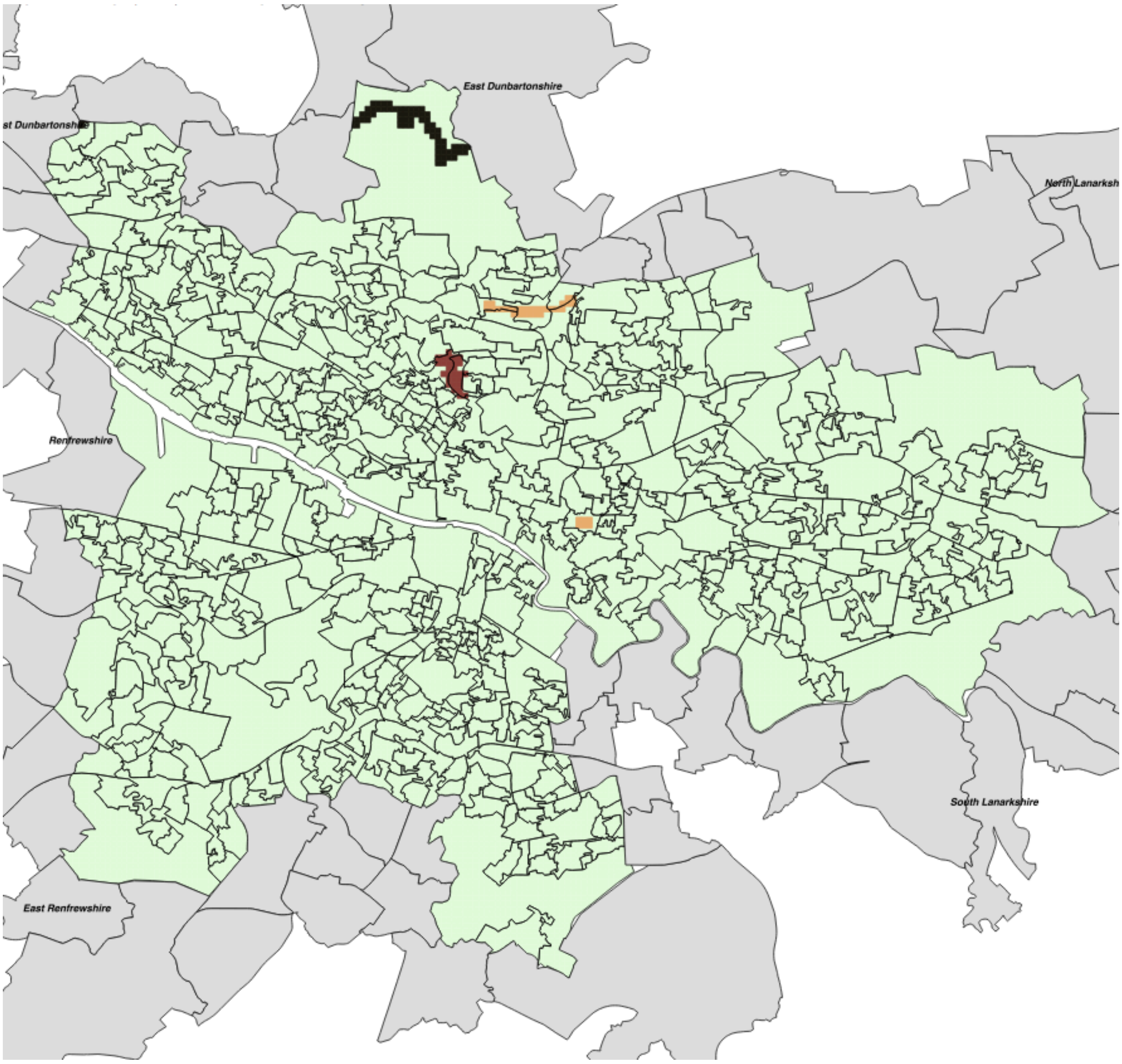

Figure 4: *Map from GoMap showing the land affected by the biodiversity policy factor*

Environmental Policy Factor

The environmental policy factor encompasses all land use policies outlined in CDP 7 – Natural Environment and CDP 9 – Historic Environment in Section 2.1, including green areas, historic conservation areas, listed buildings, SSSIs, designed landscapes etc. The total amount of land in the city restricted by environmental policies is shown below in figure 5: red areas are heavily restricted, and orange have lighter restrictions, but are still unlikely for potential clean energy developments. Due to the tiny amount of land covered by the biodiversity factor, and the overlap between these two factors, it was decided to combine them into one single policy factor when generating scenarios and obtaining results. This was also due to the fact that nearly all of the protected creature habitats in Glasgow will fall into one of the designated areas protected in CDP 7, such as an LNR, green corridor, old wood or SINC. Reducing the weighting of the environmental policy factor could represent relaxations on protections on listed buildings in historic conservation areas, for example, allowing PV on roofs, or allowing more developments on sites such as LNRs and SINCs that the city planners said could potentially have renewable energy sites built on them.

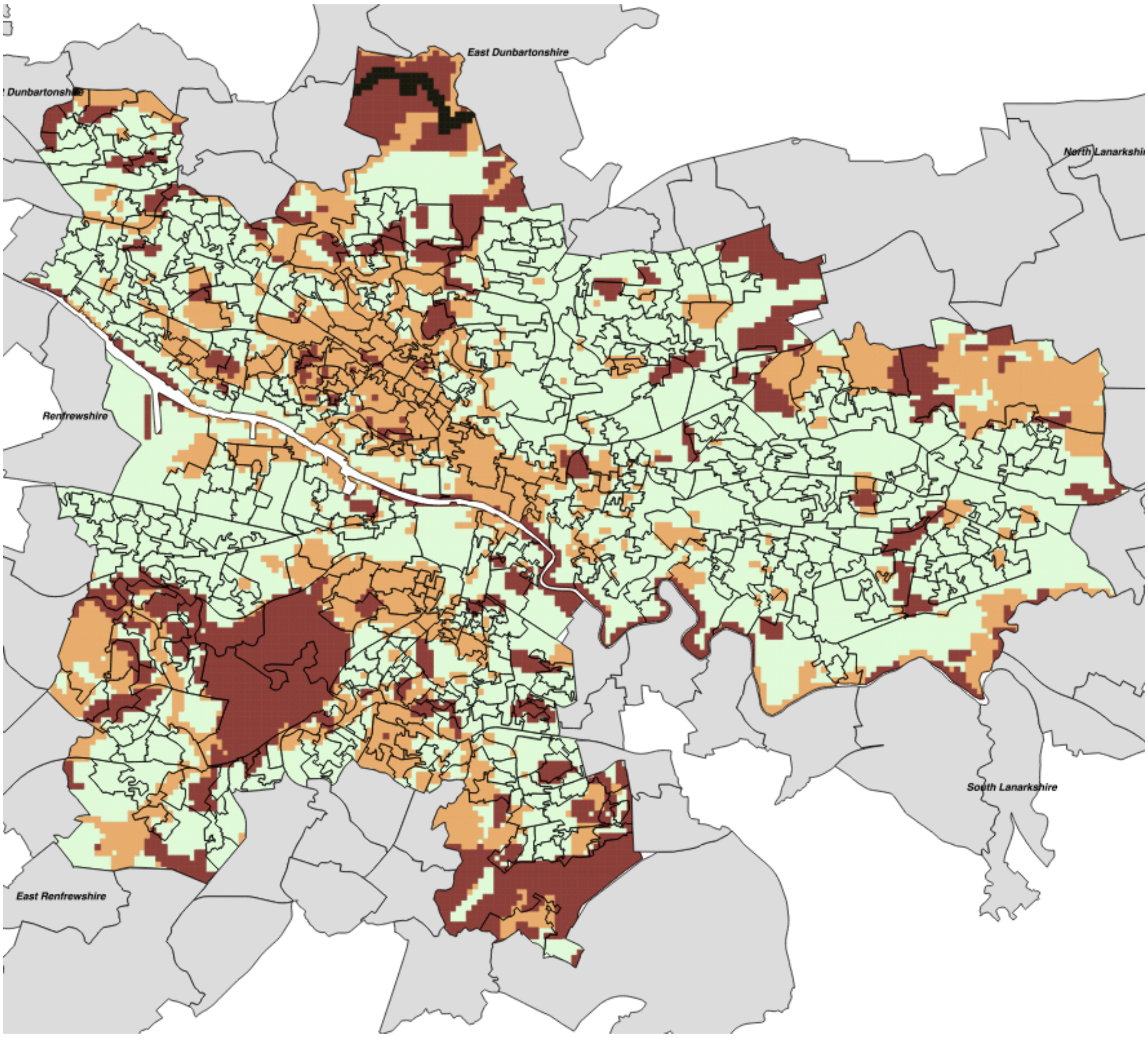

Figure 5: *Map of the city showing land restricted by environmental policies*

Developmental Policy Factor

The developmental policy factor includes policies contained within CDP 6 – Green Belt and Green Network, and also policies related to economic development in the city such as CDP 3, CDP4, CD10 and CDP 12. The land restricted by these policies is shown below in Figure 6. As clearly illustrated here this policy factor affects vast areas of the city due to it covering a variety of different types of restricted land such as the green belt, consented housing, areas marked for strategic development, potential industrial or retail sites, land marked to develop the network of centres etc. The relaxation of this policy factor could represent policy changes such as allowing development on the green belt or incentivising PV panels on all new buildings and houses in economic development areas.

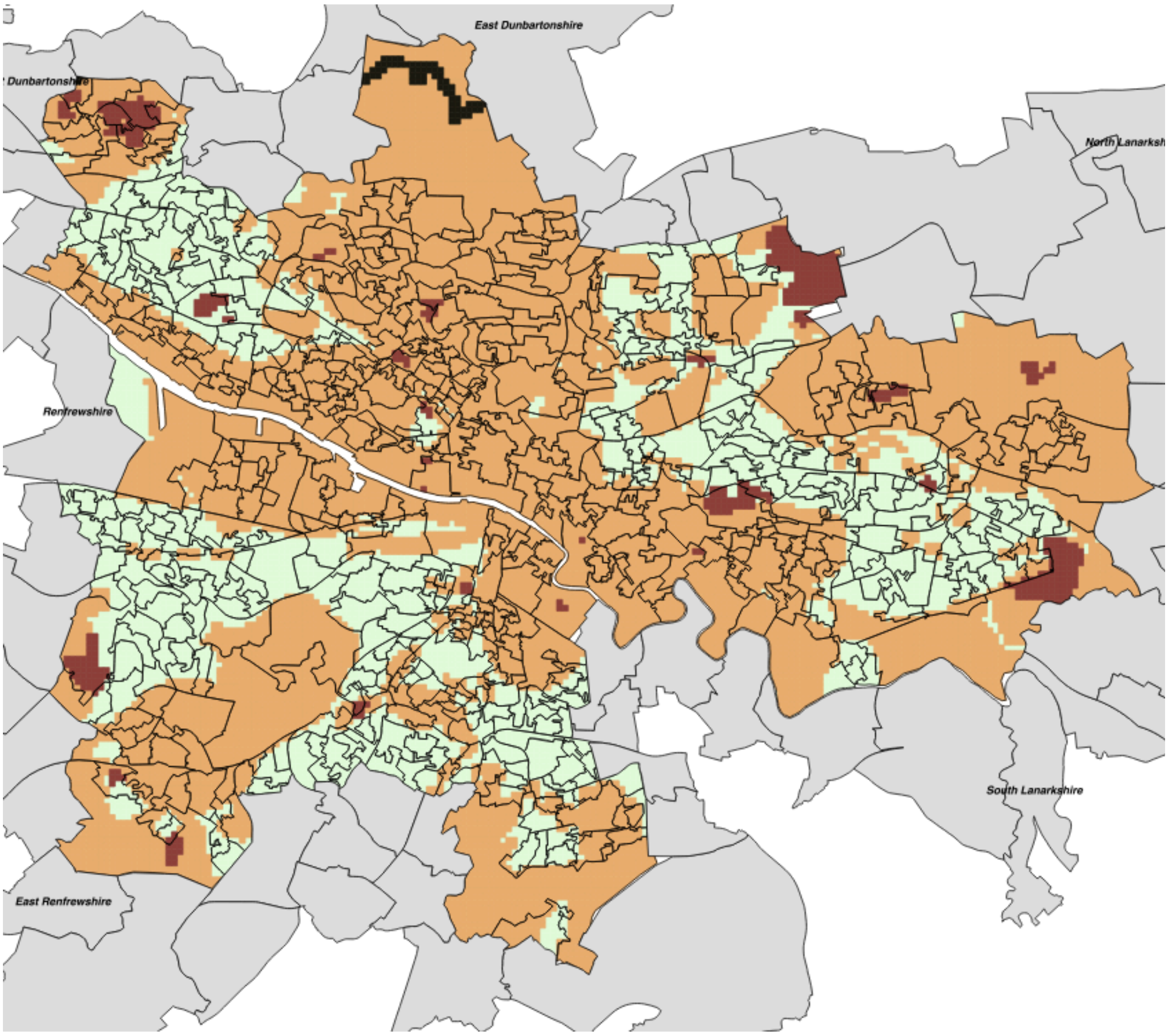

Figure 6: *Map showing land in the city restricted by developmental policies*

Social Policy Factor

The social policy factor only has one policy aspect: visual impact. This incorporates land restricted for energy developments due to its proximity to housing. The area of land restricted for this factor is shown below in Figure 7. The relaxation of this policy factor could represent a shift in planning policy to allowing developments with a large visual impact such as large PV arrays or wind turbines to be positioned closer to houses.

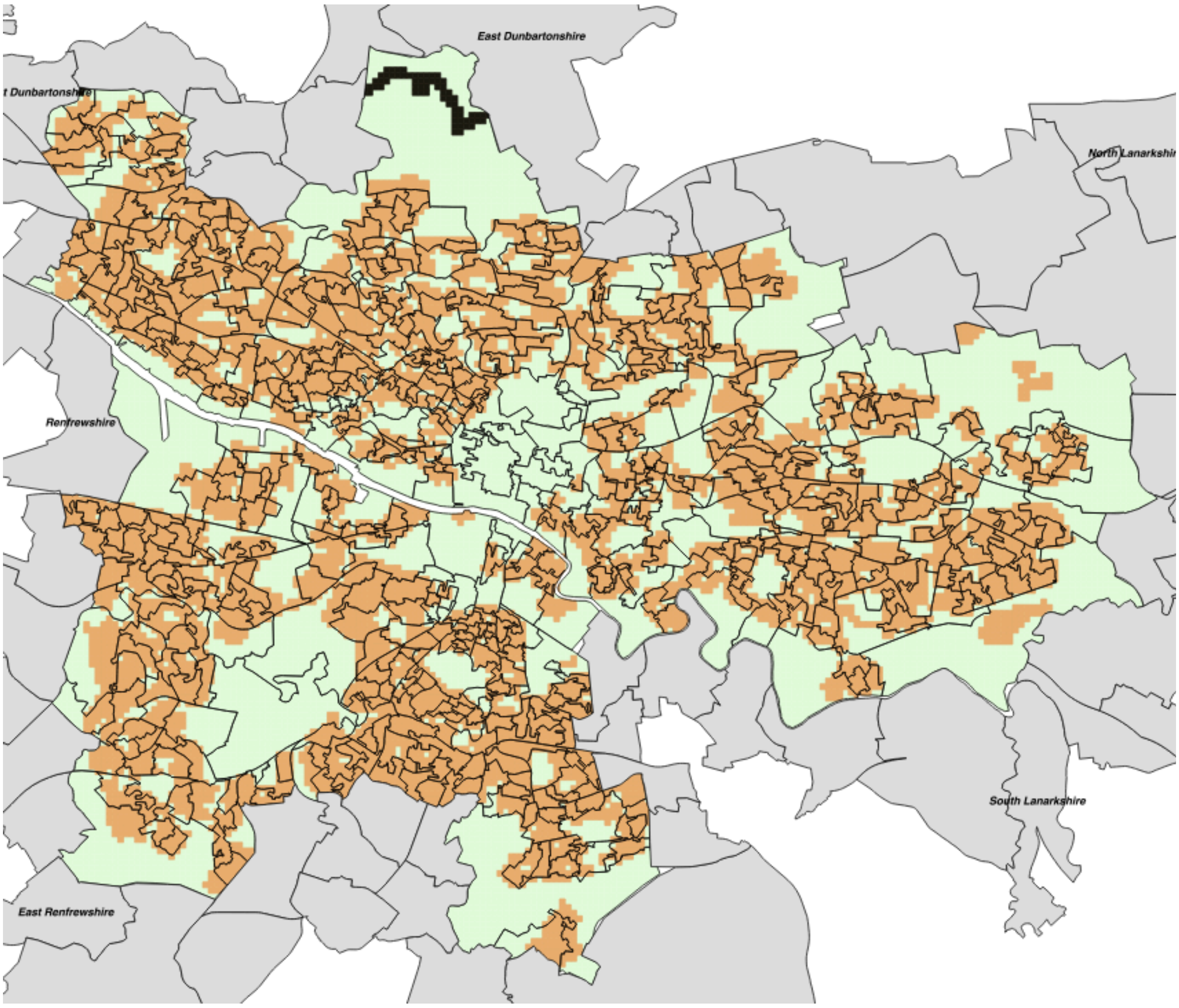

Figure 7: *Map showing areas of the city where development is restricted due to visual impacts*

Visual Intrusion Policy Factor

The visual intrusion policy factor incorporates the land restricted for energy developments due to its proximity to the airport, helipad or motorways, this is shown below in Figure 8. The land affected by the motorways and airport is shown in orange, and the red land represents the areas limited to developments due to its proximity to the helipads. This policy factor could feasibly be relaxed due to developments in technologies such as non-reflective PV panels that will not project glare onto flight paths, or wind turbines that do not interfere with radar signals. Developments may sometimes also be given the go-ahead near motorways, as during the interviews the city planners stated that there had been preliminary investigations undertaken by the council to having wind turbines next to some of the motorways in the city.

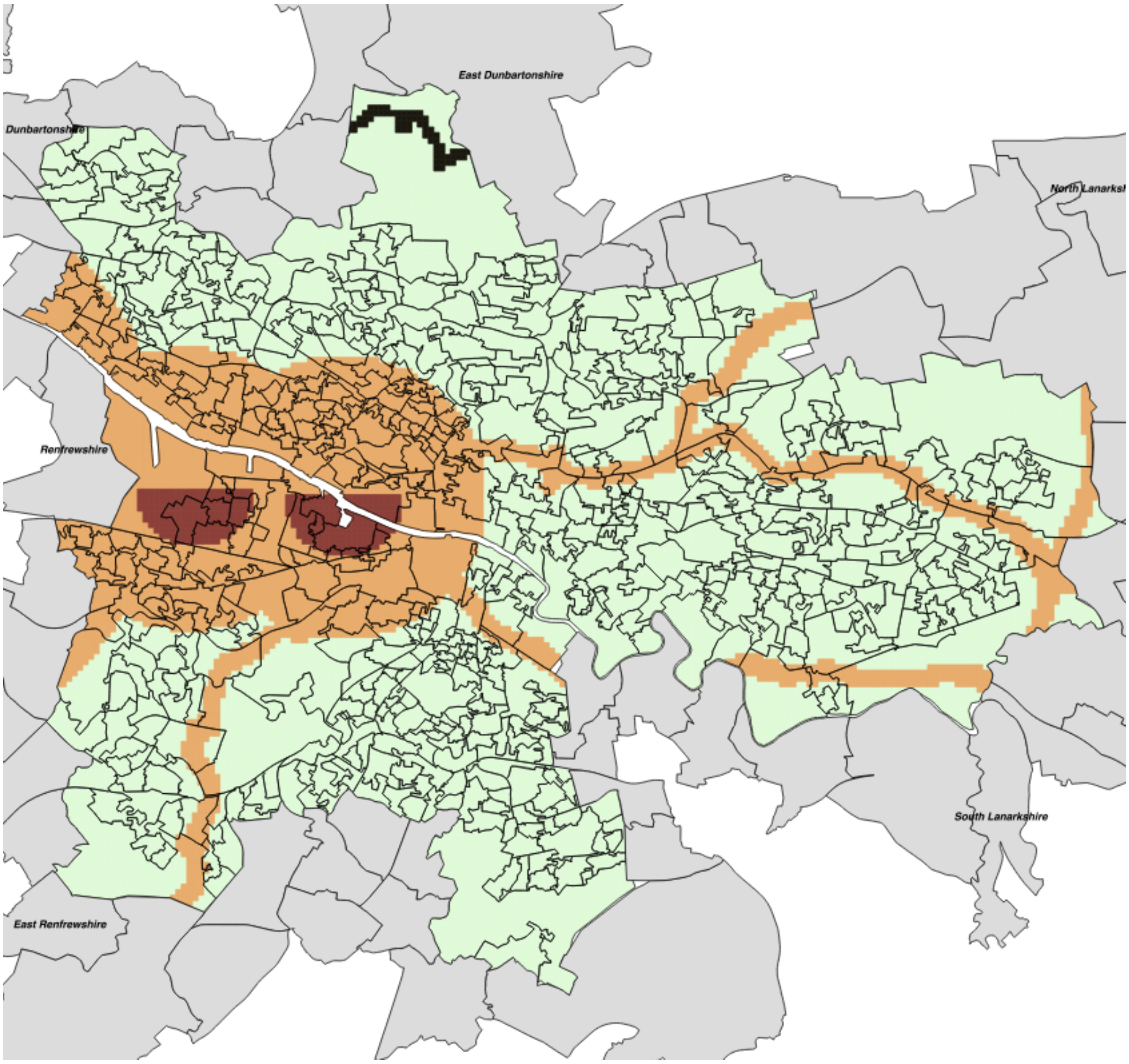

Figure 8: *Map showing restricted land due to visual intrusion*

3. Energy calculations background theory

GoMap allowed the potential areas of land that would be made available from policy relaxations to be determined. The potential energy yield that devoting this land to various renewable deployments would entail was then calculated. For this calculation, software such as HOMER, TRNSYS and EnergyPLAN were considered, but it was decided that generating mathematical models using Excel would be better suited for the purposes of the project, so that there could be full control over the variables in each calculation. Mathematical models were developed in order to to calculate the potential energy yield, if deployed on areas of land within the city, for solar PV panels, wind turbines, and GSHPs in a minewater heat recovery scheme.

3.1 Solar photovoltaics model

Solar power was chosen to be included due to it being one of the most well-established renewable technologies, with over 303 GW of PV panels having been installed worldwide as of 2016 [15]. PV panels are modular, so can be installed in large arrays or over just a few square metres, meaning they are extremely suitable for this project, where the available areas of land within the city can vary in size. Despite Scotland not having a particularly warm or sunny climate, the Scottish Institute for Solar Energy Research (SISER) claim that PV panels can still play a key role in providing cheap clean energy and reducing the carbon footprint of the nation's energy systems [16]. This chapter subsection will give an overview of how the potential energy output of PV panels can be modelled, explain the background theory behind the model that was developed and show how the model was validated.

Solar Energy Modelling Overview

The energy output of PV panels over a given time can be calculated using equation 1 [17], shown below.

$$E = A * r * H * PR \tag{1}$$

Where E is the energy output in kWh, A is the area of solar panels in m^2, r is the efficiency of the panels (typically between 10% and 25% [18]), H is the average solar radiation incident on the panel for a given time period in kWh/m^2, and PR is the performance ratio which incorporates all system losses – the standard PR value for PV panels is 0.75 [17]. Therefore, to accurately determine the annual energy yield for a PV installation, reliable H values must be obtained. Monthly average H values for Glasgow were available using data on weatherspark.com [19], however values with a higher temporal resolution – either daily or hourly – were desirable for developing the solar model. Many models and processes exist for determining hourly or daily values of H, building on initial work by Graham and Hollands [20], and making use of the relationship shown in equation 2 below.

$$H = K_t * H_0 \tag{2}$$

Where H_0 is the extra-terrestrial solar radiation incident above the earth's atmosphere in kWh, and K_t is the dimensionless clearness index, which determines the fraction of the extra-terrestrial radiation that is transmitted through the atmosphere to reach the ground on the earth. K_t has a high value on clear sunny days where there is less interference from atmospheric effects and has low values on cloudy days when less solar radiation will reach the ground.

Khatib and Elmenreich developed a model to provide hourly values for H using a generalized regression artificial neural network [21]. However, this required measured values of daily H values which were not available, so this method had to be discounted. Aguiar and Pereira provided another model for obtaining hourly values of H throughout the year using a time-dependent, autoregressive, Gaussian model [22] but this required daily clearness index values as in input, which were unavailable for Glasgow. This was also very computationally heavy and would have taken a significant amount of time to process.

Kumar and Umanand [23] developed a method for obtaining daily H values by using two separate models to obtain daily K_t and H_0 values, then subbing them into equation 2. The H_0 values are calculated as a function of latitude and day of the year so are simple to calculate for Glasgow, or anywhere in the world. Their method for calculating K_t values was not feasible as it required the calculation of an offset function determined from measured daily K_t values, which were not available for Glasgow. It also required information on levels of water vapour in the cities atmosphere throughout the year, which was also unobtainable. Thus a separate method was identified in order to calculate daily K_t values, which could be used to calculate H, by substituting the daily H_0 values obtained from Kumar and Umanand's method into equation 2.

The model used to obtain daily K_t values was developed by Santos et al [24]. It builds upon previous work by Bendt et al [25] who first discovered that daily clearness index values can be estimated from an exponential frequency distribution. The distribution depends upon the minimum and maximum measured K_t values for a given month, the monthly average K_t values, and a dimensionless factor, γ. The paper by Santos et al provided methods of calculating $K_{t, min}$, $K_{t, max}$, and γ, if measured data was unavailable, based on further work by Herzog [26] and Abdullah et al [27]. Monthly average K_t values were calculated using equation 2, substituting in the calculated monthly H_0 values and climate data from weatherspark [19]. Sequenced daily K_t values for the year were obtained from the frequency distributions by following a process developed by Knight et al [28]. The full background theory and all equations used within the solar model to calculate energy output is given in the next subsection.

Model Background Theory

The daily H_0 values, in kWh/m^2, were calculated following the method presented by Kumar and Umanapad [23], using equation 3 shown below:

$$H_0 = \frac{24 I_0}{\pi}[\cos\phi * \cos\delta * \sin\omega_{SR} + \omega_{SR} * \sin\phi * \sin\delta] \tag{3}$$

Where I_0 is the extra-terrestrial irradiance in kW/m^2, ϕ is the latititude of the location in degrees (=55.86 for Glasgow), δ is the declination angle in degrees, and ω_{SR} is the hour angle at sunrise in radians. Daily I_0 values were calculated using equation 4 shown below, and substituted into equation 3.

$$I_0 = I_{SC}\left[1 + 0.33\cos\frac{360N}{365}\right] \tag{4}$$

Where I_{SC} is the solar constant (=1.367 kW/m^2) and N is the day of the year (1st January = 1, 31st December = 365). The declination angle, δ, and the hour angle at sunset ω_{SR}, were calculated using equations 5 and 6 respectively, as displayed below.

$$\delta = 23.45\sin\left[\frac{2\pi(N-80)}{365}\right] \tag{5}$$

$$\omega_{SR} = \cos^{-1}(-\tan\phi * \tan\delta) \tag{6}$$

The process outlined above allowed an average value of the extra-terrestrial insolation for each day of the year to be calculated. The procedure to obtain daily K_t values created by Santos et al [24] was then followed. This required monthly average K_t values as input, so these had to be calculated first. These were obtained for each month by using equation 2, with the average of the calculated daily H_0 values taken for each month, and the H values obtained from Glasgow climate data on weatherspark [19]. The data used for determining the H values is shown below in Figure 9 – the graph could be zoomed in on to display only one month, showing the data points that were used. The mean value of these data points was calculated for each month to obtain the H values, for use in calculating the monthly average K_t values.

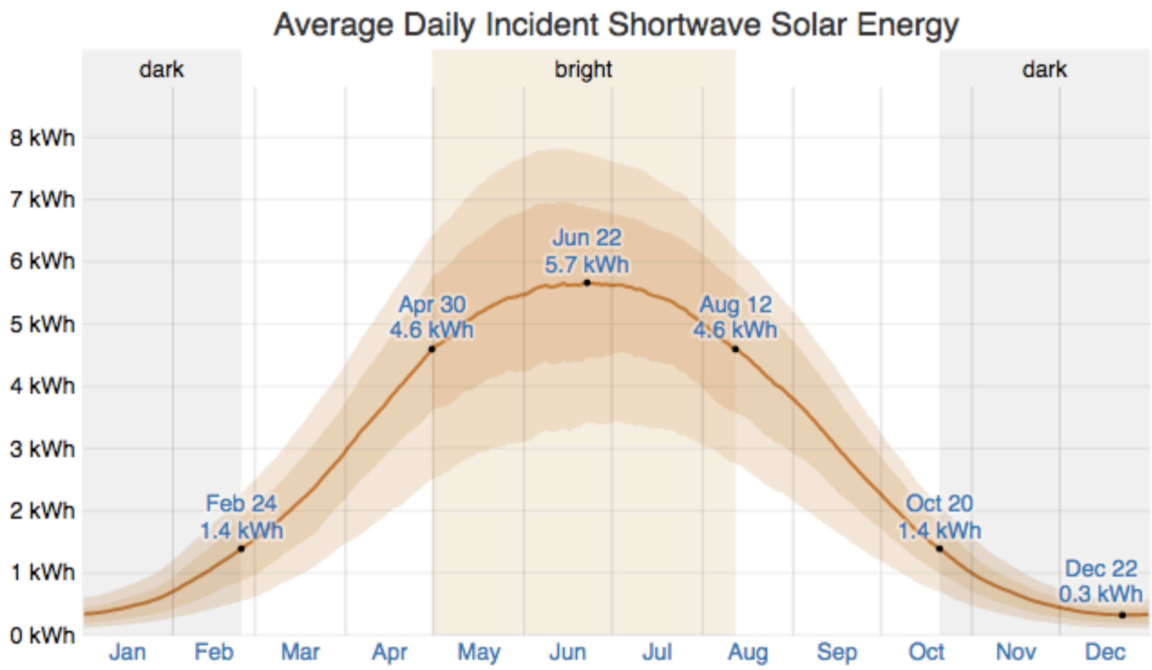

Figure 9: *The average insolation at ground level in Glasgow throughout the year, taken from weatherspark [19]*

Once monthly figures for K_t had been obtained, the process outlined by Santos et al could be followed to obtain daily K_t values. First $K_{t,\,min}$, $K_{t,\,max}$ and γ had to be determined. Bendt et al [25] ascertain that the value for $K_{t,\,min}$ is a constant, independent of locality, equal to 0.05. Thus this value was used for $K_{t,\,min}$. $K_{t,\,max}$ was calculated for each month using equation 7 shown below, proposed by Abdullah et al [27], where K_t^* average monthly clearness index value, δ is the solar declination, ϕ, is the latitude of the area, and z is the altitude of the area, taken to be 27 m for Glasgow (from elevation map [29]).

$$K_{t,max} = 0.5158 + 0.3487K_t^* + 2.3029^{-4}\,\delta + 3.4108^{-4} \tag{7}$$

To calculate γ, the dimensionless factor determining the shape of the exponention frequency distribution, equation 8 shown below was used, which was developed by Herzog [26].

$$\gamma = -1.498 + \frac{1.184\xi - 27.182\exp\,(-1.5\xi)}{K_{t,min} - K_{t,max}} \tag{8}$$

Where ξ is a dimensionless factor, calculated as shown in equation 9 below:

$$\xi = \frac{K_{t,min} - K_{t,max}}{K_{t,min} - K_t^*} \tag{9}$$

Now all variables affecting the clearness index frequency distribution functions are known, the process developed by Knight et al [28] to calculate daily K_t values and sequence them can be followed. The daily clearness index values, K_t, are calculated from equation 10 shown below:

$$K_t = \frac{\ln\left[\left(1 - \frac{nd_k - 0.5}{ndm}\right)\exp\left(\gamma K_{t,min}\right) + \frac{nd_k - 0.5}{ndm}\exp\,\left(\gamma K_{t,max}\right)\right]}{\gamma} \tag{10}$$

Where ndm is the number of days in that particular month, and $nd_k = 1,2,3,\dots,ndm$. Daily clearness index values for each month were calculated using equation 10. However, these values are randomly ordered, which is not representative of the real climate, where the K_t value on a particular day will be influenced by the days preceding it. Knight et al [28] thus propose a method of sequencing the daily K_t values, shown below in Table 1, with the particular order dependent upon the value of the average clearness index for that month, K_t^*. The right-hand column of Table 1 shows the particular sequence required for a given K_t^* value, with 1 representing the lowest daily clearness index and 28, 30 or 31 representing the highest depending upon the month of the year.

$K_t^* \leq 0.45$	24, 28, 11, 19, 18, 3, 2, 4, 9, 20, 14, 23, 8, 16, 21, 26, 15, 10, 22, 17, 5, 1, 6, 29, 12, 7, 31, 30, 27, 13, 25
$0.45 < K_t^* < 0.55$	24, 27, 11, 19, 18, 3, 2, 4, 9, 20, 14, 23, 8, 16, 21, 7, 22, 10, 28, 6, 5, 1, 26, 29, 12, 17, 31, 30, 15, 13, 25
$K_t^* \leq 0.55$	24, 27, 11, 4, 18, 3, 2, 19, 9, 25, 14, 23, 8, 16, 21, 26, 22, 10, 15, 17, 5, 1, 6, 29, 12, 7, 31, 20, 28, 13, 30

Table 1: *The sequence used to order the calculated daily clearness index values for each month*

Therefore, using the method outlined above, a clearness index value for each day of the year was calculated. These were substituted into equation 2, alongside the calculated daily H_0 values, in order to obtain an H value in kWh/m^2 of the insolation reaching the surface of the earth for each day of the year. These H values were substituted into equation 1 (without the area term) to obtain a daily value for the potential energy output of PV panels in the city in kWh/m^2. These daily energy figures were summed to give an annual energy output value of 151.61 kWh/m^2 used to calculate the potential annual yield of any sized PV array in Glasgow. For the full results showing all calculated values from following this method, see appendix I.

Model Verification

As the solar PV model for calculating potential energy yield had several processes, each with its own uncertainties, the model was validated in three steps. First the process to determine monthly K_t values was verified empirically against measured data for London and Copenhagen, as measured average monthly K_t figures were not available for Glasgow. The calculated daily H values for Glasgow were then validated empirically against measured monthly H values for Glasgow. Finally, inter-model comparison was used to validate the final energy output calculations, against the energy yield estimator in GoMap.

Validating Monthly Average K_t Values

Measured data of Glasgow's clearness index throughout the year was unavailable. However, it was available for London and Copenhagen, which were selected as they have similar climates to Glasgow compared to other cities with available data. The measured values were taken from Duffie and Beckman [31]. The process outlined in the previous section to determine Glasgow's monthly K_t values was followed but using the latitude and recorded H values of London [32] and Copenhagen [33]. These calculated values were then compared to the measured K_t figures for each city, as shown below in Tables 2 and 3 and Figures 10 and 11.

Month	**Measured K_t**	**Calculated K_t**	**% Difference**
January	0.24	0.278730343	13.90%
February	0.3	0.367128445	18.28%
March	0.34	0.390720889	12.98%
April	0.38	0.46613618	18.48%
May	0.42	0.493688271	14.93%
June	0.45	0.503178403	10.57%
July	0.4	0.491157293	18.56%
August	0.4	0.482754488	17.14%
September	0.39	0.433366374	10.01%
October	0.35	0.388205353	9.84%
November	0.31	0.385600509	19.61%
December	0.25	0.263015093	4.95%

Table 2: *The calculated clearness index figures for London compared to measured values*

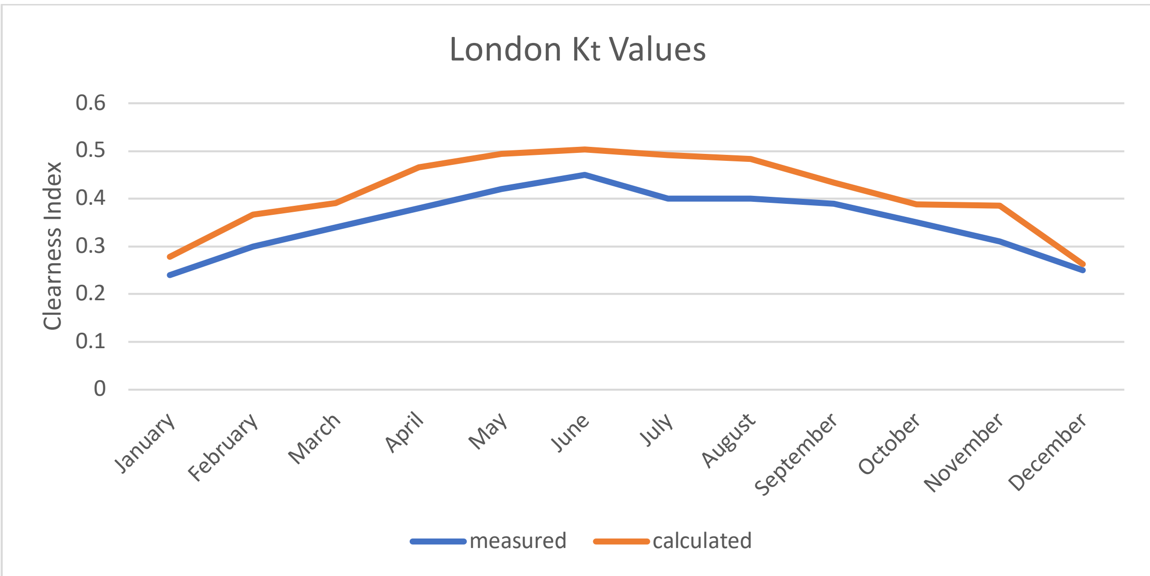

Figure 10: *Comparing measured K_t values to those calculated from the model for London*

As evident in Table 2 and Figure 10, the clearness index figure calculated for London were consistently over 10% higher than the measured values. The overall trend throughout the year was similar, but with consistently higher values. This discrepancy is likely to come from uncertainties in the data for yearly H values provided from weatherspark. The mean value for each month was determined from only 3 or 4 data points, which could induce potential errors. The weatherspark insolation data is taken from a meteorological model developed by NASA, which is likely to also have significant uncertainties. The calculated values for Copenhagen were much closer to the measured values, as shown below in Table 3 and Figure 11, however the calculated values were still consistently higher than the measured values. This means that the solar model may slightly overestimate potential PV energy yields, as the calculated K_t values may be higher than in real life.

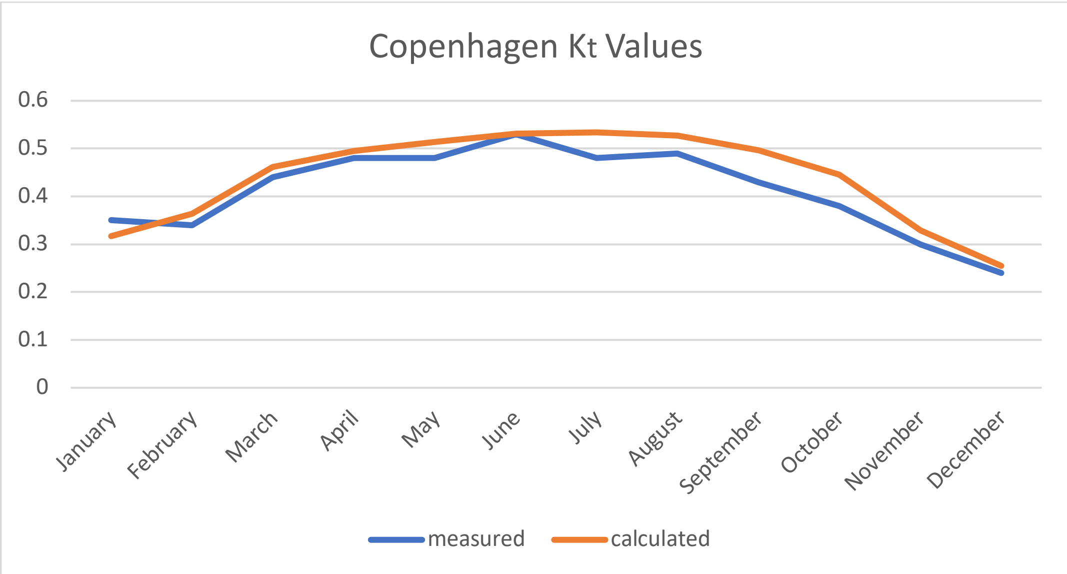

Figure 11: *Comparing calculated K_t values to measured values for Copenhagen*

Month	Measured K_t	Calculated K_t	% difference
January	0.35	0.31668086	-10.52%
February	0.34	0.364292628	6.67%
March	0.44	0.461201363	4.60%
April	0.48	0.494524972	2.94%
May	0.48	0.513865451	6.59%
June	0.53	0.531923738	0.36%
July	0.48	0.534019158	10.12%
August	0.49	0.52725382	7.07%
September	0.43	0.49586476	13.28%
October	0.38	0.445324155	14.67%
November	0.3	0.328684799	8.73%
December	0.24	0.254836981	5.82%

Table 3: *Calculated clearness index values for Copenhagen compared to measured values*

Validating Daily H Values

Empirical validation was used to determine the accuracy of the calculated daily H values obtained from Kumar and Umanapad's method of determining daily H_0 values, and Santos et al's process for obtaining daily K_t results. The mean value of the daily H results was calculated for each month, and these were compared to the mean monthly H values determined from data on weatherspark as previously described. The results are shown below in Table 4, where it can be seen that there is very little discrepancy between the two figures.

Month	Measured mean H (kWh/m²)	Calculated mean H (kWh/m²)	% difference
January	0.4	0.42091723	4.97%
February	1.1	1.11409071	1.26%
March	2.2	2.26234233	2.76%
April	3.7	3.76583497	1.75%
May	5.1	5.16524342	1.26%
June	5.6	5.61081867	0.19%
July	5.3	5.354934	1.03%
August	4.2	4.23694388	0.87%
September	2.8	2.82889773	1.02%
October	1.4	1.40359968	0.26%
November	0.6	0.60416692	0.69%
December	0.35	0.35673201	1.89%

Table 4: *Empirical validation of the calculated daily H values, from taking their monthly average*

Validating Energy Yield Calculations

In order to validate the energy yield calculations of the solar model, inter-model validation was used: comparing the results from the created model to the results from the energy yield estimator on GoMap for a given area of land. As the efficiency of PV panels the estimator in GoMap is using was unknown, two sets of results from the generated model were obtained, with efficiencies of 15% and 20%. The results are shown below in Table 5. As shown below, when an efficiency of 15% was used in the model, there was a consistent discrepancy of around 24% between the created model and GoMap. However, when the efficiency was increased to 20%, the difference between the two models reduced to 1%. The tiny difference between the estimated energy yields of the two models here affirms the accuracy of the created model to estimate the potential energy output of PV in the city.

GoMap Validation		0.15 Efficiency		0.2 Efficiency	
area (m^2)	**GoMap E (MWh)**	**model E (MWh)**	**% Difference**	**model E (MWh)**	**% Difference**
295636	44354	33614	24.21%	44819	1.04%
492727	73909	56023	24.20%	74697	1.05%
985454	147818	112046	24.20%	149395	1.06%
1478181	221727	168070	24.20%	223093	0.61%
1970908	295636	223093	24.54%	298791	1.06%

Table 5: *Comparing the estimated energy yield from GoMap to the created PV model*

3.2 Wind Energy Model

Wind energy was chosen to be modelled due to its high potential and prominence in Scotland. As of 2015, there 5238MW of installed wind power capacity in Scotland [34]. The Scottish government has set a target of 100% of electricity generation to come from renewable by 2020, and with the majority of this set to come from wind energy there is likely to be a further push for more wind developments [35]. Despite the prominence of wind power in Scotland, there are currently no wind farms in operation within the city of Glasgow. Wind turbines are uncommon in urban areas due to issues with visual impact, noise and vibration and turbulent inconsistent wind speeds. As mentioned in section 2.1, the city council undertook a spatial framework analysis for potential wind farm sites in the city, and found that none of the sites meeting the government's criteria were suitable. However, during the interview process, the planners said that wind farms could still potentially be approved within the city, in areas such as the green belt, or larger areas of green and open space. This subsection will give an overview of how synthetic windspeed data can be generated, provide the background theory behind the wind model that was developed, and explain how the model was verified.

Wind Modelling Overview

In order to calculate the potential energy yields from wind turbines within the city, a process to generate synthetic wind speed data had to be obtained. This is due to the power output of a wind turbine being directly proportional to the cube of wind speed [36], making it the dominant factor influencing power output. Negra et al [37] provide a method of obtaining synthetic wind speed data using a sequential Monte Carlo simulation, however this method had several stages, each being very computationally heavy which may have taken too long for the purposes of this project. Sahin and Zen [38] developed a model using a first order Markov chain approach, with transition matrices, to obtain hourly or wind speeds for a given site. However, this model required hourly or daily measured wind speeds as input, which were not available for Glasgow. Shamsad et al [39] provide a similar method using Markov chain processes, this time using second order transition probability matrices that take into account previous wind speeds. However, this model was discounted as it was extremely computationally heavy, such a detailed model was not required for the purposes of this project. The chosen method of obtaining wind speed data was given by Naimo [40], who models wind speed distributions as a Weibull function, that can be used to determine the probability of a certain wind speed at a given time. From knowing the number of days in a year that the wind is likely to be at a certain speed, the energy output of a specific turbine can be calculated, if the power curve for that turbine is available.

Model Background Theory

The probability of achieving a specific wind speed can be determined by fitting a Weibull distribution, of the form shown below in equation 11, that gives a probabilistic frequency distribution.

$$f(v) = \frac{k}{c} * \left(\frac{v}{c}\right)^{k-1} * exp\left[-\left(\frac{v}{c}\right)^{k}\right] \tag{11}$$

Where v is the wind speed in m/s, k is the Weibull form parameter, also in m/s, that determines the specific shape of the distribution (lower values indicate very variable winds, higher values indicate more stable wind speed variations), and c is the Weibull scale parameter that is proportional to the mean wind speed [41]. The standard value used for k is typically 2 [42], however the Encraft Warwick wind trials report [43], found that wind speeds in and around urban environments will typically have a lower k value. C. P. Quine [44] undertook the measurement of k and c values for over 20 Scottish wind farms, nearly all of which had a k value of less than 2, with a mean of around 1.8. The k value used for this project was thus taken to be 1.8, due to this information. The scale parameter c, is closely related to the mean wind speed. Ulgen and Hepsbasli [45] determined that this relationship could be approximated as shown in equation 12 below, where v_m is the mean wind speed, and Γ signifies a gamma function.

$$v_m = c * \Gamma\left(1 + \frac{1}{k}\right) \tag{12}$$

Using the equation above, re-arranged to solve for c, a separate scale parameter was obtained for each month of the year in Glasgow. Mean wind speed data for each month was obtained from weatherspark [19], using a similar method to how ground insolation values were obtained in Section 2.3.1. This allowed a distinct Weibull distribution of the wind speeds in Glasgow to be obtained for each month of the year. The curves for January and June are shown below in Figure 12.

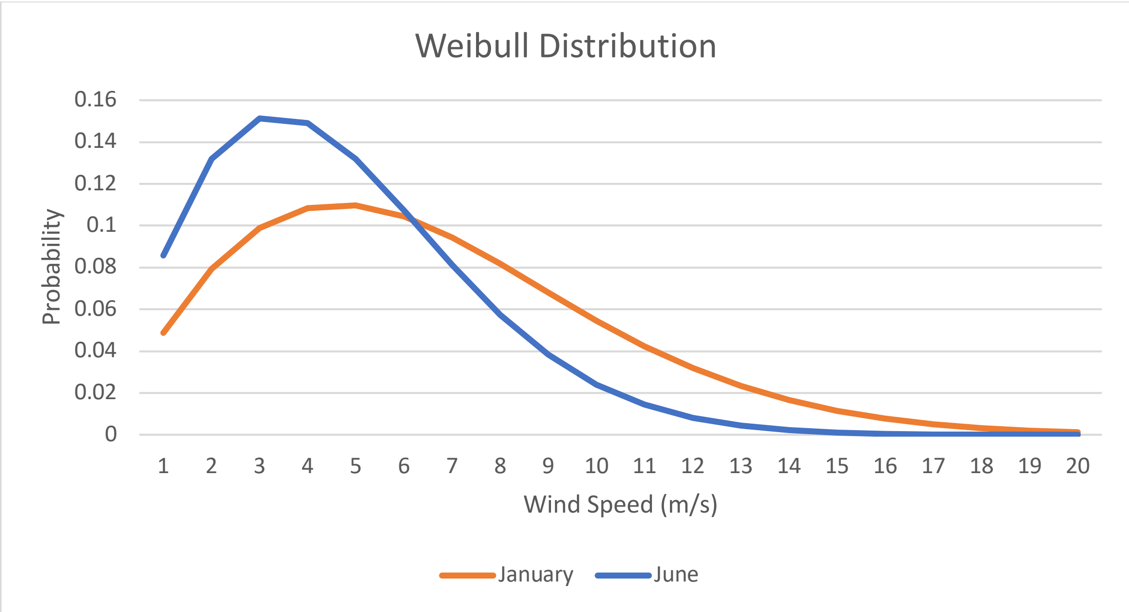

Figure 12: *The Weibull frequency distributions of Glasgow wind speed calculated for January and June*

As can be seen in Figure 12, there is a higher probability of greater wind speeds during January, with June having a higher likelihood of lower windspeeds. The Weibull distribution was then used to estimate the number of days in each month that there would be a specific windspeed in Glasgow. This was done by multiplying the probability value for each wind speed during each month by the number of days in that particular month. The number of days at a specific wind speed was then summed for the entire year, to provide an estimate of the number of days at each wind speed (from 1 m/s to 20m/s) over an annual period. The power curve of a wind turbine gives the power output at a specific wind speed. This information was then used within the model to determine the annual energy yield: multiplying the number of days at a specific wind speed by the power output of the turbine at that wind speed and then by 24 (hours in a day) gave an indication of the annual energy output when at that wind speed. This can be undertaken for each wind speed then summed to give the total annual energy yield of that turbine. Two separate turbines were inserted into the model, with the above process being followed for each: the Vestas V27 rated 225 kW [46] and the Argoblade T100 rated 100kW [47]. Two different sized turbines were chosen in order to compare which would give the highest energy yield for a given area, as the larger turbine will have a lower packing density, and the lower-rated turbine a higher packing density.

In order to calculate the potential energy yield of a wind farm site in a given area, the area required for one turbine had to be established. A common rule when establishing wind farm spacing is to allow for 3-5 rotor blade diameters in the cross-wind direction and 6-8 diameters in the main wind direction [48]. A rectangular space of 7 blade diameters by 4 blade diameters was then calculated as required for each of the two turbines. This gave a packing density of 1 turbine per 20412m^2 for the V27, and 1 turbine per 14175m^2 for the T100 turbine. It was found that the V27 gave a higher energy yield for a given area. The potential energy yield from wind turbines for a given area in the city could be determined through the model outlined above: by calculating the number of turbines that would fit in that area and calculating the annual energy yield of that turbine through information obtained from the Weibull distributions. For the full results from the wind energy model, showing the monthly mean wind speeds and Weibull curves, see appendix II.

Model Verification

In order to affirm the results from the wind model described above, empirical and intermodal validation were used. Results from the model were compared against annual energy yield estimates on the manufacturer's data sheet for each turbine, and energy yield results from the model were also compared against results from the GoMap energy yield estimator for wind.

Empirical Validation

The data sheet for each turbined\ provides an indication of the yearly energy output of the turbine for an annual mean wind speed. To replicate this in the model, the average monthly wind speeds for Glasgow were scaled so that the annual mean was equal to that of the data sheet. This was done for each annual mean wind speed provided for each turbine and the results compared. Results for the V27 turbine are shown below in Table 6, and for the T100 turbine in Table 7.

Mean Wind Speed (m/s)	Data Sheet Annual Output (MWh)	Calculated Output (MWh)	% Difference
4	160.4	201.1	20.24%
5	303.7	355.4	14.55%
6	471.3	521.6	9.64%
7	643.6	684.4	5.96%
8	806.5	817	1.29%
9	951.1	953.4	0.24%
10	1071.9	1028.1	-4.26%
11	1165.8	1212.9	3.88%

Table 6: *Empirical validation of the model for V27 turbine*

Mean Wind Speed (m/s)	Data Sheet Annual Output (MWh)	Calculated Output (MWh)	% Difference
5	212.916	188.928	-11.27%
5.5	258.628	231.744	-10.39%
6	303.481	272.592	-10.18%
6.5	346.273	313.872	-9.36%
7	386.079	354.744	-8.12%
7.5	422.191	388.224	-8.05%
8	454.089	420.168	-7.47%

Table 7: *Empirical model validation for the T100 turbine*

As can be seen in Tables 6 and 7, the outputs from the wind model match up relatively well with the results given in the manufacturer's data sheet. It predicts a slightly higher energy output for most wind speeds for the V27 turbine, and it slightly underestimates the output from the T100 turbine. There is a higher percentage of discrepancy at lower windspeeds, but this is to be expected.

Inter-model Validation

The total annual energy yield estimated by the model for a given area of land was compared to the estimated yield from GoMap for wind energy. This was undertaken for both turbines, as the power rating of turbine used in the GoMap estimator is unknown. The result are shown below in Figure 13 and Table 8.

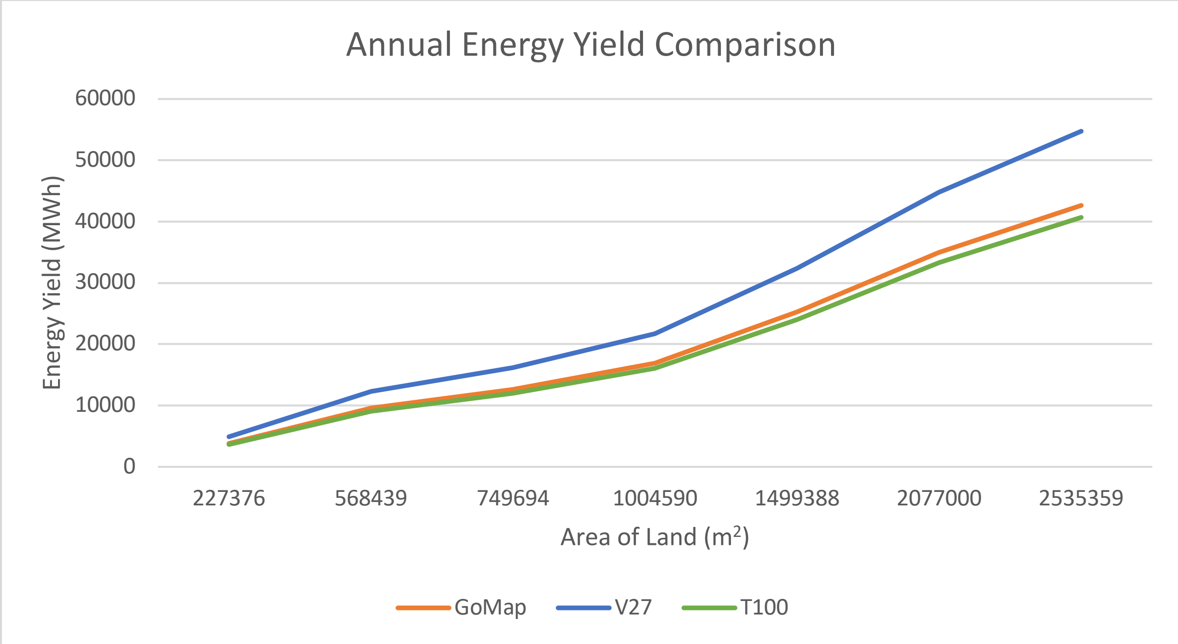

Figure 13: *A comparison of the estimated annual energy yield calculated from the model for both turbines against the estimated values from GoMap*

Area Available (m^2)	GoMap Yield (MWh)	V27 Yield (MWh)	% Difference V27	T100 Yield (MWh)	% Difference T100
227376	3824	4909.8	22.11%	3649.2	-4.57%
568439	9560	12274.5	22.11%	9122.9	-4.57%
749694	12609	16188.3	22.11%	12031.9	-4.58%
1004590	16896	21692	22.11%	16123	-4.58%
1499388	25219	32376	22.11%	24064	-4.58%
2077000	34933	44849	22.11%	33333	-4.58%
2535359	42642	54746	22.11%	40690	-4.58%

Table 8: *The calculated annual energy yield from wind energy from GoMap and the wind model*

As shown in Figure 13 and Table 8, the calculated energy yields for both turbines for different areas of land, was always the same percentage out from the GoMap estimator. The V27 turbine values were always 22% higher than GoMap, and the T100 value always around 5% lower. This implies that there is some constant value in the calculations that is different in the GoMap model. The curves shown in Figure 13 having the exact same shape validates the developed wind energy model from the GoMap estimator.

3.3 Minewater heat recovery using ground source heat pumps

Ground Source Heat Technology

Ground source heat pumps (GSHPs) make use of the geothermal energy below the ground in order to supply heat. At depths of around 15 m and below the temperature remains constant throughout the year and roughly equal to the average mean air temperature at that location [49]. Therefore, during winter months, thermal energy can be abstracted from these depths below the ground and passed through a heat exchanger in order to meet thermal energy demands. This process is outlined below in Figure 14.

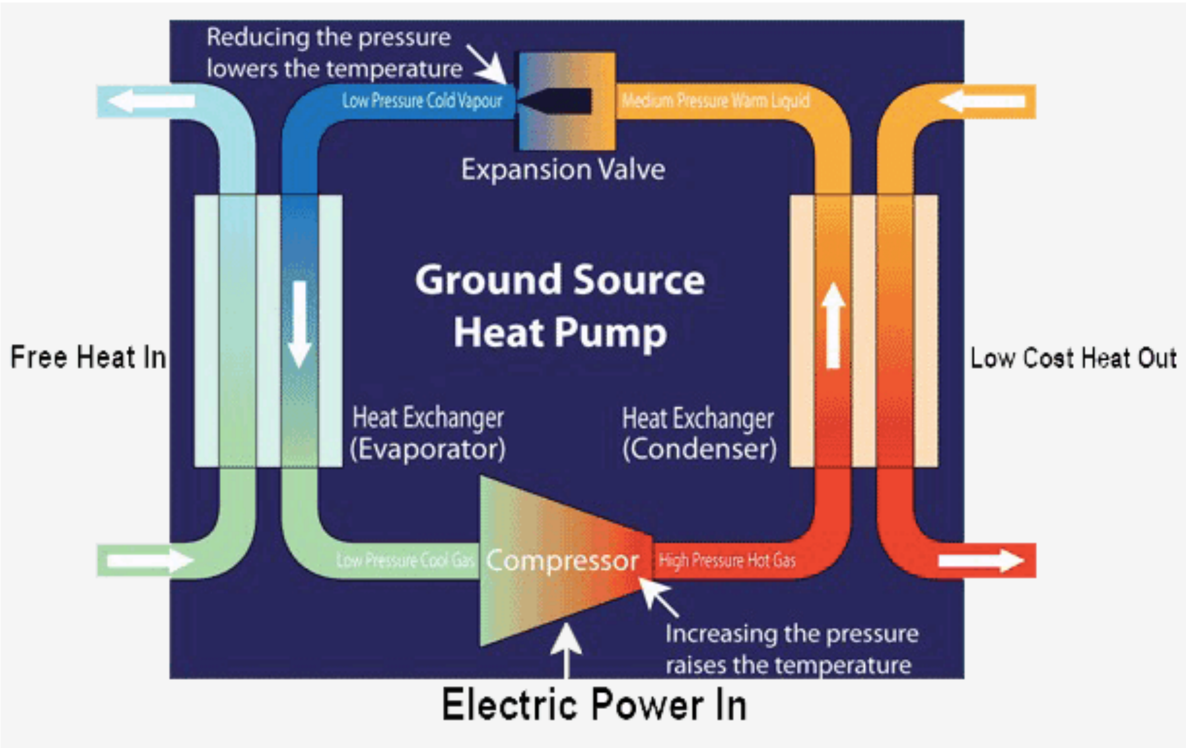

Figure 14: *The thermal cycle used by GSHPs to provide heat, from green match [50]*

In the process shown above, heat is removed from the ground via either pumped ground water or a carrier fluid. In the evaporator this heat is transferred to a refrigerant, which is then compressed to increase its pressure and temperature, before passing through the condenser where thermal energy is released to meet heating demand. The refrigerant is then expanded, returning it to its original temperature and pressure so that the process can begin again. The amount of extractable heat from the ground is determined by a number of geological conditions such as the thermal conductivity and thermal diffusivity of the rocks [48]. The process outlined above can be undertaken as either an open loop or a closed loop system. In an open loop system, heat is extracted by pumping up water directly from underground, and in a closed loop system a carrier fluid is used to extract heat, requiring a piping network. Open loop systems are generally cheaper and can provide a higher energy yield, as they do not require a piping network deep underground or periodical maintenance [49]. However, open loop systems require more criteria to be met in order to function optimally: a large aquifer is required so that significant amounts of water can be abstracted and any potential issues with contamination, water quality and temperature interference need to be identified and quantified.

Glasgow's Potential for Minewater Heat Recovery

The Scottish government has identified the decarbonisation of heat as one its key priorities in combatting climate change. It hopes to promote the uptake of renewable heat such as ground source heat pumps, incorporated into district heating schemes where possible, as outlined in the heat policy statement [51]. Uptake in schemes such as these within the UK has been slow so far, however across Europe there as an installed capacity of around 1568 MW of large-scale electric heat pumps supplying district heating schemes, the majority of which are in Scandinavia [52]. Scotland's midland valley has many abandoned mine shafts beneath it, which are now flooded. The Scottish government have identified that these flooded mines could be used a resource for open loop GSHP systems, as the vast amount of water contained within could allow for high abstraction rates and therefore a higher potential thermal output [53]. Much of the city of Glasgow is situated above land that has previously been mined, making it ideal for developments of this type. There is currently one development such as this in the city, at Shettleston, where heat from an abandoned mine is used to meet the thermal demands of a group of houses.

The British Geological Society (BGS) is currently undergoing work to generate 3D models of subterranean Glasgow, in order to determine the best potential sites for a mine-water recovery GSHP scheme [54]. The potential extractable energy is dependent upon the rate that water can be extracted, and the change in temperature between its abstraction and re-injection. These values will vary from site to site depending upon geological factors and properties of the water that is flooding the old mine, so the extractable energy at a particular site will not be able to be determined until this work is complete. Figures 15 and 16 below, courtesy of the BGS [54], show which areas of Glasgow are situated above mines and therefore over a potential site, and the temperature of the underlying bedrock across the city which is roughly equal to the temperature of water abstraction.

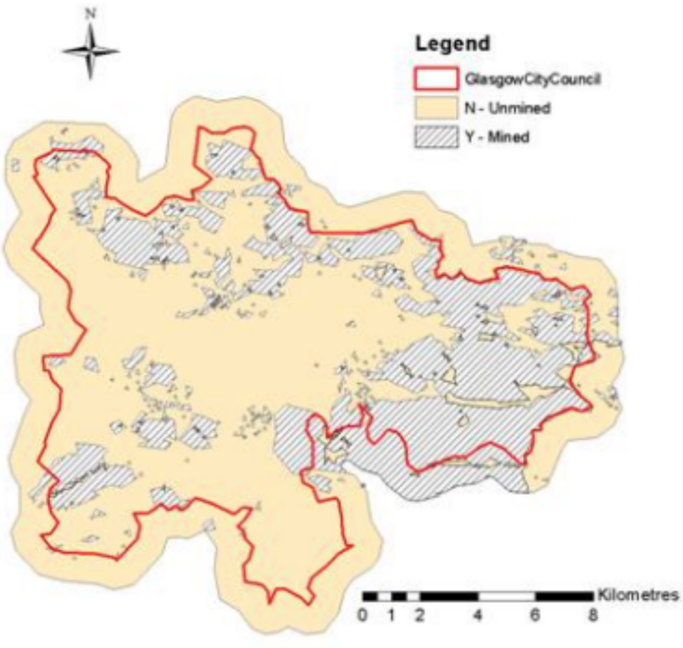

Figure 15: *The areas of land in Glasgow identified by the BGS as being situated over an abandoned mine*

As can be seen in Figure 15, much of the city's land is above a potential site for a minewater heat recovery scheme. Most of the east of the city is above an abandoned mine, as well as some parts of the north and south-west. There is some overlap between areas over abandoned mines and the areas identified for potential district heating networks in Figure 2. Figure 16 below shows which areas of the city could have a higher thermal energy yield due to the higher bedrock temperatures. As this work by the BGS is currently ongoing, potential abstraction rates and temperature drops for specific areas of the city could not be determined. However, a range of potential values for these variables can be estimated from previous work. Therefore, only a simple model to predict potential thermal energy yields from this sort of development could be created. Once the 3D modelling and borehole measurement work of the BGS was complete, this could be developed further to give accurate energy yield values for any area of the city. The background theory for the model used is outlined below.

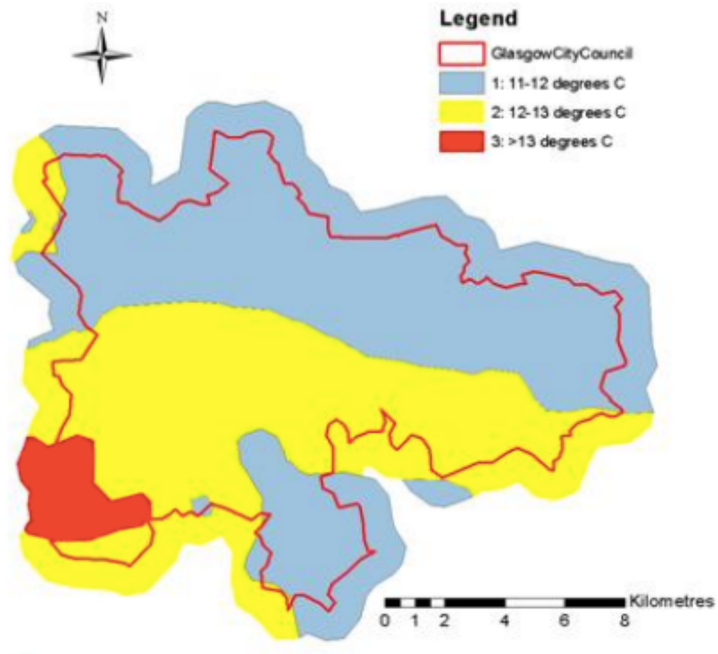

Figure 16: *The bedrock temperature beneath the city; higher values will give a higher potential thermal energy yield*

Background Theory

Hytiris et al [55] determined that the potential extractable heat from mine-water with a ground source heat pump, is dependent upon the rate that the water can be abstracted, and the temperature difference between the pumped water and re-injected water. This is shown below in equation 13, where G is the extractable heat in Watts, Z is the flow rate of abstracted water in l/s, ΔT is the temperature difference in Kelvin, and c_w is the specific heat of water (taken to be 4180JL^{-1}K^{-1}).

$$G = Z * \Delta T * c_w \qquad (13)$$

The proportion of this extractable heat that can be used to meet thermal energy demands is dependent upon the coefficient of performance of the heat pump being used (typical values range between 3 and 5). This is shown below in equation 14, where H is the usable heat in Watts and COP is the heat pump coefficient of performance.

$$G = H * \left(\frac{1}{COP}\right) \qquad (14)$$

Therefore, in order to estimate the useable heat for a given site in Glasgow, equations 13 and 14 can be combined to produce equation 15 below.

$$H = \frac{Z * \Delta T * c_w}{\left(1 - \frac{1}{COP}\right)} \tag{15}$$

Equation 15 was used to estimate the potential thermal energy yield for any minewater recovery developments in the city. COP values were assumed to range between 3 and 5, and c_w was taken to be a constant of 4180 $JL^{-1}K^{-1}$. Appropriate values for Z and ΔT will vary for each site depending on geological properties, chemical properties of the water, and the amount of water available for abstraction. These must be obtained from borehole readings, which the BGS is currently undertaking for areas in Glasgow. Banks [56] provides information on all current minewater heat recovery schemes in operation in the UK, which have widely varying abstraction rates: ranging from 0.25l/s at Allen Hill Saw in Derbyshire, up to 120 l/s at Horden in County Durham. The temperature-drop values showed less variation, with most ranging between 7 and 12 Kelvin. Work from Macnab [57], determines that geology in Glasgow is likely to allow for abstraction rates of between 5 and 10 l/s, with some sites allowing for up to 20 l/s, so these values were used in the model. At the Shettleston site, water is abstracted at around 12 degrees and re-injected at 3 degrees, this gives a temperature drop of 9 Kelvin. However, not all sites will be suitable operations such as this, as if the water is re-injected with too high a temperature drop it can cause temperature interference issues affecting local geology and the chemical composition of the water.

To determine the range of potential thermal energy yields for minewater recovery sites in Glasgow, the potential energy yield for the range of likely abstraction rates and temperature drop values were calculated. The results of which are shown below: Figure 17 displays how the potential thermal energy yield varies with the extraction rate, for three different COP values, with a constant temperature drop of 7 Kelvin. Figure 18 shows how the energy yield will vary with changes to the temperature drop, for the same three COP values as Figure 17, with a constant water extraction rate of 7.5 l/s.

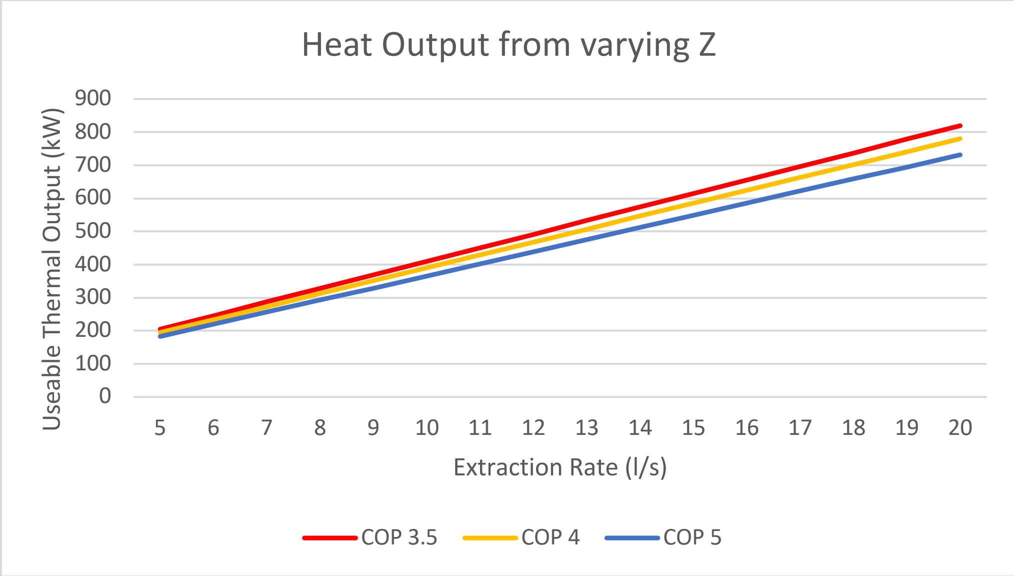

***Figure 17:** Displaying how the energy output will vary with the extraction rate*

As seen in Figure 17, the useable energy output is directly proportional to the rate at which water is extracted. Abstraction rates expected at Glasgow sites of between 5 and 10 l/s will give a thermal output of between 200 and 400 kW. For any sites where higher extraction rates of up to 20l/s are achieved, the thermal output will increase to around 800kW. The COP of the heat pump used has little effect on the energy yield, as can be seen in the graph where each COP value has a similar line. Figure 18 below shows how the thermal output varies with the temperature drop, for a constant extraction rate of 7.5 l/s.

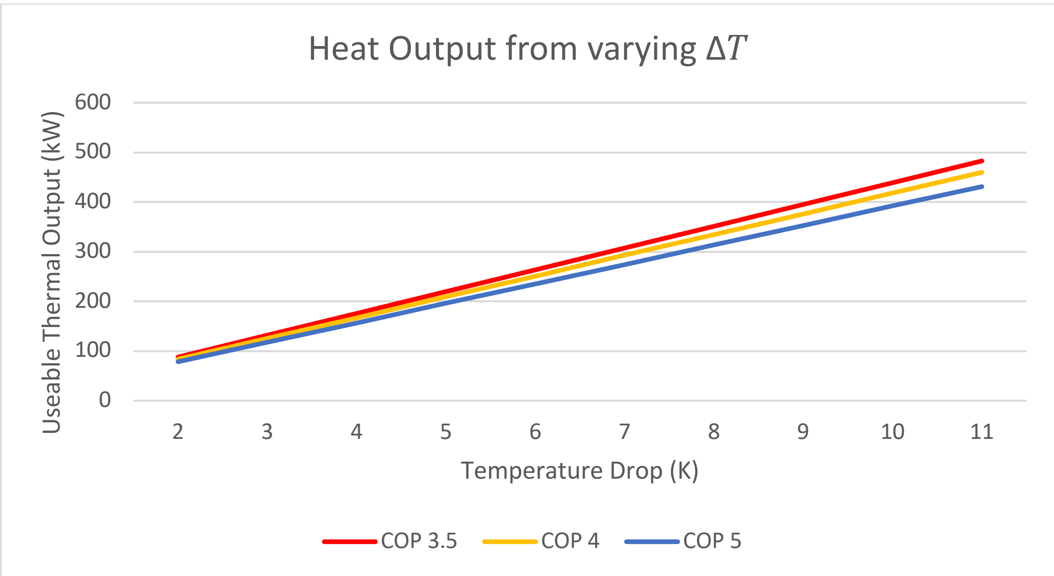

***Figure 18:** Displaying how changing the temperature drop affects thermal output*

As shown in Figure 18, the thermal output from a potential minewater heat recovery site is also directly proportional to the temperature difference between the water extracted and water re-injected. The potential energy yield will depend heavily upon how much the temperature of the water can feasibly be reduced to without creating potential issues. An extraction rate of 7.5 l/s will yield less than 100kW of useable heat with a temperature drop of 2 degrees, but this will rise to over 400kW if a temperature difference of 10 degrees can safely be achieved. For a full list of calculations from the minewater recovery model, see Appendix III.

As evident from the results given above, the potential output from a minewater heat recovery site will vary greatly depending on site specific factors. If a temperature drop of just 3 degrees and an extraction rate of 5 l/s is the most a site can accommodate then the potential thermal output will only be 88 kW. However, some sites within the city may have a potential extraction rate of 20l/s at a temperature drop of ten degrees which would give a thermal output of 1170 kW. For the final energy yield calculations, potential minewater heat recovery sites were assumed to have an extraction rate of 7.5 l/s with a temperature drop of 7 Kelvin, giving a thermal output of 307 kW when used with a heat pump of COP 3.5. However, this is a cautious estimate, as many sites in the city will be suitable for higher thermal outputs. To calculate the annual energy yield of a minewater heat recovery site, it was assumed that on average, a district heating network would require 12 hours of heating a day for 6 months. For a system with an output of 307 kW, this gave an annual yield of 663120 kWh of heat.

Model Verification

The model for calculating the energy yield from minewater heat recovery was validated against work by Macnab [57], who estimated that a mine in the Tollcross area could provide a thermal output of around 463kW. A calculation was carried out for that same site using the method outlined above. A COP value of 3.5 and extraction rate of 7.5 l/s was assumed. Tollcross falls within the yellow region of Figure 16, where the bedrock temperature is between 12 and 13 degrees. A return temperature of 3 degrees was selected, as the Shettleston site is nearby so a similar return temperature being suitable here was assumed. Three potential values were then calculated, for a bedrock temperature of 12 degrees, 12.5 degrees and 13 degrees. The results are shown below in table 9, where it can be seen that there was little discrepancy between the calculated results from the model and from Macnab.

Ground Temp (°C)	Calculated Output (W)	% Difference (from Macnab value)
12	395010	14.68%
12.5	416955	9.94%
13	438900	5.21%

Table 9: *Showing the calculated potential thermal output for the Tollcross site*

3.4 Combining models for final results

In order to process the potential energy yields for the various policy relaxation scenarios enacted as described in Section 2.2, a method to incorporate all three models had to be found. For each policy scenario, the map of the city provided by GoMap would be examined in order to determine the percentage of the total land availability to be processed through either the wind or solar model. As suitable areas of wind within the city are limited, as previously described, most of the land availability would go through the solar model. For policy relaxation scenarios where there were large areas of land available around the city edges or in larger green spaces, then a higher percentage of the land would be processed in the wind model. A utilisation factor variable was also added to both the solar and wind models, which determined the fraction of available land dedicated to wind or solar, from the scenario, that would get used for energy generation. This is because it is highly unlikely that all unrestricted land in the city will be used for wind turbines and PV panels. The minewater recovery model was kept separate, as it requires very little land as only boreholes are required: a mine-water recovery scheme could be implemented on the same land as wind turbines or a solar array. To determine the potential of these schemes for each scenario, the areas of available land shown on GoMap were compared to the areas above abandoned mines shown in Figure 15. Where there was more available land over abandoned mines, it was assumed there would be the potential for a higher number of minewater heat recovery sites.

For each scenario, the number of homes powered and heated and the potential carbon reduction from the uptake in renewables were also calculated. To calculate the equivalent number of homes powered for each scenario, first the total amount of electricity provided by solar and wind energy were summed to give the total amount of electricity provided by renewables. This figure was then divided by the annual electricity consumption figure for a standard UK household to give the number of homes powered for that scenario. The value for a typical household annual electricity consumption was taken to be 3500kWh, which was determined using Ofgem's typical domestic consumption values [58]. A similar process was followed to determine the number of houses heated, by dividing the total output from minewater heat recovery schemes by an average UK housholde's typical annual energy consumption for heating (12,000 kWh), again from Ofgem [58].

To determine the carbon emission reduction that the uptake in renewables for each scenario would entail, first the carbon emissions from if that energy had been supplied from the grid was calculated. This was done by multiplying the total annual energy output from solar and wind by the carbon trusts conversion factor for UK grid electricity, 0.351 $kgC02_e/kWh$ ([59]. This gave the total carbon emissions if this energy had been provided by the grid. The carbon content of this energy being produced from wind and solar was then calculated, using conversion factors of 0.011 $kgC02_e/kWh$ for wind [60] and 0.04 $kgC02_e/kWh$ for solar energy [61]. The fraction of the total energy yield delivered by either wind or solar was multiplied by the corresponding conversion factor, these two figures were then summed to give the total resulting carbon content. The difference between the carbon emissions from this energy being provided from the grid, and the emissions from it being provided by wind and solar energy, was then taken to calculate the carbon saving of that scenario.

4. Estimating urban energy potentials

The results obtained from following the procedures outlined in Section 2 will be displayed and analysed here. The chapter will be split into two main sections: Land Availability, in which the amount of land freed up from various policy relaxations using GoMap will be presented and discussed; and Energy Calculations, where the potential energy yield and resultant equivalent number of homes powered and carbon emission reductions from these policy relaxation scenarios shall be examined.

4.1 Land Availability Results

The results from this subsection were determined as outlined in Section 2.2 and will provide the areas of land that could potentially be made available from the relaxation of policy factors in several scenarios. In the tables and graphs of this section, the following abbreviations will be used when referring to specific policy factors from GoMap: BE will represent the combination of the biodiversity and environmental policy factors; D, the developmental factor; S, the social policy factor and VI, visual intrusion. As outlined in Section 2, there were a large number of potential policy relaxation scenarios, too many for all to be included in the report. It was decided to determine the land availability of only the most feasible combinations, and then only determine the potential energy yield of the most feasible of those combinations. Any scenario that included a zero weighting for more than one policy factor was disregarded, as it is very unlikely that all policies within multiple factors will be completely relaxed. The land availability was calculated for the following potential groups of scenarios: half weighting each policy factor, giving a zero weighting to each policy factor, giving a half weighting to all policy factors but one, and some potentially feasible combinations of giving a half weighting to two policy factors. The results are shown below.

Half Weighting Individual Policy Factors

The total land availability for giving a half weighting to each of the policy factors, whilst having the rest with an equal, full weighting is shown below in Table 10 (where D ½ represents the scenario where the developmental policy factor has been half weighted, and so on). The land availability for the current situation with all factors having an equal weighting is also shown for comparison. A comparison of the additional land made available compared to the current scenario for each factor weighting relaxation is also shown below in Figure 19. The potential policy aspect relaxations that each of these scenarios could entail was discussed in Section 2.2.

Policy Weighting	Land Availablility (m^2)
equal	5081538
BE 1/2	5597950
D 1/2	5701961
S 1/2	6007950
VI 1/2	5647950

Table 10: *The land availability for half weighting single policy factors*

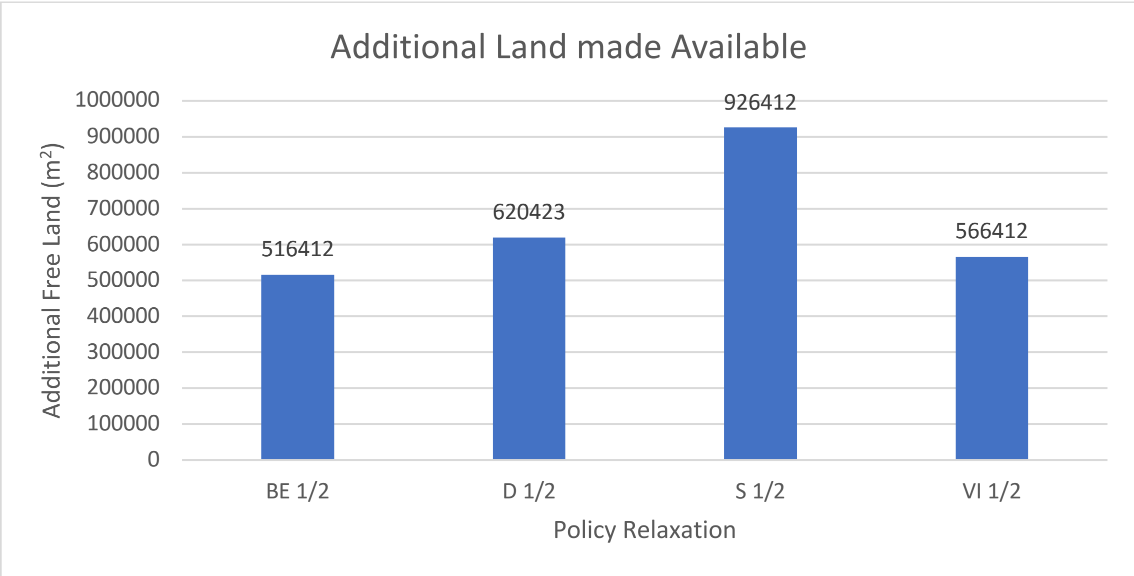

Figure 19: *The additional land made available from half weighting single policy factors, compared to an equal weighting*

As can be seen above, a reduction in the weighting of the social policy factor provided the highest amount of available land, with almost an additional 1 million m^2 of land made available. This would be the equivalent to around 130 football pitches-worth of land being made available for potential energy developments. The other three policy factors provided a similar amount of additional land when half weighted, with each providing an additional 10-12% of free land compared to when the factors are equally weighted. The much larger increase in available land from reducing social policies can partially be explained by the fact that, unlike the other factors, it does not heavily restrict any land within the city. This can be seen in Figure 7, where there is no red representing land that is heavily restricted from social policies, only orange, which represents land with lighter restrictions. The results here are promising for the potential future of clean energy deployments in the city, as the social policy factor is perhaps the most likely to be relaxed since the visual impact of technologies such as wind turbine and PV panels is a subjective issue, and GSHP has very little visual impact at all. The other three policy factors all contain restrictive policies that are protected by national law, protect land for previously agreed housing, industry or retail developments, or have a practical purpose, so may be less hard for a local government to relax.

Zero Weighting Policy Factors

The effect from giving each individual policy factor a zero weighting, whilst keeping the rest equal, was then investigated. It is unlikely that any of the policy factors could be completely dismissed by a local authority, so the results shown here were for investigative purposes only to determine the potential land availability that could arise from discounting a whole policy factor. These policy relaxations are highly unlikely to be used as a potential scenario for energy generation in the future, unless a large increase in clean energy generation was required from a drastic change in circumstances. The land availability results obtained from this are shown below in Table 11.

Policy Weighting	Land Availablility (m^2)	Additional Free Land (m^2)
Equal	5081538	0
BE 0	8421303	3339765
D 0	5081538	0
S 0	5081538	0
VI 0	5081538	0

Table 11: *Land availability from giving single policy factors a weighting of zero*

As can be seen in Table 11, when given a weighting of zero, each of the policy factors except biodiversity and environmental provided the same output as the base case scenario with equal weightings. This can partially be explained by the scoring method of GoMap: the total percentage of weighting for each policy factor must equal 100%, so when the weighting of one factor is reduced, the others must be increased to compensate. Therefore the lack of additional land from giving a zero weighting to a factor can partially be explained by the increase in the weightings from other factors when determining restricted land. This was not the case for biodiversity and environmental policies, which is likely to be due to the large amounts of highly restricted land from these policies, as shown by the red areas in Figure 5. It can then be concluded that if one policy factor was to be completely disregarded to promote the uptake of clean energy, removing biodiversity and environmental policies would provide the most free land. However, this policy factor is one of the least likely to be completely relaxed, due to the wide range of types of land protected under it (historical protections, habitats, nature reserves etc.) as well as restrictions from national law on sites such as SSSIs. The results shown here should be examined with scrutiny, as the lack of additional land made available from completely relaxing certain policy factors is a result of the scoring system of GoMap; if any of these policy factors was to be removed absolutely, then there would almost definitely be at least some additional land made available, even if restrictions from other policies were made more stringent.

Half Weightings for Multiple Policy Factors

The potential land availability from giving multiple policy factors a half weighting will be examined here. The effect on available land from giving three of the factors a half weighting, whilst keeping one with a full weighting will be displayed. The results from giving two policy factors a half weighting together was also examined, for the combinations that seemed the most feasible for those particular policy factors to be relaxed together.

The land availability results from giving three factors a half weighting while keeping one factor fully weighted in shown below in Table 12. Figure 20 shows the additional land made available for each of these scenarios compared to the case where all factors have an equal weighting. These policy scenarios could represent a potential future where there is a large push for clean energy deployment, with most planning policy restrictions being reduced to accommodate this.

Policy Weighting Scenario	Land Availability (m^2)
equal	5081538
All ½ except VI	5516207
All ½ except S	5185387
All ½ except BE	8992516
All ½ except D	5597950

Table 12: *The land availability from scenarios giving a half weighting to all but one policy factor*

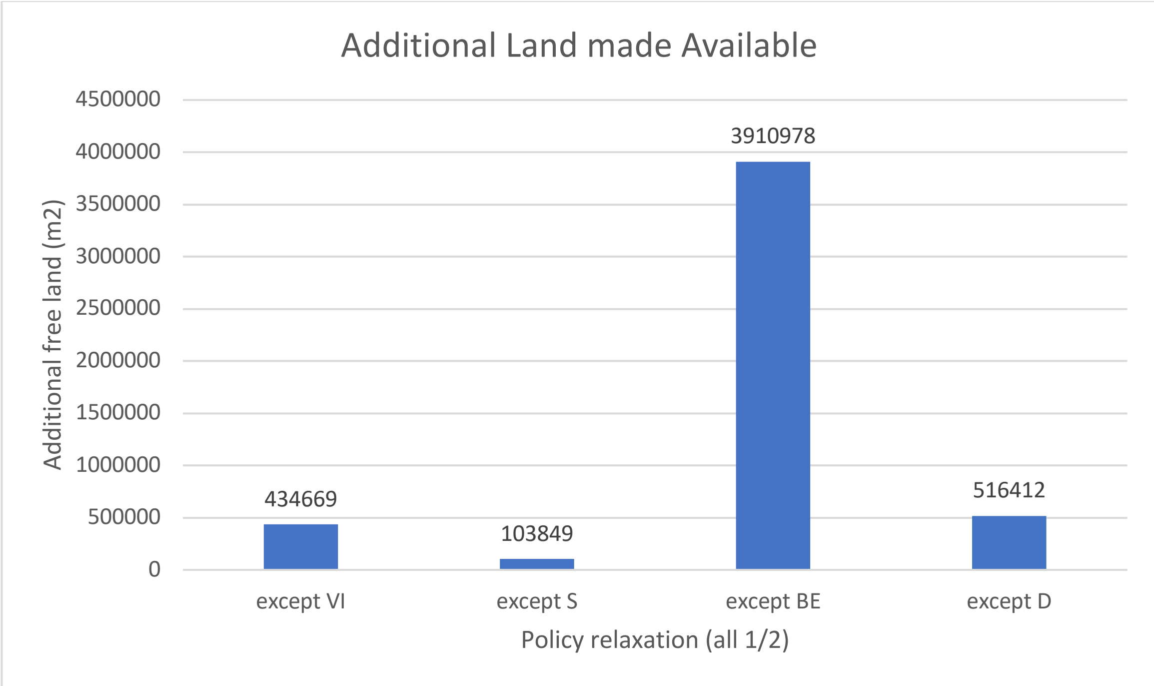

Figure 20: *The additional land availability from these scenarios compared to an equal weighting of policy factors*

As can be seen in Table 12 and Figure 20, giving three factors a half weighting does not provide a much higher yield of available land compared to giving just one factor a half weighting. This is made evident by comparing the results of Table 12 and Figure 20 to those of Table 10 and Figure 19. The exception to this is the scenario where all factors except biodiversity and environmental have a half weighting. This policy scenario provided an additional area of nearly 4 million m^2, representing an increase in land availability of over 75% compared to the base case scenario with equal policy factor weightings. Therefore, if an aggressive approach to reducing planning policy restrictions was to be enacted, relaxing the other policy factors whilst keeping the restrictions from biodiversity and environmental policies would yield the highest amount of available land. This would entail relaxing policies surrounding visual impact/intrusion, the green belt and consented land for housing and economic development, whilst keeping restrictions on historical sites and protected green spaces such as woodland, LNRs, SSSIs etc. This could present a feasible policy scenario if an aggressive push for land availability for clean energy projects was required in the future.

The effect of relaxing the visual intrusion and social policy factors together, and developmental, biodiversity and environmental factors together was then explored. These policy relaxation combinations were chosen due to the overlap between the selected policy factors. The visual intrusion and social factors are both concerned with visual impact, so could be relaxed together if issues surrounding the visual impact around houses were to be deemed less important, alongside an uptake in technologies such as non-reflective PV panels, and wind turbines that do not interfere with radar, to limit the effect on the helipads and airport. The developmental, biodiversity and environmental policy factors were relaxed together, as all are concerned with protecting areas of land that serve some practical purpose for the city, either aesthetically, by being suitable for housing or economic development, or providing a key function such as natural habitats or drainage systems. These factors could be relaxed together if it was determined in the future that the need for a local secure energy supply outweighed some of the benefits described above from these areas of protected land. The results from these policy relaxations are shown below in Table 13, displaying the total land availability and additional land availability compared to the policies being equally weighted.

Policy Weighting Relaxation Scenario	Total Land Availability (m^2)	Additional Free Land (m^2)	% Additional Free Land
equal	5081538	0	0.00%
S, VI 1/2	8992516	3910978	76.96%
BE, D 1/2	5123644	42106	0.47%

Table 13: *Land availability results for selected policy scenarios*

As can be seen in Table 13, half weighting the policy factors concerned with visual impact yielded a much higher area of free land than half weighting the policy factors concerned with protecting land due to it having a key functionality for the city. The amount of land made available from relaxing the biodiversity, environmental and developmental factors produced less additional free land than any of the scenarios where only a single factor was half weighted. This may partially be caused by the resultant higher weighting placed on the land that is lightly restricted from the social policy factor, which covers much of the city. The additional free land obtained from relaxing the social and visual intrusion factors together was exactly the same amount as the scenario relaxing all factors except biodiversity and environmental; therefore the developmental policy relaxations for that scenario are unnecessary in order to free up land. This scenario makes a large amount of land available for potential clean energy deployments within the city and could also be implemented feasibly as each factor is only half weighted, not removed altogether. This could be achieved by reducing restrictions on energy developments near houses and adopting anti-reflective PV panels and radar masking wind turbines for use around helipads and the airport.

Confirming Feasible Scenarios for Energy Generation

Due to time constraints and practical considerations, only some of the various policy relaxation scenarios outlined above were selected to be processed through the energy yield calculation models. Scenarios to process and analyse were chosen based on their feasibility for future implementation. This was decided based off of information on each of the policies contained within each factor, and how likely those policies are to be relaxed, determined from the city development plan and the interviews with city planners. Justification for the scenario selection decisions is given below.

All of the scenarios where a single policy factor was given a half weighting were carried forward for the energy calculations. This is because these four scenarios are four of the most likely to be implemented, with each only relying upon some policy relaxations within one policy factor. None of the policy scenarios where a factor had a weighting of zero were carried forward. This is because a complete abandonment of all policy aspects affecting land use within a policy factor is highly unlikely. Three of these scenarios did not provide any additional land compared to the current equal weighting situation. The scenario here that did provide a substantial amount of free land, where biodiversity and environmental policies had a zero weighting, is not feasible as several of the land restrictions under this category are protected by national law. Of the scenarios where a combination of policy factors have a half weighting, only the scenario where the visual impact and social policy factors are both half weighted was selected for energy calculations. The feasibility of this scenario has been outlined above. The other scenarios here were deemed to be either unfeasible or did not provide enough additional free land to be taken forward. The potential energy yield, equivalent number of homes that could power, and resultant carbon emission reductions for the selected scenarios are displayed and discussed in the next subsection.

4.2 Energy Yield and Carbon Reduction

The potential energy yield results for the land availability scenarios were calculated as outlined in section 2.3.4. A utilisation factor of 50% was used for each scenario: this assumes that 50% of the available land for each scenario will get used for energy developments.

Equal Weightings

First, the potential energy yield for the current situation with all policy factor weighted equally, and technical factors discounted was calculated. This was to be used as a base case scenario from which to compare additional energy yield form the other scenarios against. The land availability map for this case is shown below in Figure 21.

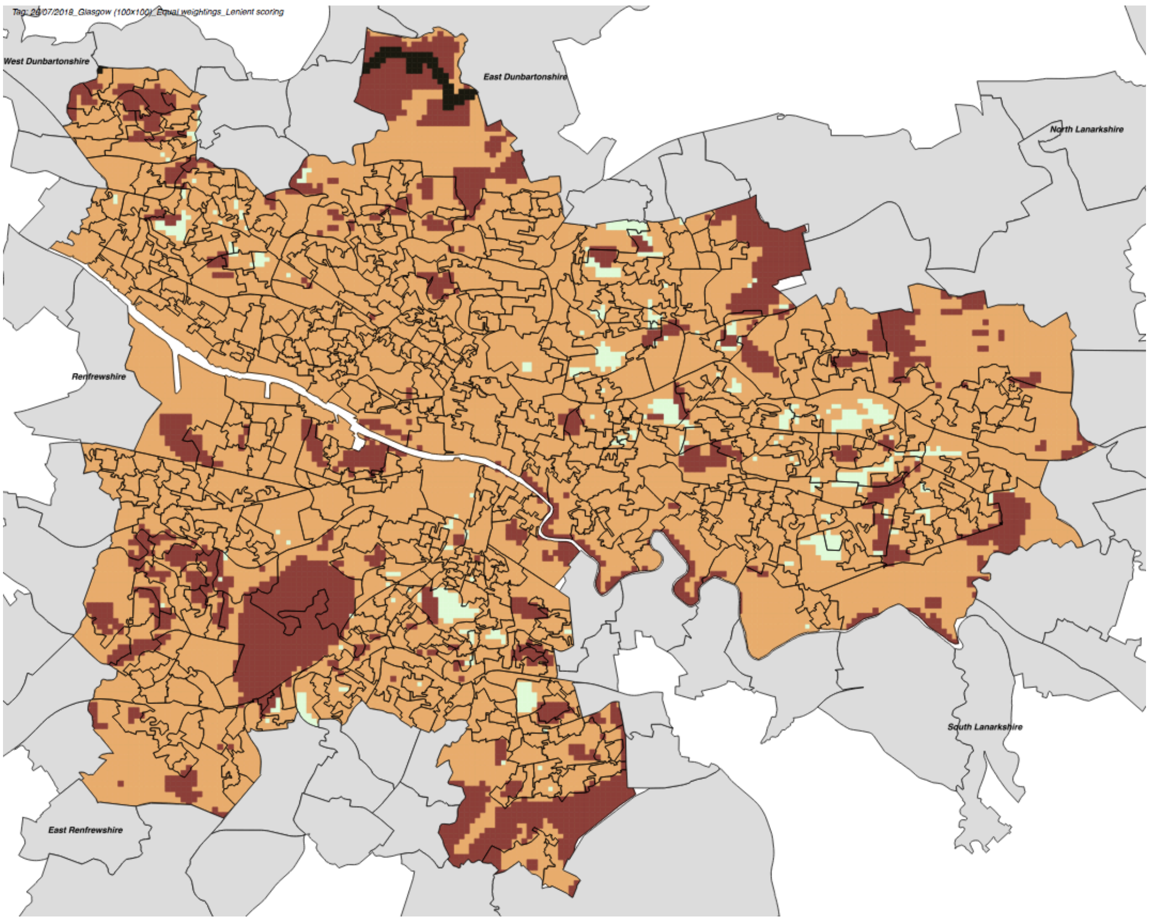

Figure 21: *The output map from GoMap for equal policy factor weightings with technical factors discounted*

The land availability map for an equal policy factor weighting shows most available land clustered around the east of the city, with a couple of large areas in the south, and some in the north west. Due to the lack of land free in the green belt around the edge of the city, 75% of the land available was used in the solar model, and 25% in the wind model. This 25% could represent wind farms in the small areas of available green belt land, or in the larger areas of available land over green spaces. It was assumed that around 6 minewater heat recovery schemes could be implemented in this case, around the available land in the east of the city that overlaps with the land identified in Figure 15. This is probably a conservative estimate, as developments such as this are likely to be allowed in many areas of restricted land within the city, such as the GSHP scheme being implemented at Kelvingrove Museum. The results for the equal weighting scenario are shown below in Table 14.

Policy Weighting Scenario	Equal
Land Availability (m^2)	5081538
Total Renewable Energy Electrical Yield (GWh)	302.602284
Equivalent Number of Homes Powered	86457.79543
Total Renewable Heat Yield (GWh)	3.9787
Number of Homes Heated	332
Carbon Emission Reduction (tC02e)	91329.31804

Table 14: *Energy production and carbon emission reduction results for the base case scenario with all policy factors on an equal weighting*

The results for this scenario imply that if half of all currently available land in the city was used for solar and wind developments, then this could provide over 300GWh of energy on an annual basis. This is the equivalent amount of energy to powering around 86,000 homes for a year, which is over a quarter of the current number of households in Glasgow (identified to be around 290,000 by the National Records of Scotland [62]). The actual number of households that could be powered from these energy developments is likely to be far lower, due to the stochastic nature of renewable energy sources. The 6 minewater recovery schemes could provide enough heat to meet the demand of 332 households for a year, however this may be a conservative estimate due to some sites having the potential for a higher energy yield than the 663120kWh estimated in section 2.3.3, and also the potential for a larger number of schemes like this being developed. The additional renewables generation here would cut carbon emissions in the city by over 90,000 tonnes per year, calculated as outlined in section 2.3.4. This may seem a significant amount, however it will only go part of the way to meeting the reduction of 657,596 tonnes per year identified in the Energy and Carbon Masterplan as being required within the city by 2030 [10]. A reduction in emissions from the transport sector and through increasing building efficiency could help meet the rest of this identified target.

Half Weighted Policy Factors

The energy results from giving single policy factors a half weighting are given here. The land availability map for the social policy factor having a half weighting is displayed below in Figure 22. The maps for the other policy factors being half weighted showed available land in similar parts of the city, and can be seen in Appendix IV.

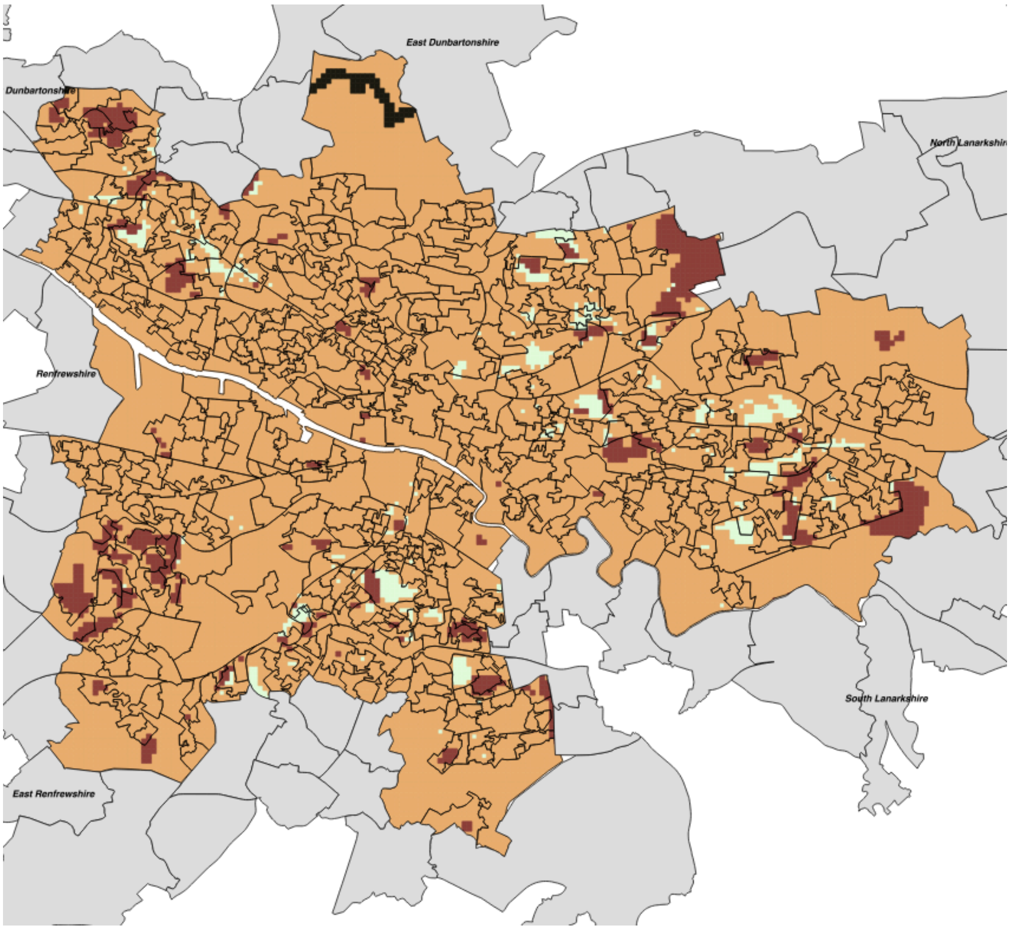

Figure 22: *The GoMap output map for the policy relaxation scenario with the social policy factor half weighted*

Figure 22 shows land availability in very similar areas to Figure 21, where the policies have an equal weighting. So, a split of 75% of the land for solar and 25% of the land for wind, with 6 minewater heat recovery schemes was again implemented. The additional energy yield and carbon reduction from each of these scenarios compared against the baseline scenario are shown below in Figures 23 and 24.

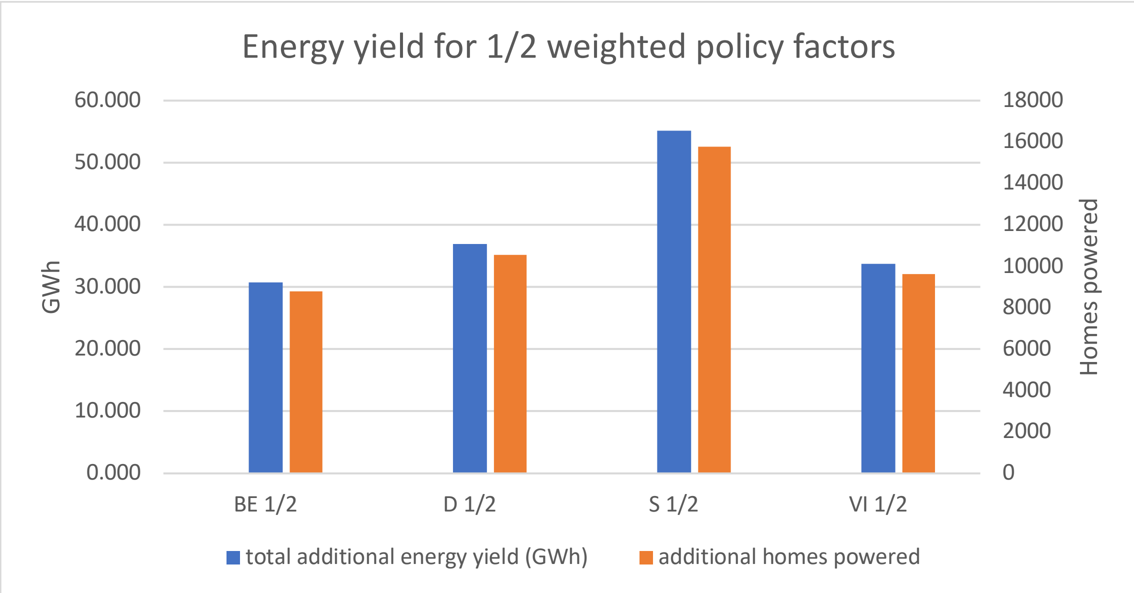

Figure 23: *Comparing the additional energy output and resultant number of homes powered for the half weighted single policy factor scenarios*

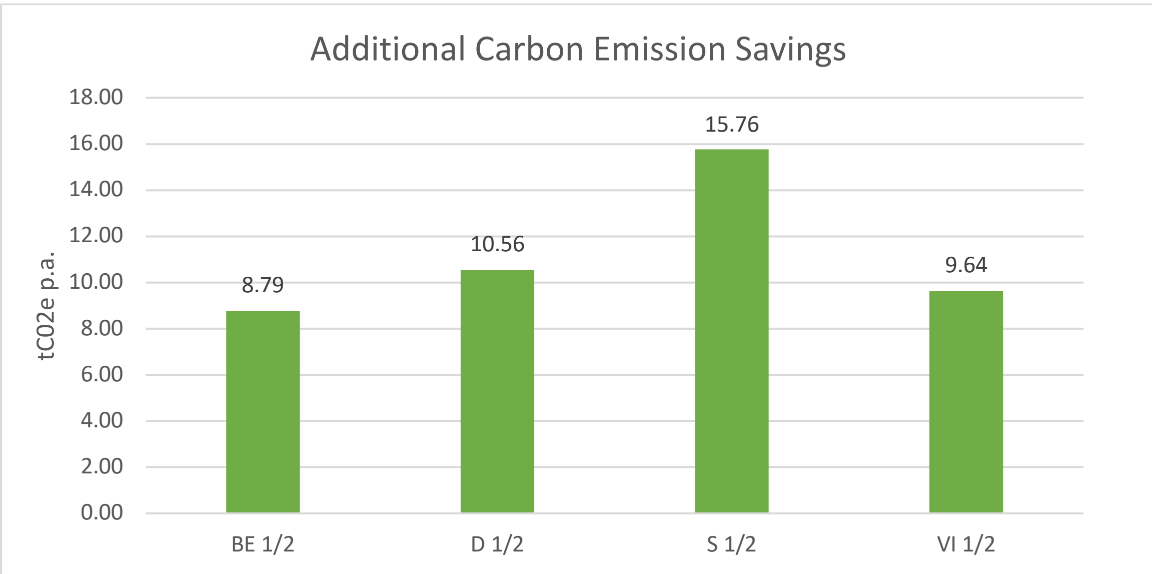

Figure 24: *The additional carbon emission reductions for each of the half weighted policy factor scenarios*

As would be expected, the results from the figures above show a similar pattern to Figure 19 showing the land availability of each of these scenarios. When half weighted, the biodiversity and environmental, visual intrusion, and social policy factors provide only an extra 10-12% additional clean energy yield and carbon reduction, compared to the baseline scenario where all factors are equally weighted. Reducing the restrictions from these policy factors is perhaps not the best option for the city, as each of these factors protects land that has a particular use or value, which may be lost if deregulated for energy developments. When the increase in energy yield compared to using land currently available with all factors fully and equally weighted is only between 10 and 12%, relaxing these policies does not seem like the best option. Relaxing the social policy factor concerned with visual impact on houses seems to be a more feasible option, providing almost double the additional energy yield compared to the other policy factors. This policy factor is also likely to be easier to relax, as it does not involve developing on land that has restrictions based on national or international law.

Half Weighting Social and Visual Intrusion Policy Factors

The half weighting of the social and visual intrusion policy factors was identified in section 3.1 as being a feasible policy relaxation that would also provide a significant amount of available land. The land availability for this policy relaxation scenario is shown below in Figure 25. Comparing Figure 25 to Figure 21, it can be seen that additional areas of available land are present in the north, north west and south of the city as well as along the Clyde, compared to the baseline scenario with equal weightings. The clustered areas of land in the east of the city shown in Figure 21 are still present for this policy relaxation scenario. A ratio of 75% solar and 25% wind for the available land was implemented again, as there were very few new areas of available land around the green belt or over larger open spaces. The new areas of available land in the north and south-west of the city overlap well with the abandoned mine sites identifies in Figure 15. It was therefore assumed that twice as many minewater recovery schemes could be implemented for this scenario compared to baseline scenario, giving twelve sites in total. The results for this policy relaxation scenario are shown below in Table 15, where the total land availability and energy yields for this scenario are compared against the baseline case.

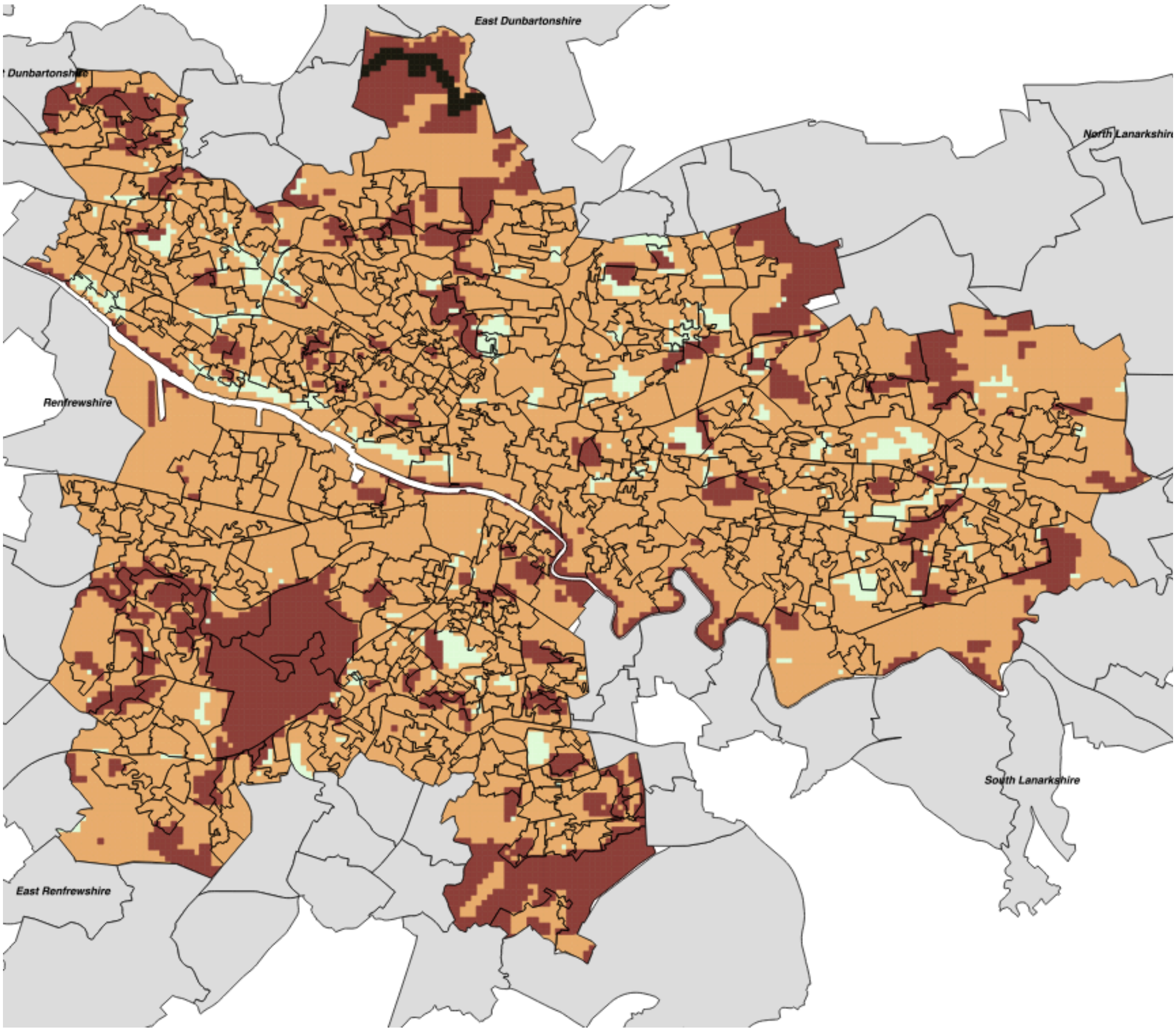

Figure 25: *The GoMap land availability map for the social and visual intrusion policies having a half weighting*

Policy Scenario	Land Available (m²)	Electrical Yield (GWh)	Homes Powered	Heat Yield (GWh)	Homes Heated	CO_2e Reduction (tCO_2e)
equal	5081538	302.6	86458	3.9787	332	91329
S, VI 1/2	8992516	535.5	153000	11.936	995	161620
% Increase	76.96%	76.96%	76.96%	200.00%	200.00%	76.96%

Table 15: *The energy yield results for social and visual intrusion policy factors being half weighted, compared against the results for the baseline scenario*

As evident above, this policy relaxation scenario represents an opportunity to greatly increase the land available for potential clean energy developments in the city. The energy yield, homes powered and carbon emission reductions for this scenario are nearly 80% higher than the baseline scenario with equal policy factor weightings. Enough energy is provided to power 153,000 homes over the course of a year, which is over half the number of households in Glasgow. The carbon reduction listed above would make up a quarter of the city's 2030 carbon reduction target, which is a significant amount considering it is solely from carbon reductions based on energy consumption. Combined with reductions in the transport sector and building efficiencies, this policy relaxation scenario could make a significant contribution to achieving this carbon reduction target. The heat provided from minewater recovery schemes in this scenario would be enough to heat nearly 1000 homes across the year. However, this is again likely to be a conservative estimate, with higher potential outputs likely to be achieved due to a larger number of sites being implemented, or higher outputs being available from those sites. The results above highlight the significant potential for clean energy deployments in the city through relaxing these two policy factors. The energy yields and carbon reductions would be increased even further if a higher utilisation factor than 50% was used when allocating clean energy developments to the available land.

The results displayed and summarised here indicate that a significant increase in clean energy generation in the city could be achieved using currently available land without relaxing any planning policies. Reducing the weighting of single policy factors does not in general provide a substantial increase to land availability and the resultant energy yield that could entail. Reducing land restrictions based on visual impact, as represented by the social policy factor, could however provide a moderate increase to potential energy yields. Combining this policy relaxation with a relaxation in visual intrusion policies has the potential to significantly increase the cities clean energy output and carbon emission reductions, if half of the available land was used for PV panels and wind turbines, alongside the development of some minewater recover schemes. The next subsection will investigate how the results summarised here are affected by certain variables which may have a different value in real life to what was assumed in this project, potentially creating a discrepancy between predicted and real energy outputs.

4.3 Sensitivity Analysis

Utilisation Factor

For each policy scenario, the utilisation factor determined what percentage of the land dedicated to wind or solar in each scenario would actually get used to host a wind farm or PV array. A value of 0.5 was used for all results shown in Section 3.2. The effect on energy yield of using other values: 0.25, 0.75 and 1 is examined in Figure 26 below. The results shown are for the base case scenario with equal policy factors, with a 75:25 solar/wind energy split as in Section 3.2.

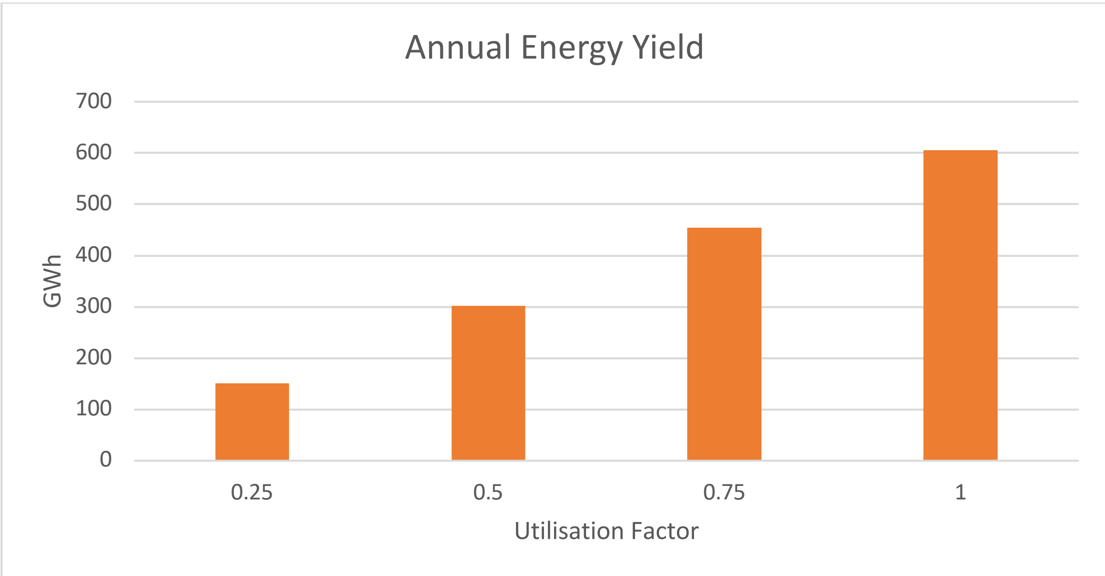

Figure 26: *The effect on energy yield from changing the utilisation factor*

As shown in Figure 26, the energy yield is directly proportional to the utilization factor; reducing it to 0.25 will half the energy yield and increasing it to 1 will double the yield. Figure 26 shows the effect of changing the utilisation factor on the results for the base case scenario, but the effect will be the same for all scenarios. A factor of 1 is highly unrealistic to achieve, is it would entail 100% of the available land in the city being used for clean energy projects. If a push for clean energy developments within the city was to be undertaken by the council, the utilization factor could range between 25% and 75%. This means all energy yield results in Section 3.2 could realistically range between half the given value, for a U.F of 0.25, or 1.5 times the given value for a U.F. of 0.75.

Wind/Solar Split

For all policy relaxation scenarios in Section 3.2, the available land was split with 75% being dedicated to solar energy, and 25% being dedicated to wind farms. This was determined by examining the land availability maps from GoMap, to identify any potential areas for wind farms, which are more limited within the city. The effect on the potential energy yields of having a different ratio of land dedicated to each technology is shown below in Figure 27. The results shown below were calculated with the additional land generated from half weighting social and visual intrusion policies taken as an input (around 3.9 million m^2), with a utilization factor of 0.5.

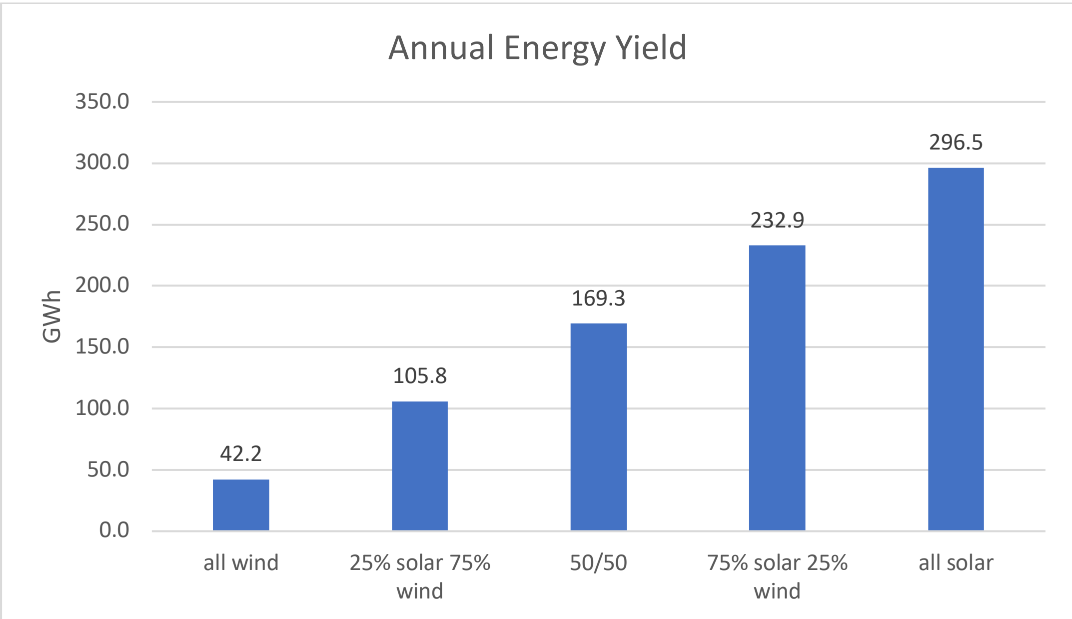

Figure 27: *The effect on energy yields of changing the fraction of land assigned to either wind or solar energy*

As can be seen in Figure 27, the energy output increased significantly as the percentage of land dedicated to solar energy increased. The case where all free land is dedicated to wind farms provided an energy output of less than 15% of the output when all land is dedicated to solar. Using results from the wind and solar models, it was found that wind energy has an energy density of around just 11kWh/m^2, whereas the solar energy model provided a density of around 150kWh/m^2. The much lower value for wind can be explained due to the packing density of only 1 turbine per 20412m^2 that was calculated for the turbine used in the model. As free land is very limited within the city boundaries, sites where multiple turbines could be placed were limited, restricting the potential energy output of wind. The results here imply that if the city is to promote clean energy development, then arrays of PV panels are a much more efficient option in terms of energy output per metre squared compared to wind energy, which is more suited for rural areas with a larger amount of free space.

Turbine Packing Density

The effect of changing the packing density used to determine the number of turbines that could fit in a particular area of land was then investigated. As outlined in Section 2.3.2, each turbine was assumed to take up a rectangular area equal to 7 blade diameters multiplied by 4 blade diameters, giving a density of one turbine per 20412m^2. However, this was calculated based on the rule of using a packing density of 3-5 rotor diameters in one direction and 6-8 in the other [48]. Therefore, packing densities of 3 diameters by 6 diameters, and 5 diameters by 8 diameters were also feasible. The effect on energy output of using these minimum and maximum packing densities is shown below in Table 16. The results were calculated by changing the packing density in the wind model, and using the land availability from the base case scenario with a utilisation factor of 0.5,

Packing Density (m^2/turbine)	Energy Yield (GWh)	Energy Density (kWh/m^2)
13122 (3dx6d)	42.67	33.59
20412 (4dx7d)	27.43	21.59
29160 (5dx8d)	19.20	15.12

Table 16: *The effect on wind energy yields of changing the turbine packing density*

As shown in the table above, using the maximum potential packing density of one turbine every 13122 m^2 does have the potential to significantly increase the potential energy yield of wind energy in the city, increasing the energy yield by a factor of 1.5 compared to the packing density used in Section 3.2. However, even when using this value, the potential energy density of wind power in the city is still far less than the figure for solar energy of around 150kWh/m^2. Potential clean energy yields from wind energy can be increased by increasing the packing density, however solar power is still the more feasible and efficient option if there is a lack of available land for energy deployments.

Solar Panel Efficiency

In the solar model described in Section 2.3.2, an efficiency of 20% was assumed for the PV panels. This is at the upper end of efficiencies of panels available on the market, with some giving an efficiency of just 15%. However, Kabir et al [62] predict that there could be panels with efficiencies of 25% and 30% available at competitive prices within the next couple of decades. The effect on energy output from PV panels of using a lower or higher efficiency of panel was therefore investigated. The land availability of the base case scenario was used, and the results were determined by changing the efficiency used within the solar model. The results are shown below in Table 17.

PV Panel Efficiency	Annual Energy Yield (GWh)	Energy Density (kWh/m2)
0.15	144.44	113.7
0.2	192.598	151.6
0.25	240.75	189.5
0.3	288.89	227.4

Table 17: *The effect on solar energy yield from changing the efficiency of PV panels used*

As can be seen in Table 17, even if a lower efficiency PV panel of 15% was used, there is still a higher energy density in terms of kWh/m^2 for solar panels than wind energy within the city. Possible future efficiencies of 25 and 30% have the potential to further increase the energy output and energy density of solar panels. If the city was to wait until panels with higher efficiencies are available on the market at a competitive price before adopting an aggressive deployment of PV arrays across the city, then a very significant energy output could be achieved. However, this would likely have to be supplemented with energy storage, as the output from PV will drop significantly over the winter months and is not available at all at night time.

Minewater Heat Recovery Variables

When determining the potential thermal output from minewater heat recovery sites in the city, it was assumed that each site on average could provide an output of 307kW, based on an average water extraction rate of 7.5l/s and an average temperature drop of 7 degrees Kelvin. However, these assumptions may represent conservative estimates, as the site at Shettlestone has a temperature drop of around 10 Kelvin, and some sites in the city may allow for extraction rates of up to 20l/s. Therefore, an investigation was undertaken to see if increasing these factors would significantly affect the potential number of homes that could be heated from sites such as these. This was done using a scenario-based approach, the given variables for each scenario are shown below in Table 18, and the results showing the potential annual thermal output and homes heated of each scenario is given in Figure 28. A constant COP of

3.5 was assumed and the calculation method was followed as described previously in section 2.3.3. The energy yield results were assuming the operation of six schemes across the city, as in the baseline and single policy factor half weighted scenarios.

Scenario	Extraction Rate (l/s)	Temperature Drop (K)
1	7.5	7
2	7.5	10
3	10	7
4	10	10

Table 18: *The key variables for each scenario*

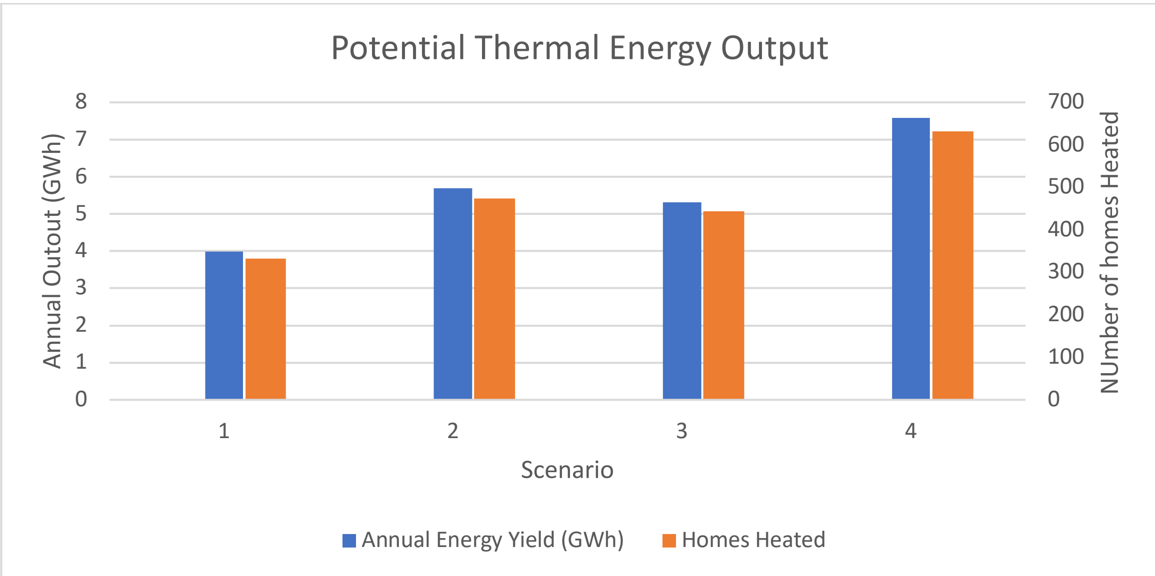

Figure 28: *The thermal energy yield results for each scenario.*

In the results above, Scenario 1 represents the values that were assumed in the results given in Section 3.2. Scenarios 2, 3 and 4 outline the increase in thermal energy yield that could be achieved if potential sites in the city allowed for a higher rate of water extraction or a higher temperature drop between extracted water and re-injected water. If 6 sites were found that could allow an extraction rate of 10l/s and a temperature drop of 10 K, then this could meet thermal energy demands for around 650 households in the city. This may not seem like a significant amount of energy, but accounts for around 7.8 GWh of thermal energy over the course of the year, using Ofgems standard consumption value of 12000kWh. As sites like these can often be consented on land that is heavily restricted, there is the potential for a larger number to be developed than just six. However, this would be dependent upon suitable conditions being determined from borehole readings. Developments such as these would provide city households with a clean and cheap source of heating, aiding the council's targets of decarbonising heat and reducing fuel poverty.

5. Conclusions and Further work

5.1 Conclusions

Various feasible policy relaxations and their resultant potential energy yields were calculated and assessed. Research into the national and local policies affecting land use and development plans in the city alongside an interview process with city planners allowed for the policies that restrict the most land, and that were most likely to be relaxed, to be determined. GIS software, GoMap, was used in order to assess the potential land that would be made available from relaxing certain policy groupings within the city. Two probabilistic mathematical models were created and verified, that generate synthetic climate data in order to calculate the potential energy yields from solar or wind energy within the city for a given area. A simpler model was developed in order to assess the potential thermal outputs from using ground source heat pumps in minewater heat recovery schemes within the city. The resulting Energy yields from various policy relaxations were assessed and compared.

It was found that relaxing social policies concerned with visual impact would yield a higher amount of available land than relaxing environmental, biodiversity, developmental or visual intrusion policies. These social policies are also the most likely to potentially be relaxed, as they do not protect land that performs key function for the city, or that is protected by national or international law. When social policies and visual intrusion policies are relaxed together, a considerable amount of land that could be used for energy generation is made available. It was found that under current land restrictions, there is 5081548 m^2 of land that could be potentially made available for energy developments. If half of that land is used for clean energy, with 75% of that half used for solar and 25% used for wind, then enough energy could be produced in order to power nearly 90,000 homes, which is just less than a third of the cities total number of households. This would result in a carbon emission reduction of 90,000 tonnes. Relaxing land protected by social policies could provide enough energy to power a further 15,000 homes. If social and visual intrusion policies are relaxed together then enough energy could be produced to power over 150,000 homes, over half of the city. If six minewater heat recovery schemes are implemented in the city, then this could provide annual heating needs for between 300 and 700 homes. If additional sites were identified then this number would increase. It was found that for Glasgow solar energy is a much more efficient clean energy source, in terms of land use, compared to wind energy. Solar energy in the city provides an energy density of around 150 kWh/m^2, whereas wind can provide a maximum of only 30 kWh/m^2. Therefore, if Glasgow city council was to aggressively pursue the deployment of clean energy technologies, solar power represents the better option due to its higher energy yield per square meter. Wind is unsuitable due to the packing density required for turbines and the large areas of restricted land within the city. A combination of solar power and minewater heat recovery schemes has the potential to provide a significant amount of clean electricity and heat for the city if so required.

5.2 Future Work

There is substantial scope for future work building on what has been achieved in this project. GoMap was only used simplistically here, changing the weighting of each of the policy factors to examine the effect on land availability. However, the effect of individual policy aspects could have been examined, each of which represents an individual policy affecting land use. These can be turned on or off, or the method in which they are scored changed, in order to examine the effects of individual policy changes on land use in the city. For example, in GoMap SINCs currently display as red, however the city planners said that developments such as PV and GSHPs could take place on these areas of land depending on site specific circumstances. Therefore the scoring system for SINCs could be reduced, or the policy turned off on GoMap to determine potential energy yields from using these areas of land for Energy developments.

For this project, a resolution of 100m x 100m was used in GoMap, meaning that it broke the city down into squares of 100m by 100m. However, this resolution can be increased to 50m by 50m which would greatly increase the accuracy of the results. Using a higher resolution on GoMap puts more strain on the computers processer, but with a powerful enough machine, a study similar to this project could yield more accurate results by using a higher resolution such as 50m by 50m or even 25m by 25m.

When calculating the energy outputs from using available land in the city for solar, wind or GSHP, excel models were developed for this project. These models contained several assumptions and variables with high uncertainties, which will limit the accuracy of the results for potential energy yields. For any of the three technologies, a more detailed specific investigation into how it could be used in the city could be undertaken. This could involve using software such as PVsys, or professional windspeed modelling tools, and would provide a much more accurate depiction of the potential energy yield from a particular technology. Once the BGS has finished obtaining and analysing its borehole readings for various sites across the city, then a full investigation into the best potential sites for minewater heat recovery schemes could be undertaken. This would allow for the individual variables affecting thermal energy yield to be determined for each individual site, which would lead to more accurate calculations on the potential energy yields from this technology used within Glasgow. Further improvements to the accuracy of the energy modelling calculations could be achieved by considering aspects that are unique to urban energy systems, such as shading, microclimates, and reflected longwave radiation, which were exempt from the models developed for this project.

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Appendix I – Solar Climate Model Results

Daily H_0 Values Calculation

Day of Year, N	I_0 (kW/m^2)	declination (degrees)	ω_{SR} (radians)	H_0 (kWh/m^2)
1	1.391891269	-22.93034672	0.89798472	1.223621204
2	1.349357921	-22.84244568	0.901384826	1.199780828
3	1.322639701	-22.74777633	0.905031647	1.190379473
4	1.335687982	-22.64636671	0.908920987	1.217709271
5	1.376805718	-22.53824689	0.913048452	1.272391354
6	1.409133182	-22.42344889	0.917409468	1.321031146
7	1.403690629	-22.30200673	0.921999293	1.33578749
8	1.365357	-22.17395639	0.926813044	1.319767311
9	1.328496228	-22.03933582	0.931845708	1.305163453
10	1.326151912	-21.89818491	0.937092165	1.324974269
11	1.360425599	-21.75054547	0.942547201	1.383064779
12	1.400592865	-21.59646125	0.948205531	1.44965591
13	1.410646026	-21.43597792	0.954061808	1.487222253
14	1.381572991	-21.26914302	0.960110647	1.484375551
15	1.339436093	-21.09600598	0.966346633	1.467233792
16	1.32200868	-20.91661811	0.972764339	1.477073995
17	1.344913444	-20.73103256	0.979358342	1.533290122
18	1.387617557	-20.53930432	0.986123229	1.614810797
19	1.411839195	-20.3414902	0.993053616	1.677673012
20	1.395865029	-20.13764881	1.000144156	1.694232122
21	1.354014995	-19.92784056	1.007389548	1.679138797
22	1.323805284	-19.7121276	1.014784549	1.677785508
23	1.332317196	-19.49057386	1.022323982	1.726133397
24	1.371920282	-19.26324499	1.030002742	1.817377295
25	1.407112613	-19.03020833	1.037815808	1.906250236
26	1.406346253	-18.79153295	1.045758242	1.948740568
27	1.370308201	-18.54728955	1.0538252	1.942484129
28	1.331304533	-18.29755052	1.062011935	1.930865524
29	1.324299835	-18.04238985	1.070313803	1.965376674
30	1.355573422	-17.78188315	1.078726263	2.058774034
31	1.397090291	-17.5161076	1.087244882	2.171549644
32	1.411632914	-17.24514196	1.095865338	2.245704984
33	1.386164652	-16.96906651	1.104583421	2.257096861
34	1.343516362	-16.68796305	1.113395036	2.239209548
35	1.321919827	-16.40191489	1.122296198	2.255166933
36	1.34073512	-16.11100676	1.131283043	2.341194641
37	1.383095394	-15.81532489	1.140351817	2.472070419
38	1.411027057	-15.51495686	1.149498883	2.581343294
39	1.399490951	-15.20999169	1.158720718	2.620380872
40	1.358828544	-14.90051974	1.168013912	2.603874038

41	1.325491385	-14.5866327	1.177375168	2.599354158
42	1.329364355	-14.26842359	1.186801298	2.667678494
43	1.366975553	-13.94598668	1.196289225	2.806819403
44	1.404608667	-13.61941752	1.205835979	2.95075123
45	1.408527736	-13.28881286	1.215438693	3.027063979
46	1.375219536	-12.95427068	1.225094607	3.023144851
47	1.334542986	-12.6158901	1.234801058	3.000534209
48	1.322962316	-12.27377137	1.244555485	3.041849585
49	1.350858941	-11.92801588	1.254355421	3.17589875
50	1.393225114	-11.57872607	1.264198492	3.348757037
51	1.412081954	-11.22600543	1.274082415	3.469481797
52	1.39052537	-10.86995848	1.284004997	3.491887043
53	1.347879621	-10.51069072	1.293964126	3.458922417
54	1.322374212	-10.14830859	1.303957775	3.467226896
55	1.3368733	-9.782919486	1.313983997	3.580832867
56	1.378379273	-9.414631658	1.324040918	3.77098077
57	1.40968437	-9.043554236	1.334126741	3.938432451
58	1.402725342	-8.669797172	1.344239738	4.001406275
59	1.363740563	-8.293471211	1.354378246	3.971287599
60	1.327677685	-7.914687861	1.364540671	3.946131429
61	1.326865041	-7.533559356	1.374725477	4.024421313
62	1.36203112	-7.150198627	1.384931188	4.214818438
63	1.401651519	-6.764719264	1.395156382	4.424491462
64	1.410208789	-6.377235488	1.40539969	4.539976132
65	1.380031821	-5.98786211	1.415659794	4.530233826
66	1.338172562	-5.596714505	1.42593542	4.478357494
67	1.322155472	-5.20390857	1.436225339	4.510008433
68	1.346338968	-4.809560695	1.446528361	4.680043506
69	1.389043911	-4.413787728	1.456843335	4.919534571
70	1.411987734	-4.016706937	1.467169145	5.094047411
71	1.394602595	-3.61843598	1.477504704	5.124099904
72	1.352473289	-3.219092865	1.487848956	5.05989583
73	1.323366359	-2.81879592	1.498200871	5.040215897
74	1.333374522	-2.417663754	1.508559441	5.168774069
75	1.373526026	-2.015815224	1.518923677	5.418120142
76	1.407827317	-1.6133694	1.529292609	5.64998539
77	1.405529225	-1.210445528	1.539665281	5.737646457
78	1.368691859	-0.807162996	1.550040748	5.682052937
79	1.330337838	-0.403641298	1.560418074	5.615351328
80	1.324849373	0	1.570796327	5.68468799
81	1.357146564	0.403641298	1.58117458	5.918366042
82	1.398276803	0.807162996	1.591551905	6.196023637
83	1.411369156	1.210445528	1.601927372	6.353534664
84	1.384687067	1.6133694	1.612300045	6.331279232
85	1.342149522	2.015815224	1.622668977	6.231837873
86	1.321889026	2.417663754	1.633033213	6.231552018

87	1.34206797	2.81879592	1.643391782	6.42203279
88	1.384597069	3.219092865	1.653743697	6.724023816
89	1.411351391	3.61843598	1.66408795	6.954407507
90	1.398347196	4.016706937	1.674423509	6.989896502
91	1.357242012	4.413787728	1.684749318	6.88106533
92	1.324884312	4.809560695	1.695064293	6.811319138
93	1.330280947	5.20390857	1.705367315	6.933684663
94	1.368594138	5.596714505	1.715657234	7.230623349
95	1.405478274	5.98786211	1.72593286	7.525213201
96	1.407868812	6.377235488	1.736192963	7.637726351
97	1.373622768	6.764719264	1.746436272	7.549020786
98	1.333439788	7.150198627	1.756661466	7.422191693
99	1.323341641	7.533559356	1.766867176	7.459008868
100	1.352380746	7.914687861	1.777051982	7.717447391
101	1.394525187	8.293471211	1.787214407	8.055308523
102	1.411994852	8.669797172	1.797352916	8.254409576
103	1.389129175	9.043554236	1.807465912	8.216918709
104	1.346425943	9.414631658	1.817551735	8.057105769
105	1.32216619	9.782919486	1.827608657	8.002580745
106	1.338097415	10.14830859	1.837634878	8.190242647
107	1.379938174	10.51069072	1.847628528	8.539878445
108	1.410180591	10.86995848	1.857587657	8.822023837
109	1.401714048	11.22600543	1.867510238	8.862845296
110	1.362128323	11.57872607	1.877394162	8.70304505
111	1.32690978	11.92801588	1.887237233	8.565519041
112	1.327629855	12.27377137	1.897037168	8.657019408
113	1.36364304	12.6158901	1.906791595	8.980315054
114	1.40266555	12.95427068	1.916498047	9.327500495
115	1.40971591	13.28881286	1.926153961	9.464206176
116	1.37847387	13.61941752	1.935756675	9.341446024
117	1.336946154	13.94598668	1.945303428	9.143540011
118	1.322360013	14.26842359	1.954791355	9.125513396
119	1.347791098	14.5866327	1.964217486	9.383393783
120	1.390441878	14.90051974	1.973578742	9.764340503
121	1.412078339	15.20999169	1.982871936	10.00057283
122	1.393304616	15.51495686	1.992093771	9.949741327
123	1.350950291	15.81532489	2.001240837	9.725874179
124	1.322983623	16.11100676	2.010309611	9.60044916
125	1.33447515	16.40191489	2.019296455	9.759328155
126	1.375123367	16.68796305	2.028197618	10.13323854
127	1.408489445	16.96906651	2.037009232	10.45640702
128	1.404662579	17.24514196	2.045727316	10.50385085
129	1.36707334	17.5161076	2.054347772	10.29536208
130	1.329418355	17.78188315	2.062866391	10.0811629
131	1.325453192	18.04238985	2.07127885	10.11902372
132	1.358732395	18.29755052	2.079580718	10.4414241

133	1.399423039	18.54728955	2.087767454	10.82313199
134	1.41104826	18.79153295	2.095834412	10.98122211
135	1.383186706	19.03020833	2.103776846	10.82982452
136	1.340814684	19.26324499	2.111589911	10.56010627
137	1.321916318	19.49057386	2.119268672	10.47103695
138	1.343432926	19.7121276	2.126808105	10.7007779
139	1.386076084	19.92784056	2.134203106	11.10011936
140	1.41161861	20.13764881	2.141448498	11.36388655
141	1.397163074	20.3414902	2.148539037	11.30455294
142	1.355668046	20.53930432	2.155469424	11.0226087
143	1.324331475	20.73103256	2.162234312	10.81883589
144	1.331244826	20.91661811	2.168828314	10.92503222
145	1.37021067	21.09600598	2.175246021	11.29435271
146	1.40629833	21.26914302	2.181482007	11.64096525
147	1.407157258	21.43597792	2.187530845	11.69553491
148	1.372017473	21.59646125	2.193387123	11.4480488
149	1.332379807	21.75054547	2.199045452	11.15893513
150	1.323777188	21.89818491	2.204500489	11.12656311
151	1.353921378	22.03933582	2.209746945	11.4187775
152	1.395789814	22.17395639	2.21477961	11.81013424
153	1.411849808	22.30200673	2.21959336	11.98286322
154	1.387704484	22.42344889	2.224183186	11.81231602
155	1.34499876	22.53824689	2.228544201	11.48033599
156	1.322015904	22.64636671	2.232671667	11.31338956
157	1.339358749	22.74777633	2.236561007	11.48960328
158	1.381480413	22.84244568	2.240207827	11.8777344
159	1.410621205	22.93034672	2.243607934	12.15370697
160	1.400658051	23.01145341	2.24675735	12.0911793
161	1.360522356	23.08574171	2.249652337	11.76546556
162	1.326193502	23.15318961	2.252289405	11.48698172
163	1.328445368	23.21377713	2.254665337	11.52303901
164	1.365259283	23.2674863	2.256777196	11.85745442
165	1.403633652	23.31430123	2.258622346	12.20426917
166	1.409168022	23.35420803	2.260198461	12.26397188
167	1.376901143	23.38719489	2.261503538	11.99251207
168	1.335758449	23.41325202	2.262535907	11.6413418
169	1.32262204	23.43237171	2.263294239	11.53206921
170	1.349267965	23.44454829	2.263777554	11.76778514
171	1.391809658	23.44977816	2.263985225	12.14031803
172	1.412110894	23.44805976	2.263916984	12.31689895
173	1.391972763	23.43939361	2.263572918	12.13876013
174	1.349447961	23.42378226	2.262953475	11.76357734
175	1.32265757	23.40123035	2.262059455	11.52388819
176	1.335617662	23.37174457	2.260892013	11.62868961
177	1.376710247	23.33533364	2.259452646	11.97613972
178	1.409098144	23.29200835	2.257743191	12.24531368

179	1.403747433	23.24178155	2.255765812	12.18430309
180	1.365454725	23.18466811	2.253522989	11.83588565
181	1.328547269	23.12068496	2.25101751	11.49849234
182	1.326110513	23.04985105	2.248252451	11.45810356
183	1.360328872	22.97218738	2.245231167	11.73207373
184	1.400527521	22.88771696	2.241957272	12.05449629
185	1.410670641	22.79646481	2.238434626	12.1154155
186	1.3816655	22.69845797	2.234667314	11.83857895
187	1.339513566	22.59372549	2.230659632	11.44870757
188	1.322001668	22.4822984	2.226416066	11.26893142
189	1.344828232	22.36420971	2.221941275	11.43108963
190	1.387530533	22.23949441	2.217240073	11.75877605
191	1.411828372	22.10818945	2.21231741	11.92693614
192	1.395940108	21.97033375	2.207178355	11.75357083
193	1.354108673	21.82596816	2.201828074	11.36164524
194	1.323833584	21.67513543	2.196271821	11.0671127
195	1.332254748	21.51788028	2.190514912	11.09506824
196	1.371823067	21.35424929	2.184562715	11.37918205
197	1.407067779	21.18429094	2.178420632	11.62322458
198	1.406393991	21.00805561	2.172094086	11.5676633
199	1.370405716	20.8255955	2.165588503	11.22129838
200	1.331364409	20.63696468	2.158909303	10.85111606
201	1.324268396	20.44221904	2.152061885	10.74150439
202	1.355478852	20.2414163	2.145051618	10.94010486
203	1.397017366	20.03461593	2.137883827	11.21755196
204	1.411647008	19.82187923	2.130563784	11.27503053
205	1.38625313	19.60326922	2.123096702	11.01177011
206	1.343599909	19.37885069	2.115487722	10.61292405
207	1.321923547	19.14869012	2.107741909	10.38124125
208	1.340655679	18.91285572	2.099864245	10.46562694
209	1.383004006	18.67141735	2.091859619	10.73009366
210	1.411005646	18.42444658	2.08373283	10.87846814
211	1.399558711	18.17201656	2.075488574	10.7205157
212	1.358924731	17.9142021	2.067131445	10.34027191
213	1.325529774	17.65107959	2.05866593	10.01761338
214	1.329310531	17.38272699	2.050096407	9.976206717
215	1.366877768	17.10922381	2.041427144	10.18494391
216	1.404554579	16.83065111	2.032662293	10.3892226
217	1.408565832	16.54709141	2.023805896	10.34099413
218	1.375315665	16.25862874	2.014861878	10.01966524
219	1.334610975	15.96534858	2.005834048	9.647080008
220	1.322941215	15.66733781	1.996726102	9.48629216
221	1.350767667	15.36468475	1.98754162	9.606727195
222	1.393145488	15.05747907	1.978284071	9.825482956
223	1.412085356	14.7458118	1.968956807	9.874258077
224	1.39060875	14.42977528	1.959563071	9.639570877

225	1.347968234	14.10946316	1.950105997	9.261139117
226	1.32238862	13.78497035	1.940588609	9.003229115
227	1.336800588	13.45639299	1.931013825	9.017421322
228	1.378284622	13.12382845	1.921384458	9.209857335
229	1.40965263	12.78737527	1.911703221	9.329228068
230	1.402784965	12.44713313	1.901972726	9.193170112
231	1.363838101	12.10320286	1.892195487	8.849081561
232	1.3277257	11.75568636	1.882373925	8.527566877
233	1.32682049	11.4046866	1.872510368	8.433933081
234	1.361933941	11.05030759	1.862607055	8.56632706
235	1.401588827	10.69265432	1.852666138	8.721654561
236	1.410236784	10.33183278	1.842689686	8.680176473
237	1.380125408	9.967949874	1.832679687	8.401010707
238	1.338247845	9.601113422	1.822638051	8.054596938
239	1.322144964	9.231432121	1.812566614	7.866798066
240	1.346252089	8.859015508	1.802467139	7.91724291
241	1.388958544	8.483973933	1.792341321	8.072017472
242	1.411980405	8.106418522	1.782190787	8.107423901
243	1.394679874	7.726461146	1.772017104	7.910536053
244	1.352565901	7.344214387	1.761821777	7.576739401
245	1.323391282	6.959791508	1.751606255	7.320145111
246	1.333309415	6.573306414	1.741371933	7.280889674
247	1.373429254	6.184873622	1.731120156	7.402800987
248	1.40778563	5.794608227	1.720852218	7.488182125
249	1.405579994	5.402625865	1.710569372	7.376646493
250	1.368789573	5.009042684	1.700272825	7.086253902
251	1.330394901	4.613975302	1.68996375	6.792817416
252	1.324814632	4.217540781	1.679643279	6.670006051
253	1.357051162	3.819856585	1.669312513	6.735675289
254	1.398206263	3.42104055	1.658972524	6.840403652
255	1.411386712	3.021210846	1.648624354	6.804457993
256	1.384776982	2.620485945	1.638269023	6.577722633
257	1.342231192	2.218984584	1.627907528	6.280325835
258	1.321889238	1.816825728	1.617540849	6.091436583
259	1.341986534	1.41412854	1.607169948	6.089099815
260	1.384506989	1.011012339	1.596795776	6.184301189
261	1.411333417	0.607596571	1.586419273	6.204770912
262	1.398417442	0.20400077	1.576041373	6.049835494
263	1.357337506	-0.199655478	1.565663004	5.777168545
264	1.324919449	-0.603252566	1.555285093	5.546855943
265	1.330224229	-1.006670909	1.544908571	5.476741086
266	1.36849641	-1.40979097	1.534534369	5.539756475
267	1.405427143	-1.812493305	1.524163428	5.59261267
268	1.407910114	-2.214658591	1.513796698	5.506181657
269	1.373719479	-2.616167664	1.503435142	5.279013633
270	1.333505211	-3.016901556	1.49307974	5.03429479

271	1.323317128	-3.416741528	1.482731487	4.906901543
272	1.352288272	-3.815569105	1.472391404	4.924053044
273	1.394447649	-4.213266114	1.462060534	4.985130693
274	1.412001759	-4.609714714	1.451739946	4.954977673
275	1.389214335	-5.004797437	1.441430742	4.784312338
276	1.346513015	-5.398397218	1.431134055	4.550056663
277	1.322177119	-5.790397432	1.420851054	4.382930852
278	1.338022403	-6.180681927	1.410582949	4.350312925
279	1.379844466	-6.569135061	1.400330991	4.399299235
280	1.41015219	-6.955641733	1.390096474	4.407887899
281	1.401776415	-7.34008742	1.379880743	4.295070727
282	1.362225548	-7.722358209	1.369685191	4.090575624
283	1.326954708	-8.102340831	1.359511267	3.904390445
284	1.32758221	-8.479922697	1.349360476	3.826831971
285	1.363545533	-8.854991927	1.339234383	3.849894518
286	1.402605591	-9.227437386	1.329134615	3.878267545
287	1.409747248	-9.597148718	1.319062867	3.816715595
288	1.378568413	-9.964016375	1.309020901	3.653828815
289	1.337019149	-10.32793165	1.299010551	3.468611061
290	1.322346024	-10.68878672	1.289033728	3.357298055
291	1.347702665	-11.04647466	1.279092417	3.348084873
292	1.390358277	-11.40088948	1.269188688	3.379245089
293	1.412074513	-11.75192618	1.259324691	3.357195006
294	1.393383995	-12.09948072	1.249502665	3.240064942
295	1.351041716	-12.44345015	1.239724936	3.072248121
296	1.323005137	-12.78373252	1.229993924	2.941692655
297	1.334407467	-13.12022703	1.220312143	2.90080933
298	1.375027161	-13.45283396	1.210682204	2.922045547
299	1.408450959	-13.78145475	1.201106817	2.925606884
300	1.404716314	-14.10599205	1.191588796	2.851797552
301	1.367171125	-14.42634968	1.182131057	2.712501749
302	1.329472532	-14.74243273	1.172736623	2.577561656
303	1.325415193	-15.05414753	1.163408627	2.510927019
304	1.358636284	-15.36140173	1.154150309	2.514851897
305	1.399354974	-15.66410428	1.144965022	2.530717867
306	1.411069257	-15.96216549	1.135856234	2.493191282
307	1.383277942	-16.25549705	1.126827522	2.387802874
308	1.340894371	-16.54401204	1.117882581	2.261317014
309	1.321913022	-16.82762496	1.10902522	2.177959674
310	1.343349601	-17.1062518	1.100259363	2.162343458
311	1.385987426	-17.37980998	1.091589048	2.179710889
312	1.411604097	-17.64821845	1.08301843	2.169096191
313	1.397235715	-17.91139768	1.074551772	2.097932613
314	1.355762723	-18.1692697	1.066193452	1.989293276
315	1.324363315	-18.42175808	1.057947956	1.899156865
316	1.331185286	-18.66878802	1.049819878	1.865882908

317	1.370113125	-18.91028632	1.041813912	1.877399683
318	1.406250223	-19.14618143	1.033934855	1.884033304
319	1.407201714	-19.37640344	1.026187596	1.843692545
320	1.37211464	-19.60088415	1.018577117	1.758404728
321	1.33244258	-19.81955703	1.01110848	1.670603175
322	1.323749294	-20.0323573	1.003786827	1.624191308
323	1.353827822	-20.2392219	0.996617368	1.626006681
324	1.395714463	-20.44008953	0.989605377	1.641400399
325	1.41186021	-20.63490068	0.982756178	1.626340217
326	1.387791313	-20.82359763	0.976075139	1.566388943
327	1.345084179	-21.00612445	0.969567658	1.488148186
328	1.32202334	-21.18242708	0.963239155	1.43428141
329	1.339281535	-21.35245327	0.957095058	1.425459305
330	1.381387768	-21.51615264	0.951140788	1.443070157
331	1.41059618	-21.67347668	0.945381748	1.447027503
332	1.40072308	-21.82437878	0.939823306	1.411738191
333	1.360619144	-21.96881423	0.93447078	1.34804392
334	1.326235285	-22.10674023	0.929329423	1.292419893
335	1.32839469	-22.23811592	0.924404403	1.274054288
336	1.365161574	-22.36290235	0.919700791	1.289427121
337	1.403576503	-22.48106257	0.915223537	1.306432105
338	1.409202664	-22.59256156	0.910977457	1.293480672
339	1.376996521	-22.69736627	0.906967211	1.247280603
340	1.335829062	-22.79544567	0.903197288	1.194943049
341	1.322604587	-22.88677068	0.899671986	1.169289803
342	1.349178092	-22.97131425	0.896395392	1.179772537
343	1.39172793	-23.04905132	0.893371369	1.204677999
344	1.412110576	-23.11995886	0.890603534	1.210968685
345	1.39205414	-23.18401587	0.888095243	1.183685693
346	1.349538083	-23.24120335	0.885849578	1.138827307
347	1.322675648	-23.29150438	0.883869327	1.108669536
348	1.33554749	-23.33490403	0.882156975	1.112946074
349	1.37661473	-23.37138946	0.880714691	1.141534014
350	1.409062908	-23.40094984	0.879544312	1.163774683
351	1.403804065	-23.42357643	0.878647343	1.155876514
352	1.365552457	-23.43926252	0.878024938	1.12198519
353	1.32859849	-23.44800346	0.877677905	1.09032449
354	1.326069306	-23.44979666	0.877606694	1.087983167
355	1.360232177	-23.44464159	0.877811396	1.11679599
356	1.400462019	-23.43253977	0.878291746	1.151720761
357	1.410695051	-23.4134948	0.879047122	1.163141735
358	1.381757939	-23.38751231	0.880076547	1.143302413
359	1.339591169	-23.3546	0.881378696	1.113354932
360	1.321994867	-23.31476764	0.882951904	1.104641993
361	1.344743124	-23.26802701	0.884794169	1.130718606
362	1.387443413	-23.21439197	0.886903171	1.175008207

363	1.411817337	-23.15387841	0.889276275	1.205298831
364	1.396015051	-23.08650426	0.891910549	1.202457083
365	1.354202411	-23.01228948	0.894802777	1.177852097

Average Monthly K_t Values Calculation

Month	H0 (kWh/m^2)	H (kWh/m^2)	Kt
January	1.574313353	0.4	0.25407902
February	3.014583979	1.1	0.3648928
March	5.415995098	2.2	0.40620421
April	8.287481775	3.7	0.44645649
May	10.70163702	5.1	0.4765626
June	11.84328066	5.6	0.47284196
July	11.23445464	5.3	0.471763
August	9.100982838	4.2	0.46148862
September	6.247374021	2.8	0.44818831
October	3.587932073	1.4	0.39019691
November	1.820768482	0.6	0.32953119
December	1.172910522	0.35	0.29840298

Dailly K_t values calculation factors

Month	mean H (kWh/m^2)	$K_{t,min}$	$K_{t,max}$	E factor	gamma
January	0.42091723	0.05	0.619197828	1.558938683	-2.8626682
February	1.11409071	0.05	0.659962382	2.067181528	0.50861692
March	2.26234233	0.05	0.677202457	2.314415167	1.52465378
April	3.76583497	0.05	0.693744751	2.603215943	2.43933671
May	5.16524342	0.05	0.70588668	2.860086431	3.09709766
June	5.61081867	0.05	0.704899676	2.822141314	3.00211024
July	5.354934	0.05	0.704501523	2.812175263	2.9777456
August	4.23694388	0.05	0.699854817	2.726287625	2.76858363
September	2.82889773	0.05	0.6929574	2.626791637	2.51716339
October	1.40359968	0.05	0.670001012	2.215839592	1.15447187
November	0.60416692	0.05	0.646219507	1.88266971	-0.4659179
December	0.35673201	0.05	0.633696235	1.740852922	-1.3867957

Dailly H, K_t and Energy Output Results

Day of Year, N	H_0 (kWh/m^2)	Kt	H (kWh/m^2)	E_{out} (kWh/m^2))
1	1.223621204	0.378436171	0.463062524	0.052094534
2	1.199780828	0.486281484	0.583431201	0.06563601
3	1.190379473	0.16104246	0.191701638	0.021566434
4	1.217709271	0.278285532	0.338870873	0.038122973
5	1.272391354	0.261291069	0.332464497	0.037402256
6	1.321031146	0.073416129	0.096984993	0.010910812
7	1.33578749	0.06386051	0.08530407	0.009596708
8	1.319767311	0.083240508	0.109858101	0.012359036
9	1.305163453	0.136990738	0.178795304	0.020114472
10	1.324974269	0.296149237	0.392390118	0.044143888
11	1.383064779	0.200542442	0.277363189	0.031203359
12	1.44965591	0.355977192	0.51604444	0.058055
13	1.487222253	0.125558661	0.186733635	0.021007534
14	1.484375551	0.229597869	0.340809463	0.038341065
15	1.467233792	0.314975918	0.462143311	0.051991122
16	1.477073995	0.428213429	0.63250292	0.071156578
17	1.533290122	0.214768153	0.329301888	0.037046462
18	1.614810797	0.148809638	0.24029941	0.027033684
19	1.677673012	0.334875344	0.561811328	0.063203774
20	1.694232122	0.245085163	0.415231156	0.046713505
21	1.679138797	0.093349201	0.156746266	0.017633955
22	1.677785508	0.054559336	0.091538863	0.010298122
23	1.726133397	0.103759158	0.179102148	0.020148992
24	1.817377295	0.519388574	0.943925001	0.106191563
25	1.906250236	0.17371925	0.331152362	0.037254641
26	1.948740568	0.114488888	0.223109141	0.025099778
27	1.942484129	0.596824101	1.159321344	0.130423651
28	1.930865524	0.555965053	1.073493754	0.120768047
29	1.965376674	0.456042264	0.896294829	0.100833168
30	2.058774034	0.186873454	0.384730215	0.043282149
31	2.171549644	0.402438918	0.873916089	0.09831556
32	2.245704984	0.573821419	1.288633621	0.144971282
33	2.257096861	0.650575433	1.468411768	0.165196324
34	2.239209548	0.301408053	0.674915789	0.075928026
35	2.255166933	0.473463268	1.067738706	0.120120604
36	2.341194641	0.452761942	1.060003832	0.119250431
37	2.472070419	0.112839633	0.278947519	0.031381596
38	2.581343294	0.08794427	0.227014351	0.025539114
39	2.620380872	0.137423704	0.360102445	0.040511525
40	2.603874038	0.255934207	0.666420437	0.074972299
41	2.599354158	0.493948898	1.283948123	0.144444164
42	2.667678494	0.367705603	0.980920329	0.110353537
43	2.806819403	0.554155423	1.555414193	0.174984097

44	2.95075123	0.232796696	0.686925138	0.077279078
45	3.027063979	0.41069369	1.243196076	0.139859559
46	3.023144851	0.514223281	1.554571465	0.17488929
47	3.000534209	0.612572947	1.838046082	0.206780184
48	3.041849585	0.389317133	1.18424416	0.133227468
49	3.17589875	0.278802596	0.885448816	0.099612992
50	3.348757037	0.534290729	1.789209838	0.201286107
51	3.469481797	0.431840329	1.49826216	0.168554493
52	3.491887043	0.161704171	0.564652699	0.063523429
53	3.458922417	0.062729629	0.21697692	0.024409904
54	3.467226896	0.185688441	0.643823958	0.072430195
55	3.580832867	0.323756554	1.159318109	0.130423287
56	3.77098077	0.209383655	0.789581737	0.088827945
57	3.938432451	0.631666006	2.487773896	0.279874563
58	4.001406275	0.345853876	1.383901871	0.15568896
59	3.971287599	0.593292654	2.356135759	0.265065273
60	3.946131429	0.571415393	2.25488024	0.253674027
61	4.024421313	0.629948605	2.535178592	0.285207592
62	4.214818438	0.334307034	1.409043451	0.158517388
63	4.424491462	0.490038998	2.168173361	0.243919503
64	4.539976132	0.472477982	2.145038761	0.241316861
65	4.530233826	0.129690973	0.587530431	0.066097173
66	4.478357494	0.098966462	0.443207196	0.04986081
67	4.510008433	0.159040392	0.717273508	0.08069327
68	4.680043506	0.288822033	1.351699679	0.152066214
69	4.919534571	0.507142061	2.494902902	0.280676577
70	5.094047411	0.397116767	2.02293164	0.22757981
71	5.124099904	0.555927841	2.848629797	0.320470852
72	5.05989583	0.264839224	1.340058883	0.150756624
73	5.040215897	0.435879153	2.196925036	0.247154067
74	5.168774069	0.523810452	2.70745788	0.304589011
75	5.418120142	0.601334741	3.258103874	0.366536686
76	5.64998539	0.416784272	2.354825047	0.264917818
77	5.737646457	0.311958746	1.789908995	0.201364762
78	5.682052937	0.540065717	3.068681992	0.345226724
79	5.615351328	0.454433814	2.551805519	0.287078121
80	5.68468799	0.187132551	1.063790162	0.119676393
81	5.918366042	0.066731646	0.394942308	0.04443101
82	6.196023637	0.214070755	1.326387457	0.149218589
83	6.353534664	0.643800638	4.090409668	0.460171088
84	6.331279232	0.355918865	2.253421715	0.253509943
85	6.231837873	0.239946079	1.495305063	0.16822182
86	6.231552018	0.67065679	4.179232676	0.470163676
87	6.42203279	0.657366162	4.221627048	0.474933043
88	6.724023816	0.6157977	4.140638402	0.46582182
89	6.954407507	0.376841231	2.620707485	0.294829592

90	6.989896502	0.586545655	4.09989342	0.46123801
91	6.88106533	0.616566308	4.242633046	0.477296218
92	6.811319138	0.665753303	4.534658213	0.510149049
93	6.933684663	0.397262509	2.754492968	0.309880459
94	7.230623349	0.545408641	3.943644453	0.443660001
95	7.525213201	0.52956504	3.985089829	0.448322606
96	7.637726351	0.16298904	1.244865687	0.14004739
97	7.549020786	0.1214519	0.916842919	0.103144828
98	7.422191693	0.200702017	1.489648841	0.167585495
99	7.459008868	0.3500299	2.610876127	0.293723564
100	7.717447391	0.560662637	4.326884402	0.486774495
101	8.055308523	0.459250305	3.699402899	0.416182826
102	8.254409576	0.603288726	4.979792241	0.560226627
103	8.216918709	0.324202551	2.66394601	0.299693926
104	8.057105769	0.495913388	3.995626617	0.449507994
105	8.002580745	0.57536934	4.604439604	0.517999455
106	8.190242647	0.641897068	5.257292739	0.591445433
107	8.539878445	0.477991574	4.08198994	0.459223868
108	8.822023837	0.374326074	3.302313548	0.371510274
109	8.862845296	0.589566668	5.22523817	0.587839294
110	8.70304505	0.513084415	4.46539678	0.502357138
111	8.565519041	0.235235999	2.014918431	0.226678323
112	8.657019408	0.075226611	0.65123823	0.073264301
113	8.980315054	0.267085515	2.398512068	0.269832608
114	9.327500495	0.677180239	6.316399015	0.710594889
115	9.464206176	0.418983369	3.965344987	0.446101311
116	9.341446024	0.296637978	2.771027656	0.311740611
117	9.143540011	0.688297278	6.293473698	0.708015791
118	9.125513396	0.653998695	5.968073854	0.671408309
119	9.383393783	0.439611039	4.125043491	0.464067393
120	9.764340503	0.629427306	6.145942538	0.691418536
121	10.00057283	0.629692787	6.297288582	0.708444966
122	9.949741327	0.662357347	6.590284266	0.74140698
123	9.725874179	0.429943712	4.181578445	0.470427575
124	9.60044916	0.566625726	5.439861471	0.611984415
125	9.759328155	0.552386778	5.390923837	0.606478932
126	10.13323854	0.188201155	1.907087202	0.21454731
127	10.45640702	0.139772739	1.461520653	0.164421074
128	10.50385085	0.230304322	2.419082251	0.272146753
129	10.29536208	0.384326457	3.956780037	0.445137754
130	10.0811629	0.580263176	5.849727598	0.658094355
131	10.11902372	0.488174492	4.939849271	0.555733043
132	10.4414241	0.618026552	6.453077338	0.7259712
133	10.82313199	0.35884872	3.883867059	0.436935044
134	10.98122211	0.521874263	5.730817191	0.644716934
135	10.82982452	0.593347895	6.425853579	0.722908528

136	10.56010627	0.331187052	3.49737046	0.393454177
137	10.47103695	0.605922947	6.344641561	0.713772176
138	10.7007779	0.407940022	4.365275578	0.491093503
139	11.10011936	0.672550297	7.465388571	0.839856214
140	11.36388655	0.300931641	3.419753032	0.384722216
141	11.30455294	0.267545269	3.024479656	0.340253961
142	11.0226087	0.082776759	0.912415825	0.10264678
143	10.81883589	0.651832101	7.052064534	0.79335726
144	10.92503222	0.682431293	7.455583866	0.838753185
145	11.29435271	0.450543094	5.088592622	0.57246667
146	11.64096525	0.537490816	6.256911918	0.703902591
147	11.69553491	0.701329936	8.202428746	0.922773234
148	11.4480488	0.692018864	7.922265725	0.891254894
149	11.15893513	0.50546384	5.640438199	0.634549297
150	11.12656311	0.469906717	5.228446744	0.588200259
151	11.4187775	0.640952162	7.318890129	0.82337514
152	11.81013424	0.636213554	6.223173897	0.700107063
153	11.98286322	0.66968099	8.024695702	0.902778266
154	11.81231602	0.432190225	5.105167516	0.574331346
155	11.48033599	0.571667516	6.562935165	0.738330206
156	11.31338956	0.557109158	6.302792929	0.709064205
157	11.48960328	0.187689066	2.156472907	0.242603202
158	11.8777344	0.139215589	1.653565786	0.186026151
159	12.15370697	0.229996379	2.795308593	0.314472217
160	12.0911793	0.385799857	4.66477524	0.524787215
161	11.76546556	0.585616146	6.890046599	0.775130242
162	11.48698172	0.491533067	5.64623136	0.635201028
163	11.52303901	0.624266347	7.193445466	0.809262615
164	11.85745442	0.359932972	4.267888806	0.480137491
165	12.20426917	0.525932232	6.418618517	0.722094583
166	12.26397188	0.599004073	7.346169115	0.826444025
167	11.99251207	0.331886982	3.980158636	0.447767847
168	11.6413418	0.61187464	7.12304182	0.801342205
169	11.53206921	0.409801981	4.72586481	0.531659791
170	11.76778514	0.680129095	8.00361305	0.900406468
171	12.14031803	0.301260681	3.657400475	0.411457553
172	12.31689895	0.267530721	3.295148859	0.370704247
173	12.13876013	0.082466797	1.001044672	0.112617526
174	11.76357734	0.658894525	7.750956701	0.871982629
175	11.52388819	0.690259422	7.954472401	0.894878145
176	11.62868961	0.453168012	5.269750156	0.592846893
177	11.97613972	0.541885318	6.489694285	0.730090607
178	12.24531368	0.700090734	8.572830644	0.964443447
179	12.18430309	0.509176503	6.203960838	0.697945594
180	11.83588565	0.472902577	5.597220824	0.629687343
181	11.49849234	0.647747047	7.448114466	0.837912877

182	11.45810356	0.626410648	7.177478083	0.807466284
183	11.73207373	0.659855361	7.74147175	0.870915572
184	12.05449629	0.423328295	5.10300936	0.574088553
185	12.1154155	0.561998901	6.808850203	0.765995648
186	11.83857895	0.547489212	6.481494257	0.729168104
187	11.44870757	0.182921887	2.094219196	0.23559966
188	11.26893142	0.135866375	1.531068859	0.172245247
189	11.43108963	0.224187052	2.56270228	0.288304006
190	11.75877605	0.377405653	4.437828551	0.499255712
191	11.92693614	0.575907561	6.868812707	0.77274143
192	11.75357083	0.482228962	5.667912263	0.63764013
193	11.36164524	0.614478911	6.9814914	0.785417783
194	11.0671127	0.351852326	3.893989343	0.438073801
195	11.09506824	0.516441839	5.729957447	0.644620213
196	11.37918205	0.58926301	6.705331069	0.754349745
197	11.62322458	0.324193287	3.768171382	0.423919281
198	11.5676633	0.602107577	6.964977725	0.783559994
199	11.22129838	0.40115133	4.501438765	0.506411861
200	10.85111606	0.670302261	7.273527632	0.818271859
201	10.74150439	0.294050076	3.15854018	0.35533577
202	10.94010486	0.260932035	2.854623829	0.321145181
203	11.21755196	0.081126078	0.910035991	0.102379049
204	11.27503053	0.649073014	7.318318044	0.82331078
205	11.01177011	0.680433958	7.492782323	0.842938011
206	10.61292405	0.444131034	4.713528927	0.530272004
207	10.38124125	0.532324194	5.526185876	0.621695911
208	10.46562694	0.699824023	7.32409715	0.823960929
209	10.73009366	0.690268916	7.406650116	0.833248138
210	10.87846814	0.499770901	5.436741827	0.611633456
211	10.7205157	0.463719965	4.971317166	0.559273181
212	10.34027191	0.63793296	6.596400265	0.74209503
213	10.01761338	0.618392571	6.194817694	0.696916991
214	9.976206717	0.653211071	6.516568677	0.733113976
215	10.18494391	0.409917351	4.17498523	0.469685838
216	10.3892226	0.551672975	5.731453339	0.644788501
217	10.34099413	0.536711462	5.550130082	0.624389634
218	10.01966524	0.173289707	1.736304855	0.195334296
219	9.647080008	0.128888726	1.243399852	0.139882483
220	9.48629216	0.212825221	2.018922229	0.227128751
221	9.606727195	0.363680675	3.493781034	0.393050366
222	9.825482956	0.566039321	5.561609696	0.625681091
223	9.874258077	0.46977182	4.638648188	0.521847921
224	9.639570877	0.605998343	5.841563979	0.657175948
225	9.261139117	0.338134997	3.131515249	0.352295466
226	9.003229115	0.504790151	4.544741382	0.511283405
227	9.017421322	0.579856044	5.228806256	0.588240704

228	9.209857335	0.310644147	2.860988274	0.321861181
229	9.329228068	0.593163655	5.53375902	0.62254789
230	9.193170112	0.387538354	3.562706013	0.400804426
231	8.849081561	0.664109303	5.876757384	0.661135206
232	8.527566877	0.280887298	2.395285214	0.269469587
233	8.433933081	0.248457057	2.095470196	0.235740397
234	8.56632706	0.078254438	0.670353112	0.075414725
235	8.721654561	0.641973754	5.599073317	0.629895748
236	8.680176473	0.674688313	5.856413624	0.658846533
237	8.401010707	0.430990314	3.620754243	0.407334852
238	8.054596938	0.52110333	4.197277284	0.472193694
239	7.866798066	0.694959844	5.467108755	0.615049735
240	7.91724291	0.684966273	5.423044372	0.610092492
241	8.072017472	0.487705203	3.936764918	0.442886053
242	8.107423901	0.450901313	3.65564808	0.411260409
243	7.910536053	0.63037557	4.986608671	0.560993475
244	7.576739401	0.617148644	4.675974448	0.526047125
245	7.320145111	0.665484921	4.871446193	0.548037697
246	7.280889674	0.400407362	2.91532183	0.327973706
247	7.402800987	0.547065155	4.04981447	0.455604128
248	7.488182125	0.531432501	3.979463354	0.447689627
249	7.376646493	0.165407855	1.220155272	0.137267468
250	7.086253902	0.123178143	0.872871595	0.098198054
251	6.792817416	0.20357679	1.382859962	0.155571746
252	6.670006051	0.353383262	2.357068493	0.265170205
253	6.735675289	0.562105884	3.786162713	0.425943305
254	6.840403652	0.461912326	3.159666765	0.355462511
255	6.804457993	0.604086283	4.110479736	0.46242897
256	6.577722633	0.327604534	2.154891755	0.242425322
257	6.280325835	0.498191176	3.128802913	0.351990328
258	6.091436583	0.576597883	3.512309438	0.395134812
259	6.089099815	0.642051466	3.909515462	0.439820489
260	6.184301189	0.480465729	2.971344782	0.334276288
261	6.204770912	0.377590671	2.342863612	0.263572156
262	6.049835494	0.590579785	3.572910548	0.401952437
263	5.777168545	0.515159416	2.976162772	0.334818312
264	5.546855943	0.238397857	1.322358569	0.148765339
265	5.476741086	0.075919595	0.415791963	0.046776596
266	5.539756475	0.270411285	1.498012667	0.168526425
267	5.59261267	0.676702899	3.784537206	0.425760436
268	5.506181657	0.421984485	2.323523233	0.261396364
269	5.279013633	0.300036248	1.583895444	0.178188237
270	5.03429479	0.687612789	3.461645479	0.389435116
271	4.906901543	0.653940949	3.208823851	0.360992683
272	4.924053044	0.442449813	2.178646348	0.245097714
273	4.985130693	0.629795151	3.139611136	0.353206253

274	4.954977673	0.555648104	2.75322395	0.309737694
275	4.784312338	0.618508157	2.959136207	0.332902823
276	4.550056663	0.312648045	1.422566319	0.160038711
277	4.382930852	0.470059065	2.06023638	0.231776593
278	4.350312925	0.451877506	1.965808556	0.221153463
279	4.399299235	0.12013424	0.528506469	0.059456978
280	4.407887899	0.09275814	0.408867481	0.045997592
281	4.295070727	0.146671562	0.629964731	0.070871032
282	4.090575624	0.26838063	1.097831262	0.123506017
283	3.904390445	0.487866825	1.904822568	0.214292539
284	3.826831971	0.375076288	1.435353931	0.161477317
285	3.849894518	0.539193519	2.075838174	0.233531795
286	3.878267545	0.245368598	0.95160507	0.10705557
287	3.816715595	0.414327815	1.581371431	0.177904286
288	3.653828815	0.505315845	1.846337594	0.207712979
289	3.468611061	0.587648226	2.038323137	0.229311353
290	3.357298055	0.394924367	1.325878808	0.149161366
291	3.348084873	0.290797095	0.973613355	0.109531502
292	3.379245089	0.522420294	1.765386214	0.198605949
293	3.357195006	0.433306117	1.454693133	0.163652977
294	3.240064942	0.17241998	0.558651933	0.062848342
295	3.072248121	0.064488503	0.198124681	0.022289027
296	2.941692655	0.197425049	0.580763816	0.065335929
297	2.90080933	0.63353539	1.837765369	0.206748604
298	2.922045547	0.333961312	0.975850164	0.109783143
299	2.925606884	0.221728487	0.648690389	0.072977669
300	2.851797552	0.662829666	1.890256019	0.212653802
301	2.712501749	0.648306361	1.758532139	0.197834866
302	2.577561656	0.603215615	1.554825439	0.174917862
303	2.510927019	0.354762723	0.890783306	0.100213122
304	2.514851897	0.57179593	1.43798208	0.161772984
305	2.530717867	0.502250888	1.271055297	0.142993721
306	2.493191282	0.589698399	1.470230908	0.165400977
307	2.387802874	0.240401136	0.574030523	0.064578434
308	2.261317014	0.397725415	0.899383248	0.101180615
309	2.177959674	0.377417576	0.822000261	0.092475029
310	2.162343458	0.093825373	0.202882681	0.022824302
311	2.179710889	0.076187694	0.166067147	0.018682554
312	2.169096191	0.111609194	0.242091077	0.027235246
313	2.097932613	0.202808126	0.425477781	0.04786625
314	1.989293276	0.418227239	0.831976634	0.093597371
315	1.899156865	0.298054842	0.5660529	0.063680951
316	1.865882908	0.480934591	0.897367633	0.100953859
317	1.877399683	0.184255691	0.345921575	0.038916177
318	1.884033304	0.33736941	0.635615205	0.071506711
319	1.843692545	0.43892679	0.80924605	0.091040181

320	1.758404728	0.545529311	0.959261321	0.107916899
321	1.670603175	0.31762211	0.530620506	0.059694807
322	1.624191308	0.221522325	0.359794635	0.040476896
323	1.626006681	0.459827919	0.747683268	0.084114368
324	1.641400399	0.357300087	0.586472505	0.065978157
325	1.626340217	0.1295416	0.210678715	0.023701355
326	1.566388943	0.058693777	0.091937283	0.010342944
327	1.488148186	0.147625096	0.219688019	0.024714902
328	1.43428141	0.612128548	0.877964597	0.098771017
329	1.425459305	0.259447479	0.369831822	0.04160608
330	1.443070157	0.165862248	0.239350861	0.026926972
331	1.447027503	0.634795583	0.918566668	0.10333875
332	1.411738191	0.567500237	0.801161758	0.090130698
333	1.34804392	0.278664354	0.375651788	0.042260826
334	1.292419893	0.523781018	0.676945006	0.076156313
335	1.274054288	0.443608785	0.565181675	0.063582938
336	1.289427121	0.538734374	0.694658713	0.078149105
337	1.306432105	0.200126964	0.261452291	0.029413383
338	1.293480672	0.340021	0.439810591	0.049478691
339	1.247280603	0.320976484	0.400347742	0.045039121
340	1.194943049	0.083013234	0.099196086	0.01115956
341	1.169289803	0.069626029	0.081413005	0.009158963
342	1.179772537	0.096653685	0.114029363	0.012828303
343	1.204677999	0.169017636	0.203611827	0.022906331
344	1.210968685	0.359582174	0.435442752	0.04898731
345	1.183685693	0.249462041	0.295284648	0.033219523
346	1.138827307	0.421666503	0.480205328	0.054023099
347	1.108669536	0.15395221	0.170682126	0.019201739
348	1.112946074	0.284333061	0.316447364	0.035600328
349	1.141534014	0.379688823	0.433427706	0.048760617
350	1.163774683	0.489604098	0.569788853	0.064101246
351	1.155876514	0.266686781	0.308256986	0.034678911
352	1.12198519	0.184404547	0.206899171	0.023276157
353	1.09032449	0.400372242	0.436535661	0.049110262
354	1.087983167	0.302422034	0.329030082	0.037015884
355	1.11679599	0.11055715	0.123469781	0.01389035
356	1.151720761	0.056482838	0.065052458	0.007318401
357	1.163141735	0.12473397	0.145083286	0.01632187
358	1.143302413	0.564614625	0.645525264	0.072621592
359	1.113354932	0.216199845	0.240707164	0.027079556
360	1.104641993	0.139195111	0.153760765	0.017298086
361	1.130718606	0.619340303	0.700299604	0.078783705
362	1.175008207	0.591458425	0.694968503	0.078183957
363	1.205298831	0.513750889	0.619223346	0.069662626
364	1.202457083	0.23263917	0.279738618	0.031470595
365	1.177852097	0.466239771	0.549161492	0.061780668

Appendix II – Wind Climate Model Results

Monthly mean wind speeds and resultant scale parameter

month	mean v (m/s)	scale parameter, c (m/s)
January	6.5	7.309228579
February	6.15	6.915654733
March	5.81	6.533325853
April	5.28	5.9373426
May	4.85	5.453809017
June	4.69	5.273889544
July	4.47	5.026500269
August	4.81	5.408829149
September	5.14	5.779913061
October	5.36	6.027302336
November	5.63	6.330916446
December	5.92	6.657020491

Monthly Weibull probability distributions for determining wind speeds (Rounded to 4 decimal places in table below)

potential wind speeds (m/s)	January	February	March	April	May	June	July	August	September	October	November	December
1	0.0488	0.0537	0.0593	0.0700	0.0810	0.0858	0.0932	0.0822	0.0733	0.0682	0.0627	0.0574
2	0.0792	0.0867	0.0949	0.1102	0.1255	0.1320	0.1416	0.1271	0.1149	0.1077	0.0997	0.0921
3	0.0988	0.1068	0.1155	0.1310	0.1455	0.1513	0.1596	0.1469	0.1356	0.1285	0.1205	0.1126
4	0.1084	0.1156	0.1231	0.1352	0.1453	0.1490	0.1537	0.1462	0.1385	0.1334	0.1271	0.1206
5	0.1097	0.1150	0.1199	0.1268	0.1309	0.1318	0.1324	0.1312	0.1284	0.1259	0.1224	0.1183
6	0.1043	0.1071	0.1091	0.1103	0.1087	0.1072	0.1043	0.1083	0.1101	0.1104	0.1099	0.1086
7	0.0943	0.0946	0.0938	0.0901	0.0841	0.0810	0.0760	0.0834	0.0885	0.0909	0.0930	0.0942
8	0.0816	0.0797	0.0768	0.0696	0.0611	0.0573	0.0516	0.0602	0.0671	0.0709	0.0747	0.0779
9	0.0679	0.0644	0.0600	0.0510	0.0419	0.0382	0.0329	0.0410	0.0482	0.0526	0.0573	0.0616
10	0.0545	0.0501	0.0450	0.0357	0.0273	0.0241	0.0197	0.0265	0.0330	0.0372	0.0420	0.0468
11	0.0424	0.0376	0.0325	0.0239	0.0169	0.0144	0.0112	0.0162	0.0216	0.0252	0.0296	0.0342
12	0.0319	0.0273	0.0226	0.0153	0.0099	0.0082	0.0060	0.0095	0.0135	0.0164	0.0201	0.0241
13	0.0233	0.0191	0.0152	0.0094	0.0056	0.0044	0.0030	0.0053	0.0081	0.0102	0.0131	0.0164
14	0.0165	0.0130	0.0098	0.0056	0.0030	0.0023	0.0015	0.0028	0.0046	0.0061	0.0083	0.0108
15	0.0114	0.0086	0.0062	0.0032	0.0015	0.0011	0.0007	0.0014	0.0026	0.0036	0.0050	0.0069
16	0.0077	0.0055	0.0037	0.0017	0.0008	0.0005	0.0003	0.0007	0.0014	0.0020	0.0030	0.0043
17	0.0050	0.0034	0.0022	0.0009	0.0004	0.0002	0.0001	0.0003	0.0007	0.0011	0.0017	0.0026
18	0.0032	0.0021	0.0013	0.0005	0.0002	0.0001	0.0000	0.0001	0.0003	0.0006	0.0009	0.0015
19	0.0020	0.0012	0.0007	0.0002	0.0001	0.0000	0.0000	0.0001	0.0002	0.0003	0.0005	0.0008

20	0.0012	0.0007	0.0004	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	0.0001	0.0003	0.0005

Number of days at each wind speed (rounded to 3 decimal places for table below)

potential wind speeds (m/s)	January	February	March	April	May	June	July	August	September	October	November	December
1	1.512	1.504	1.839	2.101	2.512	2.575	2.888	2.548	2.200	2.115	1.880	1.780
2	2.457	2.427	2.942	3.307	3.891	3.959	4.390	3.939	3.447	3.339	2.992	2.856
3	3.062	2.991	3.582	3.931	4.510	4.539	4.949	4.554	4.067	3.985	3.616	3.491
4	3.362	3.238	3.815	4.057	4.505	4.469	4.766	4.533	4.156	4.135	3.814	3.739
5	3.401	3.219	3.717	3.805	4.058	3.955	4.105	4.067	3.851	3.902	3.672	3.668
6	3.234	2.999	3.383	3.310	3.368	3.216	3.233	3.358	3.303	3.421	3.296	3.365
7	2.924	2.648	2.909	2.703	2.606	2.430	2.356	2.584	2.654	2.818	2.789	2.920
8	2.530	2.232	2.380	2.087	1.895	1.720	1.601	1.866	2.013	2.197	2.241	2.413
9	2.106	1.804	1.861	1.531	1.300	1.147	1.020	1.272	1.447	1.630	1.718	1.909
10	1.691	1.404	1.396	1.071	0.846	0.722	0.611	0.821	0.991	1.154	1.261	1.450
11	1.313	1.053	1.007	0.717	0.523	0.431	0.346	0.503	0.647	0.782	0.889	1.060
12	0.988	0.764	0.700	0.459	0.308	0.245	0.185	0.294	0.404	0.508	0.603	0.748
13	0.722	0.536	0.470	0.283	0.173	0.132	0.094	0.163	0.242	0.317	0.394	0.510
14	0.512	0.365	0.305	0.167	0.093	0.068	0.045	0.087	0.139	0.190	0.248	0.336
15	0.354	0.241	0.191	0.095	0.048	0.033	0.021	0.044	0.077	0.110	0.151	0.214
16	0.238	0.154	0.116	0.052	0.023	0.016	0.009	0.021	0.041	0.061	0.089	0.133
17	0.155	0.096	0.068	0.028	0.011	0.007	0.004	0.010	0.021	0.033	0.051	0.080
18	0.099	0.058	0.039	0.014	0.005	0.003	0.001	0.004	0.010	0.017	0.028	0.046
19	0.062	0.034	0.022	0.007	0.002	0.001	0.001	0.002	0.005	0.009	0.015	0.026
20	0.037	0.020	0.012	0.003	0.001	0.000	0.000	0.001	0.002	0.004	0.008	0.014

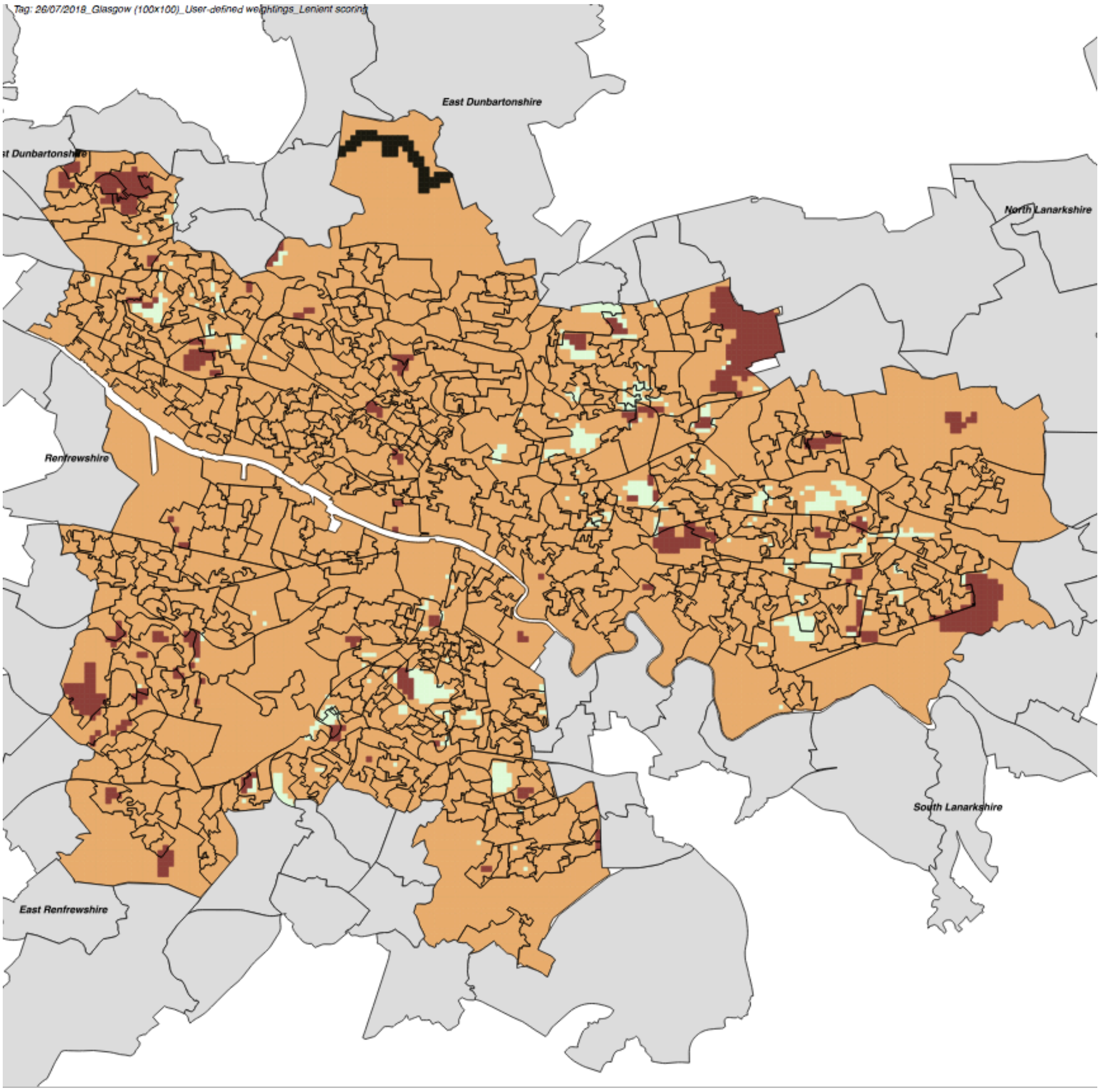
Appendix III – Minewater heat recovery model full results

The full range of calculated potential heat outputs from a minewater heat recovery scheme in the city is shown below. Potential temperature drop values (in degrees Kelvin) are presented in the top row, highlighted red, and potential flow rate values (in litres per second) are shown in the furthermost left hand column, highlighted in blue. The rest of the cells display the corresponding calculated available thermal output in Watts, for a heat pump with a COP of 3.5

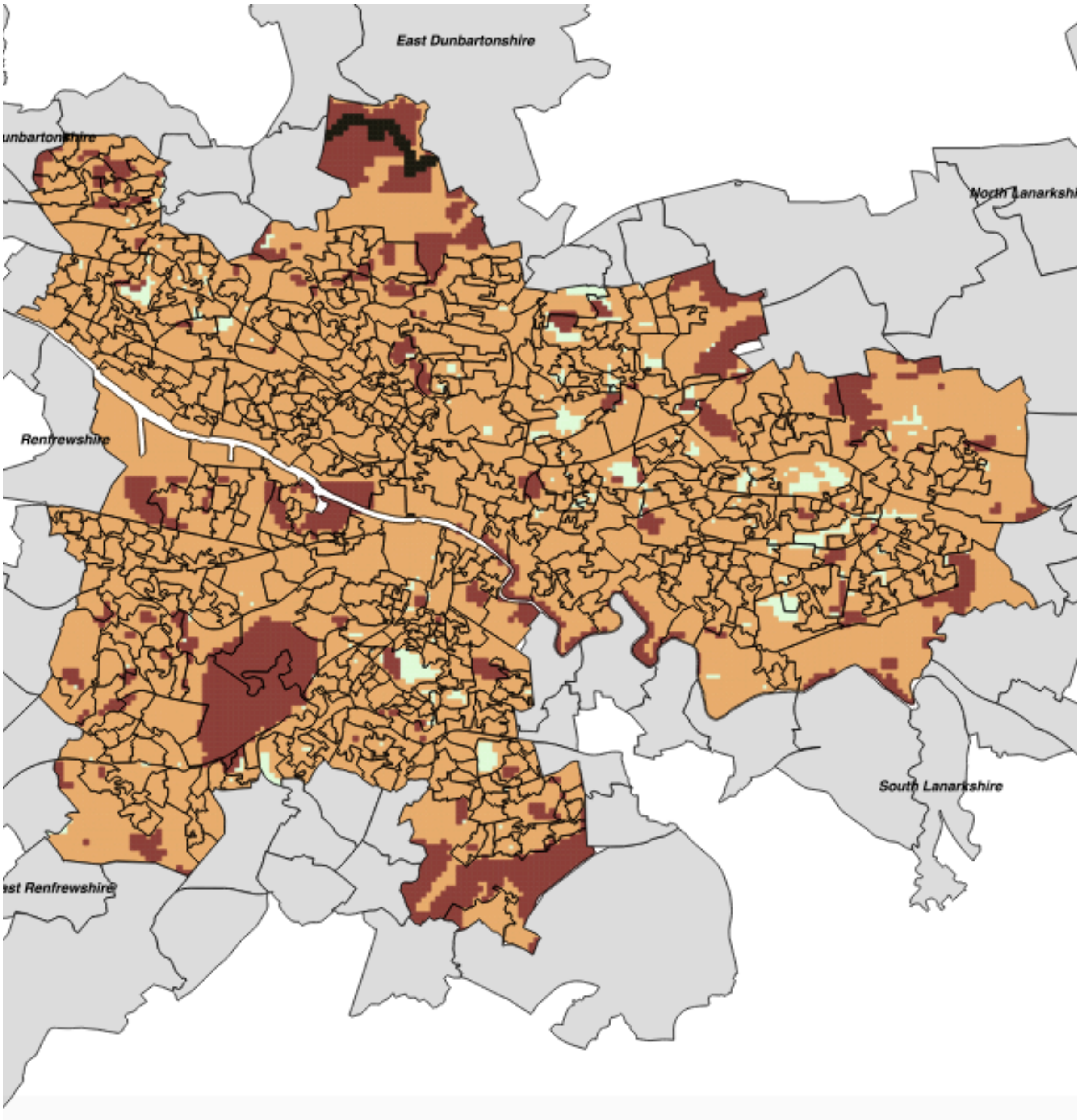
	2	3	4	5	6	7	8	9	10
5	58520	87780	117040	146300	175560	204820	234080	263340	292600
6	70224	105336	140448	175560	210672	245784	280896	316008	351120
7	81928	122892	163856	204820	245784	286748	327712	368676	409640
8	93632	140448	187264	234080	280896	327712	374528	421344	468160
9	105336	158004	210672	263340	316008	368676	421344	474012	526680
10	117040	175560	234080	292600	351120	409640	468160	526680	585200
11	128744	193116	257488	321860	386232	450604	514976	579348	643720
12	140448	210672	280896	351120	421344	491568	561792	632016	702240
13	152152	228228	304304	380380	456456	532532	608608	684684	760760
14	163856	245784	327712	409640	491568	573496	655424	737352	819280
15	175560	263340	351120	438900	526680	614460	702240	790020	877800
16	187264	280896	374528	468160	561792	655424	749056	842688	936320
17	198968	298452	397936	497420	596904	696388	795872	895356	994840
18	210672	316008	421344	526680	632016	737352	842688	948024	1053360
19	222376	333564	444752	555940	667128	778316	889504	1000692	1111880

Appendix IV – GoMap Land availability Maps

Biodiversity and Environmental Policy Factor half weighting



Developmental Policy Factor half weighting



Visual Intrusion Policy Factor half weighting