Department of Mechanical Engineering

Project
Spatial Mapping of Renewable Energy Potential in Springburn, Glasgow

Author: ADEKOYEJO A. OLUGBILE

Supervisor: Dr JAE MIN KIM

A thesis submitted in partial fulfilment for the requirement of the degree
Master of Science
Sustainable Energy: Renewable Energy Systems and the Environment

2011

Copyright Declaration

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

Signed: Adekoyejo Olugbile Date: 09/09/2011

Abstract

With increase in climate change effects around the world and buildings being responsible for a high contribution of carbon emissions especially urban areas, local authorities need to take the lead and responsibility in setting up climate change mitigating schemes which would include increase in micro energy generation through introduction of low carbon technologies in order to reduce carbon emissions, eradicate fuel poverty and provide job opportunities. However there is presently a minute level of implementation of low carbon technologies within the urban community.

This study investigates the feasibility of implementing renewable power energy generation within Springburn a suburban community at microgeneration scale and predicting the potential energy supply per identified location and analysis of the demand-supply matching. It describes how tools like Google Earth can be used to acquire data in a cost effective approach by identifying potential roof tops of 10,400 dwellings for PV mount and vacant lands for wind turbines that would be geo-referenced in a GIS environment in order to predict potential energy.

The objectives of the study are to determine a methodology for site selection of microgeneration of power; spatially identify and assess the renewable energy potential of sites in Springburn; assess the energy demand/supply matching within the study area; generate a GIS based demand and renewable energy map of Springburn community; and formulate recommendations for community micro power generation.

The investigation revealed thermal requirement were achieved via electric supply in most dwellings; low energy/km^2 hence only 20% of electrical consumption is met via renewable energy sources; and energy supply was best reserved for commercial energy users.

This led to recommendations for the local governing authorities of Glasgow that include review of existing policies, introduction of new electricity trading schemes and increased roll out of energy/carbon reduction initiatives. Demand and supply energy geo - database and maps were generated and a GIS based decision support tool was created.

Table of Contents

List of Figures

List of Tables

Acknowledgments

I wish to thank the Almighty God for the conclusion of this thesis in good health and peace of mind.

I wish to express my sincere appreciation to my supervisor Dr Jae-min Kim for his constant support throughout the preparation and write up of this thesis. I remember the feel when he broached the subject of learning GIS in order to pursue this thesis to a logical conclusion; he helped to push me beyond my supposed limits. I really cannot thank him enough.

I would like to thank David Forbes, Gavin Slater and Rohit Ramanchadran of Development and Regeneration Services department of Glasgow City Council for expressing interest in my thesis and supporting it till the completion.

A special thanks to the course director Dr Paul Strachan and all the esteemed members of the ESRU team whose familiarity with the needs and ideas of the class was helpful during the program phase of this undertaking; never have I received such academic support

I would like to thank my parents and siblings for bestowing me this opportunity to enrol on a master's program and the invaluable professional advice in GIS techniques which played a significant role in this study.

In addition, a big thank you to the members of this course, my super friends in Glasgow you were all wonderful I cannot begin to mention you all.

Chapter 1 Introduction

1.1. Background

Tackling climate change is a global issue as its threat are becoming surreal as years go by and neglecting it could lead to several terrible consequences for the human race. The human race needs to rise to the challenge of mitigating and or reversing climate change in order to avoid possible extinction from earth. (7) (8).This has necessitated policy makers, governments, scientists, engineers, developers and others to use technology to assess and understand the impacts of climate change and eventually plan effective solutions to combat this change. (9)

Cities are responsible for around 80% of the world's greenhouse gas emissions. (10) The UK urban environment is responsible for a large amount of carbon emissions from buildings with most of these emissions coming from residential buildings (11). The use of electrical and heat energy in buildings is responsible for these high carbon emissions. The UK government in 2008 through the Climate Change Act set a greenhouse gas emission target of 34 % by 2020 in an attempt to meet the 2050 target of 80 % greenhouse gas cut. (12) While in 2009 the Renewable Energy Directive set 15% energy consumption from renewable sources by 2020. (13). The Scottish government on the other hand is more ambitious and as such set 31 % and 50 % gross electricity generation from renewable sources for Scotland and an equivalent of 11 % heat demand from renewable sources by 2011 and 2020. (14).

But in order to achieve such ambitious goals, the built environment would need to be fully involved as most of the buildings existing presently would still be in use by 2050. (10) This thus necessitates the need to transform the urban community into a low carbon community by minimizing energy consumption whilst developing and implementing clean energy sources and technologies. (15) This would include such measures as improving energy efficiency and microgeneration through retro-fitting of renewable energy sources or low carbon technologies within the urban environment. (10)

Microgeneration according to the DECC, is the generation of low, zero or renewable energy at a micro scale. (16) Under the UK Energy Act of 2004, micro generation is defined as heat generation at less than 45kW and less than 50kW for electricity generation within community scale capacities. (16). Some of the benefits of microgeneration highlighted by the DECC are:

1. Reduction in energy bills and immunity of consumers to future rises in energy costs
2. Reduction in transmission losses through decentralized electricity generation and gas distribution.
3. The Feed - In -Tariff incentive to drive consumers to invest in renewable energy sources and even a reduced VAT for purchase.

However with the above benefits and incentives, resistance to change on local individual ownership of renewable energy sources still subsists. (17) This could thus slow down the possibility of achieving the set targets by governments in order to mitigate climate change effects as argued by others. (18). Although the Renewables Obligation policy was enacted in order to promote generation (18) but it does not seem to have achieved its purpose as anticipated. This is worthy of examination, in order to enact newer policies that would encourage other groups of individuals, communities, local authorities to invest in microgeneration of heat and power based on findings after this study.

The success of implementation of renewable energy sources at microgeneration scale would involve a lot of intelligent decision making, planning and monitoring by the local authorities, since the approach is at a microgeneration scale needing the use of effective tools to strategically site and assess the potential of renewable energy source available geographically through the use of Geographic Information System (GIS) as renewable energy sources have geographical qualities which are suitable for geographic analysis in the strategic planning of new facilities (19).

1.2. Geographic Information and Local Governments

Vanessa Lawrence, the director general and CEO of Ordnance Survey Great Britain, in her foreword to the book Geographic Information Management in Local Government acknowledged local governments as pioneers of digital information having recognized the potential of digital geographic data way ahead of their central counterparts and operators in the private sector. (20) Thus the local governments have from an early start relied upon geographic data for their day to day service delivery. (21). However the local governments are now saddled with the task of strategic policy decision-making role at the local level, and needs to meet wide range requirement of government targets (21), hence the need for the evolution of geographic information system (GIS) from mapping and visualization tools to predictive analysis and trend tools there by facilitating policy making, grant allocation, community strategy and public service delivery.(21) Decision making based on geography is a rudimentary human process which governments, policy makers, architects, engineers, investors, merchants all apply in order to make strategic decisions.

Geographic Information System is a technological tool for comprehending geography and making intelligent decisions. (22). Another source describes GIS as a system that allows one to view, understand, question, interpret and visualize data in many ways that reveal relationships, patterns and trends in the form of maps, reports and charts. (23). While the Chorley report describes GIS as "a system for capturing, storing, checking, integrating, manipulating, analysing, and displaying data which is spatially referenced to the earth" (DOE, 1987, cited in (20 p. 6)).

According to a revised version of Longley's (2005) representation of relationship of governments and communities with decision making depicted in Fig 1, shows the different echelons of decisions making and responsibilities from the central governments to the local communities

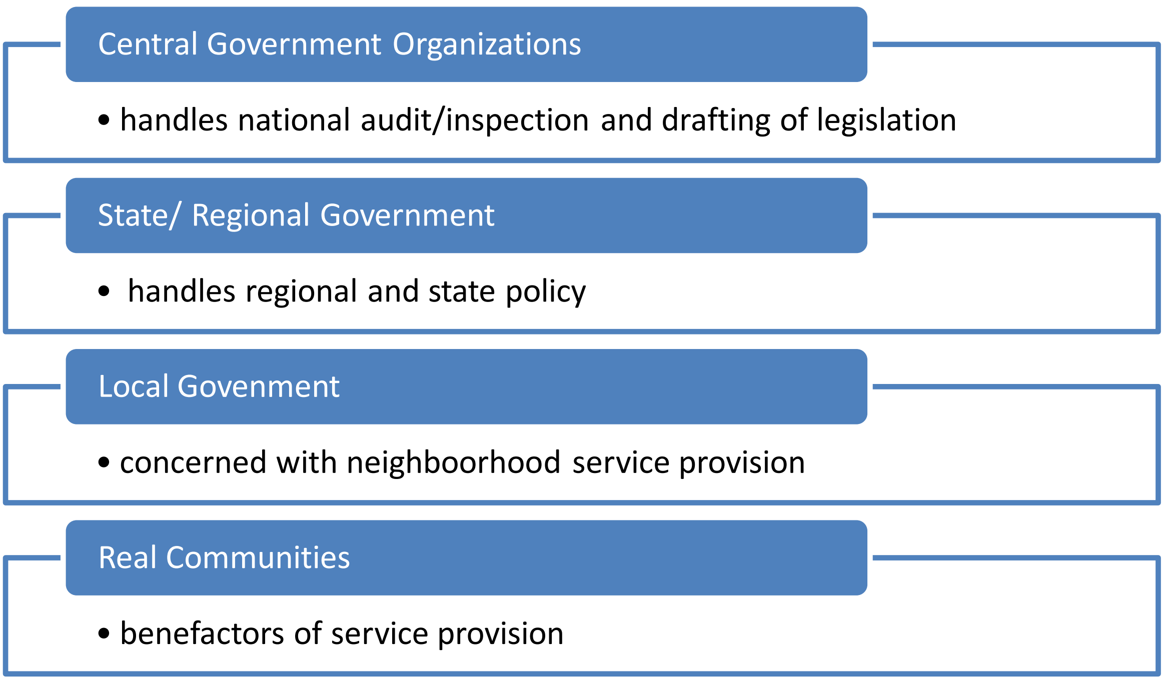


Figure 1 Use of GIS at different levels of Government decision making (21)

However this study focuses on the bottom two of the echelons, who are directly linked to the transformation of the community to a low carbon one and must therefore work together as a team.

1.3. Importance of Geographic Information

The importance of information and geographic information as adopted by Masser (1998) are summerised as follows:

1. A Resource as acknowledged by Cleveland (1985) who delves on to differentiate this from the economic terminology for resources. He argues *viz.*: information is expandable and increases with use; information is compressible and can easily be summerised; information is substitutable with other resources like physical facilities; information is diffusive; and in Eaton and Bawden’s (1991) view, information is sharable, not exchangeable, can be given away and retained at the same time (24).
2. A Commodity which can be traded and yet retained by the seller for another future transaction to another wilful buyer (24).
3. An Asset that needs to be effectively managed by governments in the national interest (24).
4. An Infrastructure comparable with transport networks, power, healthcare etc. that needs to be provided by the government (24).

The importance of geographic information can consequently be appreciated to be immeasurable within the confines of governments and its robust use within the departments cannot be overstated. However limited availability of GIS facilities and trained GIS users in units other than GIS unit within central and local governments are responsible for the slow pace of GIS application in other sectors apart from land and property. (25) This is buttressed by Longley *et al* (2005) who claims there are just about 4 million users of GIS spread across 2 million sites across the world. (21)

In Glasgow city council, the use of GIS technology is most active in the land and property units than in the energy efficiency and renewable energy units even though the units fall under the Development and Regeneration Services department. These units being no island depend on each other for the functionality of the larger department. However if each unit had a trained GIS user it could help in facilitating the job description of each of the several units.

In an enlightening interview session with members of the Sustainable Glasgow and the Energy efficiency teams, there was a concord on the use of GIS technology to aid the work of these teams via the Energy maps that would depict the energy consumption of buildings within the city and the potential renewable energy supply that can be generated at a per building level of analysis. This is in line with the Sustainable Glasgow report which advised for the following:

1. Creation of an energy masterplan for the city (10 p. 21)
2. Development of agreed indicators for measuring city's progress
3. Creation of a decision support system and
4. Monitoring impacts of progress (10 p. 22)

The creation of a decision support system is tied to the creation of an energy masterplan as the attributes of the latter are built on to achieve the former.
A GIS based tool effectively handles the requirement of the Sustainable Glasgow report and can be used to monitor the impacts of progress from the update of the GIS energy database.
The report also identified the key drivers to achieving a sustainable city as:

1. Carbon Reductions
2. Eradication of fuel poverty and
3. Provision of Job opportunities (10 p. 10)

With the introduction of a GIS based decision support tool, the first two key drivers would be achieved, and with the implementation of the carbon reductions technologies and GIS monitoring, job opportunities would be created within different sectors of the economy.
In view of the highlighted concerns, there was a need to study a much smaller area of Glasgow city that can be scaled up for use anywhere within the Glasgow city boundary. Considering Glasgow is a large city, Springburn Community was chosen; a suburban area within Glasgow city with a large population density, a mix of domestic and commercial activities and within 3 km distance from Glasgow city centre and also benefits from amenities and infrastructure as the larger city.

1.4. Project Requirement

In order for local governments to achieve their goal towards a low carbon economy, the already built environment would need to be carried along as 70% of buildings that would exist in 2050 have been built (26). As such, these buildings would need to be retrofitted with low energy renewable technologies in order to reduce their carbon foot print. Previous research have concentrated effort on zero carbon economies which are strongly associated to new builds or new cities like the MASDAR city in the United Arab Emirates until research proved that existing buildings generate a significant amount of carbon foot print.

To achieve a low carbon economy, the local governments would need to make strong political commitment in order to drive change and make use of their planning and enabling powers. (26) They would need geographic tools like GIS energy maps to accurately identify areas with good economic energy potentials and renewable technologies that could be placed in these identified sites.

The importance of this area of study is thus to generate a decision support tool that will facilitate and guide the local authority's decision makers planning a low carbon community and also aid the award of grants and incentives to site owners with suitable energy potential for micro heat and power generation.

1.5. Research Focus

The Energy and Climate Change minister Greg Baker in June 20011 clamoured for a revolution in energy generation at a local level, giving genuine power to the people. If this is to be achieved, local governments across the UK have to put up an intelligent strategic plan in order to accomplish the Energy minister's directive (27). Local governing authorities have a key role to play in coordinating action, making full use of planning powers and acting as pioneers and champions for the development of decentralized energy networks (26)

This research embarks on using Google Earth (GE) as a spatial resource in conjunction with GIS techniques to put up a framework for achieving a low carbon community through micro heat and power generation for Springburn community, a suburb within Glasgow. The potential of the following renewable sources would be studied and its economics of scale taking into consideration:

1. Photovoltaic
2. Solar thermal collectors
3. Combined heat and power (CHP)
4. Wind Turbine

5. Biomass

With the energy supply potential of the above mentioned renewable sources identified, a GIS based energy map of Springburn area would be prepared to establish the siting of each of the renewable technologies. These energy maps can then be useful for policy makers, local council, engineers, developers, architects, and investors in selecting sites for microgeneration of heat and power from these renewable energy sources available within Springburn community and predict the energy potential available from these sites. A renewable energy database of the identified prospective sites would also be created in order of potential energy available.

The energy maps and potential energy supply database of properties would help to facilitate award of grants to site owners with best energy potential while helping to eliminate the award of grants to sites with little or no feasible energy potential.

1.6. Overall Research Aim and Individual Research Objectives

The general objective of this study is to geographically identify and analyse the potential of feasible sites for micro heat and power generation using renewable technologies like PV, Solar thermal collectors, Wind turbines, CHP and Biomass within Springburn, a suburban community within Glasgow in order to achieve a low carbon community and to develop an updatable Renewable Energy GIS database for the properties identified based on this study for effective planning and monitoring for decision makers and investors.

The individual objectives of this study are to:

1. Determine a methodology for microgeneration of heat and power site selection

2. Spatially identify and assess the renewable energy potential of sites in Springburn

3. Assess the energy demand/supply matching within the study area

4. Generate a GIS based demand and renewable energy map of Springburn Community

5. Formulate recommendations for community micro heat and power generation

Chapter 2 Literature Review of Existing Cities and Approach

2.1. GIS use in Analysis of Profitability of Potential Wind Power Sites

California, United States

The energy crisis of the seventies in the United States led to the establishment of the Solar Energy Research Institute which later became National Renewable Energy Laboratory (NREL) (28) which was mandated to advance work on renewable resources including wind, solar, biomass and geothermal. (22)

The most prominent research of NREL was on wind energy, which coupled with GIS technologies, the team determined most favourable locations for wind farms based on transmission cost, location of load centres in connection with proximity to national electric grid. The benefactors of this project included utility developers who had all the information the needed about potential site without having to physically visit the site.

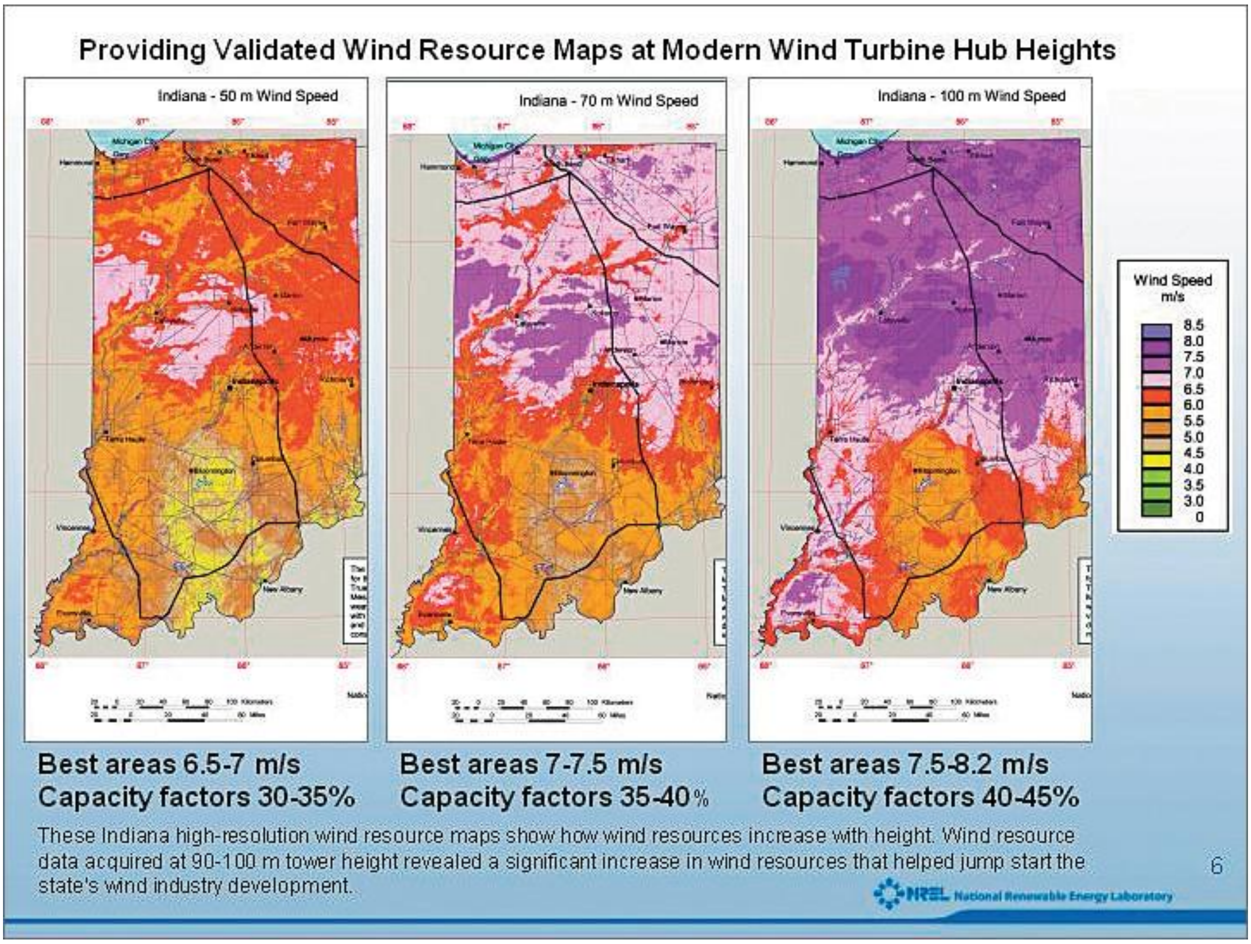


Figure 2 Indiana Wind Resource Map (22)

2.2. GIS use as a Marketing Strategy for Wind Energy Investment

Cascade County, Montana, United States

The Cascade county, used GIS technology to create business for the county through investment in production of wind energy maps with which information such as best wind power resource areas within the county, wind speeds in these areas, wind speed estimates 50 meters above the ground within the county, topography and parcels of lands that fall in this choice category available for lease by the county.

The county uses this valuable information as a key marketing strategy to steer investors and developers to invest in the county thereby encouraging local investment in the county and as admitted by the Cascade county commissioner Peggy Beltrone "the advantage of using GIS in the marketing of wind is that it gives developers a lot of information that they need to decide whether or not placing a wind turbine in this area is going to work for their power needs and their budgets"

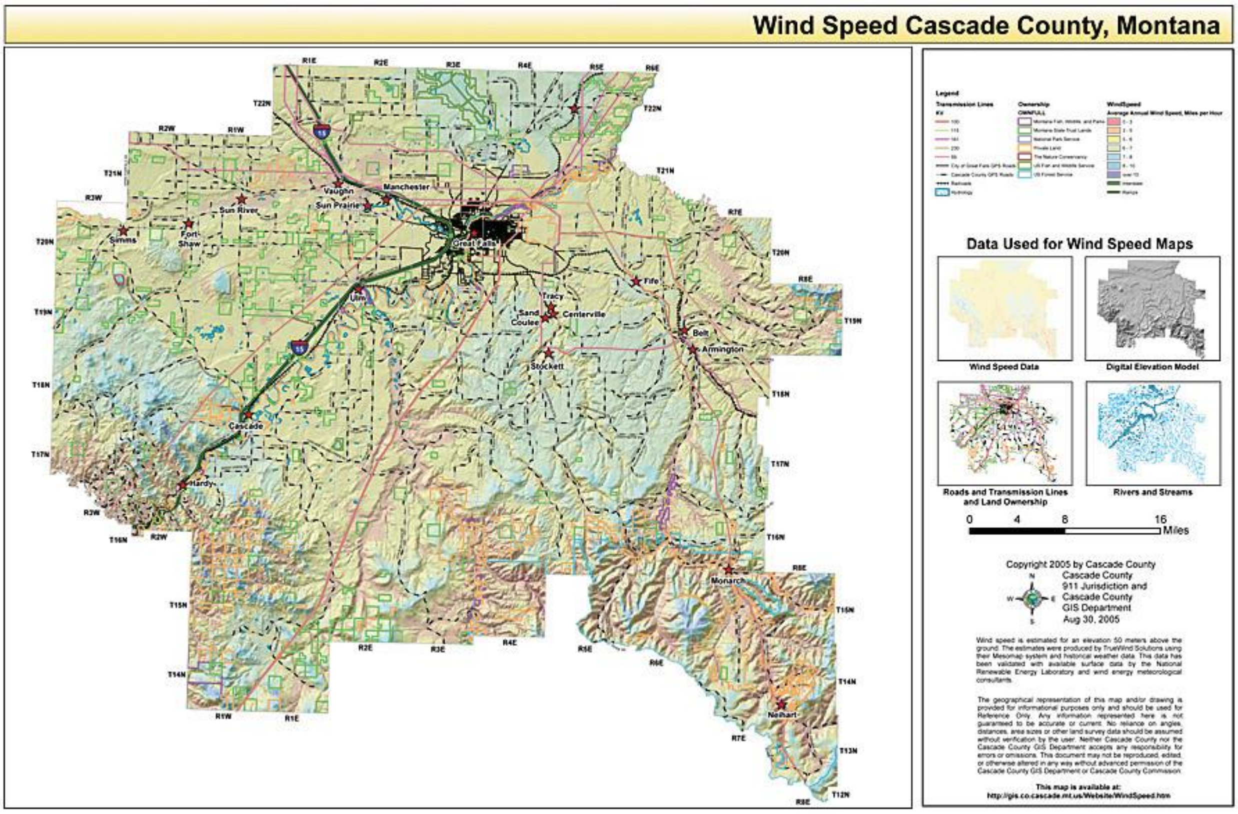


Figure 3 Wind Speed Map (22)

The county also provides custom wind maps for clients who require further information. This has helped to facilitate the development of wind farms within the county in a shorter time frame than if the investors were to carry out their own analysis.

2.3. GIS use in Development of Solar Power Investment

Boston, United States

In 2007, the mayor of Boston, Thomas Menino initiated the Solar Boston project in order to encourage and develop the extensive use of solar power through the city in order to meet the city's greenhouse gas reduction targets. A target of 25MW of solar power by 2015 was set by mayor and in order to achieve this, GIS techniques were employed to map current installations and thus track their progress. Although the city did not have maps showing potential solar roof tops and hence potential solar energy until there was a need to encourage investors to buy into the scheme consequently achieving their target within the set period.

This was achieved by developing a digital elevation model (DEM) of the city that was a base for use in the solar radiation tool available in the spatial analyst of the ArcGIS software to calculate the annual solar radiation per roof top. The consideration for the solar model includes elevation variation, roof orientation and slope, and shading caused by other buildings or features in sight. (22). Though a novel approach, this model could have left out buildings with south facing roof tops but inappropriate roof slope which could mean considerable roof tops missing out of the potential PV cover.

Since most of the buildings that would be available by 2050 exist now, if roof slopes were considered a strong enough reason not to install a PV system, then achieving the 2020 target might prove a little more challenging. (10). A south facing roof top with inappropriate roof slope need not be untapped as PV panel bracing can be adjusted to fit the roof slope angle and thus generate solar energy.

2.4. Predicting Solar Potential of Roof Tops using Laser Scanner

Osnabruck, Germany

The SUN – AREA project led by Prof. Dr Martina Klarle and team of researchers developed an interactive map and database which calculates the solar power potential per roof area in the different cities within the country. This was achieved through the use of an aircraft scanner to survey the city's roof tops in order to calculate the roof area and angle, its alignment and potential shading. (7)

The methodology adopted seems a rather expensive way of gathering roof information even though it had an accuracy of approximately 15cm in building position and height. Google Earth resource would provide about the same information in 3-dimensional view without the need to leave the desk. With Google earth, the roof areas can be calculated and effects of shading grasped and geographical location pinpointed all in one view.

Figure 4 SUN-AREA with Aircraft Scanner (29)

2.5. GIS use in Developing a Low Carbon City

Nottingham City Council, United Kingdom

In 2011 the Nottingham City Council appointed the ESRI UK, the leader in GIS technology to develop an interactive energy map aimed at carbon reduction emissions across the city. The interactive map would highlight information such as street that would benefit from greater wall insulation, to properties with south-facing roofs suitable for PV panels.

The council anticipates the use the interactive map as a decision support tool for both energy generation and energy efficiency initiatives. ESRI also plans to introduce LocalView Fusion, a GIS solution for Local authorities that would impact positively on their service delivery and in a cost effective manner. (30)

The benefactors of this project include council planners, energy managers and local businesses that can access and query necessary information from the internet when it is hosted. It would suffice to say that Nottingham City council has decided to leverage with GIS technology in its service delivery, but it would have been much more effective if several departments where linked together by GIS in order to have a very robust network of information.

2.6. Summary

The study of the relevant use of GIS in planning, implementing and monitoring of microgeneration of renewable energy within the urban environment is quiet challenging yet rewarding process that is still relatively new all around the world and especially in the UK.
The review clarifies the terms microgeneration and the scales involved, the impacts of microgeneration along with the policies enacted and incentives provided in order to encourage individuals to invest in the micro generation schemes. (18). The importance of GIS was properly elucidated and its invaluable use within government departments discussed.

The review of the literature stressed the need for governments to have a GIS based infrastructure that would act as a decision support tool for all energy actors involved in policy making, energy planning, and the local authorities who are to enforce the decisions agreed upon. Thereby strengthen the effectiveness of the policies enacted. (24). The Cascade County in Montana United States used its GIS infrastructure as a marketing strategy for interested energy developers in wind farm technology to lease land from the county thus primarily investing in the community and indirectly providing new jobs within the county. (22). In Nottingham the council authorities acknowledges the capabilities of GIS and its ability to effectively help in the city-wide carbon reduction strategy unlike most councils in the UK who have restricted the GIS use to other administrative activities within their offices.
In the case study of the SUN-AREA in Germany the data collection approach is prone to error considering the use of aircraft scanner flying over the city and capturing data.

Chapter 3 Methodology

3.1. Development of Analysis Framework

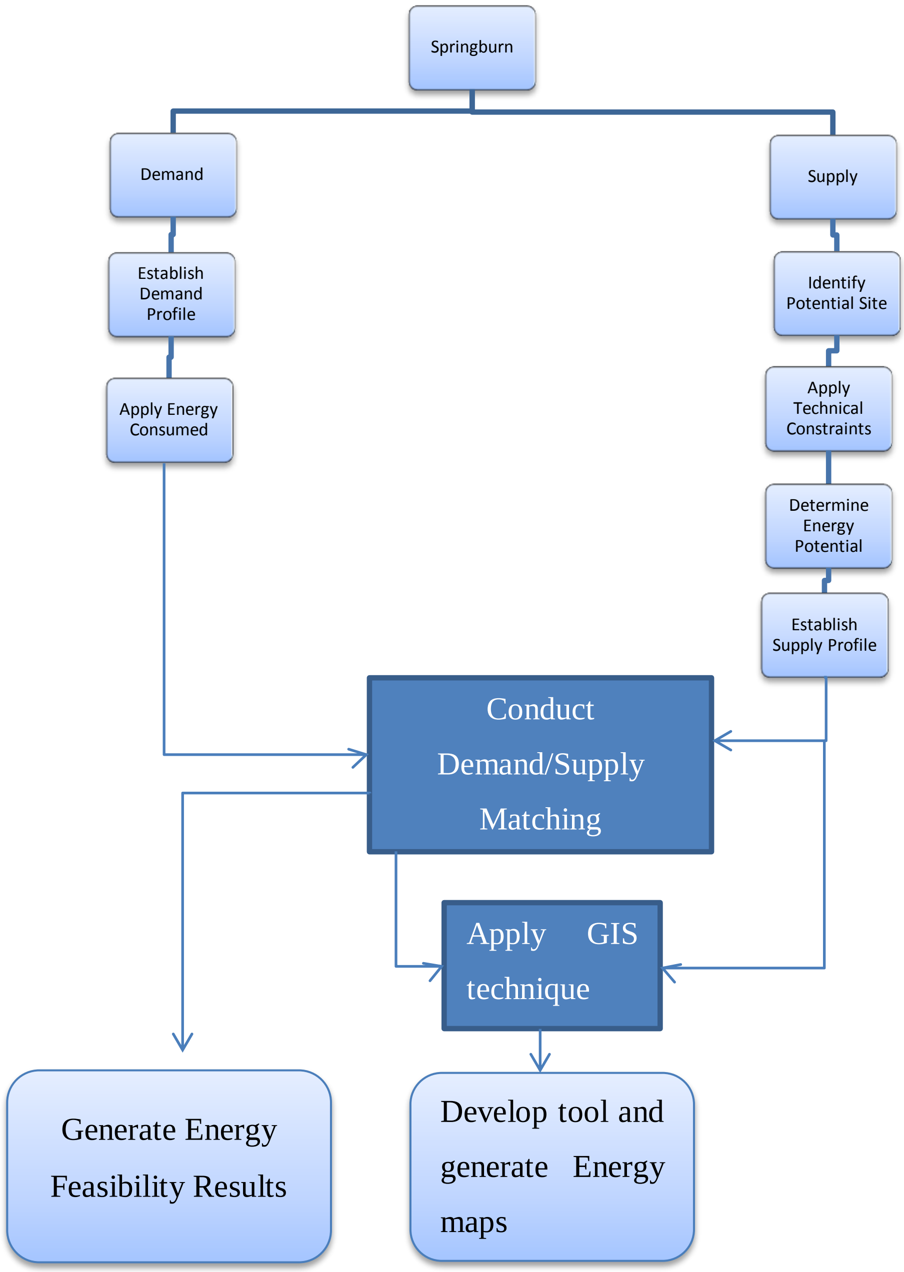
The research strategy that would be used is a case study approach. This approach has been adopted in order to generate the same objective using a different data collection approach, thereby building on readily available resource. (31)

In the SUN-AREA study in Germany, the team collated the empirical data with the use of an aircraft scanner which flew over the city in order to prepare a solar map of suitable roof tops for solar energy use. The approach to be taken by this study would be to substitute the air craft scanner with Google Earth (GE) as the first hand for data gathering which also offers visualization benefits of buildings and their roof tops, potential shading constraints and land area for wind farms. There is a need to experiment with other information resource that has invested in similar projects or research such as GE.

GE is a geographical software that lets the user virtually fly around the world virtually to view satellite imagery, aerial imagery, maps, terrain and 3 – dimensional building down to street view level (32). This is very similar to the use of an aircraft scanner but with the added advantage of exploring the possibilities per roof top at a controlled pace; viewing the effects of shading on the roof tops; and measuring the area of concern.

An important contribution of this study is the preparation and analysis of spatial data and geographic database for renewable energy sources in Springburn community that would enhance the level of service delivery in Glasgow City council and would validate the use of the Google earth resource as a substitute for physical site data gathering. The data to be gathered for analysis includes geographic location of properties, roof orientation of buildings, roof area for GIS mapping preparation; climate data, energy demand data of Springburn community, census data of Springburn which includes property and household data for renewable energy demand matching; and basemaps or shapefiles of Springburn, that would include administrative and boundary information. The results from the analysed data will be used to prepare the GIS based decision support tool.

3.2. Methodology Process



This process would be carried out with the aid of spatial tools, GIS techniques and demand-supply matching tool. This though can only be conducted by collating data that would be used at the different stages of this process. Once data collection is achieved the demand and supply profiles would be established and analysed to derive the potential energy supply present per identified site and the generation of the GIS based energy tool.

3.3. Data Collection

The method adopted is tailored at reducing feasibility cost while providing useful and realistic results that can be used in implementing microgeneration from low energy technologies. Some of the demand data would be accessed from Glasgow City council and the remainder from Intermediate Geography Zone (IGZ) of the DECC while the geographic data for potential sites would be gathered from Google Earth. The vector data of Springburn would be accessed from Ordnance Survey Great Britain and the meteorology from the NASA meteorology site.

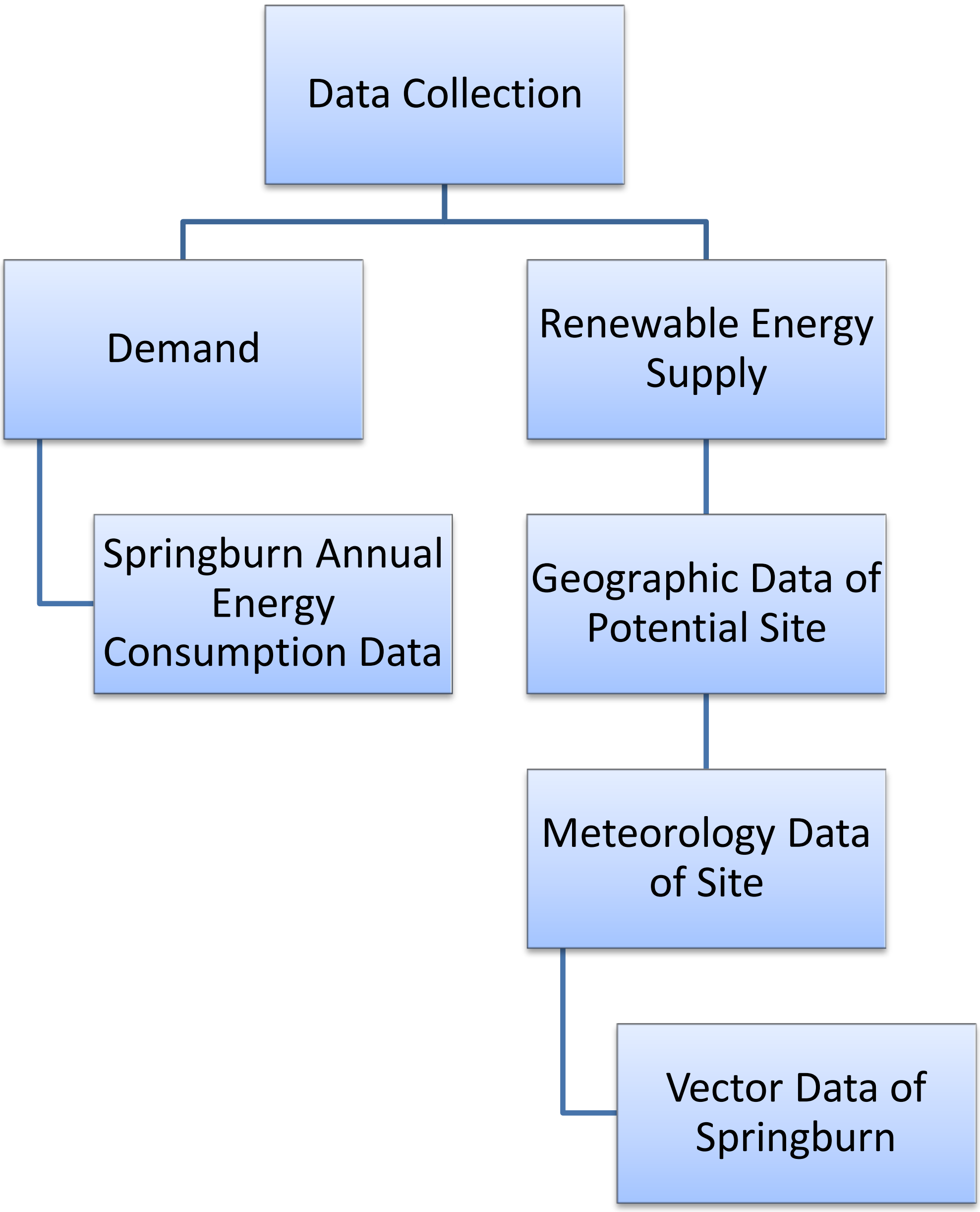


Figure 5Data Collection Process

3.4. Framework for Data analysis

In order to predict potential energy available from each individual building's roof top or vacant / agricultural land within the case study area, there is a need to collect data would be referenced with technical constraints of the potential renewable energy source. The following steps were taken for the research of this study:

3.4.1. Identification of Potential Sites

The digital map of Springburn was used extensively to gather the geographic data of potential renewable energy sites located through visualization of the potential sites in order to consider topographical elements that can pose a challenge in the implementation of renewable energy technologies.

1. **Procedure for Identifying Potential Solar Roof Tops**

For locating potential solar roof tops, the visual orientation of the roof tops were taken in to account considering the potential roof tops orientation, roof height of at least 6 meters for security of PV panels and shade free from trees, buildings and chimneys. Geographic coordinates and roof area of roof tops that conforms to the above rule are recorded.

The area A of each roof top measured in terms of length L and breadth B is calculated as

A = (L-2) m * (B-2) m

This is to allow for installation and roof access consideration.

2. **Procedure for identifying potential Wind Farm location.**

Vacant lands were selected for wind farm siting with at least a 500m distance from major roads and buildings; and the area calculated. The altitude of the selected area was also recorded. Vacant land with at least 1 km^2 area of space was considered.

3.4.2. Preparation of GIS Database

Geographic coordinate captured from potential roof tops and vacant land area were converted into a coordinate system usable in GIS. The number of PV panels was determined by dividing the Area of potential roof tops by the area of a 165 W panel and the rounded down figure admitted. The annual energy supply from a potential roof top area using a 165 W PV system is determined as a product of number of panels and the annual supply from a single 165 W PV panel.

Having known the annual energy supply potential from each roof top captured, a summation of the annual energy supply was carried out according to roof orientation identified and recorded as Flat, south S, south west SW, and south east SE. These four different summations were each used as a PV supply profile for simulation.

3.4.3. Analysis of Demand And Supply

The analyses of demand and supply data was done in order to predict a reasonable match rate and to determine the potential gross energy supply from the system. The following load profiles used and accessed from the UK Energy Research Centre (UKERC) were half-hourly electricity daily load profiles for standard UK profile class:

1. Domestic Unrestricted (33)
2. Non-domestic Unrestricted (33)

And the other load profiles used are:

1. School
2. Health Institution
3. Sports centre electrical
4. Industrial Electrical

The two load profiles from UKERC were in five seasons over a half-hourly time step and thus had to be converted into an annual data. This was done by representing each season with the months they occur as in Table 1 and merging the monthly result to generate an annual data.

Seasons	Months
Winter	1st DECEMBER – 28th FEBUARY
Spring	1st MARCH – 31st MAY
Summer	1st JUNE – 31ST AUGUST
Autumn	1ST SEPTEMBER – 30TH NOVEMBER

Table 1 Seasons and Months they occur

The load profiles were all scaled up to assume the annual electric energy consumption of Springburn in 2007 and 1st April 2010 to 31st March 2011 figures.

Demand Profile	Consumption Data Applied
domestic	electric domestic consumption figure of 2007
school	schools within the Springburn community in 2010/2011
health institution	Elderly people's home 2010/2011
Sports centre	Sport centres and leisure centres 2010/2011
Industrial	Businesses known 2010/2011
Non-domestic	All other commercial sites 2010/2011

Once the annual demand /supply analysis was done, the analysis of the critical months December and June for PV and June and January for Wind turbine were also investigated. The effect of low and high solar and wind resource was analysed for the four critical months.

A new 100kW wind turbine profile was created and added into the programme's database. The wind turbine specification was accessed from the Altergen website and input in the database of the program.

The climate site assumed for Springburn was Glasgow at latitude 55.5^0 N and longitude 4.15^0 W with an altitude of 80m above sea level. The table represents the simulation dates defined for each period.

Annual	1st of January 1972 – 31st of December 1972
January	1st of January 1972 – 31st of January 1972
June	1st of June 1972 – 30th of June 1972
July	1st of July 1972 – 31st of July 1972
December	1st of December 1972 – 31st of December 1972

3.4.4. GIS Analysis

In order to conduct this analysis, the basemap of Springburn was created and the demand and supply data already prepared were geo – referenced unto the created basemap. The following layers and geo - databases were created:

1. Commercial Demand;
2. Solar Potential Roof Top; and
3. Vacant land for Wind Turbine

The next stage was the classification of the suitability of the solar and wind farm resource according to a categorization scale developed. This would include a mix of roof top orientation, roof top area and quantity of potential energy feasible for potential solar suitability and a vacant land greater than $3km^2$ for the siting of wind farms for wind turbines.

3.5. Constraints and Assumptions

1. Roof tilt or slope was not considered in potential roof top selection, considering roof tilt are installation constraints that could be adjusted by the PV bracing and should therefore not be classed as a technical constraint.
2. Shading caused by trees, nearby buildings and trees were avoided around roof tops in this study and the actual use of identified potential roof tops should be subject to structural test before PV installation.
3. Roof tops with areas less than $9m^2$, with a height of under 6 meters and roof tops of petrol stations were not considered for security and economic reasons.
4. Flat roof tops were assumed to be south facing considering installation would site south. All roof tops in south east and south west orientation were all assumed to be 45^0 even though most roof tops were much less than 30^0 either side of the south position. This was to lower the risk of errors since the exact degree of orientation could not be measured from the GE approach.
5. The study focuses on the possible implementation of renewable energy sources rather than other economically viable use of land area.

Chapter 4 General Knowledge of Springburn

4.1. Geography of Springburn Community

Springburn is a suburban community within the city of Glasgow, Scotland in the United Kingdom and lies within latitude 55^0 53'0" North and longitude 4^0 13' 0" West sprawling a little over $5km^2$. (1) It is located north-west of Glasgow city centre and about 2.5km from the city centre and is about 80m above sea level as depicted in Figure 6 and Figure 7It is bordered by Bishopbriggs in the North, Cowlairs Industrial Estate in the East and St Rollox Business and Retail Park. It is a suburban community with both residential and industrial activities.

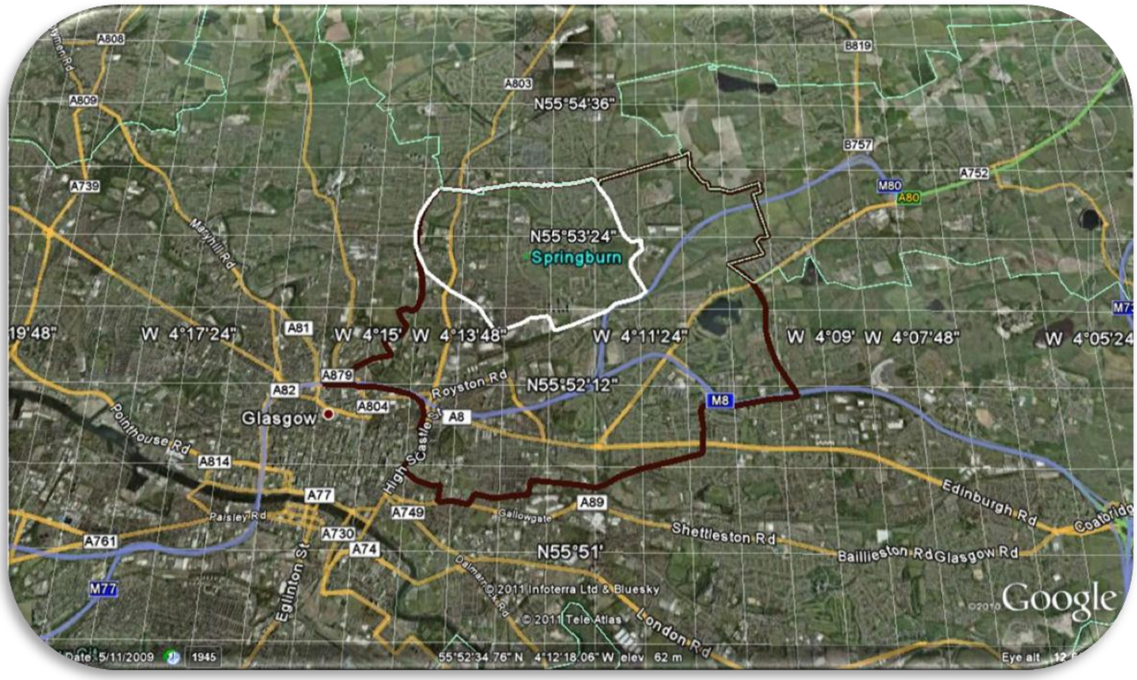


Figure 6 Aerial view of Springburn (34)

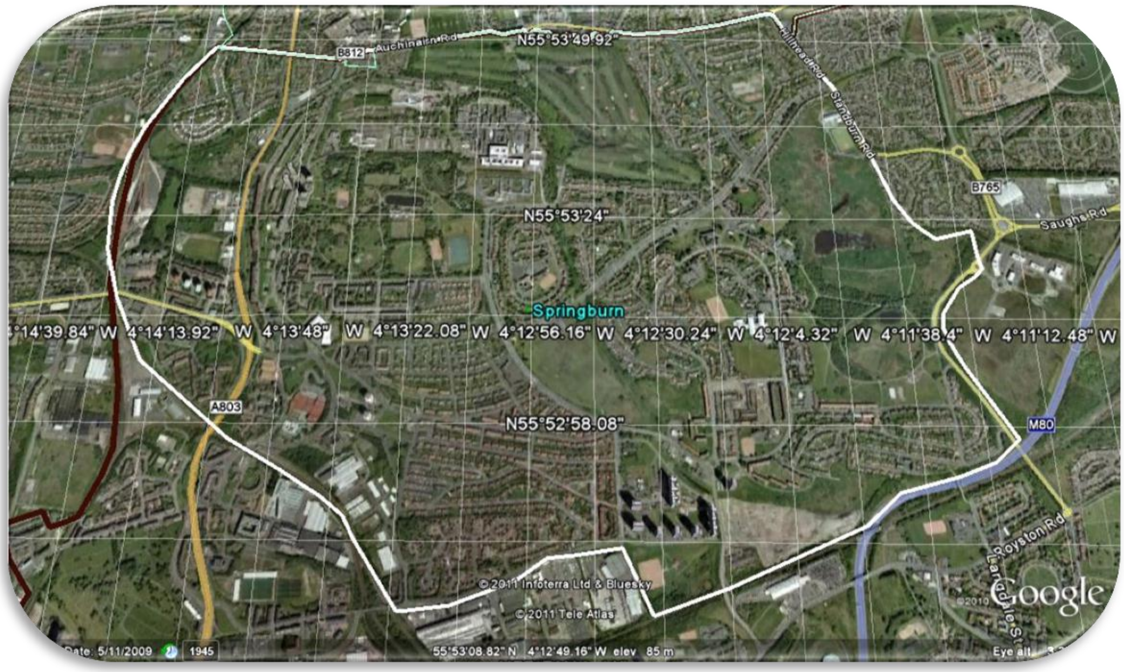


Figure 7 Springburn Imagery (34)

The Springburn community constitutes two census wards and includes postcode areas G 21, G 64 and G33 and it constitutes the following areas:

1. Petershill;
2. Barmulloch;
3. Springburn;
4. Springburn east and Cowlairs and
5. Balornock.

4.1.1. Census Data of Springburn

According to the Intermediate Data Zone (IGZ) Scotland, the total population and household figures of Springburn in 2008 were 20,958 and 10,406 respectively as seen in Table 2 2008 Springburn population and Household Figures

Table 2 2008 Springburn population and Household Figures (1)

IGZ Code	IGZ Name	Population- 2008	Households-2008
S02000680	Petershill	4,876	2,500
S02000687	Barmulloch	3,366	1,821
S02000691	Springburn	4,525	2,375
S02000694	Springburn east and Cowlairs	4,405	2,220
S02000697	Balornock	3,786	1,490
	Total	20,958	10,406

The property statistic of Springburn is shown in Table 3 Springburn Housing Stock by dwelling type with total dwellings of 10,406 and almost 8,000 of these households live in flats and with few people living in houses. (1) The community has a population density of 3,976 per km^2 thus implementation of renewable sources around here could pose potential challenges that may not be limited to energy supply. Table 2, further highlights the high population density as most households occupy flats category of dwelling in the community. It is important to note the total number of dwellings does not represent the total number of roof tops available especially with the very high volume of flats present.

Table 3 Springburn Housing Stock by dwelling type (2)

IGZ Name	Total Dwellings	Flats	Terraced	Semi-Detached	Detached	Unknown Dwelling type
Petershill	2,500	2,220	131	133	16	0
Barmulloch	1,821	1,201	211	387	21	1
Springburn	2,375	1,961	213	192	9	0
Springburn east and Cowlairs	2,220	1,722	192	241	64	1
Balornock	1,490	874	327	269	14	6
Total	**10,406**	**7,978**	**1,074**	**1,222**	**124**	**8**

There are several businesses and industries within the Springburn community as well which include sectors like manufacturing, hospitality, construction, wholesale and retail, finance etc. statistics represented in Table 4 Business Sectors in Springburn

Table 4 Business Sectors in Springburn (2)

IGZ Name	D	F	G	H	I	J,K	M,N	O	Total
Petershill	5	5	0	5	0	15	10	5	**45**
Barmulloch	0	0	5	5	0	10	0	5	**25**
Springburn	5	5	35	10	5	15	15	20	**105**
Springburn east and Cowlairs	0	0	5	5	0	5	5	5	**25**
Balornock	0	0	5	0	0	0	5	5	**15**
Total	**10**	**10**	**50**	**25**	**5**	**45**	**35**	**40**	

The letters above represent the following sectors:

1. D Manufacturing
2. F Construction
3. G Wholesale, Retail and Repairs
4. H Hotels
5. I Transport, Storage and Communication
6. J,K Finance
7. M,N Education
8. O Other community businesses

4.1.2. Energy Consumption data of Springburn

The latest published energy consumption data of domestic and commercial /industrial users within Springburn community for 2007 is shown in Figure 8 Energy Consumption of Springburn in 2007 (35)

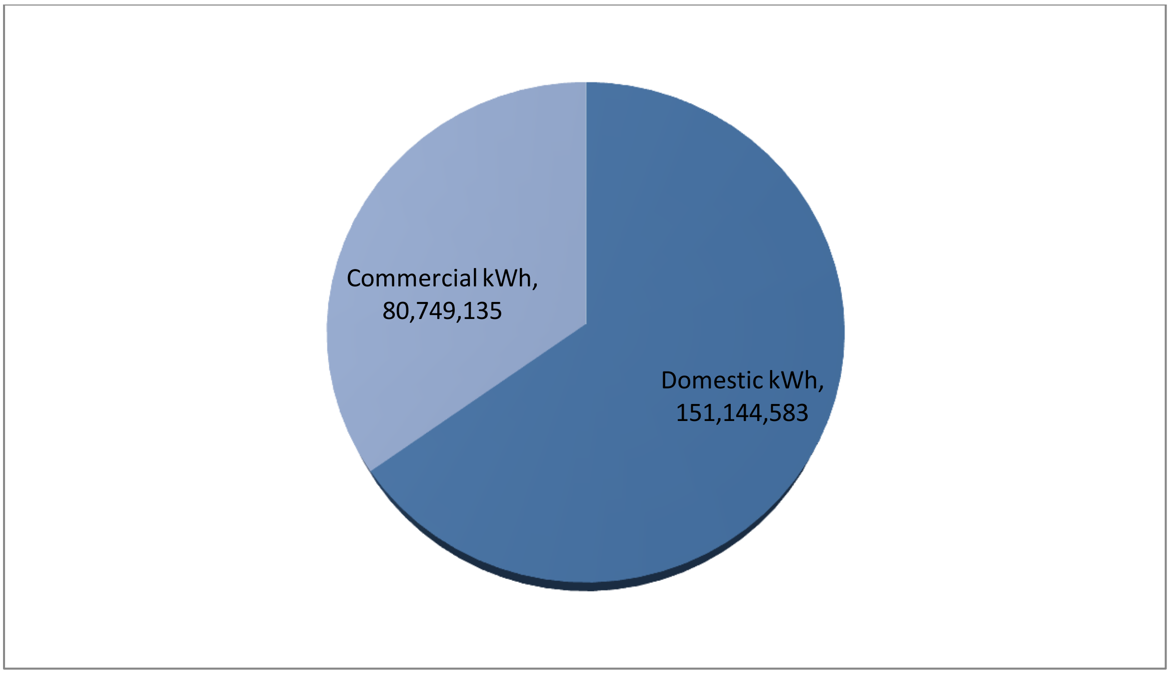


Figure 8 Energy Consumption of Springburn in 2007 (1)

As presented in Figure 7, Springburn community consumed 231.8GWh of energy in 2007, and most of its energy users are in the domestic energy category a figure that almost doubles that of the commercial / industrial energy users. A breakdown of this huge consumption into electrical and gas use, it is observed that 26.9% of the annual energy consumed is via electrical use as depicted in Table 5.

Table 5 Breakdown of 2007 Energy consumption in Springburn (1)

Energy Category	Electric kWh/year	Gas kWh/year
Domestic	49,753,667	101,390,916
Commercial / Industrial	12,772,822	67,976,313
Total	62,526,489	169,367,229

The energy consumption in Springburn in 2007, were measured from 12,455 and 6,531 electric and gas meters respectively which shows that only about half of these homes use gas for space heating and domestic hot water use, while the vast remainder rely on electricity for their space heating and domestic hot water demands. This is displayed in Table 6 Energy Meters in Springburn.

Table 6 Energy Meters in Springburn (1)

Energy Meters	Electric	Gas
Domestic	12,081	6,456
Commercial/Industrial	374	75
Total	12,455	6,531

Thus from the data presented,

The average domestic electric energy consumption per meter = $\frac{Energy\ consumption\ kWh}{meter}$

$$\therefore = \frac{49,753,667}{12,081}$$

= 4,118 kWh (e)

The average domestic electric energy consumption per meter $= \frac{101,390,916}{6,456}$

= 15,704.9 kWh (t)

And average Com / Industrial electric energy consumption per meter = $\frac{12,772,822}{374}$

= 34,152 kWh (e)

average Com / Industrial electric energy consumption per meter = $\frac{67,976,313}{75}$

= 906,350.8 kWh (t)

According to the household distribution data in Table 7 Springburn Dwelling, most household are in the 1-3 bedroom categories.

Table 7 Springburn Dwelling (2)

IGZ Name	1-3 rooms %	4-6 rooms %	7-9 rooms %	10+rooms %	Unknown%
Petershill	75.44	22.52	0.04	0.00	2.00
Barmulloch	57.28	28.50	0.00	0.05	14.17
Springburn	66.57	28.80	0.55	0.04	4.04
Springburn east and Cowlairs	65.59	28.15	0.45	0.05	5.77
Balornock	4.03	91.81	0.00	0.07	4.09

In the NEED report (2007), the mean electric and gas domestic energy consumption for a UK 2-3 bedroom dwelling were 4,007 – 4592 kWh and 14,271 – 18,169 kWh respectively. (3)

Table 8 Report Comparison of Energy consumption (1) (3)

	Domestic Energy Consumption per dwelling	
	Electric kWh (e)	Gas kWh (t)
NEED	4,007- 4592	14,271 – 18,169
Scottish Government	4,118	15,705

Table 8 relates the domestic energy consumption per dwelling of the measured Scottish governments energy data and the NEED report estimated data. It is observed that there is a close relationship in the domestic energy consumption per dwelling values.

According to the 2010/2011 commercial / industrial energy consumption data from Glasgow city council for Springburn community, the total electrical and gas consumption were 8.10 GWh and 14.43 GWh respectively. (6).

In the data set received, it was observed a large number of buildings either had no record for gas consumption or an omission occurred at the point of data collation. If the gas consumption values were missing, it could suggest that space heating and domestic hot water demands were met by electric supply which is further proven by the large disparity between electric and gas meters within the community as shown in Table 6. This observation led the study to focus on the electrical demands of the community. This choice was largely due to the demonstrable data sets from different sources that were cross-referenced and were within range as expressed in Table 8.

There was also a disparity in the commercial / industrial energy consumption data of 2010/2011 and the data from IGZ in 2007, a variance of 4.1GWhe which could have been due to incomplete 2010/2011 data or an upgrade in the energy efficiency or an implementation of a renewable energy source which has helped reduce the commercial / industrial electrical energy demand.

4.1.3. Renewable Energy Resource potential in Springburn

The resource potential in Springburn was restricted to solar and wind. Biomass and geothermal resource were abandoned at the point of data collection due to inaccurate and reliable thermal energy consumption data and the prevalent use of electricity for space and domestic hot water heating in most residential buildings within the study area as depicted in Table 6.

Solar resource in Springburn is identical to that of Glasgow city which is suitable for energy generation and the wind resource present is significant for microgeneration. This was established by comparing several locations within the study area with that of Glasgow city using NASA’s surface meteorology and solar energy site which consists of a 22 year compilation of average monthly data from several locations.

Using the location of Springburn the annual average global horizontal radiation of 2.66kWh/m^2/d with a minimum and maximum radiation of 0.38kWh/m^2/d and 5.06kWh/m^2/d that occurs in December and June respectively were determined. The study area also has an annual average wind speed of 5.97m/s with a minimum and maximum value of 4.74 m/s and 7.24 m/s that occurs in July and January respectively. The meteorology data sets of Springburn are summerised in Figure 9 and Figure 11.

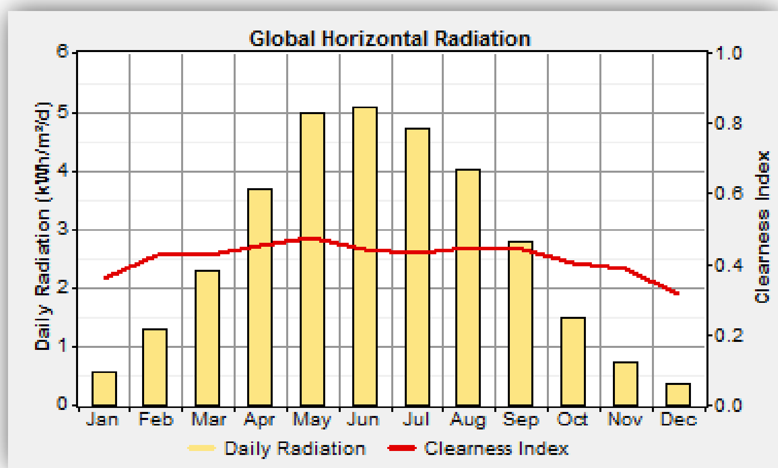
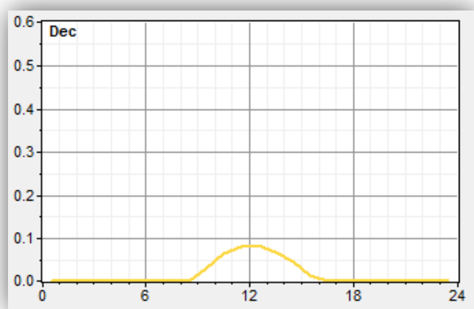


Figure 9 Solar Radiation data of Springburn (4)



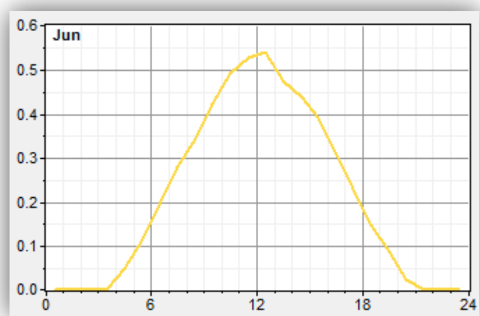


Figure 10 Minimum and Maximum Solar Radiation (4)

In Figure 9 the most interesting months are the months of December where there is reduced solar capture as the hours of daylight are shortest during this period; and the June which has the most amounts of daylight hours. This could result to inadequate power from the PV in the winter month of December and a waste of energy in the summer month of June. The duration of sunlight hours of the months of concern are depicted in Figure 10.

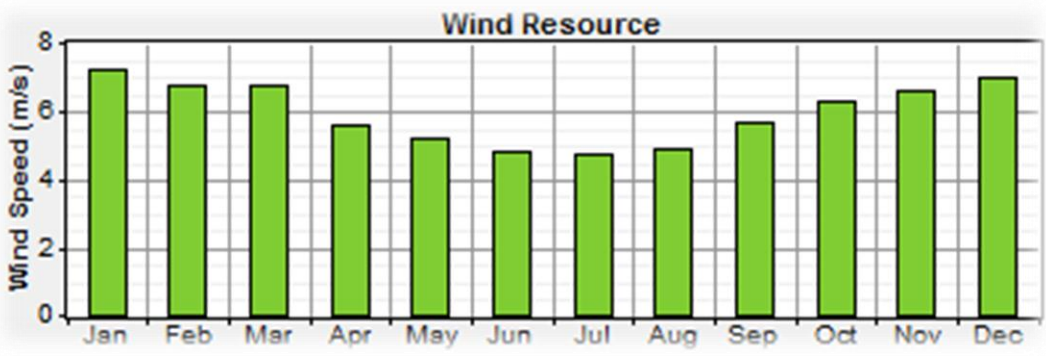


Figure 11 Wind speed of Springburn (4)

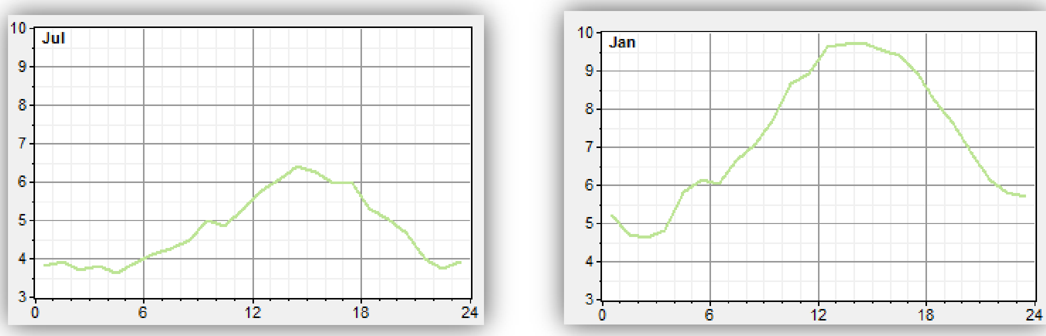


Figure 12 Minimum and Maximum Wind Speed (4)

In Figure 11the most interesting months are the months of July where there is reduced wind speed; and the January which has the greatest strong wind period. This could result to inadequate power from the wind turbine in the summer month of July and an excess energy generation in the winter month of January. The duration of wind availability for the two curious months is depicted in Figure 12.

4.2. Analysis of Data

4.2.1. Supply Profile

In order to ensure the validity of results a simulation was carried out to determine the annual electricity that can be generated from a single Sharp 165 W PV and the results derived was used in the preparation for the GIS database. The optimum tilt angle for Springburn was determined by assuming south facing PV panels with varying tilt angles from 35^0 – 50^0 and the most energy supply was found to occur at 45^0 tilt angle.

Table 9 Energy supply versus Orientation (5)

Tilt	Orientation	Energy Supply kWh
45^0	South 0/360^0	181.07
45^0	South East 30^0	178.33
45^0	South West 345^0	178.04

The table above depicts the energy supply value generated at different roof orientation within the study area which was also used to determine the amount of solar potential on an identified roof top (shown in Table 10). Hence the summation of energy supply potential from flat roofs, south, south west and south east facing roofs were done and summerised in Table 11

Table 10 Solar Calculation

Ref Id	GIS_XREF	GIS_YREF	Area m^2	PV Panels	Install Capacity	Annual Energy kWh	Roof Orientation
1	260306	668508	1162.56	886	146.19	160463	Flat
2	260326	668569	357.3	272	44.88	49262	Flat
3	260328	668631	173.3	132	21.78	23907	Flat
4	260411	665813	1246.8	951	156.915	172236	Flat
5	260288	665786	722.94	551	90.915	99792	Flat

Table 11Energy Supply per Roof top Orientation

Roof Orientation	Total Panels	Gross Energy GWh/year
Flat	6,893	1.25
South	11,077	2.01
South West	10,511	1.83
South East	10,329	1.81

4.2.2. Demand Profile

Table 12 Energy Demand data used in Merit (6) (1) (5)

Load Profile	**Annual Consumption kWh**	**Season**			
		Winter		Summer	
		Peak kWh	Base kWh	Peak kWh	Base kWh
Domestic	49,753,667	12,033	2,674	8,022	2,406
School	2,887,090	847	190	190	186
Sports/leisure	2,466,999	396	176	350	170
Health	396,230	69.70	36	69.70	30.98
Industry	2,352,730	800	92	650	40
Other Commercial	4,669,774	1,392	250	1,007	170

The demand profile table is a summary of the demand data used for analysis. The annual consumption data was based on the 2007 energy consumption data of Springburn and the 2010 commercial consumption data from the council imposed on the demand profiles from the simulation tool's demand list. This shows the peak loads in the winter and summer seasons which is used to compare the supply peaks of the renewable energy sources especially since energy supply is at its bottom and peak during these periods.

Chapter 5 Results and Discussion

5.1. Renewable energy Supply Simulation Results

According to the simulation results, the total annual PV supply of potential roof tops analysed is 6.9 GWh with a peak output value of 6552kW and an operational period of 4,384 hours per year and the wind turbines generate an annual of 5.85 GWh with a peak output of 2,529kW and an operational period of 8,212 hours per year as shown in Figure 13 and Figure 14. The total annual demand and renewable supply of Springburn is depicted in Figure 15, while Figure 16 and 17 depicts the total demand compared with the total PV supply or total wind supply.

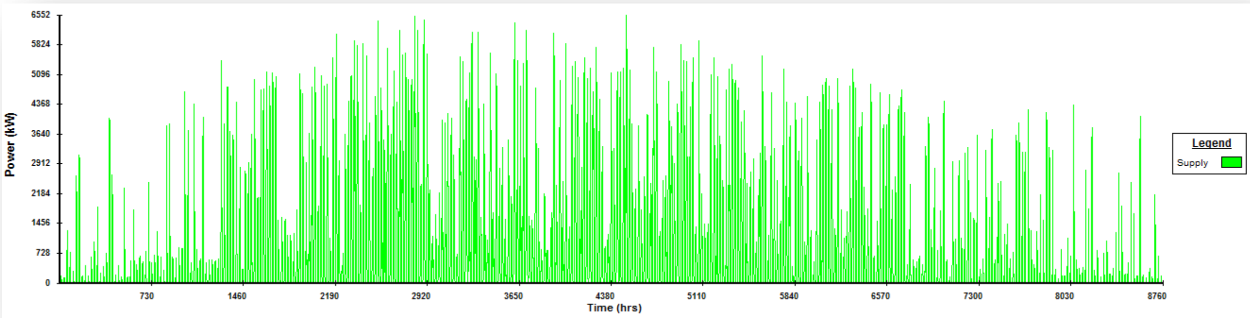


Figure 13 Total Annual PV supply (5)

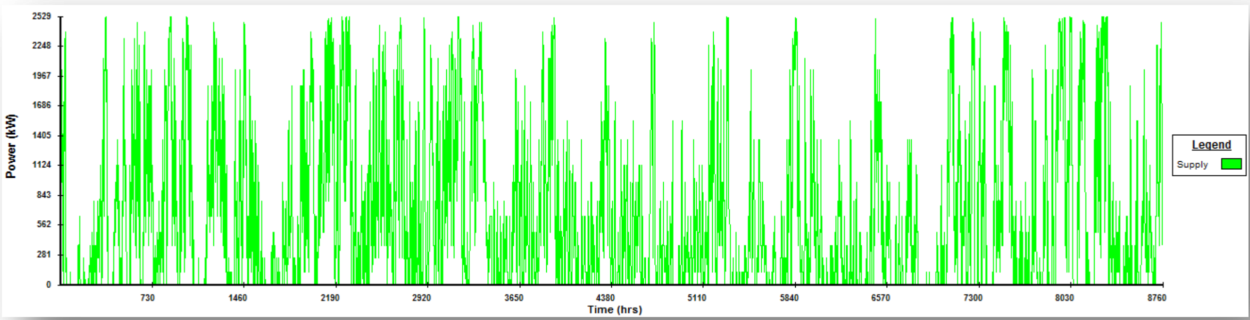


Figure 14 Total Annual Wind Turbine supply (5)

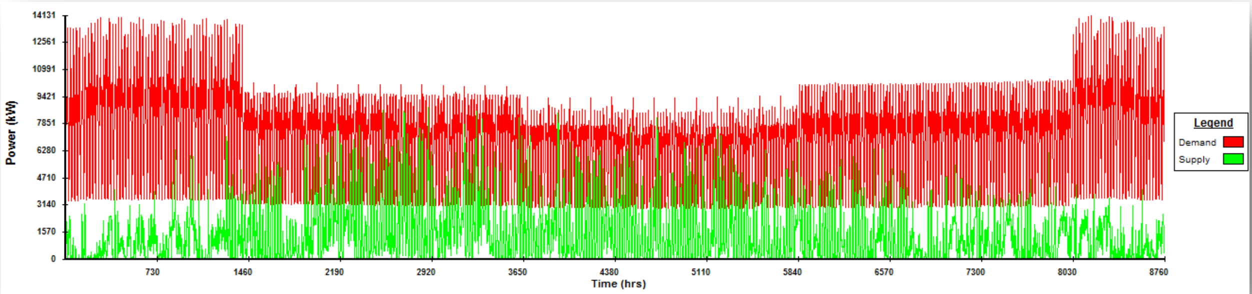


Figure 15 Annual Demand and Renewable Energy Supply Profile (5)

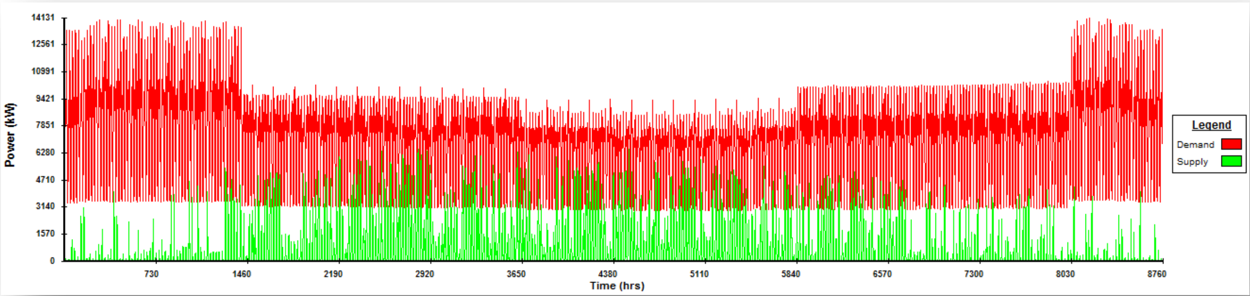


Figure 16 Annual Demand and PV Supply (5)

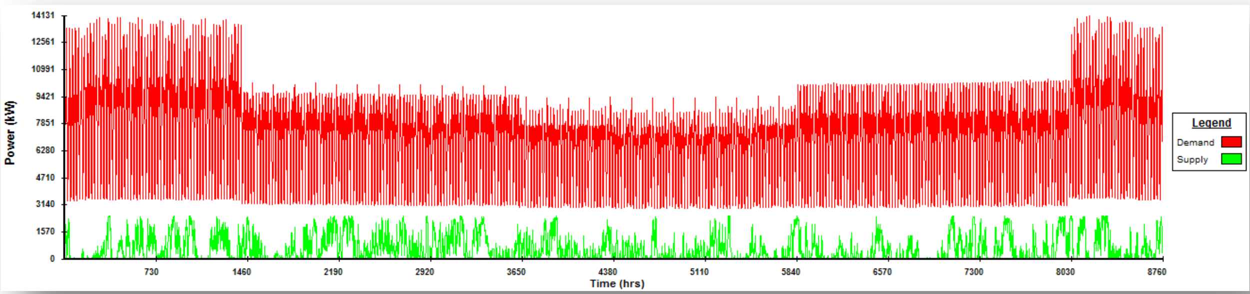


Figure 17 Annual Demand and Wind turbine Supply (5)

Table 13 Summary of Demand/Supply Matching (5)

Demand Profile	Supply Combo	Total Demand GWh	Total Supply GWh	Match Rate (%)	Energy Delivered GWh	Energy Surplus MWh	Energy Deficit GWh
A+B+C+D+E+F	PV_TOT	62.53	6.90	24.49	6.90	0.00	55.62
A+B+C+D+E+F	WT	62.53	5.85	18.82	5.85	0.00	56.67
A+B+C+D+E+F	PV_TOT + WT	62.53	12.75	35.19	12.73	18.93	49.78

Table 14 shows the meaning of each notation used in the results above and subsequent ones

	Energy Class	Profile	Notation
Demand	Domestic	Domestic	A
	Commercial	School	B
		Sport centre	C
		Health Institution	D
		Industrial	E
		Non- domestic	F
Supply	PV_TOT	Sum PV Flat, S, SE, and SE facing	PV_TOT
	WT	Wind Turbines	WT

Table 13 shows a summary of total energy demand with total RE supply and with only PV or WT supply. It is observed from the table that the match rate of any of the 3 combination is poor with the worst occurring with only WT supply to the total demand of the community. Although the difference between the total supply and total delivered is relatively zero across all cases suggesting no energy waste. Table 14 depicts the notations or abbreviations used to represent the different profiles and energy class.

5.1.1. Analysis of Domestic and Commercial Demand Compared with RE Supply

It was observed that the annual renewable energy supply available represents only a fifth of the annual electric consumption of Springburn community stated in Table 5. But when compared in terms of Domestic and commercial energy users, it is slightly different as shown Figure 18 and Figure 19

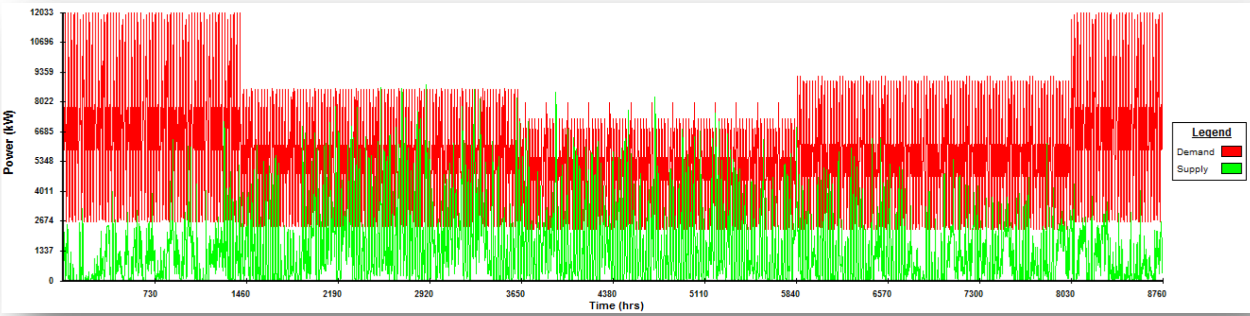


Figure 18 Domestic demand and RE Supply (5)

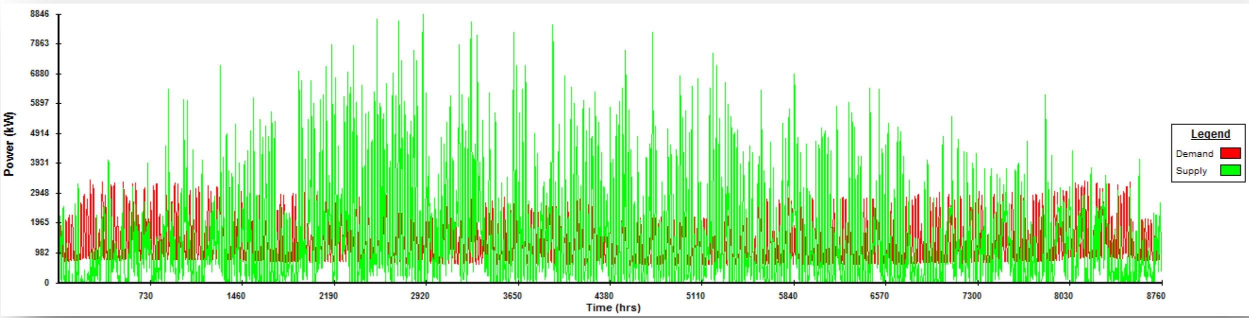


Figure 19 Commercial demand and RE Supply (5)

The total annual RE supply is almost equal to the annual demand from the commercial classed energy users of 12.75 GWh and 12.77 GWh respectively. This is summerised in Table 15.

Table 15 Matching between Domestic and Commercial Energy Users (5)

Demand Profile	Supply Combo	Total Demand GWh	Total Supply GWh	Match Rate (%)	Energy Delivered GWh	Energy Surplus MWh	Energy Deficit GWh
Domestic & Commercial	WT	62.53	5.85	18.82	5.85	0.00	56.67
Domestic & Commercial	PV_TOT	62.53	6.9	24.49	6.9	0.00	55.62
Domestic & Commercial	PV_TOT + WT	62.53	12.75	35.19	12.73	18.93	49.78
Commercial	WT	12.77	5.85	52.78	4.85	962.64	7.88
Commercial	PV_TOT	12.77	6.9	57.2	4.74	2070	7.95
Commercial	PV_TOT + WT	12.77	12.75	62.98	8.16	4480	4.51
Domestic	WT	49.75	5.85	22.32	5.85	0.383	43.9
Domestic	PV_TOT	49.75	6.9	27.72	6.84	50.19	42.88
Domestic	PV_TOT + WT	49.75	12.75	39.48	12.47	241.63	37.21

In Table 15 it is observed the best match occurs when annual commercial demand is supplied by the RE sources. It is also observed that the annual commercial demand matched with any of the RE sources presents a better match than with domestic demand or total annual demand of Springburn unlike the low match rate figure in Table 13. This is presented in

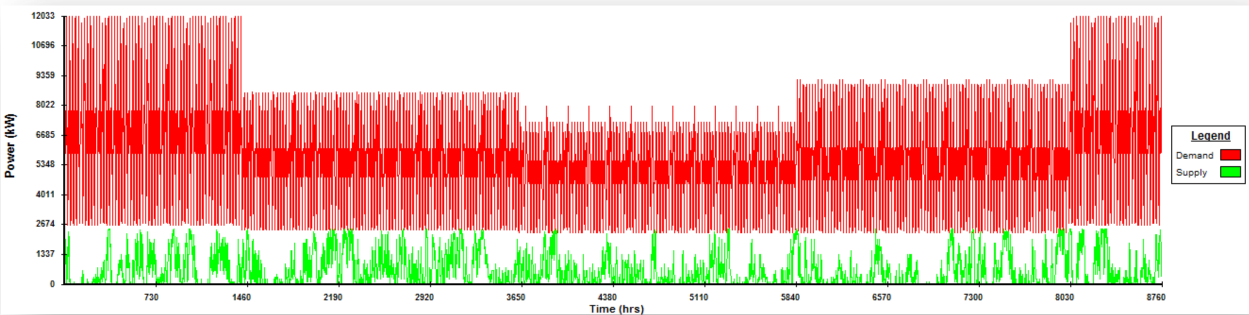


Figure 20 - Figure 23

WT Supply Matched with Domestic / Commercial Demand

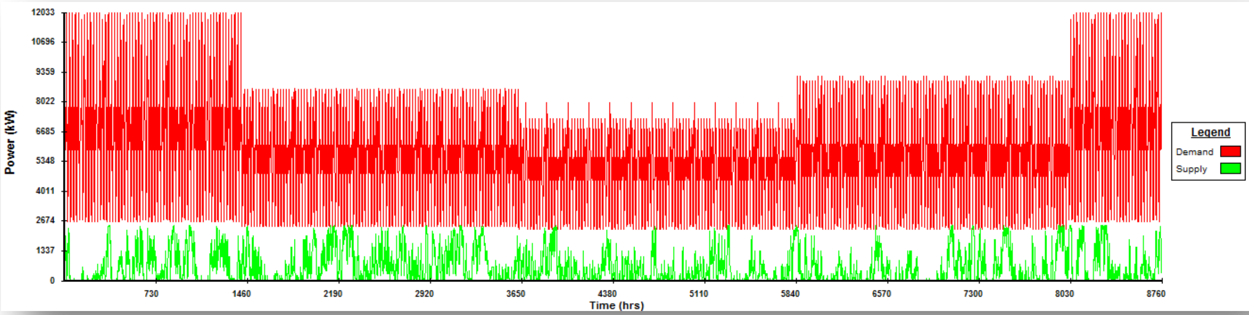


Figure 20 Domestic demand and WT Supply (5)

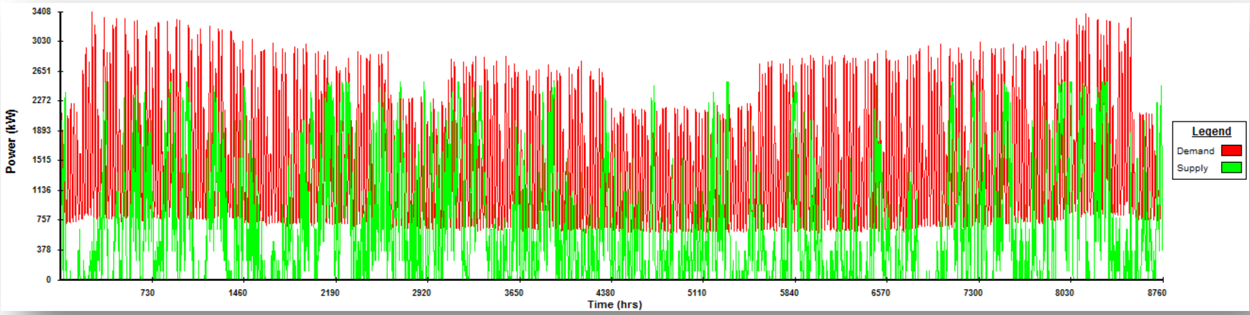


Figure 21 Commercial demand and WT Supply (5)

PV Supply Matched with Domestic / Commercial Demand

Figure 22 Domestic demand and PV Supply (5)

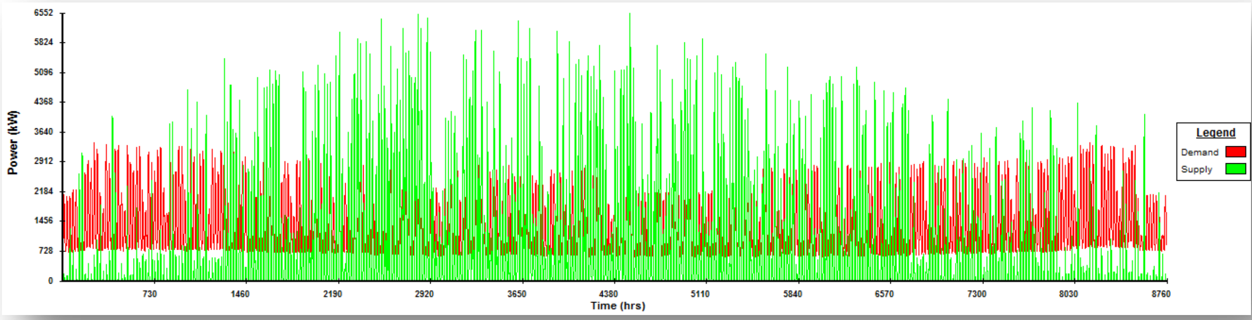


Figure 23 Commercial demand and PV Supply (5)

It is realized in Figure 20, the WT supply is poorly matched with the domestic demands hence a match rate of 22.32% but when matched with the commercial demand a match rate of 52.28% is achieved. The same case is observed with PV supply which reflects the highest match rate when matched with commercial energy users.

5.1.2. Analysis of RE Energy Supply during the Critical Months

The critical months according to this study are the period when solar or wind resource is lowest and at highest in the year. The critical months identified for solar resource were December and June and for the wind resource it was July and January as depicted in the graphs in Figure 10 and Figure 12 of section 4.1.3. The Figure 24 – Figure 27 show the graphs of RE energy supply these four crucial months in order to identify the effect of demand- supply matching during these period.

RE Energy Supply

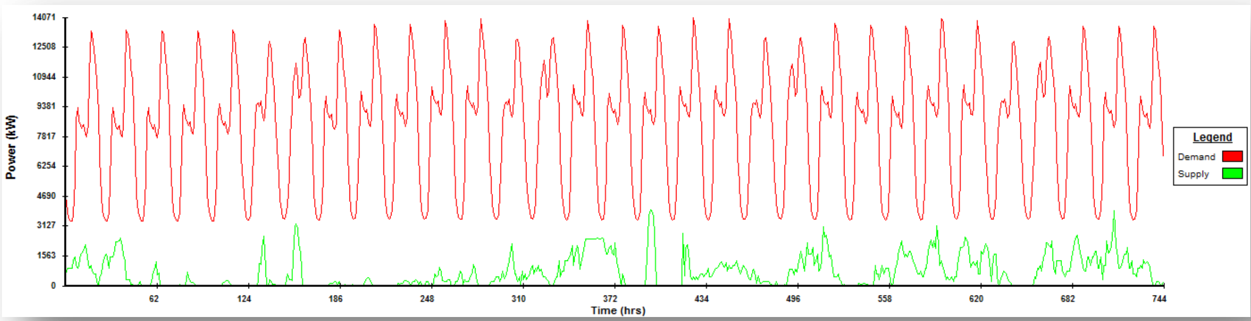


Figure 24 January Demand and Renewable Energy Supply Profile (5)

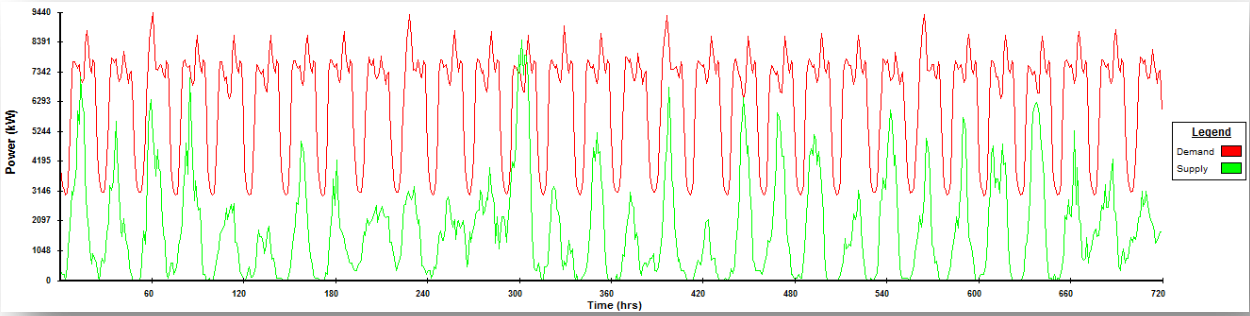


Figure 25 June Demand and Renewable Energy Supply Profile (5)

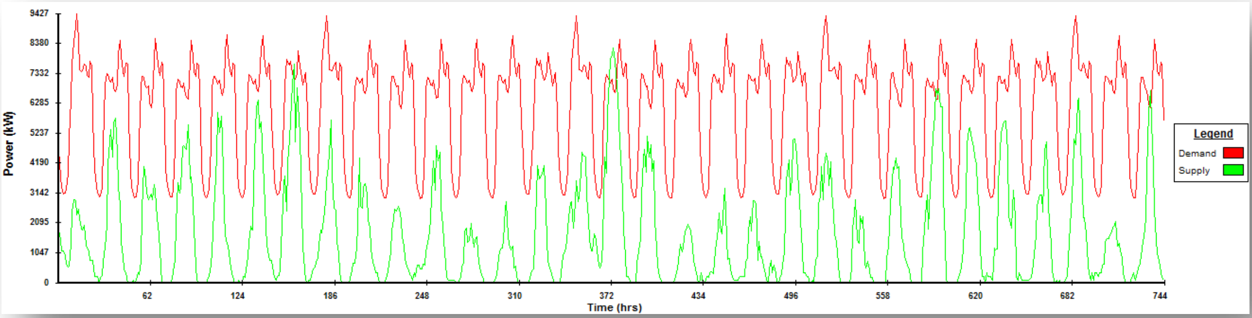


Figure 26 July Demand and Renewable Energy Supply Profile (5)

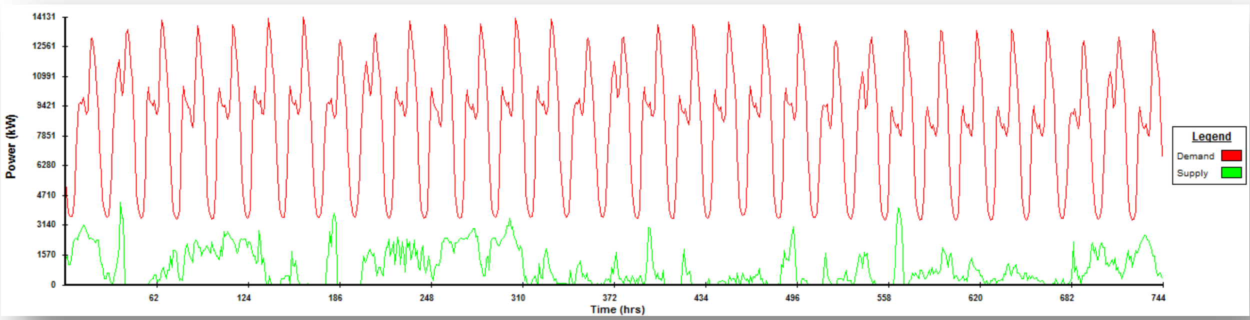


Figure 27 December Demand and Renewable Energy Supply Profile (5)

It is observed the winter months of December and January are the lowest energy supply period even though the wind resource is highest in the latter month while in the summer months of June and July when solar resource is at its peak the solar energy supply is much higher which creates the illusion of a better match. A clearer depiction of this is shown in Figure 28 - Figure 31 from the supply generated independently from PV and WT in these critical months.

PV Supply

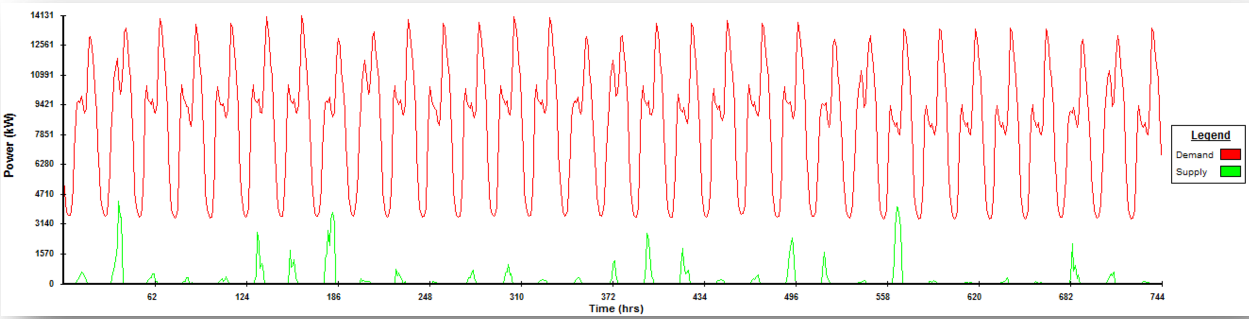


Figure 28 December Demand and PV Supply (5)

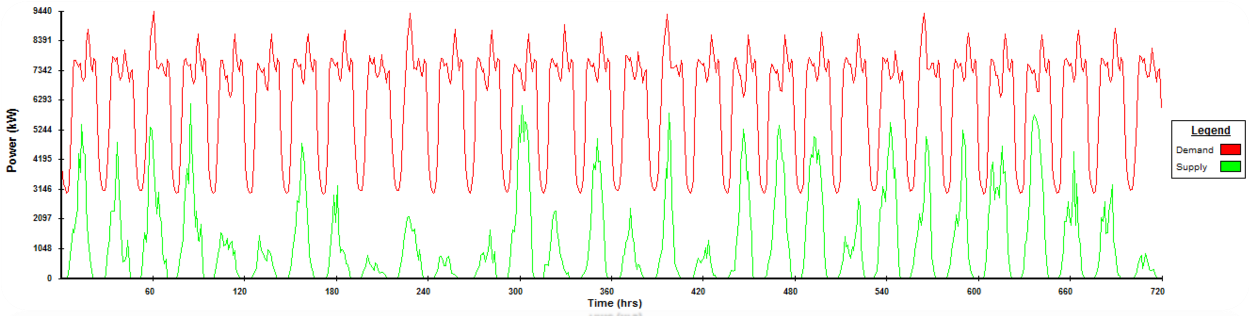


Figure 29 June Demand and PV Supply (5)

WT Supply

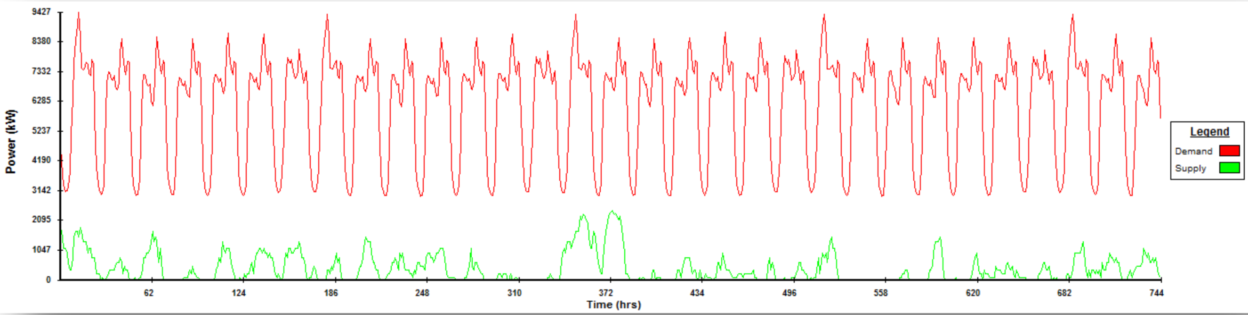


Figure 30 July Demand and WT Supply (5)

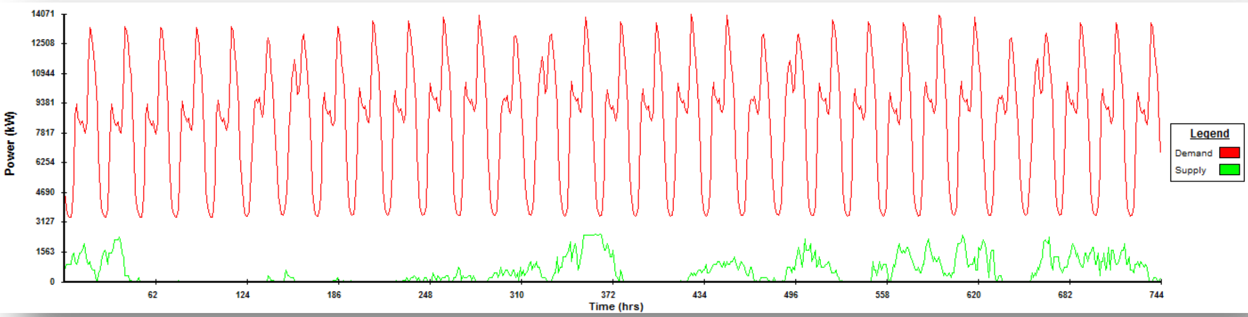


Figure 31 January Demand and WT Supply (5)

From the figures above, it is clear electric demand is much higher in the winter with inadequate PV energy supply to aid WT energy supply.

A further analysis into the manner energy supply during these critical months' impacts on the two categories of energy users (domestic and commercial) would help to reveal the energy use within Springburn.

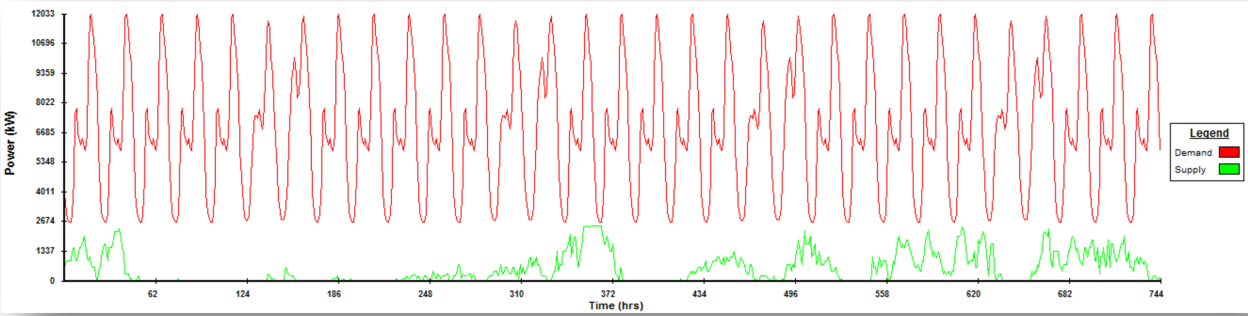


Figure 32 Domestic demand and WT in January (5)

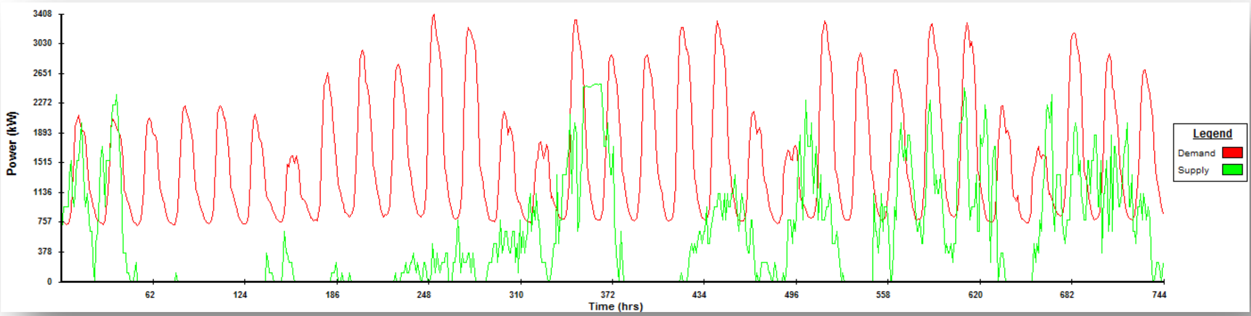


Figure 33 Commercial demand and WT in January (5)

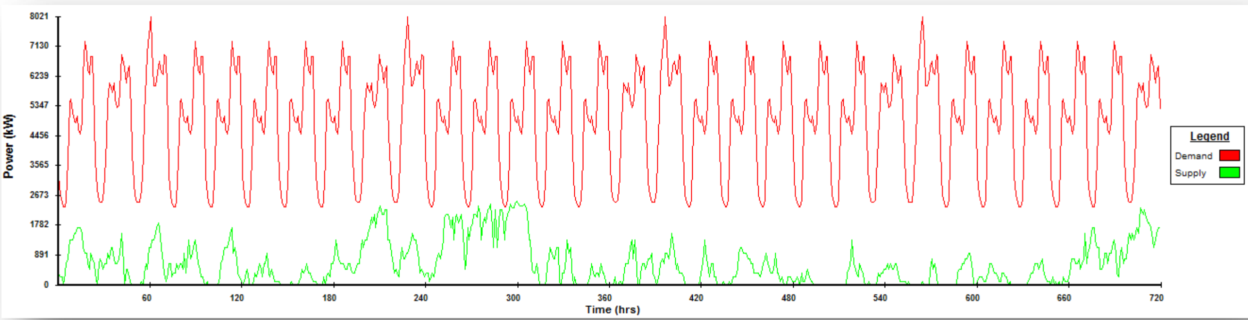


Figure 34 Domestic demand and WT in June (5)

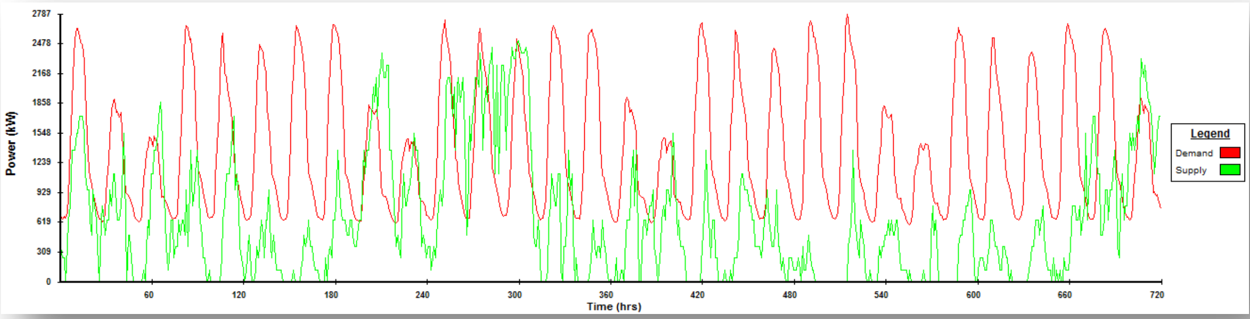


Figure 35 Commercial demand and WT in June (5)

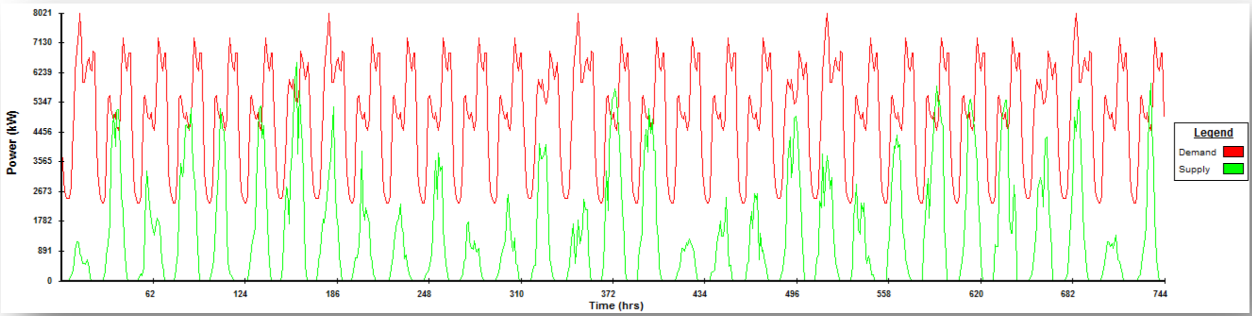


Figure 36 Domestic demand and PV in July (5)

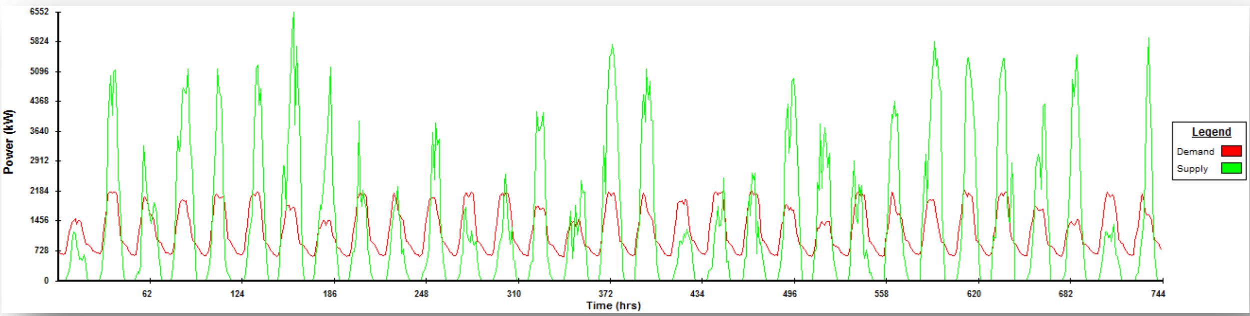


Figure 37 Commercial demand and PV in July (5)

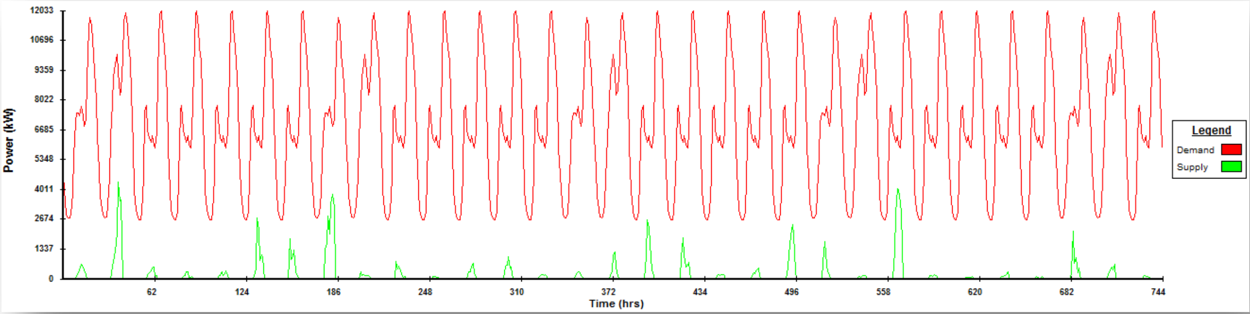


Figure 38 Domestic demand and PV in December (5)

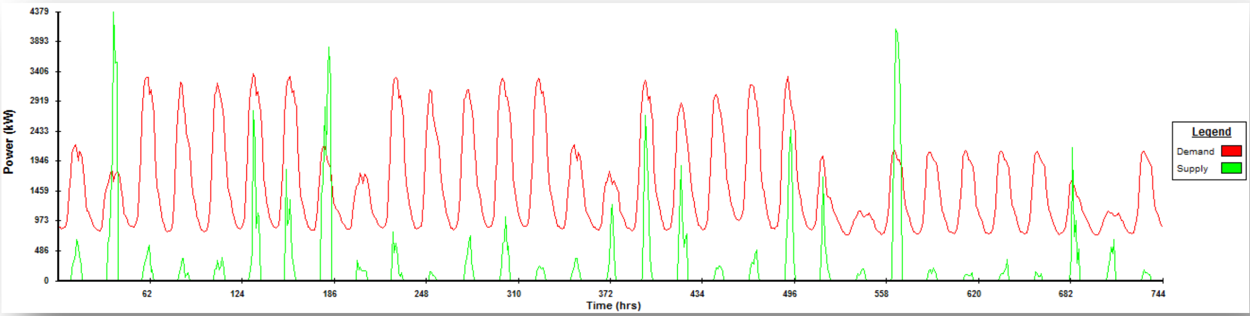


Figure 39 Commercial demand and PV in December (5)

It is observed that throughout the year, there is no instance when the wind resource is worth being matched with domestic demands even though it would slightly reduce grid import but the economics of it is not attractive at least for the moment. But for the solar resource there is savings to be made there annually considering the amount of potential energy available from the roof tops. The best periods are the summer months of June and July when the PV supply to domestic demand match rate is much higher. Although this is a tricky match considering people travel and leave there homes during summer or are usually often outdoors in the day and thus there is a false sense of low demand, hence the high match rate occurence for domestic and RE supply.

On the other hand the match rate of the commercial energy demand users is fairly constant throughout the year even though there is a drop in demand when the schools are on holiday especially during Christmas and summer. Supply from the wind resource is also better matched with the commercial energy users than with the domestic.

Table 16 shows the summary of the match rate of between domestic and commercial energy users and the combination of RE sources used to achieve the match. The best match occurs most frequently when the commercial users are supplied by the RE sources especially PV. But the constant value of above 40% is maintained with the WT supply throughout the year unlike the domestic whose match rate goes as low as 16% which is very unattractive for investment.

Table 16 Match Rate of Energy Users in Critical Supply Months (5)

Month	Demand Profile	Supply Combo	Total Demand GWh	Total Supply MWh	Match Rate (%)
	Domestic	WT	5.09	440.22	16.9
	Domestic	PV_TOT	5.09	124.54	8.31
	Commercial	WT	1.17	440.22	48.1
January	Commercial	PV_TOT	1.17	124.54	30.46
	Domestic	WT	3.56	471.5	25.37
	Domestic	PV_TOT	3.56	852.3	40.93
	Commercial	WT	0.993	471.5	55.17
June	Commercial	PV_TOT	0.993	852.3	64.7
	Domestic	WT	3.69	319.69	18.85
	Domestic	PV_TOT	3.69	969.23	43.24
	Commercial	WT	0.919	319.69	48.65
July	Commercial	PV_TOT	0.919	969.23	62.11
	Domestic	WT	5.1	571.96	20.91
	Domestic	PV_TOT	5.1	137.39	9.25
December	Commercial	WT	1.16	571.96	53.36
	Commercial	PV_TOT	1.16	137.39	32.26

5.2. Results from Spatial Analysis

Figure 40 Identified Potential Roofs (34)

Figure 41 Plan View of a South facing Roof top (34)

Figure 42 Elevation view of the South facing roof top (34)

The figures above depict the potential roof selection, where the orientation of a shade free roof is considered and the area measured. The red patch was used to identify selected roofs in order to avoid double selection. The potential of the roof top is inspected at both the plan and elevation levels in order to have a virtual site reconnaissance. This also helped to identify roof tops with curved structures that make installation challenging or roof tops with easy access for theft.

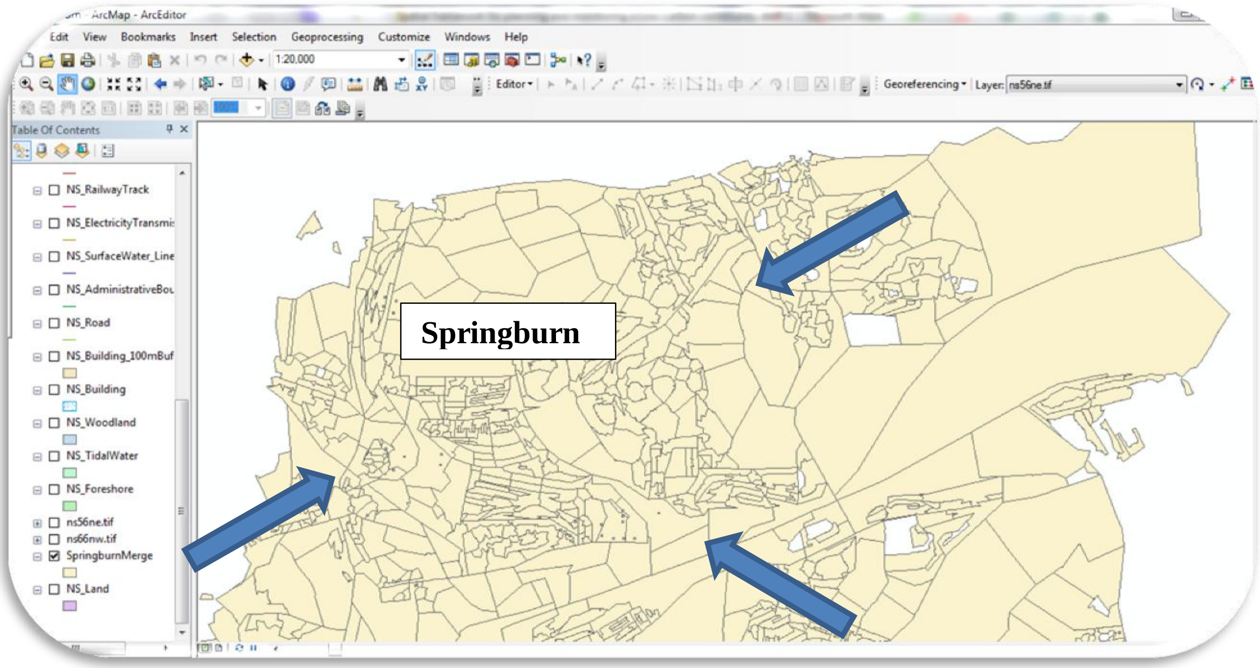


Figure 43 Shapefile of Springburn (36)

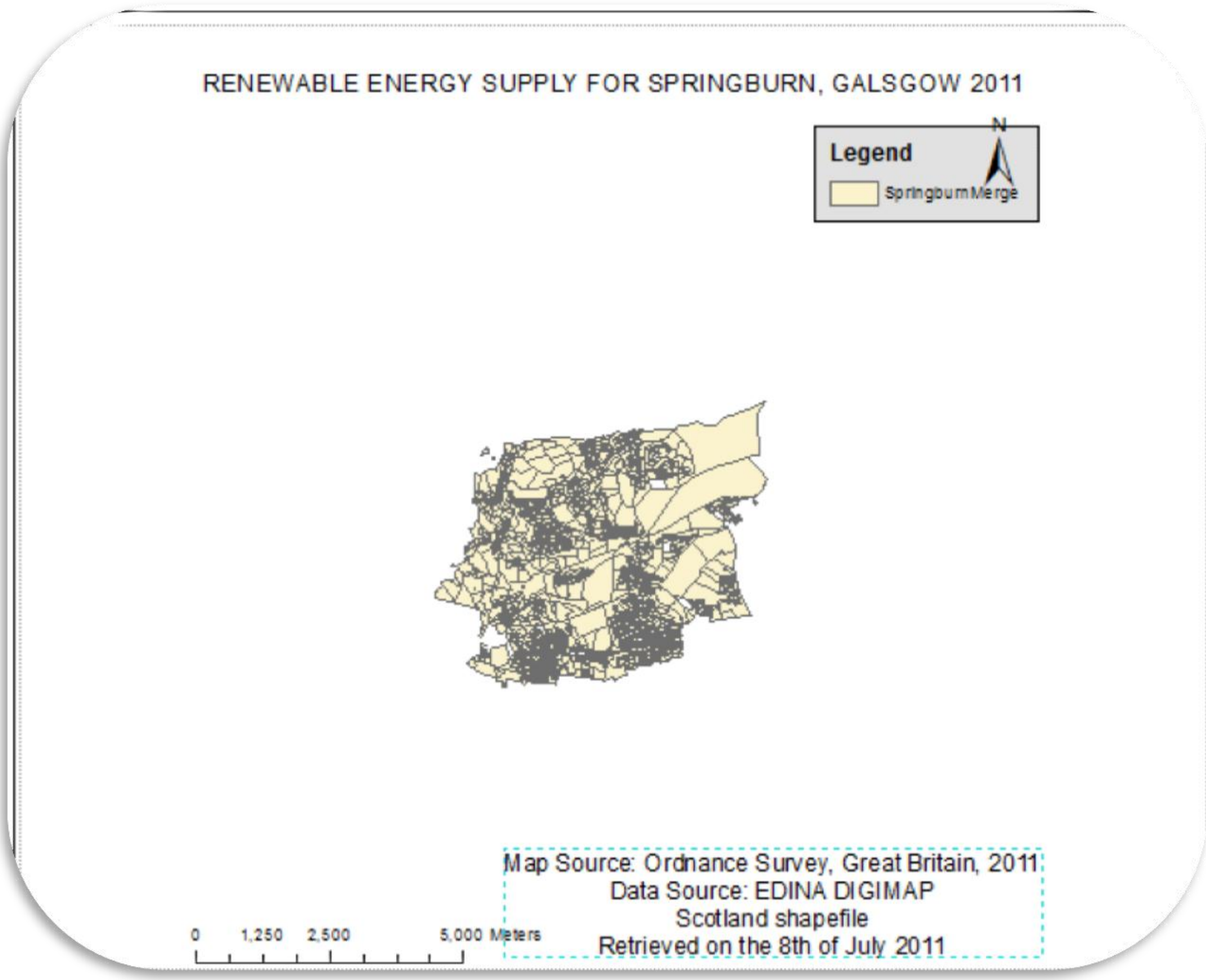


Figure 44Map Layout of Springburn (36)

From the result of potential roof tops identified in GE, and the calculation of potential solar energy available, the spread sheet of commercial energy demand and RE supply were geo-referenced on the shapefile of Springburn in the GIS platform. The RE supply was developed in terms of solar and wind energy shapefiles with the possibility of querying the data to receive results needed by different users of the GIS tool. Figure 43 and Figure 44 depict the basemap of Springburn in GIS environment.

The solar resource shapefile was classified in terms of the roof top orientation, installation capacity and a combination of both roof top orientation and installation capacity. The roof top orientation was classified according to:

1. South, S
2. South east SE or

3. South west SW
4. Flat roofs were assumed to be south facing hence there inclusion in the south facing category.

The installation capacity of potential roof tops was classified according to OFGEM's Feed-In-Tariff structure for PV:

1. 1 kW - ≤ 4 kW;
2. 4 kW - ≤ 10 kW;
3. 10 kW - ≤ 50 kW;
4. 50 kW - ≤ 100 kW;
5. 100 kW - ≤ 150 kW; and
6. 150 kW - ≤ 200 kW;

Roof top Orientation in combination with installation capacity was also classified as:

1. S/SE/SW and = 1 kW - ≤ 4 kW;
2. S/SE/SW and = 4 kW - ≤ 10 kW;
3. S/SE/SW and = 10 kW - ≤ 50 kW;
4. S/SE/SW and = 50 kW - ≤ 100 kW;
5. S/SE/SW and = 100 kW - ≤ 150 kW; and
6. S/SE/SW and = 150 kW - ≤ 200 kW;

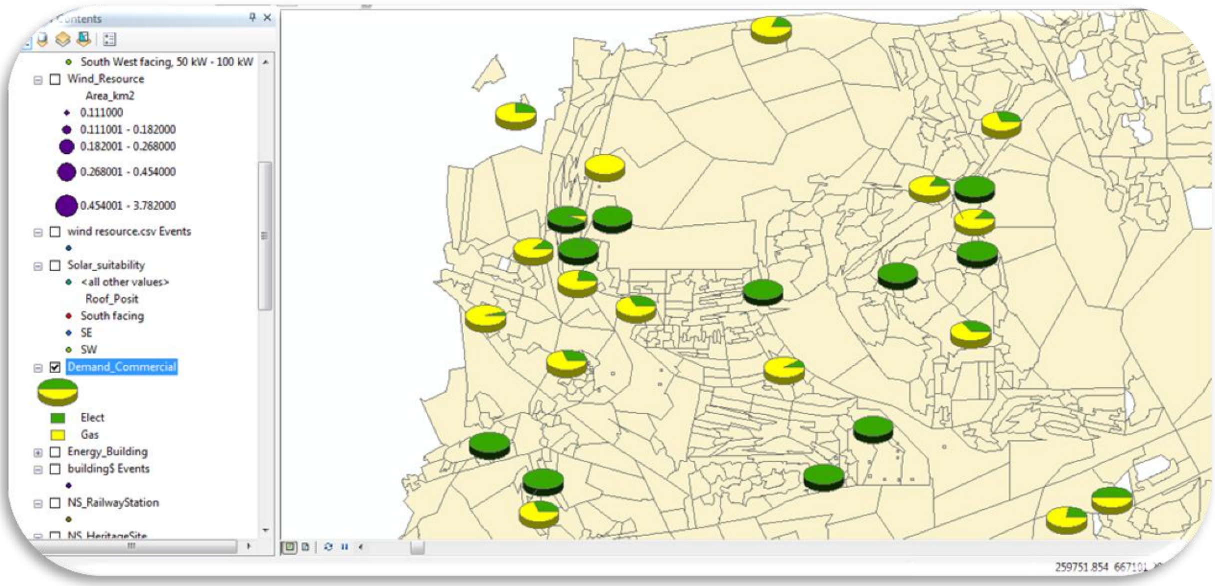


Figure 45Commercial Energy Use Map Layer

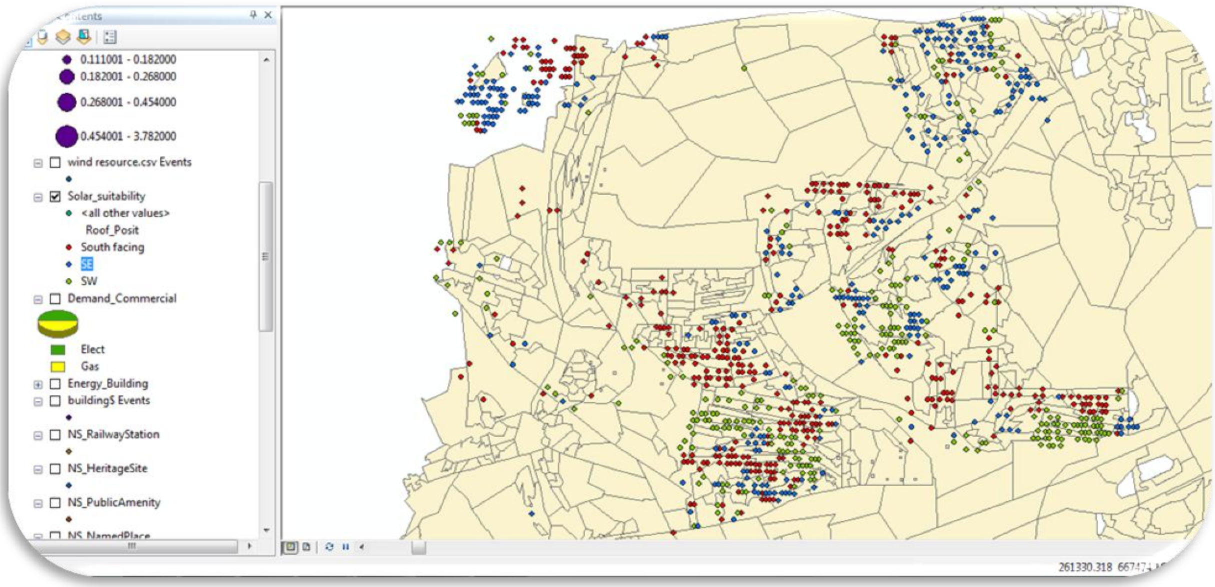


Figure 46 Identified Potential Roof tops (36)

Figure 45 depicts the commercial energy demand of Springburn. This includes both the electric and gas consumption energy use represented by green and yellow respectively. This data represents 27 locations of commercial energy classed users. It would be observed the green stands out more in the map than yellow; in some cases it is just completely green reflecting a heavy reliance on electric energy rather than a combination use of electric and gas. This was one of the observations that supported the claim on the excessive electricity use of the community. *Figure 46* on the other hand represents the orientation of all identified potential roof tops within Springburn. Flat and south facing roof tops are represented by red while the south east and south west facing roof tops are represented by blue and green respectively. There are more SE and SW facing roof tops than south facing ones. Although the energy difference is minimal compared to the west and east facing roof tops. *Figure 47* shows a selection of south east or south west facing roof tops by performing a query search on the geo-database of potential roof tops and output as a map layer.

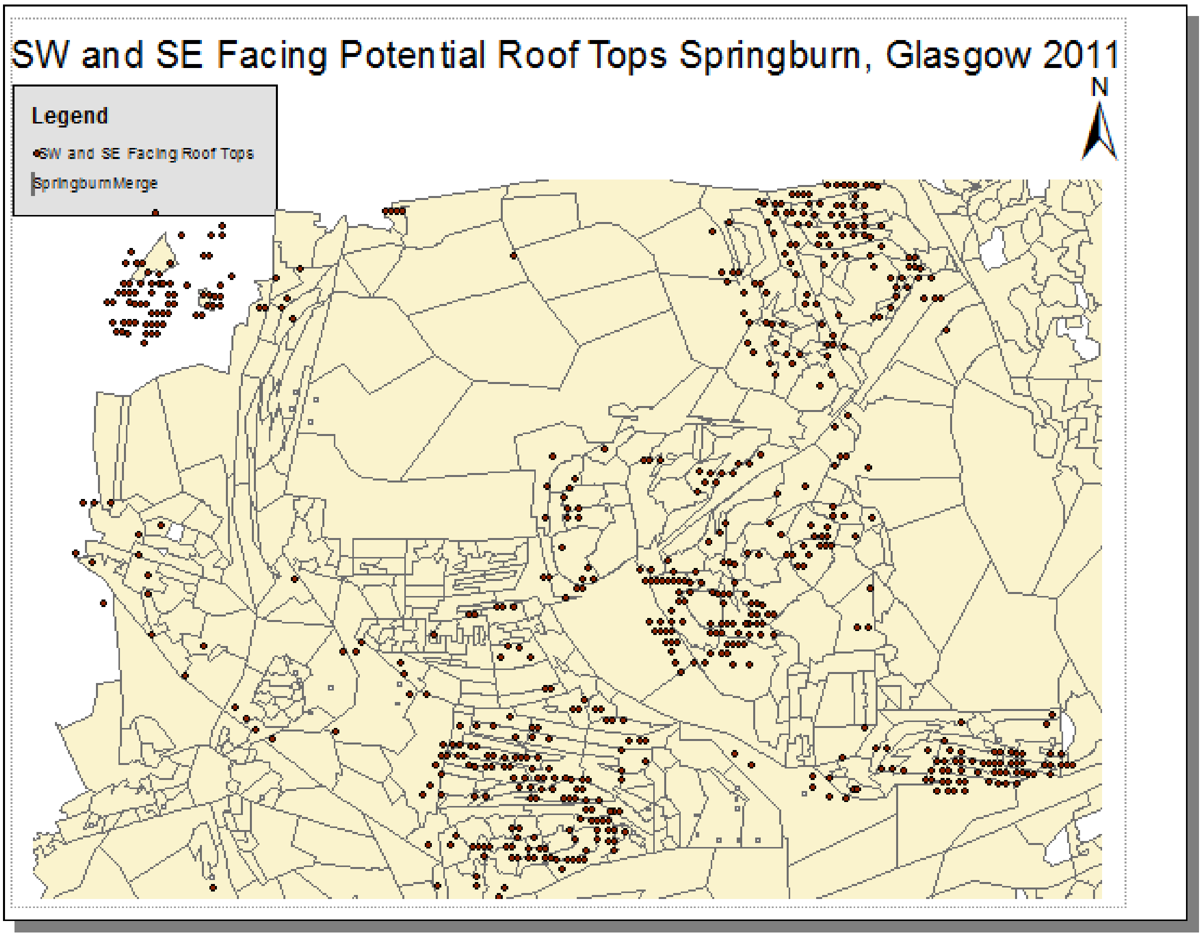


Figure 47Selection of SE and SW Facing Roof tops

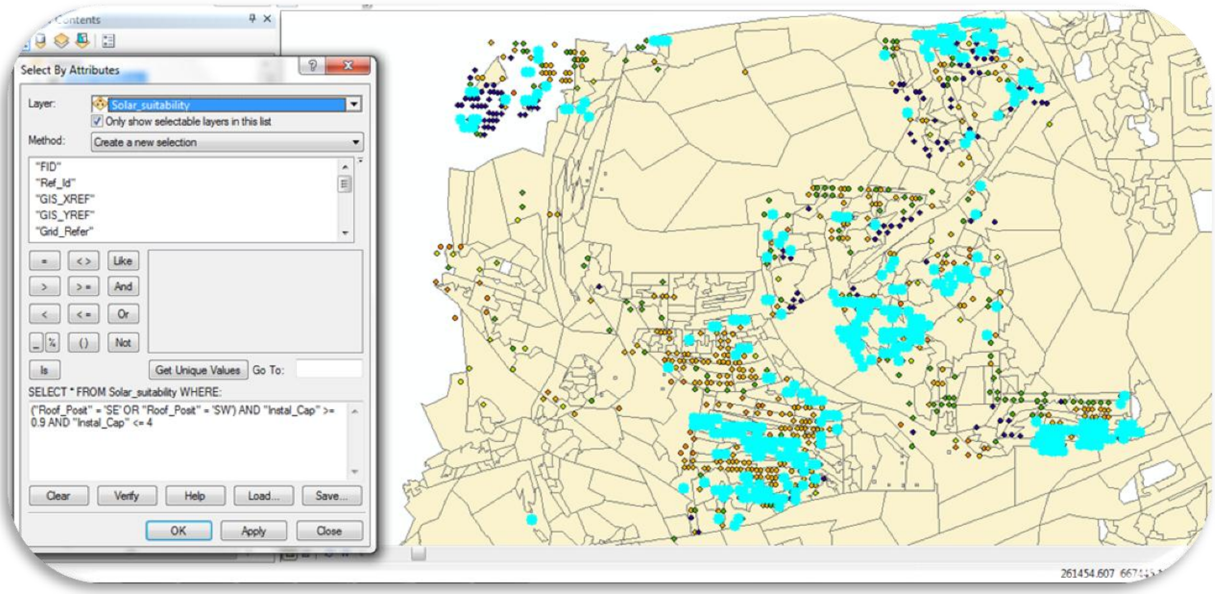


Figure 48 0.9 – <=4kW Installation Capacity of Potential SW and SE facing Roof Tops

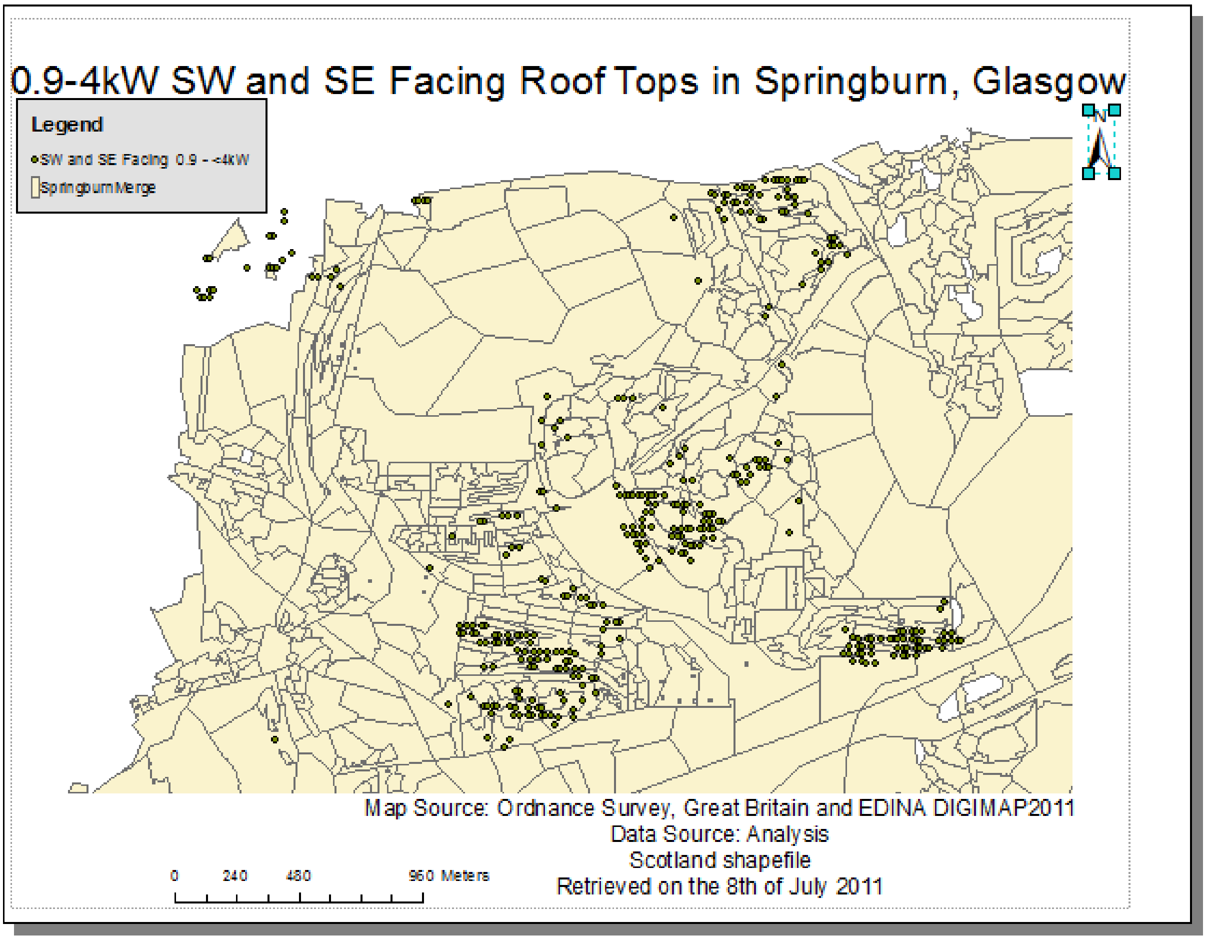


Figure 49 Map Layer of 0.9 – <=4kW Installation Capacity of Potential SE and SW facing Roof Tops

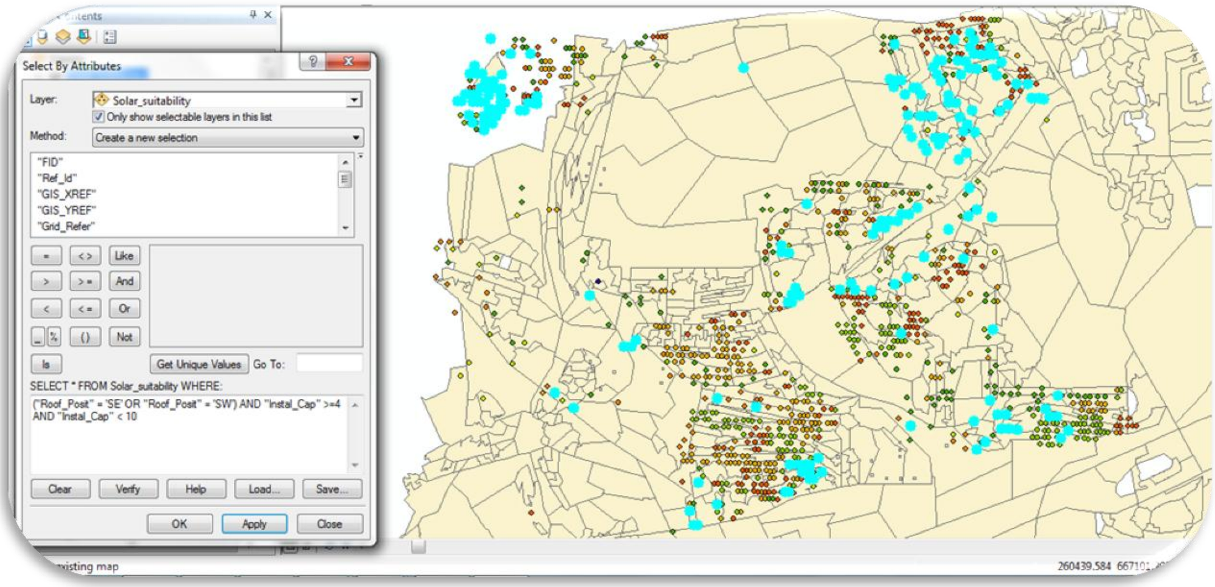


Figure 50 4 – <=10kW Installation Capacity of Potential SE and SW facing Roof Tops

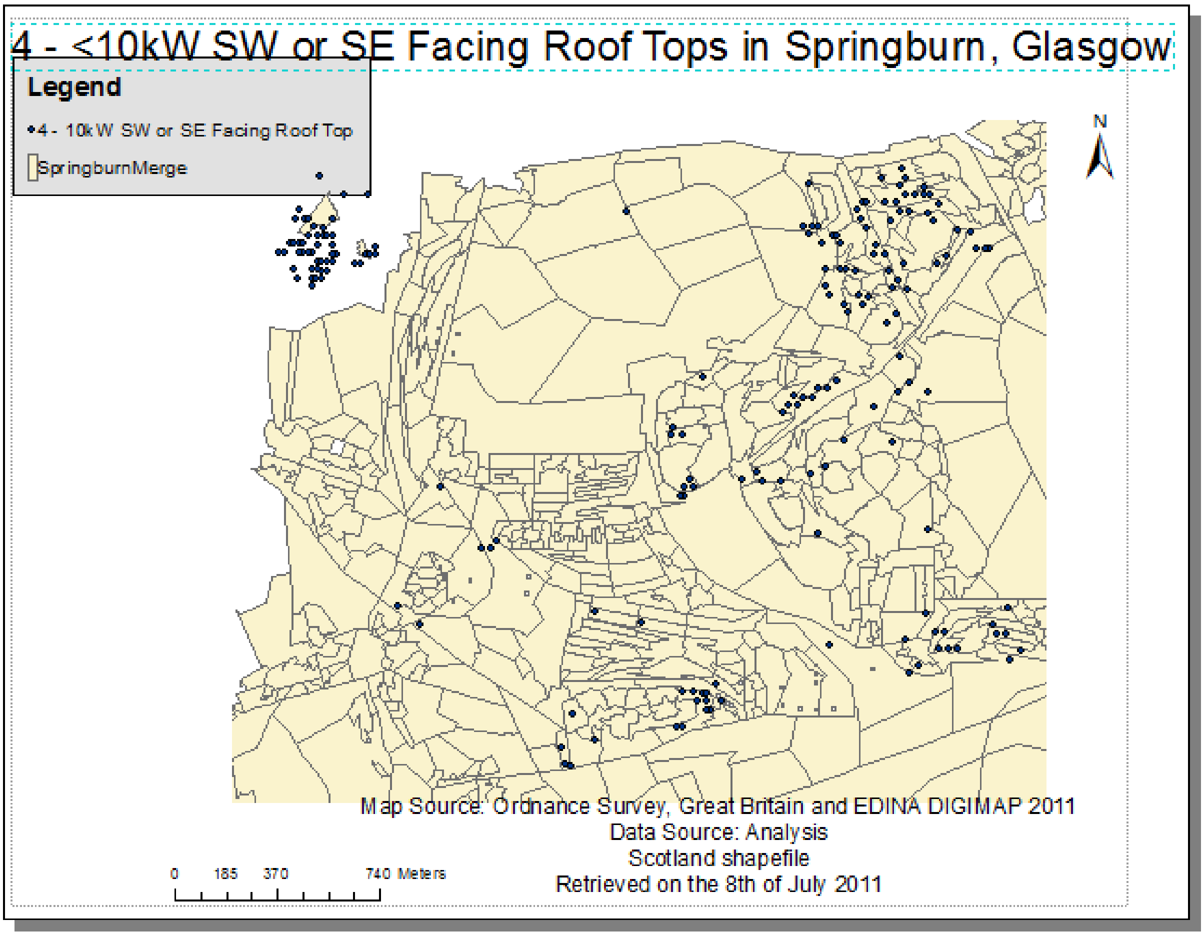


Figure 51 Map Layer of 4 – <=10kW Installation Capacity of Potential SE and SW facing Roof Tops

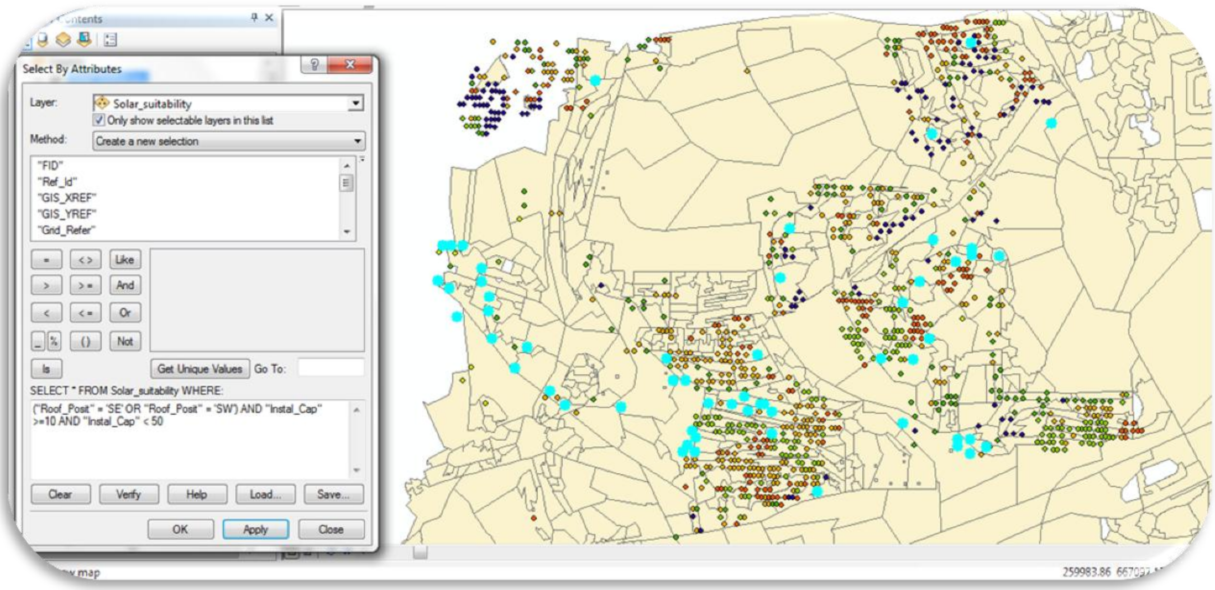


Figure 52 10 – <=50kW Installation Capacity of Potential SE and SW facing Roof Tops

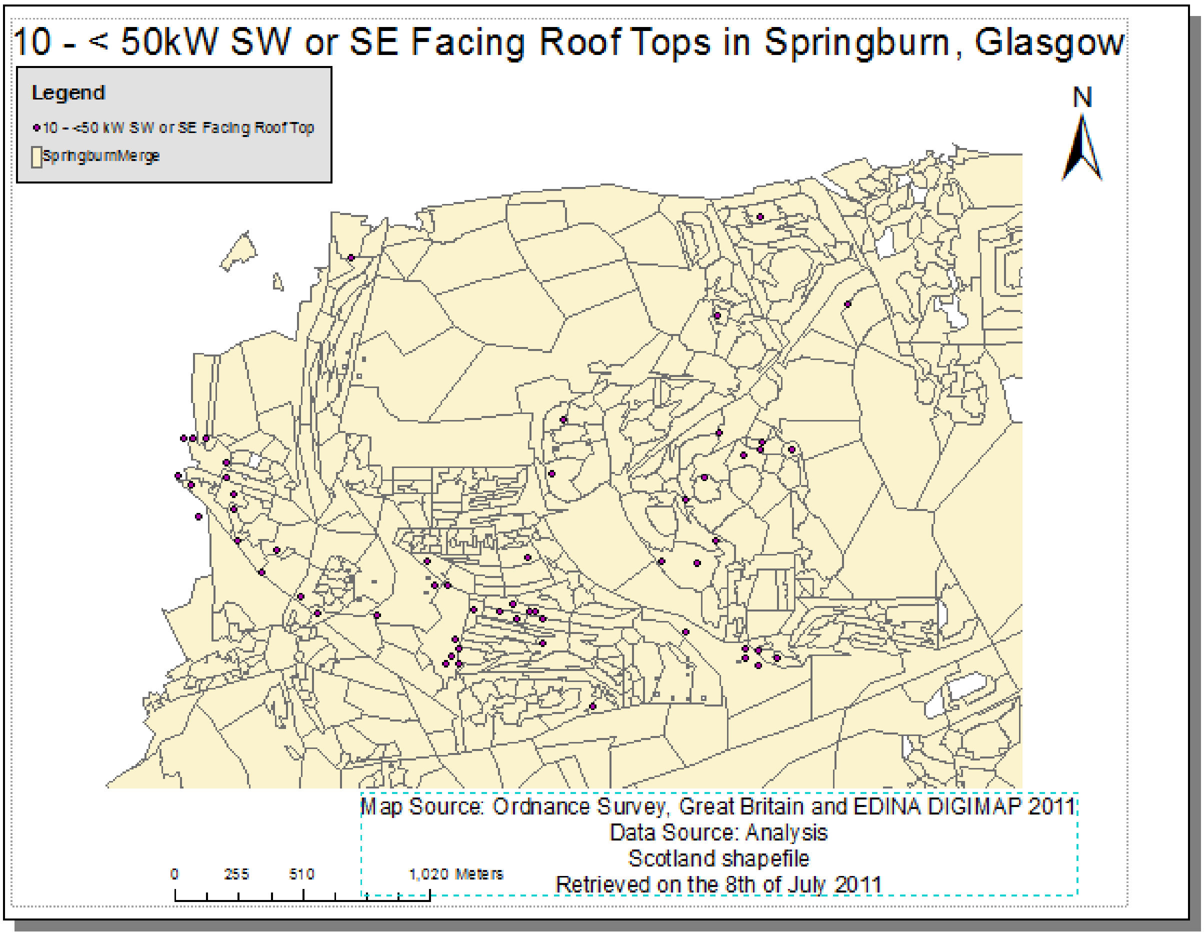


Figure 53 Map Layer of 10 – <=50kW Installation Capacity of Potential SE and SW facing Roof Tops

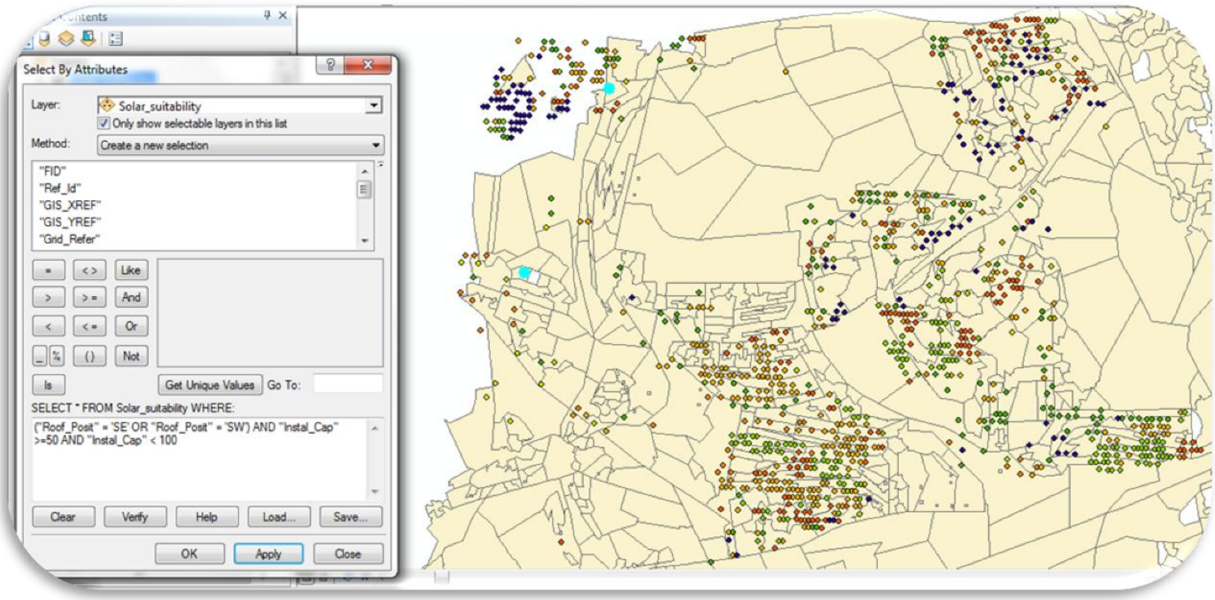


Figure 54 50 – <=100kW Installation Capacity of Potential SE and SW facing Roof Tops

Figure 48 – 53 shows the impact of merging the SE and SW facing roof tops different categories of the defined installation capacities as a result of querying the already prepared potential roof top database. The selection is highlighted in green and upon conversion into a map layer; the corresponding points are mapped out. These show a selection of different installation capacities from SW and SE facing roof tops. It would be observed *Figure 48, 50* and *52* are a subsection of *Figure 46* which represents the total identified potential roof tops for PV mount and as such each of the points on the three map layers above all represent unique locations. From the map layers it found most of the roof tops in the SW and SE position fall mostly in the 0.9 – 4 kW installation capacity range and reduces significantly as the installation capacity range is increased. This is due to the small roof area of these potential sites. In *Figure 54* it is observed only two locations occur within the 50 – 100kW PV installation band. *Figure 55* also clearly defines that most locations with SW or SE facing roof tops fall in the installation capacity band of 0.9 – 10kW.

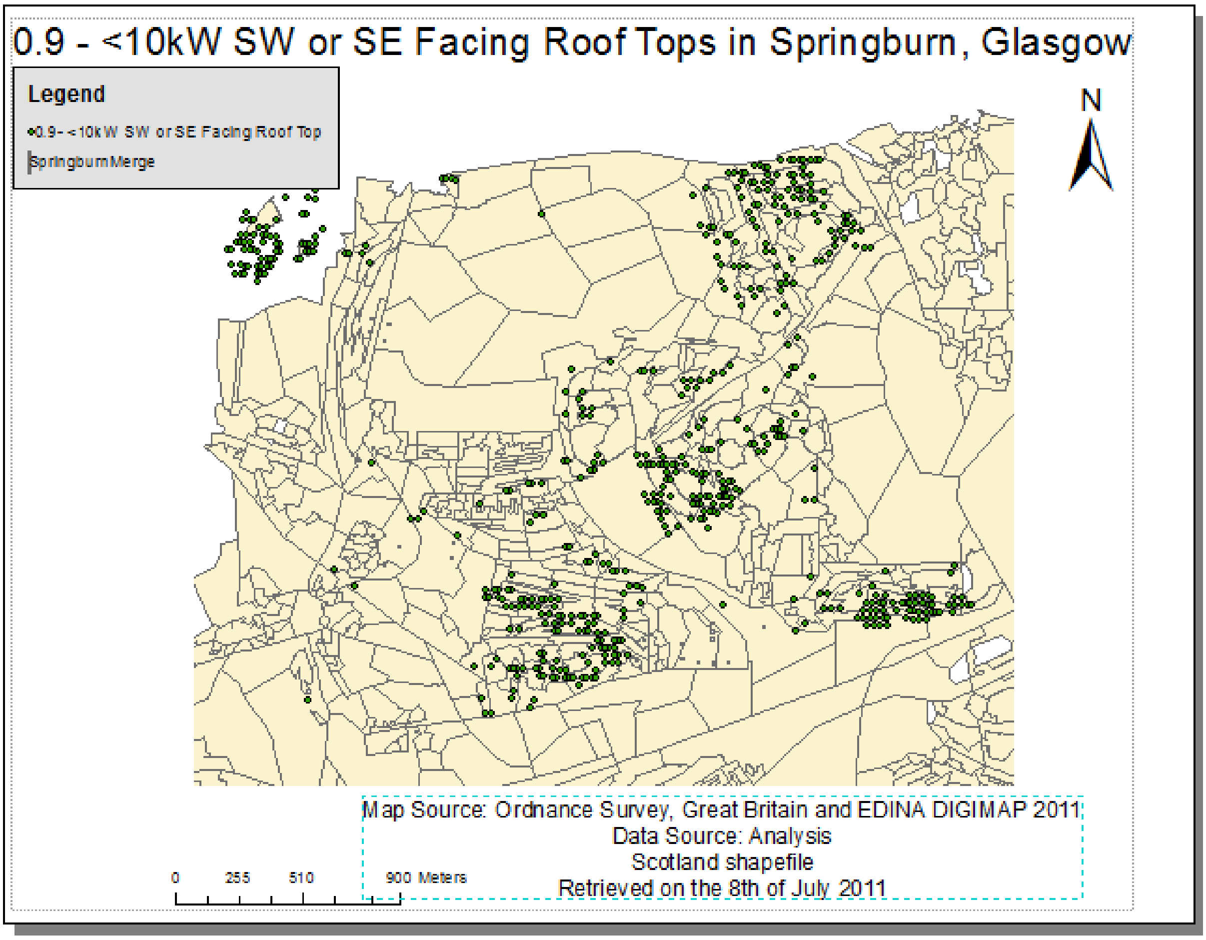


Figure 55 0.9 – <=10kW Installation Capacity of Potential SE and SW facing Roof Tops

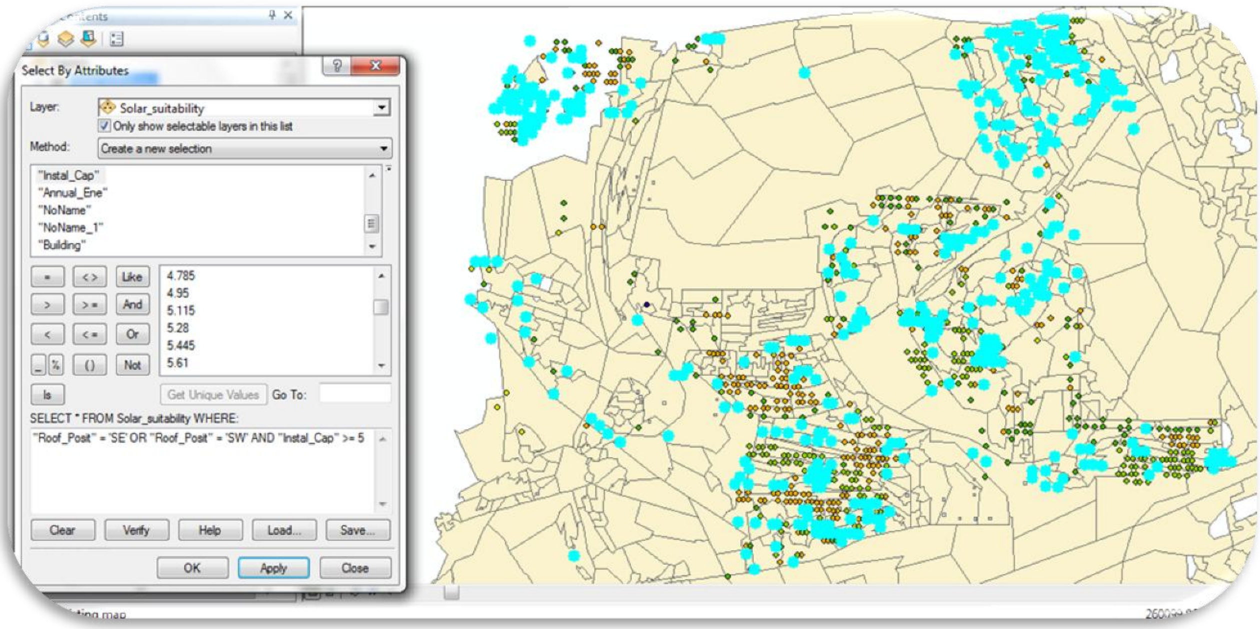


Figure 56 >=5kW Installation Capacity of Potential SE and SW facing Roof Tops

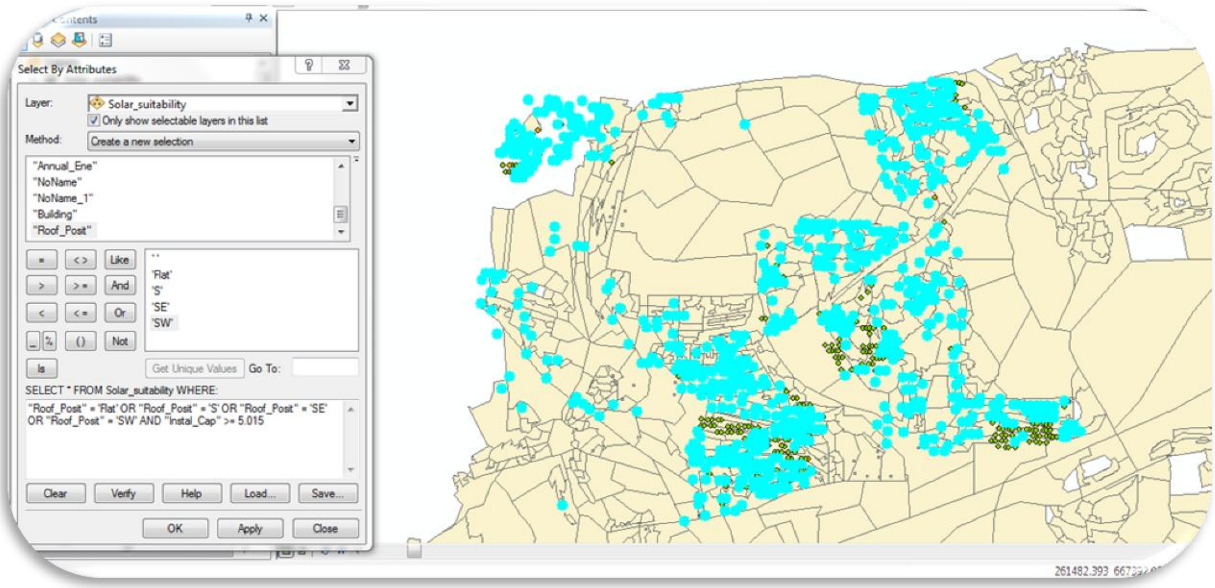


Figure 57 >=5kW Installation Capacity of Potential South, SE and SW facing Roof Tops

Figure 56 and 57 depicts map layers with installation capacities of 5kW and above. The first shows that for SW and SE facing roof tops, while the second show that for all roof tops. It would be gathered from the level of highlighted locations that most identified potential roof tops in Springburn have a PV installation capacity of at least 5kW. Figure 58 and 59 below also show some of the possible combinations from South facing roof tops only while Figure 60 represent south facing roof tops with annual energy supply above 4,200kWh.

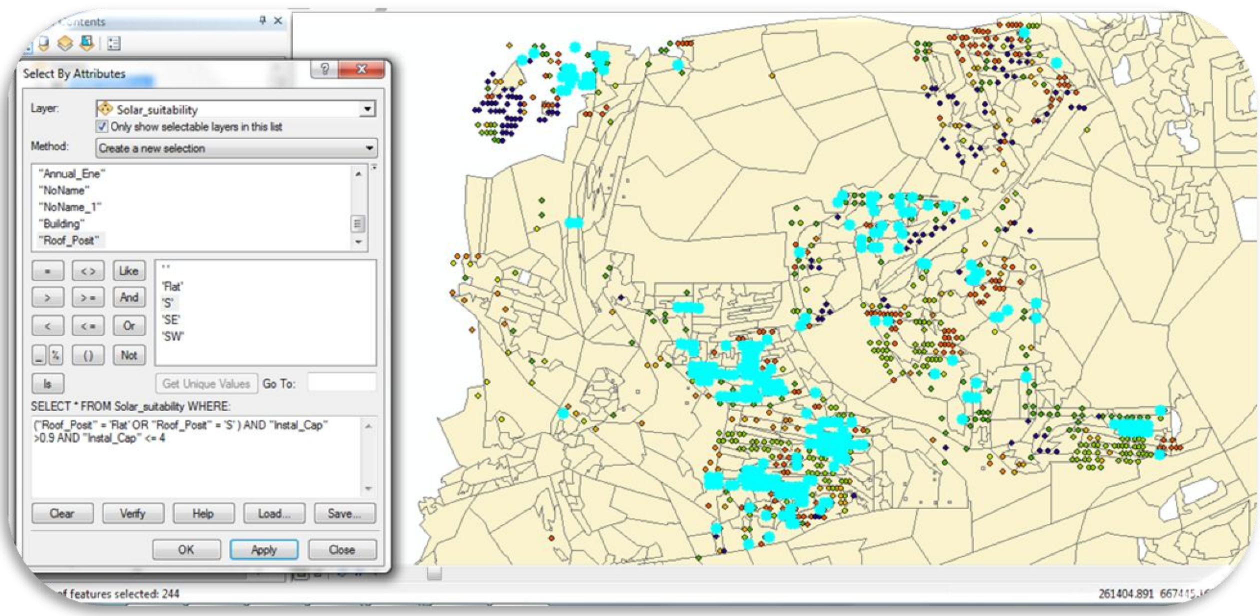


Figure 58 0.9 – <=4kW Installation Capacity of Potential South facing Roof Tops

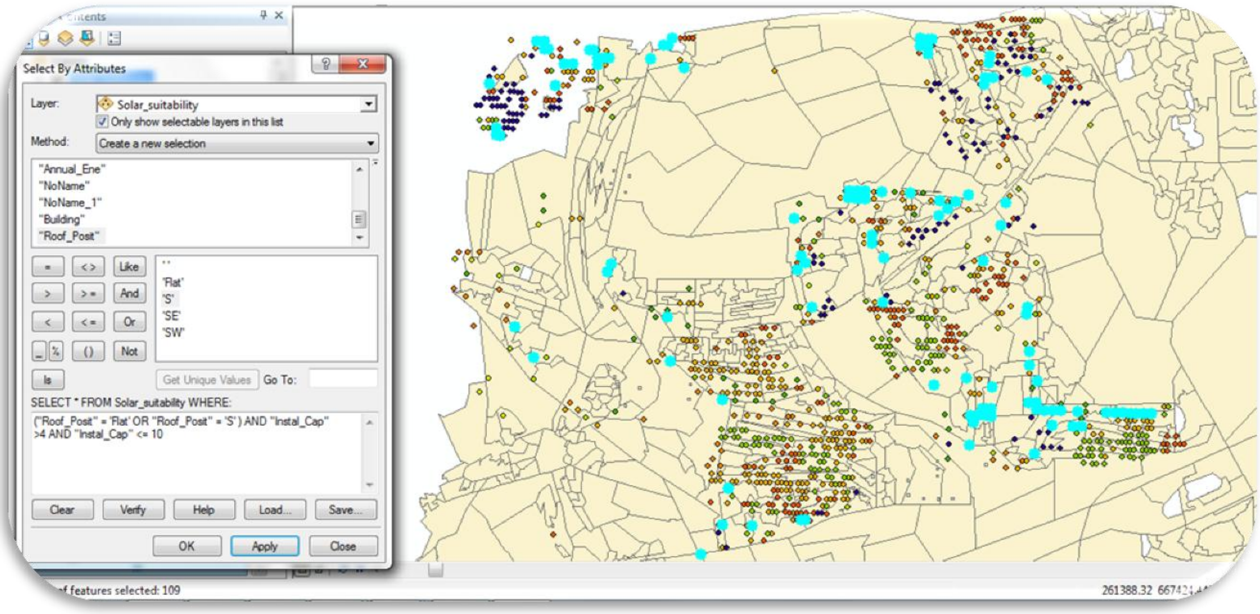


Figure 59 4 – <=10kW Installation Capacity of Potential South facing Roof Tops

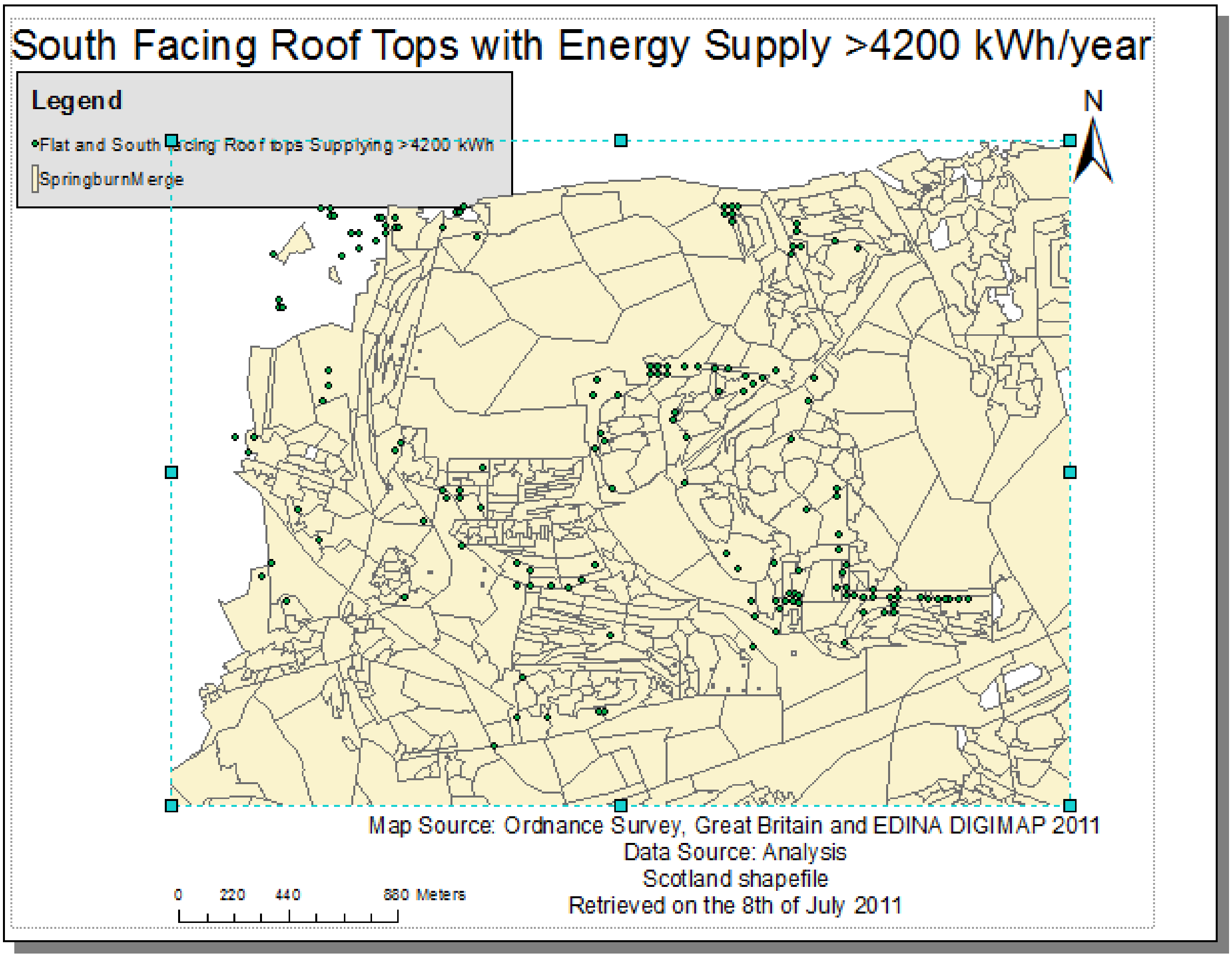


Figure 60 South facing Roof Tops with Energy Supply >4,200kWh/year

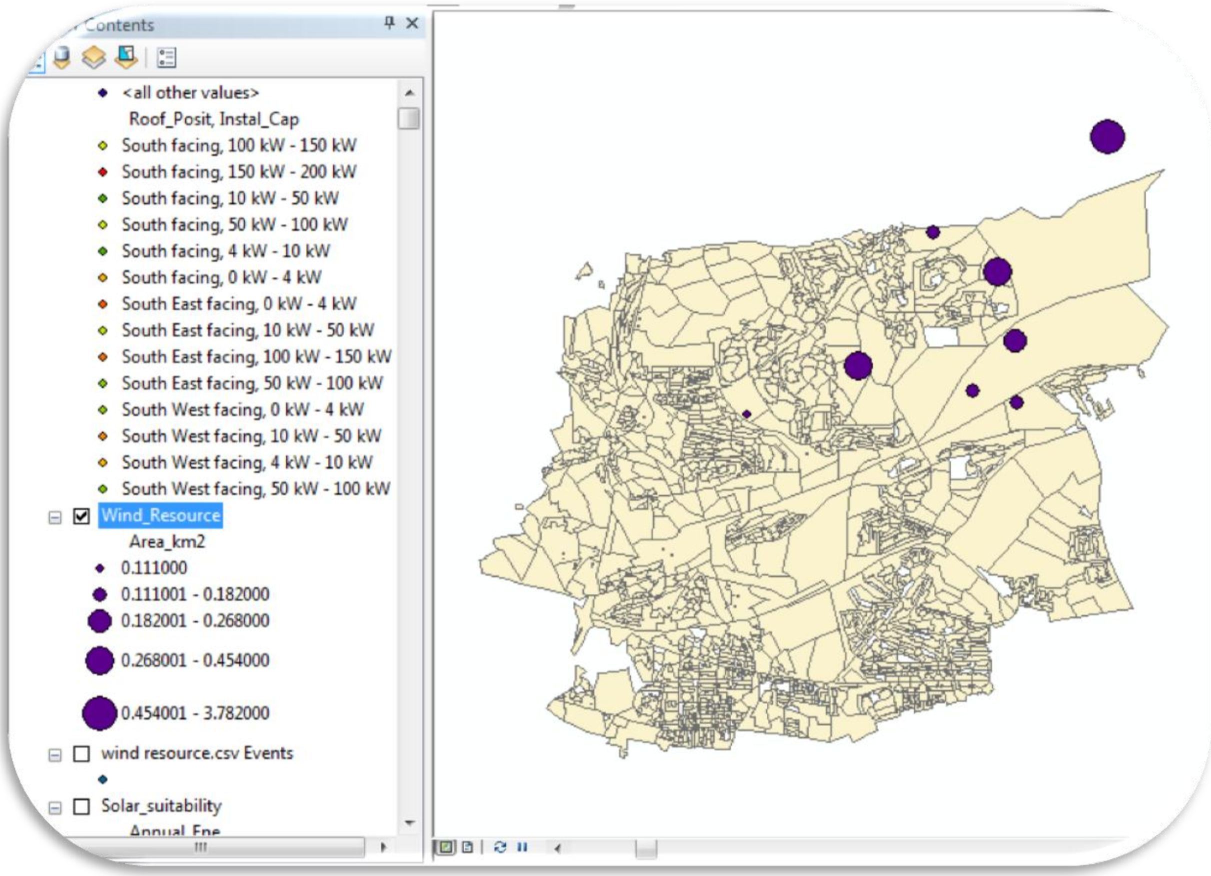


Figure 61 Land available for Wind Farm (36)

The wind resource was classified according to the area of land available that is greater than $3km^2$. It was observed only about 1,000 roof tops with Springburn had the potential for solar installation. This is such a low number considering the technical constraint attributed to tilt angle was not considered in this study since it was assumed to be treated as an installation challenge that can be rectified. Figure 61 represents the sites available to install WT which show only one major area sprawling over $3.5km^2$ with a capacity to site 25 100kW WT. Most of the other smaller sites identified have been earmarked for housing. This signifies a tussle between providing new housing and providing enough RE power to supply the already built environment.

5.3. Summary of Findings

Springburn is an area with a high population density of 3,976 per km^2 according to section 4.2.1, hence a tough challenge ensues in balancing energy demands with RE supply. The total potential RE supply from the hybrid of PV and WT will only supply a fifth of Springburn energy consumption based on the 2007 data. This figure represents a challenge for the future of 100% RE supply in the near future even with the aggressive microgeneration strategy.

Although the study focuses on electric energy use within the community, it was inferred from Chapter 4, that only about half the households in Springburn have access to gas supply to meet their thermal requirements. Thus the use of electricity for space heating, domestic hot water and cooking purpose might be responsible for the high electric consumption within this community.

The annual demands of commercial energy users were more constant than the domestic energy users that fluctuates arbitrarily. Due to this fairly constant energy demand of commercial energy users it was observed a better match rate occurred when RE supply was matched to it than when matched with domestic users or both class of energy users. The disparity between energy supplied and energy delivered was found to reduce with increased energy demands when matched with the RE supply. Thus eliminating energy waste that would have occurred if the excess energy generated was not consumed.

Only a thousand roof tops within the Springburn community are south, SE or SW facing with majority in the SE and SW position. The average installation capacity in the community is a 5kW PV system from the survey of the identified roof tops while the range is 0.9 – 10kW for the SW and SE facing roof tops. There is only one identified vacant land for WT development within the community as a result of the consideration for the most economic returns a piece of land would generate for the government.

Chapter 6 Conclusion

6.1. Conclusion

According to the results of the study area, micro energy generation can only contribute 20 % of Springburn's electric energy consumption from the hybrid of PV and WT assuming electrical consumption remains at the 2007 electric energy rate. This could impact negatively on the possibility of Springburn achieving its carbon reduction target except some aggressive steps are taken. Micro energy generation is not sufficient to increase RE penetration within the suburb of Springburn. There is a need for a mixture of RE technologies, localized policies attributed to the peculiarity of Springburn, law enforcement and effective monitoring. With the aid of the GIS based potential energy supply layer, the local authorities can easily identify properties with potential energy sites for fast tracked grant allocation or planning.

The following recommendations are advised to the Glasgow city council that possesses the enabling powers needed to effect change:

1. The council needs to demonstrate leadership by establishing low carbon technologies across its property portfolio.

2. There is a need to extend gas supply to areas without gas links and an introduction of incentives for gas consumers in order to encourage the switch due to the present low figures of gas consumers identified in Springburn. However cost and benefit of a introducing a gas supply network might need further research in order to make an informed decision. Household compliance can be enforced by enacting a regulation that mandates the council to fine households for non - compliance if gas supply access is present within close proximity of the buildings premises.

3. The council needs to either motivate the commercial energy users to invest in the installation of RE sources on the potential roof tops and vacant lands identified or invest in the community and set up a microgeneration utility company. This not only complies with the future 100% RE target, but tackles the key drivers to a sustainable city as identified in the Sustainable Glasgow report (2010). The utility company will help to cut carbon emissions, create job opportunities and also reduce or eradicate fuel poverty. To achieve the establishment of the council's utility company, these steps could be considered:

1. A cooperative scheme that would involve suitable potential roof top households, commercial energy users and the council to pool resources together and set up the utility company. Although if this is agreed there is a need to tie supply from RE sources to the grid rather than to individual households. This helps to reduce energy waste thus encouraging effective energy use during the day. This is due to the poor match rate of domestic energy users or total Springburn energy use to RE supply identified in Table 16.

2. Introduction of a "Day time" tariff structure an equivalent of the Economy 7 tariff which would suit the domestic energy users. Considering the cost of electricity export from RE supply to the grid is 3.1pence/kWh while the current cost of electricity from utility companies like EON is about 26pence/kWh for domestic energy users, this provides a reasonable profit margin to sell the energy at a reduced price and the benefit of income from FEED - IN- TARIFF, would sustain the operations of the would be Springburn community utility company.

4. An introduction of Net – Metering with established memorandum of understanding from stakeholders like the existing utility companies who needs to assume their corporate social responsibility position realizing carbon emission reduction targets can only be achieved when all stakeholders are fully involved.

   Net – metering according to Faden is a legal tool designed to facilitate the use RE sources which permits individuals who installs RE sources on their property to sell the excess electricity back to the local utility company at the same rate it buys from the utility company. (37) Net – metering was introduced in California, USA in 1995 in a bid to encourage installation of RE technologies at microgeneration level hence making it more economical to invest in. (38) This policy was enacted to encourage investment by individuals on their property and not for major investors. But a modification of this policy could be adopted for Springburn. This would help to allay the concern of Elliot discussed in section 1.1, who argues individuals need more incentives to support the wide scale ownership of RE technologies.

5. Timely monitoring and submission of energy consumption data from households, utility companies, Glasgow Housing Association and other private residential landlords. This can include measures such as the addition of a "monthly energy

consumption per household” form on the council’s website to encourage householders input their consumption periodically which can be scaled up to include the utility companies. This would help to increase first-hand information of energy data within the council.

6. There is a need to build the GIS capacity of every unit within the council as it would help in the expedient way of sharing data and information since geographic information is reusable and updatable easily within the council’s network of users. This complies with Marais in 2008, who suggests the training of more GIS users in order to promote its effective use (25) especially with the benefit of revenue generation by the council from information seekers as performed by the Cascade County in the United States as discussed in section 2.2.

7. There is a need for stricter enforcement of energy efficiency improvements for households within the community in order to cut present energy consumption values.

8. A modification of the architecture of buildings within the community that would allow addition of PV facades to south facing buildings with large surface areas. This is an attempt to tackle the RE supply challenge posed by the high dwelling density in Springburn and a minute number of potential roof tops within the PV installation orientation.

These recommendations if considered should promote increase in micro energy generation using RE sources within the Springburn community.

6.2. Suggestions for Further work

This study was limited by the access to individual energy demand or consumption data of households within Springburn, thus restricting the focus of the study to electric demands of the community and the suggestion of a grid tie of RE supply instead of individual energy use.

It thus would be suggested for access to real energy demand data of households within this community is achieved before engaging on any further analysis in terms of micro energy generation within Springburn. This would help to improve the quality and reliability of the demand/supply matching. The implication of an inclusion of auxiliary supply could also be investigated in order to improve the energy supply during winter when solar resource is at its minimum.

Bibliography

1. **Scottish Government.** Socio-Economic data for MLSOA,IGZ and LLSOA Electricity and Gas Estimates. [Online] 25 March 2010. [Cited: 18 08 2011.] http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/regional/electricity/mlsoa_llsoa/mlsoa_llsoa.aspx.

2. **Office for National Statistics.** Scottish Neighbourhood Statistics. *Scottish Neighbourhood Statistics.* [Online] 15 12 2008. [Cited: 19 August 2011.] http://www.sns.gov/Downloads.

3. Energy Consumption in the UK: Domestic data table. *Department Energy and Climate Change.* [Online] 11D/806, 28 July 2011. [Cited: 20 August 2011.] http://www.decc.gov.uk/en/content/cms/statistics/publications/ecuk/ecuk.aspx.

4. **HOMER.** *HOMER Renewable Energy Planning Software.* 2011.

5. **MERIT.**

6. **Glasgow City Council.** 2011.

7. *SUN-AREA TOWARDS LOCATION-BASED ANALYSIS FOR SOLAR PANELS BY HIGH RESOLUTION REMOTE SENSORS (LIDAR).* **Ludwig, Dorothea, Lanig, Sandra and Klarle, Martina.** Santiago : International Cartographic Association, 2009. International Cartographic Association. p. Abstract.

8. *GIS-based decision support for solar energy planning in urban environments.* **Rylatt, M, Gadsden, S and Lomas, K.** 6, Leicester : Pergamon, November 2001, Computers,Environment and Urban Systems, Vol. 25, p. 579. 0198-9715.

9. **Barker, Jack Dangermond and Dr. James.** GIS for Climate Change. *ESRI.* [Online] FEBRUARY 2010. [Cited: 21 July 2011.] http://www.esri.com/library/bestpractices/climate-change.pdf.

10. Sustainable Glasgow Report. *Sustainableglasgow.* [Online] 27 January 2010. [Cited: 21 July 2011.] http://www.sustainableglasgow.org.uk/News/Pages/20100127_SustainableGlasgowLaunch.aspx.

11. *Consumer- Supplier - Government traingular relations: Rethinking the UK policy path for carbon emissions reduction from the UK residential sector.* **Parag, Yael and Darby, Sarah.** 10, Oxford : Elsevier, October 2009, Energy Policy, Vol. 37, p. 3984. 0301-4215.

12. **DECC.** Climate Change Act. *Department of Energy and Climate Change.* [Online] 26 November 2008. [Cited: 21 July 2011.] http://www.decc.gov.uk/en/content/cms/legislation/cc_act_08/cc_act_08.aspx.

13. Renewable Energy Directive. *The Department of Energy and Climate Change.* [Online] 5 June 2009. [Cited: 21 July 2011.] http://www.decc.gov.uk/en/content/cms/meeting_energy/renewable_ener/renewable_ener.aspx.

14. Renewable Action Plan. *The Scottish Goverment.* [Online] 01 July July 2009. [Cited: 21 July 2011.] http://www.scotland.gov.uk/Publications/2009/07/06095830/4.

15. *GIS - based evaluation of multifarious local renewable energy sources: a case study of the Chigu area of southwestern Taiwan.* **Yue, Cheng-Dar and Wang, Shi-Sian.** 6, s.l. : Elsevier, 28 August 2004, Energy Policy, Vol. 34, pp. 730-742.

16. **DECC.** Department of Energy and Climate Change. *Department of Energy and Climate Change.* [Online] June 2011. [Cited: 16 08 2011.] http://www.decc.gov.uk/en/content/cms/meeting_energy/microgen/microgen.aspx.

17. *Renewable Energy and Sustainable Futures.* **Elliot, Dave.** 3-4, Milton Keynes : Pergamon Press, April 2000, Futures , Vol. 32, p. 269. 0016-3287.

18. *Additional Renewable Energy Growth though Small-Scale Community oriented Energy Policies.* **Hain, J J, et al., et al.** 9, Glasgow : Elsevier Press, June 2005, Energy Policy, Vol. 33, p. 1199.

19. *Geographical information systems applied in the field of renewable energy sources.* **Domínguez, Javier and Amador, Julio.** 3, April 2007, Computers & Industrial Engineering, Vol. 52, pp. 322-326. 0360-8352.

20. **Gilfoyle, Ian and Thorpe, Peter.** *Geographic Information Management in Local Government.* Florida : CRC Press, 2004.

21. **Longley, Paul A, et al., et al.** *Geographic Information Systems and Science.* Second. Chichester : John Wiley and Sons, Ltd, 2005.

22. GIS for Renewable Energy. *An ESRI website.* [Online] January 2010. [Cited: 8 August 2011.] http://www.esri.com/library/bestpractices/renewable-energy.pdf.

23. *Geographic Information Systems (GIS) for Facility Management.* **Rich, Stuart and Davis, Kevin H.** Houston : IFMA Foundation, 2010. International Facility Management Association. p. 5.

24. **Masser, Ian.** *Governments and Geographic Information.* London : Taylor and Francis Ltd, 1998. p. 11.

25. *The Challenges of GIS Education and Training: GIS Use by Municipal Urban and Regional Planning.* **Marais, Hester J.** Cape-Town : OSGeo, 2008. Free Open Source software for Geospatial Conference. p. 387. 978-0-620-42117-1.

26. **Dodd, Nick.** *Community Energy: Urban Planning For A Low Carbon Future.* Oldham : TCPA and CHPA, 2008.

27. **DECC.** *Action Plan for Microgeneration.* London : DECC, 2011.

28. *Energy: Encouraging the Use of Solar Energy- A Needs assessment for Oklahoma.* **Review, Oklahoma Law.** Oklahoma : s.n., 1983, Oklahoma Law Review, Vol. 36, p. 136.

29. *SUN-AREA.* [Online] [Cited: 25 August 2011.] http://www.sun-area.net/SUN-AREA.8.0.html.

30. **Webb, Sarah.** About ESRI UK:Press Releases ESRI UK. *ESRI UK.* [Online] 08 March 2011. [Cited: 25 August 2011.] http://www.esriuk.com/aboutesriuk/pressreleases.asp?pid=659.

31. *Combining Google Earth and GIS mapping technologies in a Dengue surveilance system for Developing Countries.* **Chang, Aileen Y, et al., et al.** 49, s.l. : BioMed, 23 July 2009, International Journal of Health Geographics, Vol. 8, p. Abstract.

32. Google Earth Download. *Google website.* [Online] 2011. [Cited: 26 August 2011.] http://www.google.com/earth/download/ge/.

33. **Elexon Ltd.** Electricity user load profiles by profile class. *UK ENERGY RESEARCH CENTRE.* [Online] November 1997. [Cited: 16 August 2011.] http://data.ukedc.rl.ac.uk/browse/edc/Electricity/LoadProfile/data.

34. **GoogleEarth.** 05 November 2009.

35. **Department of Energy and Climate Change.** Middle Layer Super Output Area (MLSOA) and Intermediate Geography Zone (IGZ) Electricity and Gas Data 2007: Frontpage. *Department of Energy and Climate Change.* [Online] 19 March 2009. [Cited: 19 August 2011.] http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/regional/regional.aspx.

36. **ArcGIS 10.** ArcGIS 10. s.l. : ESRI, 2011.

37. *Net Metering of Renewable Energy: How Traditional Electricity Sppliers Fight to Keep You in the Dark.* **Faden, Valerie J.** s.l. : HeinOnline, 2000, Widener Journa;l of Public Law, Vol. 10, p. 109.

38. **Starrs, Thomas J and Renewable Energy Policy Project.** *Net Metering: New Oppurtunities for Home Power.* California : College Park, Md. : Renewable Energy Policy Project, 1996.

39. Specification Sheet for Sharp 165 W PV. *Texas Solar Power Company.* [Online] [Cited: 5 Sept 2011.] http://www.txspc.com/documents/165.pdf.

40. Technical Specifications of 100kW Northwind Wind turbine. *Northern Power.* [Online] [Cited: 21 August 20011.] http://www.northernpower.com/pdf/brochure-northwind-100.pdf.

41. **Renewable Energy World.** How to Exit the Age of Oil: Closing the Renewables Gap (Podcast). *www.renewableenergyworld.com.* [Online] 18 08 2010. [Cited: 11 08 2011.] http://www.renewableenergyworld.com/rea/news/podcast/2010/08/how-to-exit-the-age-of-oil-closing-the-renewables-gap.

42. **Rapier, Robert.** *Peak Oil Interview for the Global Footprint Conference.* 22 09 2010.

43. **News, National Geographic.** Global Warming Fast Facts. *National Geographic News.* [Online] 14 06 2007. [Cited: 11 08 2011.] http://news.nationalgeographic.com/news/2004/12/1206_041206_global_warming.html.

44. **The Directorate-General for Climate Action.** Combating climate change within and outside the EU. *European comission, Climate action.* [Online] 2010. [Cited: 11 08 2011.] http://ec.europa.eu/dgs/clima/mission/index_en.htm.

45. **King, Mark.** The Guardian. *British Gas raises gas and electricity prices.* [Online] 08 07 2011. [Cited: 11 08 2011.] http://www.guardian.co.uk/money/2011/jul/08/british-gas-raises-gas-electricity-prices.

46. **Department of Energy & Climate change.** Energy Price Statistics, International comparisons. *Department of Energy & Climate change.* [Online] 30 06 2011. [Cited: 11 08 2011.] http://www.decc.gov.uk/en/content/cms/statistics/energy_stats/prices/prices.aspx.

47. **Community Energy Plus.** Strong Interest in community renewable energy. *Community Energy Plus.* [Online] 28 03 2011. [Cited: 11 08 2011.] http://www.cep.org.uk/2011/03/28/strong-interest-in-community-renewable-energy-schemes/.

48. **Sioshansi, Fereidoon P., [ed.].** *Generating Electricity ia a Carbon-Constrained World.* San Diego : Elsevier Academic Press, 2010.

49. **Robert Foster, Majid Ghassemi, Alma Cota.** *Solar Energy: Renewable Energy and the Environment.* [ed.] Abbas Ghassemi. s.l. : CRC Press, 2009.

50. **Posharp/a.** Photovoltaic Modules with Monocrystalline Cell Technology database. *Posharp, The Source For Renewables™.* [Online] [Cited: 12 08 2011.] http://www.posharp.com/photovoltaic/database.aspx?ctype=7&sort=eff&dt=asc&pg=208.

51. **Posharp/b.** Photovoltaic Modules with Polycrystalline Cell Technology database. *Posharp, The Source For Renewables™.* [Online] [Cited: 12 08 2011.] http://www.posharp.com/photovoltaic/database.aspx?ctype=10&sort=eff&dt=asc&pg=213.

52. **Markvart, Tomas, [ed.].** *Solar Energy.* Second. Chichester : John Wiley & Sons, 2000.

53. **Faiman, David.** Challenges of Large-scale solar cell electricity production. [ed.] Larry Partain Lewis Fraas. *Solar cells and their applications.* Second. New Jersey : John Wiley & Sons, 2010.

54. **PVResources (a).** Large-scale photovoltaic power plants database. *PVResources.* [Online] [Cited: 12 08 2011.] http://www.pvresources.com/en/top50pv.php.

55. **PVResources (b).** Large-scale roof mounted/roof integrated. *PVResources.* [Online] [Cited: 12 08 2011.] http://www.pvresources.com/en/top25bipv.php.

56. **National Grid.** *Investigation Into Transmission Losses on UK Electricity Transmission System.* s.l. : National Grid – Publicly Available Technical Report, 2008. p. 20, Publicly Available Technical Report.

57. **RenewableUK.** UKWED Statistics. *Renewable UK, the vioce of wind & marine technology.* [Online] 2011. [Cited: 13 08 2011.] http://www.bwea.com/statistics/.

58. **Mertens, Sander.** *Wind Energy in the Built Environment.* Essex : Multi-Science, 2006.

59. **Harry L. Wegley, James V.Ramsdell, Montie M.Orgill, Ron L. Drake.** *A Siting Handbook for Small Wind Energy Convercion Systems.* St. Johnsbury : WindBooks.

60. **D.A.Spera, T.R.Richards.** *Modified power law equations for vertical wind profiles.* U.S. Department of Energy. 1979. NASA TM-79275.

61. **Olimpo Anaya-Lara, Nick Jenkins, Janaka Ekanayake, Phill Cartwright, Mike Hughes.** *Wind Energy Generation - modelling and control.* s.l. : John Wiley & Sons, 2009.

62. **M.Ragheb.** Control of Wind turbines. [Online] 05 06 2009. [Cited: 14 08 2011.] https://netfiles.uiuc.edu/mragheb/www/NPRE%20475%20Wind%20Power%20Systems/Control%20of%20Wind%20Turbines.pdf.

63. **Gipe, Paul.** *Wind power: renewable energy for home, farm, and business.* s.l. : James & James, 2004.

64. **Proven Energy.** Products. *Proven Energy.* [Online] [Cited: 15 08 2011.] http://www.provenenergy.co.uk/our-products/.

65. **Stephen Wilcox, Christian A. Gueymard.** Spatial and Temporal Variability of the Solar Resource in the United States. [Online] [Cited: 16 08 2011.] http://rredc.nrel.gov/solar/new_data/variability/Documentation/ASES_47760_final.pdf.

66. **NERC Data.** Met Office MIDAS station data. *British Atmospheric Data Centre.* [Online] [Cited: 16 08 2011.] http://badc.nerc.ac.uk/cgi-bin/midas_stations/station_details.cgi.py?id=1006.

67. **Department of energy and climate change (A).** Windspeed database, mid-1970s to mid-1980s. *Department of energy and climate change, UK.* [Online]

68. **Hyundai Solar.** Hyundai Solar Module, SF series. *Hyundai Solar.* [Online] November 2010. [Cited: 18 08 2011.] http://www.hyundaisolar.com/eng/image/SF-Series%20Datasheet_ENGLISH%20%282010.02%29.pdf.

69. **Sunny Tripower (A).** STP 1700TL-10. *Tritec Energy, SMA Sunny Tripower.* [Online] [Cited: 18 08 2011.] http://www.tritec-energy.com/tritec/popup/language/en/aid/4220.

70. **Sunny Tripower (B).** STP 10000TL-10. *Tritec Energy, SMA Sunny Tripower.* [Online] [Cited: 18 08 2011.] http://www.tritec-energy.com/tritec/product/popup.php?language=en&aid=4217&pid=155&oid=3.

71. **Enercon.** ENERCON Wind energy converters, Product overview. *Enercon.* [Online] July 2010. [Cited: 18 08 2011.] http://www.enercon.de/p/downloads/EN_Productoverview_0710.pdf.

72. **Endurance.** E-3120 50kW Wind Turbine. *Endurance Wind Power.* [Online] [Cited: 18 08 2011.] http://www.endurancewindpower.com/wp-content/uploads/2010/08/E-3120-Product-Brochure-North-America.pdf.

73. **Northern wind.** Northern Power 100 wind turbine specifications. *Northern Power.* [Online] [Cited: 18 08 2011.] http://www.northernpower.com/pdf/Northern-Power-100-Spec-Sheet-US.pdf.

74. **Highway agency.** Network strategy spatial planning advice note: SP 04/07. *Highway agency.* [Online] 04 2007. [Cited: 19 08 2011.] Planning applications for wind turbines sited near to trunk roads. http://www.highways.gov.uk/aboutus/documents/CRS_558501_SP0407.pdf.

75. **M.Ragheb.** Wind Shear, Roughness Classes and Turbine Energy Production. [Online] 02 02 2011. [Cited: 19 08 2011.] https://netfiles.uiuc.edu/mragheb/www/NPRE%20475%20Wind%20Power%20Systems/Wind%20Shear%20Roughness%20Classes%20and%20Turbine%20Energy%20Production.pdf.

76. **J.F. Manwell, J.G. McGowan, A.L.Rogers.** *Wind Energy Explained - Theory, Design and Application.* s.l., USA : John Wiley & Sons, 2009.

77. **Milborrow, David.** Breaking down the cost of wind turbine maintenance. *Windpower Monthly.* [Online] 15 06 2010. [Cited: 22 08 2011.] http://www.windpowermonthly.com/news/1010136/Breaking-down-cost-wind-turbine-maintenance.

78. **Poul-Erik Morthorst, Shimon Awerbuch.** The Economics of Wind Energy. *the European Wind Energy Association.* [Online] 03 2009. [Cited: 22 08 2011.] http://www.ewea.org/fileadmin/ewea_documents/documents/00_POLICY_document/Economics_of_Wind_Energy__March_2009_.pdf.

79. **RenewableUK .** The economics of wind energy. *Renewable UK.* [Online] [Cited: 22 08 2011.] http://www.bwea.com/ref/econ.html.

80. Operation and Maintenance Costs of Wind Generated Power. *Wind Energy. The Facts.* [Online] [Cited: 22 08 2011.] http://www.wind-energy-the-facts.org/en/part-3-economics-of-wind-power/chapter-1-cost-of-on-land-wind-power/operation-and-maintenance-costs-of-wind-generated-power.html.

81. **Wiggelinkhuizen, E.J., Rademakers L.W.M.M., Verbruggen, T.W.** *Conmow Final Report, Energy recearch centre of the Netherlands*. 2007. p. 72.

82. **EPRI.** Addressing Solar Photovoltaic Operations and Maintenance Challenges. *Smart Grid News.* [Online] 07 2010. [Cited: 24 08 2011.] http://www.smartgridnews.com/artman/uploads/1/1021496AddressingPVOaMChallenges7-2010_1_.pdf.

83. **PVResources (c).** Photovoltaic economics. *PVResources.* [Online] [Cited: 24 08 2011.] http://www.pvresources.com/en/economics.php.

84. **Met Office.** Western Scotland: climate. *Met Office.* [Online] 1996-2005. http://www.metoffice.gov.uk/climate/uk/ws/print.html.

85. **Ofgem E-Serve.** *Feed-in Tariff Update, Key facts. Issue 4.* 2010.

86. **Ofgem.** FIT payment rate table 1 August 2011. *Ofgem Feed-In tariffs.* [Online] 29 07 2011. [Cited: 25 08 2011.] http://www.ofgem.gov.uk/sustainability/environment/fits/Documents1/Feed-in%20Tariff%20Table%201%20August%202011.pdf.

87. Payback Period Definition. *Investopedia, Dictionary.* [Online] [Cited: 26 08 2011.] http://www.investopedia.com/terms/p/paybackperiod.asp.

88. **Weed, Carolyn.** EXAMPLES OF NOISE STANDARDS AND WIND TURBINE NOISE REGULATIONS. [Online] 07 08 2006. [Cited: 27 08 2011.] http://docs.wind-watch.org/Weed-examples-noise-regulations.pdf.

89. **Ayrshire Birding.** Bitding Map. *Ayrshire Birding.* [Online] 02 10 2010. [Cited: 28 08 2011.] http://www.ayrshire-birding.org.uk/index.php/where-to-watch-birds/birding-map.

90. **Kevin Waite.** Birdwatching in Ayrshire and Arran. *Ayrshire Birding.* [Online] 11 2005. [Cited: 28 08 2011.] http://www.ayrshire-birding.org.uk/images/stories/documents/locationguide.pdf.

91. Net Present Value - NPV. *Investopedia, Dictionary.* [Online] [Cited: 29 08 2011.] http://www.investopedia.com/terms/n/npv.asp.

92. *The economic impacts of wind farms on Scottish tourism.* Scottish Government. 2008.

93. **EWEA (B).** Wind Energy and the Environment. *Energia verda SA.* [Online] [Cited: 29 08 2011.] http://www.enerverde.eu/cms/download/factsheet_environment2.pdf.

94. **EWEA (A).** Executive summary. Wind Energy - The Facts. *Renewable UK.* [Online] [Cited: 29 08 2011.] http://www.bwea.com/pdf/WindEnergyTheFacts.pdf.

95. *Impacts of Array Configuration on Land-Use Requirements for Large-Scale Photovoltaic Deployment in the United States.* **Paul Denholm, Robert M. Margolis.** San Diego, California : s.n., 2008. American Solar Energy Society. p. 4. NREL/CP-670-42971.

96. *Our sense of Snow: The Myth of John Snow in Medical Geography.* **McLeod, Kari S.** 7-8, New Haven : Pergamon Press, April 2000, Social Science and Medicine, Vol. 50, p. 923.

97. **Gatrell, Anthony C, et al., et al.** Spatial point pattern analysis and its application in geographical epidemiology. [Online] 25 May 1995. [Cited: 22 August 2011.] http://www.dpi.inpe.br/cursos/ser301/referencias/gattrel_paper.pdf.

98. **Snow, John.** The John Snow archive. *The John Snow archive and research companion.* [Online] [Cited: 20 August 2011.] http://johnsnow.matrix.msu.edu/images/online_companion/chapter_images/fig12-5.jpg.

99. *Evaluation of Renewable Energy Potential Using a GIS Decision Support System.* **Voivontas, D, et al., et al.** 3, Athens : Elsevier Science Ltd, March 1998, Renewable Energy, Vol. 13, pp. 333-344. S0960-1481.

100. *The use of Geographic Information Systems in Climatology and Meteorology.* **Chapman, Lee and Thornes, John E.** 3, s.l. : Sage, September 2003, Progress in Physical Geography, Vol. 27, p. 323.

101. *The ethics of Google Earth: Crossing thresholds from spatial data to landscape visualization.* **Sheppard, Stephen R and Cizek, Petr.** 6, May 2009, Journal of Environmental Management, Vol. 90, pp. 2102-2117. 0301-4797.

102. **DMAP.** Transverse Mercato Calculator. *DMAP.* [Online] [Cited: 20 August 2011.] http://www.dmap.co.uk/ll2tm.htm.

Appendix

A. Further results from MERIT

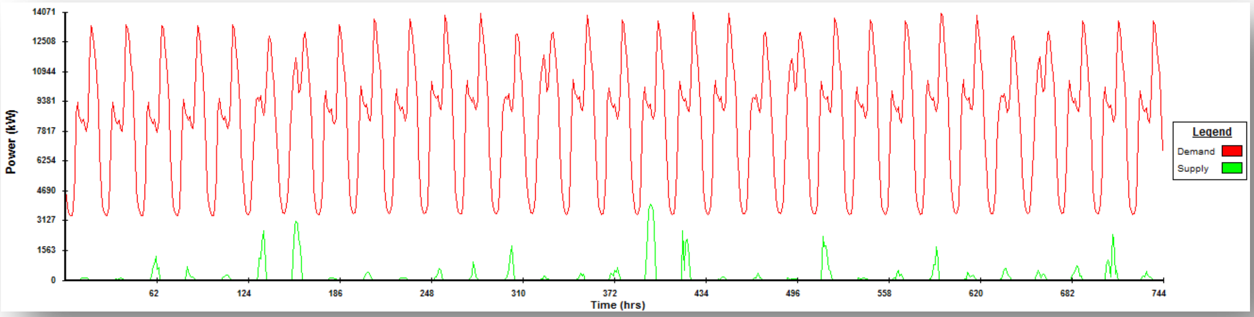


Figure 62 January Demand and PV Supply

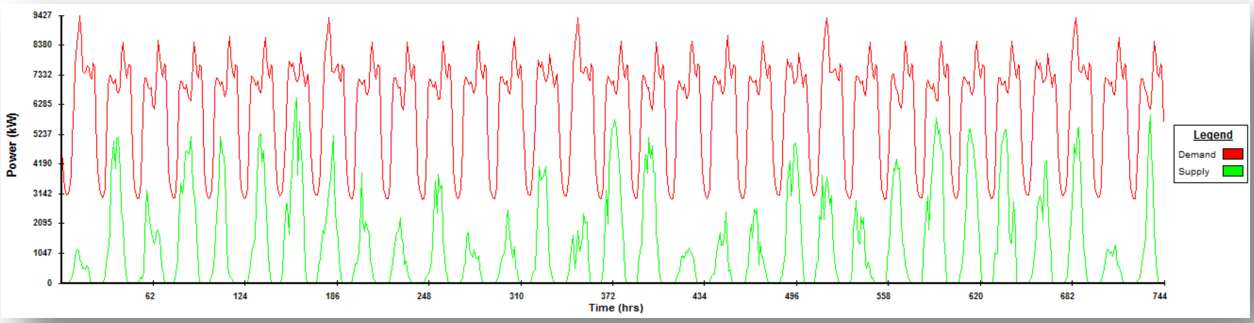


Figure 63 July Demand and PV Supply

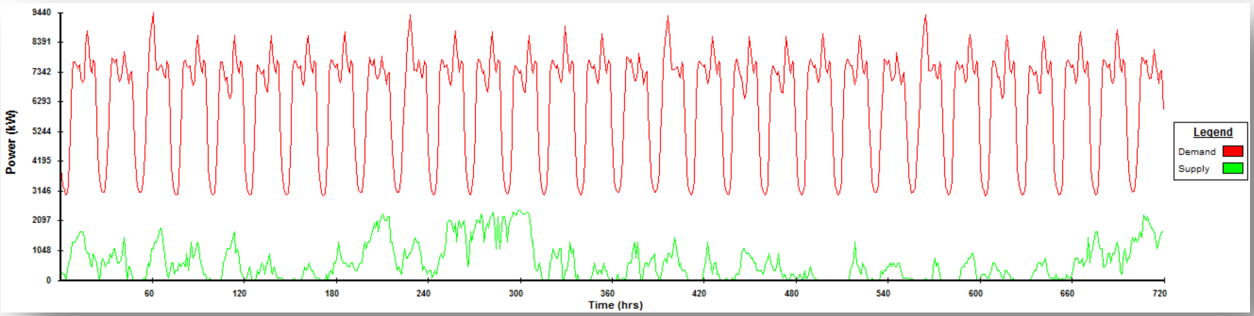


Figure 64 June Demand and Wind turbine Supply

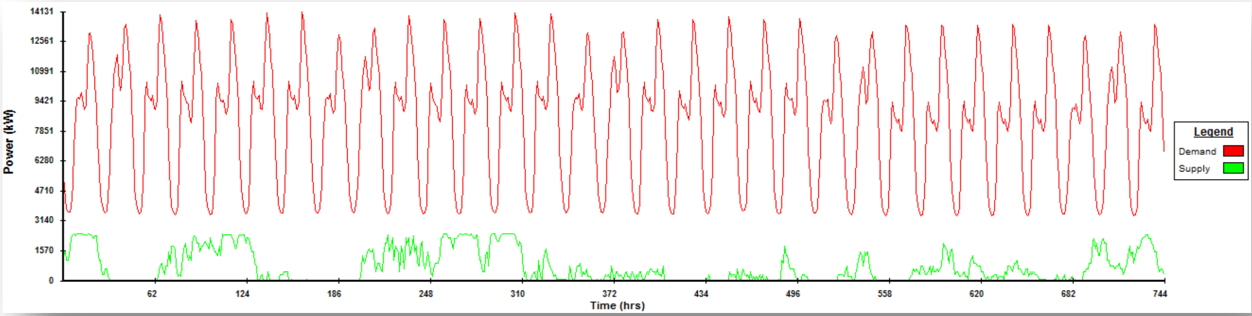


Figure 65 December Demand and Wind turbine Supply

Graphs of Demand and Supply in Critical months

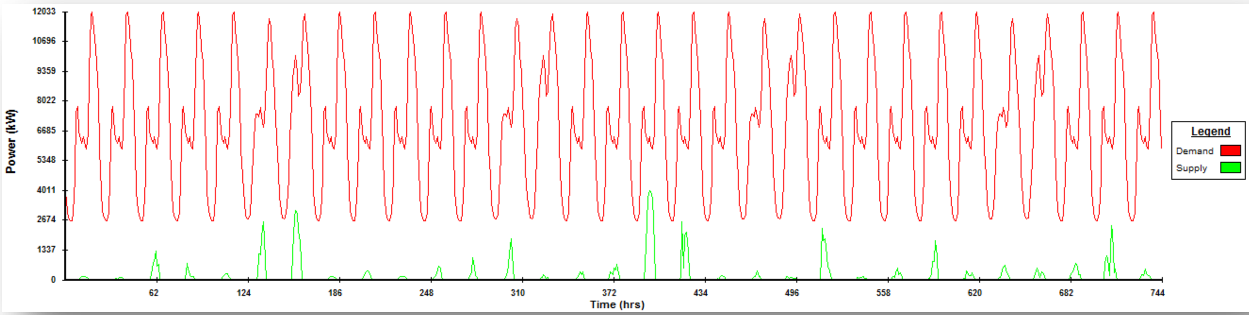


Figure 66 Domestic demand and PV in January (5)

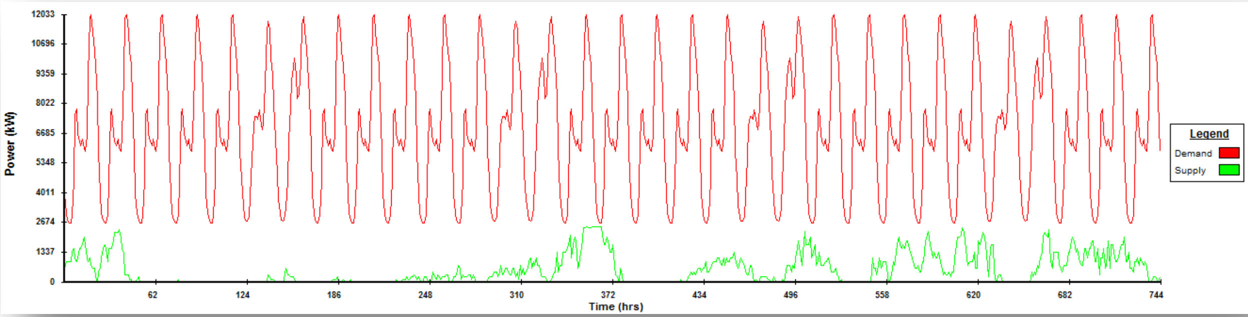


Figure 67 Domestic demand and WT in January (5)

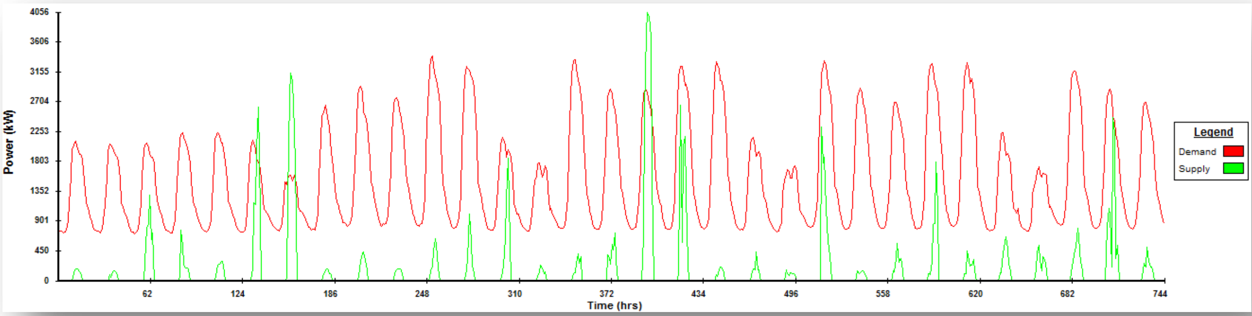


Figure 68 Commercial demand and PV in January (5)

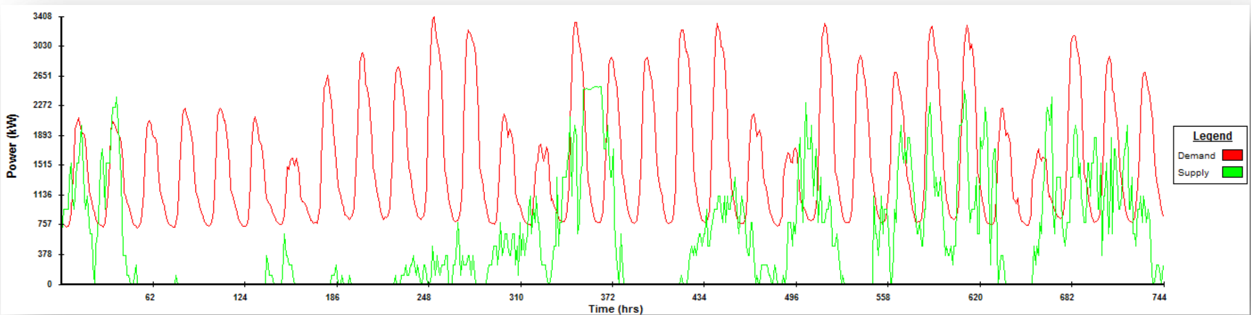


Figure 69 Commercial demand and WT in January (5)

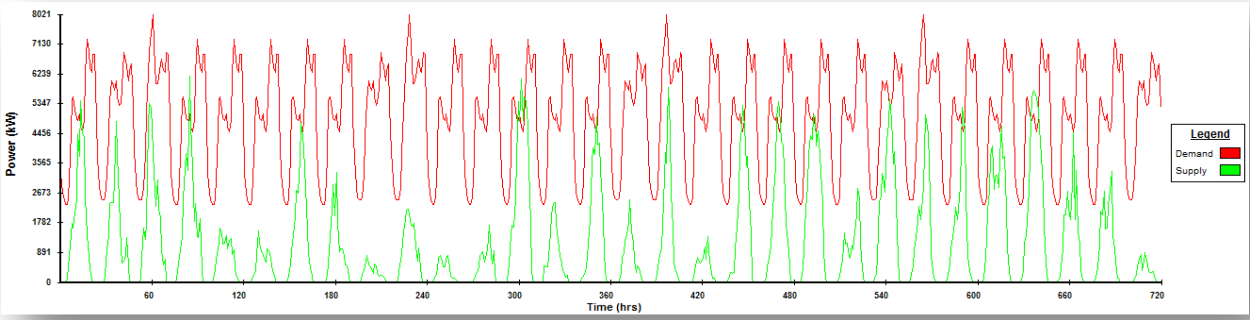


Figure 70 Domestic demand and PV in June (5)

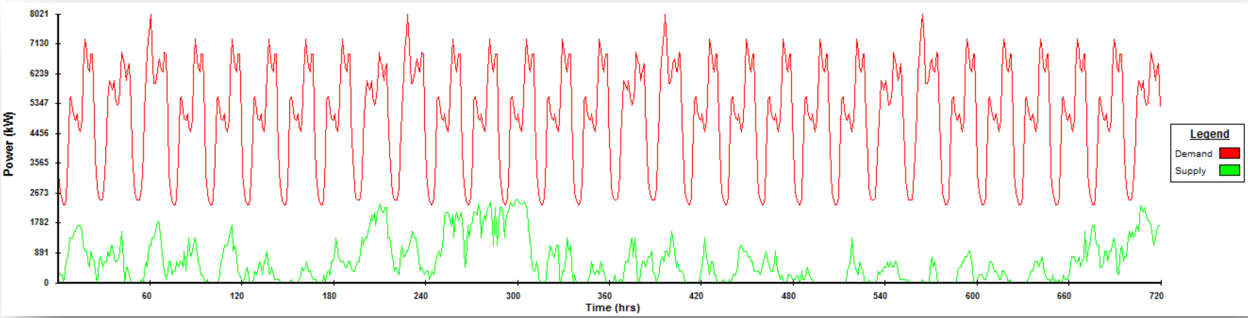


Figure 71 Domestic demand and WT in June (5)

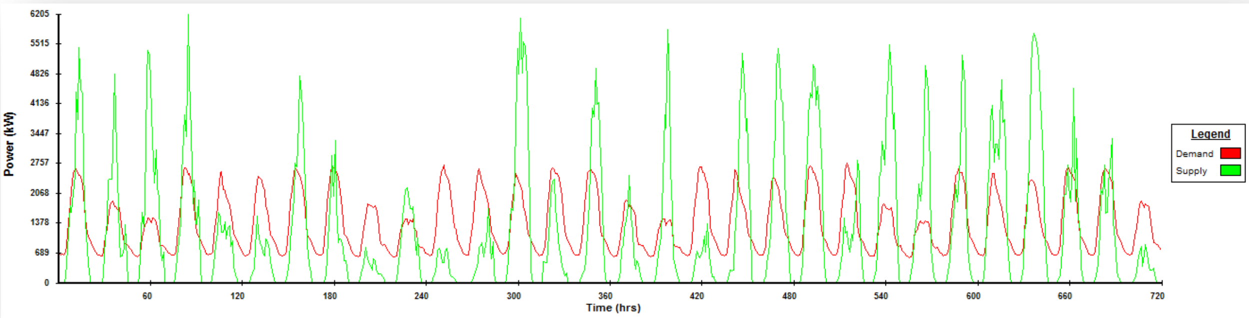


Figure 72 Commercial demand and PV in June (5)

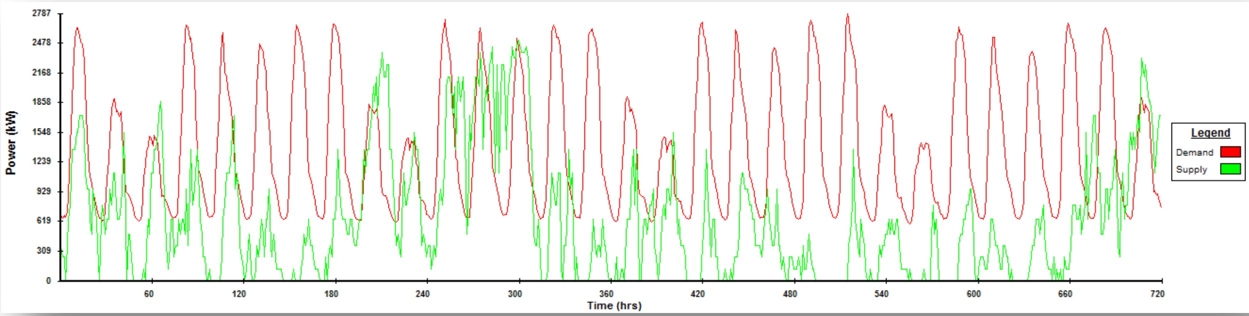


Figure 73 Commercial demand and WT in June (5)

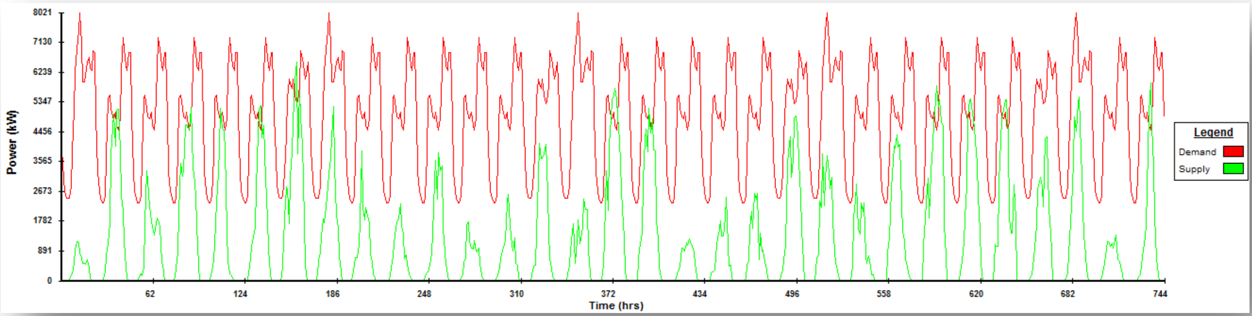


Figure 74 Domestic demand and PV in July (5)

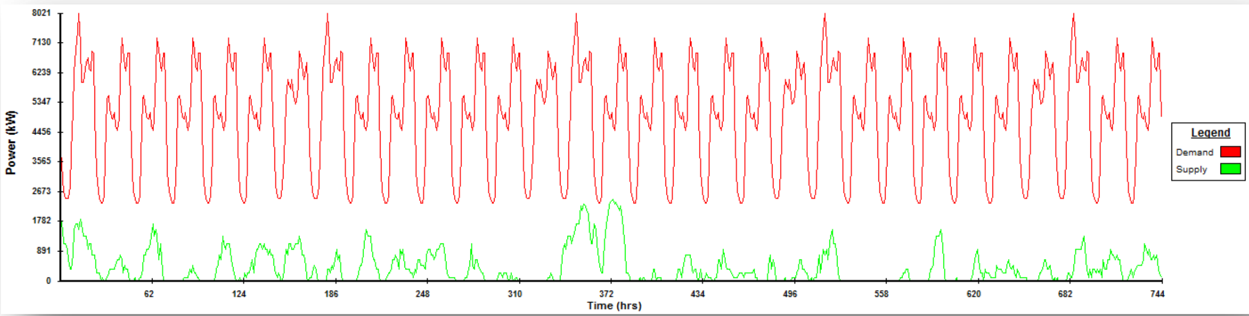


Figure 75 Domestic demand and WT in July (5)

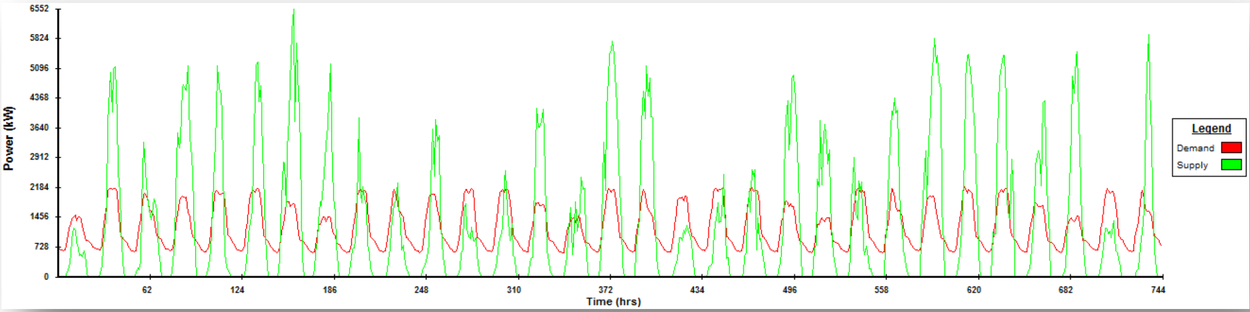


Figure 76 Commercial demand and PV in July (5)

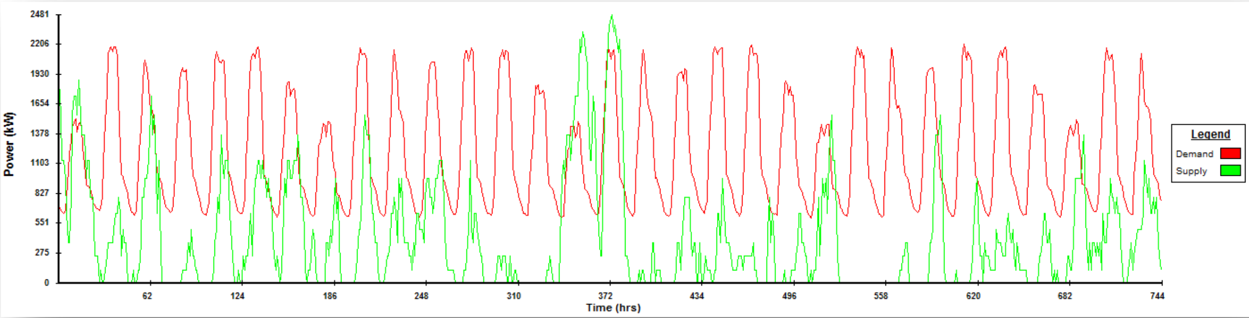


Figure 77 Commercial demand and WT in July (5)

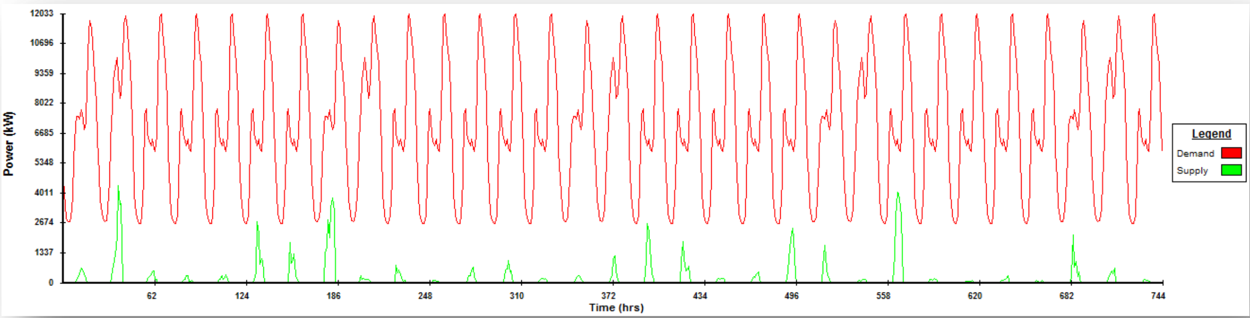


Figure 78 Domestic demand and PV in December (5)

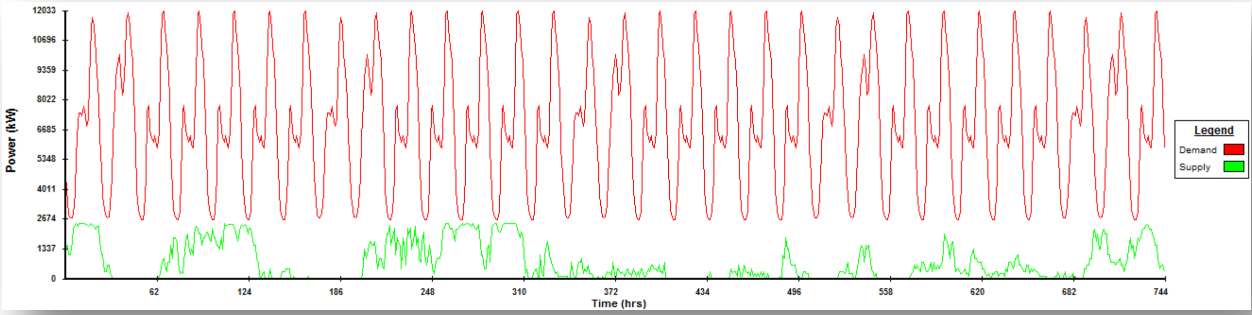


Figure 79 Domestic demand and WT in December (5)

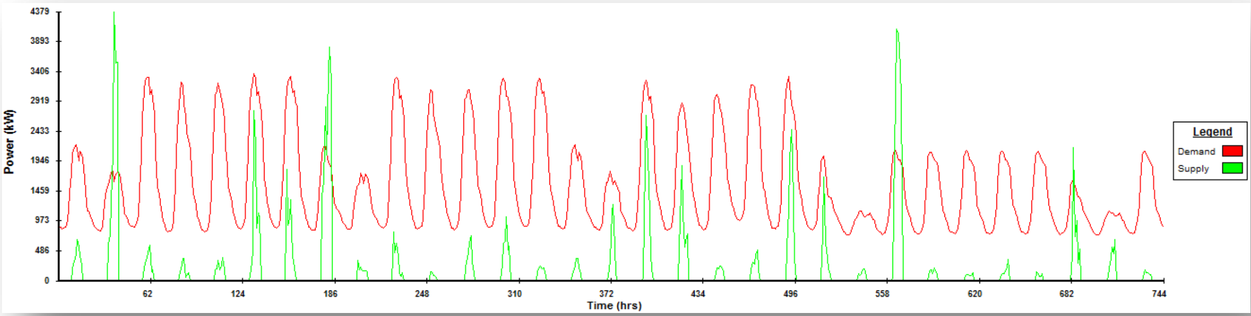


Figure 80 Commercial demand and PV in December (5)

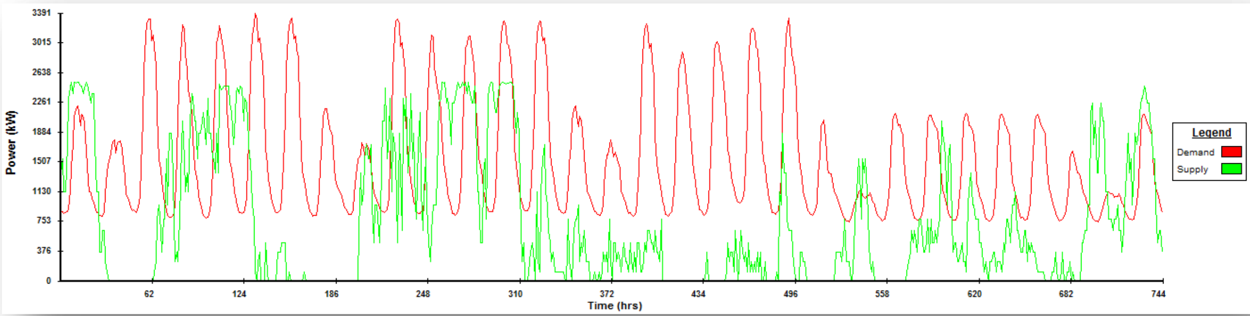


Figure 81 Commercial demand and WT in December (5)

Summary of Energy Users and Critical Supply Months

Month	Demand Profile	Supply Combo	Total Demand GWh	Total ReSupply MWh	Match Rate (%)	Energy Delivered MWh	Energy Surplus MWh	Energy Deficit GWh
	Domestic	WT	5.09	440.22	16.9	439.77	0	4.64
	Domestic	PV_TOT	5.09	124.54	8.31	124.54	0	4.96
	Commercial	WT	1.17	440.22	48.1	370.87	64.87	0.79
January	Commercial	PV_TOT	1.17	124.54	30.46	113.82	9.81	1.05
	Domestic	WT	3.56	471.5	25.37	470.44	0	3.09
	Domestic	PV_TOT	3.56	852.3	40.93	839.07	9.89	2.71
	Commercial	WT	0.993	471.5	55.17	408.06	59.14	0.582
June	Commercial	PV_TOT	0.993	852.3	64.7	569.03	275.62	0.417
	Domestic	WT	3.69	319.69	18.85	318.69	0	3.36
	Domestic	PV_TOT	3.69	969.23	43.24	953.41	12.98	2.72
	Commercial	WT	0.919	319.69	48.65	290.07	27.24	0.626
July	Commercial	PV_TOT	0.919	969.23	62.11	570.31	387.88	0.341
	Domestic	WT	5.1	571.96	20.91	571.08	0	4.53
	Domestic	PV_TOT	5.1	137.39	9.25	137.39	0	4.96

Month	Demand Profile	Supply Combo	Total Demand GWh	Total ReSupply MWh	Match Rate (%)	Energy Delivered MWh	Energy Surplus MWh	Energy Deficit GWh
December	Commercial	WT	1.16	571.96	53.36	452.23	115.34	0.707
	Commercial	PV_TOT	1.16	137.39	32.26	117.33	17.75	1.04

Technical Sheet for Sharp 165 W Polycrystalline PV

(39)

NE-165U1 MULTI-PURPOSE MODULE

165 WATT

ELECTRICAL CHARACTERISTICS

Cell	Multi-crystal silicon
No. of Cells and Connections	72 in series
Open Circuit Voltage (Voc)	43.1V
Maximum Power Voltage (Vpm)	34.6V
Short Circuit Current (Isc)	5.46A
Maximum Power Current (Ipm)	4.77A
Maximum Power (Pm)*	165W
Minimum Power (Pm)*	148.5W
Encapsulated Solar Cell Efficiency (ηc)	14.44%
Module Efficiency (ηm)	12.68%
PTC Rating (W)**	144.80
Maximum System Voltage	600VDC
Series Fuse Rating	10A
Type of Output Terminal	Lead Wire with MC Connector

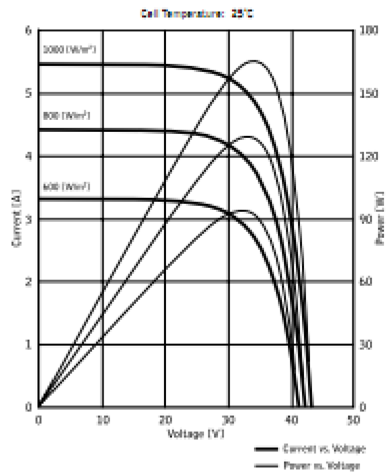
MECHANICAL CHARACTERISTICS

Dimensions (A x B x C below)	62.01 x 32.52 x 1.81" / 1575 x 826 x 46mm
Weight	37.485lbs / 17.0kg
Packing Configuration	2 pcs per carton
Size of Carton	66.93 x 38.19 x 5.12" / 1700 x 970 x 130mm
Loading Capacity (20 ft container)	168 pcs (84 cartons)
Loading Capacity (40 ft container)	392 pcs (196 cartons)

ABSOLUTE MAXIMUM RATINGS

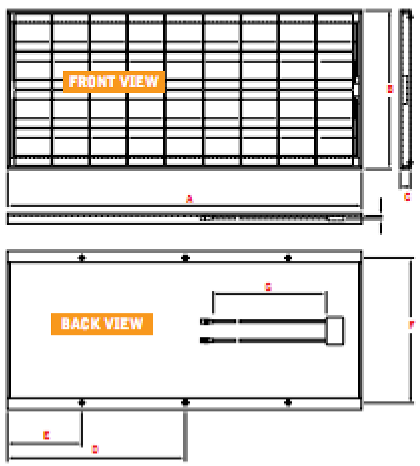
Operating Temperature	-40 to 194°F / -40 to +90°C
Storage Temperature	-40 to 194°F / -40 to +90°C
Dielectric Isolation Voltage	3200 VDC max.

IV CURVES



Current, Power vs. Voltage Characteristics

DIMENSIONS



D	E	F	G
30.93"/785.5mm	7.3"/185.5mm	30.43"/773mm	51.2" +/- 2"/1300mm+/-50mm

Specifications are subject to change without notice.

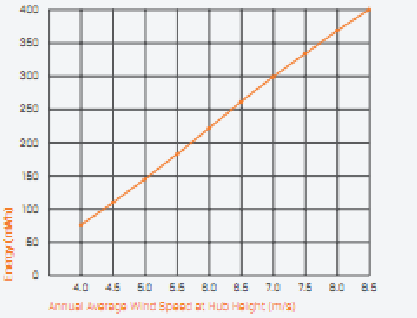
* (STC) Standard Test Conditions: 25°C, 1 kW/m², AM 1.5
** (PTC) Pacific Test Conditions: 20°C, 1 kW/m², AM 1.5, 1 m/s wind speed

In the absence of confirmation by product manuals, Sharp takes no responsibility for any defects that may occur in equipment using any Sharp devices. Contact Sharp to obtain the latest product manuals before using any Sharp device.

SHARP

Annual Energy Production: 21-Meter Rotor

Standard Air Density, Rayleigh Wind Speed Distribution



Specifications

Model	Northern Power® 100
Design Class	IEC IIA (air density 1.225 kg/m³, average annual wind below 8.5 m/s, 50-yr peak gust below 59.5 m/s)
Design Life	20 years
Hub Height	37 m (121 ft)
Rotor Diameter	21 m (69 ft)
Rated Electrical Power	100 kW, 3 Phase, 480 VAC, 60 Hz
Cut-in Wind Speed	3.5 m/s (7.8 mph)
Gearbox Type	No gearbox (direct drive)
Generator Type	Permanent magnet, passively cooled
Apparent Noise Level	55 dBA at 30 meters (98 ft)

For detailed information, see the Northern Power 100 Specifications Sheet. All specifications subject to change without notice.

Northern
POWER SYSTEMS
WWW.NORTHERNPOWER.COM
1 877 90 NORTH +01 802 461 2955

Northern Power Systems has over 30 years of experience in developing advanced, innovative wind turbines. The company's next generation wind turbine technology is based on a vastly simplified architecture that utilizes a unique combination of permanent magnet generators and direct-drive design. This revolutionary new approach delivers higher energy capture, eliminates drive-train noise, and significantly reduces maintenance and downtime costs. Northern Power Systems is a fully integrated company that designs, manufactures, and sells wind turbines into the global marketplace from its headquarters in Vermont, USA.