Department of Mechanical and Aerospace Engineering

On the rational sizing of low energy communities

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Signed: *Eleni Veniamidou* Date: 6th September 2014

Abstract

Over the last few years, there has been triggered an unprecedented debate on the sustainable development. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. Climate change, economic growth and urbanisation, are only few of the topics which consist the framework around the ongoing considerations on the desirability and prospects of the sustainable development. However, the main barrier towards achieving a sustainable development remains the lack of an accurate and efficient sizing procedure at the design stage of the community, which will inform the decisions.

Key objective of this project was to create a rational sizing protocol of hybrid sustainable community systems. A quantitative evaluation tool, which matches hourly electricity demands with renewable sources, was used in order to assess this investigation. The core of the sizing technique which was followed, was based on the division of the renewable energy supply technologies into small increments. Subsequently, these increments were then combined with each other, with the aim of ascertaining which mixture delivers the best matching ratio to accommodate the energy demand of the under investigation communities.

Research has shown that, the currently used techniques towards achieving a superior match between the demand and supply for a low energy community scheme, are not sufficient. The adopted approach in this study, has certified to successfully eliminate the gaps between the theoretical and practical implementation of such a scheme. The rational procedure, which was developed for these purposes, may seamlessly integrate to any development. Based on the research results, suitable future policies should be targeted towards rationalising the current practices.

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1. Project Background

In the recent years, communities have evolved into major infrastructure, market, culture as well as recreation centres. The rapid population growth, combined with the continual expanding and enhancing of the urban fabric, generates social, economic and environmental problems. The communities have to face the persistent challenge of improving living standards and reducing the environmental impact.

Communities play a significant role regarding issues of climate change and sustainable development (UK Department of Energy and Climate Change, 2012). This argument becomes even more distinctive if we take into consideration the fact that in the recent decades urban areas have recorded a rapid growth in size and population, with 80% of the European population be mainly found in the cities.

The quality of the urban environment is increasingly recognised as a key means of promoting economic revitalisation of European cities, and the high quality of the environment is an essential factor in attracting socially and environmentally responsible investments which create competitive advantages.

Nowadays, it becomes even clearer than ever, that the improvement of the urban environment and sustainable development are imposed as pillars for the operation and progress of the modern city (Heerwagen, 2000). A new model for the urban development is required. This model should be based among others, on the successful exploitation of the existing land and infrastructure, on the transformation of the city from a consumer to a producer and on the reconfiguration of the relationship with the urban periphery and rural areas. In the European cities there are being developed several new networks and collectives, as well as plenty of cooperative forms of organisations targeted on housing, energy production from renewable energy sources, testing and integration of natural resources and raw materials in a circular economy.

Renewable Energy Sources (RES) are by definition, the energy sources such as sun, water and wind, which are considered to be abundant in the natural environment. They were the first forms of energy to be used by societies, almost exclusively, up until the early 20th century, when they turned to the extensive use of carbon and hydrocarbons (IPCC, 2013).

The interest for the wider use of renewable energy and the development of reliable and cost-effective technologies that block their potential, appeared initially after the first oil crisis of 1979 and was confirmed in the last decade, after the public awareness of global environmental problems. The inherent advantages of the renewable energy sources and particularly their substantial contribution to humanity's energy independence from exhaustible energy resources, can be perceived as a plea for this turn.

For many countries, renewables are an important domestic energy source with great potential for development at the local national level. They contribute significantly towards achieving or maintaining an energy balance, aiding towards reducing the dependence on expensive and imported conventional energy sources and strengthening the security of their energy supplies. At the same time, they contribute to the protection of the environment, as it has now been realised that the energy sector is mainly responsible for the pollution of the environment (UK Department of Energy and Climate Change, 2012 ; Edenhofer, et al., 2013).

One of the greatest challenges facing the European Union is the design and adaptation of cities to smart sustainable environments. Nearly three quarters of the EU population lives in cities, consuming 70% of energy. Smart urban technologies can contribute significantly to tackling many urban challenges (Heerwagen, 2000). At present, there are many barriers that limit the ability for innovative and intelligent solutions. In difficult economic times, businesses and cities are reluctant to upgrade and develop new technologies, despite the potential cost savings and long-term reductions in emissions.

1.1. Low Energy Communities

- **The notion of the autonomous communities**

The fundamental shift in the way that people live and organise their communities has become apparent especially the last few years. The notion that societies live beyond their means, has become even more evident as we look upon the impact that human activity has on the environment, both at a small and at a great scale. The inability of the societies to explore new ways of dealing with their persistent problems poses threats to their future prosperity. This lack of an effective action towards protecting and preserving the environmental sources, not only for the present but also the future generations, remains the Achilles heel of the society.

Common knowledge and general fact is that the earth's climate is continuously changing, however in recent years this changes have been greater than ever. The Intergovernmental Panel on Climate Change (IPCC) made a prediction regarding how the global temperature will rise in the next century between 1.4°C and 5.8 °C. The earth has been warming up in the past 50 years, and most of the warming has been caused by the human activity, according to the (IPCC, 2007).

The Stern Review in 2006 pointed out the seriousness of the consequence of the global warming and urged quick and responsible responses as soon as possible. The main problem with global warming is that the impact will be disproportional, meaning the poorer countries will be the first ones to face serious problems due to global warming. But developed richer countries will also face the economic consequences (Stern, 2006).

Autonomous sustainable communities are still a future scenario. Despite the efforts from both the governmental and the private sector towards achieving an energy independence on a local scale, no signs of a successful implementation of such a scheme has been recorded so far. Local communities from all around the United Kingdom, in particular, have been engaged to developing approaches and absorbing governmental funds towards implementing sustainable solutions to energy issues.

- **Renewable streams**

Wind energy

Generally, wind energy is the energy which is being produced by exploiting the existence of the wind on a local level. This type of energy is characterised as a clean source of energy, as it does not produce any pollutants. Another advantage of the wind energy is that, wind turbines do not release any chemical substances to the environment, which would cause acid rain and greenhouse gases.

Advantages of the wind energy:

- Wind farms do not pollute the atmosphere with harmful gases
- Wind farms produce electricity from a renewable energy source

Disadvantages of the wind energy:

- Are generating noise
- The blades of a wind turbine pose a threat to birds
- The implementation and construction of a wind farm is costly
- Wind is a vital element for the energy production, but wind cannot blow all year long in a certain location in order to produce adequate energy.

Solar energy

The solar energy is being exploited through technologies that take advantage of the heat and the electromagnetic waves of the sun. Photovoltaic systems are a category of such technologies. Photovoltaics (PVs) transform the solar energy directly into electric energy. Photovoltaics consist of one or more panels and all the required components for the storage of the produced energy as well as the control and proper usage of that energy production.

Advantages of the photovoltaic systems:

- They do not require maintenance
- They do not require distribution lines of electricity
- They do not need fuels in order to operate
- They have a long lifecycle
- They are reliable systems
- They have a low operation cost

Disadvantages of the photovoltaic systems:

- Their construction is expensive
- They have a low performance rate in terms of energy efficiency and production
- Their construction causes pollution

- **Renewables are varying randomly**

One of the main implications concerning wind and solar developments for energy supply is the element of the disparity amongst the energy availability and demand. Wind and solar technologies are highly dependent on parameters such as weather, while energy demand is by far independent of these factors. Taking into consideration that scientific finding, the whole investigation around defining the best approach to confront and deal energy issues becomes prominent (Ward & Phillips, 2014 ; Vick & Moss, 2013).

The renewable energy sources, which have been considered available for generating and addressing the energy requirements of the under investigation communities, are wind and solar. These energy supplies are frequently referred to as variable generation sources, as their energy production levels show a discrepancy contingent on the wind and solar availability (Sovacool, 2009; Massetti & Ricci, 2013).

It must also be noted, that both the electricity demand and loads are also variable parameters. The occurrence of short-range changes in the load are taken as having low significance, and are mostly accredited to random events which cause a differentiation of demand. The long-standing changes in the load are more likely to be foreseen and properly addressed. The core discrepancy between these two load differentiations is that there is yet a better understanding around the occurrence of load variations than wind and solar variations.

Variations caused in the wind or solar renewable sources may be predicted if a more thorough investigation upon their availability is to be conducted (B.Blarke & Jenkins, 2013; Hirth, 2013). Given that the wind availability is quite considerable, someone would expect that the same variation on the wind variability would continue to be observed regardless of the size of the plant. On the contrary, it has been measured and documented that the variability of the wind varies with the size of the multiple deployment of wind turbines. This aggregated power generation is less variable in comparison with the power generation which is produced by a single wind turbine.

The size of the available land, in order to accommodate a larger wind farm, shows a significantly less variability. Another factor, which has been recognised as causing a reduction to the variability of the wind, is the time. In particular, it has been measured that the variability of a large wind farm over seconds is smaller than the one observed over some hours.

Following the same consideration as in the case of the wind variability, some characteristics of the solar variability may be as well characterised as being predictable. The time occurrence of the sunrise and sunset, as also a sporadic cloud concentration in the sky, are just some of the sources of solar variability. Nonetheless, this observed solar variability does not differ significantly from the corresponding wind availability. A solar plant covering a wide land area, tends to reduce the level of the variability.

Issues on the variability of the specific renewable sources are subjected to the relevant energy systems operator. The penetration level into the energy production of such variable technologies, has an impact on the grid. As the penetration of variable technologies remains at low levels, the impact on the network remains minor. On the other hand, when the penetration levels are high, then this poses threats to the network, as the variability of the renewable energy systems exceeds the load variability.

- . **Demands are varying randomly**

The energy demands are characterised by a variability regarding their occurrence over a period of time. The energy demands are strongly linked with the activities of people and the building types in which people are being present. Residential buildings vary from commercial buildings not only in structure and characteristics, but also in terms of energy requirements. Each building type serves different activities and has to comply with specific rules. The energy requirements of each development are closely related to factors such as the occupancy level, operation hours and structural characteristics which correspond to a certain level of energy efficiency.

- **The existing techniques are very arbitrary**

The existing approaches towards selecting and deploying the appropriate, at any specific case, combination and utilisation of hybrid renewable energy systems, is to be characterised as being far from rational. This argument is being based on the fact that in most of the times, the reasons for communities to turn to renewables is driven by governmental initiatives or funds. So, the current approach according to that case, is to deploy as many renewables as possible without a deeper consideration on practical matters.

Up until now, communities are investing on renewable energy technologies due to incentives provided by governmental initiatives. Nonetheless, it is imperative that before implementing any schemes, a thorough investigation must be conducted in advance. The availability of the energy supply technologies, for the specific site location and the accessible land use for these purposes, are key parameters for a comprehensive demand-side management of a sustainable community (Andrews, et al., 2013).

- **There is a lack of a rational approach to sizing low energy communities**

The current drivers towards the shift to low energy communities and implementing environmental principals in a community level, remain purely financial, despite the private and public attempts for raising awareness on environmental concerns. Financial drivers are a definite motivational instrument for a wide implementation of statutory initiatives and motives, but are for sure not adequately efficient.

Nowadays, more than ever, there is an unprecedented opportunity to explore the available technologies in depth and apply the best technique for each case, so that the best outcome can be obtained. A sensible policy to tackle environmental concerns, such as the energy demand and supply correlation, is considered to be imperative.

The lack of such a rational approach on behalf of the relevant parties when selecting to turn to renewables, is so obvious that immediate changes in these currently followed methods should be applied. A shift to low energy technologies can be achieved by a well justified method, which in many cases, may lead to an advantageous on environmental terms outcome.

1.2. Objectives

In the present study, the issue under scrutiny is how to achieve and implement a rational sizing procedure towards addressing the energy requirements of a community, which relies on renewable energy sources. The issue of whether autonomous low energy communities can become a wide phenomenon in the near future, is clouded by the fact that they don't currently exist in the real world and any attempts towards this direction are being fostered only by economic initiatives.

Creating a sensible protocol poses an unprecedented opportunity to explore the various methods, which could provide a clear and objective solution to addressing the energy demand and supply management problem.

The method adopted in the project was a "Demand Side Management" (DSM) approach, towards investigating ways of rationally sizing representative communities. It is necessary to emphasise that by using the term "rational", when referring to the sizing procedure of the sustainable communities, the significance of this approach is adherent to both the current lack of such an approach and the beneficial contribution towards addressing the energy demand problem of each case study.

From the comprehensive investigation of the energy demands, the site characteristics and the availability of renewable resources for the case study community, the best method to successfully tackle the energy problem on a community level is to be determined. The developed method and its outcomes will provide a solid answer to the pressing issue of achieving autonomous low energy communities.

The approach which is being introduced in this research study, aims to address the major issue of energy consumption and supply correlation in a sensible way. Therefore, the results of the research study will determine the value of the suggested approach in comparison with the current one. Depending on the variability of the results, between the suggested and currently applied technique, it will be determined the appropriateness of the one method over the other.

This research method provides the opportunity to explore current approaches towards creating sustainable communities. In case that the project validates the current approaches, then this would suggest that the present methods are adequately employed and deliver an accurate method. In case that the project displays different outcomes, then this would imply that chunking approaches are important. And so, future recommendations relevant to a better deployment of this method will be put in place. Third possible scenario to this project is for the results to be marginally different, which then would suggest that the way of chunking the renewable supply technologies is of a minor importance.

The chunking process which was investigated for the purposes of this project, is for sure rational, as it provides the best match out for every combination of supply technologies, so as to meet the energy demand.

2. Project Method

The matching investigation takes place right after the explicit definition of the different characteristics of each demand profile and the analytical supply profiles are carried out (Richardson, et al., 2008). This matching procedure applies to both profiles and evaluates the level of appropriateness of the selected supply for the given demand profile.

To reach this goal, the computational matching tool, MERIT has been properly applied. This tool provides a "Matching Rate", as a percentage of the average hourly assessment of the existing variance amongst the energy supply and demand.

With the purpose of performing the matching procedure for all the possible combinations, certain steps had to be taken, and those were the following:

- Load climate data: Annual climate data from Glasgow were imported. A representative summer day (4^{th} July) and winter day (25^{th} December) were carefully chosen, depending on the specific community which was investigated as a case study.
- Load the demand profile that needs to be examined, and which has been earlier brought into MERIT.
- Load the different renewable energy supply sources, which in this case were wind and photovoltaics.
- After the completion of the demand and supply matching investigation, all the results are obtained, which determine the rate of the suitability for the available renewable technologies.

Weather Data

The weather data, which have been used for the purposes of establishing a rational sizing tool for hybrid renewable systems, derived from MERIT's database. The days which were selected for the simulations where July 4^{th} and December 25^{th}. These summer and winter days were selected from a conducted validating process which considered up-to-date weather data and also weather data which were part of the original housing demand profiles.

- **Recent weather data**

The weather data, which were considered to be useful and therefore were obtained for the purposes of this investigation, were recorded every minute as atmospheric pressure, rainfall, wind speed, wind direction, surface temperature, relative humidity and solar flux (School of Geosciences Weather Station, 2014). In order to transform these data into being suitable for MERIT, the values for wind speed, wind direction, temperature, relative humidity and solar flux were averaged for both the chosen winter and summer day. The following table illustrates these values:

Table 1: Average values of wind for a winter and a summer day (as derived from real data)

Average values	Wind speed (m/s)	Wind direction (degrees azimuth)	Temperature (°C)	Relative humidity (%)	Solar flux (W/m^2)
Winter day	7.9	198.3	5.1	67.6	0.0
Summer day	4.5	190.4	15.1	84.4	0.1

- **Integrated in the housing demand profiles weather data**

Comparatively valuable weather data were available as part of the dwelling profiles which were used (Edwards, 1990). These values were averaged for the selected winter and summer days to guarantee that any inconsistency between the weather at the time of the results being collected would be avoided, as that could have influenced the profiles to be differently formed.

Table 2: Average values of wind for a winter and a summer day (as derived from the housing profiles)

Average values	Wind speed (m/s)	Direct Solar	Temperature (°C)
Winter day	5.7	20	5.1
Summer day	3.8	180.3	14.4

Matching Criteria

The "Match Rate" is a criterion integrated inside the computational modelling tool, which has been used for establishing a realistic demand and supply management for the predefined communities. It describes the ratio of supply that meets the required energy demand.

2.1. MERIT

MERIT is a computational tool which enables the user to conduct an evaluation of the best combination of renewable energy sources for a given location. Energy demand profiles are integrated into the program, but there is also the ability to input real data from any under examination case study. The energy demand profiles may derive from a vast variety of dwelling types, such as domestic, industrial or even whole communities (Clarke, et al., 2012). All these demand profiles are being compared and investigated so that the best possible match with renewable energy sources may be obtained (Clarke, et al., 2013).

Steps that need to be taken towards this process of framing the parameters of the case study, are the identification of the climate characteristics of the selected site location. The user can either use the embedded to the tool climate and weather data, or import their own database. The kind of renewables that are to be considered for the investigation is dependent on the user's preference for the specific site location. The renewable energy sources which may be taken into consideration and selected are photovoltaics (PVs) and wind technologies. These technologies are being matched so that they meet the electrical demands of the specific project (Clarke, 2002).

Another feature which provides an enhanced measurement and assessment for a proper demand side management is the ability to consider auxiliary systems such as batteries, pumped storage and flywheel systems. The tool provides a thorough investigation of the most suitable combination of renewable systems, so that multiple energy demands and supplies can be best matched. The outcome of each calculation is demonstrated with relevant tables and graphs, at the completion of each simulation (Born, et al., 2001).

2.2. Scenario Communities

For the purposes of creating a rational sizing protocol for autonomous low energy communities, a proper selection and justification of the selected case study was piloted. Initially it was determined that the characteristics of the community should comply with two main parameters which are as mentioned below.

First of all, the structure and composition of the community needs to abide to the current status of the building requirements and approaches from the contractors side. This notion derived from the fact that there is a general construction code which is being followed when building new dwellings. The size of the dwellings is varying depending on their destined use, e.g. domestic or industrial (Owen, et al., 2013; Levine, et al., 2007). And so, for the purposes of this project, a certain combination of the available dwelling types was considered, in order to accommodate the current trends on the building sector (Yohanis, et al., 2008).

Another issue which was of a greatly importance, while determining the sort of the community to be investigated, was the power distribution network. Taking into consideration the total number of houses that can be connected into a substation, supplied vital information on the size of the community.

The location of the community was vital, as the availability of the renewable energy sources would determine the feasibility of the investigation. Adequate access to wind and solar sources was needed, and therefore the selection of the most appropriate site location was essential.

Finally, the buildings which comprise the case study, are considered to be electric heated only, as this would provide a better evaluation of the energy demands and supply requirements for the specific scheme.

So, for the above reasons it was decided that the case study should be comprised by two representative communities which would have specific characteristics so as to address the topic appropriately. Both communities are located in the west coast of Scotland, as the availability of the two categories of energy sources in that area were recognised, through the evaluation process, as compatible with the project's needs.

The Community 1 is a small community of 40 residential buildings, while the Community 2 is a large community of 200 buildings, both residential and commercial. Additional information about the characteristics, size and occupancy level can be found in the Appendix. The implemented elements to the project research were derived after thorough investigation and consideration on the current trends in the building sector. Therefore, a compliance with the publications of both the latest UK Census 2011 (Office for National Statistics, March 2011) and the English Housing Survey: Energy Efficiency of English Housing 2012 (UK Department of Communities and Local Government, 2014) as well as the English Housing Survey: Profile of English Housing 2012 (UK Department of Communities and Local Government, 2014) was adopted.

Diversified loads were considered for both of the communities. The diversity factor is a term used to describe the likelihood of the energy demand to be occurred simultaneously (Dickert & Schegner, 2010). This means that electrical equipment and appliances are most likely to be turned on and used at the same period of time. This would cause an augmented energy demand for the specific time and also impact the electricity grid. The variation of the diversity factor for each building type is an indication of the occupancy levels and occupant behaviour (Hesmondhalgh, et al., 2014). The diversity factors are being extensively used for assessing spatio-temporal occupancy in building performance simulation (Bourgeois, 2005). It should be noted that as the total number of dwellings which comprise a community increases, the maximum value of the diversity factor decreases and as a result, the uncertainty diminishes greatly.

The type of the appliances which are installed or being used in a residential dwelling have also an impact on the overall energy demand over time (Richardson, et al., 2010).

Table 3: Average energy consumption of appliances in the UK

Average energy-consumption of appliances in the UK

Appliance	Average annual consumption per household (kWh/day)	Average annual consumption per capita (kWh/day)	Ownership level (%)
Electric hob	1.33	0.39	37
Electric oven	0.74	0.22	56
Microwave oven	0.23	0.07	74
Refrigerator	0.82	0.33	53
Fridge-freezer	1.9	0.56	58
Freezer	1.9	0.55	55
Colour-television set	0.91	0.27	97
Video recorder	0.3	0.09	76
Clothes-washing machine	0.8	0.20	88
Tumble-drier	0.78	0.28	49
Dishwasher	1.72	0.48	16
Electric kettle	0.78	0.28	5
Iron	0.3	0.09	100
Vacuum cleaner	0.15	0.04	100
Miscellaneous	1.1	0.33	100

Source: (Yao & Steemers, 2005)

Table 4 is representative of the occupancy level based on building type. Non-residential buildings differ from residential significantly. Most of their energy demands are being occurred during their operation times and for a certain period of time. This variation of the occupancy level can be considered as beneficial for the energy distribution networks, as it creates a more stable and smooth energy demand over time.

Table 4: Overall spatio-temporal occupancy for various building types

Source: (Kavcic, et al., 2012)

Building Type	**Building or Thermal Zone End Use**	**Operating Hours**	**Operating Days per Week**	**Annual Operating Months**
Residential	House, apartment buildings	18	7	12
Office	Office rooms	10	5	12
Education	Elementary school classrooms	8	5	9 (Sept.-May)
	High school/ university classrooms and auditoriums	13	5	10 (Sept.-June)
Hospital	Hospital rooms	24	7	12
	Patient rooms	24	7	12
	Operating rooms	8	5	12
	Waiting rooms	8	5	12

Occupancy patterns and different building types vary the occurrence of the peak energy demand by time, and aid the load shifting. Depending on the use purposes of each building the operating times may vary. Residential and non-residential buildings comprise the case study communities of this project. Nevertheless, many dissimilarities can be found within non-residential buildings, with regard to their load requirements. To be more precise, hospitals appear to have a relatively large energy consumption which is attributed to reasons such as required good indoor air quality, availability of hot water and 24 hour operation throughout the year. Schools, on the other hand, appear to have lower energy consumption as they don't operate during the summer months, have limited daily operating hours and are equipped with modest heating systems.

Table 5: Average thermal heat dissipation and occupancy diversity factors for various types of buildings.

Building Type	**Building or Thermal Zone End Use**	**Thermal heat dissipation per person [W/person]**	**Thermal heat dissipation per unit floor area [W/m^2]**	**Average Diversity Factor**
Residential	House, apartment buildings	80	4	0.75
Office	Office rooms	80	8	0.30

Education	Elementary school classrooms	80	40	0.16 – 0.18
	High school/ university classrooms and auditoriums	80	40	0.32
Hospital	Hospital rooms	90	27	1.00
	Patient rooms	70	15	0.75
	Operating rooms	90	0	0.24
	Waiting rooms	80	44	0.24

Source: (Kavcic, et al., 2012)

The above Table 5 provides an insight on the values of the diversity factors which have been considered and adjusted in the project. These diversity factors have been altered at some cases, as specific characteristics of the buildings required a slight adjustment due to differentiation between the size and purpose of each building type.

The houses which were used and analysed in the project displayed incorporated energy efficient features such as enhanced wall, roof and floor insulation, as well as double glazing. By this way, all these buildings correspond to the UK building standards.

Community 1

The Small Community consists of 40 houses. All of these buildings correspond to a mixture of residential dwellings. The dwelling types are defined as detached, semi-detached, mid-terrace and end-terrace houses. The maximum occupancy level of the houses can vary between 1 and 7 occupants. The maximum approximated number of the occupants for each household was derived from the latest report on the Population and Household Estimates for the United Kingdom (Office for National Statistics, March 2011).

The value of the applied diversity factor, which would correspond to the occupancy level of this community as a complete system, was 0.70. This was determined after considering the number of the residential buildings which would consist the community, the average square footage of the dwellings, the peak demand expressed in KW. These considerations were made in terms of compliance to the general approach with regard to the diversity factor, which indicates that, it is a fraction of the average required kW load to the supplied kW load on a utility transformer depending on the number of customers which are connected to the transformer.

Community 2

The Large Community consists of 200 buildings. These buildings correspond to a combination of residential and non-residential developments. The residential dwelling are defined as detached, semi-detached, mid-terrace and end-terrace houses. The maximum occupancy level of the houses can vary between 1 and 7 occupants. The non-residential buildings are small offices, a school, a sports centre and a small medical clinic.

The approach for determining the appropriate diversity factor and applying it to the large community system, complies with the method used previously for the small community.

The combined demonstration of the demand profiles for a winter day, for both the small and the large community is shown in the figure below. As it can be seen, the demand profile for the small community presents a less variation over time. The peak energy demand for both the communities is aligned with the type of buildings which comprise each community. Taking into consideration that, the vast majority of the building types in the communities are residential, the time occurrence of the peak energy demand is shifted towards the times that the dwellings' occupants are being present in them. The peak demand is being regarded to be occurring during the morning hours around 9:00 and during the afternoon times around 21:00. These timescales are sensible when considering the lifestyle of the residents. During the morning times they probably get ready for work and during the night time it is when they have returned and fully occupy the residence.

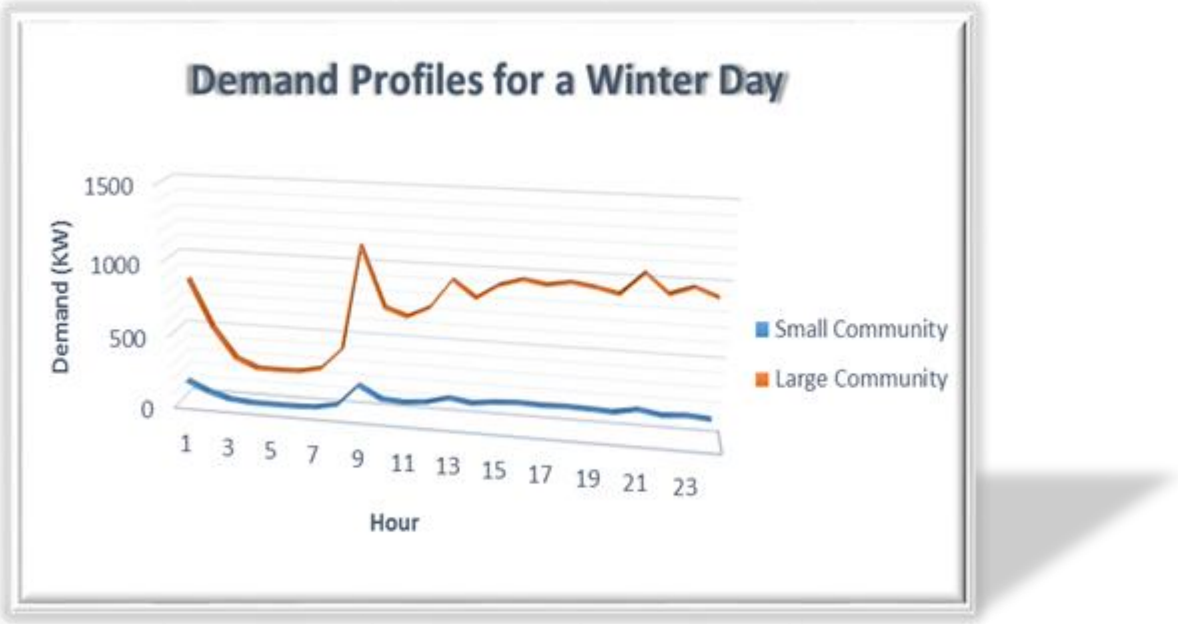

Figure 1: Demand profiles for a winter day, for both of the case study communities

With regards to the demand profile for both of the communities and for a summer day, a differentiation in the peak energy demands has been detected. The peak energy demands still occur in the same timescale but there is a significant fluctuation between the peak and off peak demand. This variation is due to the fact that during the summer period, the energy demands for cooling or other relevant needs are causing an increase in the required power from the grid. Extreme values in temperature due to weather characteristics, in terms of sudden, temporal and unpredicted events, are parameters which affect the energy requirements and the power distribution network.

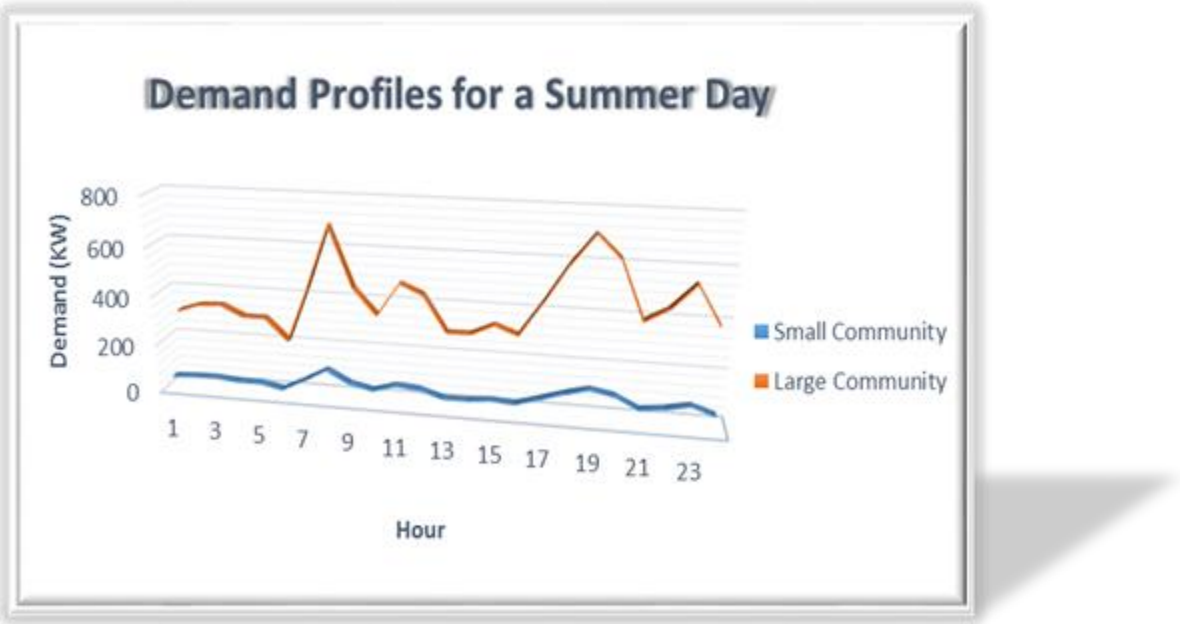

Figure 2: Demand profiles for a summer day, for both of the case study communities

2.3. “Chunking” Approaches

The careful selection of a representative renewables scheme size, was considered to be of a highly importance for the purposes of the examined investigation. A new hybrid sizing procedure was considered essential to be defined, so that a rational approach could be implemented.

The fundamental consideration for creating and justifying the most appropriate sizing procedure was directed towards dividing all the renewable supply technologies into small “chunks”, and then investigate which of the combinations deliver the best match for each case study.

This new sizing technique can be summarised in the following distinctive steps:

1. Demand data for each of the under investigation communities, is imported.

2. Climate data of the selected site location, is imported.

3. Renewable energy technologies (wind and PVs) are loaded in 5%, 10%, 15%, 20% and 40% “chunks”.

4. Supply is sized: After the successful addition of all the supply technologies which were to be used in the case study, the multiple combinations of each of them takes place. To be more precise, each wind turbine is initially combined with one photovoltaic (PV), then with two photovoltaics (PVs) and so on, until all the possible combinations between the supply technologies are being explored.

5. Results are exported: After all the possible combinations are carried out and finished, the results are exported and gathered together so that the evaluation of the best match rate can be conducted. The higher the match rate the best the specific renewable energy technologies mix for the selected community.

Photovoltaic panels (PVs) are simple to be considered when using this analysis as they can be measured linearly. The amount of those who are needed to be added into the computational model varies according to how many Watts are needed to make up to the specific and under investigation percentage of the peak demand.

Wind is considerably more difficult to investigate than PVs in this sizing technique. A non-linear mathematical approach needed to be followed to meet the requirements of selecting the correct increments of this supply technology. This fact came on the surface during the computational methods, as it was discovered that a bigger wind turbine does not produce the same amount of power as its equal subdivisions.

The objective of defining a suitable chunking approach was related to the discovery of the most appropriate sizing options for the available renewable energy sources. Since there were confines with regard to wind energy installations, the selection of smaller than 5% increments was initially excluded.

3. Project Results

MERIT has been used to ascertain the best combination of renewable energy system supplies for each of the examined communities. Simulations for each of the incrementation percentages of the supply technologies, as they have been justified in the previous chapter, have been run.

The investigation upon the best match between supply and demand, for each of the two case study communities, was focused on the period of time in which the calculations were carried out and the several chunks of the supply technologies. Given that, the calculations which were carried out can be summarised in the main categories as shown below:

Table 6: Demand and supply best matches for the small community, for a winter day.

Small Community			
WINTER	15%	20%	40%
Total Demand	3.62 MWh	3.62 MWh	3.62 MWh
Total RE Supply	1.40 MWh	1.56 MWh	1.06 MWh
Percentage Match	52.12	55.60	43.03

Table 7: Demand and supply best matches for the small community, for a summer day.

Small Community			
SUMMER	15%	20%	40%
Total Demand	1.98 MWh	1.98 MWh	1.98 MWh
Total RE Supply	1.17 MWh	0.90 MWh	1.06 MWh
Percentage Match	60.00	55.74	49.32

It is worth noting that the systematic calculations which have been carried out, can be repeated for any community level, either rural or urban. Also, there are no restrictions about the location of the community which is to be investigated. The availability of the renewable sources at that specific location is the most important factor which will provide a more comprehensive research on the best match between supply and demand.

Representative results of the carried out calculations are shown in the Tables 6 to 9. The best demand and supply matches are being group according to the time of period and the chunking percentage.

The sizing of the supply technologies, so as to meet the energy demand, was taken as equivalent to meet the peak energy demand. What was derived as an immediate result after the completion of the simulations, was that when sizing the technologies in order to meet the peak energy demand of the system, the required supply energy is greater. Depending on the size of the community system and the energy demand load, the required supply varies significantly. The larger the community, the larger the percentage of the renewable energy systems that need to be installed in order to meet the demand.

Another factor that influences the best correlation between the energy demand and supply is the period of the simulation. The availability of each of the renewable energy technologies which are to be considered for any scheme, are highly variable and this has been shown also in the results.

Table 8: Demand and supply best matches for the large community, for a winter day.

Large Community			
WINTER	15%	20%	40%
Total Demand	20.67 MWh	20.67 MWh	20.67 MWh
Total RE Supply	6.09 MWh	6.64 MWh	5.16 MWh
Percentage Match	44.68	47.49	39.55

Table 9: Demand and supply best matches for the large community, for a summer day.

Large Community			
SUMMER	15%	20%	40%
Total Demand	12.60 MWh	12.60 MWh	12.60 MWh
Total RE Supply	7.51 MWh	8.33 MWh	6.64 MWh
Percentage Match	63.78	65.20	61.64

3.1. "Chunking" Impact

Representative increments of the supply technologies have been explored, which correspond to 5%, 10%, 15%, 20% and 40% of the given hybrid supply systems availability and could meet the community's peak demand. The 5% and 10% increments delivered approximately the same results as the 15% incrementation, and from 20% onwards the results started to differentiate. This variation of the results for the larger percentages of supply technologies is attributed to the fact that from 20% and up the available supply technologies are being represented by bigger chunks. The smaller the increments to be considered, the more precise the received results will be.

All the available supply technologies were sized in order to meet the peak demand of each community. All the best matches for each scenario for the small community are gathered in the following graph.

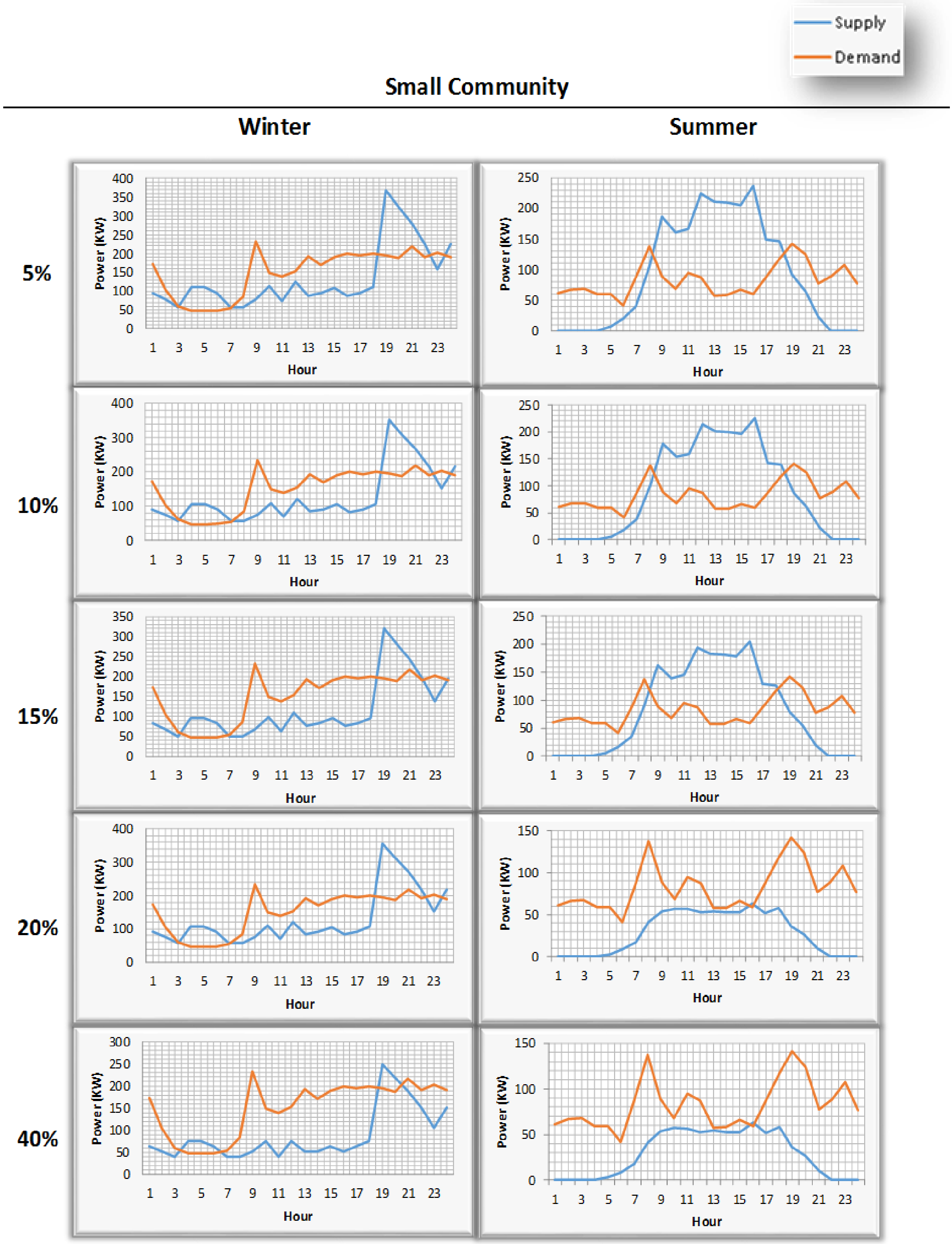

Figure 3: All the demand and supply matches for the small community.

As it can be seen from the overall presentation of the results, there is a clear match between supply and demand for the scenarios which involve smaller chunks of the renewables. From 5% to 15% incrementation of the hybrid renewable energy sources, the energy supply corresponds to the energy demand, with results varying from slightly poor to reasonably good for the community scheme.

The variations between the supply and demand match for the different periods of time that have been investigated, does not show to have a considerable effect on the demand-supply matching rate. Wind and solar renewable sources are vary variable. It was expected that during the winter season the availability of the wind would surpass the one of the solar PV. Following the same consideration, the availability of the solar PV would be more in comparison to the wind during the summer season. Overall, the availability of the one technology over the other, seemed to cover the gap and succeed to sustain a certain level of a positive energy supply to the system.

As we move away from the small incrementations of the renewable energy sources towards the bigger ones, there is a clear mismatch between the energy demand and supply of the system. Chunks of 20% or 40% of the available renewable energy sources appear to have a negative effect on the studied approach. These chunks of the renewables involve a bigger percentage of uncertainty into the calculations and appear to be incapable of addressing adequately the energy demand and supply management approach.

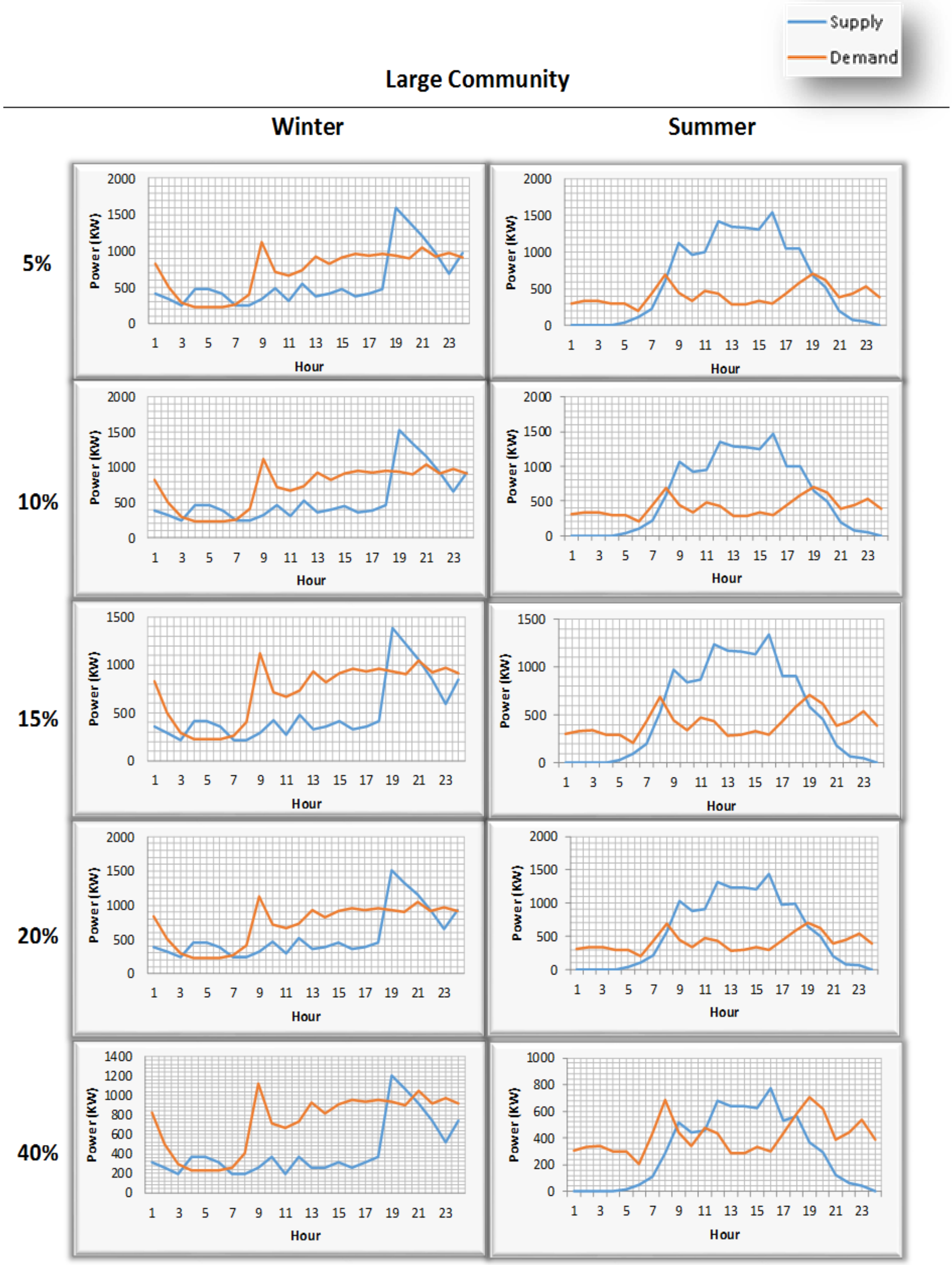

Figure 4: All the demand and supply matches for the large community.

The results from the rational sizing procedure for the large community provide a superior match between the supply and the demand, and therefore validate the judgement regarding the quality of the selected approach.

The matching outcome between the energy demand and energy supply for the large community during a summer day exceeds the analogous outcome for the summer simulation.

3.2. Rational Sizing

The sizing approach which has been followed and thoroughly clarified in previous sections, was based on the dynamic of the supply technologies being sized in order to meet the peak demand, as a prerequisite. However, upon investigation, it was found that the results from the demand and supply management of the communities vary when selecting to size the available supply technologies in order to meet 200% of peak demand or even a greater percentage.

The results obtained in this research has shown that, the impact of chunking process has a significant effect on the best combination of the available renewable supply technologies. If the level of sizing process is optimised to meet a greater value than the peak demand, then this implies that the specific method produces even more useful results for matching out the supply with the demand. Although, a better match can be achieved through this approach, the disadvantages may be relevant to the required size of the plant. In that case, the next best suggestions which comply to land availability can be deployed.

4. Conclusions and Further Study

In the recent years, green development has become a promising solution to the world's energy problem. The challenge is an alternative which will provide an insight on the current needs of the societies and address the issue with innovative and provident solutions. A smooth transition to a sustainable society is one of the principal values of the modern world. However, the sustainable development cannot be conceived as being just a futuristic strategy concerned with environmental issues. It is an incorporated policy which can be come into effect by coordinated and collective work.

Autonomous low energy communities may remain at present only future scenarios, but the shift towards sustainable living makes these scenarios more realistic. In order to achieve autonomy on a community level, there are many factors which need to be taken into consideration while developing an approach towards delivering the appropriate supply technologies to meet the energy requirements of that community scheme.

Energy autonomous communities remain a key issue when the examined community is situated on a remote area with no access to the grid. The availability of the renewable supply technologies is crucial for the feasibility of a 100% autonomy of the system. However, the variability of the hybrid renewable technologies, such as wind and solar, is a perplexing concern which has to be taken on board during the stage of the feasibility investigation. Energy storage could stand as a solid solution, as the produced energy surplus could be stored and used when there is a lack of the required amount of power generation. Batteries aid to eliminate the intermittency problems associated with renewable energy sources. Improvements and innovative work on the field of practical and efficient ways to store energy, for sustainable community schemes, are issues which are gradually gaining some ground and will dominate future actions in the grid and power generation area.

The framework of the rational sizing approach, which was investigated for different community scenarios, provides a better understanding on the ways that renewable energy sources may be exploited to the fullest for a given community scheme. The more detailed and thorough the investigation upon the availability of the renewable energy technologies is, the better the deployment of these technologies can be. Sizing the renewables in order to meet the peak energy demand of the system can provide adequate power to deal with the energy consumption rate. However, when sizing for a greater rate than the peak demand, the match between supply and demand raises significantly.

Naturally, there are some constraints to the deployment of the supply technologies, such as wind and photovoltaics, which are relevant to financial issues as well as practical. There are cases where the best combination of renewables needed to meet the energy demand cannot be implemented in reality, as the cost for such an installation may be unbearable or the availability of the required land use is limited. This research study didn’t take into consideration financial constraints and possible implications of this issue. However, future works in that field may take on board economic considerations when selecting establishing a rational approach for a sustainable development. All these factors should be considered in advance and during the investigation of the renewables energy scheme, so as to gain the most from this rational sizing procedure.

As far as the energy efficiency of the buildings is concerned, there is an evident move towards enhancing and optimising their performance. It is worth noting that, an increase in the buildings' energy efficiency leads to a noticeable reduction of their energy demand. Any improvements on the fabric or features of the buildings tend to aid their energy performance and thus lower their energy requirements. As far as the best match between the demand and supply management of the sustainable communities is concerned, continuous improvements of the energy efficiency of the buildings will cause a considerable mismatch between the supply and the demand. The key aspect of this argument is that, as we move towards low energy communities there will be a constant need to resize the available supply technologies, so that they meet the new energy demand. Nonetheless, it would be useful if recommendations on the possible energy efficiency improvements were being documented in advance, before the implementation of any kind of building refurbishment.

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Glossary

Chunking process: The process which involves the incrementation of a certain amount of a system into considerable subdivisions.

Chunks: The increments of a unit.

The following terms have been taken from the Energy Housing Survey 2012-2013 (UK Department of Communities and Local Government, 2014) and are consistent with the analogous definitions from the Census 2011 (Office for National Statistics, March 2011).

Dwelling: A unit of accommodation which may comprise one or more household spaces (a household space is the accommodation used or available for use by an individual household). A dwelling may be classified as shared or unshared. A dwelling is shared if:

- the household spaces it contains are ‘part of a converted or shared house’, or
- not all of the rooms (including kitchen, bathroom and toilet, if any) are behind a door that only that household can use, and
- there is at least one other such household space at the same address with which it can be combined to form the shared dwelling.

Dwellings that do not meet these conditions are unshared dwellings.

Dwelling type: Dwellings are classified, on the basis of the surveyor's inspection, into the following categories:

- small terraced house: a house with a total floor area of less than $70m^2$ forming part of a block where at least one house is attached to two or more other houses.
- medium/large terraced house: a house with a total floor area of $70m^2$ or more forming part of a block where at least one house is attached to two or more other houses.
- end terraced house: a house attached to one other house only in a block where at least one house is attached to two or more other houses.
- mid-terraced house: a house attached to two other houses in a block.
- semi-detached house: a house that is attached to just one other in a block of two.
- detached house: a house where none of the habitable structure is joined to another building (other than garages, outhouses etc.).
- converted flat: a flat resulting from the conversion of a house or former non-residential building. Includes buildings converted into a flat plus commercial premises (such as corner shops).
- purpose built flat, low rise: a flat in a purpose built block less than six storeys high. Includes cases where there is only one flat with independent access in a building which is also used for non-domestic purposes.
- purpose built flat, high rise: a flat in a purpose built block of at least six storeys high.

Energy efficiency rating (EER) bands: The 1-100 SAP energy efficiency rating is also presented in an A-G banding system for an Energy Performance Certificate, where Band A rating represents low energy costs (i.e. the most efficient band) and Band G rating represents high energy costs (the least efficient band). The break points in SAP (see below) used for the EER Bands are:

- Band A (92–100)
- Band B (81–91)
- Band C (69–80)
- Band D (55–68)

Household: One person living alone, or a group of people (not necessarily related) living at the same address who share cooking facilities and a living room or sitting room or dining area.

Household type: The main classification of household type uses the following categories:

- married/cohabiting couple with dependent child(ren) – may also include nondependent child(ren).
- married/cohabiting couple under 60 with no dependent children or with nondependent child(ren) only.
- married/cohabiting couple age 60 or over with no dependent children or with non-dependent child(ren) only.

- lone parent family (one parent with dependent child(ren) – may also include nondependent child(ren)).

- other multi-person household (includes flat sharers, lone parents with nondependent children only and households containing more than one couple or lone parent family).

- one person aged under 60.

- one person aged 60 or over.

The married/cohabiting couple and lone parent household types (the first four categories above) may include one-person family units in addition to the couple/lone parent family.

Useable floor area: The total useable internal floor area of the dwelling as measured by the surveyor, rounded to the nearest square metre. It includes integral garages and integral balconies but excludes stores accessed from the outside only, the area under partition walls and the stairwell area. Dwellings are also grouped into the following five categories:

- less than $50m^2$

- 50 to $69m^2$

- 70 to $89m^2$

- 90 to $109m^2$

- $110m^2$ or more.

Appendix

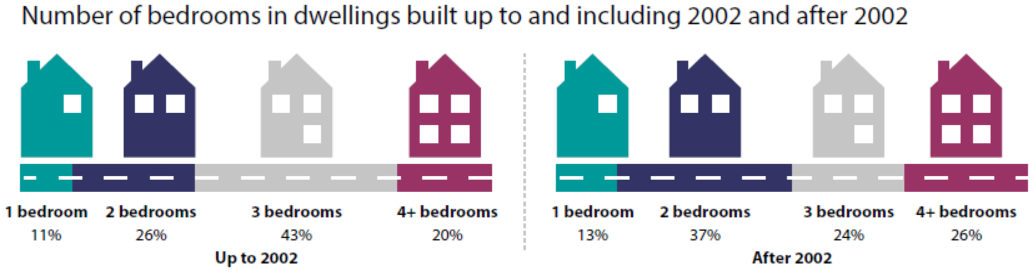

Figure 5: Number of bedrooms in dwellings built up to and including 2002 and after 2002.

Source: (UK Department of Communities and Local Government, 2014)

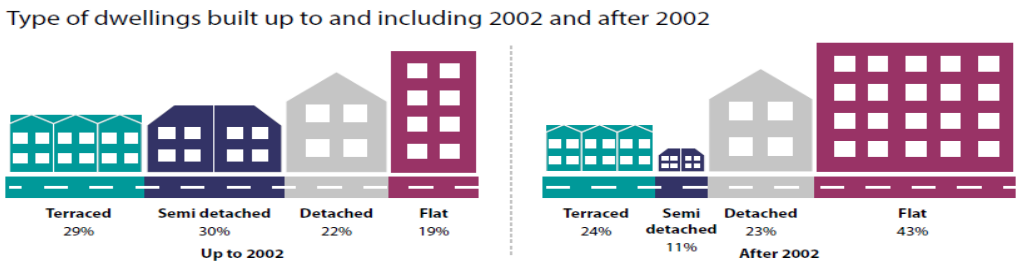

Figure 6: Type of dwellings built up to and including 2002 and after.

Source: (UK Department of Communities and Local Government, 2014)

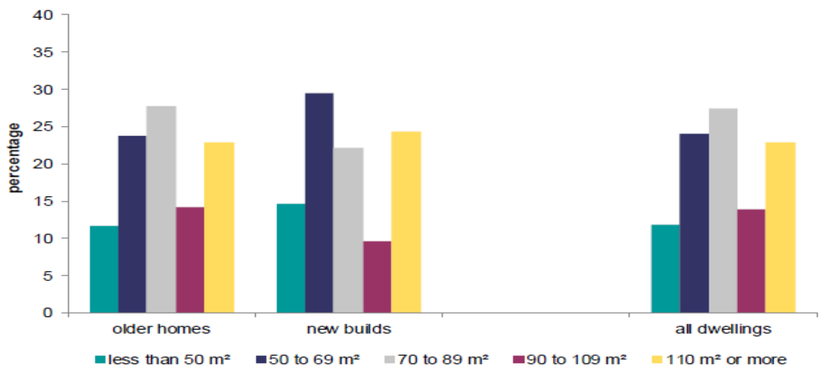

Figure 7: New build and older homes, by banded floor area.

Source: (UK Department of Communities and Local Government, 2014)

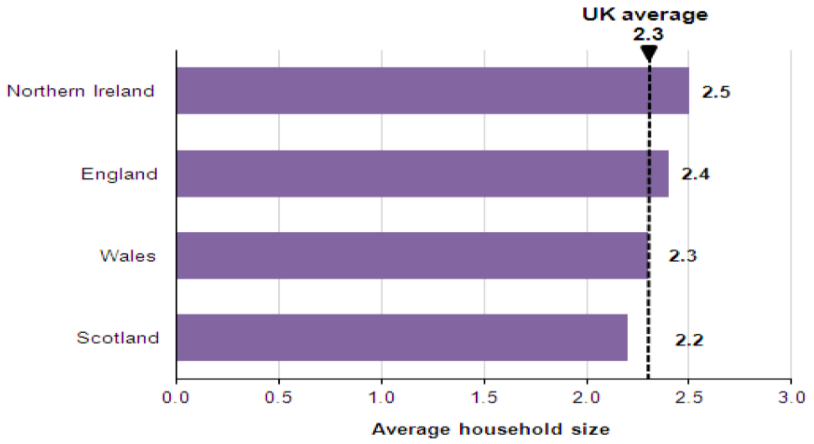

Figure 8: UK Average household size.

Source: (Office for National Statistics, March 2011)

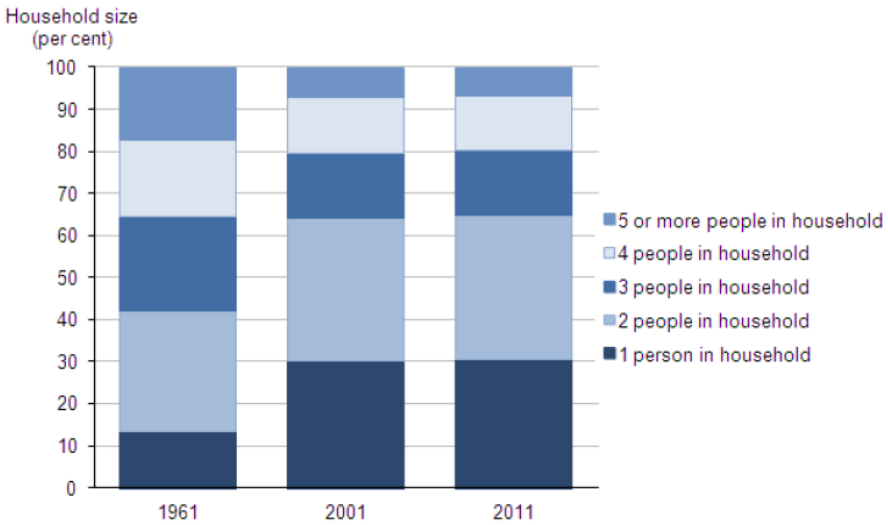

Figure 9: Household size by number of people in household as a proportion

Source: (Office for National Statistics, March 2011)

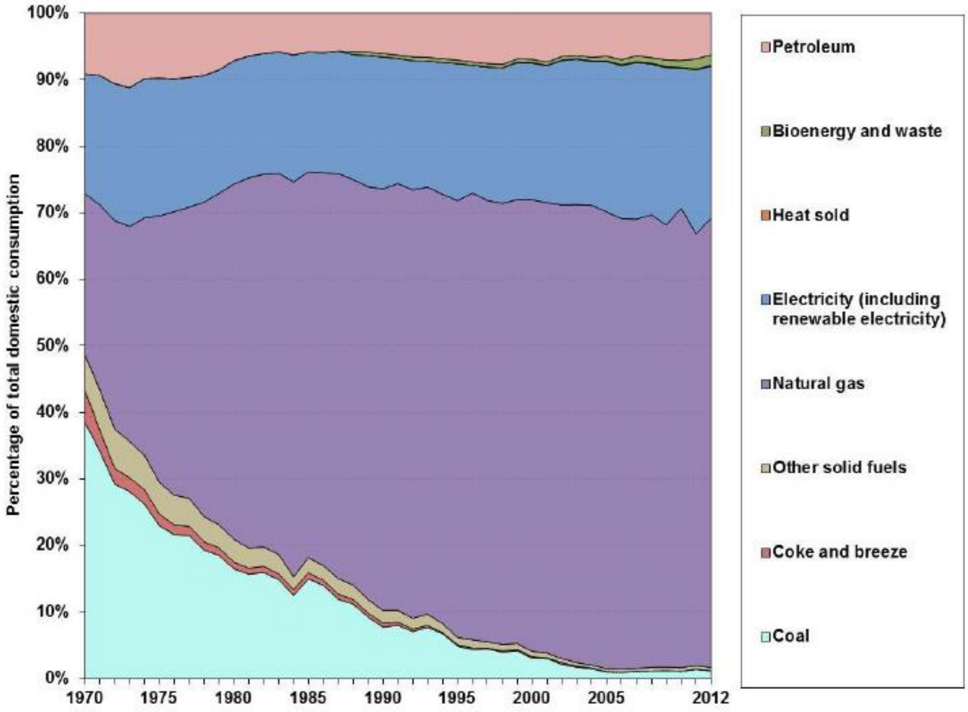

Figure 10: Domestic consumption by fuel, UK (1970 TO 2012)

Source: (UK Department of Energy and Climate Change, 2014)