Northern Periphery and Arctic Programme
2014–2020

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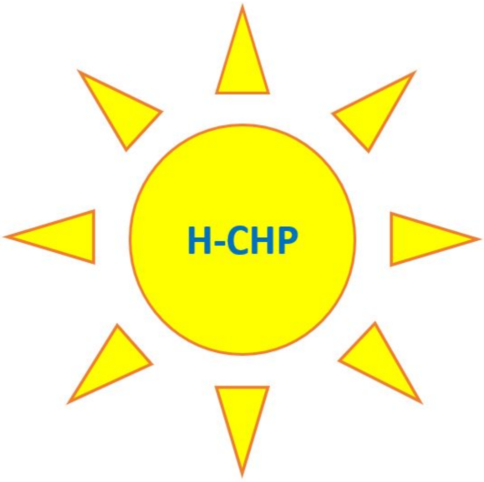

CHP AND RENEWABLES INTERACTION IN SMALL COMMUNITIES

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Abstract

Study on how CHP (Combined Heat and Power) derived technologies -such as Micro CHP- could be integrated in small communities along Renewable Energy Generation alternatives, such as Solar PV, Windfarms or others, producing a multi-variable model able to simulate and give detailed results on the actual efficiency and economic benefits of such projects.

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Glossary

Acronym	Definition
£	United Kingdom pound
ASHP	Air Source Heat Pump
CHP	Combined Heat and Power
CO_2	carbon dioxide
COD	chemical oxygen demand
deg C	degrees Celsius
ED	electrodialysis
EDR	electrodialysis reversal
ERDF	European Regional Development Fund
ES	Energy Storage
EU	European Union
EV	electric vehicle
FO	forward osmosis
GW	gigawatt
GWh	gigawatt hours
HP	heat pump
HWS	hot water system
ICE	Internal Combustion Engines
Ir	iridium
kg	kilogram
kJ	kilojoule
kV	kilovolts
kW	kilowatt
kWel	kilowatt electrical
kWh	kilowatt hours
kWp	kilowatt peak
kWth	kilowatt thermal
L	litres

MD	membrane distillation
MoD	Ministry of Defense
MW	megawatt
MWh	megawatt hours
Na_2CO_3	sodium carbonate
NaCl	sodium chloride
NF	nanofiltration
NPA	Northern Periphery and Arctic Programme
OECD	Organisation for Economic Co-operation and Development
ORC	Organic Rankine Cycle
PEM	Proton Exchange Membrane
PHES	pumped hydroelectricity energy storage
PHEV	plug-in electric vehicle
PSP	Point and Sandwick Power
PSH	pumped storage hydroelectricity
Pt	platinum
R&D	Research and Development
RE	Renewable Energy
REG	Renewable Energy Generation
RES	Renewable Energy Sources
RHI	Renewable Heat Incentive
RO	reverse osmosis
ROC	Renewable Obligation Certificates
ROI	Return on Investment
SOFC	Solid Oxide Fuel Cells
Solar PV	solar photovoltaic
SSE	Scottish and Southern Energy
TDS	total dissolved solids
uPVC	unplasticised polyvinyl chloride
UK	United Kingdom
V	volt
Wh	watt hours
WT	Wind Turbine

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Abstract

The main purpose of this document is to show the logical process which brought about the creation of a complex energy simulation model which includes the possibility of adding most of the RE (Renewable Energy) sources to the grid of any location in the Western Isles (Outer Hebrides), in Scotland, and also including one or more (up to three) CHP (Combined Heat and Power) configurations. In the future, the same research could be extended to every other country in the NPA (Northern Periphery and Artic programme) area.

The CHP portion of the examination has been focused on Biomass (i.e. scrap lumber, forest debris, wood pellets, etc.) as fuel class, based on the information collected in previous reports.

This document will also briefly describe what the potential improvements to the model are, and the current status of all its sections. It will also list a description and the working parameters and details of the chosen Biomass CHP utility, to give the reader the whole panorama.

In conclusion, a condensed list of some different scenario simulation results will be provided, in both graphical and tabular format, explaining every point with the necessary description.

Introduction

The H-CHP project aims to potentially increase energy efficiency and accelerate the adoption of renewable and sustainable energy solutions in any region. There is a specific focus on individual rural households with low population density and low accessibility to affordable energy. Domestic dwelling in sparsely populated areas is subject to unpredictable power interruptions. The proposed solution will:

- guarantee electricity during peak heat demand periods;
- place less strain on grids;
- reduce demand spikes;
- smooth the generation profile from power stations.

The purpose of the project is to promote the uptake of Combined Heating and Power systems (CHP) in the region using solid renewable biomass and gasification methods that will be appropriate for remote households.

The Northern Periphery Area has abundant natural fuel resources but is subject to a harsher climate than the rest of Europe and this results in the need for increased domestic energy. Attempts to exploit natural energy resources for households has been mixed, and as a consequence, there is significant fuel poverty in the region.

A key component is the high cost of electricity. It has been estimated that up to 70% of electrical energy can be lost in production and transmission lines before reaching the end user – primarily as heat loss.

The principle of CHP is to use some of the heat in the home to generate electricity; this is intrinsically highly efficient. The project will analyse the energy needs of remote households in the region. The available fuel is mainly solid which is unsuitable for existing gas CHP.

We propose a new affordable solution that uses local renewable solid biofuel in a small-scale micro CHP system. The advantage of this approach is that all fuel used is carbon neutral, transport costs are minimal, and there are reduced CO_2 emissions. This helps with carbon legislation compliance, reduced transmission losses from the grid, and the electricity-to-heat production ratio is a good match for the colder parts of Europe.

A 20-kW heat and 3-6 kW electricity with smart control system will be designed, manufactured and trialled in all participants' areas. This system will demonstrate the energy efficient use of locally sourced, renewable bioenergy in family homes, especially in remote and sparsely populated regions.

Up to now high capital costs have been a barrier to widespread adoption of household CHP and this project will examine the factors that can make such systems affordable.

The NPA (Northern Periphery and Arctic Programme) in Brief

The Northern Periphery and Arctic 2014-2020 forms a cooperation between 9 programme partner countries. The NPA 2014-2020 is part of the European Territorial Cooperation Objective, supported by the European Regional Development Fund (ERDF) and ERDF equivalent funding from non-EU partner countries.

Despite geographical differences, the large programme area shares a number of joint challenges and opportunities that can best be overcome and realised by transnational cooperation. The programme's vision is to help to generate vibrant, competitive and sustainable communities, by harnessing innovation, expanding the capacity for entrepreneurship and seizing the unique growth initiatives and opportunities of the Northern and Arctic regions in a resource efficient way.

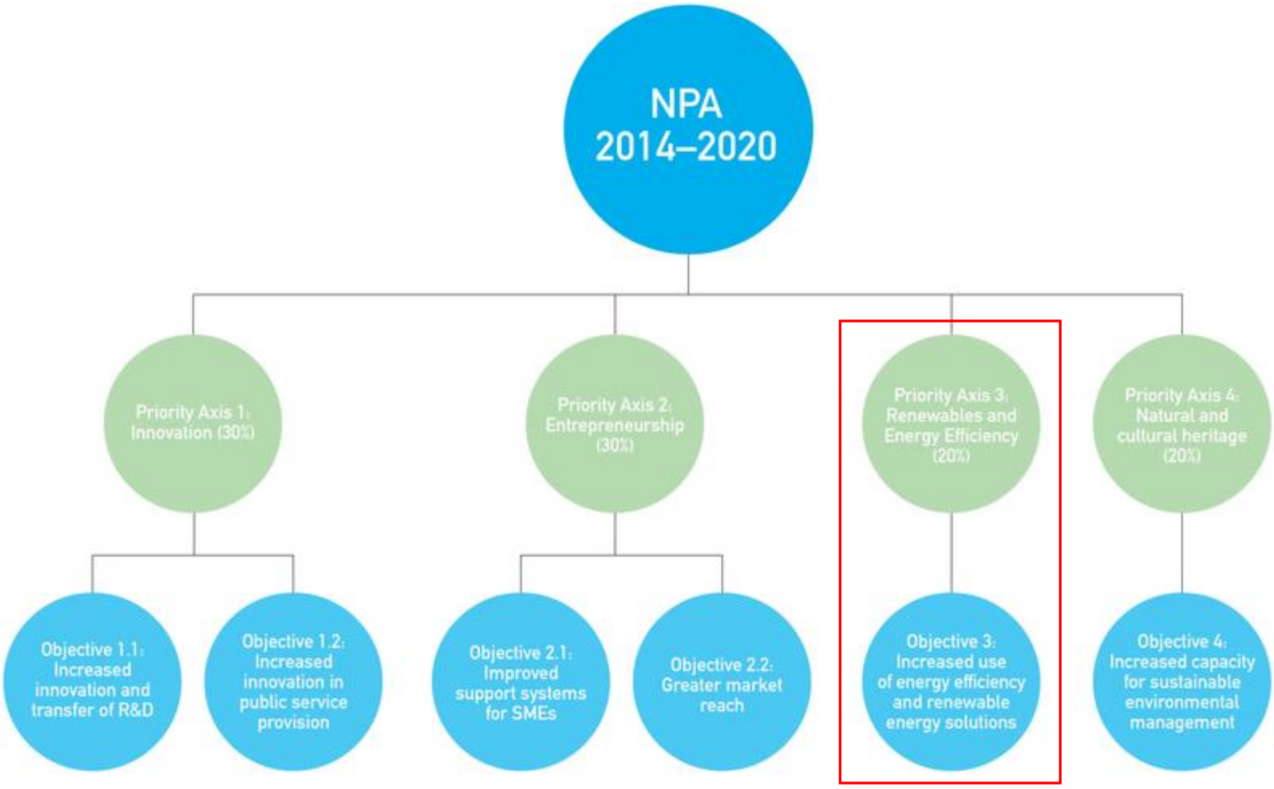

Figure 1: NPA Programme Priority Axes (NPA INTERREG 2014)

The Northern Periphery and Arctic 2014-2020 Programme is part of the European Territorial Cooperation Objective, also known as Interreg, in the framework of the cohesion policy, supported by the European Regional Development Fund.

The programme operates in a multi-layered policy landscape, making it well positioned to contribute to and align with the Europe 2020 Strategy, national and regional policies and development strategies, macro regional and sea basin strategies, and other programmes covering parts of the geographical area. In addition, increased interest and rapid developments in Arctic regions have resulted in a more explicit recognition of the programme's Arctic dimension in regional development.

The Northern Periphery and Arctic Programme area comprises the northernmost part of Europe including parts of the North Atlantic territories. The name of the Programme highlights the peripheral and northern position of the Programme area compared to Europe in general. In addition, the Arctic dimension is underlined in the Programme title at the request of the European Commission. The background for this is the growing international and EU interest in the developments in the Arctic area, mainly driven by climate change and the new challenges and opportunities that it brings.

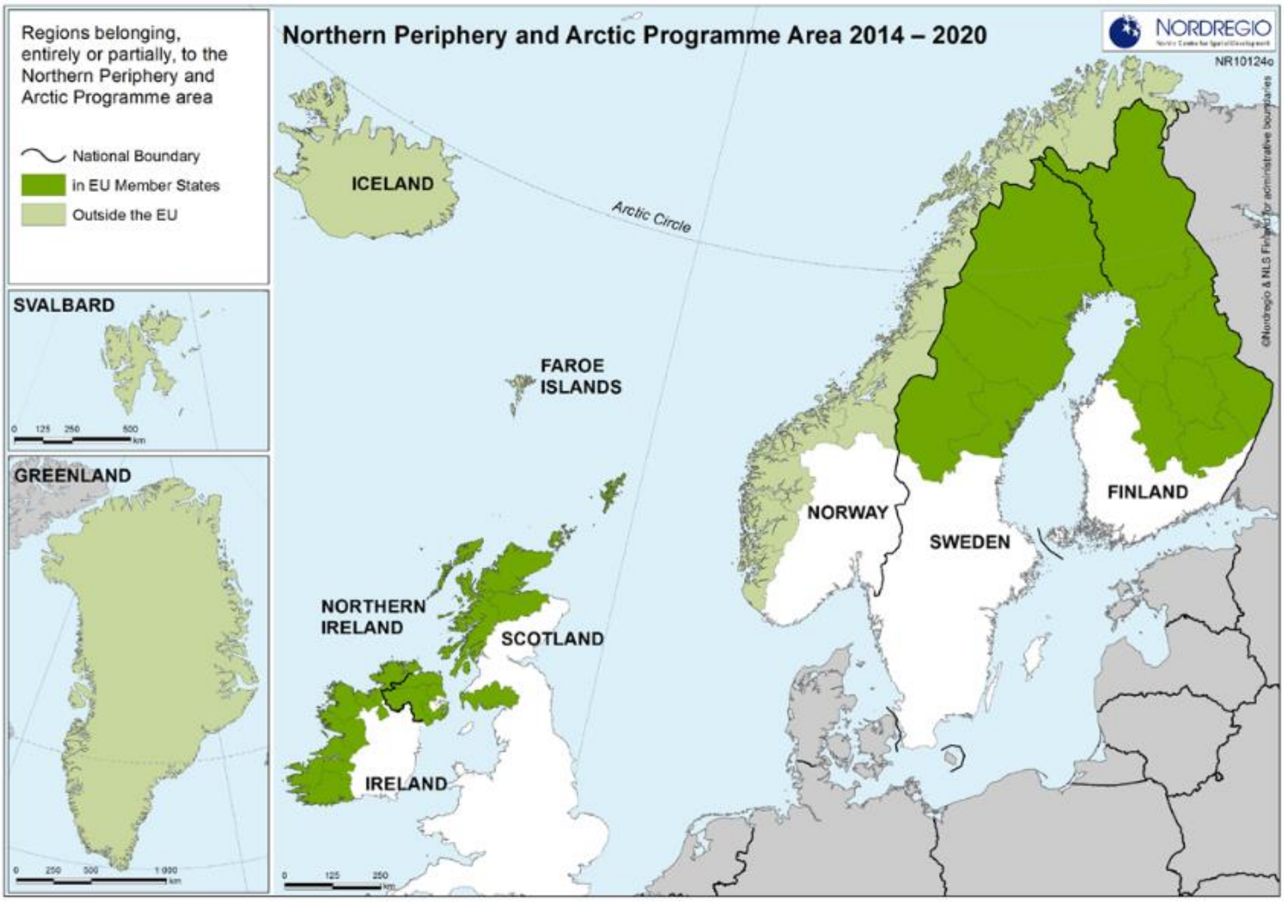

Figure 2: NPA Programme Area of Interest (NPA INTERREG 2014a)

The Programme area is in many respects diverse. A considerable part of the Programme area is located north of the Arctic Circle, while other areas belong to the subarctic or the northern temperate zone. The area has an extensive coastline, numerous islands and a high proportion of mountainous regions.

The primary characteristics that draw the area together are peripherality and low population density. Other related and shared features include sparse and imbalanced settlement structures, dispersed business base, long distances and physical barriers between the communities, difficulties for communications and accessibility, and extreme climates. Furthermore, the Programme area suffers from relatively low economic diversity, which means that the regions are dependent on relatively few economic sectors, such as fishery or forestry.

As well as these common development challenges, the Programme area is characterised by shared and common development resources, including the area's abundant natural resources, high-quality biophysical environment, and versatile business sector. The main common characteristics of the Programme area are outlined below.

- Low population density - As a whole, the average population density in the ice-free part of the NPA land area is 6 inhabitants per km² – compared to the European Union average of 117 inhabitants per km². Only 'pockets' of similarly sparsely populated areas can be found in other parts of the EU. Thus, the Programme area is unique in a European context.

  As well as low population density, the Programme has an unevenly distributed and increasingly concentrated population. As a result, the Programme area's small number of larger cities and towns have an increasingly dominant position, while more peripheral areas suffer from out-migration, brain drain and ageing populations;

- Low accessibility - Extremely low population density is linked to long distances between small and scattered settlements and low accessibility to large conurbations. Within the NPA Programme area, the time and distances involved in travelling to regional centres are particularly high, even compared to other sparsely populated areas of the EU. While sparsely populated areas in Central Spain and France are within 2-3 hours of metropolitan areas, many parts of Northern Scotland and the Nordic countries are located more than a 5-hour drive from large regional centres.

  Long distances, both internally between towns and settlements and internationally, mean that many communities are dependent on-air transport. In addition, many areas suffer from extremely poor connectivity, – with air routes often only connecting peripheral areas with capital-city regions and a few other larger cities.

  Lack of connectivity reduces market access and is an obstacle to achieving critical mass. In addition, the Faroe Islands, Greenland and Iceland face the specific challenges of being island economies with long sea-distances separating them from neighbouring countries. The Scottish island groups (Orkney, Shetland and the Hebrides) have similar characteristic;

- Low economic diversity - Viewed in a historical perspective, most of the NPA territory has been dependent on natural resources, with the exploitation of, for example, fish, wood and energy resources playing a key role in many of the local economies. More recently, industries based on natural resources such as mining and nature-based tourism have become increasingly important, which underlines that the NPA still depends on the exploitation of natural resources.

  Additionally, the public sector plays a crucial role as a major employer across the Programme area. In many cases, the public sector is the only opportunity locally for higher-skilled workers;

- Abundant natural resources - The NPA Programme area as such has abundant natural resources, for example the gas and oil in the North Sea and Europe’s most important mineral resources in Northern Sweden and Finland. The Arctic part of the Programme area in particular contains mineral, oil and gas resources. In 2008, it was estimated that 5–13% of the world’s oil reserves and about 20–30% of the natural gas reserves are located in the Arctic. Besides oil and gas reserves, considerable mineral reserves can be found in Greenland. In addition, the Programme area contains vast renewable resources as biomass (wood, fish, seaweed) and renewable energy (wind, hydro, wave, geothermal).

  Linked to these resources, the rising interest from international investments, for example in new mega-sized mining projects, results in tensions between economic, social and environmental interests;

- High impact of climate change - The climate varies considerably across the NPA territories from an Arctic climate in Greenland, the northern part of Iceland and the other Nordic countries to an oceanic climate in the Faroe Islands, coastal Norway, Scotland, Northern Ireland and Ireland.

  However, climate change projections predict that temperatures will rise higher and earlier in the Arctic region and neighbouring areas than in rest of the world. It is also expected that levels of precipitation will increase across the Programme area. Altogether, climate change will affect a wide range of human activities and welfare in different ways and to different extents.

  According to the OECD (Organisation for Economic Co-operation and Development), a defining characteristic of the effects of climate change is that they will be ‘mixed’ – increasing environmental challenges, but also new opportunities for regional economies. Furthermore, the OECD states that long-term economic development will depend on timely adaptation and reasonable management of the region’s environment and natural resources.

All of the challenges and potentials that have been highlighted in the preceding analysis are to a great extent interrelated, which means that they cannot be treated as individual or independent problems or possibilities. Crucially, they also reach beyond local, regional and national borders, making them particularly relevant to transnational territorial cooperation.

Taking these factors together means that the NPA 2014–2020 has to address a complex range of transnational, often long-standing and interrelated, challenges and opportunities.

Background

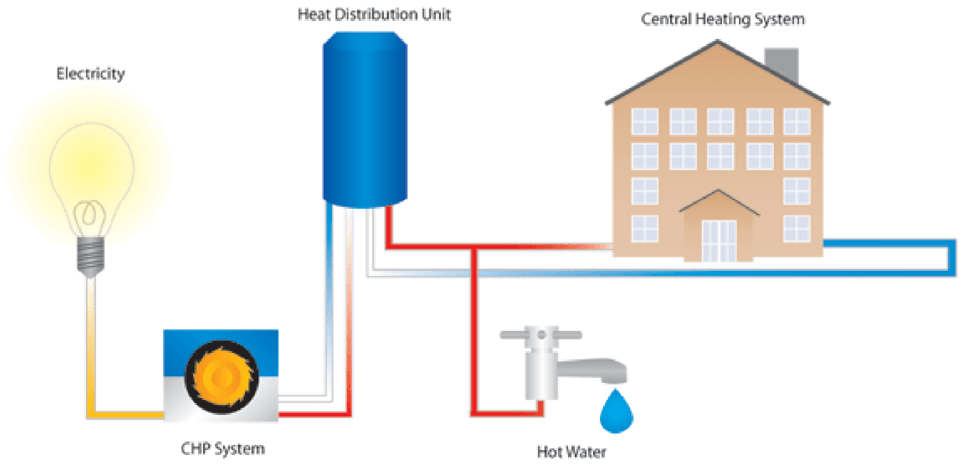

Figure 3: CHP Cogeneration System (BioEnergyConsult 2019)

CHP (Combined Heat and Power) are systems that produce electrical and thermal loads at the same time. Until recently the production of electricity was made in power plants where huge amounts of heat energy were lost in the environment. The principal idea of CHP is to take advantage of the thermal energy from the production of electricity. Thus, CHP are high efficiency systems.

As micro CHP the EU (2004/8/EC) has defined small scale systems (less than 50 kW). These usually are applied for space and water heating to individual dwellings and small commercial buildings replacing the conventional boilers.

CHP provides furthermore fuel savings, reducing as a result emitted gas and the operational cost. The systems can function in parallel to the grid exporting energy or backing it up in case of a break down.

Micro CHP seems like a promising new solution with substantial growth and prospects being appreciated worldwide. Governments consider these systems as reliable solutions. Industry is developing new technologies, introducing alternative fuels and making the systems simpler and more accessible to all.

The most commercial systems are the ICE (Internal Combustion Engines) while the external combustion engines such as Stirling engines, micro gas turbines and ORC (Organic Rankine cycle) systems are aiming for the biggest market share. Fuel cells are still not commercially available.

Micro CHP are usually gas or petroleum fuelled. However, alternatives like biomass have become available maintaining high efficiencies and reducing carbon emissions to minimum levels.

Micro CHP systems are easily installed more or less as conventional boilers. They have similar volume and having to follow the same noise regulations, they are well sound insulated.

- *External combustion engines:*

  Most of the micro CHP systems are external combustion engines such as Stirling and Rankine cycle engines. These systems are providing higher efficiency, can work with various types of fuel, have low gas emissions, low levels of noise and vibration. External combustion engines are using a part of fuel gas to drive the engine and produce electricity. The fuel (helium, hydrogen, etc) has been preheated in a heater alternator. Due to the external combustion, damages to the engine are limited but require good isolation to avoid leakage. Main disadvantage is the reliable life span;

- *Internal combustion engines:*

  These are more popular in bigger scale systems. Currently industry is constructing high efficiency engines also in small scale systems. These engines are applicable to a wide range of usage and their operation can work also with liquid and gas fuels. Their operation is similar to car engines. Their main disadvantage is high maintenance cost and higher level of noise and gas emissions;

- *Fuel cells:*

  Fuel cells are electrochemical engines that convert the chemical energy of fuel to electricity without combustion. The principal operation is that hydrogen and oxygen reacting with an electrolyte produce water electricity and heat.

  Main advantages of fuel cells are high electricity efficiency, easy in usage, low level of noise and emissions. Due to the high efficiency and the type of fuel used, the emissions are 10 to 100 times lower than other system. The disadvantages that are limiting their popularity are high cost and low lifetime. Two most common types of fuel cell systems are the PEM (Proton Exchange Membrane) and SOFC (Solid Oxide Fuel Cells).

External combustion engines are more popular in Europe, while in America internal combustion engines prevail. The Japanese market is focused mostly on fuel cells.

Expected Results

The project main results can be condensed in the following list:

- Displaces the use of fossil fuels by using renewable fuels, principally biomass;
- Supports citizen-led action at a domestic level and encourages new local industries to source local biomass fuels, resulting in local job creation;
- Municipalities, governments and Utility Companies can meet obligations through investment in micro CHP and re-focus investment on low carbon technologies rather than grid reinforcements based on traditional energy generation and distribution;
- Provides very efficient power and affordable energy solutions for remote communities in fuel poverty. Supports the Energy Efficiency Directive 2012/27/EU (commonly known as EED). EED promotes CHP technologies and allows Member States the opportunity to assess current legislation and develop an appropriate policy structure that is supportive of micro-CHP technologies. It aims to stimulate the market and help realise the significant potential for energy savings and CO_2 emission reductions;
- Is fully in accordance with the Commission Communication Energy Roadmap 2050 “the long-term energy planning policies for the Baltic Sea Region are energy infrastructure, renewable energy, energy efficiency, and security of supply at affordable prices”. Micro-CHP plants help the EU’s targets in reducing the dependency on imported oil/gas, reducing greenhouse gas emissions and using renewables to securing reliable electricity supply;
- Makes available a renewable power system to households in the NPA region that is currently not available;
- Stimulates manufacturers to design and build novel micro CHP system solutions;
- Using micro CHP will guarantee electricity during peak heat demand periods, place less strain on grids, reduce demand spikes and smooth the generation profile from power stations. All the above correlate significantly with the result indicator for Priority Axis 3.

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Biomass H-CHP Systems

Figure 4: Biomass Medium Scale CHP Unit (Myriadproducts 2019)

Combined Heat and Power (CHP) is a process that provides both heat and power on site in one single, highly efficient process.

CHP generates electricity and as a by-product of the generation process, heat is produced. This heat can be used on site while using the power generated. In contrast, our traditional coal and gas power stations can lose up to two thirds of the heat produced. By generating the heat and power on site, CHP systems can achieve in excess of 80% efficiency.

Wood Biomass is fed into the system similar to a normal biomass boiler. Instead of feeding it oxygen to burn the fuel, it is heated in an environment that has no oxygen present. At around 700 degrees Celsius, all the gases from the wood are extracted and instead of being burnt, run through cooling coils and filters that produce a synthesis gas or Syngas. The gas is then fed to an engine that runs on the gas. Connected to the engine is a generator to provide electricity and the heat produced by the engine, instead of going to a radiator, can be fed into a heating system.

By using biomass, a carbon neutral fuel to power the CHP systems, substantial reductions in CO_2 emissions can be achieved.

With the government's commitment to reducing carbon emissions, several schemes have been initiated to help bring renewable technology to the market. Most renewable technologies take advantage of one or two of the tariffs to help pay back the cost on the system. Biomass CHP can take advantage of all the schemes due to generating both renewable heat and power.

The schemes are as follows:

- *The Renewable Heat Incentive:*

  This rewards people for generating heat from a renewable heat source such as biomass. A heat meter is placed on the system that records generation and the government's scheme pays the owner of the equipment a certain tariff depending on the technology and size. Biomass boiler installations over the last 5 years have boomed with the introduction of this tariff;

- *Renewable Obligation Scheme:*

  The RO scheme was initially implemented for large power generators using alternative fuel sources. For every 1000kW of energy generated, the scheme issues certificates. These certificates are bought by the energy supply companies, so they meet the government criteria on having some of their energy generated from renewables. Biomass CHP systems are classed as advanced combustion technologies and gain the highest certificate value for the energy generated.

The use of biomass is classed as being 'Carbon Neutral' and therefore does not contribute to Global Warming. As trees grow, they absorb carbon dioxide from the atmosphere during photosynthesis. When the wood is subsequently burnt, that same amount of Carbon is released back into the atmosphere and thus there is no net increase in Carbon and no impact on the environment. Compare this with the burning of fossil fuels such as oil and gas where the Carbon has been locked away for millions of years – until it is burnt and released.

Biomass Renewable is also a renewable energy. Trees are specifically grown to produce biomass fuel in sustainable forests that are constantly replanted as trees are felled. The fuel can be grown in many parts of the world and thus we are not dependant on the traditional fossil fuel sources. Waste wood from sawmills and manufacturers which may otherwise end up as landfill can also be used for the production of wood pellets.

Even the ash makes a great fertilizer for the garden. Installing a Biomass CHP system will dramatically improve the Environmental impact of premises, reducing the use of fossil fuels and reducing the carbon footprint. This is a very valuable public relations story for the customers who are increasingly aware of global warming and the need to work with companies with impressive Green credentials.

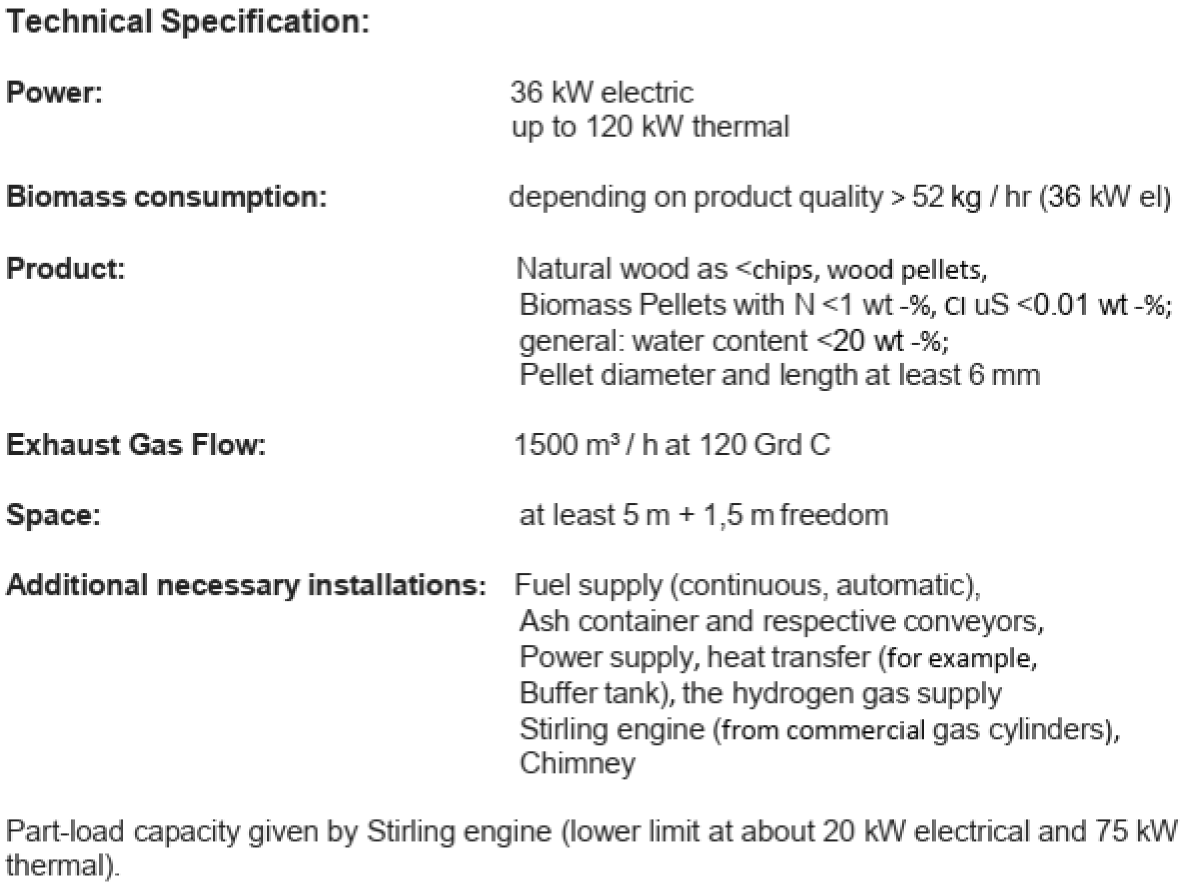
Compact Biomass CHP Units – 100 kW nominal rating

Figure 5: Qalovis Q PowerGen CHP Unit (Qalovis 2019)

An example of a relatively 'small' CHP unit can be found in the *Qalovis Q PowerGen* system. This one is a Stirling engine-based biomass gasification CHP for parallel generation of heat and electricity.

It produces in steady state operation 36 kW electrical and 120 kW thermal power (kWel and kWth).

The Q PowerGen system consists essentially of a gasifier VHG 30, air supply, recuperator, exhaust heat exchanger, burner and combustion chamber, Hot gas duct, Stirling generator unit FleXgen G38 and control via PLC.



Technical Specification:

Power:	36 kW electric up to 120 kW thermal
Biomass consumption:	depending on product quality > 52 kg / hr (36 kW el)
Product:	Natural wood as <chips, wood pellets, Biomass Pellets with N <1 wt -%, Cl uS <0.01 wt -%; general: water content <20 wt -%; Pellet diameter and length at least 6 mm
Exhaust Gas Flow:	1500 m³ / h at 120 Grd C
Space:	at least 5 m + 1,5 m freedom
Additional necessary installations:	Fuel supply (continuous, automatic), Ash container and respective conveyors, Power supply, heat transfer (for example, Buffer tank), the hydrogen gas supply Stirling engine (from commercial gas cylinders), Chimney

Part-load capacity given by Stirling engine (lower limit at about 20 kW electrical and 75 kW thermal).

Figure 6: Qalovis CHP System Technical Sheet (Qalovis 2019)

The biomass solids CHP can use biomass in form of wood chips and pellets. The chips can be supplied over a sliding floor container and pellets via a mounted station.

With a tubular chain conveyor, the product reaches the upper end of the reactor/gasifier, where the fuel will be dropped from the tube chain conveyor, falling over a feed chute into the gasification fixed bed reactor.

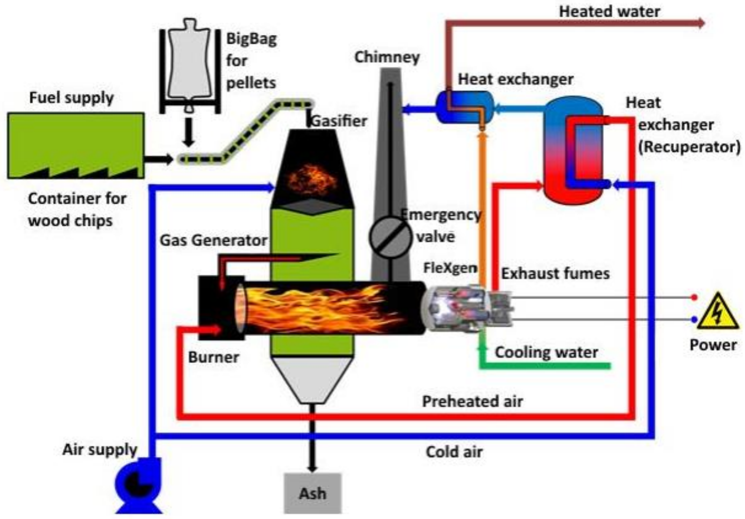


Figure 7: Qalovis Q PowerGen System Diagram (Qalovis 2019)

The chute is superimposed on the barrier gas air principle. Also, a slider, which is opened only for the charging process, prevents in a standard case the exit of produced gas upwards into the chute. With a level sensor inside the fixed bed reactor the loading operation is initialized and terminated.

At different heights the air will be supplied to the fixed-bed reactor. After one single electric ignition of the gasification process, the process itself runs autothermally. Ash and generator gas will be distributed to the lower part of the reactor, there the ash will be separated and discharged from the reactor by screw conveyors (level sensor controlled). The gas is removed from the reactor via the so-called gas guide tube and supplied to the burner.

This burner is mounted in front of the combustion chamber, which crosses the lower part of the reactor. In the burner uncooled generator gas will be mixed and burned to about 400°C temperature level by means of preheated air. At the back end of the combustor 1000°C can be achieved. This hot gas stream then impinges on the heat exchanger head of the Stirling engine, which extracts the heat from hot gases and converts them first into mechanical work. A generator is ultimately seated on the drive shaft, it converts the mechanical energy into electrical energy.

The exhaust gases of combustion are cooled in the Stirling up to app. 600°C and then enter the recuperator in which they are further cooled. While the burner store of combustion is supplied, the exhaust gases pass again an air-water heat exchanger and exit via the exhaust fan the plant towards the chimney.

A supply air fan with an "air tree", called air distributor, ensures on the entrance side, the supply of the gasification and the combustion air but ensures on the other hand the required air flows for cooling and the capacity of air needed as safety air.

The heat extraction from the system is carried out through the cooling water of the Stirling and secondly through the already mentioned air-water heat exchanger in the exhaust stream behind the recuperator.

A special feature of the system is the so-called "emergency chimney": in the case of abnormal operating condition, such as a power failure, a hard wired safety chain and / or spring-loaded actuators ensure that the air supply is cut off from the gasification reactor, thus allowing the combustion process to run out safely.

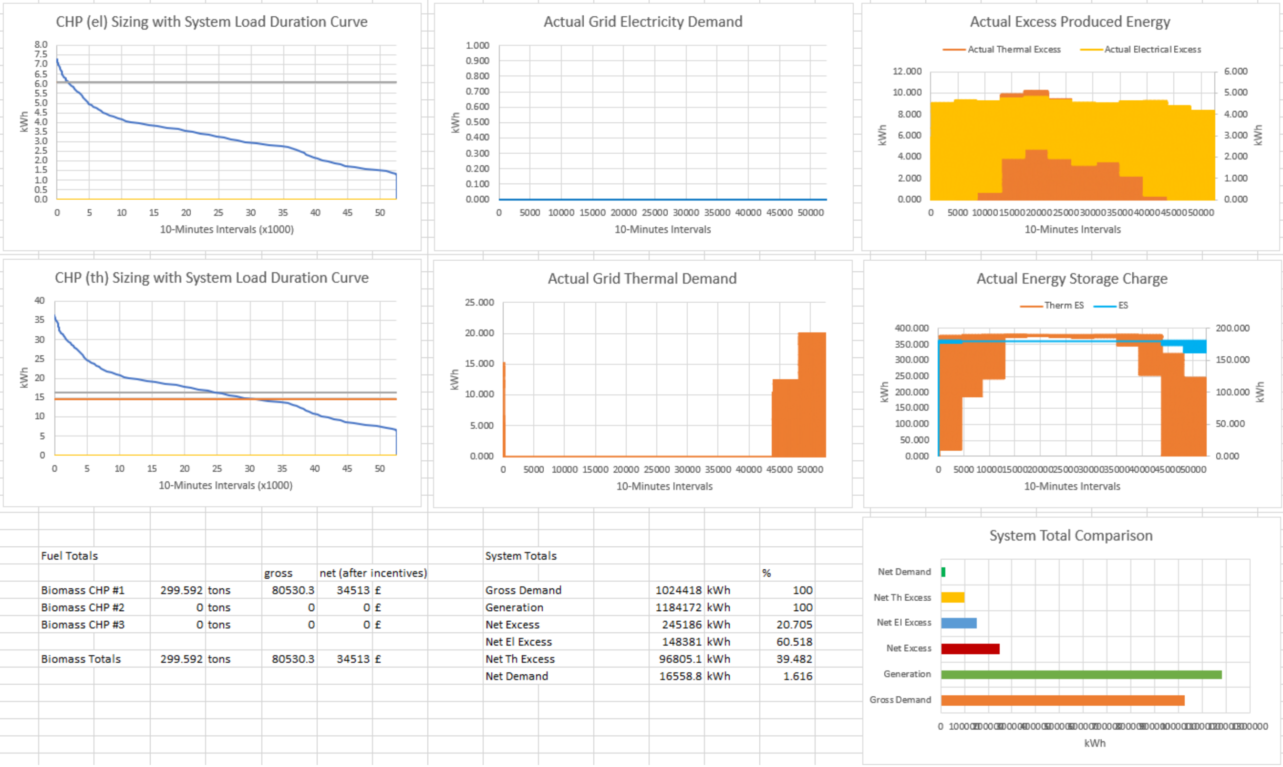
The Energy Model

The first step in the Energy Model creation was to define which energy sources had to be used, for subsequent inclusion into the model itself. Solar PV (Photovoltaic) and Wind renewables energy generation were a natural choice, having already looked at them for previous research and projects.

Compared to them, however, this model has been planned and built to delve even more inside the simulation, incorporating a greater number of variables, elements, and a 10-minutes timestep, compared to the older one of 1 hour, for an entire year.

This will allow any simulation result to be even more precise and detailed, and thus, all the derivative products that can come out from such results will be nearer and nearer to a realistic situation. Which is the final aim of the model itself.

A still from the result page of a generic simulation is visible below, with many charts that will help in displaying every possible variable from the calculations.



Fuel Totals					
			gross	net (after incentives)	
Biomass CHP #1	299.592	tons	80530.3	34513	£
Biomass CHP #2	0	tons	0	0	£
Biomass CHP #3	0	tons	0	0	£
Biomass Totals	299.592	tons	80530.3	34513	£

System Totals			
			%
Gross Demand	1024418	kWh	100
Generation	1184172	kWh	100
Net Excess	245186	kWh	20.705
Net El Excess	148381	kWh	60.518
Net Th Excess	96805.1	kWh	39.482
Net Demand	16558.8	kWh	1.616

Figure 8: Energy Model Results Panel

All the charts will be shown, explained and discussed in the next sections of this report.

The Wind energy generation data has been provided by The Point and Sandwick Trust, which has access to the 10-minutes values from the Beinn Ghrideag windfarm, located near Stornoway, on the Isle of Lewis, in Scotland's Outer Hebrides.

In the next page it is possible to see the charts for the monthly totals, and the seasonal ones, for a single 3 MW wind turbine.

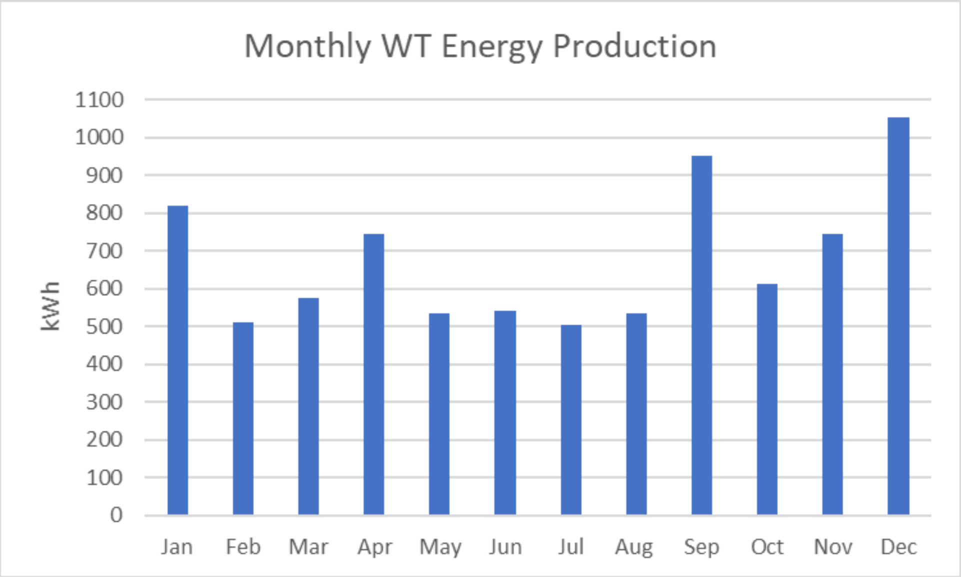


Figure 9: Monthly 3 MW Wind Turbine Energy Production

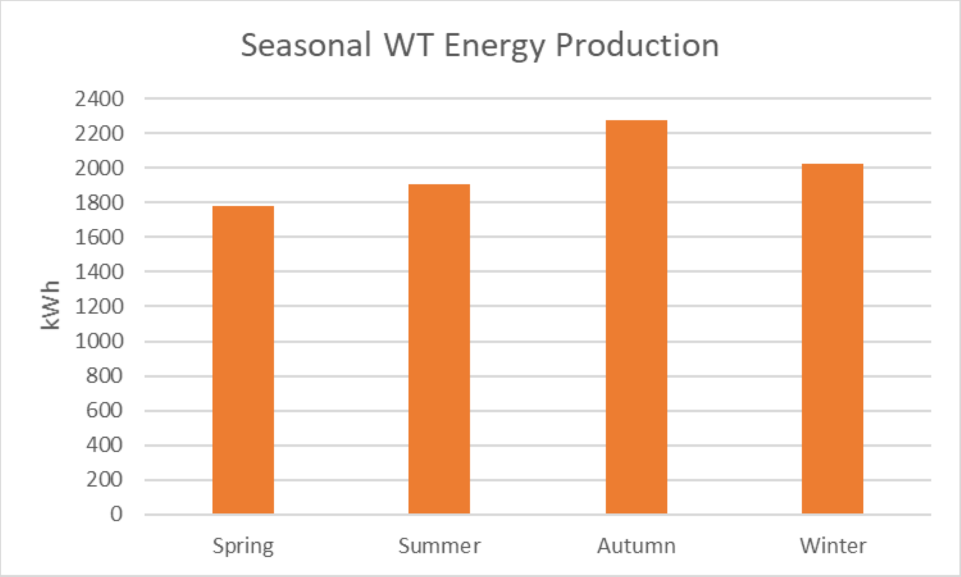


Figure 10: Seasonal 3 MW Wind Turbine Energy Production

The data shown above was filtered, validated and obtained producing an averaged comparison between the three 3 MW wind turbines on the windfarm location, to include the maximum possible number of datapoints available, and create as a result a wind/energy generation profile that would have been as realistic as possible.

The following chart, instead, shows the Active Power generated from the turbine, for the whole simulated year. It is easily possible to notice the many gaps due to low (or high) winds and maintenance periods, as well as the general variability of this renewable energy source.

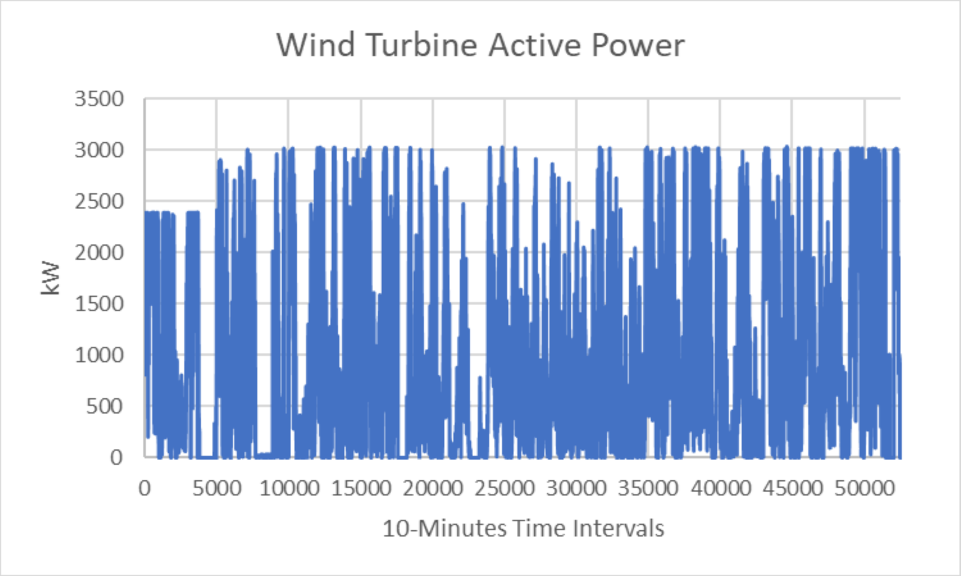


Figure 11: 10-Minutes Data Active Power for a 3 MW Wind Turbine

Another information that it is possible to derive from the extensive dataset is the average of the wind main direction, which for the location is 192 degrees, so just a bit beyond the pure South direction (180 degrees). This is in compliance with the climate of the area, which can experience even long periods of winds coming from the southernly or westerly quadrants.

The second renewable source generation curve, the Solar PV, instead, had to be modelled starting from the Solar Irradiance data, which was found and validated from online sources.

Converting it into feasible values, and then calculating the amount of generated energy from different sized Solar PV installations (from 1 kWp to 5 kWp) for the location of Stornoway, the following charts could be made.

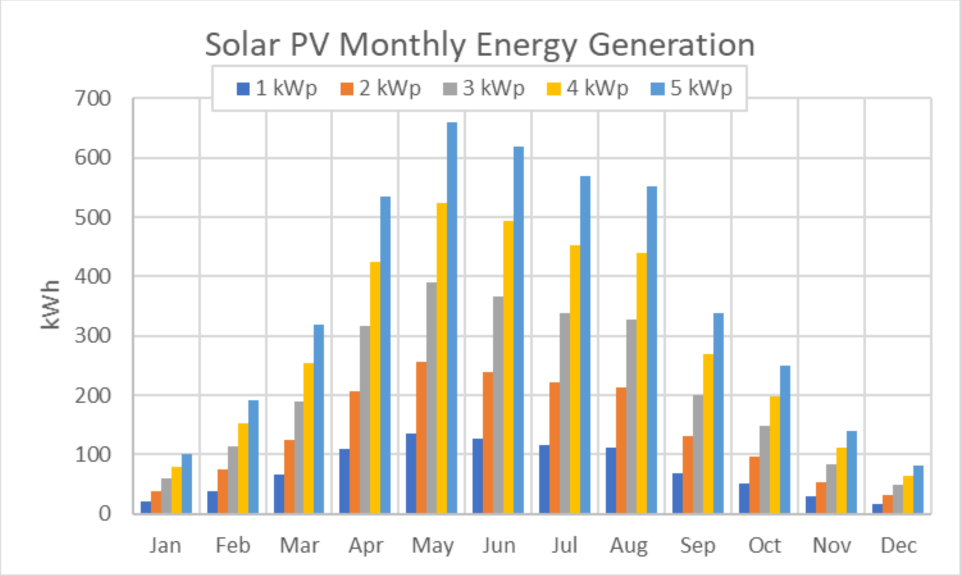


Figure 12: Different Size Solar PV Installations Monthly Energy Production

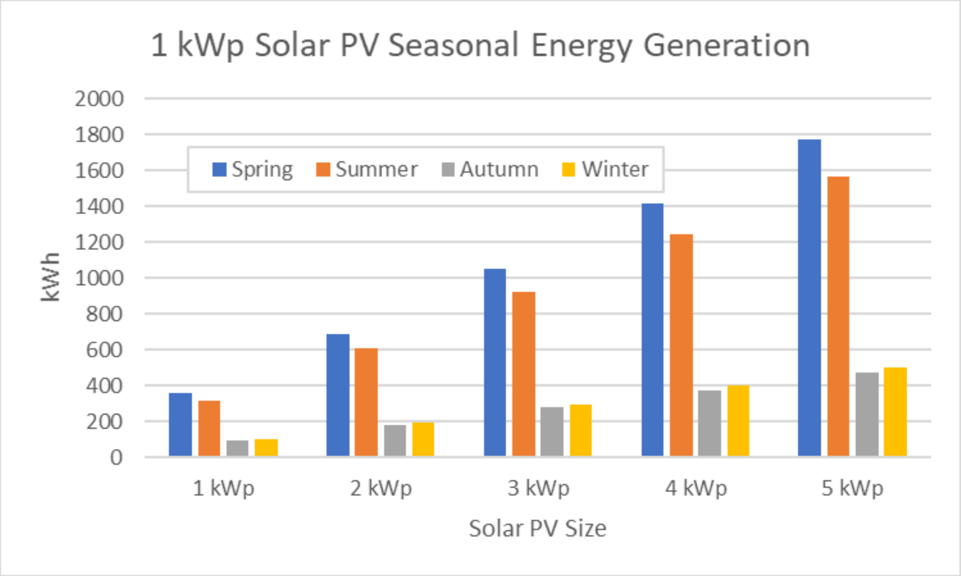


Figure 13: 1 kWp Solar PV Installation Seasonal Energy Generation

An interesting pattern appears, especially from the second one, where Spring is statistically (for the simulated year) the best season to obtain energy from the Sun (in particular, the month of May, compared to all the others), followed by Summer (with the longest days of the year, and the highest number of sunlight hours). Winter and Autumn, instead, prove how much cloudy weather and short days can impact energy production, while however -and this is an important factor to consider- continuing to provide a very useful minimum that otherwise could not be obtained.

In fact, the point is that, even if any day of the year is a cloudy one, there is still some energy that will be generated. This fact can (and will) prove useful in the general modelling view, since it can provide a baseline for minimum generation that can help the whole grid (if paired with a suitably sized Energy Storage) in managing its supply in a more efficient way.

The chart below shows this concept in a practical visualization, for a 3 kWp Solar PV installation.

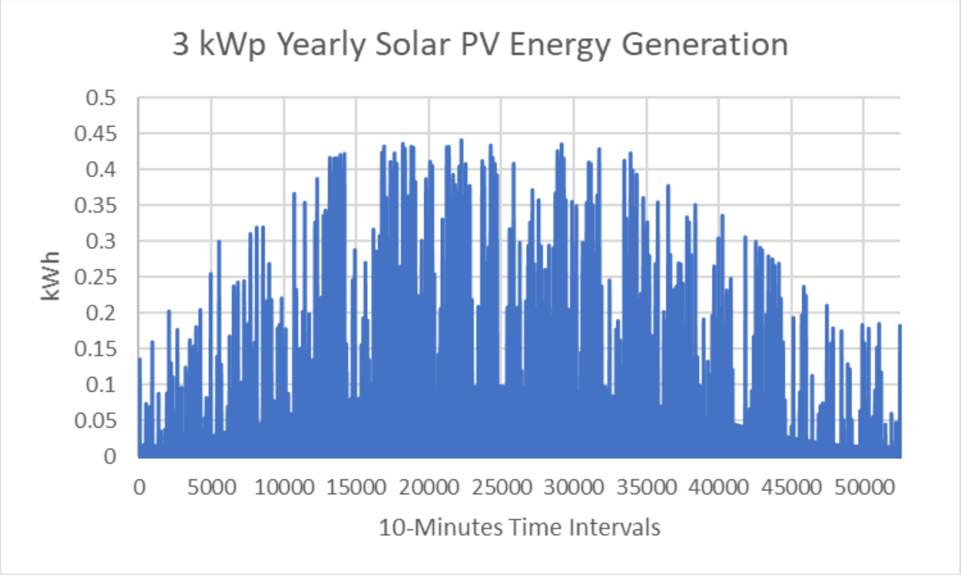


Figure 14: 3 kWp Solar PV Installation 10-Minutes Intervals Energy Production

Crossing over, from the Generation section to the Demand section of the model, the household load was more difficult and complex to obtain, because it had to take into account all the different appliances and energy usages for a normal average family.

A point that is worth mentioning is that even in the case of having less (or more) family members, less (or more) children, less (or more) working adults, this does not impact the general model performance, because the simulation can be adapted to any kind of situation in any kind of community/village/city.

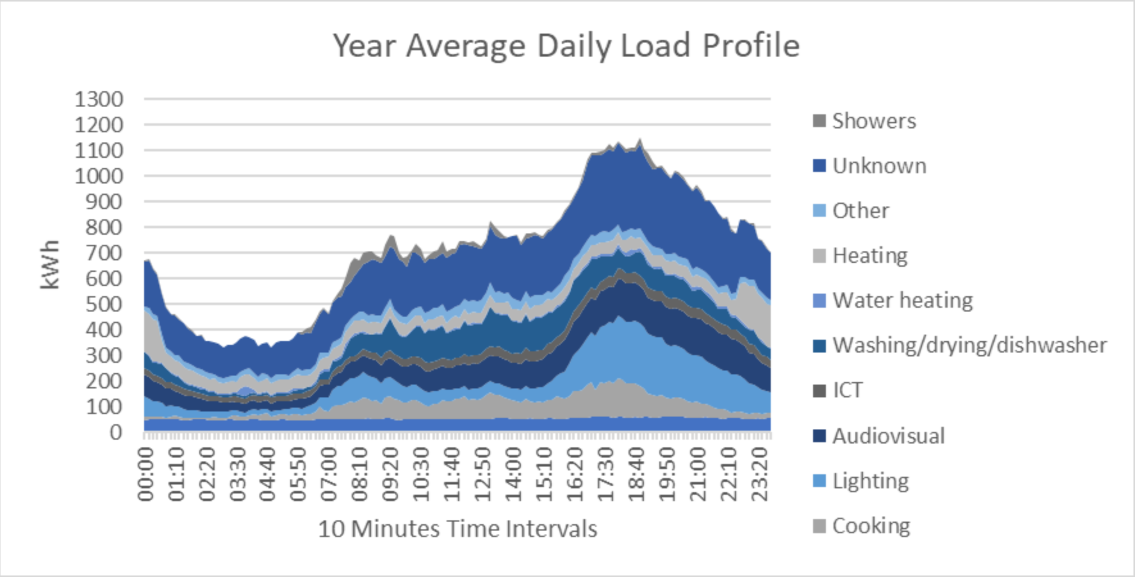


Figure 15: Typical Household Yearly Average Daily Load Profile Breakdown

The chart above shows the yearly average daily load for a single average household, with every shade displaying a single (or a sum) of different appliances inside the dwelling.

The evening peak demand period appears clearly, as well as the night low demand interval. This simulation has been extended from a general yearly average to a monthly/daily/hourly/ten-minutes time interval, to match the energy generation sources described before in this section, obtaining thus the following detailed charts.

They show with their three-dimensional format, at a glance, the evolution of the demand along every ten-minute interval in a whole year (thus using more than 50000 datapoints). Locating the winter peaks and higher demand (on the sides, for the first graph, in the middle for the second) is immediate, as well as recognizing the lower summer demand (the ‘valley’ in the first graph, the sides in the second one).

These are very helpful in planning for future improvements to the energy grid, since households are the primary concern in this new energy distribution strategy that is being planned. Electricity load profiles in residential areas are expected to change in the coming decades, due to new available energy sources and due to the rise of the usage of EV (Electric Vehicles) and Heat Pumps. The model can, and if needed, will be able to be upgraded and adapted to suit any new future requirements.

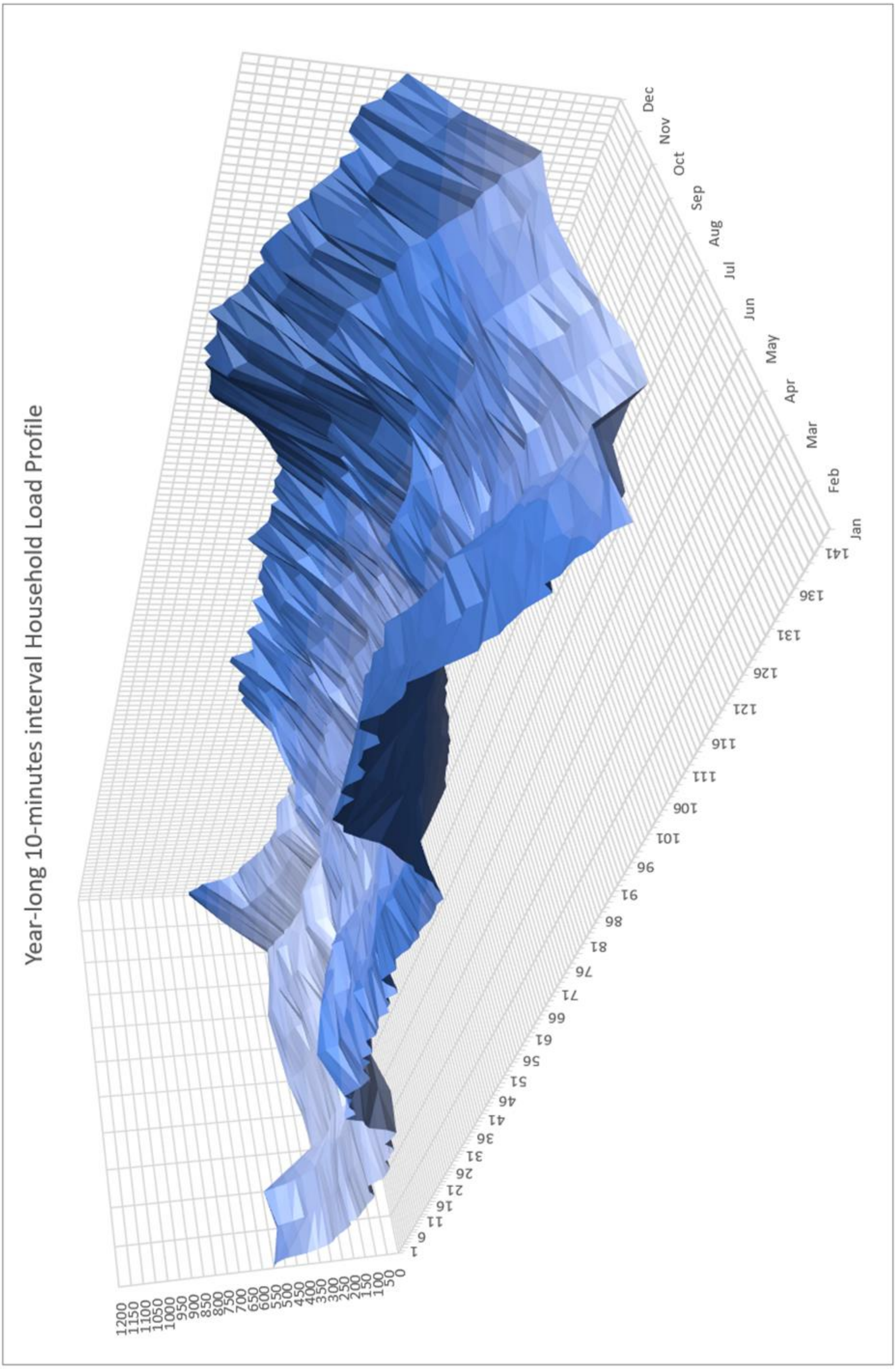


Figure 16: Typical Household 3D Yearly Load Profile Visualization (Summer Centred)

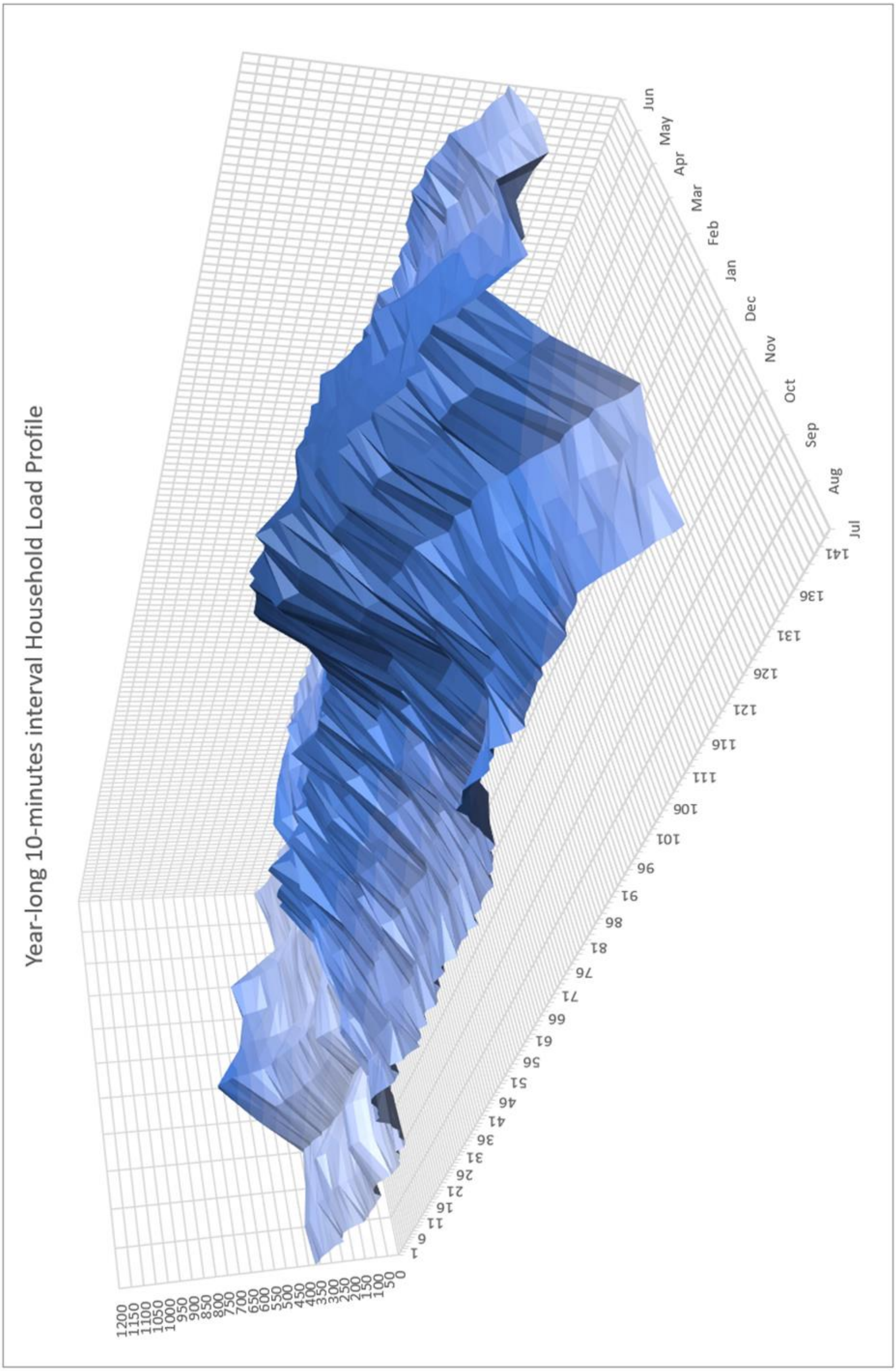
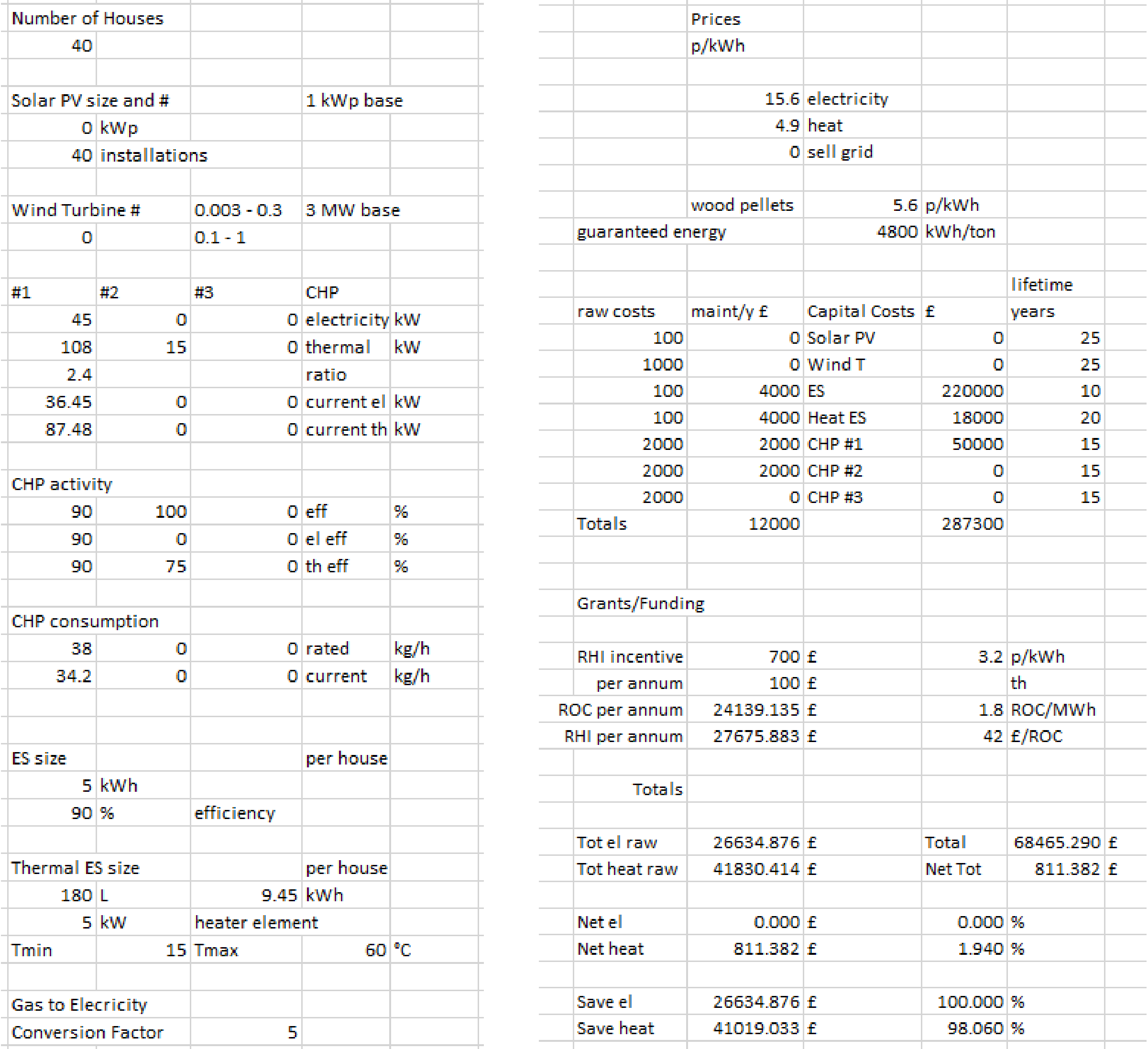


Figure 17: Typical Household 3D Yearly Load Profile Visualization (Winter Centred)

All the previous datapoints (Solar PV, Wind Energy, Household consumption) converge then into the final Energy Profiles model. This new worksheet is complex, possibly intricate, but it generates a detailed energy and economic simulation based on many different variables (50+).

The main ones are:

- Number of Households;
- Number and Size of eventual Solar PV installations;
- Number and Size of eventual Wind Turbines;
- Up to three completely customizable CHP installations (electricity to heat ratio, CHP efficiency, CHP usage percentage);
- Both Electrical and Thermal Energy Storage;
- Heat to Electricity ratio;
- Revenue/Cost/Profit calculations in the Economic panel;
- ROI estimation with possibility of grants/funding already included in the formulae.



Number of Houses				
40				
Solar PV size and #			1 kWp base	
0	kWp			
40	installations			
Wind Turbine #		0.003 - 0.3	3 MW base	
0		0.1 - 1		
#1	#2	#3	CHP	
45	0	0	electricity	kW
108	15	0	thermal	kW
2.4			ratio	
36.45	0	0	current el	kW
87.48	0	0	current th	kW
CHP activity				
90	100	0	eff	%
90	0	0	el eff	%
90	75	0	th eff	%
CHP consumption				
38	0	0	rated	kg/h
34.2	0	0	current	kg/h
ES size			per house	
5	kWh			
90	%	efficiency		
Thermal ES size			per house	
180	L	9.45	kWh	
5	kW	heater element		
Tmin	15	Tmax	60	°C
Gas to Elecricity				
Conversion Factor		5		

	Prices				
	p/kWh				
	15.6	electricity			
	4.9	heat			
	0	sell grid			
	wood pellets		5.6	p/kWh	
guaranteed energy			4800	kWh/ton	
				lifetime	
raw costs	maint/y £	Capital Costs	£	years	
100	0	Solar PV	0	25	
1000	0	Wind T	0	25	
100	4000	ES	220000	10	
100	4000	Heat ES	18000	20	
2000	2000	CHP #1	50000	15	
2000	2000	CHP #2	0	15	
2000	0	CHP #3	0	15	
Totals	12000		287300		
Grants/Funding					
RHI incentive	700	£	3.2	p/kWh	
per annum	100	£		th	
ROC per annum	24139.135	£	1.8	ROC/MWh	
RHI per annum	27675.883	£	42	£/ROC	
Totals					
Tot el raw	26634.876	£	Total	68465.290	£
Tot heat raw	41830.414	£	Net Tot	811.382	£
Net el	0.000	£	0.000	%	
Net heat	811.382	£	1.940	%	
Save el	26634.876	£	100.000	%	
Save heat	41019.033	£	98.060	%	

Figure 18: Simulation Model Control Panels

In the schematics visible in the last page it is possible to see the full extension of the variables and the results which are involved in and that can be obtained from the Energy Model Calculations. They are also summarized, for a better representation, in the following table:

Energy Model Variables and Results	
Number of Houses	Thermal Energy Storage Min Water Temp
Number of Solar PV Installations	Thermal Energy Storage Max Water Temp
Size of Solar PV Installations	Household Gas to Electricity Factor
Number/Size of Wind Turbines	Electricity Price
CHP #1 Electricity Output	Gas/Oil/etc. (Thermal Heating) Price
CHP #1 Thermal Output	Possibility of Selling Back to the Grid
CHP #1 Th/El Ratio	Wood Pellets (Biomass) Price
CHP #1 General Efficiency	Wood Pellets Guaranteed Energy
CHP #1 Electrical Efficiency	Capital Costs
CHP #1 Thermal Efficiency	Raw Maintenance Costs
CHP #1 Biomass Consumption	Lifetime of System Elements
CHP #2 Electricity Output	Funding: RHI Incentive
CHP #2 Thermal Output	Funding: ROC per annum
CHP #2 Th/El Ratio	Possibility of Boiler Installations
CHP #2 General Efficiency	Possibility of Thermal Solar Installations
CHP #2 Electrical Efficiency	Net Electricity Demand
CHP #2 Thermal Efficiency	Net Thermal Demand
CHP #2 Biomass Consumption	ROI Calculations
CHP #3 Electricity Output	Energy Future Forecasts
CHP #3 Thermal Output	Community System Revenue
CHP #3 Th/El Ratio	Community System Cost
CHP #3 General Efficiency	Community System Profit
CHP #3 Electrical Efficiency	Biomass Total Costs
CHP #3 Thermal Efficiency	Total Profit per Household
CHP #3 Biomass Consumption	Average Cost vs. Market Price Values
Electrical Energy Storage Size	Electricity Savings compared to Normal
Electrical Energy Storage Efficiency	Thermal Savings compared to Normal
Thermal Energy Storage Size	Net Electricity Excess Production
Thermal Energy Storage Heater Element Power	Net Thermal Excess Production

Table 1: Energy Model Variables and Results List

This means that multiple and different situations can be simulated at the user's leisure, for example alternating between different CHP installations, or differentiating between analysing the output of a certan number of Solar PV connections and the influence of a small wind turbine in the general energy distribution grid. Or even adding some boilers into the equation, and seeing how the increase of stored water temperature affects all the calculations.

Furthermore, with the ability to select the different sizes of electrical and thermal Energy Storages (ES), it is possible to replicate how much the system would be self-sufficient in case of any kind of different emergency situation which would cause a disconnection event from the main grid. Since the sizing of the ES can be adapted, the entire system can be optimized to suit any kind of requirement.

After keying in the Solar PV energy generation profile, the Wind Turbine(s) energy generation profile, and the demand from the households (which have to be as complete as possible to obtain realistic results), it is possible to proceed in modifying the variables in the control panels. A necessary reminder is that the CHP units are not capable of variable production, and they will generate the same fixed amount throughout all their operating time.

From this, the Energy Model will do everything by itself, it will run a new simulation each time a variable is changed, and it will provide its programmed outcomes, charts and data.

For a practical example, the next section will show the model results after it has been run using the data from a real neighborood in the Eye Peninsula, near Stornoway.

The First Simulation

The small housing scheme of Seaview, near Knock, Point, in the Eye Peninsula of the Isle of Lewis is only 7 km (4.5 mi) west of Stornoway, and it is composed of 44 habitative units, all in a semi-detached configurations (therefore having 22 buildings) in a compact formation.

This was an ideal representation of a neighborood where a CHP installation could be implemented, tue to the closeness of the different households, and its almost 'isolated' location along the A866 road from Stornoway to Portnaguran.

Figure 19: Seaview Small Housing Scheme (Google Earth 2019)

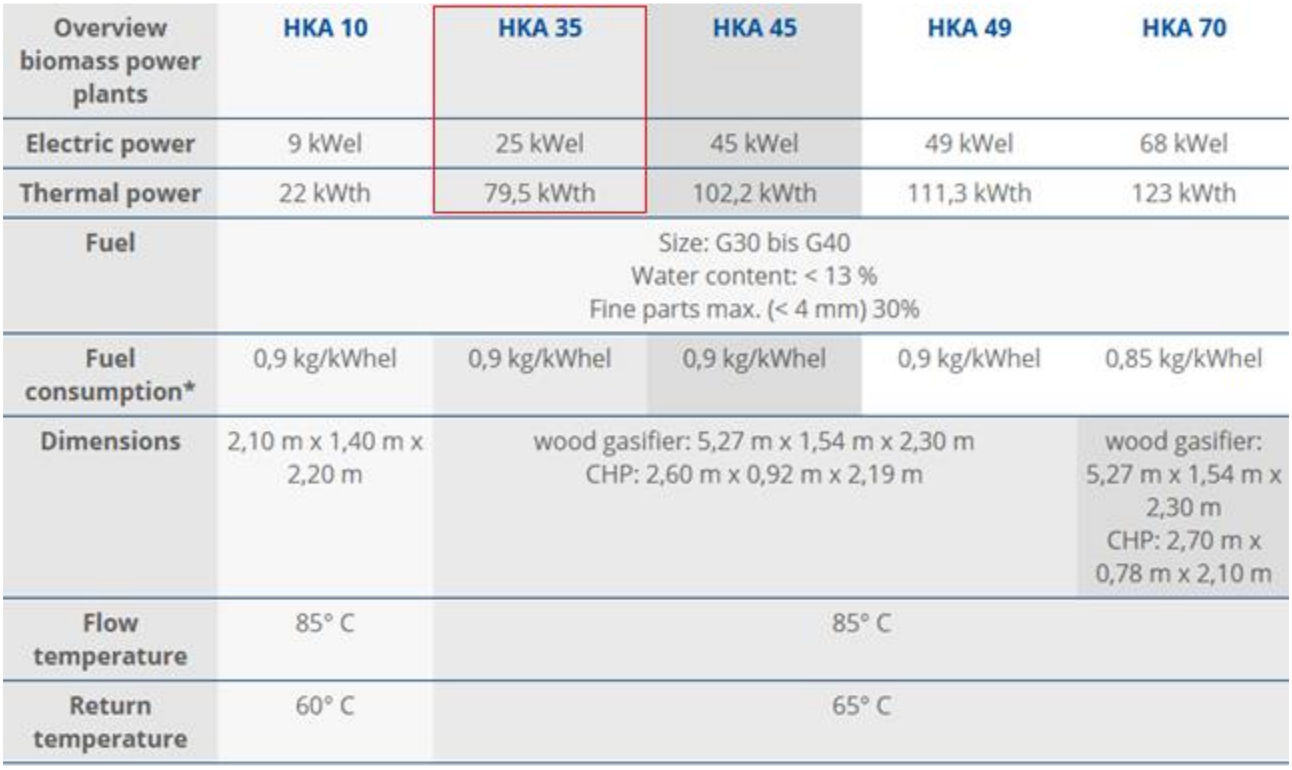
The internal structure of the dwellings can be summarized with this list:

- Kitchen/Diner;
- Lounge;
- Rear Vestibule;
- Hallway;
- Three Bedrooms.

They also possess double glazing uPVC on windows and exterior doors and present a full electrical consumption, heating included. For this simulation, however, it has been assumed not so: this has been done to be able to replicate the scenario of older or even more isolated households, where the heating came (or still comes) from fossil fuels, like oil or gas. The model is however capable to analyse and compute the other (full electrical) option too.

Thus, in this example situation, the community has 44 households, with an Electricity to Heating ration of 5 (to simulate older dwellings). The setup configuration continues into adding a 3 kWp Solar PV installation for each dwelling pair, totalling 22 installations. No wind turbines are actually put into the model at this stage.

For the CHP section, a single *Spanner Re² GmbH* HKA 35 has been selected as a first choice, to see how much the system is still missing (or exceeding) with the usage of this installation. Its technical data are shown in the following image:



Overview biomass power plants	HKA 10	HKA 35	HKA 45	HKA 49	HKA 70
Electric power	9 kWel	25 kWel	45 kWel	49 kWel	68 kWel
Thermal power	22 kWth	79,5 kWth	102,2 kWth	111,3 kWth	123 kWth
Fuel	Size: G30 bis G40 Water content: < 13 % Fine parts max. (< 4 mm) 30%				
Fuel consumption*	0,9 kg/kWhel	0,9 kg/kWhel	0,9 kg/kWhel	0,9 kg/kWhel	0,85 kg/kWhel
Dimensions	2,10 m x 1,40 m x 2,20 m	wood gasifier: 5,27 m x 1,54 m x 2,30 m CHP: 2,60 m x 0,92 m x 2,19 m			wood gasifier: 5,27 m x 1,54 m x 2,30 m CHP: 2,70 m x 0,78 m x 2,10 m
Flow temperature	85° C	85° C			
Return temperature	60° C	65° C			

Figure 20: Spanner Re GmbH Biomass CHP Datasheet (Holz-Kraft 2019)

Also, there are both thermal and electrical energy storages, (the first activating only when the second is fully charged, up to the batteries efficiency, but discharging every time there is the need), with a 5 kWh electrical battery and a 250L water tank with double 3 kW electric heater element per dwelling. Minimum water temperature inside the tanks is set at 15°C, while the maximum is at 60°C.

Energy Storage, such as batteries or hot water tanks have proven to be very useful in lowering the peaks of electricity/heating demands, or in general, in reducing the grid demand. It will be made clear by a chart confrontation in the following pages, with, however, the downside of the costs.

Adding larger amounts of ES can definitely help, but it increases the total capital costs (and so, the eventual final ROI) of the whole system much more than any other element in the system itself (Solar PV installations, CHP installation, etc.).

This point will be expanded in the conclusions of this report, since it is an issue that deserves its own proper space.

The results of this first simulation are shown from this page on, with the appropriate commentary.

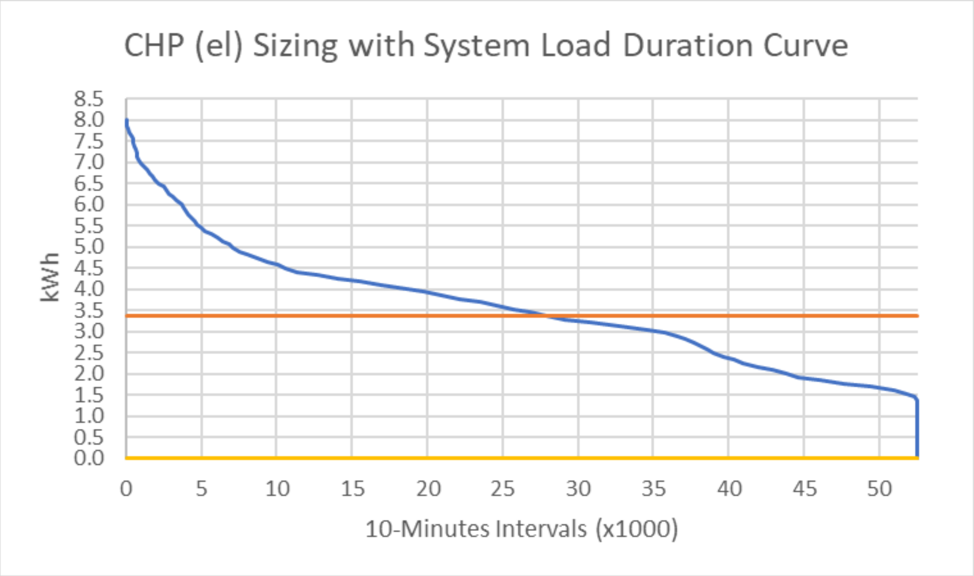


Figure 21: System Load Duration Curve (Electrical) for CHP Sizing (First Scenario)

This first graph shows the System Load Duration Curve (in blue) for an entire year, while the orange line is showing how much energy the CHP installation is producing. Immediately, it is possible to recognize that around a tenth of this production is actually excess energy, which can be used to charge up the Energy Storages, or in other different ways, to avoid it going to waste.

A chapter of this report will be dedicated in a further exposition of different possible methods which are viable to spend the Excess Energy produced by the system.

This chart is very useful in correctly sizing and optimizing a CHP fitting for the community, showing for how much time there will be a certain load on the electrical grid. A similar graph can be obtained for the thermal side of the system.

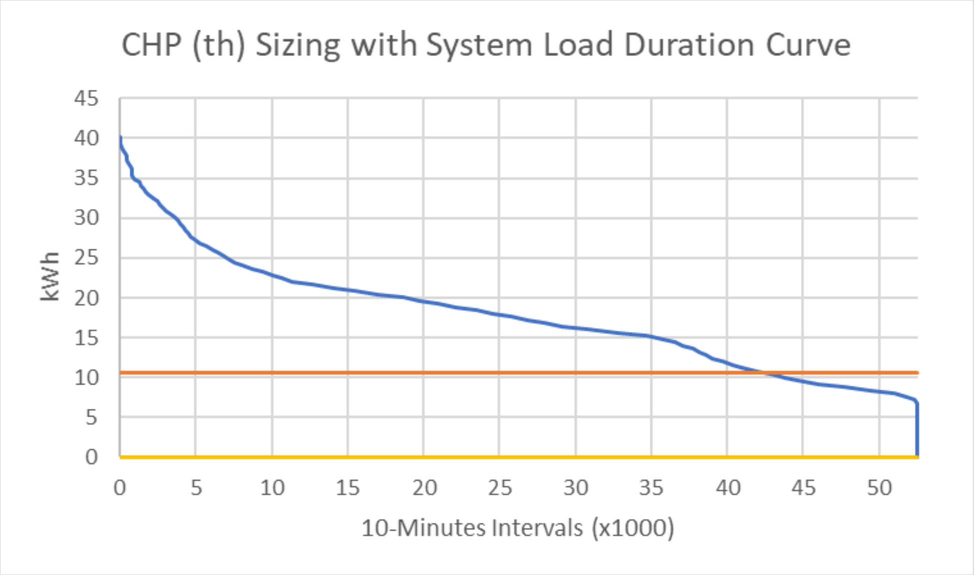


Figure 22: System Load Duration Curve (Thermal) for CHP Sizing (First Scenario)

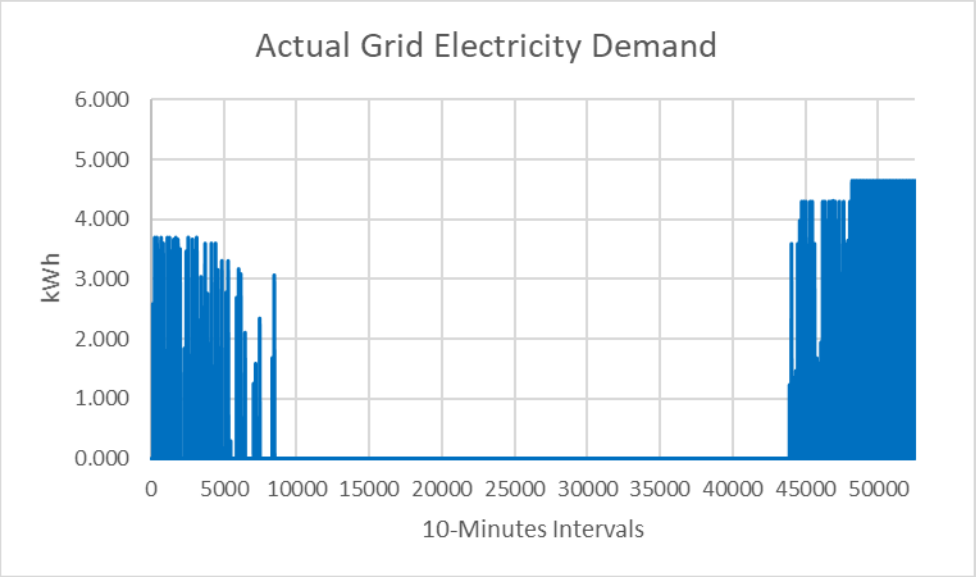


Figure 23: System Actual Grid Electricity Demand (First Scenario)

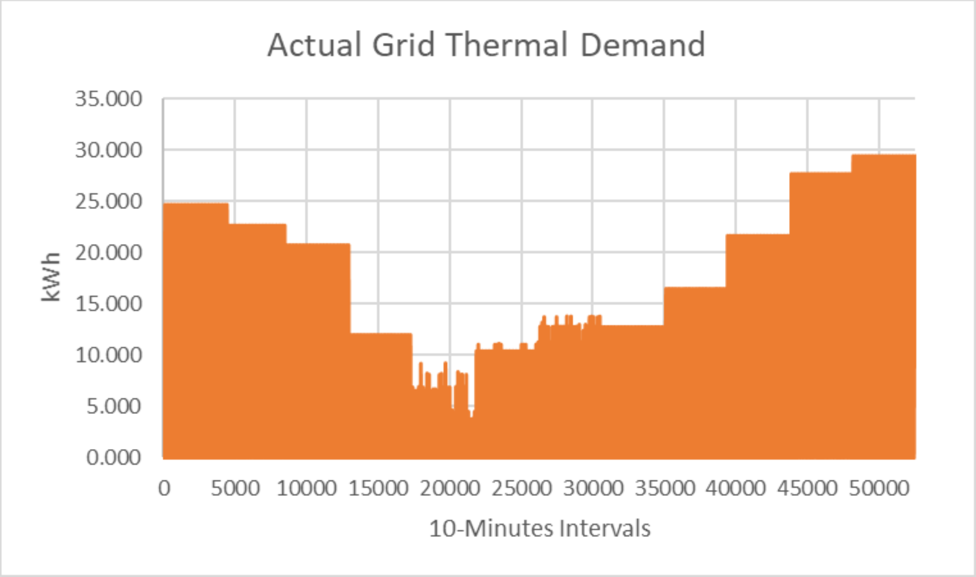


Figure 24: System Actual Grid Heating Demand (First Scenario)

These two charts show, instead, how much the system still needs from the grid itself, giving the user an immediate outlook on what is still needed. As it can be easily surmised, only the peak demands during the Winter season (which is, temporally, at the opposite extremes of the chart) are still a grid requirement, while all the rest of the year is covered with the introduction of the CHP installation.

This is a valid truth for the electricity portion of the system, but it is all the opposite for the heating (thermal) part. Having a CHP with an electricity-to-heat ratio of 3.16 benefits the situation, but the produced heat is not sufficient enough to supply the 44 dwellings of the neighborood.

Already this fast display of precise data shows the potential of the Energy Model itself, giving the user an immediate and at-a-glance situational overview over the simulated system.

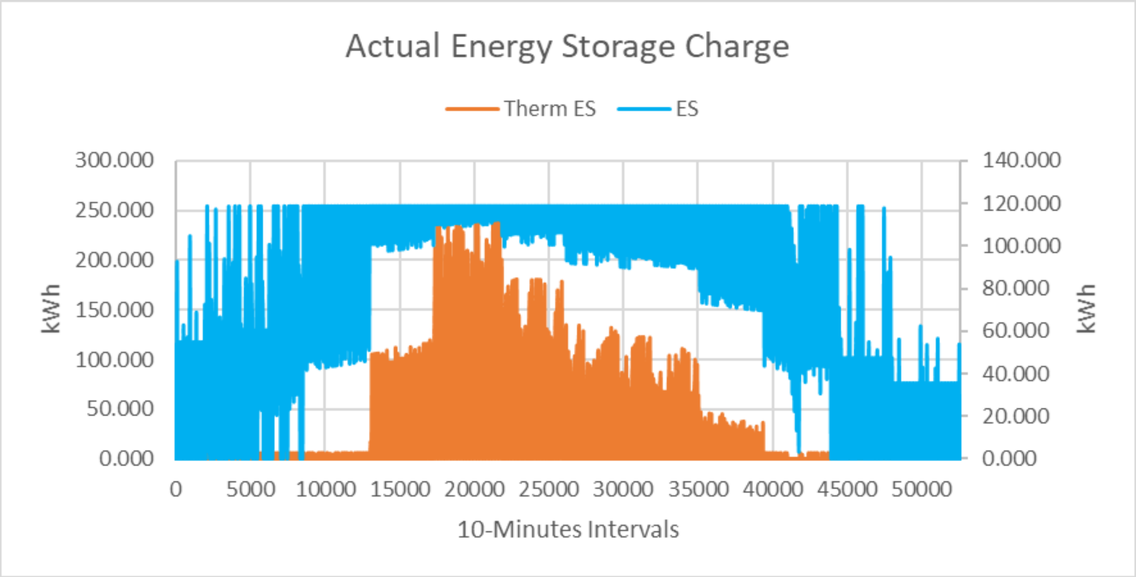


Figure 25: System Actual Energy Storages Charge (First Scenario)

Thanks to the introduction of both Energy Storages which, it can be seen at least for the electrical one (azure graph), are mostly charged up for the duration of summertime, and only start to display normal charging/discharging behaviour during the other three seasons -as it can be expected-, the system is able to regulate itself autonomously, covering a large portion of the year without the need of the classic energy distribution grid.

It is possible to see here the continuing consequences of not producing enough heating, since the Thermal Energy Storage is never filled, and helps in a less pronounced way compared to its electrical counterpart.

The final element for this first simulation gives the user the general view on the entire system.

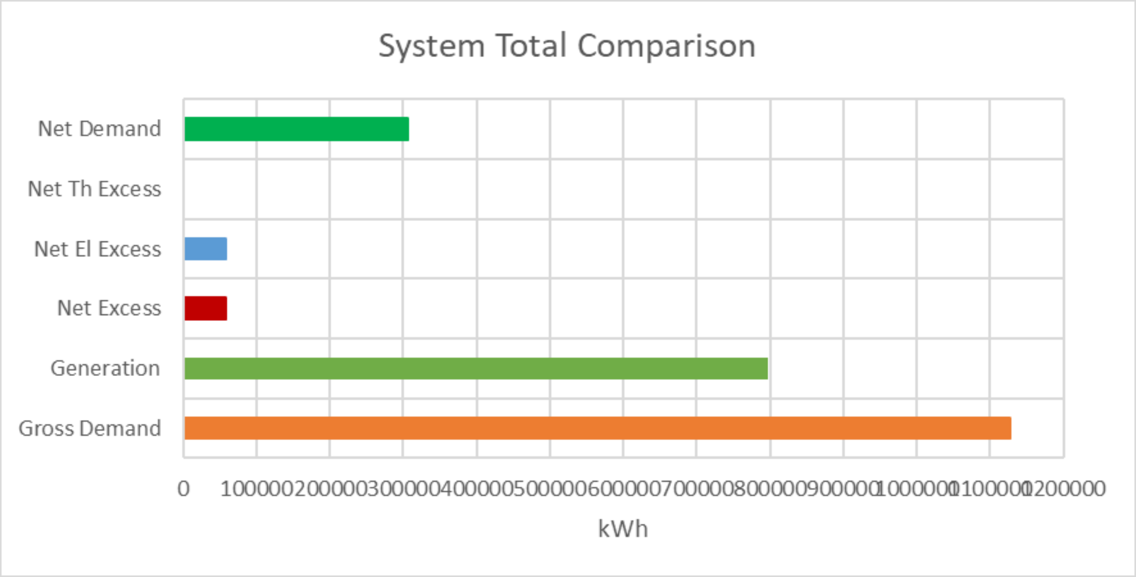


Figure 26: System Total Comparison between Excess Energy, Net and Gross Demand (First Scenario)

It is possible to see that the Net Demand (which is the actual demand compared to the original one of the system, without any new installation connected to it) has dropped down to a third of what was originally required (orange bar), with very low excess energy production around ten percent of the generated energy. This excess can also be divided between Electrical and Thermal (Heating), to give more reference figures.

Going on to the economic aspects of the simulation, the resulting ROI is just short of 28 years, even considering the RHI incentive and the ROC certificates bonuses, and this total is already a not acceptable one, since it extends beyond the operative life of the components of the system, first amongst all the electrical batteries of the Energy Storage.

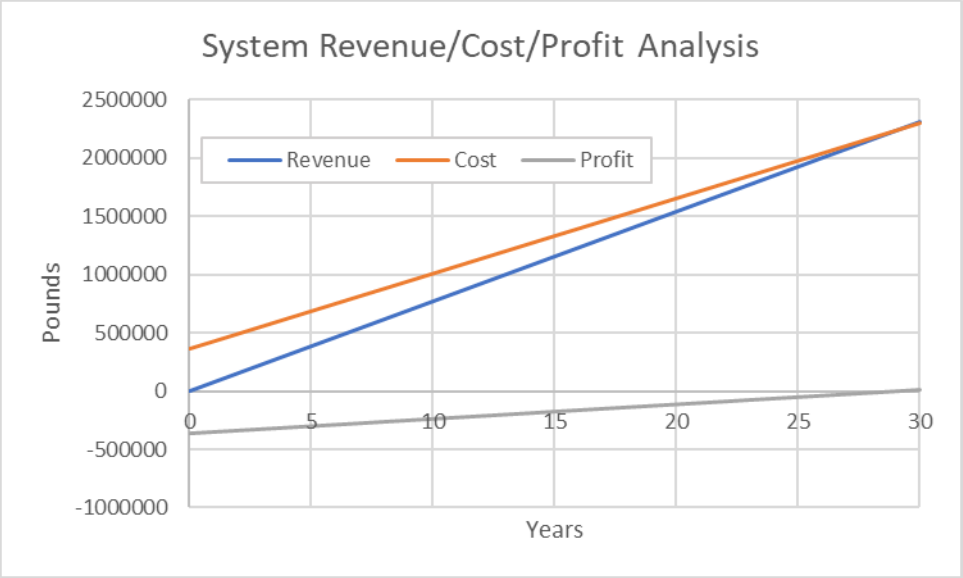


Figure 27: System Economic Analysis (First Scenario)

It is clear to see that this could not be a solution that a user could have been looking for because, while it almost reduces the electrical demand to a minimum, the heating demand is still almost all there. The model makes it possible then to go back to the beginning, choose a different setup and redo the simulation from the start.

However, as it was possible to see, the introduction of the Solar PV installations, while adding to the capital costs, is useful to keep the system feed with electricity even when the weather is not favourable. This was done to replicate what is already existing in many little communities, where adding solar panels to a dwelling has almost become a constant.

The introduction of a new energy source, and more importantly, of a continuous one that will produce electricity for as long as the sun is in the sky, even with low irradiance due to clouds, is clearly a positive one, as can be seen in the simulation results.

The Second Simulation

Two questions come to mind now, before a second scenario reproduction:

- Is the Energy Storage really necessary, in the light of adding much capital cost to the system, which in consequence extends the ROI significantly (and possibly beyond the Service Life of the equipment itself)?
- If a suitable CHP is found and chosen, which has high enough electrical and thermal output, are the Solar PV installations still useful or they can be discarded?

The answer to the first question is both a positive and a negative one. Their positive influence is shown in the following two charts:

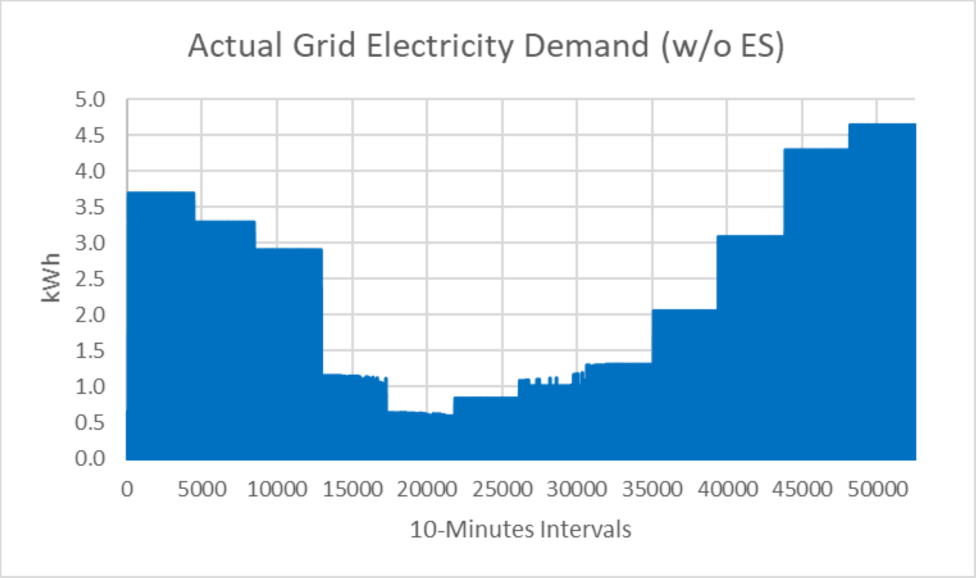


Figure 28: Grid Electricity Demand without Energy Storage

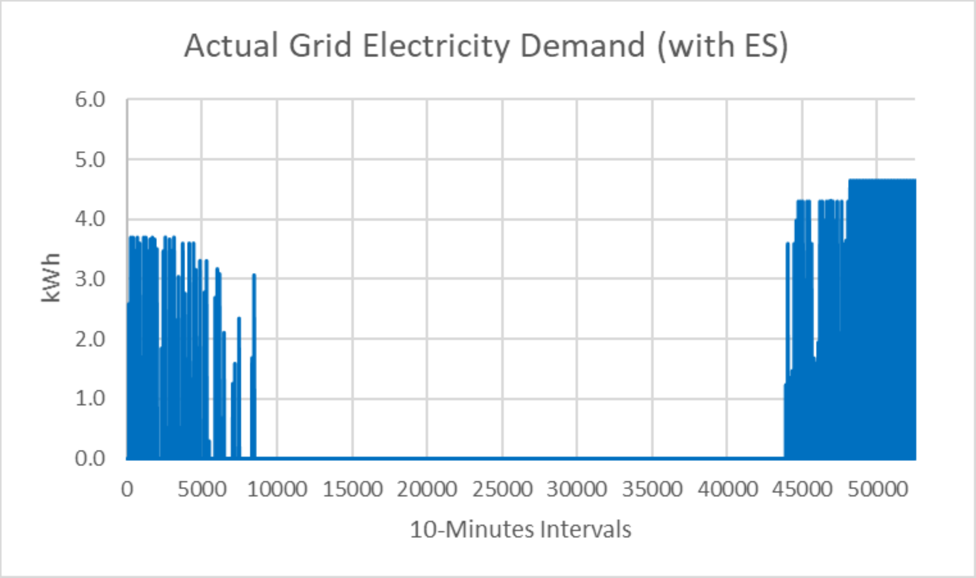


Figure 29: Grid Electricity Demand with Energy Storage

It is very obvious that the introduction of even a simple 3 kWh electrical battery per dwelling drastically changes the whole grid demand panorama, with the system being able to store the excess produced energy and being able to release it when needed.

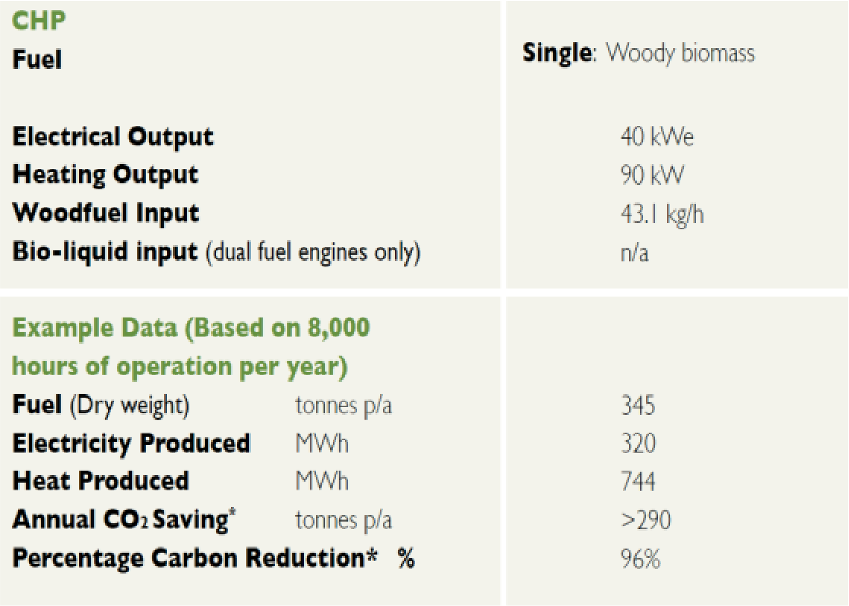
The only time of the year when the support of the Energy Storage is still not enough is, predictably, during the Winter. In this case not even increasing it to very large capacities (not caring, for a moment, for their costs) manages to solve the problem.

This brings the conclusion that adding Energy Storage is very efficient, but at the same time, the same efficiency continues to diminish sharply after a certain point, before it becomes virtually useless to add something more.

On to the costs portion of the question, unfortunately as of now the pricing of Energy Storages (electrical ones) is still around 1000 to 1200 pounds per installed kWh, so they need a substantial investment to be made available for each dwelling (or even acquiring a bigger one for the whole settlement). This will represent the main concern in which most of the funds that will be dedicated to any similar project will have to be addressed.

The second question will be instead answered by the results of this second simulation. The system data is again, the following: in this second example situation, the community still has 44 households, with an Electricity to Heating ration of 5 (again, to simulate older dwellings). The setup configuration continues into adding a 3 kWp Solar PV installation for each dwelling pair, totalling 22 installations. No wind turbines are actually put into the model at this stage.

For the CHP section, a single Arbor ElectroGen 40 has been selected this time, to see how much the system is still missing (or exceeding) with the usage of this installation. Its technical data are shown in the following image:



CHP		
Fuel		**Single**: Woody biomass
Electrical Output		40 kWe
Heating Output		90 kW
Woodfuel Input		43.1 kg/h
Bio-liquid input (dual fuel engines only)		n/a
Example Data (Based on 8,000 hours of operation per year)		
Fuel (Dry weight)	tonnes p/a	345
Electricity Produced	MWh	320
Heat Produced	MWh	744
Annual CO_2 Saving*	tonnes p/a	>290
Percentage Carbon Reduction*	%	96%

Figure 30: Arbor ElectroGen 40 Technical Sheet (arborhp 2019)

There are both thermal and electrical energy storages, (the first activating only when the second is fully charged, up to the batteries efficiency, but discharging every time there is the need), with a 3 kWh electrical battery and a 250 litres water tank with double 3 kW electric heater element per dwelling. Minimum water temperature inside the tanks is set at 15°C, while the maximum is at 60°C.

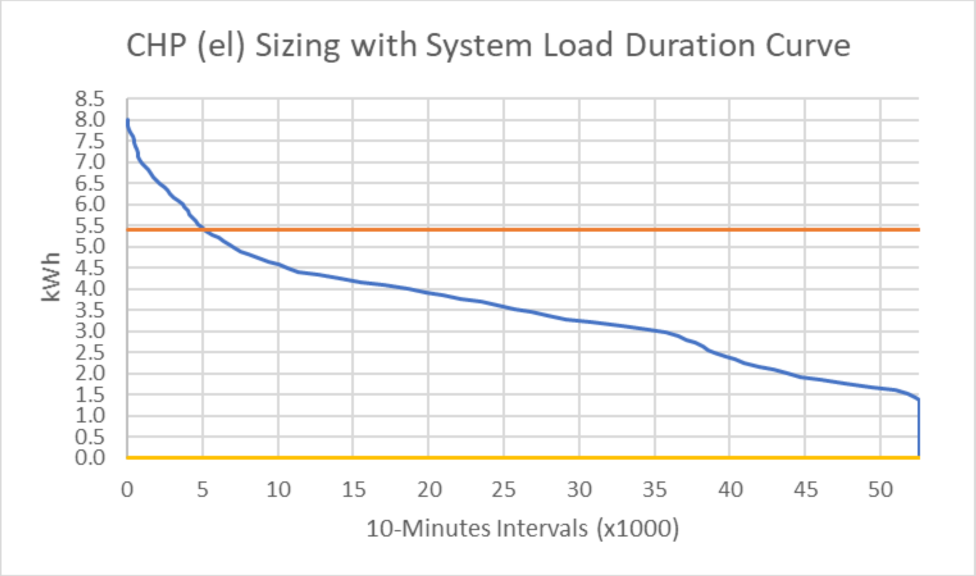


Figure 31: System Load Duration Curve (Electrical) for CHP Sizing (Second Scenario)

Once more, the first graph shows the System Load Duration Curve (in blue) for an entire year, while the orange line is showing how much energy the CHP installation is producing. It is possible to see that, this time, the electricity production excess is much more compared to the amount of the first one, which can seem counterproductive since in appearance, this would be wasted energy.

But, with the introduction of the Energy Storage concept, in fact, much less of that amount will be effectively wasted (around 15% of the total production). A similar graph can be obtained for the thermal side of the system.

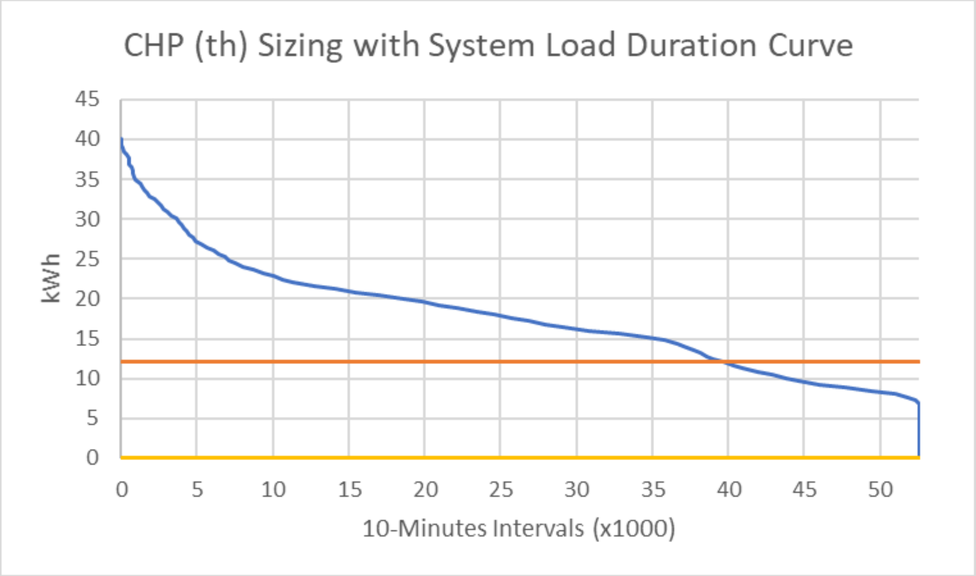


Figure 32: System Load Duration Curve (Thermal) for CHP Sizing (Second Scenario)

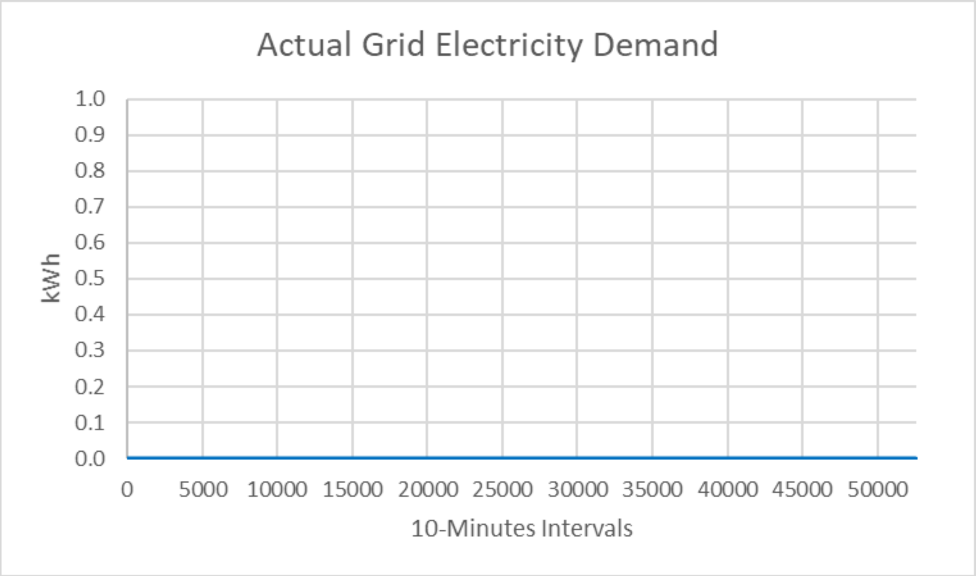


Figure 33: System Actual Grid Electricity Demand (Second Scenario)

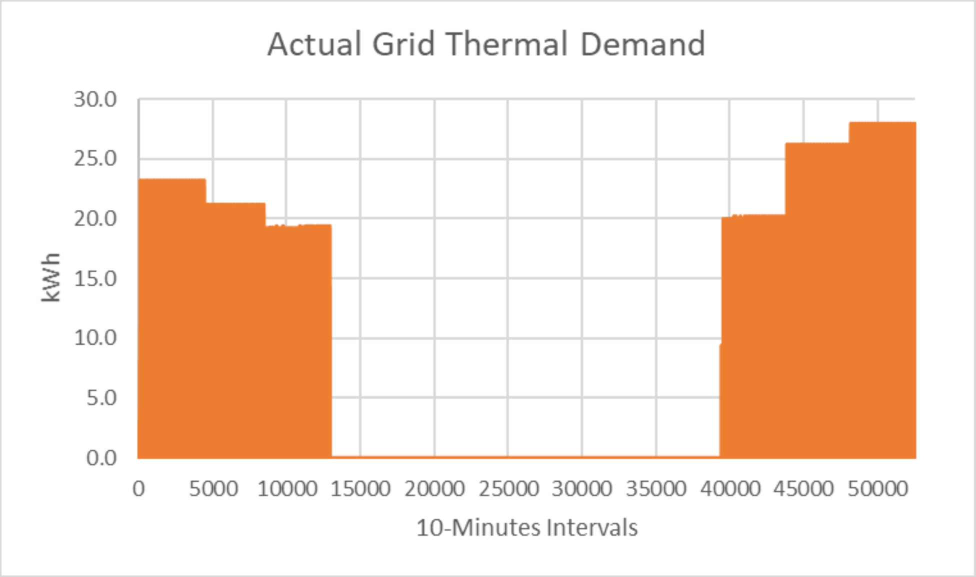


Figure 34: System Actual Grid Heating Demand (Second Scenario)

These two charts show, instead, how much the system still needs from the grid itself, giving the user an immediate outlook on what is still needed.

It is already possible to see the difference compared to the first run. Effectively, the small 44-households community has become independent (electrically speaking) from the grid, with the CHP/Solar PV/Energy Storage trio working optimally.

This is a valid truth for the electricity portion of the system, but the heating (thermal) part still needs something more to achieve the same result.

This fast display of precise data again shows the potential of the Energy Model itself, giving the user an immediate and at-a-glance situational overview of the whole simulated system.

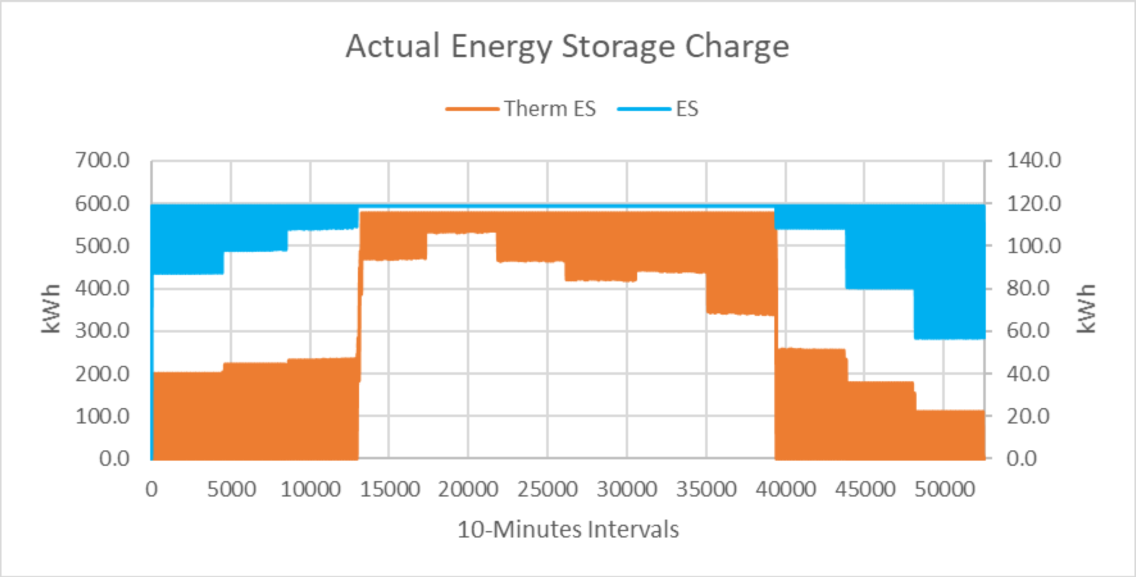


Figure 35: System Actual Energy Storages Charge (Second Scenario)

Even if the electrical Energy Storage is smaller than the one used before (current 3 kWh vs previous 5 kWh) it is filled for every timestamp of the model (except, obviously, the initial charging), while the thermal storage manages to supply everything that is needed during the warmer days of the year, leaving the early Spring/late Autumn/Winter peaks still to be addressed.

However, like the first simulation, both of the storages display nominal charging/discharging behaviour, proving again that the system is able to regulate itself autonomously, covering a large portion of the year without the need of the classic energy distribution grid.

The final element for this second simulation is again the general view on the entire system.

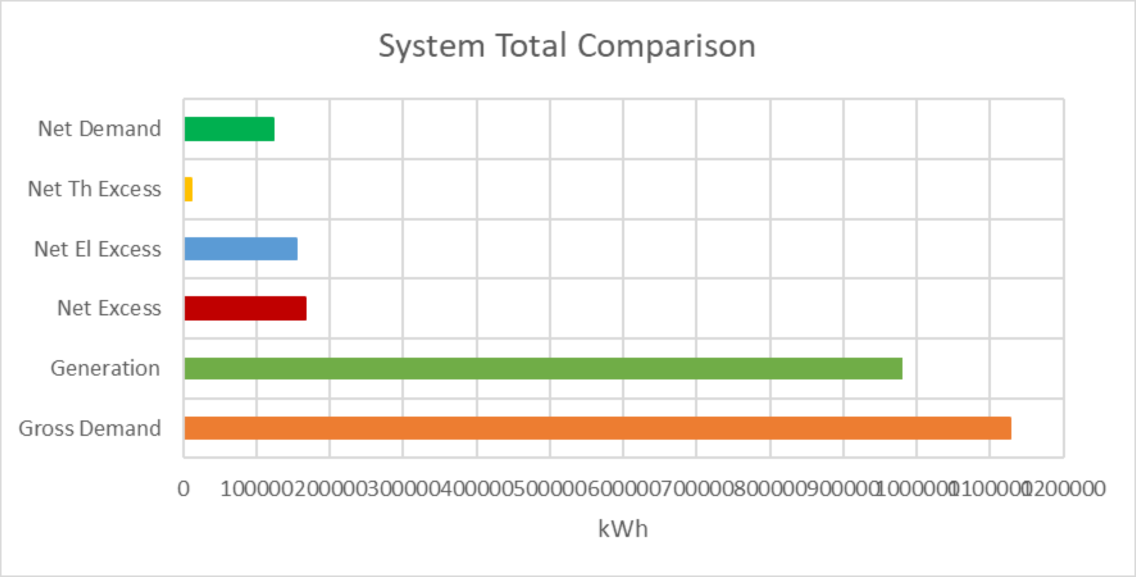


Figure 36: System Total Comparison between Excess Energy, Net and Gross Demand (Second Scenario)

Compared to before it is easy to notice the further decrease of Net Demand (both electrical and thermal) which now reaches only the 10% of what was needed before from the Grid. On the opposite side, the Net Excess is obviously higher, since the system is producing more.

More specifically on the side of electricity against heating (92% vs 8%), it is possible to add other electrical boilers to supply the households with the missing warm water needed for the washing/heating the living spaces. In this case, the model is able to replicate the addition of normal boilers too and insert them in its general calculations.

Another important aspect, which answers the second question set at the beginning of this section (If a suitable CHP is found and chosen, which has high enough electrical and thermal output, are the Solar PV installations still useful or they can be discarded?) has to be noticed and considered.

Since the CHP unit is bigger, and it is producing more electricity compared to before, the Solar PV installations become indeed not relevant anymore, and bringing the number of solar panels to nothing does not change anything (except lowering the capital/maintenance costs) in the system. So, it is possible to zero that variable, managing to save money.

This is a case where, even if the Solar PV energy source is a continuous one, that will produce electricity for as long as the sun is in the sky, even with low irradiance due to clouds, the CHP unit simply surpasses its eventual production, making it impractical and anti-economic.

Going then onto the economic aspects of the simulation, the resulting ROI is now only 6.7 years, which is a well more appreciated result, since it is definitely below the operative lives of every component of the new energy system.

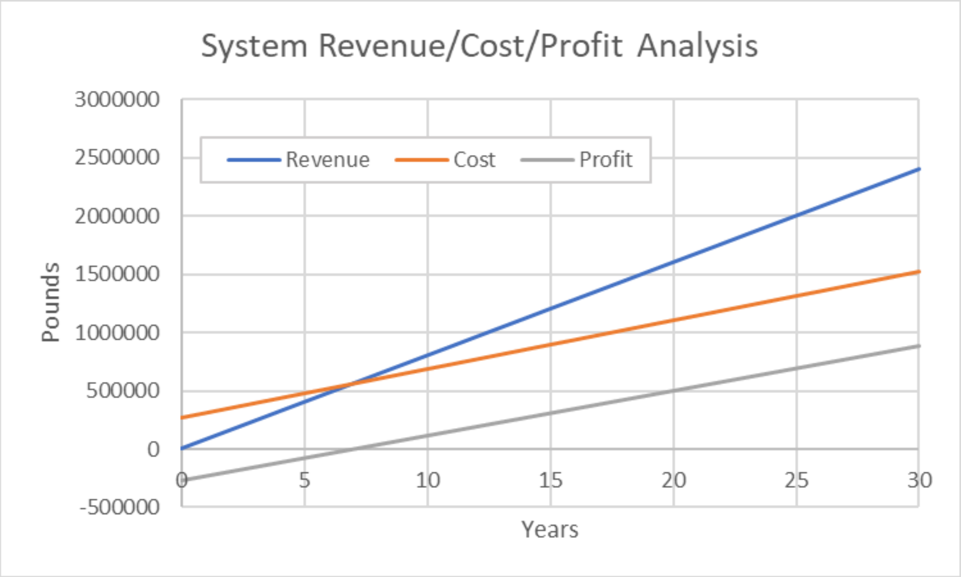


Figure 37: System Economic Analysis (Second Scenario)

This becomes a much more welcomed solution to the initial problem, with the small community becoming completely electrical-independent, and dependent on other means of energy generation for heating purposes only during the colder periods of the year.

But what if the user wanted to know in which way the little neighborood could become completely independent, like if it was a simulation of an isolated off-grid village which aims to be self-sufficient?

It is naturally possible to recreate this new scenario, and a resume of all three calculations is summarized in the following table, which gives a fast insight on the different situations.

Scenario	Variable	Result
Normal grid connection (no Solar PV, no CHP, no ES…)	Gross Electrical Demand	187810 kWh
	Gross Heating Demand	939050 kWh
	Grid Demand	100%
No Wind Turbines 22 x 3 kWp Solar PV units 1 x 25/79.5 kW CHP unit 5 kWh electrical ES per house 250 L x 6 kW heating element thermals ES per house	System Electrical Demand	8780 kWh
	System Heating Demand	296615 kWh
	System Total Grid Demand	27.1 %
	System El Excess Production	56944 kWh
	System Th Excess Production	0 kWh
	System Capital Costs	~ £ 399675
	System Maintenance Costs	~ £ 8600 per year
	System ROI	27.8 years
	Biomass Costs	~ £ 39644
No Wind Turbines No Solar PV units 1 x 40/90 kW CHP unit 3 kWh electrical ES per house 250 L x 6 kW heating element thermals ES per house	System Electrical Demand	0 kWh
	System Heating Demand	128490 kWh
	System Total Grid Demand	11.4%
	System El Excess Production	95946 kWh
	System Th Excess Production	11133 kWh
	System Capital Costs	~ £ 223000
	System Maintenance Costs	~ £ 6400 per year
	System ROI	6.7 years
	Biomass Costs	~ £ 29315

Table 2: Original System, First and Second Simulation Scenarios Detailed Data

Here, instead, is what would be required to zero the Grid Demand for the small community:

Scenario	Variable	Result
Normal grid connection (no Solar PV, no CHP, no ES…)	Gross Electrical Demand	187810 kWh
	Gross Heating Demand	939050 kWh
	Grid Demand	100%
No Wind Turbines 44 x 3 kWp Solar PV units 2 x 40/90 kW CHP unit 3 kWh electrical ES per house 250 L x 6 kW heating element thermals ES per house	System Electrical Demand	0 kWh
	System Heating Demand	0 kWh
	System Total Grid Demand	0 %
	System El Excess Production	438295 kWh
	System Th Excess Production	370546 kWh
	System Capital Costs	~ £ 424000
	System Maintenance Costs	~ £ 10600 per year
	System ROI	58.6 years
	Biomass Costs	~ £ 58527

Table 3: Possible Zero Grid Demand Scenario Simulation Data

It is very apparent that a complete off-grid project is still feasible, from an engineer's point of view, but it becomes unfeasible and anti-economical when the user gets to the financial section of the mode.

It is always important to consider both of these aspects in any kind of project simulation, because as this last demonstration shows, what could be a good solution in theory proves to be a not convenient one in reality.

In any case, there is much Excess Energy produced, even more if a Wind Turbine is added and if every kind of heating equipment in the dwellings is switched to using electricity as its source, there will still be the problem of some periods with simply too much production. The next section will illustrate some possible methods of spending or storing this.

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Possible Uses for Renewable Energy Sources (RES) Excess Production

Water Heating

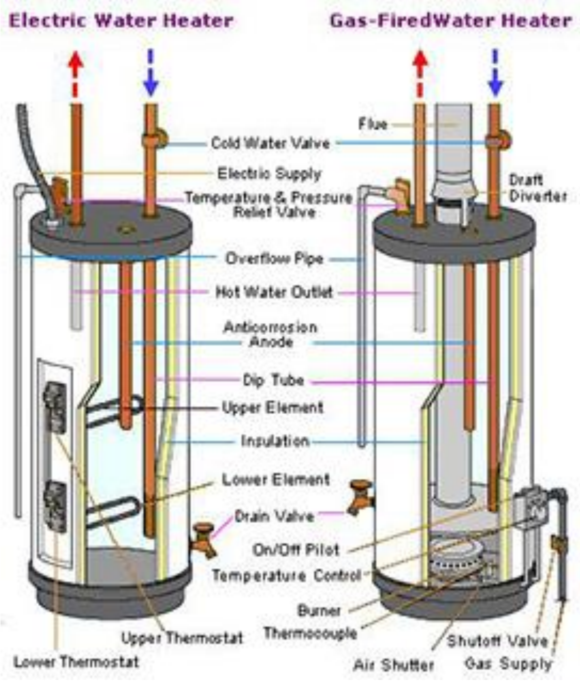


Figure 38: Electrical Water Heater vs Gas Water Heater (Don Vandervort, Home Tips 2016)

A storage water heater, or a hot water system (HWS), is a domestic water heating appliance that uses a hot water storage tank to maximize heating capacity and provide instantaneous delivery of hot water. Conventional storage water heaters use a variety of fuels, including natural gas, propane, fuel oil, and electricity.

Less conventional water heating technologies, such as heat pump water heaters and solar water heaters, can also be categorized as storage water heaters.

A major energy demand in any home (often around 20%) is for hot water. Most homes have gas-fired, electric-resistive, or rooftop solar thermal water heaters. But gaining in popularity, given its now favourable economics and lower environmental footprint, is the hot water heat pump.

Hot water and space-heating heat pumps work like fridges and air conditioners. They use a refrigeration cycle to pump heat “uphill”, from a colder zone to a warmer one. The benefit we enjoy with fridges and air conditioners is the cooling that occurs when heat is pumped from somewhere, we don’t want it (such as from the lounge room on a hot summer’s day) to somewhere else (the air outside). For hot water heat pumps, it’s the other way around – we want to gather and use the ambient heat that is always present in the air outside homes – the way that a reverse-cycle air conditioner does when it is on heating mode.

The best hot water heat pumps can capture up to 3.5 times as much heat energy from the air outside as they use in electrical energy, meaning that the resulting tank of hot water represents a net gain of free renewable energy.

Energy Consumption

An average centred around 3.5 kilowatt hours per day is necessary to supply hot water to a typically sized home. A 1-kilowatt solar system would be enough to provide this amount of electricity and heat the water. However, given that the average new rooftop solar system is now around 4.5 kilowatts, there may well be plenty of excess solar electricity generating capacity available on many homes.

The bottom line is: instead of paying around £225/year for gas to heat water, someone with a large rooftop solar system might instead use their excess electricity, which their retailer values at just £45/year. The result is that the homeowner is better off by £180/year.

This analysis ignores the up-front cost to replace a gas hot water heater with a hot water heat pump.

System Readiness

Ready and available on the market. Can be used as a full substitute of a previous gas-powered water heater, without having to change the plumbing and radiators inside a household/office/building.

It will be important to study the impact that the transitioning from gas-fuelled water heaters will make on any electricity grid, and where/when additional generators (possibly RE) could be added to sustain the new hot water system.

Benefits

Electric water heating has clear advantages over fuel-fired water heating in almost all situations. Electric resistance water heating's primary disadvantage is a higher operating cost relative to gas-fired water heating under many utility rates. Even in such cases, the other advantages of electric water heating often outweigh any operating cost differences. Heat pump water heaters and other high-efficiency electrotechnologies offer operating costs lower than or similar to those of fuel-fired units under all rates.

Operating Costs

Under some utility rates, the cost of heating water with an electric resistance water heater is greater than the cost with a gas-fired water heater, liquid propane, and fuel oil. However, the cost difference is frequently overstated by not considering the efficiency of the water heaters.

Water heating energy and demand cost is only one of the many components of the total cost of owning and operating a water heating system. Electric water heaters typically offer cost advantages over fuel-fired systems for these other cost components, including design, installation, maintenance, service life, and effect on space conditioning loads. Where the total cost of ownership and operation are considered, electric water heating often has an overall cost advantage.

Even in situations where electric water heating is more expensive, it is frequently the preferred choice. Any cost difference is usually viewed as a small price to pay for avoiding the potential safety hazards and inconveniences associated with fuel-fired water heaters.

Safety

- Electric water heaters are safer than fuel-fired water heaters because they avoid the hazards and problems associated with using a combustion process to heat water;
- Combustible vapours. Fuel-fired water heaters present a potential safety hazard where flammable vapours may be present. Examples are garages, basements, and storage rooms where gasoline, paints, and cleaning fluids are stored. Flammable vapours are usually heavier than air and tend to collect near the floor. The draft effect of water heater pilot lights and burners causes the vapours to be drawn to the water heater where the pilot or burner can cause them to explode.

Technical Advantages

Electric resistance water heaters are more efficient than fuel-fired units. They are also simple and, consequently, they are the simplest and most convenient way to heat water in both residential and commercial buildings.

The maximum energy factor listed for fuel-fired units with power burners is 0.86. For units with atmospheric burners, the maximum energy factor is 0.64. Electric water heaters have energy factors as high as 0.95.

Because they are much better insulated, electric resistance water heaters have standby losses than fuel-fired units. Fuel-fired storage water heaters lose substantial amounts of heat through their flues and the un-insulated tank bottom. Typical fuel-fired water heaters lose about 3.5% of their stored heat per hour. Typical electric water heaters lose only about 1% per hour. Where hot water usage is low, the cost of operating an electric water heater can be lower than the cost for a natural gas unit.

Applications

- *Availability* - Electric service is available almost everywhere a water heating system would be installed. Natural gas is not available in many areas, particularly in rural locations. While all buildings have electric service, natural gas service is optional;
- *Point-of-use service* - Electric water heaters are ideal for point-of-use water heating systems, where the water heaters are installed at or near the locations where hot water is required. Fuel-fired systems must be located where combustion air is available, and fuels can be installed. Locating the water heater closer to the hot water usage points reduces piping costs and piping heat loss and reduces the wait for hot water at the fixtures. The need for recirculation loops and pumps is also reduced;
- Electric water heaters are readily incorporated as a supplement with solar water heaters, heat pump water heaters, and refrigeration heat reclaim water heaters;
- Electric water heaters are convenient for use as booster heaters where higher-temperature water is required for special functions, such as dishwashing.

Electric Vehicles Charging (Cars, Buses, Ferries, Cargo Ships, Tankers, etc.)

Figure 39: EV Charging Station in Japan (raneko 2012)

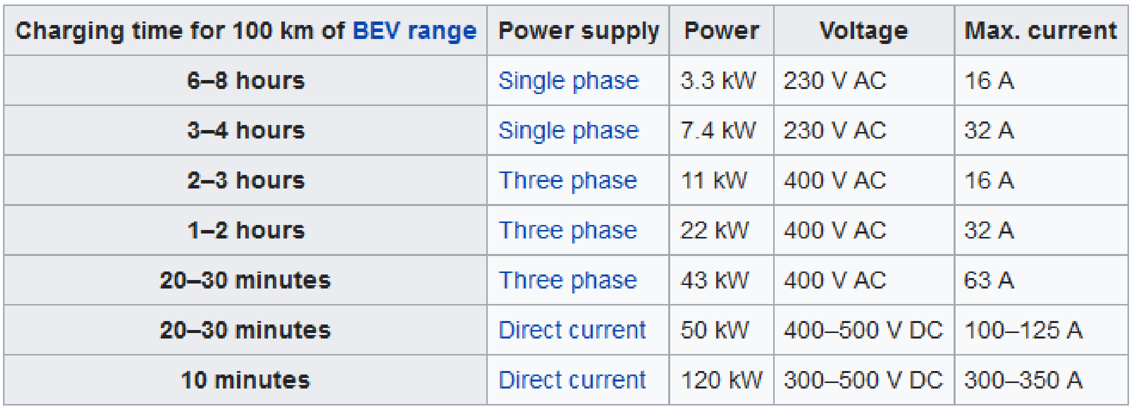
An electric vehicle charging station, also called EV charging station, electric recharging point, charging point, charge point, ECS (electronic charging station), and EVSE (electric vehicle supply equipment), is an element in an infrastructure that supplies electric energy for the recharging of EVs, such as plug-in electric vehicles, including electric cars, neighbourhood electric vehicles and plug-in hybrids.

Charging stations for electric vehicles may not need much new infrastructure in developed countries, less than delivering a new alternative fuel over a new network. The stations can leverage the existing ubiquitous electrical grid and home recharging is an option.

Also, most driving is local over short distances which reduces the need for charging mid-trip. Nevertheless, longer drives between cities and towns require a network of public charging stations or another method to extend the range of electric vehicles beyond the normal daily usage. One challenge in such infrastructure is the level of demand: a station along a busy highway may see hundreds of customers per hour if every passing electric vehicle has to stop there to finish its trip. In the first half of the 20th century, internal combustion vehicles faced a similar infrastructure problem.

Energy Consumption

It will mainly depend on the sizing of the charging stations and the vehicles that need to be recharged. However, in general, the following table shows a reasonable list:



Charging time for 100 km of BEV range	Power supply	Power	Voltage	Max. current
6–8 hours	Single phase	3.3 kW	230 V AC	16 A
3–4 hours	Single phase	7.4 kW	230 V AC	32 A
2–3 hours	Three phase	11 kW	400 V AC	16 A
1–2 hours	Three phase	22 kW	400 V AC	32 A
20–30 minutes	Three phase	43 kW	400 V AC	63 A
20–30 minutes	Direct current	50 kW	400–500 V DC	100–125 A
10 minutes	Direct current	120 kW	300–500 V DC	300–350 A

Figure 40: Different Charging Times/Modes Comparison (Wikipedia 2019)

System Readiness

Ready and available on the market. However, a proper deployment plan has to be made, to make sure that every relevant location is covered.

It is also fully feasible to implement this technology in a 50/50 phase, using hybrid fossil fuels/electric vehicles, before making the transition to full electrical ones. The most important point is to study how the energy production will be able to sustain it.

Personal/Business Benefits

- *Tenant attraction and retention*: offering charging is a direct way for property owners and managers to attract and retain tenants who own electric cars. Hosting an EV charging station is a highly visible way to exemplify a building's or property management company's environmental values.

  This may help contribute to a green image that attracts and retains tenants and customers who share these values. By offering this service free of charge, as many facilities currently do, companies will add a new dynamic to their corporate branding;
- *User charging and parking fees*: charging-station hosts have the opportunity to generate revenue directly from people who use the station's services.

  Although the re-selling of electricity at a higher rate than specified by the utility is prohibited in some areas, owners can collect revenue for charging through pay-for-parking services.

  Using these types of systems typically requires installation of advanced EV charging station products. However, it should be noted that to date, many facilities are opting out of charging for use of the station and are instead providing it as a free service;
- *Employee attraction and retention*: buildings or companies that offer charging may be able to attract and retain employees who want to charge EVs during the day. In addition, it can be very important to many employees, even those who do not drive EVs, that their building or employer is proactive with transportation planning;
- *Advertising opportunities*: every time an EV driver visits a charging station, there is an opportunity to advertise. A station host could advertise its own products or services in this way or sell advertising space to another organization.

Grid Benefits

A practical example would be the one operated by *Nissan* and *Ovo*, one of the United Kingdom's largest energy suppliers, that will offer the "vehicle-to-grid" service to buyers of the carmaker's new Leaf next year. According to Stephen Fitzpatrick, Chief Executive Officer of Ovo, savings from vehicle-to-grid services would cover the annual cost of charging an EV.

The owner of the car will have to install a special charger at home and the supplier will manage the car's battery. Ovo will automatically trade electricity from the car's battery to the grid during peak times when costs are highest, potentially providing a monetary return to the owner. The car's battery will be charged during off-peak times when costs are lowest.

This development demonstrates that vehicle-to-grid services could be used (in other countries) during peak hours to release stored electricity onto the grid and decrease charging costs. Balancing the supply and demand of electricity with electric cars also could result in avoiding costly upgrades to the grid, such as investing in new power plants. Thus, transportation costs and electricity bills could diminish with vehicle-to-grid services.

As more customers adopt electric vehicles, vehicle-to-grid services should be considered to help even out electricity supply and demand. This option may be especially useful in cities that have adopted electric buses for public transportation. These electric buses could provide electricity to the grid when not in use, decreasing costs for the city and customers.

Some caution should be taken as more electric vehicles are connected to the grid. Big spikes in demand for electricity could cause stress and strain that could affect stability, efficiency, and operating costs of the grid itself.

Adding an electric car on the grid is equivalent in some cases to adding three houses. An electric vehicle could consume as much electricity in a single charge as an average refrigerator does in a month and a half. Thus, the impact of charging an electric vehicle is dependent on where it is located on the grid and the time of day it is charged.

Utilities aim to use distributed resources, such as renewable energy production, storage and demand response, to partially control charging impacts of electric vehicles. Smart grid technologies such as advanced metering infrastructure could prove helpful in managing the charging of electric vehicles.

Such devices allow charging stations to be integrated with time-based rates that encourage off-peak charging. They also allow utilities to analyse charging station usage and charging behaviours to inform investment decisions.

Furthermore, algorithms that effectively schedule the charging and discharging of electric vehicles are necessary for the grid to operate efficiently. However, developing such algorithms is difficult due to the randomness and uncertainty of future events.

More electric vehicle charging stations in convenient locations are necessary to balance demand on the grid and increase convenience. If an EV needs to charge during a long road trip, it would have to stop at the nearest charging point. But the closest may not be along the driver's path, potentially increasing electricity consumption and decreasing convenience.

Several oil companies are seeking to provide electric car charging stations to benefit from a market that is moving away from diesel and petrol cars. Shell will provide electric vehicle charging points in the United Kingdom and Netherlands this year. BP, Total, and PKN Olen also are considering building or installing charging stations for electric vehicles.

Wireless charging is another resourceful way to make electric vehicle charging more convenient and may help balance demand on the grid. *Plugless* offers such a solution for many electric vehicles on the road today, including today's Tesla's Model S.

In addition, in the U.S.A., the *Department of Energy's Vehicle Technologies Office* is supporting a project with the *Oak Ridge National Laboratory and Industry* to develop a 20-kilowatt wireless electric car charging system with 90% efficiency. This means an average all-electric vehicle could be fully charged within an hour or two.

Microgrids could also boost reliability when charging electric vehicles in a neighbourhood or work place. Smaller communities with distributed resources such as solar, wind and storage would reduce the strain on the power grid. Perhaps looping storage into local microgrids would further enhance electricity resilience.

As customers adopt EVs, it is important to consider all the potential benefits these cars could provide to the grid. The grid could become more flexible during peak times for less cost and expensive infrastructure updates could be avoided with vehicle-to-grid services.

Hybrid Engines Features

Plug-in hybrid electric vehicles–known as PHEVs–combine a gasoline or diesel engine with an electric motor and a large rechargeable battery. Unlike conventional hybrids, PHEVS can be plugged-in and recharged from an outlet, allowing them to drive extended distances using just electricity. When the battery is emptied, the conventional engine turns on and the vehicle operates as a conventional, non-plug-in hybrid.

Because they can run on electricity from the grid—and because electricity is often a cleaner energy source than gasoline or diesel—plug-in hybrids can produce significantly less global warming pollution than their gas-only counterparts. They don't emit any tailpipe pollution when driving on electricity, and they gain fuel efficiency benefits from having an electric motor and battery. Since they use less gas, they also cost less to fuel: driving a PHEV can save hundreds of pounds a year in gasoline and diesel costs.

While not all models work the same way, most plug-ins can operate in at least two modes: "all-electric," in which the motor and battery provide all of the car's energy; and "hybrid," in which both electricity and gasoline are used. PHEVs typically startup in all-electric mode, running on electricity until their battery pack is depleted: ranges vary from 10 miles to over 40. Certain models switch to hybrid mode when they reach highway cruising speed, generally above 60 or 70 miles per hour.

The electric motor and battery help PHEVs use less fuel and produce less pollution than conventional cars, even when in hybrid mode. Idle-off turns off the engine while idling at stoplights or in traffic, saving fuel. Regenerative braking converts some of the energy lost during braking into usable electricity, stored in the batteries. And because the electric motor supplements the engine's power, smaller engines can be used, increasing the car's fuel efficiency without compromising performance.

Aeroponics – Hydroponics - Aquaponics

Figure 41: Hydroponic Culture (Louis Hiemstra 2018)

Aeroponics is the process of growing plants in an air or mist environment without the use of soil or an aggregate medium (known as geoponics).

Aeroponic culture differs from both conventional hydroponics, aquaponics, and in-vitro (plant tissue culture) growing. Unlike hydroponics, which uses a liquid nutrient solution as a growing medium and essential mineral to sustain plant growth (a method of growing plants without soil by using mineral nutrient solutions in a water solvent); or aquaponics which uses water and fish waste (any system that combines conventional aquaculture -raising aquatic animals such as snails, fish, crayfish or prawns in tanks- with hydroponics in a symbiotic environment.), aeroponics is conducted without a growing medium.

Despite its high demand for energy, hydroponics remains a promising technology. Several factors could influence the feasibility of hydroponic production of crops, specifically lettuce, in the future. As more sophisticated control devices become available, the cost of maintaining the controlled environment of hydroponic greenhouses could decrease.

The future availability of water, land, and food will also influence feasibility through increased demand. Increasing land and water scarcity will make the more land- and water-efficient hydroponic systems more appealing to city planners. Government and local grass-roots support could also influence the future of hydroponic farming, as subsidies could be used to offset the high initial cost of hydroponic infrastructure or more simplified hydroponic systems take hold.

Energy Consumption

A small cultivation light uses 4.8 kWh per month, if used for 16 hours per day, so it its £ 0.154 a kWh that is 73p a month or £8.76 a year.

A large light is instead 7.68 kWh per month, if used for 16 hours per day so that is £1.18 a month or £14.16 a year.

All of the above figures are based on an average electricity cost.

An easy way to work this out would be to assume that electricity is at least £ 0.1 a kWh – that would be 48p a month or £5.76 a year to run the smaller light and 76p a month or £9.12 to run the bigger. Rounding it down it’s at least a fiver for the smaller light and £9 for the larger.

Polytunnels / Greenhouses

Figure 42: Polytunnels (Val Vannet 2005)

A polytunnel is a tunnel typically made from steel and covered in polythene, usually semi-circular, square or elongated in shape. The interior heats up because incoming solar radiation from the sun warms plants, soil, and other things inside the building faster than heat can escape the structure. Air warmed by the heat from hot interior surfaces is retained in the building by the roof and wall.

Temperature, humidity and ventilation can be controlled by equipment fixed in the polytunnel or by manual opening and closing of vents. Polytunnels are mainly used in temperate regions in similar ways to glass greenhouses and row covers. Besides the passive solar heating that every polytunnel provides, every variation of auxiliary heating (from hothouse heating through minimal heating to unheated houses) is represented in current practice. The nesting of row covers and low tunnels inside high tunnels is also common.

Polytunnels can be used to provide a higher temperature and/or humidity than that which is available in the environment but can also protect crops from intense heat, bright sunlight, winds, hailstones, and cold waves. This allows fruits and vegetables to be grown at times usually considered off season; market gardeners commonly use polytunnels for season extension.

Besides season extension, polytunnels are also used to allow cold-hardy crops to overwinter in regions where their hardiness isn't quite strong enough for them to survive outdoors. Temperature increases of only 5° to 15° above outdoor ambient, coupled with protection from the drying effect of wind, are enough to let selected plant varieties grow slowly but healthily instead of dying. The effect is to create a microclimate that simulates the temperatures of a location closer to the equator (and protects from wind as well).

Energy Consumption

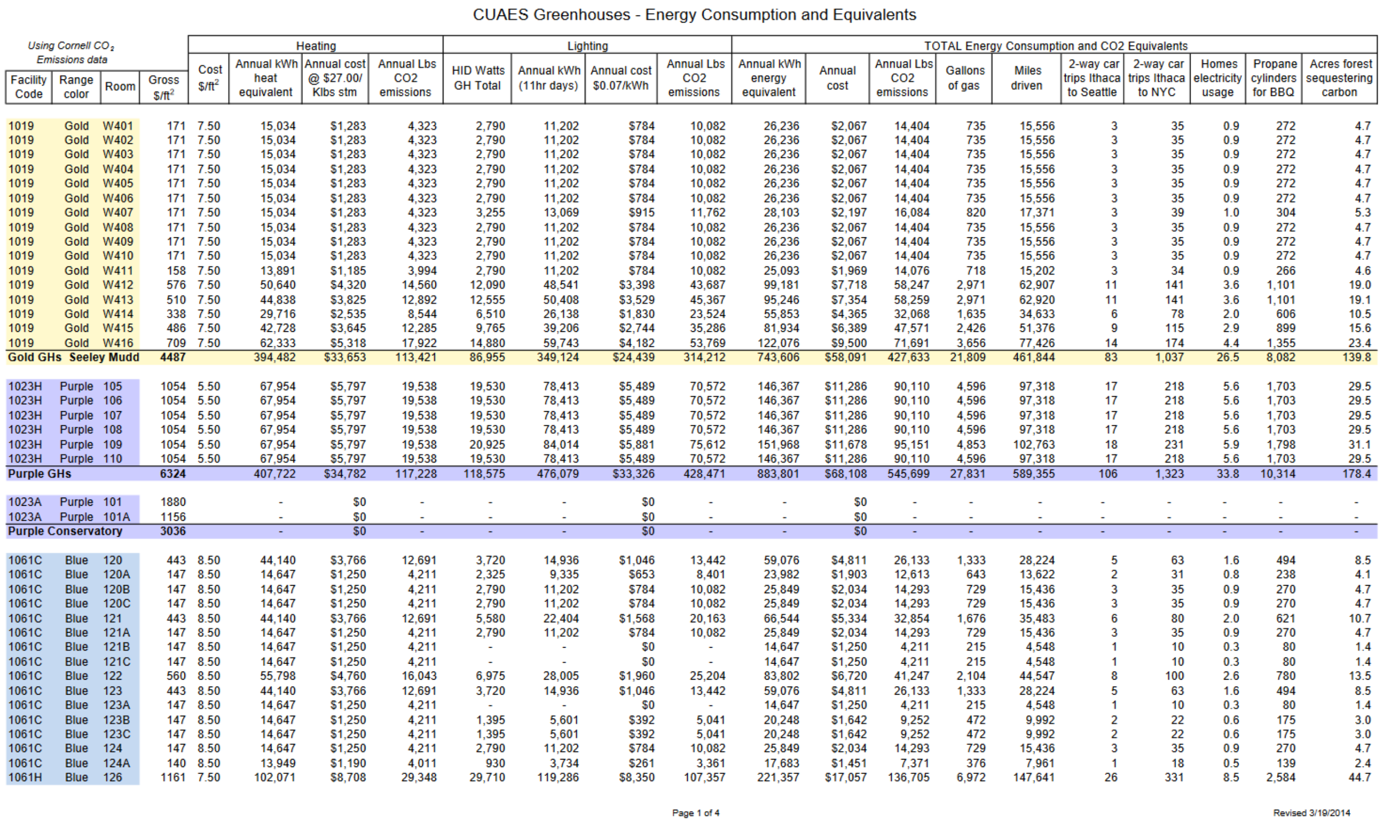
Energy consumption varies for each greenhouse and growth chamber, depending on size, construction, controls, lighting and more. It also depends on how each facility is used: different crops and project goals naturally require different conditions.

Measuring the energy consumption of each plant growth chambers over a 24-hour period, while set to average conditions with the lights were set to the highest setting for 14 hours and off for the remaining time. The day temperature was set to 24°C, and to 18°C at night.

To estimate the energy consumption and cost for each greenhouse as accurately as possible, the following assumption was made: Energy consumption data for heating are estimates based on measured heating requirements of several greenhouses over four years and assume an average indoor temperature of 21°C. Lighting energy consumption data assume the installed growth lights provide a 14-hour photoperiod throughout the year, but are turned off during periods of high sunlight intensity, resulting in an annual average of 11 hours actual operation per day.

System Readiness

Ready and available on the market. To use the most of any dedicated energy, however, the greenhouses should be of adequate size, and not simple household-sized small ones.



CUAES Greenhouses - Energy Consumption and Equivalents

Using Cornell CO₂ Emissions data				Heating				Lighting				TOTAL Energy Consumption and CO2 Equivalents									
Facility Code	Range color	Room	Gross $/ft²	Cost $/ft²	Annual kWh heat equivalent	Annual cost @ $27.00/ Klbs stm	Annual Lbs CO2 emissions	HID Watts GH Total	Annual kWh (11hr days)	Annual cost $0.07/kWh	Annual Lbs CO2 emissions	Annual kWh energy equivalent	Annual cost	Annual Lbs CO2 emissions	Gallons of gas	Miles driven	2-way car trips Ithaca to Seattle	2-way car trips Ithaca to NYC	Homes electricity usage	Propane cylinders for BBQ	Acres forest sequestering carbon
1019	Gold	W401	171	7.50	15,034	$1,283	4,323	2,790	11,202	$784	10,082	26,236	$2,067	14,404	735	15,556	3	35	0.9	272	4.7
1019	Gold	W402	171	7.50	15,034	$1,283	4,323	2,790	11,202	$784	10,082	26,236	$2,067	14,404	735	15,556	3	35	0.9	272	4.7
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1019	Gold	W406	171	7.50	15,034	$1,283	4,323	2,790	11,202	$784	10,082	26,236	$2,067	14,404	735	15,556	3	35	0.9	272	4.7
1019	Gold	W407	171	7.50	15,034	$1,283	4,323	3,255	13,069	$915	11,762	28,103	$2,197	16,084	820	17,371	3	39	1.0	304	5.3
1019	Gold	W408	171	7.50	15,034	$1,283	4,323	2,790	11,202	$784	10,082	26,236	$2,067	14,404	735	15,556	3	35	0.9	272	4.7
1019	Gold	W409	171	7.50	15,034	$1,283	4,323	2,790	11,202	$784	10,082	26,236	$2,067	14,404	735	15,556	3	35	0.9	272	4.7
1019	Gold	W410	171	7.50	15,034	$1,283	4,323	2,790	11,202	$784	10,082	26,236	$2,067	14,404	735	15,556	3	35	0.9	272	4.7
1019	Gold	W411	158	7.50	13,891	$1,185	3,994	2,790	11,202	$784	10,082	25,093	$1,969	14,076	718	15,202	3	34	0.9	266	4.6
1019	Gold	W412	576	7.50	50,640	$4,320	14,560	12,090	48,541	$3,398	43,687	99,181	$7,718	58,247	2,971	62,907	11	141	3.6	1,101	19.0
1019	Gold	W413	510	7.50	44,838	$3,825	12,892	12,555	50,408	$3,529	45,367	95,246	$7,354	58,259	2,971	62,920	11	141	3.6	1,101	19.1
1019	Gold	W414	338	7.50	29,716	$2,535	8,544	6,510	26,138	$1,830	23,524	55,853	$4,365	32,068	1,635	34,633	6	78	2.0	606	10.5
1019	Gold	W415	486	7.50	42,728	$3,645	12,285	9,765	39,206	$2,744	35,286	81,934	$6,389	47,571	2,426	51,376	9	115	2.9	899	15.6
1019	Gold	W416	709	7.50	62,333	$5,318	17,922	14,880	59,743	$4,182	53,769	122,076	$9,500	71,691	3,656	77,426	14	174	4.4	1,355	23.4
Gold GHs	**Seeley Mudd**		**4487**		394,482	$33,653	113,421	86,955	349,124	$24,439	314,212	743,606	$58,091	427,633	21,809	461,844	83	1,037	26.5	8,082	139.8
1023H	Purple	105	1054	5.50	67,954	$5,797	19,538	19,530	78,413	$5,489	70,572	146,367	$11,286	90,110	4,596	97,318	17	218	5.6	1,703	29.5
1023H	Purple	106	1054	5.50	67,954	$5,797	19,538	19,530	78,413	$5,489	70,572	146,367	$11,286	90,110	4,596	97,318	17	218	5.6	1,703	29.5
1023H	Purple	107	1054	5.50	67,954	$5,797	19,538	19,530	78,413	$5,489	70,572	146,367	$11,286	90,110	4,596	97,318	17	218	5.6	1,703	29.5
1023H	Purple	108	1054	5.50	67,954	$5,797	19,538	19,530	78,413	$5,489	70,572	146,367	$11,286	90,110	4,596	97,318	17	218	5.6	1,703	29.5
1023H	Purple	109	1054	5.50	67,954	$5,797	19,538	20,925	84,014	$5,881	75,612	151,968	$11,678	95,151	4,853	102,763	18	231	5.9	1,798	31.1
1023H	Purple	110	1054	5.50	67,954	$5,797	19,538	19,530	78,413	$5,489	70,572	146,367	$11,286	90,110	4,596	97,318	17	218	5.6	1,703	29.5
Purple GHs			**6324**		407,722	$34,782	117,228	118,575	476,079	$33,326	428,471	883,801	$68,108	545,699	27,831	589,355	106	1,323	33.8	10,314	178.4
1023A	Purple	101	1880		-	$0	-	-	-	$0	-	-	$0	-	-	-	-	-	-	-	-
1023A	Purple	101A	1156		-	$0	-	-	-	$0	-	-	$0	-	-	-	-	-	-	-	-
Purple Conservatory			**3036**		-	$0	-	-	-	$0	-	-	$0	-	-	-	-	-	-	-	-
1061C	Blue	120	443	8.50	44,140	$3,766	12,691	3,720	14,936	$1,046	13,442	59,076	$4,811	26,133	1,333	28,224	5	63	1.6	494	8.5
1061C	Blue	120A	147	8.50	14,647	$1,250	4,211	2,325	9,335	$653	8,401	23,982	$1,903	12,613	643	13,622	2	31	0.8	238	4.1
1061C	Blue	120B	147	8.50	14,647	$1,250	4,211	2,790	11,202	$784	10,082	25,849	$2,034	14,293	729	15,436	3	35	0.9	270	4.7
1061C	Blue	120C	147	8.50	14,647	$1,250	4,211	2,790	11,202	$784	10,082	25,849	$2,034	14,293	729	15,436	3	35	0.9	270	4.7
1061C	Blue	121	443	8.50	44,140	$3,766	12,691	5,580	22,404	$1,568	20,163	66,544	$5,334	32,854	1,676	35,483	6	80	2.0	621	10.7
1061C	Blue	121A	147	8.50	14,647	$1,250	4,211	2,790	11,202	$784	10,082	25,849	$2,034	14,293	729	15,436	3	35	0.9	270	4.7
1061C	Blue	121B	147	8.50	14,647	$1,250	4,211	-	-	$0	-	14,647	$1,250	4,211	215	4,548	1	10	0.3	80	1.4
1061C	Blue	121C	147	8.50	14,647	$1,250	4,211	-	-	$0	-	14,647	$1,250	4,211	215	4,548	1	10	0.3	80	1.4
1061C	Blue	122	560	8.50	55,798	$4,760	16,043	6,975	28,005	$1,960	25,204	83,802	$6,720	41,247	2,104	44,547	8	100	2.6	780	13.5
1061C	Blue	123	443	8.50	44,140	$3,766	12,691	3,720	14,936	$1,046	13,442	59,076	$4,811	26,133	1,333	28,224	5	63	1.6	494	8.5
1061C	Blue	123A	147	8.50	14,647	$1,250	4,211	-	-	$0	-	14,647	$1,250	4,211	215	4,548	1	10	0.3	80	1.4
1061C	Blue	123B	147	8.50	14,647	$1,250	4,211	1,395	5,601	$392	5,041	20,248	$1,642	9,252	472	9,992	2	22	0.6	175	3.0
1061C	Blue	123C	147	8.50	14,647	$1,250	4,211	1,395	5,601	$392	5,041	20,248	$1,642	9,252	472	9,992	2	22	0.6	175	3.0
1061C	Blue	124	147	8.50	14,647	$1,250	4,211	2,790	11,202	$784	10,082	25,849	$2,034	14,293	729	15,436	3	35	0.9	270	4.7
1061C	Blue	124A	140	8.50	13,949	$1,190	4,011	930	3,734	$261	3,361	17,683	$1,451	7,371	376	7,961	1	18	0.5	139	2.4
1061H	Blue	126	1161	7.50	102,071	$8,708	29,348	29,710	119,286	$8,350	107,357	221,357	$17,057	136,705	6,972	147,641	26	331	8.5	2,584	44.7

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Revised 3/19/2014

Figure 43: CUAES Greenhouses performance (CUAES)

Pumped Water Storage

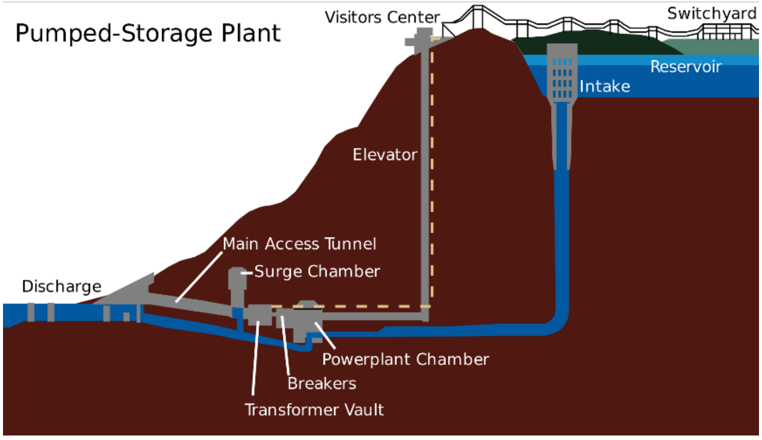

Figure 44: Pumped Water Storage schematics (Public Domain 2012)

Pumped-storage hydroelectricity (PSH), or pumped hydroelectric energy storage (PHES), is a type of hydroelectric energy storage used by electric power systems for load balancing.

The method stores energy in the form of gravitational potential energy of water, pumped from a lower elevation reservoir to a higher elevation. Low-cost surplus off-peak electric power is typically used to run the pumps. During periods of high electrical demand, the stored water is released through turbines to produce electric power. Although the losses of the pumping process make the plant a net consumer of energy overall, the system increases revenue by selling more electricity during periods of peak demand, when electricity prices are highest.

Pumped-storage hydroelectricity allows energy from intermittent sources (such as solar, wind) and other renewables, or excess electricity from continuous base-load sources (such as coal or nuclear) to be saved for periods of higher demand. The reservoirs used with pumped storage are quite small when compared to conventional hydroelectric dams of similar power capacity, and generating periods are often less than half a day.

Pumped storage is the largest-capacity form of grid energy storage available. The round-trip energy efficiency of PSH varies between 70%–80%, with some sources claiming up to 87%. The main disadvantage of PSH is the specialist nature of the site required, needing both geographical height and water availability. Suitable sites are therefore likely to be in hilly or mountainous regions, and potentially in areas of outstanding natural beauty, and therefore there are also social and ecological issues to overcome.

Energy Consumption

An example is the Dinorwing Power Station in Wales, which has 6 x 300MW turbines, and 1650 MW of installed capacity.

As one might expect pumping the water back up into Marchlyn Mawr (the top reservoir) is significantly more energy intensive than the energy it provides when working as a power station, in fact it uses almost 33% more energy to get the water back up than it produces.

However, where this hydroelectric power plant is unique is the ability to react quickly to meet peak in demand and instantly provide the power required (unlike Nuclear and Coal power plants): however, it takes seven hours to pump the water up to the Marchlyn Mawr reservoir and it will only generate power for five hours.

Desalination

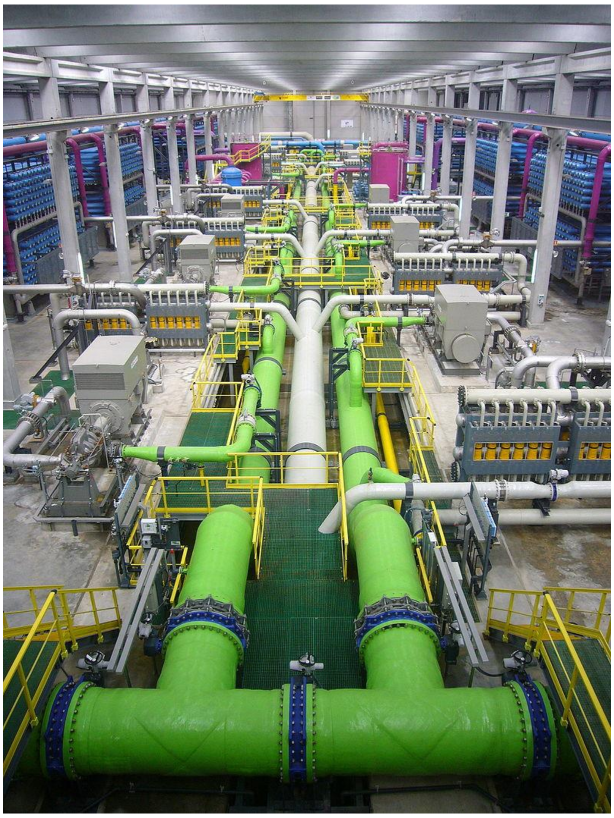

Figure 45: Desalination Plant (James Grellier 2010)

Desalination is a process that takes away mineral components from saline water. More generally, desalination refers to the removal of salts and minerals from a target substance, as in soil desalination, which is an issue for agriculture.

Saltwater is desalinated to produce water suitable for human consumption or irrigation. One by-product of desalination is salt.

Due to its energy consumption, desalinating sea water is generally more costly than fresh water from rivers or groundwater, water recycling and water conservation. However, these alternatives are not always available, and depletion of reserves is a critical problem worldwide. Currently, approximately 1% of the world's population is dependent on desalinated water to meet daily needs, but the UN expects that 14% of the world's population will encounter water scarcity by 2025.

Energy Consumption

Energy consumption of seawater desalination has reached as low as 3 kWh/m3, including pre-filtering and ancillaries, similar to the energy consumption of other fresh water supplies transported over large distances, but much higher than local fresh water supplies that use 0.2 kWh/m3 or less.

A minimum energy consumption for seawater desalination of around 1 kWh/m^3 has been determined, excluding prefiltering and intake/outfall pumping. Under 2 kWh/m^3 has been achieved with reverse osmosis membrane technology, leaving limited scope for further energy reductions.

Supplying all domestic water by desalination would increase domestic energy consumption by around 10% on average, about the amount of energy used by domestic refrigerators. Domestic consumption is a relatively small fraction of the total water usage.

Furthermore:

- Desalination requires significantly more energy than existing conventional water treatment processes. This makes it expensive and contributes to greenhouse gas emissions;
- For seawater desalination, energy use can represent 50-70% of total operating costs;
- Desalination plants are complex systems, with pre-treatment filters, high pressure pumps, energy recovery devices and chemical cleaning systems. With appropriate

material selection, equipment lifespan is comparable to the one used for conventional water treatment;
- Desalination requires sophisticated plants that have high capital costs, significant maintenance requirements and shorter operating life than traditional water plants;
- The saltier the water the more expensive it is to desalinate, so it may be cheaper to desalinate brackish (slightly salty) water or wastewater rather than seawater;
- Many desalination plants use accredited 'Green Power' by using wind energy to power desalination plants. This can result in a significant increase in operating costs, due to the premium attached to the use of renewable energy. The benefit is reduced GHG emissions, with corresponding environmental benefits.

System Readiness

Ready and available on the market. However, the equipment has a high capital cost, especially in case of the building of large plants.

Methodology of Operations

- *Reverse osmosis (RO)* and *Nanofiltration (NF)* are the leading pressure driven membrane processes. Membrane configurations include spiral wound, hollow fiber, and sheet with spiral being the most widely used. Contemporary membranes are primarily polymeric materials with cellulose acetate still used to a much lesser degree. Operating pressures for RO and NF are in the range of 50 to 1,000 psig (3.4 to 68 bar, 345 to 6896 kPa);
- *Electrodialysis (ED)* and *Electrodialysis Reversal (EDR)* processes are driven by direct current (DC) in which ions (as opposed to water in pressure driven processes) flow through ion selective membranes to electrodes of opposite charge. In EDR systems, the polarity of the electrodes is reversed periodically. Ion-transfer (perm-selective) anion and cation membranes separate the ions in the feed water. These systems are used primarily in waters with low total dissolved solids (TDS);
- *Forward osmosis (FO)* is a relatively new commercial desalting process in which a salt concentration gradient (osmotic pressure) is the driving force through a synthetic membrane. The feed (such as seawater) is on one side of the semi permeable membrane and a higher osmotic pressure "draw" solution is on the other side. Without applying any external pressure, the water from the feed solution will naturally migrate through the membrane to the draw solution. The diluted solution is then processed to separate the product from the reusable draw solution;
- *Membrane Distillation (MD)* is a water desalination membrane process currently in limited commercial use. MD is a hybrid process of RO and distillation in which a hydrophobic synthetic membrane is used to permit the flow of water vapor through the membrane pores, but not the solution itself. The driving force for MD is the difference in vapor pressure of the liquid across the membrane.

Electrochemistry

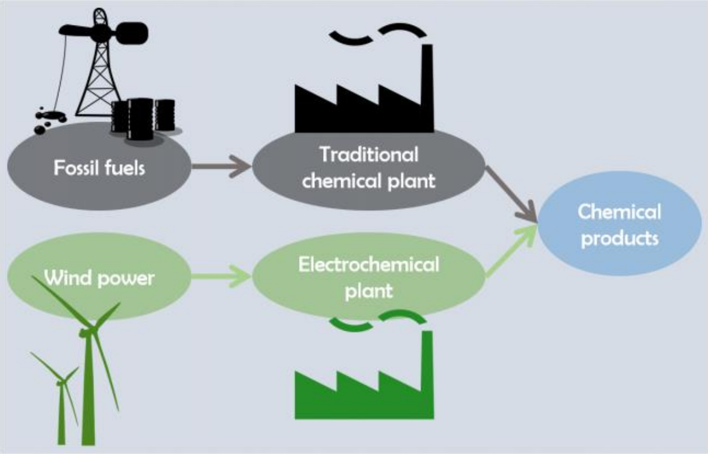

Figure 46: Electrochemistry vs Traditional processes (CAT 2010)

A huge variety of products, from building materials to medicines, are made from a range of synthetic chemicals.

A lot of the synthetic chemicals used in manufacturing are produced in chemical plants on a large scale. The conventional production of chemicals involves high temperatures and pressures to drive chemical reactions. These are usually achieved by burning fossil fuels, such as natural gas.

For example, at Copenhagen University, researchers are investigating chemical reactions that are driven by electricity, rather than high temperatures and pressures. When an electrical current is passed through a solution, chemical reactions can happen. Different reactions produce different chemicals. Scientists are looking at optimising this process, so we can produce a number of chemicals that would otherwise be made by conventional methods.

The electricity for these processes could be supplied by fossil fuels but also by renewable sources, such as wind power. It is possible because chemical demand is not always continuous, and many chemicals can be made in batches.

Turning conventional chemical production on and off can be energy and time intensive, as high temperatures and pressures have to be reached to get the reactions started.

Electrochemical reactions do not need high temperatures and pressures, so electrochemical plants could be turned on and off more easily. This means they can make use of bursts of excess wind power. Using excess wind power to produce chemicals would mean using less gas/fossil fuels.

Energy Consumption

As an example, the evaluation of energy consumption in electrochemical oxidation of Acid Violet 7 textile dye was investigated using Pt/Ir anodes in the presence of 75% NaCl +25% Na_2CO_3 supporting electrolyte mixture.

Energy consumption decreased with increasing textile dye concentration and electrolyte concentration and decreasing the current density. Depending on electrochemical reaction conditions, energy consumption values were evaluated for textile dye decolorization (t=15 min) and COD removal (t=120 min) as 2.7-18.9 kWh/kg dye decolorization and 51.0-190.7 kWh/kg COD removal, respectively.

The optimum region was determined for the energy consumption in electrochemical oxidation of Acid Violet 7 textile dye using Pt/Ir electrodes at lower than 10 kWh/kg dye decolorization and 95 kWh/kg COD removal. In this study, energy consumption values were obtained in a good agreement with the data reported in the literature.

System Readiness

In research/first devices are available on the market. However, the necessary equipment and the exchange of the old technology with the new one can have a high capital cost, especially in case of the building/improving/renovating large plants.

Methodology of Operations

Chemical manufacturing creates products by transforming organic and inorganic raw materials using chemical processes. There are over 100,000 chemicals in the marketplace.

Despite this, electrochemical synthesis of chemicals has been limited to a narrow spectrum. The reasons for this have been previously attributed to a lag in the education of chemists and engineers in electrochemistry and electrochemical engineering, a lack of suitable resources for cell construction, and most importantly the prohibitive costs involved (in many cases) in electrochemical synthesis.

Over the past 40 years, however, there have been significant developments in electrochemical synthesis and methods due to the advances in materials science and nanotechnology, the development of in-situ spectroscopy techniques, and progress in multi-scale modelling. As a result, it is timely to revisit some industrial electrochemical processes and to introduce examples of new economic opportunities for the electrochemical manufacturing of chemicals.

- *Chlor-Alkali*: this industry is one of the largest chemical processes worldwide. Its two main components – chlorine and caustic soda – are indispensable commodities that are used for a wide range of applications. Nearly 55 percent of all specialty chemical products manufactured require one of the chlor-alkali products as a precursor, with examples including: adhesives, plastics, pesticides, paints, disinfectants, water additives, rubbers, cosmetics, detergents, lubricants, vinyl and PVC, soaps, glass, cement, medical dressings, textiles, car, boat, and plane panelling, books, greases, and fuel additives;
- *Aluminium*: the electrochemical production of aluminium is one of the most successful examples of how electrochemical reactors can reduce the cost of commodities. Before the implementation of electrolysis, aluminium was as expensive as silver. Today, aluminium is about 400 times cheaper than silver. However, primary aluminium production today is ranked among the most energy and CO_2 intensive industrial processes. Specifically, it is among the world's largest industrial consumers of energy, having an energy cost which accounts for approximately 30% of its total production cost;

- *Electrochemical Synthesis of Organic Compounds*: traditionally, the synthesis of organic compounds has been accomplished via chemical routes. Alternatively, over the last century, the use of electrochemical methods for organic synthesis has been investigated at both the laboratory and industrial scale. Some of the benefits of electrochemical organic synthesis are higher product selectivity and purity, lower number of reaction steps, inexpensive starting materials, less polluting by-products, and lower consumption of energy. However, these advantages have not translated to a widespread use of electrochemical synthesis and only a few processes have been commercialized from the laboratory scale.

Future Outlooks

Due to recent technological advancements and a changing economic climate, electrochemical technologies and processes now represent a relatively untapped frontier of opportunity for unique, enabling, and translational solutions that can benefit the chemical industry. Electrochemical processes provide significant benefits including:

- *Easy integration with renewable energy (electricity) sources.* The scalability of the technologies, as well as their ability to easily operate in an on-demand mode, facilitates the technologies' ability to interface with renewable, time-varying energy sources;
- *Minimization of purification and separation costs.* Electrochemical synthesis and/or electrolysis potentially allow the direct production of pure fuels and/or chemicals;
- *Ease of operation at low temperature and pressure.* Electrochemical synthesis and/or electrolysis typically takes place at low temperatures and pressures as compared to traditional heterogeneous catalytic synthesis. This could represent significant cost savings;
- *Mid-term impact.* The timeframe for implementation of these technologies could be mid-term to long-term (five to twenty years from now);
- *Ease of storage and transportation of feedstock and fuels.* Liquid fuels catalysed through these processes can be transported, stored, and used using existing technology and infrastructure.

Bitcoin Mining

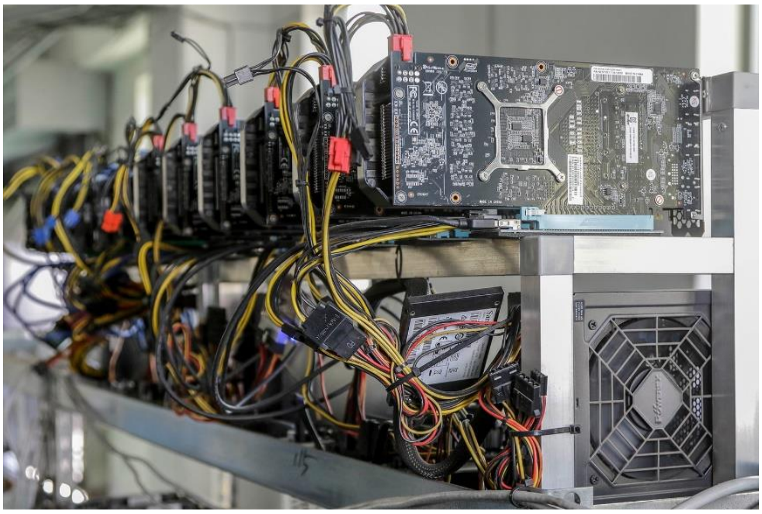

Figure 47: Bitcoin Miners (NurPhoto/Getty Images)

While traditional money is created through (central) banks, bitcoins are “mined” by Bitcoin miners: network participants that perform extra tasks. Specifically, they chronologically order transactions by including them in the Bitcoin blocks they find. This prevents a user from spending the same bitcoin twice; it solves the “double spend” problem.

Skipping over the technical details, finding a block most closely resembles a type of network lottery. For each attempt to try and find a new block, which is basically a random guess for a lucky number, a miner has to spend a tiny amount of energy. Most of the attempts fail and a miner will have wasted that energy. Only once about every ten minutes will a miner somewhere succeed and thus add a new block to the blockchain.

This also means that any time a miner finds a valid block, it must have statistically burned much more energy for all the failed attempts. This “proof of work” is at the heart of Bitcoin’s success.

Bitcoin mining is however a competitive endeavour. As bitcoins have become more difficult to mine, computer hardware manufacturing companies have seen an increase in sales of high-end products.

Computing power is often bundled together or "pooled" to reduce variance in miner income. Individual mining rigs often have to wait for long periods to confirm a block of transactions and receive payment. In a pool, all participating miners get paid every time a participating server solves a block. This payment depends on the amount of work an individual miner contributed to help find that block.

Bitcoin data centres prefer to keep a low profile, are dispersed around the world and tend to cluster around the availability of cheap electricity.

Energy Consumption

As of 2015, The Economist estimated that even if all miners used modern facilities, the combined electricity consumption would be 166.7 megawatts (1.46 terawatt-hours per year).

To lower the costs, bitcoin miners have set up in places like Iceland where geothermal energy is cheap and cooling Arctic air is free. Chinese bitcoin miners are known to use hydroelectric power in Tibet to reduce electricity costs.

Flywheels

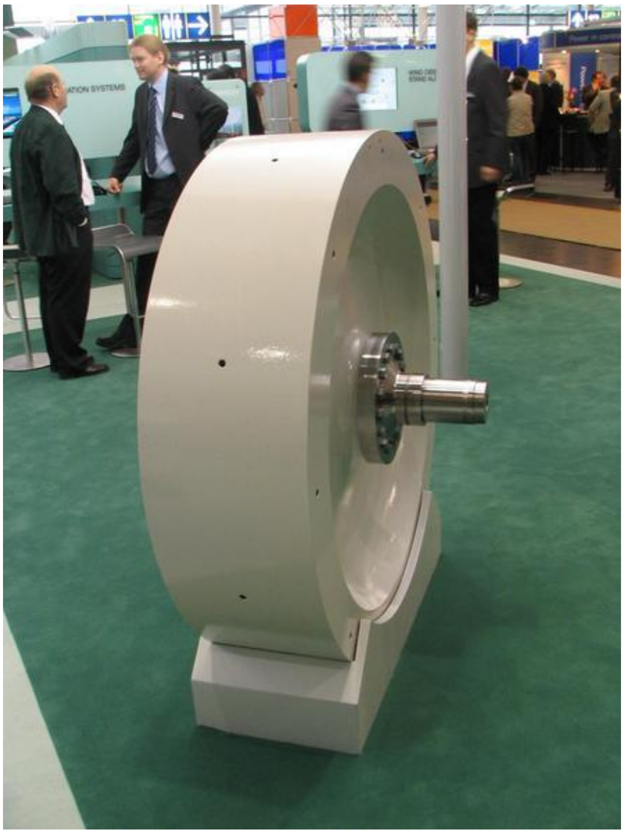

Figure 48: Industrial Flywheel (Volin 2008)

A flywheel is a mechanical device specifically designed to efficiently store rotational energy. Flywheels resist changes in rotational speed by their moment of inertia.

The amount of energy stored in a flywheel is proportional to the square of its rotational speed. The way to change a flywheel's stored energy is by increasing or decreasing its rotational speed by applying a torque aligned with its axis of symmetry.

Flywheels are often used to provide continuous power output in systems where the energy source is not continuous. For example, a flywheel is used to smooth fast angular velocity fluctuations of the crankshaft in a reciprocating engine.

Another example is the friction motor which powers devices such as toy cars. In unstressed and inexpensive cases, to save on cost, the bulk of the mass of the flywheel is toward the rim of the wheel. Pushing the mass away from the axis of rotation heightens rotational inertia for a given total mass.

A flywheel may also be used to supply intermittent pulses of energy at power levels that exceed the abilities of its energy source. This is achieved by accumulating energy in the flywheel over a period of time, at a rate that is compatible with the energy source, and then releasing energy at a much higher rate over a relatively short time when it is needed. For example, flywheels are used in power hammers and riveting machines.

Energy Consumption

Compared with other ways to store electricity, FES systems have long lifetimes (lasting decades with little or no maintenance; full-cycle lifetimes quoted for flywheels range from in excess of 105, up to 107, cycles of use), high specific energy (100–130 Wh/kg, or 360–500 kJ/kg), and large maximum power output.

The energy efficiency (ratio of energy out per energy in) of flywheels, also known as round-trip efficiency, can be as high as 90%. Typical capacities range from 3 kWh to 133 kWh. Rapid charging of a system occurs in less than 15 minutes.

The high specific energies often cited with flywheels can be a little misleading as commercial systems built have much lower specific energy, for example 11 Wh/kg, or 40 kJ/kg.

Other Various Means

There are many other, small scale, means to use excess energy provided by renewable sources. The list below explores some of them:

- Aeration for compost teas;
- Rock tumbler (slow and needs no human intervention);
- Any slow-cooked food items (cookies, brownies, breads);
- Run a kiln for pottery items for personal use or others;
- Make candles/lip balms from beeswax;
- Running power tools for woodworking projects;
- Heating and saving high pressure water, later to be released as steam at lower pressure expanded through a steam turbine;
- Compressing air into huge underground storage areas, may they be abandoned mines, empty salt mines or depleted gas fields. When needed, the high-pressure air is withdrawn through a gas turbine, using the kinetic energy of the expanding air and adding fuel to make up to five times more energy than went in;
- Electrification of transportation via fuel cells;
- Converting waste to fuels via pyrolysis and gasification;
- Fertilizer, copper, iron, concrete. paper, chemical, concrete, desalination, silicon, glass and textiles factories changing their energy usage towards a purely electrical one;
- Freezing water into ice (later used for cooling);
- Boiling water into steam (later used for heating).

An interesting project has been realized in the prototype phase by a start-up called Energy Vault, in Switzerland.

Figure 49: Energy Vault prototype (Energy Vault)

A 120-meter tall, six-armed crane stands in the middle. In the discharged state, concrete cylinders weighing 35 metric tons each are neatly stacked around the crane far below the crane arms. When there is excess solar or wind power, a computer algorithm directs one or more crane arms to locate a concrete block, with the help of a camera attached to the crane arm's trolley.

The system is "fully charged" when the crane has created a tower of concrete blocks around it. The total energy that can be stored in the tower is 20 megawatt-hours (MWh), enough to power 2,000 Swiss homes for a whole day.

When the grid is running low, the motors spring back into action—except now, instead of consuming electricity, the motor is driven in reverse by the gravitational energy, and thus generates electricity.

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Conclusions and Future Works

The model has proven to work well, in different conditions and simulation constraints. The amount of datapoints involved (more than half a million) can cause it to run slower on older and less performant computers, but it is a 'necessary evil' to reach the level of precision (10 minutes intervals between each datapoint) that can successfully approach a real time situation.

The cost/financial portion has been optimized to suit the normal project required data calculations, but it could still need some tuning up by recreating more and more scenarios. Only thus, by accumulating simulation experience, the model will be able to be improved in a constant way.

Further validation has to be done, with larger communities or very different CHP installations, even with non-average heat to electricity ratios, or with limitations to their energy production to avoid any excess to be generated. More precise and extensive data, possibly from a datalogging source, is required to enable the model to perform better in simulating the demand load from the households.

This, naturally, will lead to problems in the charging of the Energy Storages, but the situation has to be simulated accurately before being accepted as possible (or realistically feasible) or discarded.

The addition of the System Load Duration Curve has been proven useful, giving an immediate at-a-glance inside look to how much the system will be covered by the CHPs, and how much load is still missing (and thus required from the grid or from other energy sources).

The households load profile could still be upgraded, again with the analysis of more data, once the regression equations and pattern will have been improved and perfected, to show a smooth transition between days instead of 'steps'. The amount of improvement will have to be calculated, unfortunately, after the substitution with the new dataset has been done, but even if small, it should give out a more realistic feeling to the whole model.

The simulation does not cover, however, the infrastructure work and cost that would be a strict necessity when installing a CHP unit to power already existing households. Metres of hot water heat conserving pipes will have to be brought from the CHP location to each household, and this will mean roadworks, house renovations/restructuration, and all the connected deploying labour.

Furthermore, the more the dwelling is old and poorly insulated, the more the system will perform inefficiently. For example, if just the households in the neighborood had a 1 to 4 electricity-to-heat ratio, instead of the current 1 to 5, everything would change, and the system sizing would need to be readdressed from the start.

The model is capable of simulating a community by recreating each single household behavior, if needed, and not using only an average among all of them. Because, naturally, there will be consumption differences if a couple with three children lives inside a house, while in the next one there is only a single person inside.

Other simulations have been run through the model itself, to see if there were alternatives to the usage of CHP units, Solar PV installations, or Energy Storage solutions. They can be found in the list in the next page:

- *Heating the dwellings via Air Source Heat Pumps*: it is a viable solution, but older and poorly insulated households will lower the efficiency of this particular method. Furthermore, if the ASHP is the type that generates hot water too, then the CHP units would become useless, since the only need would be the one for electricity.
  In this case a Wind Turbine, if the site does not present limitations or constraints from other sources (military, airports, etc.) would be a better choice, paired with an appropriately sized Energy Storage, for providing the necessary energy;

- *Using Solar Hot Water as an accessory mean of heating and activating the CHP unit only when needed, thus limiting the biomass fuel consumption*: unfortunately, the northernly location of the small community makes the use of Solar Hot Water not properly efficient, compared to what it could be in an optimal situation.
  Furthermore, the CHP unit will be necessarily needed during wintertime, and since that is the period with the highest demand, the system would require the same sized CHP unit that has been used in the second simulation. However, if that unit is used for less time, it will naturally produce less energy, thus gaining less ROC certificates and less RHI incentives, going to increase the costs along the years, and finally increasing the ROI beyond acceptable limits. So, this solution has to be discarded;

- *Using a district heating-sized Air Source Heat Pump instead of one for each household, paired with Solar Hot Water, Solar PV and a CHP unit*: again, the northern position of the community plays against an optimal efficiency Solar Hot Water installation, and for a district heating sized ASHP there are new infrastructural costs to be considered, in addition to the CHP ones, and as already stated in the second point, if the CHP unit has to provide electricity/heating during Winter, the same sizing concerns expressed in the same point have to be applied again here. This project too has to be developed once more from the start in favour of finding and analysing a better choice of combining the different energy sources together.

In conclusion, as also stated in the opening, the overall model works, and the general calculation logic has demonstrated a good adaptability to the proposed tests, which need to be extended in any future development in the following phases. The second simulation is the one that has proven to be the most efficient one for the small community of Seaview, even if as of now the output is only a rough estimation and it needs to be improved in the future stages, to obtain a better accuracy level.

It is important to stress that, to reach the desired aim, having a very good raw starting dataset - which has to be the most complete as possible- is a primary requirement. This because the final model will produce realistic results only if the input data are thoroughly filled with a complete set of values which as of now is still missing. If this condition is not satisfied initially, the model will still function properly (and new data can always be input in any phase), but the provided results could deviate from the effective reality, generating thus only a hypothetical possible result, and not what it is needed to achieve the objective of this project.

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