EnergyREV

Perth West as a case study for the value of greenfield smart local energy systems

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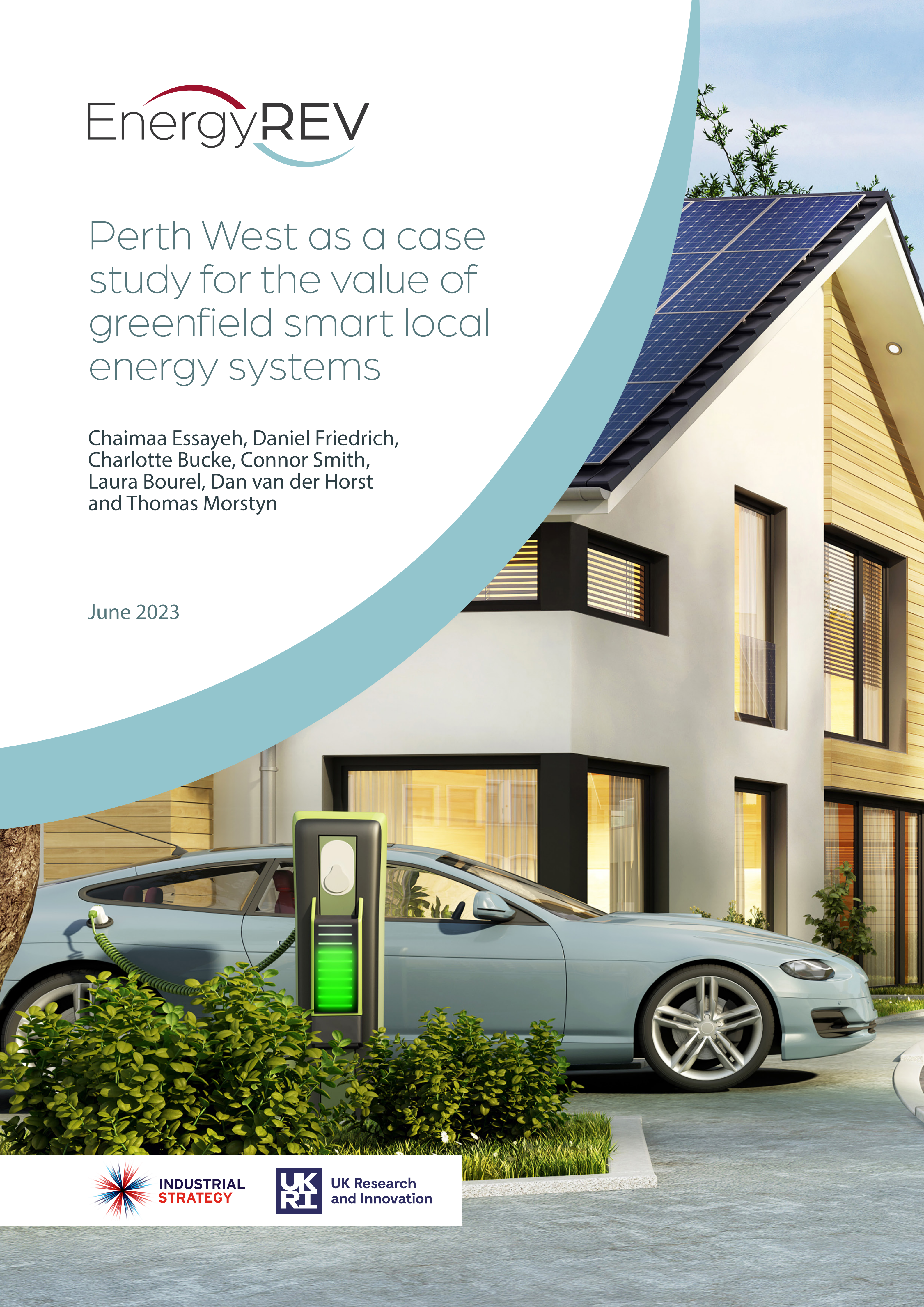

INDUSTRIAL STRATEGY

UK Research and Innovation

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Glossary

AF	Annuity factor
BESS	Battery energy storage system
CoP	Coefficient of Performance
EV	Electric vehicle
HP	Heat Pump
H2	Hydrogen
LCOE	Levelised cost of energy
PV	Photovoltaic
SC	Smart charging
SLES	Smart local energy system
V2G	Vehicle to the grid

Contents

Executive summary

Smart local energy system (SLES) can help achieve the Government target of net-zero by enabling the integration of local renewable generation and demand-side flexibility. Within the EnergyRev research consortium, our team focuses on unlocking the benefits of SLES by studying new market designs and proposing innovative business models that can be scaled out across the UK and internationally.

This report aims to provide a feasibility and options analysis into the value of SLES technologies and a 20-minute neighbourhood approach to infrastructure by focusing on a development planned for outside of Perth in Scotland.

Perth West is a Greenfield project located in the west of Perth city. Its developers aim to make it "the most desirable place in Scotland to live, work, visit and invest". Perth West aims to deliver an inclusive, green economic growth agenda to achieve this goal. This will include the incorporation of clean technologies to serve smart city growth and support decarbonised energy, heat and transport. The sustainable infrastructure will attract a cluster of new businesses and industries.

Our techno-economic feasibility study aims to determine the potential energy sources and infrastructure that will help the site reach the net zero carbon target. The results show that there is an opportunity to minimise the costs of energy delivery by building a solar photovoltaics (PV) capacity of around 47 MW and a battery capacity between 33 MWh and 48 MWh. Using the optimal combination of PV capacity and battery capacity, the site can supply up to 48 % of its demand from local renewable energy. With Smart Charging (SC) for electric vehicles (EV), where a smart system integrated with the charging device selects the most beneficial time for the charging, we need up to 7% less battery capacity installed, costs of import are reduced by up to 17% and the autonomy increases by 41% compared to non-flexibility scenarios. With vehicle to the grid (V2G), not only does the charging device shift the charging period from periods of high grid stress to off-peak periods, but also allows for the injection of power from the EV battery to the grid. This decreases the battery capacity by a further 25% compared to the SC scenario. It is recommended that the site developers enter into corporate power purchase agreements with adjacent sites that generate clean energy to complement their remaining need for supply. The excess of local energy is seasonal; 88% of excess occurs during the summer period. The seasonality of the excess energy can benefit the site through the implementation of seasonal storage, a seasonal Hydrogen refuelling station, or by entering into a utility power purchase agreement (PPA) with a licensed supplier.

The technical study was done alongside a social study, which examined citizens' behaviour and their willingness to engage in the transition to the net-zero target. We received 79 survey responses and 8 participants engaged in additional online focus groups. The social study found that local residents are willing to engage with the net zero agenda, demonstrating an appetite, in principle, to alter their transport habits and retrofit their homes.

Both focus group and survey participants were receptive to replacing their petrol/diesel vehicle with an EV, as opposed to simply getting rid of their vehicle or replacing it with a bike, bike sharing scheme or car sharing scheme. However, it became clear that replacing a petrol/diesel vehicle with an EV would be under the condition of improved affordability and more local charging infrastructure. Local charging infrastructure should be implemented in conjunction with smart charging or V2G to avoid stressing the network infrastructure. In addition, we recommend understanding community patterns and the development of affordable at-home EV charging infrastructure. If cost was not a barrier for retrofit options, 44.3% would consider air source heat pumps (ASHPs), 50.8% would consider ground source heat pumps (GSHPs), 68.2% would consider solar photovoltaics (PV), and 72.6% would consider solar water heaters. However, the reality is that the upfront cost is a major barrier suggesting the need for high-level support.

Focus group participants raised concerns that the Perth West development, alongside other close by residential developments, could exacerbate already problematic traffic congestion. This was also a clear concern drawn from the survey results. However, it is worth noting that participants did not consider this issue in relation to the Cross-Tay-Link-Road (CTLR), a construction project which proponents hope will help to ameliorate existing traffic congestion. It is conceivable that this knowledge could positively influence residents' perceptions and should therefore be considered by future research.

1. Context

1.1 Net zero target

In June 2019, the UK parliament passed the legislation to reduce the UK net greenhouse gas (GHG) emissions by 100% compared to 1990 by 2050. The Scottish Government set a tighter deadline and committed to net zero emissions of all greenhouse gases by 2045.

The UK decision came in alignment with its commitment in the 2016 Paris Agreement to hold the increase in the global average temperature to well below 2°C above pre-industrial levels.

Although the global CO2 emissions of the UK have been decreasing steadily over the last 20 years (see Figure 1), reaching the net-zero emissions target is highly challenging, yet still feasible.

In response to the UK ambition, Perth & Kinross Council (PKC) declared a climate emergency to support the UK Government reaching the net-zero target and launched the Climate Strategy and Action Plan.[1] Through their Action Plan, PKC aims at:

- Achieving Net Zero aligned with the Paris Agreement and Scottish Government targets by 2045, if not before
- Building a more resilient Perth and Kinross
- Ensuring climate change action is fair and the transition to a green economy benefits all
- Enhancing biodiversity
- Engaging young people and empowering them to take action against climate change
- Empowering businesses and communities to take climate action in line with the Perth and Kinross Offer.

The sectors that will be most affected by the decision to go net-zero are transportation, energy and heat (Figure 2). Apart from being the sectors with the highest CO2 emissions, those sectors are the ones that will need a radical reform to help the UK Government reach its target.

1.2 Perth West and its ambition

Perth West is a Greenfield site elected as a strategic development area in PKC. The vision is to develop the site into "*the most desirable place in Scotland to live, work, visit and invest*".

1 Let's work together to tackle and adapt to climate change (Phase 1) | Perth & Kinross Council

In order to meet this ambition, Perth West is well placed to help deliver an inclusive, green economic growth agenda.

- **Inclusive Growth**: Ensure Perth West is aligned with the themes identified within the Perth City Plan and that Perth West engages in the City Centre 'First' principles. City centre 'First' principles put the city centre of Perth at the heart of Perth development, and ensure that new developments support the City Centre.
- **Sustainable Growth**: Incorporate clean technologies to serve smart city growth and support decarbonised energy, heat and transport.
- **Economic Growth**: Attract new businesses to invest in the site and encourage through the implementation of the sustainable infrastructure the establishment of new business models, research ventures and industries.

Figure 1: Annual CO2 emissions over the last 35 years, UK. The emissions have been falling steadily reaching a reduction of 45.1% by 2020 compared to the baseline in 1990.

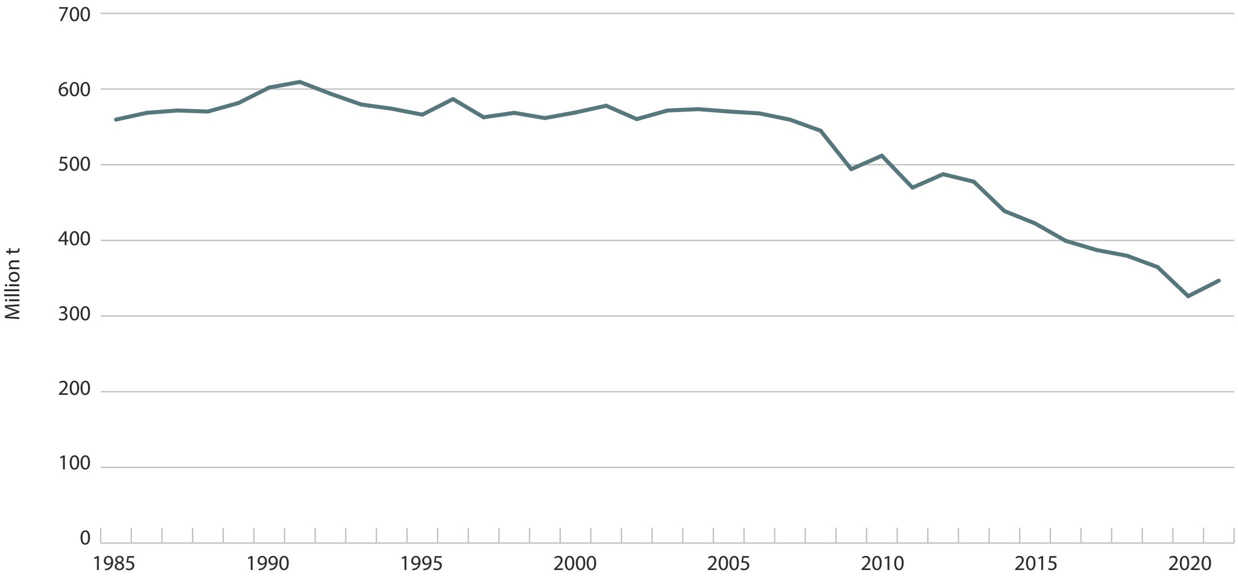
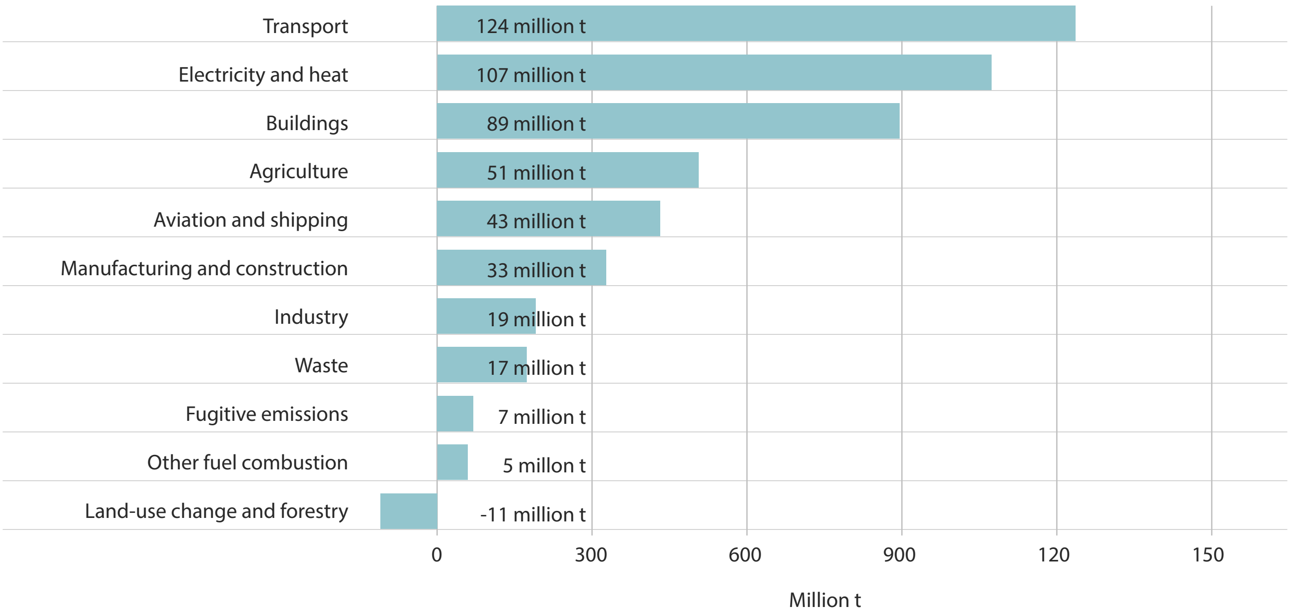


Figure 2: Contribution of sectors in GHG emissions, UK (2018).



The four main components (Figure 3) of Perth West that were determined to fulfil the aforementioned priorities are described below:

a. The Perth Innovation Highway

The Perth Innovation Highway describes a corridor that connects existing and planned city mobility, comprising physical and digital infrastructure. The digital infrastructure composed of road sensors and their underlying communication network will be used to collect relevant data that will then serve to understand the mobility profiles and support the sustainable mobility strategy. The highway places Perth West as a strategic location that will:

- Enhance further the connectivity between northern and central Scotland.
- Strengthen Perth's potential growth opportunities.
- Increase the strategic value / opportunities for Perth West.
- Actively support modal shifts to electric vehicles and active travel (e.g., walking and cycling) within and around Perth West.

b. The Perth Eco Innovation Park

The Perth Eco Innovation Park, which is a business development projected to support 2,300 gross jobs. It incorporates:

- A logistics hub: providing access to a range of transport services including active travel, infrastructure for electric vehicle charging and a last mile delivery facility.
- A knowledge hub: comprising of an R&D facility, an innovation park, office spaces and meeting room hire.
- A consolidation centre: hydrogen-refuelling facility.

3. DR.ECO Renewables Park

A utility-scale (20 MW+) PV farm that generates and distributes renewable energy to the site. The Park will connect to other flexible technologies to deliver a reliable clean energy supply. The potential for a community battery storage, seasonal and/or hydrogen storage will support the park in supplying low/zero carbon electricity and heat for consumers, buildings and mobility facilities.

4. Lamberkin Village Urban Innovation

Land for 3,500 homes within the Perth West site, including approximately 875 affordable homes. The area includes other social amenities such as primary and secondary schools, a heritage park, neighbourhood retail space.

This report aims to provide a feasibility and options analysis into the value smart local energy system (SLES) technologies and a 20-minute neighbourhood approach to infrastructure can offer Perth West. SLES can help achieve the Government target of net-zero by enabling the integration of local renewable generation and demand-side flexibility. Within the EnergyRev research consortium, our team focuses on unlocking the benefits of SLES by studying new market designs and proposing innovative business models that can be scaled out across the UK and internationally. This report includes two main components:

- A citizen engagement study which served to (a) examine potential low-carbon and sustainability synergies between the planned greenfield development (which has high potential to be low-carbon) and adjacent existing neighbourhoods (which need a low-carbon retrofit), (b) provide model population data which could represent the future residents of Perth West, in terms of (broader) sustainability concerns and interest in adopting or living with low-carbon technologies.

- An integrated smart local energy system: a techno-economic feasibility study is conducted to determine the potential energy sources, models and infrastructure that will help the site reach the net zero carbon target. This includes considering demand from heat, transport and electricity, and should be considered alongside the willingness of the community to engage.

The rest of this report is organised as follows. In Section III, we present the potential sources of generation and flexibility in the site, and elaborate a high-level estimation for the different loads, including the demand from the heat and transportation sectors. The techno-economic feasibility analysis is presented in Section IV. We report the results of the study on citizen engagement in Section V. Section VI concludes the report and provides key conclusions and recommendations.

Figure 3: Perth West plan.

1 A9 Tibbermore Junction & Hydrogen Refuelling Facility
2 Heritage Park
3 West Mid-Lamberkin Neighbourhood Centre
4 East Mid-Lamberkin Neighbourhood Centre
5 Perth Eco Innovation Park
6 Perth Innovation Highway
7 Broxden Mobility Hub
8 Broxden neighbourhood Centre
9 A9
10 West Lamberkine Wood
11 Shared Infrastructure Connection to Central area
12 Primary School

2. Mapping of potential sources of generation, demand and flexibility

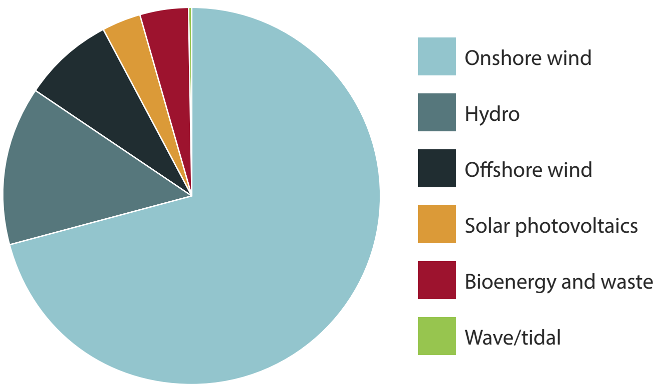
2.1 Generation

Traditionally, fossil-fuel plants have met electricity demand. With climate change and the commitment of the UK to the 2016 Paris Agreement, the generation mix has changed, and new forms of renewable generation are available. In 2020, 25.4% of Scotland's energy demand was met by renewables. (The Scottish Government , 2022)

2.1.1 Renewables

Among the different sources of renewable generation, onshore wind, offshore wind, hydro, bioenergy and waste, solar PV, and wave and tidal were the most installed technologies in Scotland (Figure 4).

Figure 4: Renewable mix for 2021. Source: Scottish Renewables.

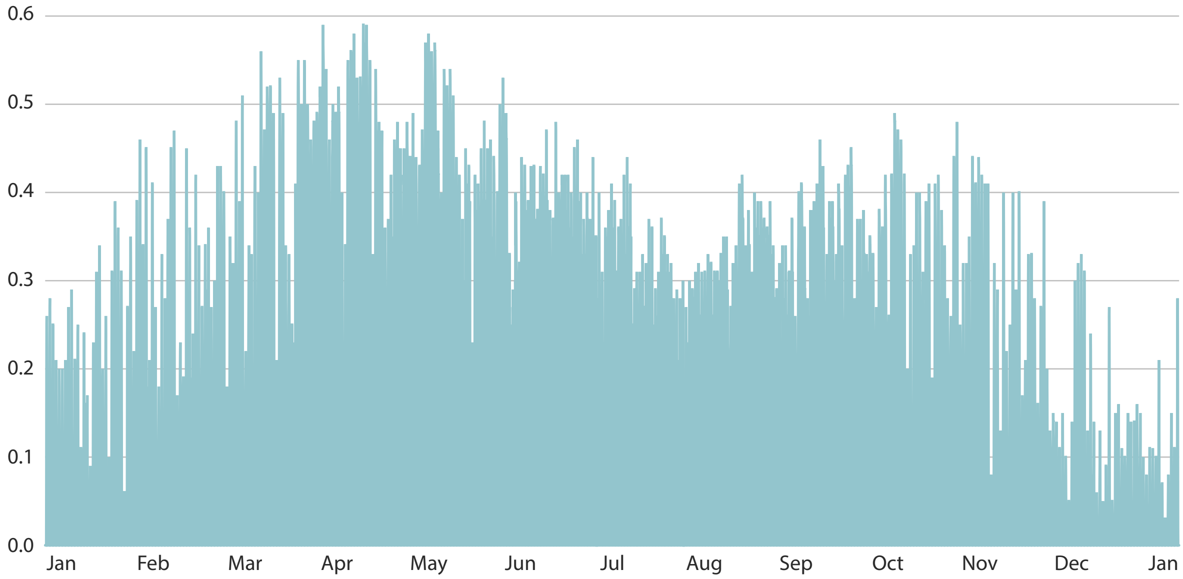


The relevant sources for Perth West are solar PV and bioenergy.

PV technologies can be divided into Ground-mounted solar PVs, which tend to be large-scale installations and Rooftop solar PVs that are generally of smaller scale and are installed behind the meter (btm PV). In coming years, btm PV is expected to continue rising, particularly in areas with new build developments (Regen , 2019). According to recent reports, 40% of new homes in the UK would have 3.6 kW PV system implemented and around 20% of domestic properties will host rooftop PV by 2050 (Regen, 2022).

Figure 5 shows the solar energy output as a ratio of the nominal capacity of a solar system for the location of Perth based on 2019 weather data. The seasonal variability is easily noticeable, with abundant output in the summer season compared to the winter season, and energy available only during daylight hours. This implies that the implementation of a solar plant should be backed up by a storage system if the autonomy of the site is to be considered.

Figure 5: Solar energy rate for the site (2019 data).



According to NREL, the overall cost of a utility-scale PV is:

- \$0.94/Wp for fixed-tilt utility-scale PV systems
- \$1.01/Wp for one-axis-tracking utility-scale PV systems

For the study, we selected the fixed-tilt type and considered the cost of PV to be 770.8 £/kW. This cost includes the hardware, installation expenses and the soft costs such as the sales tax and the transmission lines.

Bioenergy was not considered as a source in the study for several reasons. Bioenergy is the process of extracting heat and electricity from decayed living organisms such as wood and organic waste. There is an immense potential of bioenergy for heating networks by using waste heat (sources include distilleries, data centres and industry). Nevertheless, SSEN the licensed distribution operator of the north of Scotland, reports that waste technologies such as Energy from Waste (EfW), Anaerobic Digestion and Biomass all see minimal capacity increase over the period 2030-2050, reflecting the low densities of population and agriculture over much of their licence area (Regen , 2019). Furthermore, bioenergy has a detrimental impact on air quality, especially in urban areas, and can compromise the ability to meet legal obligations under air quality legislation.

2.1.2 Non-renewable supply

The site will not have local non-renewable generation. There are three options for the connection to the grid:

a Grid connection from the site

This option requires the installation of a private wire between the generator (DR.ECO in this case) and the off-taker (Perth West). The off-taker owns the grid connection that is required to be bidirectional to allow the generator to export excess generation, should the generation be higher than the demand of the site.

The import of energy should follow a utility Power Purchase Agreement (PPA) to buy electricity from a licensed supplier, or in case the electricity demand is large, the site can directly enter the wholesale market and buy energy from other generators.

The site developers aim at implementing a BESS alongside the PV system to increase the site's autonomy. However, in some cases and due to the operational limits of the battery, the excess of solar generation cannot be stored fully. In similar cases, exporting energy to the grid can be an option to avoid curtailment and increase the site profit.

For the export, the solar energy is not eligible for the Contracts for Difference (CfD) scheme, and as the solar farm to be implemented will have a capacity greater than 5 MW, it cannot benefit for the Feed-in-Tariff (FiT) or smart export guarantee (SEG) schemes (OFGEM, 2019). The only way to inject the solar energy into the grid is to negotiate a power purchase agreement (PPA) with a licensed supplier (generally, it is the same supplier for energy import), or claim the SEG if the power to be injected is always less than 5 MW. In the former case, the generator (i.e., DR.ECO) enters into a spill PPA with the licensed supplier who pays a discounted system-selling price for the excess because it has no control or visibility over it.

b Grid connection from the generator

This is similar to the first option, except that the grid connection point is located near the generation. In this case, the off-taker requires a firm supply from the generator, and the generator imports energy from the grid on behalf of the off-taker to fulfil the site demand. This implies that the generator enters into a power purchase and power supply agreement with a licensed supplier and the off-taker reimburses the generator for the imported energy.

c Two grid connections

As the solar farm (DR.ECO) and the site are not in the same location (Figure 6), the site has the option of constructing two connection points, one connection point near the DR.ECO to allow the injection of the excess and another connection near the site for the energy import. This option is unlikely to be adopted, as the costs of building two grid connections will cancel out the benefits.

The costs of a grid connection depend predominantly on the installed transformer/substation and the cables/overhead lines that connect the installed transformer(s) to the site.

The costs for the necessary reinforcements and connection to the grid were extracted from the DNO proposals. For confidentiality purposes, we do not display this information in the report. For a capacity lower than 0.76 MW, the site will need no reinforcement and the existing infrastructure is able to support the site demand. Beyond that capacity, new substations will need to be installed. The DNO estimated the costs for capacities up to 22,750 kW and the curve of the costs follows a stepwise trend, which implies that the reinforcements costs will be the same for a range of capacities.

The average half-hourly wholesale prices were extracted from the historical data of EPEX platform. The mean price is around 74 £/MWh with 90% of the data less than 100 £/MWh (Figure 7).

We used data from the EPEX platform as an estimate for the future energy prices. Nevertheless, we note that the prices can have an unpredictable behaviour due partially to the future carbon taxes and mainly to the unstable geo-political circumstances.

Figure 6: Location of the site and the planned solar farm relatively to the city of Perth and the primary substation.

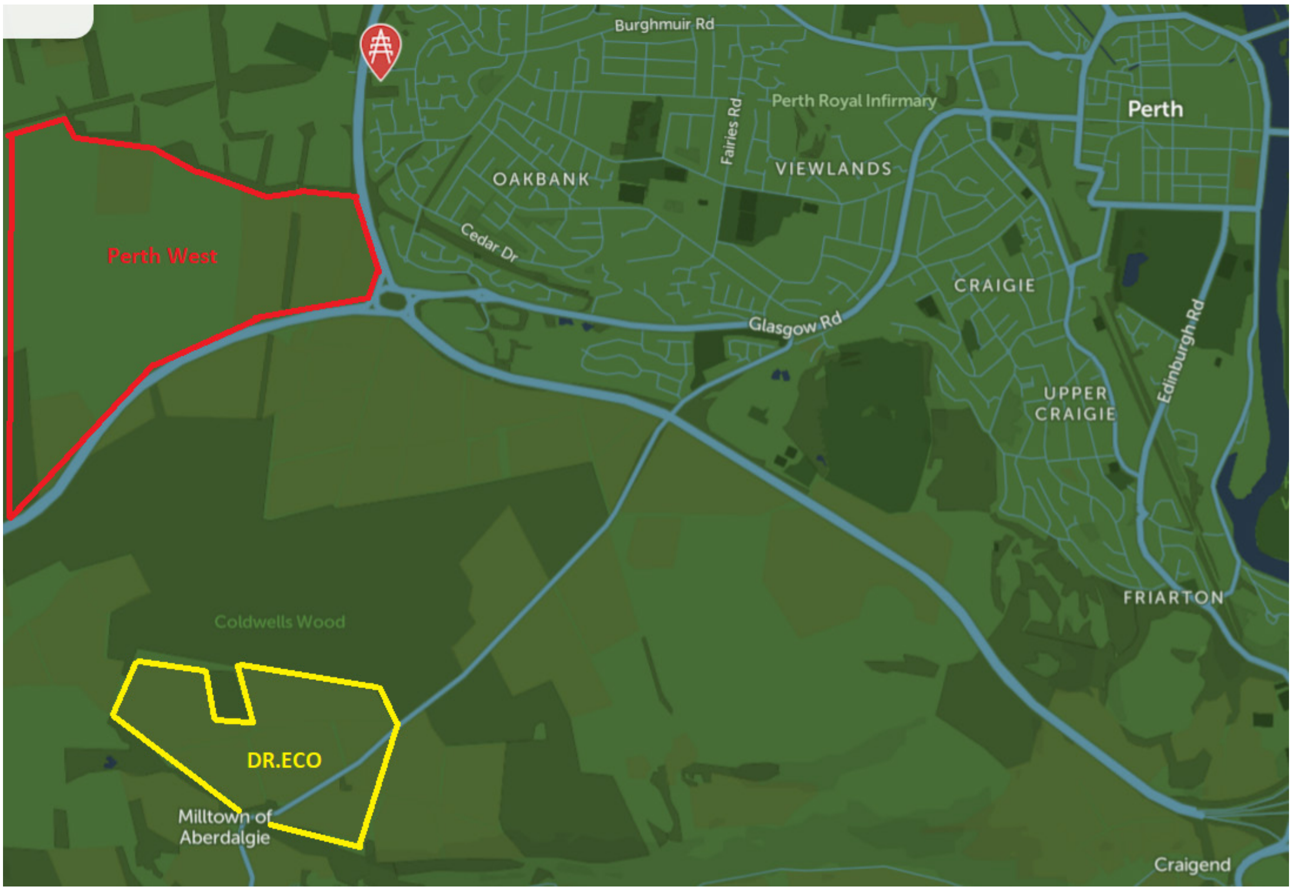
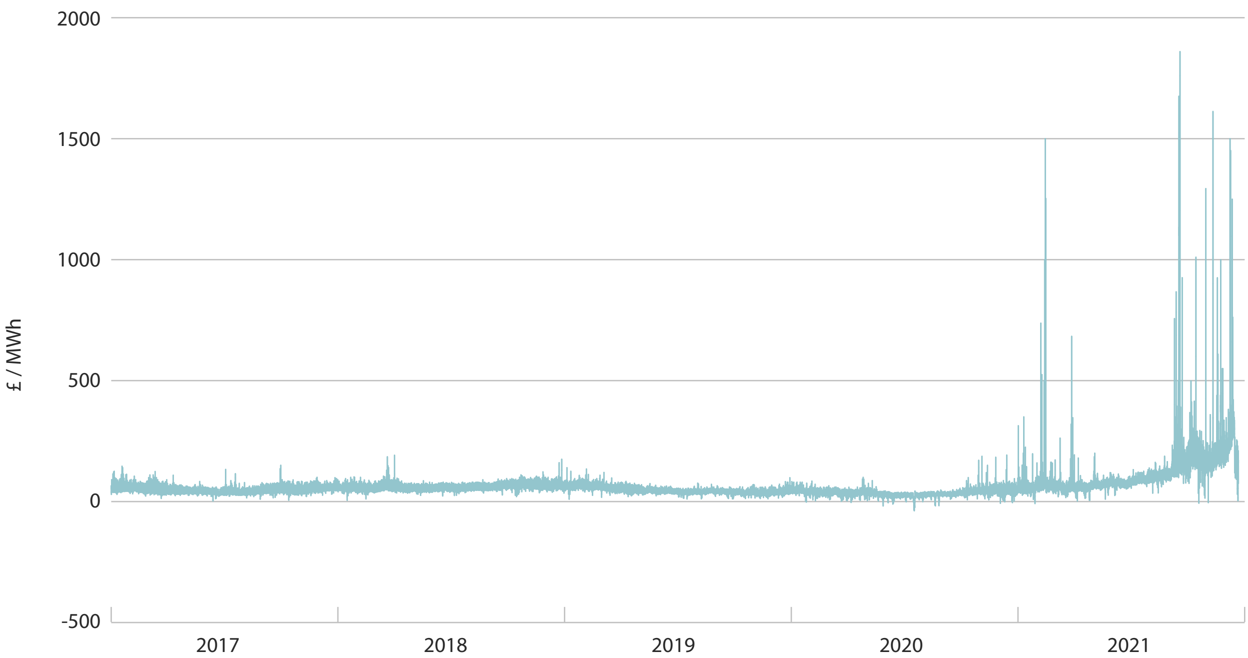


Figure 7: Average wholesale energy prices for the last 5 years.



2.2 Demand

Traditionally, electricity demand was mostly made-up of residential demand, buildings and industrial and commercial use. With the electrification of heating and transport, the estimation and forecasting of electricity demand have to consider the consumption from both of these as well.

Here, we call the conventional electricity demand the baseline demand, and we present an estimation of the electric demand of the site.

2.2.1 Baseline demand

*** Non-domestic consumption:**

The estimation of the baseline non-domestic demand for the site was based on two different inputs:

1. Data from the master plan of the site that includes the area dedicated to the commercial and business use (Table 1), and
2. Data from PKC that gives a 30-min load consumption for non-residential buildings in the local authority of Perth from the period between January 2020 and April 2022 (PKC, 2022). The types of buildings include offices, primary schools, a hostel and a nursery (Figure 8).

An electricity intensity of 100 kWh/m2/year (BEIS, 2020) is used to compute the annual consumption for the commercial buildings.

The 30-min data is useful to capture the intraday variations of the demand, which will play a crucial role in determining the appropriate size for the components of the smart energy system. The data is representative and can serve as an estimate for the site. The annual electricity consumption for non-domestic buildings in Perth is approximately 10,732 MWh. A reasonable upscaling factor (Table 1) is selected to simulate the intraday variations of energy consumption in the site.

Table 1: Data for the estimation of the yearly non-residential demand

Assessment	Cumulative area (m^2)	Cumulative load (MWh)	Scaling factor
A	45,321	4,532	0.42
B	107,202	10,720	1
C	155,254	15,525	1.45
D	203,307	20,330	1.9
E	251,359	25,135	2.34

* Domestic consumption:

Since the site is not developed yet, information on the population, house type and insulation is limited. We base the study of the domestic consumption on Profile Class 2 -Domestic Economy 7 Customers- as provided by UKERC Energy Data Centre (Elexon, 2018). The dataset provides the half-hourly electricity consumption of a household under Economy 7 tariff, for an autumn, winter, spring, summer and high summer weekday, Saturday and Sunday.

As the site hosts around 3500 residential units, the load profile was up-scaled by a factor of 3500 to approximate the electricity consumption from the residential premises of the site.

Figure 8: Electricity consumption for non-domestic buildings in Perth for the year 2021.

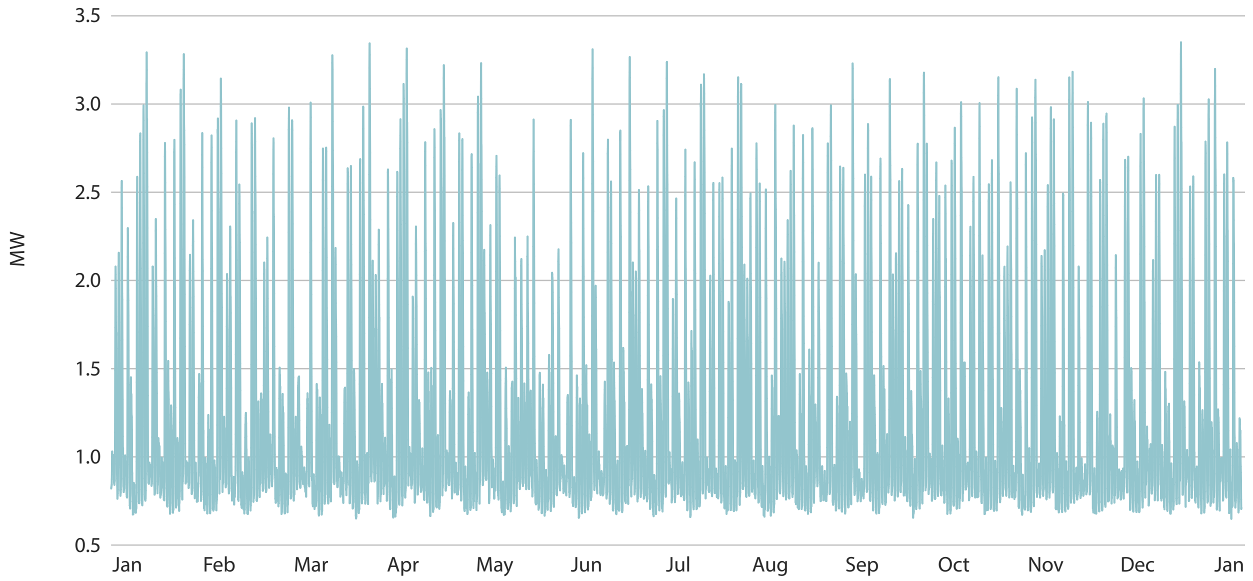
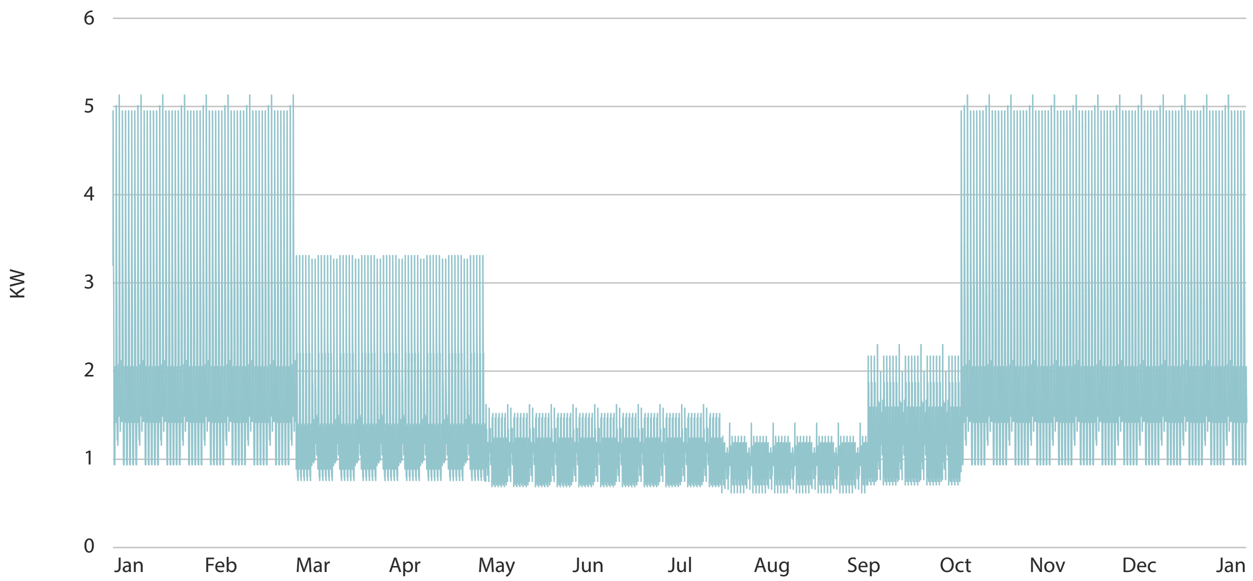


Figure 9: Load profile for a domestic building -Economy 7 Tariff Scheme.



2.2.2 Heat

Heating is one of the sectors contributing to the highest GHG emissions in the UK, this is largely due to the fact that most of heating is provided by gas networks. In Scotland, gas networks provide 81% of heating (Scottish Govenment, 2020).

The decarbonisation of heat plays a crucial role in the transition to the net-zero target. The three main options for heat decarbonisation are:

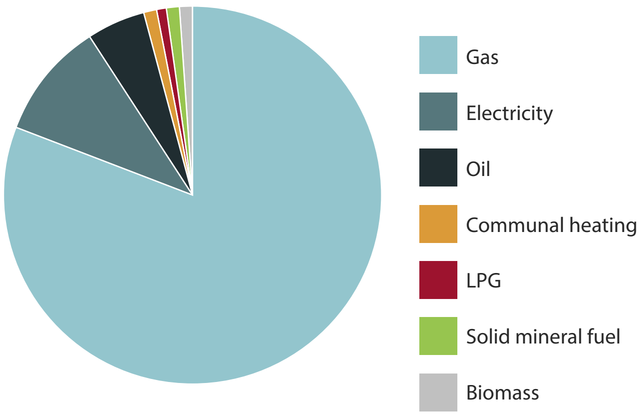
* Repurposed gas networks:

This option suggests blending gas with hydrogen in the existing gas networks. This option is attractive in densely populated regions such as urban and sub-urban areas, as it implies minimum disruption and less construction costs. From the consumer perspective, it only needs the installation of hydrogen-fitted appliances (i.e., heaters, cookers). Nevertheless, this option does not cancel the carbon emissions from the domestic heating sector, but only reduces it to a certain level. Around 20% hydrogen is often cited as the technical limit for which existing appliances can be retrofitted.[2] Currently, the UK Gas Safety (Management) Regulations (GS(M)R) permits only 0.1% hydrogen injection into the gas pipes, a rate that was debated by different entities as being a tight limit (National Grid Gas Distribution, 2020).

* District heating:

District heating can be a cost-effective way to supply heat. It can contribute to decarbonisation if the source used for heat production is low-carbon such as biomass, geothermal, large-scale heat pump (commonly water source and ground source) or otherwise unused wasted heat. The availability of otherwise unused or hard-to-use waste heat is a crucial factor in the economics of district heating systems. For example, many district heating systems in Scandinavia use the excess heat from waste to energy plants.

Figure 10: Primary heating fuel for households, Scotland 2019.



The supply temperatures of district heating systems have been reduced in subsequent generations. Currently, most new district heating systems are either 4th generation with supply temperature around 60 °C or ambient loop systems with supply temperature around 25 °C. The 4th generation district heating systems are particularly suitable for areas with a high heat demand and anchor loads such as hospitals. They require a high linear heat density, i.e., near uniform heating demand per year and per metre of district heating pipe, to be economically viable.

2 RR1047 Injecting hydrogen into the gas network – a literature search | Health and Security Executive

Such high linear heat densities are unlikely to exist in a predominantly residential development using the latest building standards.

On the other hand, ambient loop systems can be suitable for districts with lower heat densities if these sites have heating and cooling demands with sufficient temporal overlap. In this case, the ambient loop can balance the cooling and heating demand which would significantly reduce the required primary energy and costs (Gudmundsson, Schmidt, Dyrelund, & Thorsen, 2022).

While an ambient loop system might be suitable for the Perth West site, the design and analysis were beyond the scope of this study. The combination of residential and commercial properties with low-cost low temperature seasonal thermal energy storage has the potential to significantly reduce the primary energy required for cooling and heating but would require a detailed design study (Wirtz, Kivilip, Remmen, & Müller, 2020).

* Electrification:

Electrification of heating can present an interesting option for heat decarbonisation once a low-carbon electricity infrastructure is set-up. This option is likely to be adopted in less populated areas, or in regions that are off gas grid. Technologies include air source heat pumps (ASHP), and vertical or horizontal ground source heat pumps (GSHP). Delivering heat using highly efficient HPs can reduce the electricity consumption. The coefficient of performance (CoP) of these technologies can range between 2.6 and 5, i.e., for each 1 kWh of electricity, the heat pump delivers between 2.6 and 5 kWh of heat. However, the capital cost of procuring such equipment can be prohibitive for certain customers, and the cumbersome volume can be a barrier for their adoption in space-limited households.

For the site, we consider the electrification option for the following reasons:

- As the site is under development, there is no existing gas network infrastructure, and the costs for building such infrastructure will be higher than the costs of adopting the other options.
- The site does not have the minimum heat density for an efficient district heating network. A study conducted by a consultancy group on behalf of the site developers demonstrated that the site requires a large additional commercial space and/or dwelling units to achieve the minimum density that makes district heating an economically feasible solution.

We consider a conservative scenario and select a low CoP for our studies, i.e., CoP =2.7.

Next, we present the estimations of heating demand for residential and commercial premises.

* Non-domestic heat demand:

We followed the same strategy as for the non-domestic electricity demand. We extracted the gas consumption from the PKC dataset (PKC, 2022) and considered an efficiency of $\eta_{gas\ boiler} = 0.85$ to conclude the heat demand (Figure 11).

* Domestic heat demand:

According to (BEIS, 2021), the median gas consumption for households is 12,300 kWh/year. We multiplied it by the same efficiency factor $\eta_{gas\ boiler} = 0.85$ to extract the yearly heat demand, and then used the half-hourly profiles of heating technologies from UKEDC datasets (UKEDC, 2019) to estimate the consumption for domestic heat demand. The energy consumption is then deduced by considering an efficiency factor of $CoP_{heat\ pump} = 2.7$ (Figure 12).

Figure 11: Heat demand for non-domestic buildings in Perth for the year 2021.

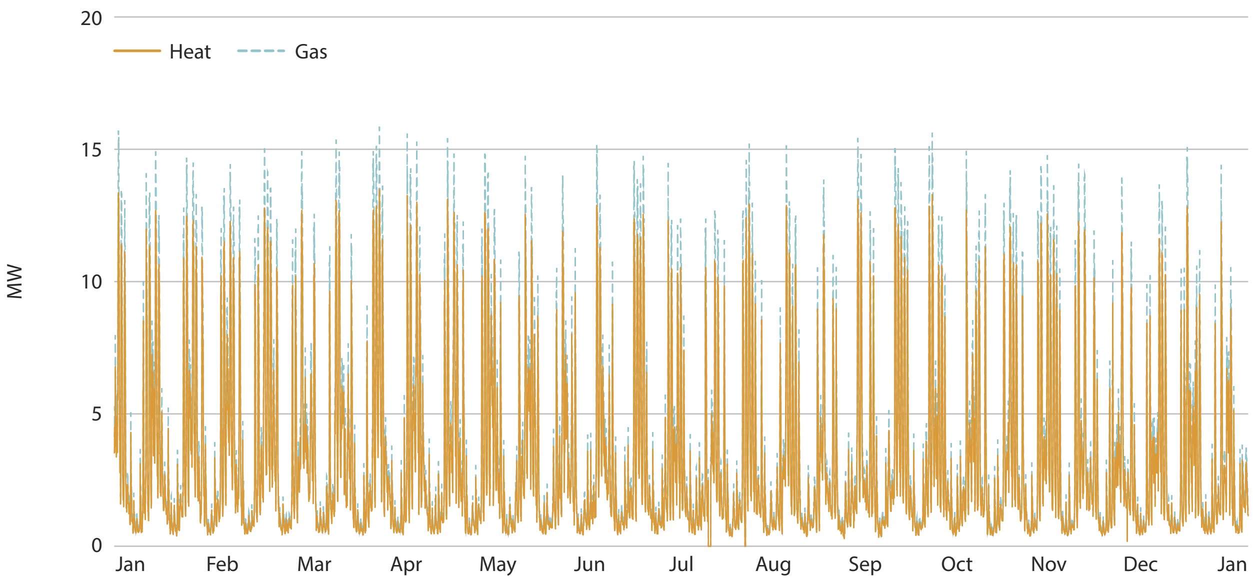
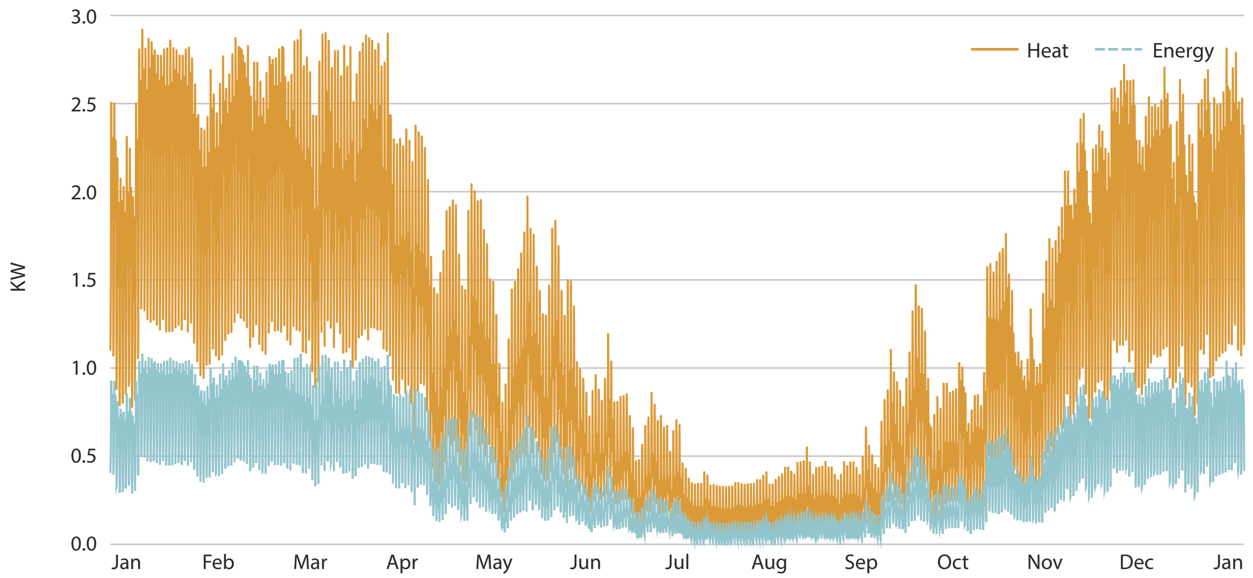


Figure 12: Heat demand profile for domestic premises.



2.2.3 Transport

Transportation is responsible for a third of the CO2 emissions in the UK. We distinguish two main solutions for the decarbonisation of this sector:

* Electric vehicles (EV):

Electric vehicles use traction battery packs to run an electric engine. Currently, the capacity of commercial cars falls in an interval of [16.7, 118] kWh with an average around 45 kWh, and the range goes from 95 km to 695 km with an average of 326 km. Note that it is likely the capacity will increase in future, allowing for greater ranges, due to battery technology improvement.

We define four main categories of charging infrastructure: Residential, Fleet, in Town and En-route. For residential infrastructure, a dedicated charging pile is installed at the owner premises, and for fleets the infrastructure is implemented in depots for cars belonging to the same entity, e.g., public transport, delivery cars/trucks of a company. Both of these are private and are only available for the designated users. The last two are public and are available for the wider community. In town is the charging infrastructure that comes as an amenity service, e.g., at a business park or a shopping mall. The last one is the equivalent of the existing petrol stations that we find at highways, inter-city roads or in the city.

The most common charging pile is AC type 1 and has an average power rate of 7 kW. It is also called slow charging as it may take between 5 to 10 hours to fully charge an EV with an average capacity. It is the type of charger implemented in residential premises. The second AC type accommodates a higher power rate and is available in public charging points. In the UK, AC charging accounts for 83 % of installed chargers. DC chargers are faster but there are currently few models in the market, and not all the existing EVs are adapted to this new charging technology.

Table 2: Types of chargers and their charging rate

AC type 1	AC type 2	DC fast	DC Rapid	DC ultra-rapid
3-11 kW	11-22 kW	50-150 kW	150-350 kW	> 350 kW

DC rapid and ultra-rapid charging technologies will be suitable for the en-route charging stations to provide last mile logistics (LaMiLo) as well as long distance travel services, while the AC type 2 and the DC fast charging can serve the in-town stations.

* Fuel cell electric vehicles (FCEV):

Fuel cell electric vehicles present the alternative of using hydrogen as a fuel. This is more suited for heavy goods vehicles (HGVs) as it allows for a greater range. The adoption of this new vehicle type will depend on the availability of the refuelling infrastructure. Compared to the EV case, there are fewer hydrogen refuelling stations. We count 14 stations[3] in the UK by the end of April 2021.

Providing LaMiLo services is one of the objectives of Perth West. The site aims particularly at the construction of two main stations: Broxden charging station located near the Broxden roundabout and the new highway service station. Broxden charging station will serve mainly EVs, while the new junction charging station will serve both EVs and FCEVs.

To estimate the EV demand of both stations by 2030, we use the existing demand of the charging points in Perth (Figure 13) and we upscale it to account for the increasing demand of EVs.

3 Where is my nearest hydrogen service station in the UK? | Hydrogen Batteries

Figure 13: Aggregated electricity consumption of all the charging points located at Perth.

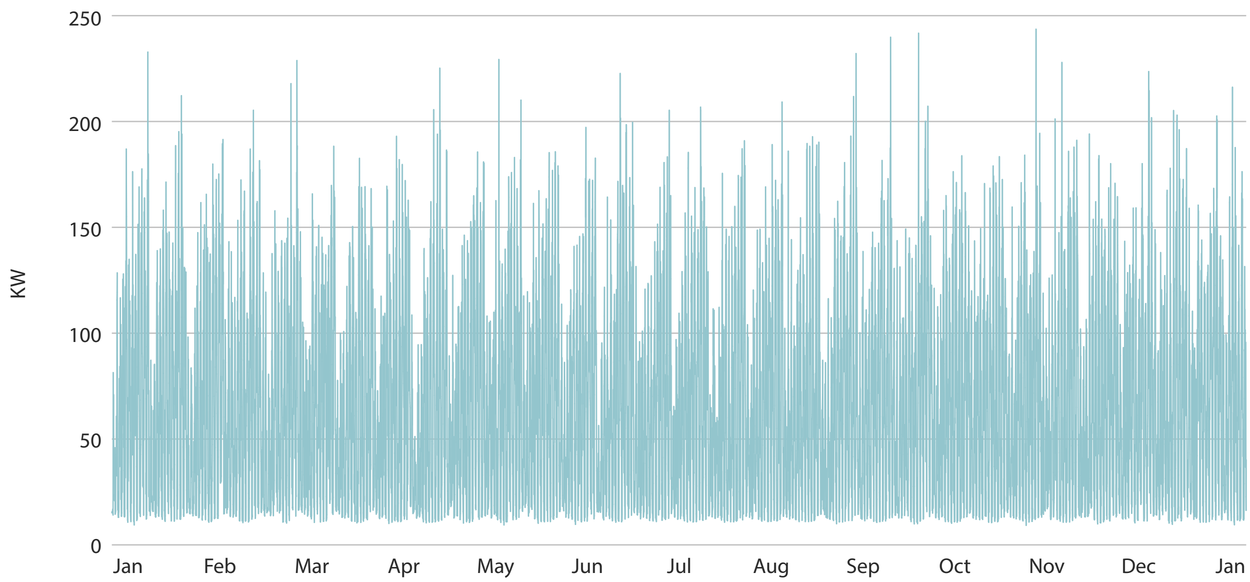


Table 3 shows the projection of the EV uptake in the Perth & Kinross authority area for both low and high uptake scenarios (Regen , 2019). We use this information to extract the upscaling factor to use with the EV demand in Perth for our estimates. For the high EV uptake scenario, the upscaling factor is 22.6. However, we assume that by 2030 PKC will have other charging stations installed other than the ones located in Perth West, Therefore, we select an upscaling factor $EV_{upscale} = 6$ to reflect the EV demand for the two charging stations at Perth West under the high EV uptake scenario.

We displayed the EV demand over one week to study the demand pattern and the results (Figure 14) show a similar daily pattern with no difference between weekdays and weekends. In addition, the results show the presence of two peaks: a first one around 9am and a second around 5pm which coincide with the start and the end of the working hours.

For residential EV demand, we consider the statistics from (Regen, 2020) that estimates ~1 vehicle per household in the region combined with the projection study (Regen , 2019) that estimates that 17% of cars would be electric by 2032 in the low uptake scenario and 50% in the high uptake scenario. As the site will host 3500 residential units, we included 595 EVs home charging for the low uptake scenario, and 1750 EVs for the high uptake scenario. The following additional assumptions are also made:

- All EVs are available at home from 9pm to 7 am
- The home charging power rate is 7 kW
- The level of charge of batteries at arrival ranges between 20% and 40%
- The level of charge at departure must be greater than 80%
- The capacity of the batteries is 70 kWh

For hydrogen refuelling, the site developers consider provisioning hydrogen from external providers instead of producing it on site, and therefore the H2 demand was not considered further in the study.

Table 3: Projection of EV uptake in the local authority of Perth & Kinross				
	2025		2032	
	Number of EVs	Scaling factor	Number of EVs	Scaling factor
Low uptake	1953	1	13,297	6.8
High uptake	6944	3.5	44,121	22.6

Figure 14: Weekly profile for charging demand.

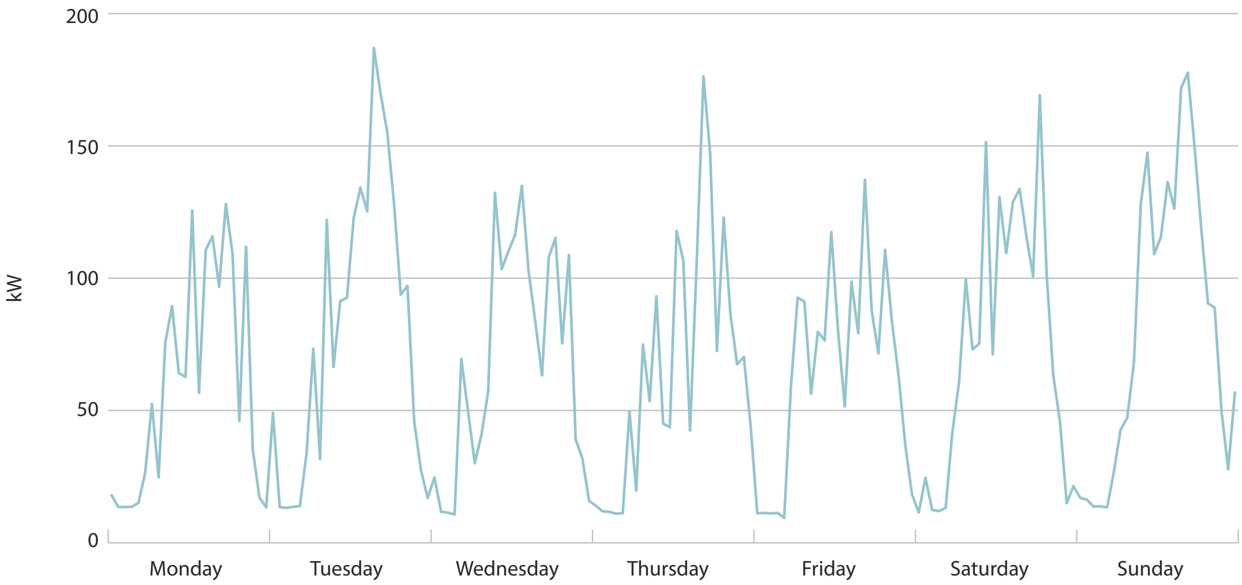
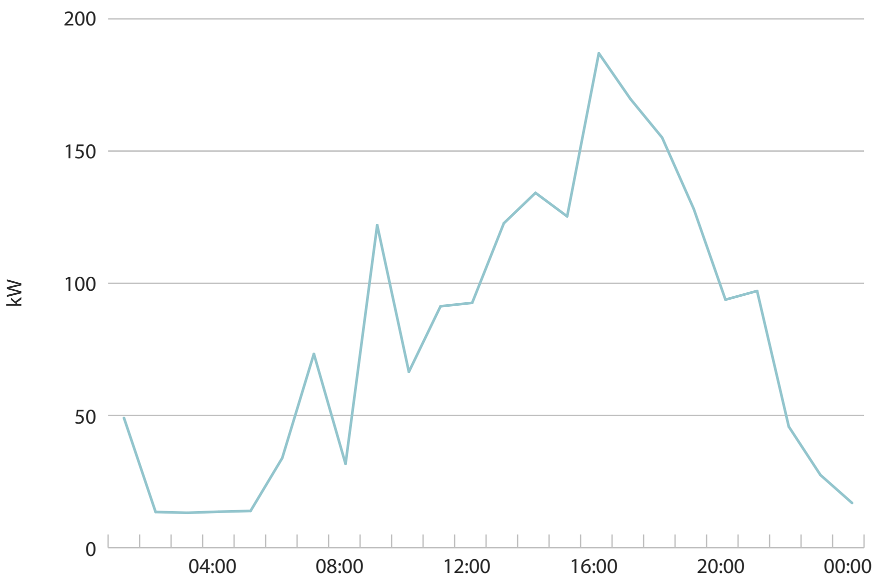


Figure 15: A Daily profile for charging demand.



2.3 Storage

2.3.1 Thermal storage

Thermal energy storage is an essential part of most decarbonisation strategies for heating and cooling at both the individual property and district scale. While combi natural gas boilers are designed to cover both heating and hot water peak demands, heat pumps are usually designed with lower peak capacity so that a thermal energy storage system is required to provide peak demand. This enables the heat pump to operate in its optimal operating point: charging the thermal storage when the demand is lower and discharging when the demand is higher. The distributed thermal energy storage could be used for demand response in the distribution grid: charge the thermal storage during off-peak times and discharge during peak times (Lizana, Friedrich, Renaldi, & Chacartegui, 2018).

Besides the short-term storage which is usually done in hot water storage tanks or phase change material storage systems, long term thermal energy storage (Lund, et al., 2016) can be used to balance heat demands over several months or even between seasons. This option is particularly interesting due to the large seasonal variations between summer and winter, and the low cost of large thermal energy storage systems compared to other energy storage systems, i.e., it can be several orders of magnitude cheaper than pumped hydro or battery storage. However, the large-scale thermal energy storage systems would need to be connected to district heating systems. While ambient loop systems were outside the scope of this study, large-scale thermal energy storage should be considered in any detailed analysis of these systems.

2.3.2 Battery storage

The most common forms of battery storage are lead-acid and lithium-ion. The use of batteries can play different roles:

1. Colocation with renewable source to store excess of energy: Integrated to a site with renewables, communal batteries help smooth the intra-day variations of energy demand and generation. These types of batteries can also serve to generate economic benefits by charging it from the grid during the off-peak period and selling the energy back in peak periods.
2. Ancillary services: In this case, the batteries provide services to the grid to help the system cope with sudden variations of supply/demand. Specifications for these batteries can be different from the communal batteries. They may for instance require a high ramp rate that allows a deep discharge in a short period of time.
3. Behind the meter (btm) batteries: When coupled with a btm renewable source such as rooftop PV panels. Btm batteries help increase the autonomy of the premises by storing the excess energy in high generation periods for use during the periods of high demand. Statistics estimate 10% of new homes will have 5 kWh batteries by 2030 (Regen, 2020).

The main role of the communal battery for Perth West is to increase site autonomy and decrease peak load. For large-scale battery storage systems, we use the data from NREL,[4] the overall projected capital cost for a 4-hour battery system are £117.26/kWh, £162.36/kWh, and £203.36/kWh in 2030 for the low, mid and high scenario respectively, and £71.34/kWh, £122.18/kWh, and £203.36/kWh in 2050.

For the study, we select the mid cost for the year 2030.

4 Cost projections for utility-scale battery storage: 2021 Update | National Renewable Energy Laboratory (NREL)

Table 4: Unit cost of battery storage systems			
£/kWh	Low	Mid	High
2030	117.26	162.36	203.36
2050	71.34	122.18	203.36

2.4 Flexibility

Figure 16 shows the potential of different technologies in providing flexibility and reducing peak demand. The figure is from a study that was conducted by SPEN in response to the future energy scenarios (FES) project launched by National Grid ESO and which aims at estimating the feasibility of reaching the net-zero target considering 4 main scenarios. Among them, steady progression (SP) is the only one that does not reach the net zero target by 2050.

Home EV charging, Depot EV charging, and I&C baseline demand are the segments that contribute the most to flexibility provision. ASHP provide flexibility too but to a less extent compared with the aforementioned segments.

2.4.1 Storage

The main sources of flexibility come from the electric storage; this includes battery storage, followed by EV home charging and EV depot charging.

The private charging infrastructure, i.e., home charging and fleet charging contribute to the delivery of flexibility and reduce the peak demand more than the public charging infrastructure. This is due to two main reasons: (1) the long duration of EV parking at homes or in a fleet depot allows more flexibility, (2) the behaviour of the private owners is generally known and follows a specific pattern, contrary to the public infrastructures that serve different customers with different consumption patterns.

There are two options for EVs to provide the flexibility service:

a Smart charging (SC):

In this option, the EV does not start charging as soon as it is plugged-in. Instead, a smart system integrated with the charging device selects the most beneficial time for the charging. Generally, the system shifts the charging from the peak period (6pm-10pm) to the off-peak period (11 pm-6am). The smart system ensures the EV is charged before the departure time of the owner.

b Vehicle to the grid (V2G):

In the V2G option, not only does the charging device shift the charging period from periods of high grid stress to off-peak periods, but also allows for the injection of power from the EV battery to the grid. The activation of this option requires the use of a bidirectional charging device that will allow the bidirectional flow of power combined with a smart system that will control the charging/discharging of the battery.

In the study, we considered the flexibility delivered from the EV home charging.

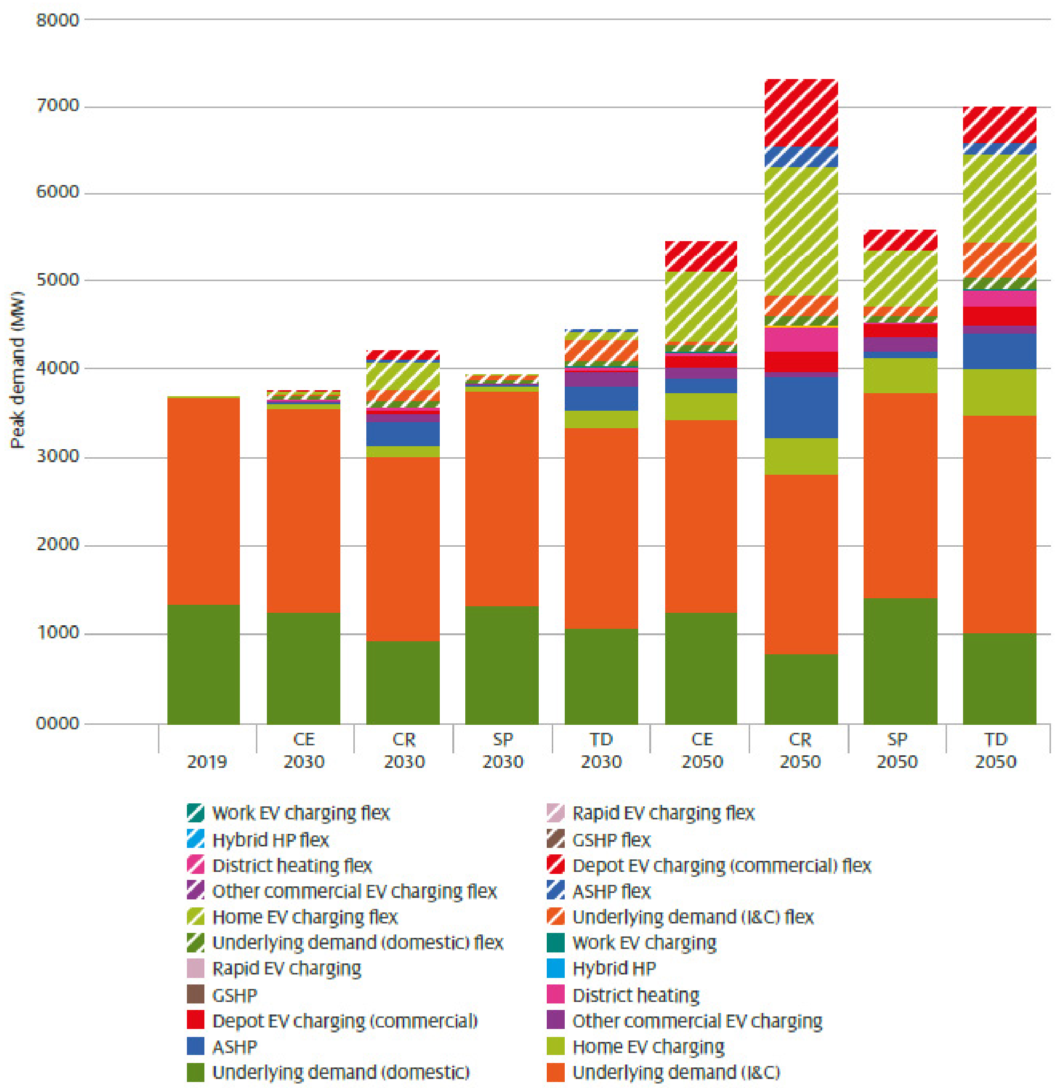
2.4.2 Underlying demand

The second largest potential for flexibility comes from the Industrial and Commercial (I&C) baseline demand. It could also provide significant flexibility and help reduce the peak demand. However, we did not consider the flexibility from this segment as the information about the nature and activities of the businesses is not available yet in these earlier phases of site development.

2.4.3 Electric Heating

Though the heating sector will be decarbonised, its potential to provide flexibility would be weak. In fact, energy efficiency measures imposed by the Government reduced the energy consumption for heat, and with highly efficient HPs (CoP>2), the energy consumption to heat the premises will reduce even further. Consequently, the heating can provide a lower amount of flexibility, which is not of the same scale as the flexibility provided by other sectors.

Figure 16: Electricity peak demand breakdown for 2030 and 2050 (SPEN).



On the other hand, electric heating can provide flexibility through heat storage (Lizana, Friedrich, Renaldi, & Chacartegui, 2018). By adding heat storage with smart control to the electric heating system, a large percentage of the charging can be performed during off-peak hours. This would significantly reduce the electricity demand for heating during the peak hours, which would reduce the strain on the distribution grid infrastructure. For a system driven by solar PV, most of the evening heat demand could be covered by charging the thermal storage during the daytime. For the case of air source heat pumps, it would also improve the CoP due to higher daytime temperatures.

Due to the lack of data at early phases of the site development, the flexibility from heating was not considered in the study, as there are not sufficiently detailed estimates on households and commercial buildings that would implement heat storage technologies.

2.5 Summary

Table 5 lists the different sources of generation, demand and potential sources of flexibility in Perth West.

Table 5: Generation, demand and flexibility in the site of Perth West

Type	Sources
Generation	PV (DRECO + btm)
	BESS (communal + btm)
Demand	Residential (Lamberkin Village)
	Non-residential (Perth Eco Innovation Park, facilities)
	fuelling station (new junction) + last mile facilities
Flexibility	EV home smart charging
	EV home vehicle to the grid

Density maps in Figure 17 and Figure 18 present an estimation of the annual energy/heat consumption per sub-area.

Figure 17: Estimation of annual electricity demand in GWh for different sub areas of the site.

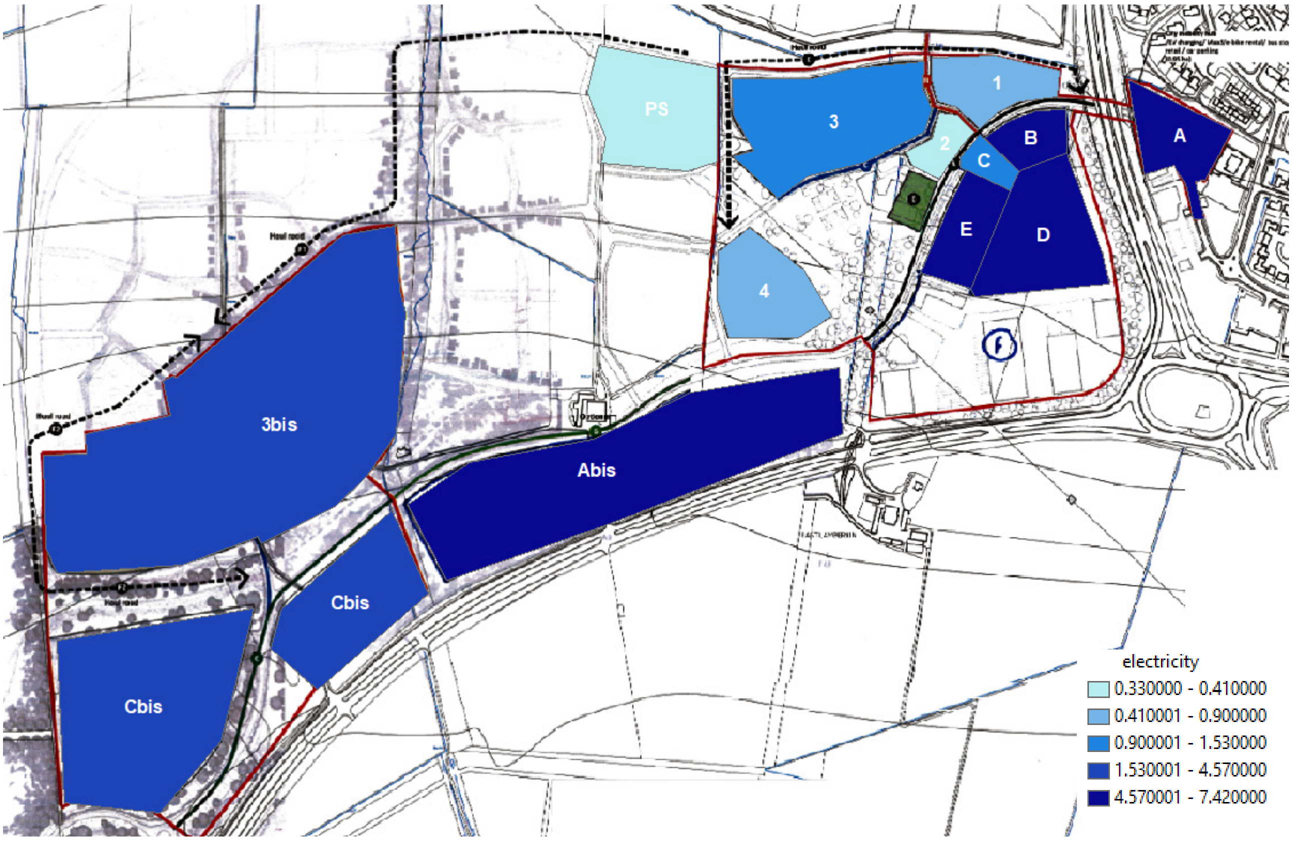
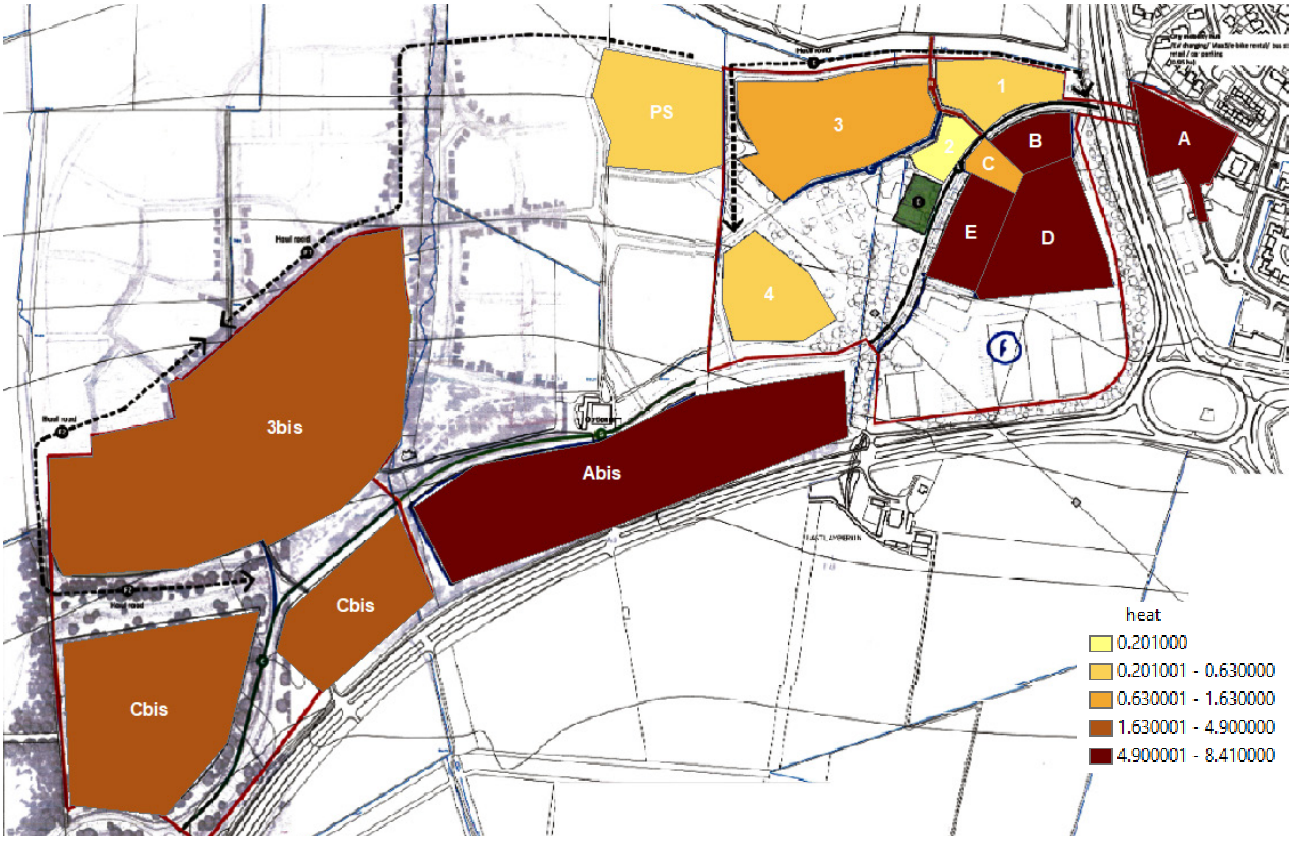
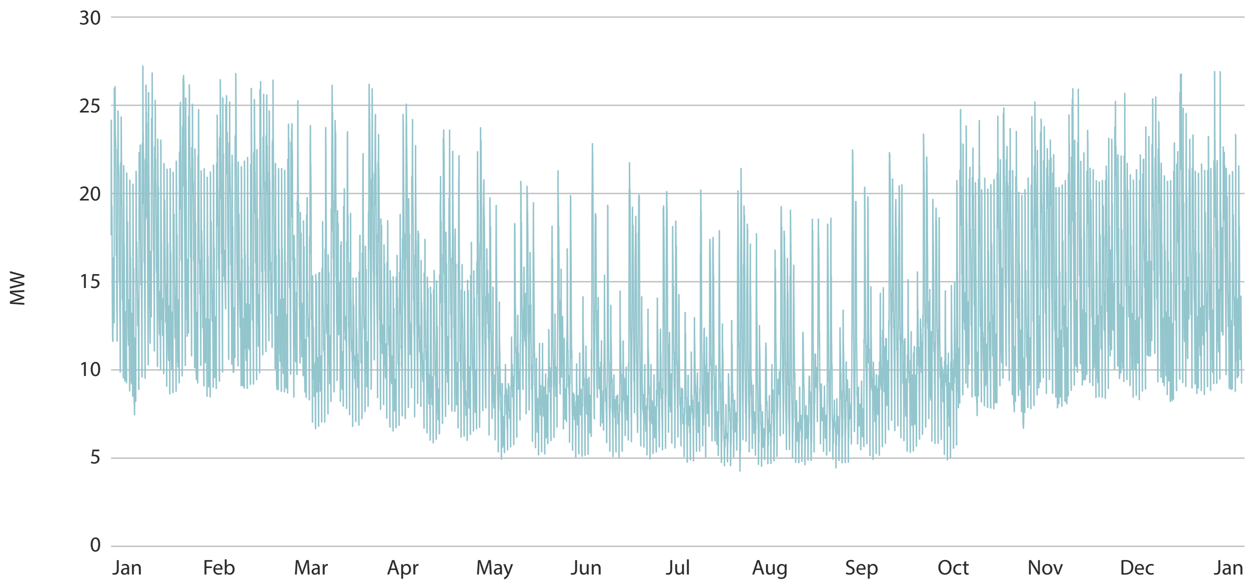


Figure 18: Estimation of annual heat demand in GWh for different sub areas of the site.



The total annual energy demand of the site, including heat demand and EV charging is around 112 GWh with a peak of 27.21 MW.

Figure 19: The estimated hourly power consumption of the site with heat and transport included for the final phase of the project.



3 Techno-economic feasibility study for a smart local energy system

The techno-economic study provides an integrated energy system model for energy, buildings and transport. We assess the optimal combination of solar capacity and communal battery capacity that returns the lowest levelised cost of energy (LCOE).

Objective = minimise (LCOE)

The LCOE includes the costs of investing in solar and storage systems, costs of network upgrade and the cost of buying energy from the grid:

$$LCOE = C_{inv} + C_{grid} = C_{inv}^{PV} / AF_{PV} + C_{inv}^{BESS} / AF_{BESS} + C_{inv}^{upgrade} / LT_{upgrade} + C_{import} * P_{import}$$

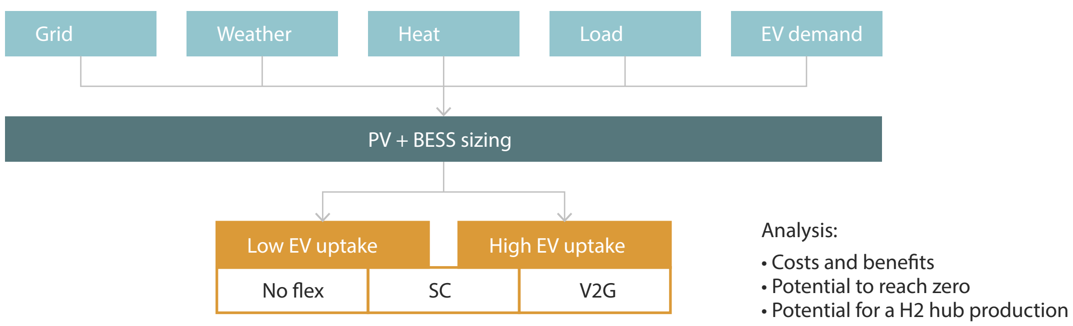
where AF is the annuity factor:

$$AF = \frac{1 - \frac{1}{(1+dr)^{LT}}}{dr},$$

LT is lifetime of the asset in years and *dr* is the discount rate considered to be 5% for the renewable projects.

We use an optimisation model to conduct the study. Figure 20 presents the flowchart of the model. It takes the estimated energy demand for electricity, heat and EV consumption, the price of buying electricity from the grid and the weather information that influences the renewable generation as inputs, and it outputs the yearly schedule of the battery, the import, the export and the overall costs. The model was run for each of the 6 scenarios: low/high EV uptake with no flexibility, with smart charging option and with vehicle to the grid option.

Figure 20: The optimisation model used by the feasibility study.



3.1 Optimal design

Table 6 shows the optimal PV and BESS capacities for the six scenarios.

Table 6: Optimal design of a Smart Energy System for Perth West

	Low uptake scenario		High uptake scenario	
	PV [MW]	BESS [MWh]	PV [MW]	BESS [MWh]
No flex	47.14	42.73	48.64	47.86
Smart Charging	47.89	44.5	47.89	44.49
V2G	45.17	35.95	44.32	33.03

The scenario that requires the most renewable generation and storage capacity is the one with a high rate of EV uptake and no activated flexibility, while the scenario that requires the least capacity is the scenario with high EV uptake with the V2G option integrated. The results in Table 6 show the importance of unlocking flexibility from the transportation sector. By allowing the interaction between the grid and the EVs (V2G), the integration of the EVs presents no threat to the grid, and instead plays a role in reducing the peak demand. The activation of the smart charging option cancels the impact of the EVs on the grid. This can be seen from the table where the results for both uptake scenarios are approximately the same under the smart charging option.

The PV capacity does not depend on the selected scenario, a difference of ± 3 MW is seen between the highest and lowest values. The BESS capacity is more impacted by the scenarios. The optimal BESS capacity varies by 10 MWh between the scenarios. With a rate of 1.6 ha/MW, the site will need approximately 48 ha of land for the installation of the PV farm, and 148.63 m^3 for the installation of lithium-ion batteries or 684.41 m^3 for the lead-acid batteries.[5]

3.2 Costs

Table 7 summarises the peak import value and the total yearly imported energy for the scenarios.

Table 7: Peak import and annual import costs for the considered scenarios

Import	Low uptake scenario		High uptake scenario	
	Peak [MW]	Cost of import [k£]	Peak [MW]	Cost of import [k£]
No flex	15.07	4.43	20.06	5.6
SC	14.08	3.98	17.7	4.63
V2G	14.64	3.87	18.33	4.01

The results show that the peak import power ranges between 14 MW and 20 MW. This will affect the network upgrade costs. The high EV uptake scenario with no flexibility and V2G options will require higher network upgrades compared to the other options.

5 Energy density is 3.34 m^3/MWh for lithium-ion batteries and 15.38 m^3/MWh for lead-acid batteries. Fact Sheet Energy Storage (2019) | Environmental and Energy Study Institute.

As smart charging neutralises the impact of EV charging on peak demand, it will be treated as the baseline scenario. The uptake of EVs (with no flexibility) increases the peak demand on the grid by 1 MW for the low uptake scenario and by 3 MW for the high uptake scenario.

The V2G option increases the peak power by 0.56 MW in the low uptake scenario and 1 MW in the high uptake scenario. This may seem contradictory to the value that V2G should bring to the system, which is decreasing the import from the grid. However, by unlocking the V2G option, the peak value of importing energy from the grid is shifted from the period of higher wholesale prices to periods of lower prices, which results in lower import costs. Comparing the smart charging and V2G options, V2G incurs less import costs even though it increases the peak import power.

3.3 Benefits

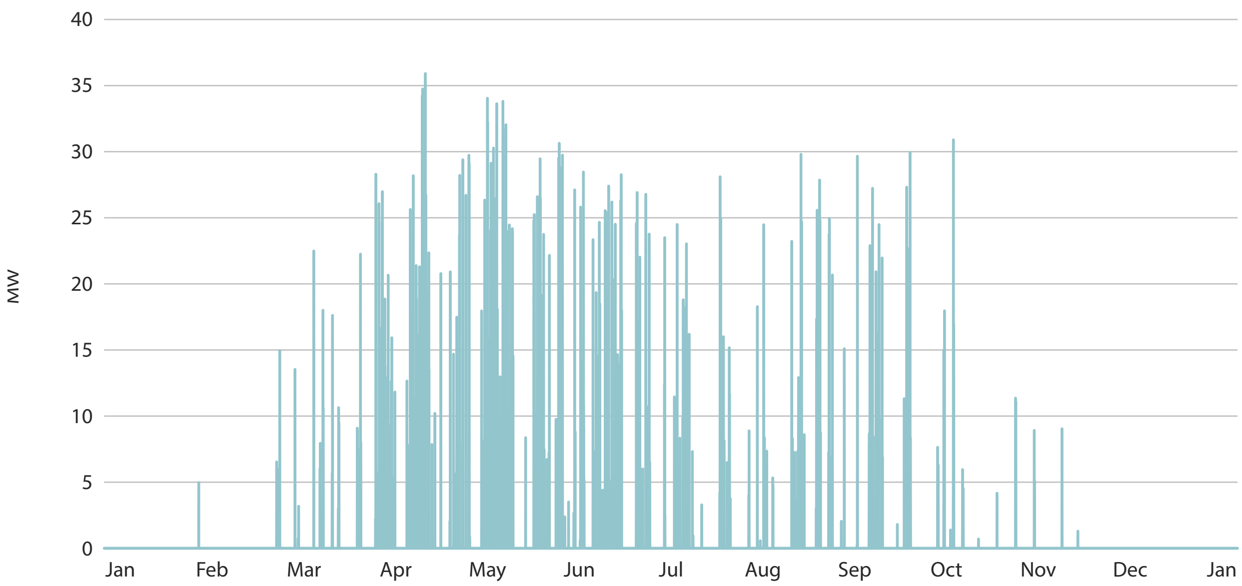
Table 8 shows the peak export power and the annual net exported energy for the different scenarios.

Table 8: Peak excess and annual excess energy for the different scenarios

Export	Low uptake scenario		High uptake scenario	
	Peak Export [MW]	Net Export [MWh]	Peak Export [MW]	Net Export [MWh]
No flex	36.52	4810.20	38.25	4987.10
SC	41.45	4952.37	38.61	4954.94
V2G	35.9	4799.37	33.08	5368.55

The export curves demonstrate a sparse availability of excess energy. In some days, there is no export and when it exists, it is present for only a few hours a day (Figure 21).

Figure 21: Annual export.



Furthermore, the export is most available during the summer season, meaning there is significant seasonality (Figure 22).

A seasonal storage of up to 4.77 GWh (see Table 9) can be implemented to store abundant energy during the summer season and deliver it in the winter.

The projected cost for producing H2, considering the input energy comes from renewables (i.e., does not include electricity price) is shown in Table 10.[6]

Figure 22: Seasonality of available excess.

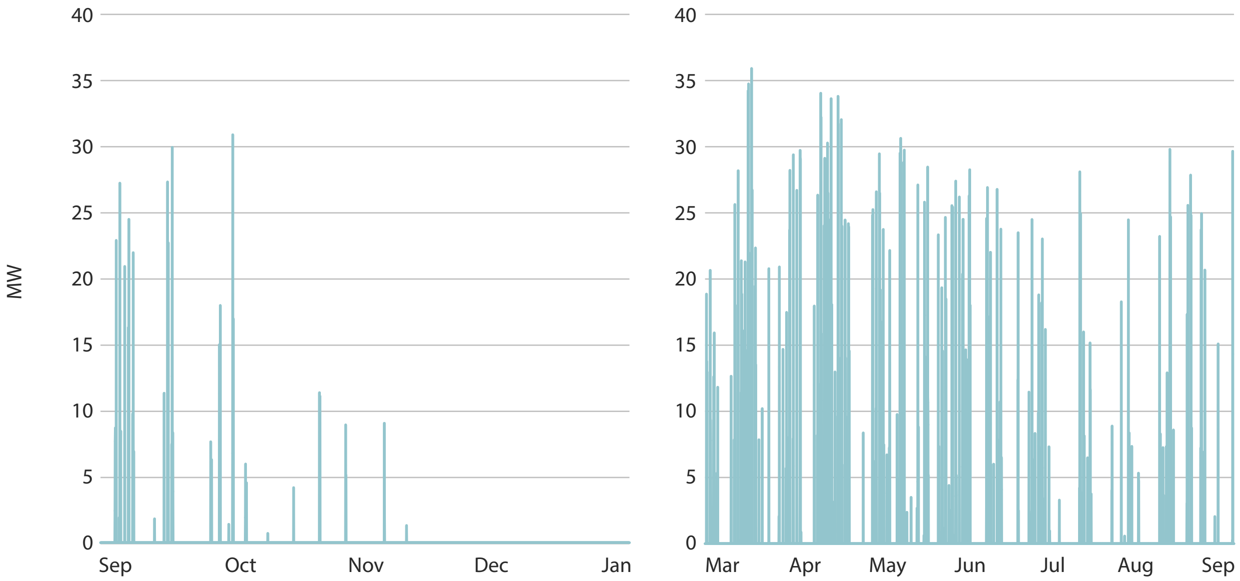


Table 9: Excess generation – Summer season		
GWh	**Low uptake scenario**	**High uptake scenario**
No flex	4.25	4.43
SC	4.38	4.38
V2G	4.24	4.77

Table 10: Costs for the production of green hydrogen		
£/MWh H2	**Alkaline**	**PEM**
2030	53	49
2050	50	47

6 Hydrogen Production Costs 2021 | Department for Business, Energy & Industrial Strategy

Compression and storage[7] counts for 32.07 £/MWh and 5.62 £/MWh respectively, considering that 1 MWh H2 (HHV) = 25.4 kg H2. We take the efficiency of the electrolyser= 0.8. A hydrogen seasonal storage can cost on average 413.5 k£ with a total unit cost of 86.69 £/MWh. As shown in Figure 7, 90% of the wholesale prices values are less than 100 £/MWh. The seasonal storage can be used in the extreme cases in which there is a high demand and help reduce the energy costs for the site. The excess can also be used for seasonal production of hydrogen for refuelling purposes.

The excess generation can produce between 107.7 t H2 and 121.15 t H2 depending on the scenario with a total unit cost of 3.2 £/kg H2. According to Table 10, the projected cost of green hydrogen using PEM technology and curtailed energy from renewables is 1.83 £/kg H2 and 1.44 £/kg H2 by 2030 and 2050 respectively. This suggests that the seasonal production of hydrogen will not be economically beneficial for the site.

3.4 Carbon reduction

Table 11 and Table 12 show respectively the percentage of supply delivered by clean energy and the amount of CO2 that we avoid emitting by using the renewable system. For the CO2 emissions, we use the conversion coefficient[8] = 0.233 kg of CO2e per kWh of electricity as provided by the Government report.

Table 11: Amount of energy delivered by renewables

Clean Energy (%)	Low uptake scenario	High uptake scenario
No flex	42.13	25.92
Smart Charging	46.98	36.72
V2G	48.53	44.7

Table 12: Carbon reduction per scenario

Carbon Reduction (x103 t)	Low uptake scenario	High uptake scenario
No flex	10.62	3.53
Smart Charging	11.85	9.26
V2G	12.24	11.27

The site can supply on average 40% of its demand from local energy, which implies that at least 40% of the site demand is met by clean technologies. This rate can be improved if the energy mix of the grid hosts renewables.

7 Hydrogen station compression, storage, and dispensing technical status and costs | National Renewable Energy Laboratory (NREL)

8 Greenhouse gas reporting: conversion factors 2020 | Department for Energy Security and Net Zero and Department for Business, Energy & Industrial Strategy

Nonetheless, the results indicate that the site will rely on the grid connection to supply more than half of its demand. We conducted another feasibility study for which the objective is to supply 75% and 100% of the site demand from the renewable mix while minimising LCOE (e.g., the annualised costs of infrastructure, equipment and energy import). Table 13 and Table 14 show the results for the respective cases.

Table 13: Optimal PV and BESS capacities to supply 75% of the site demand

	Low uptake scenario		High uptake scenario	
	PV [MW]	BESS [MWh]	PV [MW]	BESS [MWh]
No flex	72.4	142.68	82.97	186.2
Smart Charging	69.86	132.23	75.44	155.22
V2G	66.8	119.66	66.42	118.0

Table 14: Optimal PV and BESS capacities to supply 100% of the site demand

	Low uptake scenario		High uptake scenario	
	PV [MW]	BESS [MWh]	PV [MW]	BESS [MWh]
No flex	76.9	491.48	94.19	531
Smart Charging	74.04	484.59	85.28	511.65
V2G	74.07	443.02	85.30	389.21

The optimal battery capacity for 100% case study is 4 times the optimal capacity for the 75% case study. To ensure 100% autonomy, the battery should have an important capacity to cover the days with no solar outputs, particularly during winter.

To supply 100% of demand from a PV-BESS system, the site will need 150.7 ha of land for the PV farm and 1773.54 m^3 for lithium-ion batteries or 8166.78 m^3 for lead-acid batteries.

4 Social Study

4.1 Research aims and rationale

The research aim was twofold:

- To explore with residents how Perth and their own lives can become more sustainable, with special attention given to energy use in housing and transport.
- To identify opportunities and barriers to low-carbon retrofit of an existing suburban neighbourhood, including potential links with the planned (and adjacent) urban development at Perth West.

The clean technologies that will be used in Perth West could also help to make existing homes more low-carbon and help lower heating and transport bills. In principle, a technical assessment of how houses and the neighbourhood could be 'retrofitted' to become more energy efficient and with lower energy bills for residents could be undertaken. But in practice, every house and household is different. In order to appreciate how realistic the different technical options are, we wanted to better understand how existing residents currently live, how they feel about such technical changes and what the financial and social priorities in their households are. This included exploring existing residents' views of the new development, particularly where they may see opportunities for synergies – but also where plans may create, or exacerbate existing, local issues.

Our research utilised a mixed methodology, combining a largely quantitative survey with qualitative focus group discussions. Whilst a survey may yield data that could be generalisable to the overall population in the neighbourhood, it is less suited to provide us with the deeper qualitative data which helps to establish causality, e.g., help us understand why people think the way they think. Interviews (semi-structured or in-depth) and focus group discussions are the go-to tools for collecting such qualitative data. We chose to run the focus groups on-line rather than in-person because this was the preference of the vast majority of the participants. The pandemic has made many people more familiar and at-ease with online meetings, and of course it is a Covid-safe meeting format.

4.2 Survey methodology

4.2.1 Survey population selection and survey distribution

To obtain local opinions, we undertook the study in a neighbourhood adjacent to the proposed Perth West development, in central Scotland (Figure 23). There were several neighbourhoods close by to the development site, however the study area was selected due to its close proximity and the parameters of the area were determined following a steer from Perth and Kinross Council (PKC) who are familiar with the area.

Due to the targeted nature of the study, postal surveys were decided as the most time and cost effective in obtaining relevant responses. Individual surveys, alongside a pre-paid return to sender envelope, were placed in a handwritten envelope. For example, "Dear resident of 10 Lamberkin Drive". The surveys were posted to approximately every second or third house depending on the length of the street. We received 79 survey responses in total.

The topics which were queried in the survey were propelled by the two main research aims. See Appendix A for the full survey.

These topics are:

- Demographics
- Energy in your home
- Retrofitting your home
- Transport
- Environment focused activities and climate change concern

See Appendix D for a detailed overview of the survey analysis process.

Figure 23: Study area (Source: Researcher on GIS).

a) Location relative to Scotland.
b) Location relative to Perth.
c) Neighbourhood level location with Map of the

4.3 Focus group methodology

Participants for focus groups were recruited through the aforementioned residential survey. Out of the 79 survey responses, 21 residents indicated a willingness to participate in further research. Out of these 21, 10 residents responded positively and timely to follow-up emails from the research team. Ultimately, 8 residents agreed to participate, and we conducted two focus group sessions with four residents in each group. Sessions took place on-line (as requested by participants) using the "Zoom" platform. Sessions lasted approximately 90 minutes each, resulting in around 180 minutes of qualitative audio-visual data in total.

The focus group discussions were steered by a series of questions that were designed to stimulate and keep the conversation flowing in line with the research aim (see Appendix C for research design). Thematically, the questions were grouped around two distinctive parts. In part 1, discussion focussed on Perth and living sustainably in Perth: this included opportunities for residents to voice their views concerning the proposed Perth West development, in addition to broader discussions around how Perth can become more sustainable. In part 2, the research team presented several home retrofit and sustainable mobility options to residents who then discussed the extent to which these may be suitable in their own houses and lives (see ANNEX II for PowerPoint slides used in-session).

4.4 Social study results

4.4.1 Perth and sustainability

When asked to give their opinions concerning the new Perth West development, focus group participants highlighted that it is just one of several significant residential developments planned for, or under construction, locally. Concerns were raised that these developments could exacerbate already problematic local traffic congestion. This issue was also identified in survey responses, with four residents citing concerns over increased traffic congestion and one commenting on the subsequent rise in air pollution which would be expected to follow. Focus group participants also voiced concerns regarding the siting of the development, specifically concerning i) access roads for construction, ii) access roads for new residents, and iii) the fact that the development is proposed for a Greenfield site.

Concerning access roads for construction, this was raised as an issue due to the potential impact it could have on the already problematic travel congestion (at peak times) on Lamberkin Drive. Regarding the siting of the development on a Greenfield site, several focus group participants expressed cynicism at the proposal, suggesting that Brownfield sites are available around the city. It should be noted that the suggestion by certain residents that appropriately sized Brownfield sites are available around the city is in fact unfounded, yet only one participant acknowledged that development options are limited due to the geography of Perth. This highlights the need to engage with residents and make more visible information and decision-making processes that are guiding development and investment around the city.

The majority of residents engaged with throughout focus groups were sceptical and suggested that any eco benefits (e.g., carbon reductions owing to sustainable design of new homes) would be offset by the mobility habits of incoming residents. Specifically, some existing residents queried where new residents would work, suggesting that there aren't enough job opportunities locally and that this would mean many will probably be commuting to Edinburgh or Glasgow regularly. It was also noted that investment for existing residential areas has not been forthcoming over the previous decade (e.g., for fast fibre internet); in contrast, residents suggested that Perth West seems to have secured funding for a host of provisions, technologies and services that are unavailable for existing residents. Only one focus group participant suggested that the eco credentials of the new Perth West development help to compensate for the concerns highlighted above.

This suggests the potential for tension and division between incoming and existing residents. The new Perth West development could attempt to offer benefits to existing residents, thereby mitigating against this undesirable outcome. For example, social, leisure and/or employment opportunities could potentially promote a more cohesive wider community, whilst also enticing existing residents away from scepticism.

It should be noted that in order to maintain researcher integrity with regards to impartiality, the research team did not actively seek to quell any resident concerns regarding the proposed Perth West development. Furthermore, representatives from PKC were not present to take up this role or to provide information to residents concerning how Perth West relates to other local initiatives and goals. For example, the issue of traffic congestion was not framed in relation to the Cross-Tay-Link-Road (CTLR); the CTLR has received significant investment from both PKC and Scottish Government who hope the construction project will improve the flow of traffic in Perth and its surrounding areas. Such a framing could potentially influence resident perceptions in a positive manner, thus making it a line of inquiry worthy of further investigation. Similarly, the assertion that Brownfield sites are being overlooked was not challenged; greater resident knowledge concerning this issue also has the potential to influence perceptions and should be explored further. It seems likely that future consultation would be worthwhile, affording existing residents, developers and PKC further opportunity to understand each other's point of view and work towards shared goals.

4.4.2 Existing residents making sustainable changes to their mobility habits

Overview of key findings:

1. 8.5% of existing residents own an EV. This is higher than the UK average
2. 40.1% of existing residents own at least one bicycle (12.5% of which are electrified), however this was not perceived as a viable primary mode of transport by most participants
3. Displacement of current petrol/ diesel private vehicle with an electric vehicle (EV) counterpart was perceived as the most preferential sustainable mobility option
4. But concerns were highlighted regarding EV affordability and charging infrastructure
5. Initial interest in EV car clubs suggests that this service should be investigated further
6. Public transport provision is not currently attractive enough to existing residents

Survey results suggest that many existing residents (89.9%) own at least one private car, with 8.5% of these vehicles being electric (higher than the UK average) and the remaining 91.5% combustion engine (i.e., petrol or diesel). Bicycle ownership was also prevalent (40.1% own at least one bicycle) with 12.5% of these being electric and the remaining 87.5% traditional pedal bikes. Only 2.5% of survey respondents own a scooter or motorbike, none of them being electric.

For most focus group participants, displacement of their petrol/ diesel private vehicle with an electric vehicle (EV) counterpart was the most preferential sustainable mobility option. This aligns with our survey results which found that 60.8% of respondents would consider displacing their petrol/ diesel private vehicle for an EV. However, these findings are more nuanced than they first appear: survey results revealed that transition to an EV would be conditional on improved affordability (16 respondents/ 20.25%), whilst findings from focus groups suggest that EV ownership is currently financially prohibitive for many existing residents. This demonstrates that openness to transition in principle is influenced by on-the-ground contexts. Nevertheless, several focus group participants did suggest that they would like to make the transition in the future if and when prices come down.

Some consensus emerged around the suggestion that more EV charging points locally would also help increase the merits of transition in the eyes of residents. Survey responses support this finding with five respondents (6.3%) commenting that there would need to be more charging facilities available if they were to transition.

Despite the fact that our survey results found reasonably high bicycle ownership in the existing neighbourhood (40.1% own at least one bicycle), broad consensus emerged in both focus groups that cycling locally is not ideal due to the steep local landscape. When asked if electric bikes may help to mitigate against this, several residents in focus group 1 were somewhat sceptical about their merits. However, they expressed intrigue when learning that a fellow resident owned an electric bike and found it a great help in navigating the steep local streets. This could be interpreted as suggesting that lack of knowledge surrounding electric bikes (or at least lack of personal experience) potentially limits resident interest and subsequent uptake. Thus, integrating an electric bike hire or sharing scheme at the new Perth West development could promote increased opportunities for peer learning and uptake.

The undesirability of cycling into the town centre via the Glasgow Road cycle path was also raised by several residents who suggested that it is particularly dangerous. Indeed, one participant noted a painful accident that he was recently involved in whilst cycling that route. Moreover, it was suggested that the Perth town centre is not at all conducive to cycling, whilst the Scottish weather is also prohibitive. It was recognised that retrofit to the town centre cycling system would be extremely challenging due to street layout. One resident suggested that a one-way system could be employed to improve the safety and desirability of cycling in town, but that would come at the cost of increased congestion - which is bad enough already.

It is interesting to note that one focus group participant suggested cycling safety issues are a national, rather than solely local, issue. Here an international comparison was drawn between countries like the UK – who protect cyclists by trying to make them as visible and protected as possible, e.g., use of helmets and hi-vis clothing – vis-à-vis countries who design cycle routes well away from traffic and therefore do not need to focus on visibility and protection to the same extent, i.e., they are built safe to begin with. This could be interpreted as a contributing factor leading to the local perceptions (touched upon in focus groups) that cycling is seen primarily as a leisure activity, as opposed to mobility option. However, it also suggests that there may be scope to improve cycle routes which will be used by both incoming and existing residents, for example the Glasgow Road cycle path. This could also be an opportunity to mitigate against concerns regarding residential tension and division by leveraging the new development to bring benefits to all, i.e., through integrated planning for public and active travel, including separate cycling lanes from the new Perth West development, through existing neighbourhoods and into Perth town centre. An improved, safer cycle route into the town centre could potentially help to alter residents' perceptions of cycling as an unsuitable mobility choice; moreover, improved connectivity to the town centre could alleviate fears raised by residents with regards to new retail developments on the outskirts of town which may otherwise displace the (already struggling) high street.

The concept of car clubs was also raised with focus group participants. This was a hypothetical as this provision is not currently available in Perth (to the best of our knowledge and that of local residents who we engaged with). Several participants were intrigued by the concept but questioned the extent to which they would actually use such a service; for example, one resident cited care duties which mean that they need access to a vehicle at all times. In addition, this line of investigation may have been somewhat hampered by the fact that only 25% of the focus group participants owned a second car: in the research design, we hypothesised that replacement of a second private petrol or diesel vehicle with car club membership may be an attractive, sustainable and relatively affordable change to mobility habits (survey result found that 36.7% of respondents had more than one private car at their household). Nevertheless, and notwithstanding the above concerns, the level of initial interest shown by residents suggests that this could constitute a topic worthy of additional investigation.

Public transport was discussed to a lesser extent than the mobility options highlighted thus far; however, this theme was still touched upon. Broad consensus emerged in focus groups around the suggestion that public transport provision is not currently attractive enough to residents. Reasons for this included: not great value for money; elongated routes; not enough routes (especially to certain parts of the wider city); and infrequent services. Covid-19 was suggested as playing a part; however, discussions indicated that this was more a contributing factor, as opposed to the root cause of public transport provision issues locally. For one resident in particular, improved public transport provision was a must; the displacement of combustion engine vehicles with EVs was perceived negatively due to the fact that it will not get cars off the road. Survey responses also suggested that public transport provision is not currently attractive enough to residents.

Concerning active travel via foot, this too was discussed to a lesser extent than the mobility options highlighted thus far. Nevertheless, several residents did indicate that they walk regularly and that this can sometimes be just as quick as catching a local bus. However, walking, alike other forms of active travel (e.g., bicycle; electric bicycle), was deemed inappropriate for many situations and is therefore unlikely to constitute a full replacement of private vehicle use. For example, one focus group participant stated that she is always carrying bags and that walking or cycling everywhere is therefore unfeasible; this point was also highlighted as an additional comment in a survey response.

4.4.3 Resident opinions concerning technological retrofit options for existing homes

Overview of key findings:

1. Many existing residents have already invested in energy efficiency upgrades (91% of those surveyed)

    * But transition to air source or ground source heat pump perceived as unrealistic for many: the high upfront cost of heat pump technologies and the disruption that installation would bring to the home were commonly cited barriers
    * This suggests the need for policy mechanisms that encourage transition and an increased local awareness of organisations that provide free information regarding grants and interest-free loans
    * Local supply and maintenance chains would also need to mature if significant roll-out of heat pumps were to occur
    * Initial interest in peer-to-peer energy trading suggests that this could be worthy of future investigation

The majority of existing residents who participated in focus groups have already invested in energy efficiency upgrades, notably various forms of insulation and double/triple glazing windows. This aligns with our survey results which found that 91% of respondents have invested in energy efficiency upgrades. When focus group participants were asked if they would consider replacing their current heating provision (gas boiler with central heating, in some cases complimented with a wood stove or gas fire) with an Air Source or Ground Source Heat Pump, residents highlighted a number of issues that currently make transition unrealistic, notably: the upfront cost of heat pump technologies and the disruption that installation will bring to the home. This adds an extra layer of insight to our survey results which found that 44.3% would consider ASHPs whilst 50.8% would consider GSHPs: adoption of technologies is predicated on a conducive context and is quite different to willingness to transition in principle. This could be interpreted as suggesting a lack of "willingness to pay", or rather, an inability to afford such technologies, suggesting the need for policy mechanisms. Indeed, focus groups revealed that several residents had in fact recently considered and researched the possibility of replacing their gas boilers with heat pumps, only to find out that – for themselves – it was unrealistic.

It was noted that the task of getting a qualified engineer out to visit their property in Perth was another challenge within itself. This highlights the need to develop local supply and maintenance chains if significant roll-out of heat pumps were to occur. Other concerns related to heat pumps included: the aesthetics of the equipment in a garden setting; and the noise emitted by heat pumps which could be problematic when installed in close proximity to neighbours' bedrooms. One focus group participant did make the point that the barriers described in relation to heat pumps would be significantly diminished if they were already installed (and were included in the overall price) of new build properties. This chimes with an overall consensus that emerged in focus groups suggesting that the emphasis to transition to low-carbon heat in homes should not be on residents, but instead driven and enabled at a high-level (by Government). In other words, the idea of relying on individual adoption of cleaner technologies and more sustainable behaviour was challenged; people (who did try to make their individual contributions too!) clearly thought that there were structural and infrastructural issues that really had to be addressed at a higher level, with more urgency, vision and consistency (failure by 'the Government' was mentioned by many, but people were otherwise trying to avoid political discussions i.e., mentioning politicians or parties).

From a research design perspective, it should be noted that heat pump technologies were presented to focus group participants in a manner unlikely to be appealing, i.e., we informed them that they were significantly more expensive to purchase and install than gas boiler counterparts, whilst also costing more (at this moment in time) to operate. These negatives, unsurprisingly, outweighed the positives, i.e., carbon emission reductions. It is also worth noting that residents were more technologically aware than we had anticipated; many knew about heat pumps and clearly had done some homework to figure out that they would not be a suitable solution for them. However, despite this technological knowledge, residents were unaware of organisations that provide free information regarding grants and interest-free loans (e.g., Energy Saving Trust). Finally, focus group participants indicated an interest in Peer 2 Peer energy trading (e.g., by selling or gifting energy generated through Solar PV/ BESS to neighbours), suggesting this could be an interesting avenue for further research.

5 Conclusion

5.1 Conclusions

The Perth West development is a key development site for P&K and for Scotland. It would be a key future employer and economic growth hub for the creation of skilled low carbon related jobs in Perth. The ambition is to be the first in Scotland to develop an integrated approach to logistics, energy, transport and housing - all based on sustainable technologies.

The purpose of the study was to investigate how the development could achieve its net zero ambitions through the development of a SLES and the utilisation of near-site renewables. This includes the estimation of heat demand, power demand and transportation demand of the site.

Social research was also carried out with local residents about their own lifestyles, behaviour and willingness to change habits on housing energy efficiency and transport, as well as exploring attitudes toward the proposed development.

5.2 Key findings

- The implementation of a SLES composed of PV and BESS with the objective of minimising the levelised cost of energy can supply up to 48% of the site demand.
- Higher uptake of EVs will not be a threat on the grid network if managed by a smart system (SC or V2G). Using SC, we need up to 7% less BESS capacity installed, costs of import are reduced by up to 17% and the autonomy increases by 41% compared to non-flexibility scenario. By adopting V2G, the potential of EV batteries can be exploited to provide additional flexibility, which leads to a reduction of BESS capacity by a further 48% compared to SC scenario.
- The activation of such flexibility will require the implementation of new equipment.
    * SC requires the installation of smart chargers to schedule the charging.
    * V2G option requires either: (1) the installation of bi-directional chargers that will allow the two-way flow of energy, from the grid to vehicle during the charging, and from vehicle to the grid for the discharging. Currently, existing products on the market offer DC V2G chargers, or (2) the installation of on-board bidirectional chargers in the EVs. Most EVs do not come with this feature yet; however, it will likely become more common in the future to see EVs with on-board bidirectional chargers.[9]
- It is recommended that houses with off-street parking be built with an embedded EV charger.

9 Are bidirectional EV chargers ready for the home market? | Tech Crunch

- Perth West can look for potential partners like adjacent development sites with excess generation of renewables to enter into a corporate power purchase agreement with and increase the supply of clean energy to the site.
- As a next stage, it will be worth investigating the different business models for SLES implementation from a technical and commercial perspectives to help deliver value to the site.
- The role each entity will play, including public, private and academic sectors should be identified. This entails a more consistent coordination between the site developers and the DNO to avoid the risk of misaligned strategies.
- The social study found that local residents are willing to engage with the net zero agenda, demonstrating an appetite to alter their transport habits and retrofit their homes
- Specifically, many residents (61% of survey respondents) indicated a preference for replacing their current petrol/ diesel vehicle with an EV.
- Transition to active travel and public transport were perceived less positively but integrating an electric bike hire or sharing scheme at the new Perth West development could promote increased opportunities for peer learning and uptake.
- Meanwhile, 44.3% of survey respondents would consider air source heat pumps (ASHPs), 50.8% would consider ground source heat pumps (GSHPs), 68.2% would consider solar photovoltaics (PV), and 72.6% would consider solar water heaters.
- However, the reality is that the upfront cost is a major barrier; specifically, concerns were raised regarding the affordability of transition and the unfair expectation of resident behaviour change without appropriate high-level support.
- In terms of synergies and conflicts, there should be an attempt to offer social, leisure, and/or employment opportunities to existing communities, thereby mitigating probable tension, promoting a more cohesive wider community, and reducing scepticism.
- Future consultation may be worthwhile, affording existing residents, developers and PKC further opportunity to understand each other's point of view and work towards shared goals.

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Appendices

Appendix A: Survey

Perth West: a neighbourhood survey on energy saving & sustainability

Research team: Dan van der Horst; Connor Smith; Charlotte; Laura

Information for participants

A major new building project, Perth West, is being planned close to where you live; just on the other side of the A9. With the ambition to set new and better standards for sustainability, Perth West will include the construction of 3500+ homes (Lamberkin Village), and a sustainable transport, mobility and logistics hub (Perth Eco Innovation Park). These new residential and commercial properties will run on renewable energy generated locally.

The University of Edinburgh, in conversation with Perth and Kinross Council (PKC), are conducting research to explore how this new and more sustainable Perth West development can also benefit your (existing) neighbourhood. The clean technologies that will be used in Perth West, could also help to make existing homes (like yours) more low-carbon and help lower your heating and transport bills. In principle, we can undertake a technical assessment of how your house and neighbourhood could be 'retrofitted' to become more energy efficient and lower your energy bills. But in practice, every house and household is different. In order to appreciate how realistic the different technical options are, we need to understand how you currently live, how you feel about such technical changes and what the financial and social priorities in your household are. To find this out, we have developed this short survey, targeted specifically at residents living close to the planned Perth West development. Your participation would be hugely valuable to understand how Perth and the life of its citizens can become more sustainable and (more broadly) how people in suburban homes are considering their options at a time of unprecedented increases in the cost of gas and oil.

Our research (funded by the UK research councils) is for the public good and is not influenced by commercial interest or council policies. Your information will be treated with complete discretion and the summary findings of our work will be freely available to all (see more details in the survey below). Please use the enclosed envelope to post the survey back to us.

For any concerns or further questions, please do not hesitate to contact Dan, our team lead;

Professor Dan van der Horst, University of Edinburgh. dan.vanderhorst@ed.ac.uk

Demographics

Before we start with the main survey, we would like to ask a few questions about yourself and the area where you live.

1. What is your age?
2. What is your gender?
3. How many people live in your household and how many of these people are above the driving age (17 years old and over)?
4. How long have you lived in this home?
5. Please complete the table below (tick all that apply):

Type of property	ü	I have a garage	I have a driveway	I use on-street parking	I use none of these
Detached house (house not joined to another property)					
Detached bungalow (bungalow not joined to another property)					
Semi-detached (house attached only on one side to another property)					
Semi-detached bungalow (bungalow attached only on one side to another property)					

6. From the list below, please select the statement that best applies to you:

- I own my home
- I rent my home
- Other, please specify:

Energy in your home

The questions in this section will ask you about your home and the energy you use.

7. How do you usually heat your home? Tick all that apply, circle the most important.

- Gas boiler & central heating
- Gas fire(s)
- Electric heating
- Wood stove
- Other, please specify:

8. Please complete the table below:

	Yes, a lot	Somewhat	Not really	Not at all
Do you think that during the Covid-19 pandemic you were using more energy at home?				
Are you currently worried about the rising energy bills and "cost-of-living crisis"?				
Did you already worry about your energy bills last autumn?				

Retrofitting your home

9. Are you satisfied with the insulation in your home?

- No, please specify why:
- Yes

10. Have you ever invested in improving the energy efficiency in your home? If yes, please list here:

11. Do you happen to know the EPC (Energy Performance Certificate) rating of your home? If yes, please state here:

12. **If money was not a barrier**, would you consider investing in retrofitting your home with any of the following options, to make it more environmentally friendly and energy efficient?

Retrofitting option	Level of agreement				
	I am not sure what this is	I have this already	I would consider this	I would not consider this	If you would not consider this, why not?
Roof insulation					
Cavity wall insulation					
Double or triple glazing					
Air source heat pump system					
Ground source heat pump system					
Solar panel (PV)					
Solar water heater					
Other, please specify:					

13. Please list up to three words that come to mind when thinking of renewable energy for heating your home.

Transport

14. How many (working) vehicles do you have at the house?

Type of vehicle	Total number	How many of these are electric?
Cars		
Motorbikes or scooters		
Bicycles		
Other, please specify:		

15. What regular trips (at least once a week) are made by (one or more) members of the household? (Extra lines provided for different household members in work, schools etc):

Trips	Approximate distance in miles	Frequency (number of days per week)	Main mode of travel (e.g. car, bus, bike, walk, car share)	Occasional / secondary mode of travel
Work				
Work 2 (if applicable)				
School				
School 2 (if applicable)				
School 3 (if applicable)				
Shopping/ food groceries				
Sport/ recreational activities				
Sport/ recreational activities 2 (if applicable)				
Other, please specify:				
Other, please specify:				

16. Would you consider any of the following? Please let us know of any conditions that would apply

- Reducing petrol/diesel private vehicle use
- Getting rid of petrol diesel private vehicle
- Replacing petrol/diesel private vehicle with an electric vehicle
- Replacing petrol/diesel private vehicle with bike/electric bike
- Replacing petrol/diesel private vehicle with car sharing/bike sharing scheme
- Please specify any conditions that would apply:

Final section

17. Have you ever taken part in neighbourhood or community level activities that are designed to help your local area become more environmentally friendly?

- No
- Yes, please specify which activity:

18. In the future, would you like to take part in neighbourhood or community level activities that are designed to help your local area become more environmentally friendly?

- No
- Yes, please specify which activity:

19. To what extent are you concerned or unconcerned about global climate change?

- Very unconcerned
- Somewhat unconcerned
- Neutral
- Somewhat concerned
- Very concerned

20. If you would like to receive a summary of the survey results, please provide us with an email or postal address

    Email address:

    Full postal address:

21. Would you be willing to explore this topic in more detail? Building on the results of this short survey, the University of Edinburgh team wants to invite a smaller group of residents to participate in a more in-depth examination of the various options to retrofit your neighbourhood. If we receive enough interest, we will seek to organise focus group discussions. These will take place at a local neighbourhood venue and last approximately 90 minutes. Participants will have the option of receiving a £50 payment to enable their involvement:

- Yes, you can contact me about this – my contact details are provided above (Q20)
- No

End of survey

We thank you for your time and effort in completing this survey. Your responses are extremely appreciated and will help us better understand how the new Perth West development can also benefit your (existing) neighbourhood.

Please feel free to leave any final comment below and if you wish, contact us at dan.vanderhorst@ed.ac.uk

- Any final comments

Appendix B: Coding Framework for Free Associations of Q13

Code name	Theme	Code label	Code definition	Code examples
P1	Political	Positive Political	A political response that has positive connotations or indicates a better outcome from using renewable energy; suggests that the positives outweigh the negatives	None present in data
P2	Political	Negative Political	A political response that has negative connotations or indicates a worse outcome from using renewable energy. Suggests the negatives outweigh the positives	None present in data
P3	Political	Neutral Political	Any political response that indicates a general sense of uncertainty or sways neither positively or negatively	"Policy"
E1	Economic	Positive Economic	An economic response that has positive connotations or indicates a better outcome from using renewable energy; suggests that the positives outweigh the negatives	"Cheaper"
E2	Economic	Negative Economic	An economic response that has negative connotations or indicates a worse outcome from using renewable energy. Suggests the negatives outweigh the positives	"Too expensive"
E3	Economic	Neutral Economic	Any economic response that indicates a general sense of uncertainty or sways neither positively nor negatively	"Investment"
S1	Social	Positive Social	A social response that has positive connotations or indicates a better outcome from using renewable energy; suggests that the positives outweigh the negatives	"Comfort" "Desirable" "Warmth"
S2	Social	Negative Social	A social response that has negative connotations or indicates a worse outcome from using renewable energy. Suggests the negatives outweigh the positives	"Unreliable" "Disruption" "Messy complicated future"
S3	Social	Neutral Social	Any social response that indicates a general sense of uncertainty or sways neither positively nor negatively	"Suitability" "Effectiveness" "Redecoration"

Code name	Theme	Code label	Code definition	Code examples
T1	Technological	Positive Technological	A technological response that has positive connotations or indicates a better outcome from using H2 generators; suggests that the positives outweigh the negatives	"Efficient" "Constant"
T2	Technological	Negative Technological	A technological response that has negative connotations or indicates a worse outcome from using H2 generators. Suggests the negatives outweigh the positives	None present in data
T3	Technological	Neutral Technological	Any technological response that indicates a general sense of uncertainty or sways neither positively nor negatively. Stating a fact about the technology	"Solar" "Wind" "Electric"
En1	Environmental	Positive Environmental	An environmental response that has positive connotations or indicates a better outcome from using renewable energy; suggests that the positives outweigh the negatives	"Cleaner" "Reduced carbon footprint" "Saving the planet"
En2	Environmental	Negative Environmental	An environmental response that has negative connotations or indicates a worse outcome from using renewable energy. Suggests the negatives outweigh the positives	None present in data
En3	Environmental	Neutral Environmental	Any environmental response that indicates a general sense of uncertainty or sways neither positively nor negatively	"Planet" "Climate change"
L1	Legal	Positive Legal	A legal response that has positive connotations or indicates a better outcome from using renewable energy; suggests that the positives outweigh the negatives	None present in data
L2	Legal	Negative Legal	A legal response that has negative connotations or indicates a worse outcome from using renewable energy. Suggests the negatives outweigh the positives	None present in data
L3	Legal	Neutral Legal	Any legal response that indicates a general sense of uncertainty or sways neither positively nor negatively	None present in data

Appendix C: Focus group research design process

Thinking about delivery:

- FGs will be based on a series of questions that are designed to keep the conversation flowing in line with the research aim.
- However, these questions will not be set in stone; at times, we will almost certainly need think on our feet, improvise and work with the conversation.

Thinking more generally:

- The 'success' of the FGs will be determined by the extent to which we are able to engender conversation between participants.
- The more rapport and trust we can build, the more likelihood of there being a fluid exchange and co-creation of thoughts and attitudes.
- Prompts and probes will be important. So too will our sensitivity to non-verbal cues.
- We may need to encourage quieter participants and discourage overly talkative ones
- Stress that there are no right or wrong answers.
- Manage expectations (be clear regarding what we can & can't do with our findings)

Task	Time	Notes
Introduction to the project	0 mins – 5 mins	Who we are, what we're doing, thanks for being here
Intro/ general views and concerns	5 mins – 20 mins	Look for opportunities where further elaboration of survey findings can bring fresh / more detailed insights
Scenarios	20 mins – 1hr	Laura will be leading / talking through scenarios – then opening up to resident feedback
Break		
Street & neighbourhood level change	1hr – 1hr 20 mins	This is where an interactive element could be really useful: I like the idea of printing off a big map & having props that residents can utilise – e.g. toy bikes/ cars/ scooters; different coloured straws for bike lanes/ new bus routes
Perth & living in Perth more sustainable	1hr 20 mins – 1 hr 30 mins	Priority will be given to the scenario work & subsequent street level change section, therefore, we will have this section as optional depending on the time remaining in each session

Part 1: Introduction/ general views and concerns

(*note* bear in mind that we will already have resident data concerning questions already asked on the survey; it stands to reason that we don't want to simply re-ask the same questions in this section, but instead look for opportunities where further elaboration can bring fresh insights/ greater detail)

- Can you please introduce yourself? Your name and maybe tell us your favourite thing about living on this estate? (If not getting many takers, ask them to name things that annoy them about where they live..v.british)

- So, can someone start us off by telling us what they know about climate change?
- Is this something that you're concerned about?
- Have you made any behaviour changes in the past to try & be more environmentally friendly?

- Could be interesting to use the remaining time in this section to sense check/ run the results of the survey past focus group participants. Use our findings to identify relevant avenues of investigation. E.g., if Solar PV comes back as really popular, then dive into this in more detail; if heat pumps come back as really unpopular, then find out why this may be etc.

Part 2: Scenario section

(*note* this is where we will introduce Laura's scenarios)

Considerations for Laura:

- Will scenarios be introduced verbally? Or will there be visual aids (e.g., handouts/ a PowerPoint presentation etc.)
- Alternatively, we could produce material that residents digest beforehand, e.g., a recorded PowerPoint presentation or short video
- How many scenarios can we realistically hope to fit in? bearing in mind that your intro to these scenarios will also eat into time
- Will scenarios be mixed (e.g., transport & home retrofit combined) or will there be separate retrofit and transport scenarios?

- So, what are your first thoughts regarding the scenarios that Laura has just presented?
- Do any of them appeal to you? Why? Or why not?
- Would you consider getting on board with scenario X?
- How could this be improved?
- To your mind, what are the main obstacles in realising this?
- What would need to change to make Y more appealing to you?
- Are you familiar with all the technologies / models within the scenarios? Are there any that you know more about than others?
- What kind of additional information would help to inform your thinking?

- To what extent do you think Z is a realistic proposition? Could you see that happening here?
- Have we missed anything obvious? Or that you value in relation to what we're discussing?

(Generally speaking getting a sense of potential interest in various options, possibilities; exploring barriers, why certain things aren't possible – beyond 2D cost of tech; capturing a diversity of views)

Part 3: Street & neighbourhood level change

(*note* this is where an interactive element could be really useful: I like the idea of printing off a big map & having props that residents can utilise – e.g., toy bikes/ cars/ scooters; different coloured straws for bike lanes/ new bus routes;)

- So, considering all that we have spoken about so far, what kinds of actions do you think could be taken at a street or neighbourhood level?
- Why do you think this is a good idea? How would it impact upon you & your day-to-day?
- What about the other side of the coin, what kind of actions discussed so far do you think would be ill suited to street/ neighbourhood level change?

- Prompts: bicycle lanes; new public transport routes; car club parking spaces; bicycle hire/ rental; electric bicycle/ scooter rental; community energy?
- Get residents to illustrate on the map where bike lanes should be; where public transport routes could go etc.

Part 4: Making Perth (& living in Perth) more sustainable

(*note* this is how we round it all off – priority will be given to the scenario work & subsequent street level change sections, therefore, we will have this section as optional depending on the time remaining in each session)

- What do you think are the biggest climate challenges facing Perth as a city?
- And how about opportunities that this may bring?
- Are you hopeful about what the future holds? Or more anxious?
- Who do you think has the most responsibility to drive change? (Individuals; communities; the council; national politicians/ Scot Gov; Westminster; energy companies etc.)

Prompts/ probes

- And what about you X, do you agree with that?
- Is everyone in agreement with that? Or are there any other opinions?
- X, what do you think about what Y just shared with us?
- Can you elaborate on that a little more please?
- Why do you think that? Does anyone agree? Or disagree?

Appendix D: Social study methodology

Quantitative survey data design and analysis (closed-ended questions)

There were several forms of closed-ended questions adopted in the survey which yielded quantitative data. These took the form of "Yes" or "No response questions (Dichotomous questions), "Tick all that apply" questions (multiple answer questions) and one Likert Scale question. Dichotomous questions are very simple to create, respond to and analyze. Multiple answer questions are as well and as adopted in this study e.g., question 14, can include an "Other" category. This allows the data to become more inclusive to options not considered or realised by the researcher (Stockemer, 2019). Likert Scale questions are the most used questions in surveys (Kumar, 1999: 132) and use a fixed choice response format. Using them allowed us to measure opinions linearly. The Likert Scale question that we used was question 19, "To what extent are you concerned or unconcerned about global climate change?". The answer options were on a continuum from "very unconcerned" (coded 1), "somewhat unconcerned" (coded 2), "neutral" (coded 3), "somewhat concerned" (coded 4), and "very concerned" (coded 5). This is an example of a 5-point Likert Scale question; however, they can be of any size with the most used having 5, 7, or 10 points. It is debated in the literature whether to use a neutral category but in the case of this study, a neutral category was used as it avoids forcing the respondent to choose an answer that they may necessarily not feel which can invalidate the data (Stockemer, 2019). Additionally, excluding a neutral category can lead to respondent frustration, compelling them to terminate participation in the survey. Due to these reasons and as we were combating a potentially low response rate, we chose to include the neutral category.

The closed ended, quantitative question responses were analysed in the statistical software, SPSS 25.0, to identify trends in the dataset and relationships between variables. Firstly, the raw data from the paper surveys was coded and formatted onto an Excel spreadsheet. This was then input into SPSS where the data was valued and labelled appropriately for the software. To not skew the data of linear variables, some responses were coded as 'missing', such as the unanswered questions and "not applicable" responses. Frequencies and descriptive statistics were drawn out the data to obtain an initial insight into the dataset. Bivariate correlation tests were used as they measure monotonic relationships between two variables (Schober et al., 2018). Schober et al., explain two types to monotonic relationships between two variables:

1. As one variable increases, the other also increases. In this relationship, the Pearson correlation coefficient (r) is closer to +1
2. As one variable increases, the other decreases. In this relationship, the Pearson correlation coefficient (r) is closer to -1.

Considering Grabowski's (2016) review on significance, if the Pearson correlation coefficient is close to 0, the correlation is weak. If it is close to -1 or +1, the correlation is strong. However, the correlation is only statistically significant if the p value <=0.05.

Qualitative Survey data design and analysis (open-ended questions)

As it is necessary to have pre-structured, closed-ended quantitative questions in surveys, which frame responses, the survey used for this study also included questions that gave the participant opportunities to frame their own responses. These opportunities were created through open-ended questions and word association questions, such as: 'Please list up to three words that come to mind when thinking of renewable energy for heating your home' and 'Please specify any conditions that apply:'. These questions are a form of the free association method which reflects the "implicit ways of thinking about energy technologies" (Devine-Wright, 2005:10) by eliciting qualitative responses that are not constrained in choice. Qualitative analysis techniques, used for the free association questions, are described in the subsequent sub-section.

The responses to free association questions must be cleaned and homogenised to create a list of semantic associations which can be categorised into a manageable dataset (Wagner et al., 1997). However, this categorisation is subjectively classified by the researcher and, therefore, the research may become biased. This bias can be substantially restricted by using a coding framework (Wagner et al., 1997) and can be further restricted when the coding framework is subjected to inter-rater reliability tests before completing analysis (Belur et al., 2018).

To organise the free association responses, to the questions mentioned above, a thematic analysis of the responses was conducted, specifically a deductive thematic analysis. The two main types of thematic analysis are 'inductive' and 'deductive'. An inductive thematic analysis is most appropriately used if the researcher has limited knowledge on the phenomenon under discussion or has a very broad research question (Rivas, 2012). Whereas, if the reader has previously accessed the data or literature on the phenomenon, then the deductive thematic analysis approach is most suitable (Rivas, 2012). While the inductive approach reveals themes and sub-themes (codes), the deductive approach requires the researcher to begin the analysis with draft themes already established (Rivas, 2012). Additionally, deductive thematic analyses allow the researcher to tailor to analytical interest (Braun and Clarke, 2006) based on previous research, theory and, or intuition and experience.

Deductive thematic analysis conducted for the free association question asking for associations with "renewable energy for heating your home" (Question 13 of survey) was guided by the 6 stages of thematic analysis (Braun and Clarke, 2006; Kiger and Varpio, 2020). These are listed below and subsequently described:

- Stage 1: Familiarising yourself with the data.
- Stage 2: Generating Initial Codes.
- Stage 3: Searching for Themes.
- Stage 4: Reviewing Themes.
- Stage 5: Defining and Naming Themes.
- Stage 6: Producing the report/manuscript

STAGE 1: Familiarising yourself with the data

This stage requires the reader to become familiar with the dataset by actively reading through the data (Braun and Clark, 2006). Due to the primary nature of the data, researchers were able to familiarise with the data from an early stage. This extended into 'repeated reading' of the data (survey participant responses). This provides the researcher valuable orientation of the data to prepare for the next stages of analysis.

STAGE 2: Generating initial codes

Stage 2 generates codes, not themes (Kiger and Varpio, 2020) which are the basic elements of information or data that can be assessed in a meaningful manner, regarding the phenomenon. These codes must be well defined and fit within a larger coding framework. The position of the codes within a larger coding framework can be seen in Appendix B. These took the form of positive, negative, and neutral associations.

STAGE 3: Searching for themes

In a deductive thematic analysis, this is a simple step as themes are informed by the theoretical framework (Braun and Clarke, 2006). The themes for this study were predetermined by the key external factors that influence the successful implementation of renewable energy technologies.

Often, successful adoption and diffusion of innovations is assumed to be merely an issue of securing the techno-economic dimension (Valet, 2008 :8). However, the reality is that aligned views of various stakeholders (social acceptance) are necessary for successful technology developments (Valet, 2008). Additionally, stable political coalitions which are supportive of renewable energies (Van Est, 1999) and strong, early policy support have been discussed as crucial for successful renewable energy development (Krohn, 2002). Valet (2008) also advocates for inclusion of socio-economic factors to be considered in the deployment of new energy technologies. Among the many factors that influence the success and public perception of renewable energy sources, is environmental awareness and environmental impacts of the technology (Tsoutsos, 2002).

In short, the research highlighted that the key influential factors fall within the following themes: political (e.g., Government in support of renewable energies); economic; social; technological; environmental; and legal (policy support). These make up the commonly used, macro- level business analysis tool, PESTEL Analysis and therefore acted as the themes for this study's deductive thematic analysis. See ANNEX I (slide 8).

STAGE 4: Reviewing themes

Stage 4 of thematic analysis requires the researcher to, firstly, ensure each code appropriately fit within the themes. This review is complete when the researcher is confident that the codes are representative of the coded data (Braun and Clarke, 2006). The deductive nature of this study promotes a good fit and thus, speeds up this process. This is when any necessary recoding can be implemented, however this was not necessary for this study. The framework was subjected to inter-rater reliability tests.

STAGE 5: Defining and naming themes

This stage requires the researcher to focus on the most important aspect of the themes while drawing upon the data. This allows the researcher to create a coherent narrative of how the themes are interconnected and how they answer the research questions (Braun and Clarke, 2006).

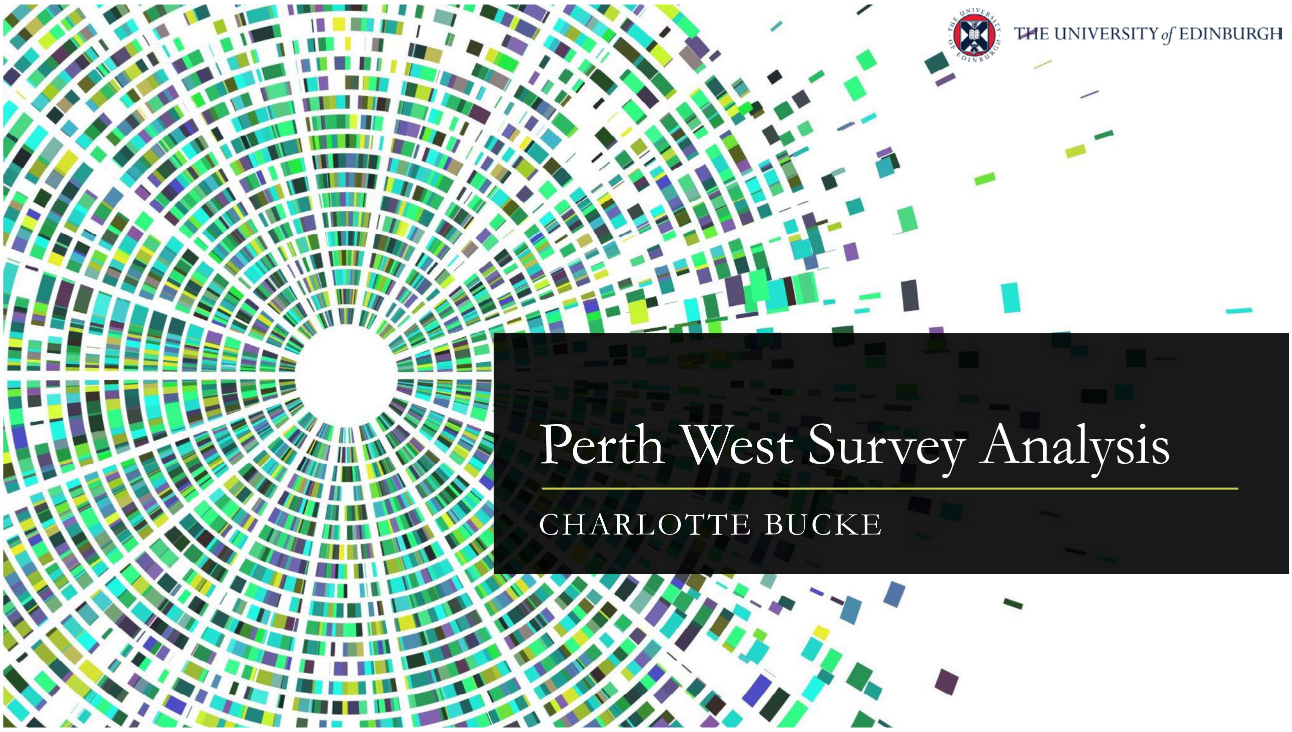
STAGE 6: Producing the report/manuscript

Rather self-explanatory, the researcher describes the findings and analysis. This stage goes beyond describing the codes and themes. This report should feature direct quotes from the data, an explanation of their importance and should answer the research questions (Braun and Clarke, 2006).

ANNEXES

ANNEX I: Survey analysis results (PowerPoint)

Slide 1



Slide 2

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Descriptive Statistics: Age, Gender, Household

Age Brackets of Survey Participants		
Age (years)	Frequency	% of participants
18-29	1	1.3
30-39	1	1.3
40-49	7	9.1
50-59	19	24.7
60-69	17	22.1
70-79	22	28.6
80-89	7	9.1
90-99	3	3.9

Number of Survey Participants who are Male and Female		
Gender	Frequency	% of participants
Female	34	44.7
Male	42	55.3

Number of People in Survey Participants' households		
No. of people in household	Frequency	% of participants
1	18	23.4
2	42	54.5
3	6	7.8
4	11	14.3
Mean = 2.13		

Number of People Above Driving Age (17y/o) in Survey Participants' Households		
No. of people in household above driving age	Frequency	% of participants
1	18	22.8
2	50	63.3
3	7	8.9
4	1	1.3
Mean = 1.88		

How Long Survey Participants Have Lived in Their Homes		
Length of time lived in current home	Frequency	% of participants
0-5	9	14.8
6-10	8	13.1
11-15	8	13.1
16-20	10	16.4
21-25	4	6.6
26-30	7	11.5
31-35	6	9.8
36-40	3	4.9
41-45	3	4.9
46-50	2	3.3
50+ years	1	1.6

Total Survey Responses: 79

Participants interested in Focus Group: 21

Home Ownership: One participant did not answer this question. Everyone who did, answered "I own my home".

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Slide 3

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Descriptive Statistics: Housing Types, Parking, Energy Efficiency

Types of Properties in the Study Area		
Type of property	Frequency	% of participants
Detached house	41	53.2
Detached bungalow	23	29.9
Semi-detached house	10	13
Semi-detached bungalow	3	3.9

Participants' Heating Types		
Type of Heating	Frequency	% of participants
Gas boiler & central heating	76	96.2
Gas fire(s)	8	10.1
Electric heating	6	7.6
Wood stove	7	8.9
Other: AGA cooker (gas)	1	1.27

Energy bills and living cost (frequency, % of participants)				
	Yes, a lot	Somewhat	Not really	Not at all
Do you think that during the Covid-19 pandemic you were using more energy at home?	17, 21.5%	31, 39.2%	29, 36.7%	1, 1.3%
Are you currently worried about the rising energy bills and "cost-of-living crisis"?	37, 46.8%	30, 38%	9, 11.4%	2, 2.5%
Did you already worry about your energy bills last autumn?	8, 10.1%	18, 22.8%	37, 46.8%	14, 17.7%

Type of Parking at Homes in the Study Area						
	Frequency, % of participants					
Type of property	Only a garage	Only a driveway	Only on-street parking	Do not use garage, driveway or on-street	Both garage & driveway	Garage, driveway & on-street parking
Parking at Detached house	6, 14%	0	0	1, 2.3	34, 79%	2, 4.7%
Parking at Detached bungalow	0	1, 4.5%	0	0	21, 95.5%	0
Parking at Semi-detached house	2, 22.2%	0	0	0	7, 77.8%	0
Parking at Semi-detached bungalow	0	0	0	0	3, 75%	1, 25%

Are Survey Participants Happy With Their Insulation?		
	Frequency	% of participants
No	24	31.6
Yes	52	68.4

How Many Survey Participants Have Invested in Energy Efficiency of Home		
	Frequency	% of participants
No	11	16.9
Yes	54	83.1

Only 2 survey participants knew their EPC rating. One participant lives in a detached bungalow whose EPC is D. The other lives in a detached house whose EPC is C.

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Slide 4

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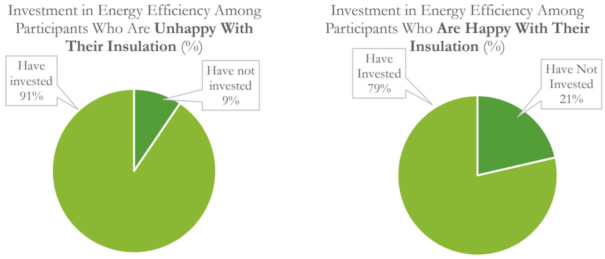
Deeper Dive into Energy Efficiency



Why are people not satisfied with the energy efficiency of their homes?:

- Require new windows and/or doors.
- Draughty despite double glazing and insulation.
- Home is cold.
- Need extra insulation despite already installing.
- Want cavity wall insulation but building structure does not support.

How have people invested in the energy efficiency of their homes?:

- New gas boiler.
- New radiators.
- Loft, cavity wall and underfloor heating.
- New windows and/or doors.
- Installed solar panels
- LED light bulbs.
- Smart thermostat & radiator valves.
- Installed draught excluders.

From the 76 people who told us if they are or are not happy with their insulation, only 63 people told us if they have or have not invested in their home's energy efficiency.
From the 63, 21 people are not happy with their insulation, while 42 people are happy with their insulation.
Therefore, at a glance, the percentages suggest false results as the percentages are of different numbers. Therefore, see the table below.

Investment in Energy Efficiency

Thoughts on their insulation	Invested in Energy Efficiency	n	% of participant who are and are not happy with their insulation
Unhappy with insulation	Have not invested	2	9.5
	Have invested	**19**	90.5
Happy with insulation	Have not invested	9	21.4
	Have invested	**33**	78.6

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Slide 5

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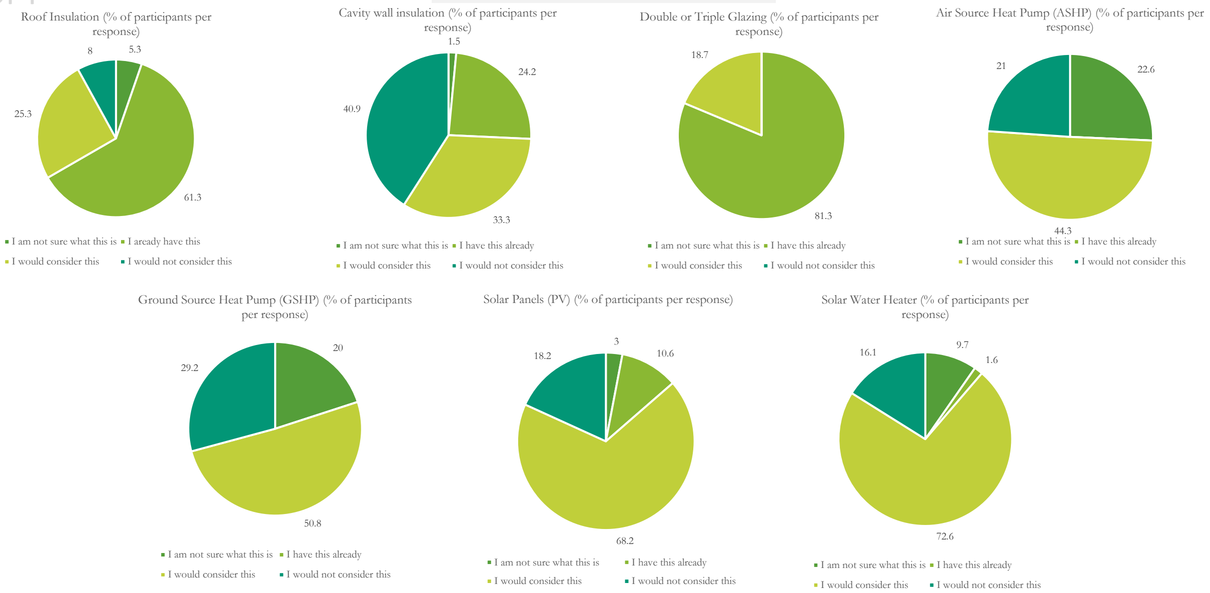
Descriptive Statistics: Retrofitting Options

General survey population's thoughts on retrofitting options



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Slide 6

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Descriptive Statistics: Retrofitting Options cntd.

Why would people not consider the following retrofitting technologies?:

- Roof insulation:
  - "Not worth hassle, stuff stored in loft"
- Cavity wall insulation:
  - "Structure not appropriate" x12
  - "Cost"
  - "No benefit to my house"
  - "Not recommended"
  - "The cavity is there for a purpose"
- Double of triple glazing:
  - N/A
- ASHP:
  - "Insufficient knowledge"
  - "Cost"
  - "Capital outlay too high"
  - "Too expensive" x2
  - "I have yet to be convinced"
  - "Recent new boiler – not a good move for a few years"
  - "Too noisy"
- GSHP:
  - "Cost"
  - "Too much change and hassle at my age"
  - "Capital outlay too high"
  - "Too expensive" x2
  - "Not enough ground space" x5
  - "Don't understand system"
- Solar panels:
  - "Cost"
  - "Too much change and hassle at my age"
  - "If problem with roof it may be a barrier"
  - "Wrong climate"
  - "No south face roof"
  - "Never recover investment"
- Solar water heater:
  - "Too much change and hassle at my age"
  - "Too expensive"
  - "Wrong climate"
  - "Never recover investment"

Survey Participants' Overall Responses to Retrofitting Options

	I am not sure what this is		I have this already		I would consider this		I would not consider this	
Retrofitting option	n	%	n	%	n	%	n	%
Roof insulation	4	5.3	46	61.3	19	25.3	6	8
Cavity wall insulation	1	1.5	16	24.2	22	33.3	27	40.9
Double or triple glazing	0	0	61	81.3	14	18.7	0	0
Air source heat pump system	14	22.6	0	0	35	44.3	13	21
Ground source heat pump system	13	20	0	0	33	50.8	19	29.2
Solar panel (PV)	2	3	7	10.6	45	68.2	12	18.2
Solar water heater	6	9.7	1	1.6	45	72.6	10	16.1

*n = Frequency/Number of people who selected the corresponding response. % = the percentage of people who **answered this question**.*

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Slide 7

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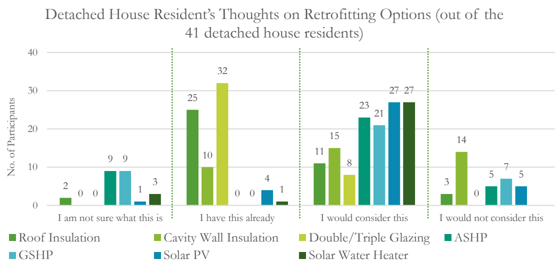
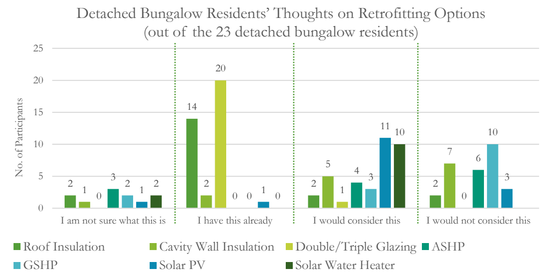
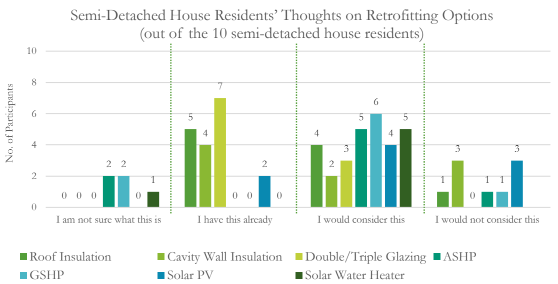
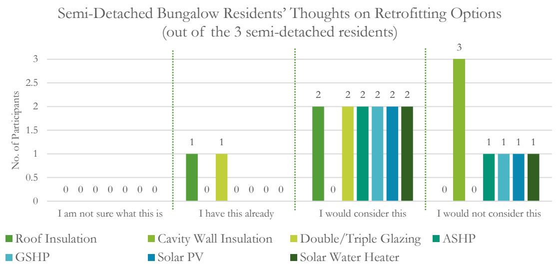
Deeper Dive into Retrofitting Options

The following shows how participants, belonging to different property types, feel about the retrofitting options.









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Slide 8

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Free Association with "renewable energy for heating your home"

1 = positive. 2 = negative. 3 = neutral/general

Economic Associations

Word/Phrase	Count	Theme	Code
Cost / Costly to install	14	Economic	E2
Cheap/Cheaper	6	Economic	E1
Expensive / too expensive	5	Economic	E2
Couldn't afford to install	1	Economic	E2
Less expensive	1	Economic	E1
Saving money	1	Economic	E1
Investment	1	Economic	E3

Environmental Associations

Word/Phrase	Count	Theme	Code
Environment/Environmental	7	Environmental	En1
Clean/Cleaner	6	Environmental	En1
Sustainable/Sustainability	4	Environmental	En1
Green/Greener	3	Environmental	En1
Reduced carbon footprint/Reducing carbon	2	Environmental	En1
Low-carbon	1	Environmental	En2
Climate change	1	Environmental	En1
Eco / Eco-friendly	4	Environmental	En1
Natural	1	Environmental	E3
Planet	1	Environmental	En3
Saving the planet	1	Environmental	En1

Social Associations

Word/Phrase	Count	Theme	Code
Reliability	3	Social	S3
Effective	2	Social	S1
Future proofing	2	Social	S1
Very good idea / good in principle	2	Social	S1
Comfort	1	Social	S1
Reliable	1	Social	S1
Unreliable	1	Social	S2
More information required	1	Social	S2
Disruption	1	Social	S2
Effectiveness	1	Social	S3
Not effective on small scale	1	Social	S2
Positive	1	Social	S1
Future	1	Social	S1
Messy complicated future	1	Social	S2
Unrealistic	1	Social	S2
Upheaval	1	Social	S2
Redecoration	1	Social	S3
Available	1	Social	S1
Desirable	1	Social	S1
Easy	1	Social	S1
Hassle	1	Social	S2
Warmth	1	Social	S1
Suitability	1	Social	S3
Unsure of benefit	1	Social	S2

Political Associations

Word/Phrase	Count	Theme	Code
Policy	1	Political	P3

Technological Associations

Word/Phrase	Count	Theme	Code
Solar (panels/power)	9	Technological	T3
Wind / Wind turbine	7	Technological	T3
Efficient	3	Technological	T1
Hydro electric power / hydro	2	Technological	T4
Efficiency	2	Technological	T3
Ground	1	Technological	T3
Ground source pump	1	Technological	T3
Heat pump	1	Technological	T3
Tide	1	Technological	T3
Electric	1	Technological	T3
Nuclear	1	Technological	T5
Water	1	Technological	T3
Hydrogen	1	Technological	T3
Constant	1	Technological	T1
Insulation	1	Technological	T3
Sun	1	Technological	T3

Top 10 free associations:
1) Cost/Costly to install (14)
2) Solar panels/Solar power (9)
3) Environment/Environmental (7)
4) Wind/Wind turbine (7)
5) Cheap/Cheaper (6)
6) Clean/Cleaner (6)
7) Expensive/Too expensive (5)
8) Sustainable/Sustainability (4)
9) Eco/Eco-friendly (4)
10) Green/Greener (3)

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Slide 9

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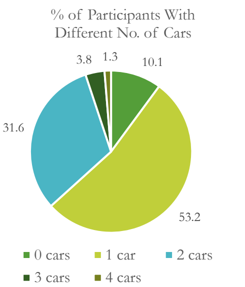
Descriptive Statistics: Vehicles at Home

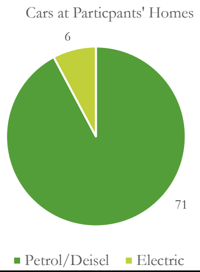
0 = participant left it blank (unanswered or zero). n = Frequency/Number of people who selected the corresponding response. % = the percentage of people who ***answered this question.***

Number of Cars belonging to Survey Participants

No. of Cars	n, %	How many are electric (n, % of cars)
0	8, 10.1%	n/a
1	42, 53.2%	2, 2.8%
2	25, 31.6%	3, 4.2%
3	3, 3.8%	0
4	1, 1.3%	1, 1.4%
Total = 71 (89.9% have cars)		**Total = 6 (8.5% of cars are electric)**

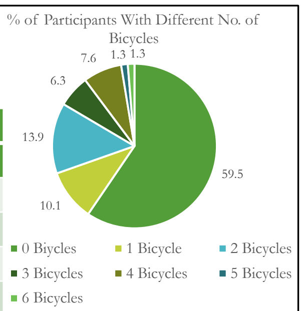
For the 143 individuals in the households above driving age, there are 71 cars.

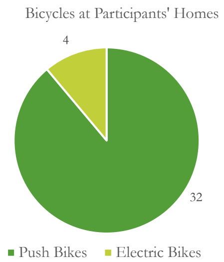




Number of Bicycles belonging to Survey Participants

No. of Bicycles	n, %	How many are electric (n, % of bicycles)
0	47, 59.5%	n/a
1	8, 10.1%	0
2	11, 13.9%	2 (at one household)
3	5, 6.3%	1
4	6, 7.6%	1
5	1, 1.3%	0
6	1, 1.3%	0
Total = 32 (40.1% have bicycles)		**Total = 4 (12.5% of bicycles are electric)**





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Slide 10

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Descriptive Statistics: Vehicles at Home cntd.

0 = participant left it blank (unanswered or zero). n = Frequency/Number of people who selected the corresponding response. % = the percentage of people who ***answered this question.***

Number of Motorbikes/Scooters belonging to Survey Participants		
No. of Motorbikes/Scooter	n, %	How many are electric (n, %)
0	77, 97.5%	n/a
1	1, 1.3%	0
2	1, 1.3%	0
Total = 2 (2.5% have motorbikes/scooters)		Total = 0

OTHER VEHICLES

Two participants have a campervan.
Neither of the campervans are electric.

Slide 11

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Descriptive Statistics: Regular Trips made by Survey Participants

n = Frequency/Number of people who selected the corresponding response. % = the percentage of people who ***answered this question (77 participants)***

No. of Participants Who Regularly Take Various Trips					
Regular Trip	n, %	Approx. distance in miles (min, max, mean)	No. of days per week (min, max, mean)	Main Modes of travel (n, % of people who takes this regular trip)	Main secondary mode of travel (n, % of people who takes this regular trip)
Work 1	31, 39.2%	Min: 2 Max: 600 Mean: 25.6	Min: 1 Max: 7 Mean: 4.28	Car: 25 83.3% Bus: 1 3.3% Bike: 1 3.3% Walk: 3 10%	Car: 3 37.5% Bus: 3 37.5% Bike: 1 12.5% Walk: 1 12.5%
Work 2	10, 12.7%	Min: 2 Max: 300 Mean: 5.05	Min: 1 Max: 5 Mean: 3.44	Car: 2 16.7% Bike: 1 8.3% Walk: 9 75%	n/a
School 1	12, 15.2%	Min: 0.25 Max: 4 Mean: 0.2	Min: 1 Max: 5 Mean: 4.17	Car: 2 16.7% Bike: 1 8.3% Walk: 9 75%	n/a
School 2	4, 5.1%	Min: 0.25 Max: 2 Mean: 0.05	Min: 2 Max: 5 Mean: 4.25	Car: 1 25% Walk: 3 75%	Walk: 1 100%
Shopping/Groceries	72, 91.1%	Min: 1 Max: 20 Mean: 3.73	Min: 1 Max: 7 Mean: 2.01	Car: 56 88.9% Bus: 5 7.9% Bike: 1 1.6% Walk: 1 1.6%	Car: 2 18.2% Bus: 9 81.8%
Sport/Recreation 1	51, 64.6%	Min: 1 Max: 100 Mean: 12.42	Min: 1 Max: 7 Mean: 2.31	Car: 31 70.5% Bus: 3 6.8% Bike: 4 9.1% Walk: 5 11.4% Motorbike : 1 2.3%	Car: 3 42.9% Bus: 3 42.9 Walk: 1 14.3%
Sport/Recreation 2	14, 17.7%	Min: 2 Max: 90 Mean: 2.84	Min: 1 Max: 4 Mean: 2.07	Car: 11 84.6% Bus: 1 7.7% Car Share: 1 7.7%	n/a
Other (Unknown)	4, 5.1%	Min: 1 Max: 70 Mean 19.5	Min: 1 Max: 2 Mean: 1.5	Car: 2 50% Walk: 1 25% Car Share: 1 25%	n/a
Other (miscellaneous lifestyle)	1, 1.3%	Min: 6 Max: 6 Mean: 6	1	Car: 1 100%	Bus: 1 100%
Other (caring duties)	7, 8.9%	Min: 3 Max: 120 Mean: 63	Min: 1 Max: 5 Mean: 2.17	Car: 6 100%	n/a
Other (church)	1, 1.3%	Min: 8 Max: 8 Mean: 8	1	Car: 1 100%	Walk: 1 100%

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Descriptive Statistics: Regular Trips made by Survey Participants cntd

Regular Trip	Days Per Week Travelled (n of people & % of people per regular trip)
Work 1	1 day: 1, 3.4%
	2 days: 3, 10.3%
	3 days: 5, 17.2%
	4 days: 2, 6.9%
	5 days: 15, 51.7%
	6 days: 2, 6.9%
	7 days: 1, 3.4%
Work 2	1 day: 1, 11.1 %
	2 days: 1, 11.1%
	3 days: 3, 33.3%
	4 days: 1, 11.1%
	5 days: 3, 33.3%
School 1	1 day: 2, 16.7%
	3 days: 1, 8.3%
	5 days: 9, 75%
School 2	2 days: 1, 25%
	5 days: 3, 75%

Regular Trip	Days Per Week Travelled (n of people & % of people per regular trip)
Shopping/Groceries	1 day: 24, 35.8%
	2 days: 28, 40.6%
	3 days: 13, 18.8%
	4 days: 2, 1.9%
	5 days: 1, 1.4%
	7 days: 1, 1.4%
Sport/Recreation 1	1 day: 16, 32.7%
	2 days: 16, 32.7%
	3 days: 9, 18.4%
	4 days: 4, 8.2%
	5 days: 3, 6.1%
	7 days: 1, 2%
Sport Recreation 2	1 day: 5, 35.7%
	2 days: 5, 35.7%
	3 days: 2, 14.3%
	4 days: 2, 14.3%
Sport Recreation 2	1 day: 5, 35.7%
	2 days: 5, 35.7%
	3 days: 2, 14.3%
	4 days: 2, 14.3%

Regular Trip	Days Per Week Travelled (n of people & % of people per regular trip)
Other (Unknown)	1 day: 2, 50%
	2 days: 2, 50%
Other (miscellaneous lifestyle)	1 day: 1, 100%
Other (caring duties)	1 day: 3, 50%
	2 days: 1, 16.7%
	3 days: 1, 16.7%
	5 days: 1, 16.7%
Other (church)	1 day: 1, 100%

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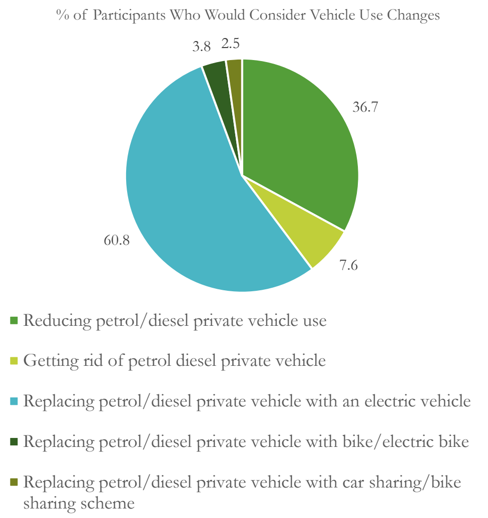
Descriptive Statistics: Alternative Vehicle Use

The survey participants were asked if they would reduce their petrol/diesel vehicle use or replace the petrol/diesel vehicle for alternative modes of transport. Here are their responses.

No. of Survey Participants Who Would Consider Different Vehicle Use Changes	
Vehicle Use change	No. of People Who Would Consider the Change, %
Reducing petrol/diesel private vehicle use	29, 36.7%
Getting rid of petrol diesel private vehicle	6, 7.6%
Replacing petrol/diesel private vehicle with an electric vehicle	48, 60.8%
Replacing petrol/diesel private vehicle with bike/electric bike	3, 3.8%
Replacing petrol/diesel private vehicle with car sharing/bike sharing scheme	2, 2.5%



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Descriptive Statistics: Alternative Vehicle Use cntd.

Participants were asked to tell us about any conditions which would need to be put in place to convince them to change their vehicle use. Upon being asked this, the participants also shared general comments about their vehicle use. It became apparent that both fell into the following themes: 'Cost & Affordability'; 'Convenience'; 'Charging Infrastructure'; 'Technology of Vehicle'; and "Environmental See below.

Conditions for Vehicle Use Change Expressed by Survey Participants

Theme	Example of Conditions	Count
Cost & Affordability	"cost" "cost neutral" "trade in and running costs" "cost of charging facilities" "make them more affordable" "At present changed to hybrid but not consider electric again until cheaper to buy" "Money to buy electric car" "Electric car prices need to reduce significantly" "As and when price of an electric care compares with that of a petrol/diesel car" "price would have to reduce" "Lower cost of electric vehicles",	16
Charging Infrastructure	"More public charging points"	5
Technology of Vehicle	Improve range, e.g., "Will not consider electric car until they can cover 600 miles"	3
Convenience	"When current car needs replaced (Not routine 3 yearly replacement)"	2
Convenience	Convenience	1
Convenience	"I would not consider giving up private vehicle if I could use public transport"	1
Environmental	"Electric vehicles would be more sustainable than currently"	1
Technology of Vehicle	"better technology/lifespan"	1
Technology of Vehicle	"Be able to tow caravan"	1

Comments on Vehicle Use Expressed by Survey Participants

Theme	Comments	Count
Cost	"Would like an electric car but can't afford, too expensive"	1
	"Providing it makes economic sense"	1
	"Public transport expensive"	1
Convenience	"Because of my age private vehicle use is necessary and helpful"	1
	"I currently need a vehicle available at all times due to caring duties"	1
	"My car is very rarely out (11-year-old Honda) this is my last car"	1
	"rail network inadequate "	1

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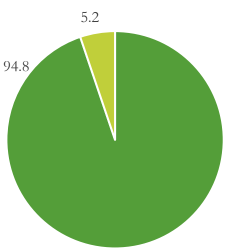
Descriptive Statistics: Environmental Community Activities

n = Frequency/Number of people who selected the corresponding response. % = the percentage of people who ***answered this question (77 participants)***

Environmental Community Activity Participation

Answer	n, %
No	73 94.8%
Yes	4 5.2%

Have Participants Partaken in Environmental Community Activities? (%)



Environmental community activities which survey participants have taken part in:

- "In Aberdeen - organised neighborhood tidy of city".
- "litter picks, school tree planting, monitoring 'no mow' wildflower areas in local greenspace".
- "I have planted trees which the council cut down".
- "Monitor wildlife friendly areas. Write to council to encourage biodiversity."

Environmental community activities which survey participants would like to take part in:

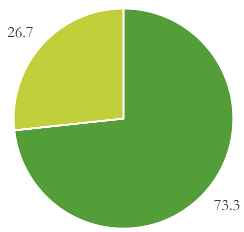
- "Any".
- "Litter picking. Planting".
- "More of the same (2nd bullet point to left).
- "Sharing experience of renewables etc. Litter clearing e.g., tuley tubes in woods, meadow cutting, raking hedgehog routes in gardens".
- "Recycling".
- "Energy efficiency".
- "Would consider options".
- "Reduce environmental impacts"

Three participants expressed that **they were unsure or unaware of which environmental community activities they have as options**. This suggests better communication about such activities must improve.

Would Participants Get Involved in Environmental Community Activities in the Future?

Answer	n, %
No	55 73.3%
Yes	20 26.7%

Would Participant Partake in Future Environmental Community Activities? (%)



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Slide 16

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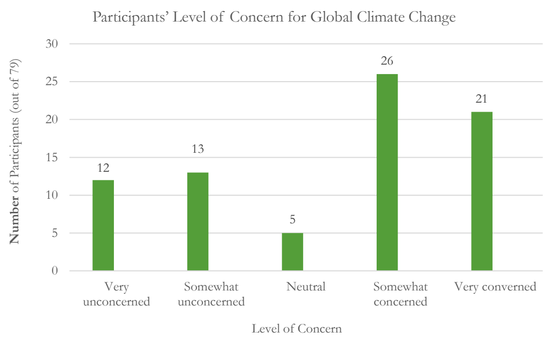
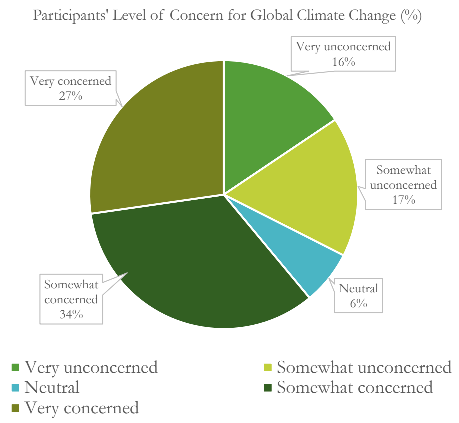
Descriptive Statistics: Environmental Concern





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Participants' Additional Comments

Comments
• I tried to insulate my home and also help with being environmentally friendly. The thing that stops me is being a career as have to drive to my parents. I would change to an electric car, but they are so expensive and not really trusting them to have a charge and get called to parents suddenly. I have also tried the solar panel battery, but this is proved expensive as well. I am now a widow and money tighter now
• At 73 I'm taking a less active role in things
• I am very concerned that this development is adding so many more new homes to Perth. It is already one big housing estate. I cite Charlotte Gate as another project. This will lead to even more cars on the road. Its human nature people will not be willing to give up their cars for public transport. We already have reduced service since the pandemic. Also, the town centre does not entice people in due to the lack of shops. Reading page 1 all the right words have been used to portray this project as just what Perth needs. However, I am of the opinion , given the pandemic and current world affairs, all options must be very carefully considered before any decisions are taken.
• Good luck with your project
• Hydrogen power for vehicles make induction boilers more efficient. I do not see any future for battery powered vehicles with the present technology. Hard charging any battery significantly reduces the life of the battery and replacement is almost as much as the car itself.
• If you want to help the environment etc do not build any more houses in the Perth area. There are already far too many houses. The Cherrybank development to name one is a total disgrace!!! Perth Council should be ashamed of themselves
• While I appreciate damage to environment by using petrol/diesel driven cars I will continue to do so until someone can explain how in 10/15 years the disposal of defunct batteries will take place! More development needed in hydrogen powered vehicles
• I lost my wife of 49.5 years at Christmas I have a great deal on my plate at present. Perth was a nice town but like many others they are suffering, too many houses being built with little thought. Our roads cannot cope in our area. More houses mean more cars. More kids being driven to school. It can be hell in this area has 3 schools with post war road systems not fit for today's traffic sorry to rant. Peter Lamond, Many years in Oakbank Road. Good luck with your survey.
• Pleased to see my old university involved. At 82 my driving s becoming more restricted an I no longer travel far afield by car. Thankfully the Park and Ride is convenient.
• Due to age any major energy saving projects would have to be carefully considered on payback durations
• I am a widow on a pension so replacing any saving device is out of the question
• Scotland has many lochs, all surrounded by hills. Why does the Scottish Government not consider expanding the hydro electric option model as at Cruachan on Loch Alvie.

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Participants' Additional Comments cntd.

Comments
• It would be good to find alternatives to air source heat pumps as the only low carbon option currently available to replace gas boilers. For example, district heating system powered by renewable energy or a hydrogen gas system using renewable energy generated electricity. I would be good to compine action for climate change with action for nature/biodiversity as they are systems of the same problems, and you can't solve one without addressing the other. Also, we are affected by poor air quality because we are close to the A9 and Broxden roundabout. Sometimes when the wind in blow from there I have to shut the bedroom window at night because I can smell the fumes and it affects my throat. I would like better air quality monitoring in the area, particularly as the new Cross Tay Road Link is expected to increase traffic levels at the A9 south junction with Broxden roundabout. Thank you.
• I understand plans are afloat to construct a pump storage Hydro scheme at loch Lochy using an existing loch for storage of water high up between meall Ina Tenga and Sronta a choire Ghairth. Considering the Cruachan scheme have proved very successful, and it begs the question why has it taken some 60 odd years to get round to thinking about this.
• Perth and Kinross have limited recycling and too much is thrown away into non-recycling bins.
• It needs full government, local & national, financial support or nothing will get done, it's easy to say we need to do this or that, but who & how it's paid for are the only question that stops progress
• Why do these surveys never mention public transport? Walking and cycling are not practical for my journeys as always carrying something, shopping, sports kit, elderly parents. We need to stop using cars of any sort so please can someone look at it: 1) more frequent buses, 2) any sort of bus on Sundays in rural Perthshire, 3) Routes to places I need to go i.e., round Perth not in and out of Perth. Replacing petrol/diesel cars with electric cars will not improve congestion
• I would like to reduce my impact on the environment. However, to make changes is expensive and finances make this prohibitive. When I recently decided to change my gas boiler I researched alternatives, but their cost was significantly higher than replacing with a gas boiler.
• I have until recently been very much against the building of new nuclear power stations. I am reconsidering this in light of recent geopolitical events and the Rolls-Royce SMR design. I am open to hearing the case for multiple SMR use (one for Perth, one for Dundee etc...). I understand that the nuclear engines powering some modern warships are not much biggers than a coffee table (Rdio 4 piece on Shipping). While I'm open to heating that case, my preference would still be for "green" energy - wave power, wind turbines, solar farms.
• Our house is reasonably insulated but we are at the top of a hill and the increased winds "suck" the heat out of the house. Nothing we can do about that.

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Correlations (Relationships between two variables)

N = number of participants who answered the corresponding question. *r* = Correlation (Pearson) Coefficient. *p* = level of significance. Significance threshold is < 0.05.

Age
N = 77

Past Community Activities: No correlation

Future Community Activities: Significant negative correlation. Correlation is significant at the 0.01 level. This means that as age decreases, the likelihood of participating in future community activities increases.

Global Climate Change Concern: No correlation

Happy With Insulation: No correlation

Invested in Energy Efficiency: No correlation

Global Climate Change Concern
N = 77

RETROFITTING OPTIONS:
Roof Insulation: No correlation

Cavity Wall insulation: No correlation

Double/Triple Glazing: No correlation

ASHP: Significant negative correlation. Correlation is significant at the 0.05 level. This means that as concern for global climate change increases, people are more likely to consider ASHP.
GSHP: Significant negative correlation. Correlation is significant at the 0.05 level. This means that as concern for global climate change increases, people are more likely to consider GSHP.

Solar PV: No correlation:

Solar Water Heater: No correlation

Past Community Activities: No correlation

Future Community Activities: No Correlation

Happy With Insulation: Significant negative correlation. Correlation is significant at the 0.01 level. This means that as concern for global climate change increases, happiness with insulation decreases.

Invested in Energy Efficiency: No correlation

No correlations with climate change concern and distance travelled for any trip

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Slide 20

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Correlations (Relationships between two variables) cntd.

N = number of participants who answered the corresponding question. *r* = Correlation (Pearson) Coefficient. *p* = level of significance. Significance threshold is < 0.05.

Global Climate Change Concern CNTD.

N = 77

Reducing petrol/diesel private vehicle use: No correlation

Getting rid of petrol diesel private vehicle: No correlation

Replacing petrol/diesel private vehicle with an electric vehicle: Significant positive correlation. Correlation is significant at the 0.01 level. This means that as concern for global climate change increases, the more likely people are to consider this option.

Replacing petrol/diesel private vehicle with bike/electric bike: No correlation

Replacing petrol/diesel private vehicle with car sharing/bike sharing scheme: No correlation

Will Participate in Future Community Activities

N = 75

RETROFITTING OPTIONS:
Roof Insulation: No correlation

Cavity Wall insulation: No correlation

Double/Triple Glazing: No correlation

ASHP: No correlation

GSHP: Significant negative correlation. Correlation is significant at the 0.01 level. This means that as people are more likely to participate in future community activities, they are more likely to consider GSHPs.

Solar PV: No correlation:

Solar Water Heater: Significant negative correlation. Correlation is significant at the 0.05 level. This means that as people are more likely to participate in future community activities, they are more likely to consider GSHPs.

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Slide 21

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Correlations (Relationships between two variables) cntd.

N = number of participants who answered the corresponding question. *r* = Correlation (Pearson) Coefficient. *p* = level of significance. Significance threshold is < 0.05.

Distance Travelled & Vehicle Use Change

WORK (Member 1)
- Reducing petrol/diesel private vehicle use: No correlation
- Getting rid of petrol/diesel private vehicle: No correlation
- Replacing petrol/diesel private vehicle with an electric vehicle: No correlation
- Replacing petrol/diesel private vehicle with bike/electric bike: No correlation
- Replacing petrol/diesel private vehicle with car sharing/bike sharing scheme: No correlation

SCHOOL (Member 1)
- Reducing petrol/diesel private vehicle use: No correlation
- Getting rid of petrol/diesel private vehicle: Significant positive correlation. Correlation is significant at the 0.05 level. This means that as distance travelled for school increased, the likelihood of getting rid of petrol/diesel car increased.
- Replacing petrol/diesel private vehicle with an electric vehicle: No correlation
- Replacing petrol/diesel private vehicle with bike/electric bike: No correlation
- Replacing petrol/diesel private vehicle with car sharing/bike sharing scheme: No correlation

SHOPPING/GROCERIES
- Reducing petrol/diesel private vehicle use: No correlation
- Getting rid of petrol/diesel private vehicle: No correlation
- Replacing petrol/diesel private vehicle with an electric vehicle: No correlation
- Replacing petrol/diesel private vehicle with bike/electric bike: No correlation
- Replacing petrol/diesel private vehicle with car sharing/bike sharing scheme: No correlation

SPORT/RECREATION (Member 1)
- Reducing petrol/diesel private vehicle use: No correlation
- Getting rid of petrol/diesel private vehicle: No correlation
- Replacing petrol/diesel private vehicle with an electric vehicle: Significant positive correlation. Correlation is significant at the 0.05 level. This means that as distance travelled for sport/recreation increased, the likelihood of replacing a petrol/diesel car with an electric car increased.
- Replacing petrol/diesel private vehicle with bike/electric bike: No correlation
- Replacing petrol/diesel private vehicle with car sharing/bike sharing scheme: No correlation

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ANNEX II: Technology scenarios presented to focus groups (PowerPoint)

Slide 1

A. Focus on heating

First step: **insulation**!

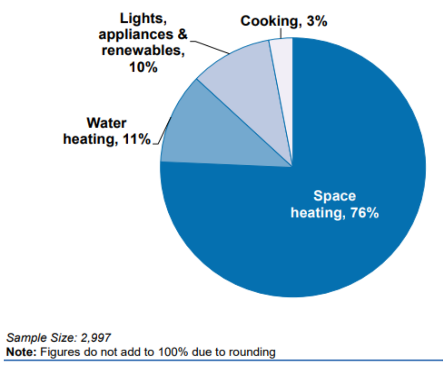

Figure 3: Mean household energy consumption by end use, 2019
Scottish house condition survey: 2019 key findings – Scottish government

Figure 4: loft insulation *Saving energy UK*

Figure 5: external wall insulation installation *Sustainable energy authority of Ireland*

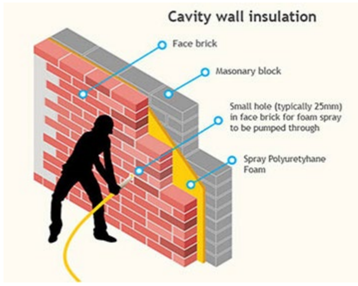

Figure 6: cavity wall insulation installation *Which? UK*

1

Slide 2

A. Focus on heating

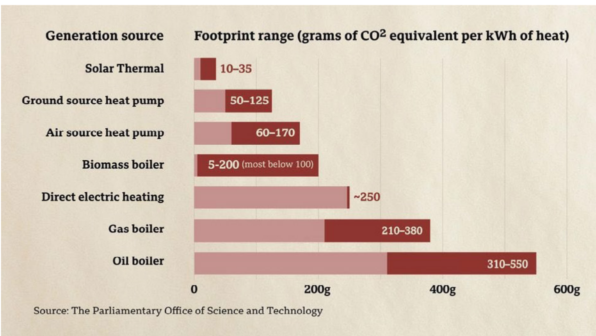

Figure 7: carbon footprints of different heating systems
Leonardo Soares for the BBC

Video 1: What is an air source heat pump? *Energy saving trust*

2

Slide 3

A. Focus on heating

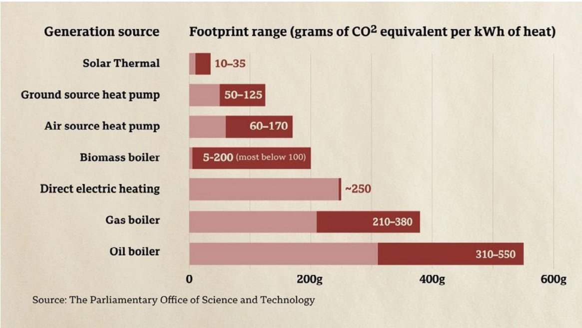

Figure 7: carbon footprints of different heating systems
Leonardo Soares for the BBC

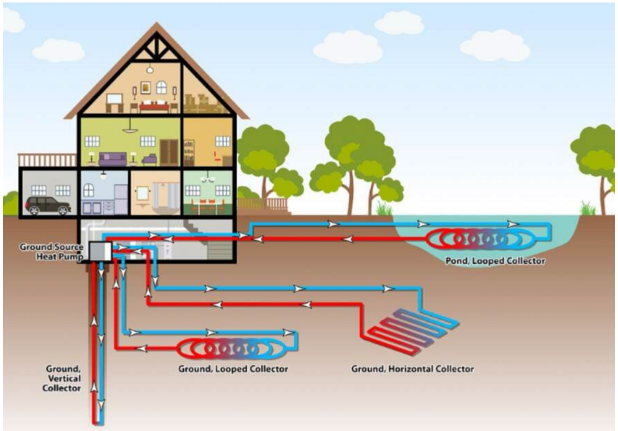

Figure 8: types of exchangers for ground source heat pumps *Climatebiz*

3

Slide 4

A. Scenario 1

~ 1000£

Figure 9: insulated house *Leonardo Soares for the BBC*

Figure 10: air source heat pump *YES Energy solutions*

Requirements for air source heat pumps:
- Clear space around the heat pump
- Works for new radiators and improved insulations

Compared to ground source heat pumps:
- Less disruptive and cheaper
- Less efficient
- Noisy (like a fridge, in winter)

Compared to gas boiler, 3x lower emissions!

~ 13,000£ for the installation

In 2022, ~ 300£ more than a gas boiler to run
(100£ less than for 2021)

Figure 11: large radiator
Hot interiors

4

Slide 5

B. Focus on mobility

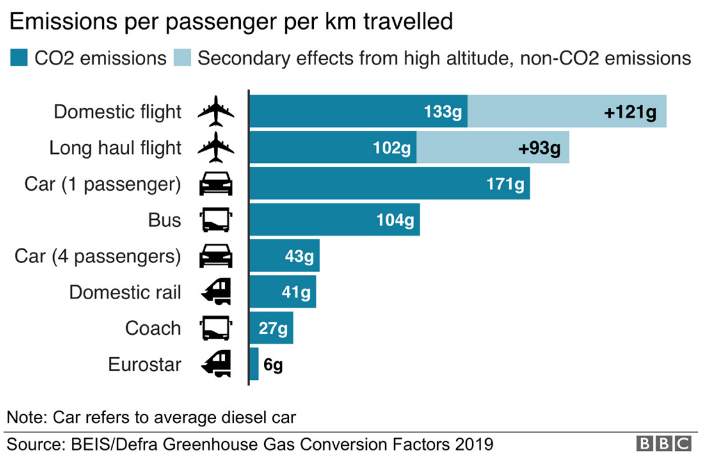

Figure 12: emissions from different modes of transport *BBC*

Many options!

5

Slide 6

B. Scenario 2

Figure 13: electric car and home charger *Auditoria*

~ 7,000£ more than a new petrol/diesel
~ 1,000£ for the charger

~ 400£/year saved on the running costs by using electricity

Swapping 2nd car with a car club
for
~ 20£/month + cheaper mileage

Compared to a petrol car, 3x lower emissions!

Figure 14: car club membership *Entreprise*

Figure 15: on-street locker for private bikes *Ciclehoop*

6

Slide 7

C. Other technologies : **solar PV panels**

- Percentage of electricity demand covered depending on roof orientation: 145% when South-facing roof, 120% if West or East and 92% if North

SMART EXPORT GUARANTEE

~ 7,000£ for the installation
1340 kgCO2e/year saved
90£/year from the SEG +
800£ saved from the electricity bill

Figure 16: roof-mounted PV panels *Greenmatch*

7

Slide 8

C. Other technologies : **water heating by solar thermal**

Figure 17: roof-mounted collector *ENSIA*

- For 2 persons
3000£ for the installation
1050 kWh/year produced

- For 4 or 5 people
4500£ for the installation
2100 kWh/year produced (~75£ saved from the bill)

Figure 18: on the ground or the wall *Build it solar*

8

Slide 9

C. Other technologies : **with the wind**

Figure 19: ridge blade *The Power Collective*

Figure 20: charging station *Flower Turbines*

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C. Other technologies : **shared charge points**

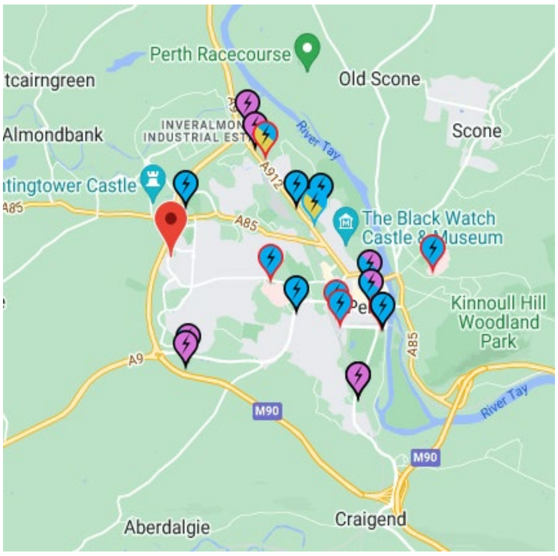

Figure 21: current available chargers *Zap-Map*

JustPark

Co Charger together we're electrifying

Bookmycharge

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C. Other technologies : **smart and flexible networks**

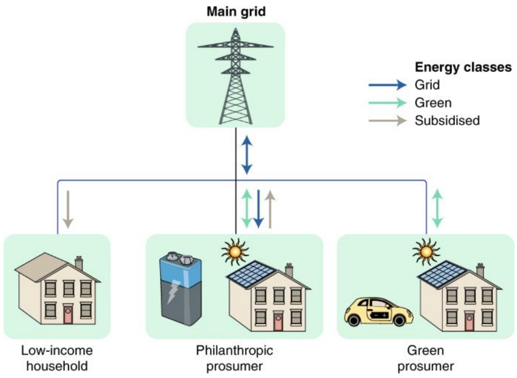

Figure 22: multi-class P2P energy trading *Nature*

Figure 23: Varta-Storage 'Pulse', garage installation (BESS)
© Varta Storage GmbHNature

- BESS = battery energy storage system
- P2P = peer-to peer
- V2G = vehicle to grid

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C. Scenario 3

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Slide 13

C. Scenario 3

Housing					Mobility			
Space heating	**Water heating**	**Heat distribution**	**Electricity**	**Energy storage**	**Car 1**	**Car 2**	**Bike(s)**	**Public transportation**
Current device	Central heating	Current radiators	From the grid	Battery	Private, petrol or diesel	Private, petrol or diesel	Private, no engine	Frequently
Air source heat pump		Larger radiators			Private, electric	Private, electric	Private, electric	Rarely
Ground source heat pump - horizontal	Solar thermal			None	Informal sharing	Informal sharing	Shared	
Ground source heat pump - borehole		Underfloor	PV panels		Car club	Car club	None	No use
					None	None		

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C. Scenario 3

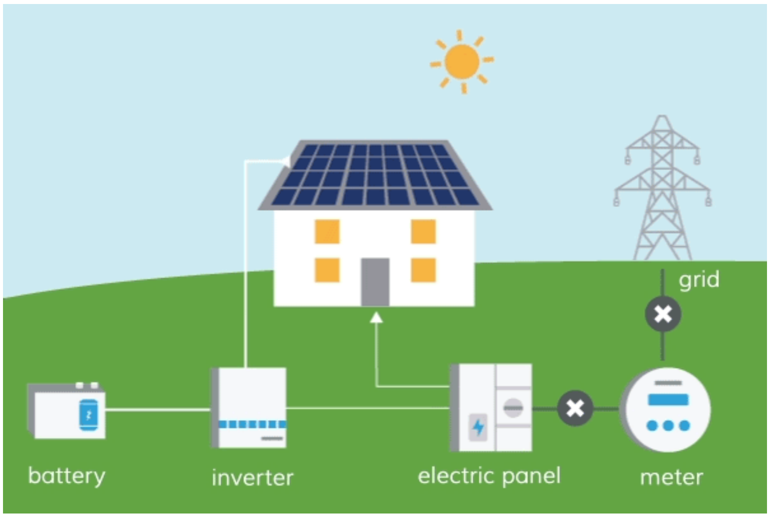

Figure 24: PV panel and battery storage system *IGS Energy*

~ 5,000£ for the battery
Very little dependence from the grid
Energy surplus sold

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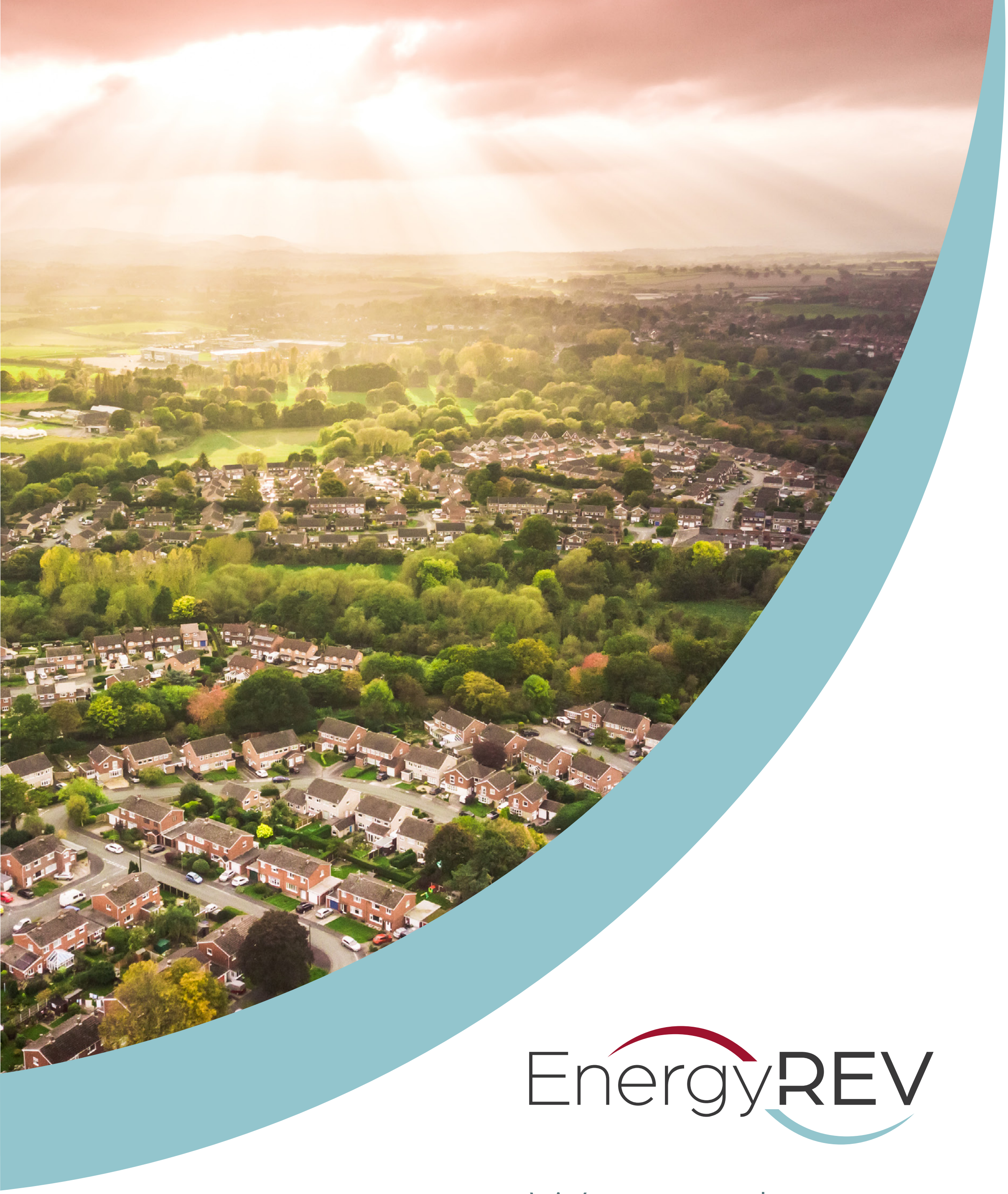

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About EnergyREV

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